MODERN PRACTICAL RADIO AND TELEVISION

A PRACTICAL AND COMPREHENSIVE TREATISE DEALING WITH EVERY PHASE OF RADIO ENGINEERING, INCLUDING DESIGN, CONSTRUCTION AND MAINTENANCE, WITH SPECIAL CHAPTERS ON TELEVISION, ETC.

BY

C. A. QUARRINGTON, A.M.Brit.I.R.E.

AND EDITED BY

W. H. DATE, B.Sc., A.M.I.E.E.

VOLUME I

THE CAXTON PUBLISHING COMPANY, LIMITED
LONDON - NEW YORK - MELBOURNE
TORONTO - WELLINGTON

First published	.	*January*	1946
Second Edition	.	*June*	1948
Reprinted	.	*May*	1949
Reprinted	.	*April*	1950
Reprinted	.	*November*	1950
Reprinted	.	*March*	1951
Reprinted	.	*June*	1951
Reprinted	.	*November*	1951
Reprinted	.	*May*	1952
Reprinted	.	*September*	1952
Reprinted	.	*December*	1955
Reprinted	.	*May*	1957

CAXTON'S
LIST OF ENGINEERING BOOKS

ENGINEERING WORKSHOP PRACTICE
ENGINEERING WORKSHOP DATA
MACHINE TOOLS AND OPERATIONS
TOOLROOM PRACTICE
GRINDING, LAPPING AND POLISHING
CENTRE, CAPSTAN AND AUTOMATIC LATHES
THE MILLWRIGHT AND MAINTENANCE ENGINEER
THE MODERN ELECTRICAL ENGINEER
THE MODERN MOTOR ENGINEER
MODERN PRACTICAL RADIO AND TELEVISION
MODERN HIGH-SPEED OIL ENGINES
MODERN MARINE ENGINEERING
MODERN WELDING PRACTICE
SHEET-METAL WORK

PRINTED AND BOUND IN ENGLAND BY
HAZELL WATSON AND VINEY LTD
AYLESBURY AND LONDON

FOREWORD

HITHERTO the works published on " Radio " and " Television " in this country and in the United States have been of two distinct classes—works of an advanced nature appealing only to the comparatively few who have a scientific knowledge of these subjects and can readily understand a mathematical approach, and popular works more suitable for armchair reading. A work which would cover every phase of Radio and Television Engineering from many viewpoints and which would appeal to radio maintenance engineers and employees in the industry has been a long felt want. To meet this growing demand has been the aim of the Publishers and Author in the production of *Modern Practical Radio and Television*; this work will also meet exactly the needs of the many National Service personnel who have acquired a good knowledge of specialised Service equipment, and who wish to mould this knowledge in order to make the best possible use of it in the radio industry.

Service and maintenance are treated comprehensively and provide information for those with a fully equipped service workshop at their disposal equally with those who possess the minimum facilities. The section dealing with Television covers a wide field and introduces many circuit arrangements and valve types, which are unknown to those who have not studied this particular field of the electronic art. There is also a section of Low Power Transmission and chapters dealing comprehensively with Frequency Modulation, Car Radio, Electrical Interference Suppression, and other specialised subjects.

The illustrations, which are an outstanding feature of *Modern Practical Radio and Television*, number over four hundred, including a special series of oscillograms which have all been prepared under the personal supervision of the Author.

The Publishers and Author alike offer this latest treatise on Radio and Television to all those connected in any way with this subject, with complete confidence.

The Author would like to thank in particular Mr. W. H. Date for his willing and constructive help at all times. In addition he would also like to thank the artists and others who have worked unceasingly to make *Modern Practical Radio and Television* possible.

C. A. QUARRINGTON.

Various circuits, devices and principles described in this volume form the subject matter of letters-patent or provisional protection.

CONTENTS OF VOL. I

CHAPTER 7

REACTANCE AND IMPEDANCE

CHAPTER 8

ALTERNATING CURRENT

CHAPTER 9

THE TUNED CIRCUIT

CHAPTER 10

THE PRINCIPLES OF THE THERMIONIC VALVE

CHAPTER 11

THE AMPLITUDE MODULATED SIGNAL ANALYSED

CHAPTER 12

AMPLITUDE MODULATION DETECTION

CHAPTER 13

REACTION AND DAMPING

CHAPTER 14

THE R.F. PENTODE AND TETRODE

CHAPTER 15

RADIO-FREQUENCY AMPLIFICATION

CHAPTER 16

THE PRINCIPLE OF THE SUPERHETERODYNE

CHAPTER 17

FREQUENCY-CHANGING VALVES

CHAPTER 18

DESIGN OF THE SUPERHETERODYNE

CHAPTER 19

PRACTICAL COIL DESIGN

CHAPTER 20

SWITCHES AND SWITCHING

CHAPTER 21

LOW-FREQUENCY AMPLIFICATION

CHAPTER 22

THE OUTPUT STAGE

CHAPTER 23

OUTPUT VALVES

CHAPTER 24

THE LOUDSPEAKER

CHAPTER 25

AUTOMATIC VOLUME CONTROL

CHAPTER 26

TUNING INDICATORS

CHAPTER 27

INTER-STATION NOISE SUPPRESSION

CHAPTER 28

AUTOMATIC TUNING

CHAPTER 29

FREQUENCY MODULATION

FULL-PAGE PLATES

VOL. I

MODERN PRACTICAL RADIO AND TELEVISION

VOL. I

CHAPTER I

SOUND

SOUND has been chosen as the subject-matter for the opening chapter of this work. It might be argued that the principles of radio technique should take precedence, but the reason for the popularity of radio is the ability to transmit sound from one place to another ; furthermore, before attempting to understand the principles and application of radio communication, it is both logical and necessary to acquire a knowledge of the principles of sound, as the nature of this phenomenon exercises a wide influence over the design of both the transmitter and the receiver.

Sound is often regarded as something emanating from, say, the string of a violin or the impact of a hammer on a piece of wood ; this belief is not strictly accurate, as sound should be regarded as a phenomenon peculiar to and arising in the ear of a human being or animal. If a bomb is exploded in the middle of the Sahara desert at a place so remote that no living creature is within earshot, there will be no sound. True, the explosion of the bomb will cause considerable air displacement and radiate a complicated set of vibrations, but unless these strike a living eardrum the explosion of the bomb will not have caused any sound.

Starting, then, with the conception that sound is a function of the ear and its associated nerves and brain, it is necessary that its limitations should be appreciated ; quite apart from the need for a proper understanding of the nature of sound-wave formation, the study of sound-wave mechanics serves as an excellent introduction to radio waves, as they are more tangible and therefore more readily understood.

Wave Motion.—If a stone is thrown into a lake it will cause a series of waves to radiate from the point where the stone entered the water, and from the behaviour of these ripples three things may be observed. First, the wave motion will travel outwards at an *even* speed until it has travelled such a distance that it has died away. Secondly, it can be seen that as the disturbance dies down the speed of the motion is still unchanged. Thirdly, if a leaf or other floating object is situated within the disturbed area it will rise on each wavecrest and fall with each trough, but it will not change its position.

Two conclusions may be drawn from this simple experiment, the more important of which is that the wave motion is purely a displacement of water in the vertical direction and not a movement in a horizontal plane; in other words, the energy expended by the stone hitting the water has travelled outwards, but when the disturbance has subsided each drop of water will occupy its original position. As a further illustration of this phenomenon, various coloured dyes may be introduced to denote definite zones and will remain unmixed by the passage of wave motion except at the actual point where the first displacement takes place, due to the entry of the stone.

If a larger stone is thrown into the water it may be observed that this will cause waves of greater height and depth or, to use the correct term, greater amplitude; the leaf referred to in the first part of the experiment will travel a proportionately greater distance in a vertical direction. There is only one conclusion to be drawn from this simple experiment, and that is that the amplitude of a wave is proportional to the energy which sets it in motion. It can also be observed that the wave motion caused by the larger stone will travel farther before it dies away.

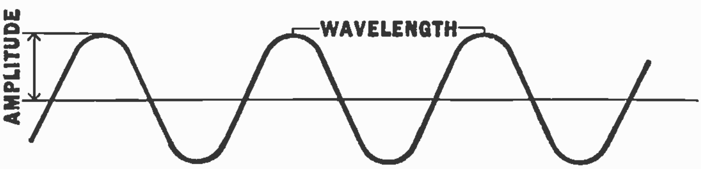


Fig. 1.—A wavetrain or series of waves showing how wavelength and amplitude are measured.

There is one more variable factor, and that is the distance between one peak and the next. This is termed the wavelength. Fig. 1 illustrates diagrammatically a succession of waves and from this illustration it may be seen how amplitude and wavelength are measured

Bearing in mind that the distance between one peak and the next is a variable factor and that the speed in the forward direction is constant, it follows that the time between each successive peak passing a fixed point is not only variable but is dependent on wavelength. The longer the wavelength the greater will be the interval between successive peaks, and conversely the shorter the wavelength the shorter will be the time interval or, in other words, the greater will be the frequency of their appearance. To summarise, a propagated wave has five characteristics: (*a*) velocity, or the speed at which it travels from its source; (*b*) amplitude, which is the measure of its strength; (*c*) wavelength, which is the distance between each successive peak; (*d*) frequency, which is determined by the time interval between each consecutive peak passing a fixed point, or, more conventionally, the number of complete cycles per second emanating from the source; (*e*) the actual shape, which is referred to as the waveform and is dealt with in a later chapter. A cycle is a complete series of recurring events and is one unit of wave motion. Fig. 2 shows diagrammatically one complete cycle, which includes a complete peak and trough, the horizontal line representing the normal undisturbed level of the water.

Sound waves and incidentally radio, heat, and light waves are peculiar inasmuch as they travel at a fixed speed irrespective of amplitude, wavelength, frequency, and in fact any consideration other than the medium through which they travel. Sound waves travel in air at 1,088 feet per second, and radio, heat, and light waves, to mention a few examples, travel in free space (the ether) at 186,000 miles per second. If a bell is struck it vibrates at a frequency determined by its mass, which we will assume is such that it vibrates at 500 times per second; this mechanical movement will alternatively compress and rarefy the air immediately surrounding the bell, which will in turn compress and rarefy the next "layer" of air, and in this way the alternating changes of pressure radiate in all directions at the fixed speed of 1,088 feet per second like an expanding ball. Each wave of high pressure slowly dies away, to be followed by a wave of low pressure, which is in turn followed by a wave of high pressure and so on, as long as the bell vibrates. Assuming this wave, or sound wave as it may be called, strikes an eardrum it will cause it to vibrate in exact sympathy with the bell, and a 500-cycle note will be heard; this is, however, only half the truth, as the listener will recognise the sound as emanating from a bell as distinct from, say, a 500-cycle note from a tin whistle.

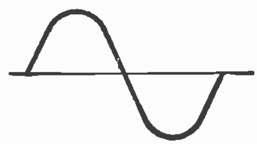


Fig. 2.—One complete cycle; a series of cycles form a wavetrain such as that shown at Fig. 1.

Harmonics.—The difference in the quality between various sounds, such as, for example, those associated with the instruments of the orchestra, is due to the presence of harmonics. A harmonic is a subsidiary wave, the frequency of which is an exact multiple of the main or fundamental wave. The second harmonic is double the fundamental frequency, the third harmonic is treble the fundamental frequency, and so on. Thus, the second harmonic of a 500-cycle note will be 1,000 cycles, the third harmonic 1,500 cycles, *ad infinitum.*

The various instruments of the orchestra have their own characteristic sounds; the French horn, for example, has a small harmonic content, whereas the violin is rich both in the number and amplitude of harmonics.

When the string of a violin is plucked it emits the fundamental note to which it is tuned, but owing to its mechanical properties it also vibrates at multiples of its fundamental frequency, notably at twice and five times. Certain instruments also produce what may be termed incidental noises such as the blowing and reed noises from the clarinet, the noise from the bow on a stringed instrument, drum rattle from the tympani, and so on; such noises are almost invariably of relatively high frequency and need not necessarily bear any mathematical or musical relationship to the fundamental note. The human voice is rich in harmonics which are responsible for the difference between various voices and almost entirely for the various sounds produced; for example, a singer may sing the vowel "e" at the same pitch as the vowel "o," but they will each be recognised by virtue of their different harmonic contents. Figs. 3–8 are actual photographs of the sound waveform of the human voice producing

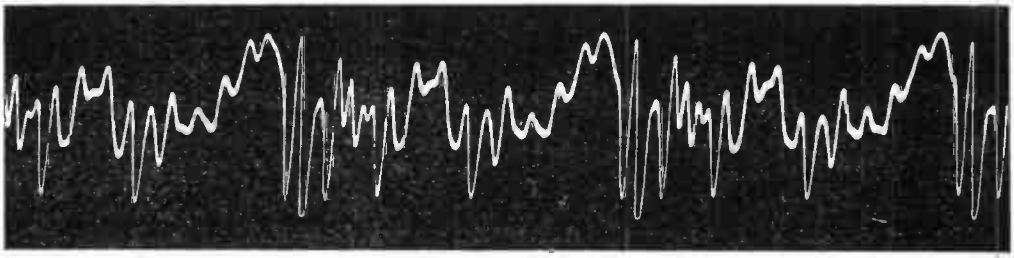


Fig. 3.—The vowel sound " a."

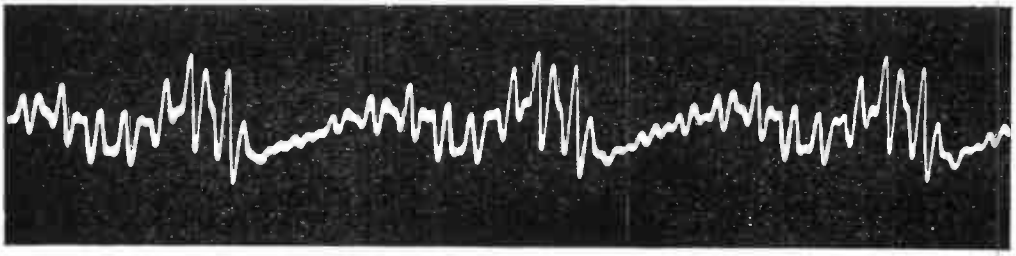


Fig. 4.—The vowel sound " e."

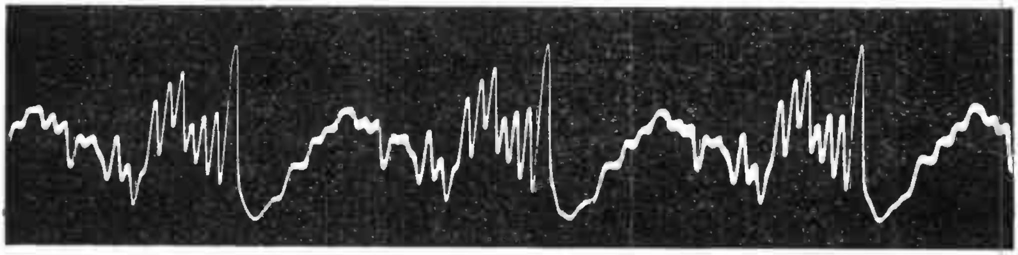


Fig. 5.—The vowel sound " i."

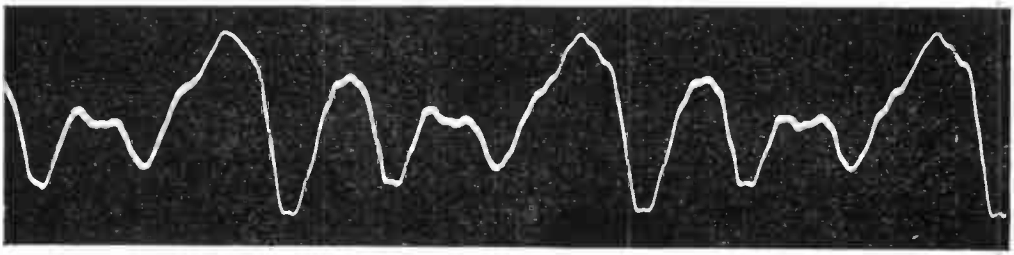


Fig. 6.—The vowel sound " o."

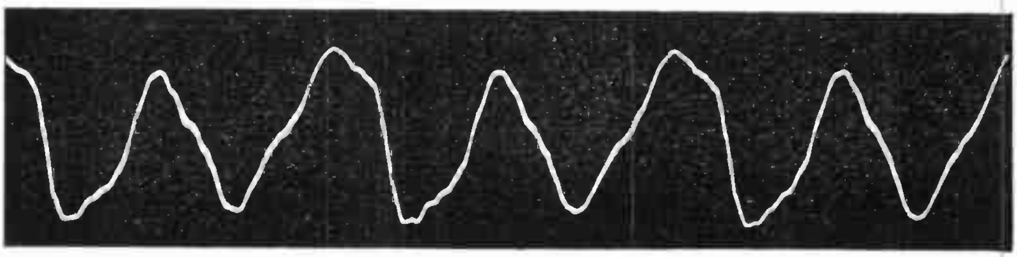


Fig. 7.—The vowel sound " u " (ōō).

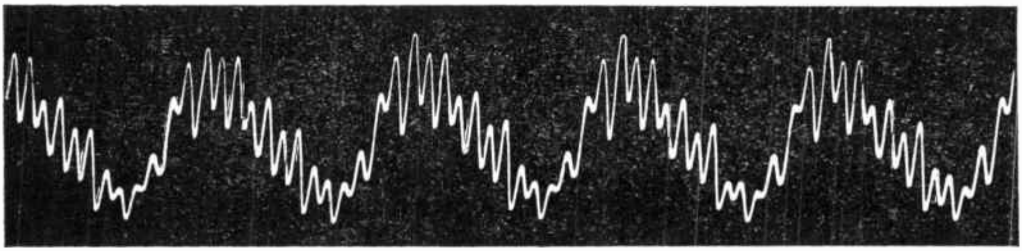


Fig. 8.—The sound "ing."

Figs. 3–8.—These illustrations are actual photographs taken with the cathode-ray oscillograph and show the true waveforms of the sounds indicated. Taken with an f. 1·9 lens in a rotating drum camera revolving at a speed of 70 feet per second using super-speed paper.

the vowel sounds "a," "e," "i," "o," "u," and the sound "ing." It may be observed that "a," "e," and "i" have a complicated waveform compared to "o" and "u." However complicated a waveform may be, it is made up solely of a series of pure waveforms such as that shown at Fig. 1. This is admittedly difficult to visualise, but some aid may be derived from Fig. 9, which shows the resultant waveform (top), which is made up by adding together the two lower pure waveforms. A pure waveform is known as a sinusoidal waveform, the exact definition of which is described in a later chapter.

It is interesting to note that the waveforms of the vowel sounds are usually quite recognisable when produced by voices that are widely divergent in quality and pitch, whereas consonant sounds have a totally different appearance and cannot be identified.

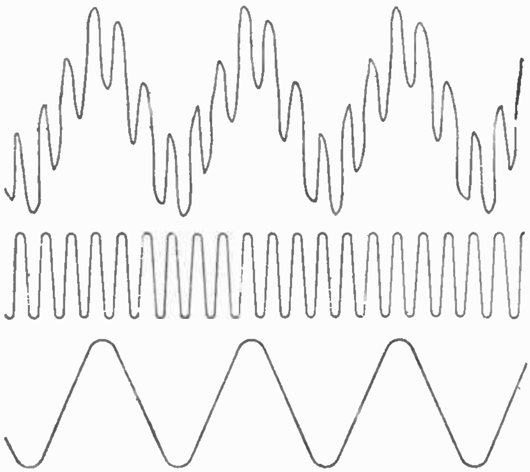


Fig. 9.—The top waveform is simply the lower two waveforms combined and illustrates that highly complicated waveforms, such as those shown at Figs. 3–8, are made up of two or more simple waves.

The Human Ear.—The frequencies of sound extend over a wide range, of which the human ear can detect a limited band; this is usually quoted as 15 cycles per second to 24,000 cycles per second, but it is extremely doubtful if such a range is audible to more than one person in five thousand. A more reasonable estimate would be 15 to 18,000 c.p.s., although it must always be remembered that the upper limit of audibility varies widely with different individuals and also that it decreases with age. It is equally important to remember that the sensitivity of the ear varies with frequency, that is to say that sounds of equal volume but different pitch will give the impression of dissimilar volume; the average ear is most sensitive to sounds at about 3,000 c.p.s., and falls off above and below this region.

The ear is somewhat insensitive to changes in volume although extremely sensitive to changes in pitch. The presence of these characteristics is fortunate, because it is comparatively easy for a musician to control the pitch of a note but difficult to control the volume. The sensitivity of the ear is logarithmic,[1] which in plain English means that the brain registers disproportionately an increase in volume. Because the sense of hearing follows a logarithmic instead of a linear law, the ear can appreciate changes over a considerable range of volume. The loudest audible sound is some 10,000,000 times the smallest sound (called the threshold of hearing) that can be detected. On the other hand, the brain of the average person would only receive the impression of a change of approximately 70 : 1.

The Decibel.—As already intimated the ear does not readily detect a change in volume, the average person being just able to detect an increase of 30 per cent., while an increase of 100 per cent. appears surprisingly small. In order to measure and compare various volume levels in a manner that gives an indication of apparent audible value, it is convenient to use a unit called the decibel. The significance of the decibel can be more readily appreciated when expressed in the following way. Assume that some means is available of producing a note of constant pitch and that it is adjusted to give a volume which can be called V_1; the volume is then doubled, giving 100 per cent. increase V_2; this, expressed in terms of the unit under discussion, is 3 decibels, and the apparent increase registered by ear would be quite small. If the volume is again doubled V_3, the increase will again be 3 decibels; note particularly that although the volume V_3 is four times V_1 the increase expressed in decibels is only doubled. If the volume is again doubled V_4, the increase will again be 3 decibels, thus the volume will have been increased by eight times although the increase in decibels is only three times; if this is repeated the actual increase in volume will be sixteen times and the increase in decibels, or apparent audible volume, only four times, and so on until such a volume is reached that the ear cannot further respond. It has already been mentioned that the ear can appreciate changes over a range of 10,000,000 : 1, which is 70 decibels, and it may be added that an increase of 1 decibel is the smallest change that can be detected by a normal person; it is conventional to abbreviate decibel by the symbol db.

Instruments of the Orchestra.—Fig. 10 shows diagrammatically the frequency range covered by the fundamental notes of various instruments compared with the keyboard of a full-scale piano (85 notes). It will be observed that extensions to these frequency bands are shown dotted; these extensions serve to indicate in general terms the range taken up by the important harmonics of each instrument. This table must only be accepted

[1] See Appendix 1.

as an approximation, as the expression " important harmonics " is necessarily an arbitrary one, but it very readily shows the important part played by the higher frequencies in determining tone as distinct from pitch, which is taken care of by the fundamental frequencies.

The frequency range covered by certain percussion instruments is quite

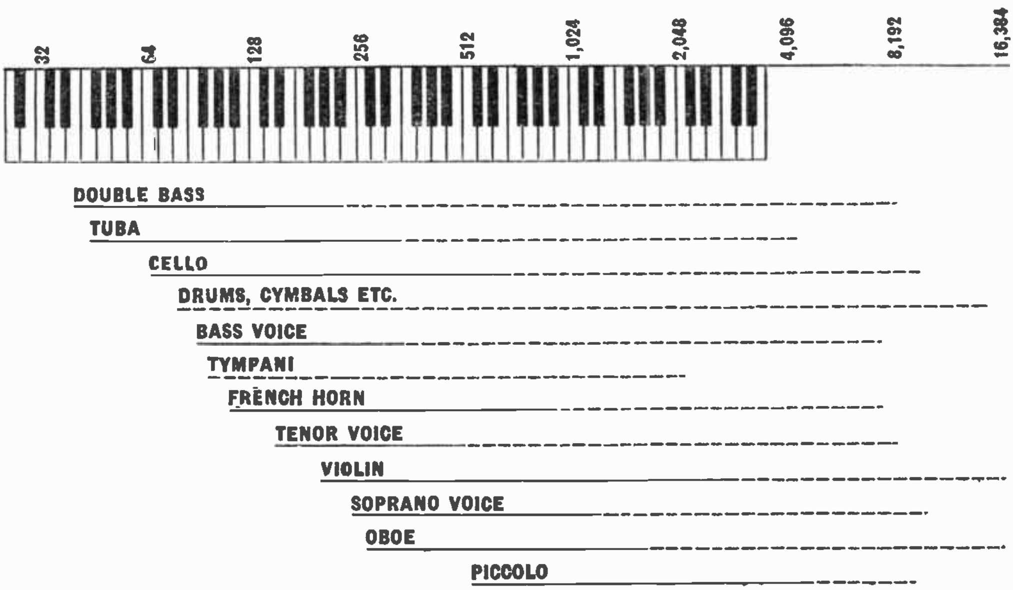


Fig. 10.—The frequency range of various instruments is shown above. The solid lines represent the fundamental notes, while the broken lines show the harmonic range necessary for true reproduction; the tympani and drums have no range of notes, but a wide frequency band is covered by harmonics, rattling noises, etc. The total scale is shown in cycles per second and extends two octaves and two notes above a full-scale piano.

surprising; the bass drum, for example, occupies a range of about 60 to 1,000 cycles; the snare drum extends to well above 10,000 cycles; and the tympani, which has a fundamental frequency of 96 cycles, extends from 65 to 2,000 cycles. Perhaps the most surprising example is the noise made by heavy footsteps on a wooden floor, which produce a prominent sound wave around 150 cycles but also produce supplementary frequencies extending up to the region of 13,000 cycles.

Sound waves are reflected, with very little loss, by hard substances such as glass, metal, and concrete, and are almost entirely absorbed by soft substances of adequate thickness such as sawdust, dry seaweed, sacking, wadding, etcetera. The hard substances mentioned reflect sound almost entirely independently of frequency, but soft substances and substances of intermediate acoustic properties, such as wood, tend to absorb high notes more readily than low notes, a phenomenon that has to be carefully taken into account when planning large buildings such as cinemas, or conversely when designing the speech- and music-reproducing apparatus for use therein.

Reference has been made to the importance of the higher harmonics without which the true characteristics of almost every broadcast item would be lost ; it would seem, therefore, that a radio receiver should be capable of reproducing these frequencies. Unfortunately practical considerations make this impossible, for reasons which are revealed in the next chapter. There is, however, another aspect of sound reproduction which is of a purely personal nature.

Many receivers are fitted with a device called a tone control, the function of which is to reduce the strength of the higher frequencies ; bearing in mind that the reproduction will almost certainly have shortcomings in this direction, it is logical to suggest that operation of the tone control must make reception less true. Investigations have shown that an important percentage of the listening public prefer to use their receivers in this manner and consider the "tone" to be improved. Whatever individual preference may demand, a radio receiver should not possess tone in the sense that it reproduces music in an individual manner ; it should necessarily aim to reproduce the original programme without loss or addition of any frequencies.

CHAPTER 2

A BIRD'S-EYE VIEW

THIS work has been very carefully planned to present each phase of radio technique in a sequence that will enable the reader to acquire, in the earlier chapters, the knowledge necessary readily to understand the chapters which follow.

When defining the order in which the chapters were to be presented, the difficulty arose that certain principles are interdependent on each other. This chapter is, therefore, devoted to a very brief outline of the whole chain between, say, a singer in a broadcasting studio and an actual listener enjoying the programme at home.

Before commencing this bird's-eye view, it is necessary that one fact should be thoroughly understood, and that is that a broadcasting station does not radiate either sound or electricity. Admittedly, the actual transmitter itself may be termed a piece of electrical apparatus, and furthermore the actual electricity consumed in a single hour by one of the main B.B.C. stations would supply the needs of an average household for several months. A broadcasting station is electrically operated from the microphone to the aerial, but not beyond; the popular idea that electricity is actually "given off" by the aerial and forms the link with the receiving aerial is a complete fallacy.

The Microphone.—This brief survey of broadcasting is diagrammatically illustrated at Fig. 11, and begins with the actual source of the sound to be broadcast; this may be a singer, a full orchestra, an announcer, it is quite immaterial. Whatever their nature the sound waves will radiate from their source and impinge upon a device called a microphone, which is placed in the broadcasting studio for that purpose. There are various types of microphones, the most familiar of which is that used in an ordinary telephone. A very much more elaborate instrument is required for broadcasting, as it must respond evenly to the wide range of frequencies necessary for the faithful handling of both speech and music.

The sole purpose of the microphone is to convert sound waves into currents of electricity that increase and diminish in exact sympathy with the sound wave. If, at some particular instant, a 500-cycle note impinges upon the microphone, it will then pass a 500-cycle current.

The sound wave and resultant current will have identical frequency and waveform, but the essential difference is that sound-wave amplitude is expressed as air pressure, because it represents the displacement in air; the amplitude of the microphone current is expressed as current which it actually represents.

If the microphone is well designed the frequency of the current will vary between 15 and 25,000 cycles per second according to the nature of the sound being broadcast, although under normal conditions the band will not be so wide as it is impracticable to broadcast above about 8,000 cycles. The relatively low frequencies of sound are unsuitable for radiating from an aerial, and even if they were suitable a difficulty would arise because it is necessary that the radiated wave shall have a fixed frequency in order that it may be selected by the receiver from among the many hundreds of stations all over the world.

The Carrier Wave.—To overcome these difficulties, the sound-frequency wave is imposed upon what is termed the carrier wave, which has a very much higher frequency, usually between 150,000 and 25,000,000 cycles per second. The carrier wave is produced by a section of the transmitter called the oscillator, and in up-to-date stations the most elaborate precautions are taken to ensure that the oscillator frequency remains absolutely unaffected by climatic or temperature changes.

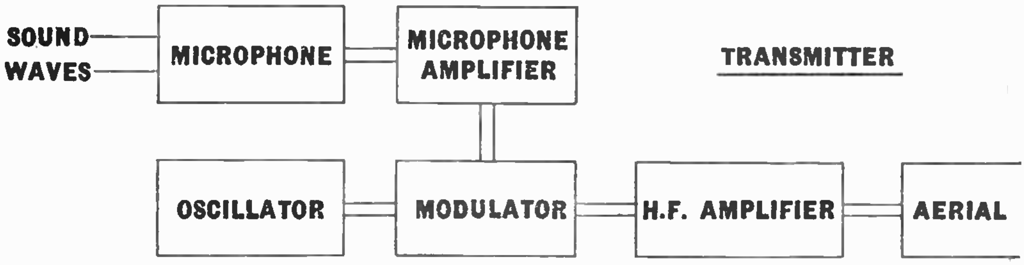


Fig 11.—A " block diagram " of the broadcasting chain showing the links
This diagram and accompanying text is based on the standard A.M. broad-

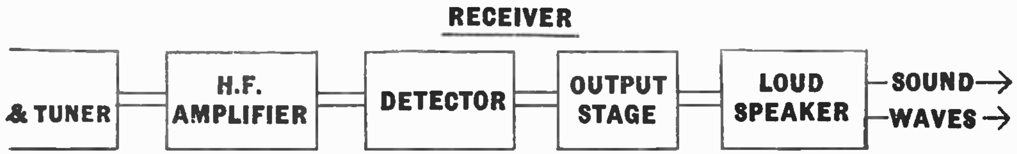
The output from the microphone, which will have been strengthened by a microphone amplifier, is fed to the modulator, the output from the oscillator being similarly treated. The duty of this section is to mix the two frequencies or, to use the correct phraseology, to modulate the steady carrier frequency by the sound frequency.

It is apparent that the output from the modulator will have a wave-form that exhibits the characteristics of both the steady carrier wave and the sound wave imposed upon it. Fig. 12 shows the form of a typical carrier wave; the solid line represents the steady high-frequency output of the oscillator, while the dotted line shows the low sound frequency. This illustration shows very clearly how the sound frequency modulates, or moulds, the shape of the carrier wave by suitably varying its amplitude.

The next link in the chain is called the high-frequency amplifier, which performs the sole duty of increasing the amplitude of the waveform to an extent that is determined by the power of the transmitting station; the output from the amplifier is fed to the aerial system, which consists of the aerial itself, which will have adequate height and, where desirable, directional properties; and of the earth system, which normally consists of a considerable number of metal plates buried at points distributed over a wide area.

The function of the aerial and earth system is to cause what may be termed, at this stage, an electrical strain in its immediate neighbourhood, which in turn causes a wave to propagate in all directions; these waves are similar in character to sound waves but of higher frequency, as already explained; but there is one essential difference between them, inasmuch as the sound wave travels in air, whereas a radio wave requires no tangible medium and will travel through a vacuum with the same ease that it will travel through a brick wall or a rain cloud.

Free Space.—Many elementary textbooks refer to a radio wave as travelling through the ether, which is a term used by scientists to mean an unknown but infinitely elastic "something" present everywhere, that is to say in solid matter, air, space, everywhere. The idea of an omnipresent ether was suggested to account for the fact that energy is transmitted through space as, for example, the light and heat from the sun. Until quite recently it was thought that energy could not travel through an empty void, but this belief is not now generally upheld. In the absence of indisputable evidence regarding the presence or absence of a medium



between the sound in the studio and its re-creation in the home of the listener.
casting system—the new F.M. (V.H.F.) system is dealt with in a later chapter.

through which radio waves travel, the author prefers to look upon them as travelling through free space; a term which will be used throughout the remainder of this book.

A brief outline has been given of the chain of events which, starting at a broadcasting studio, culminated in waves being radiated from the transmitting aerial. These waves, which are in themselves of a non-electrical character, strike the receiving aerial, are partly absorbed by it, and cause a minute electric current to flow in exact sympathy with the current in the transmitting aerial. This tiny current is fed to the receiver, which for the present purpose is assumed to be of the popular three-valve type. The first unit of the receiver is an arrangement permitting it to select, within certain limitations, the frequency radiated by any desired transmitting station; this is referred to in Fig. 11 as the tuner.

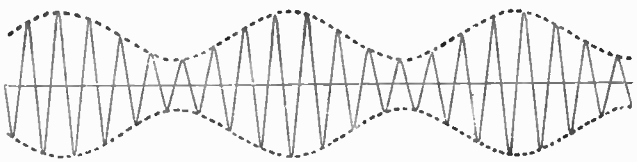


Fig. 12.—The modulated carrier wave showing both carrier and sound frequencies (amplified modulation system).

The feeble current is passed to the high-frequency amplifier which, as its name implies, increases the amplitude of the high-frequency current fed to it from the aerial.

Amplitude Modulation.—The output from the high-frequency amplifier will possess characteristics that are far removed from sound frequencies, because it still combines the two products of the transmitting station, namely the sound frequency and the carrier frequency, and in order that audible sound may ultimately be produced it is necessary, in effect, to get rid of the carrier wave. Reference to Fig. 12 will show that the sound frequency represented by the upper edge of the complete waveform is offset by its replica at the lower edge of the waveform. A moment's reflection will make it apparent that the average amplitude is, in fact, zero, because each speech-frequency " peak " is offset by an equal speech-frequency " trough " ; it is necessary, therefore, that either the upper or the lower half of the waveform be removed in order that the other half may remain as a waveform possessing a definite rise and fall in amplitude.

This rather complex change will be readily understood by referring to Fig. 13, which shows the upper dotted line shown in Fig. 12, but reproduced without its inverted duplicate and without the carrier wave, which is no longer of material importance.

Fig. 13.—The sound modulation removed from the upper half of Fig. 12.

The output from the detector will be a sound-frequency current exactly like that which flowed through the microphone at the transmitting station and will, incidentally, be of somewhat similar amplitude. This current, although several thousand times stronger than the aerial current, is still quite inadequate to work a loudspeaker ; it is therefore further increased by the output stage, which is designed to produce a power output capable of performing relatively heavy work, namely the operation of a loudspeaker.

There are numerous types of loudspeakers but they all rely upon some form of diaphragm for producing sound waves. The average type of loudspeaker has a circular diaphragm made of moulded paper about 8 inches in diameter ; it is constructed to be as light as possible consistent with mechanical strength, and mounted in such a manner that it is free to move backwards and forwards.

The sound-frequency currents flowing through the loudspeaker cause the diaphragm to move backwards and forwards in sympathy. If, for example, the vowel sound " a " is being reproduced the diaphragm will move backwards and forwards in the sequence of the appropriate waveform which is shown at Fig. 3. For really faithful sound reproduction the diaphragm would need to be capable of responding equally readily at any frequency between, say, 15 and 20,000 cycles per second ; in practice it is designed to respond to frequencies up to about 8,000 cycles per second, because this is the limit transmitted by broadcasting stations.

The diaphragm moving backwards and forwards causes the air to be compressed on the forward movement and rarefied on the backward movement, thus setting up zones of high and low pressure which radiate outwards and form sound waves which, striking upon the eardrum of the listener, give the sensation of sound which is a more or less faithful replica of the sound produced in the broadcasting studio a fraction of a second before.

The method of sound propagation has already been explained; it will be realised, therefore, that the actual air that was pushed forward by the diaphragm does not travel across the room like a draught and strike the listener, but, in simple language, the "layer" of air compressed by the diaphragm expands and compresses the "layer" next to it, which in turn compresses the next "layer," and so on.

Sidebands.—It has been stated that for really faithful reproduction a range extending up to about 20,000 cycles is required; it has also been stated that the average broadcasting station does not transmit frequencies above about 8,000 cycles. It is necessary that the reason for this limitation should be thoroughly understood, as it has a wide influence over radio technique and the design of modern receivers. For the sake of clarity the carrier wave has been referred to as a steady frequency; it has in fact a steady frequency when not modulated, *i.e.* during the programme interval, but when modulated additional frequencies appear. If, for example, a single frequency of 1,000 cycles per second is being modulated, actually three frequencies will be transmitted; the carrier frequency, carrier frequency minus 1,000 cycles per second, and carrier frequency plus 1,000 cycles per second. In practice, when the modulation is complex it occupies a definite band on each side of the carrier frequency. If the upper limit of modulation is limited to say, 8,000 cycles per second, and the carrier frequency is 1,000,000 cycles per second then that portion of the frequency spectrum will be occupied between 992,000 and 1,008,000 cycles per second.

The frequency spectrum occupied on *each* side of the carrier frequency is known as a *sideband*. The permissible sideband width is limited by the number of transmitters to be accommodated. At the present time their number is such that they are usually spaced 9,000 cycles apart. Consequently, they are unable to transmit the higher audio frequencies because overlapping between neighbouring stations would result. The frequency variation in the carrier is small compared to the carrier frequency, therefore, comparatively speaking, it may be said to have a steady frequency.

Cycles, Kilocycles, and Megacycles.—In order to assist all comparisons, all frequencies in this chapter have been referred to in cycles per second; it is conventional to refer to sound frequencies in this manner, but radio frequencies are referred to in terms of kilocycles or megacycles. A kilocycle is 1,000 cycles and a megacycle is 1,000,000 cycles.

As the speed of a radio wave is fixed, it is possible to convert frequency to wavelength and vice versa. To convert frequency in kilocycles to wavelength in metres divide 300,000 by the number of kilocycles.

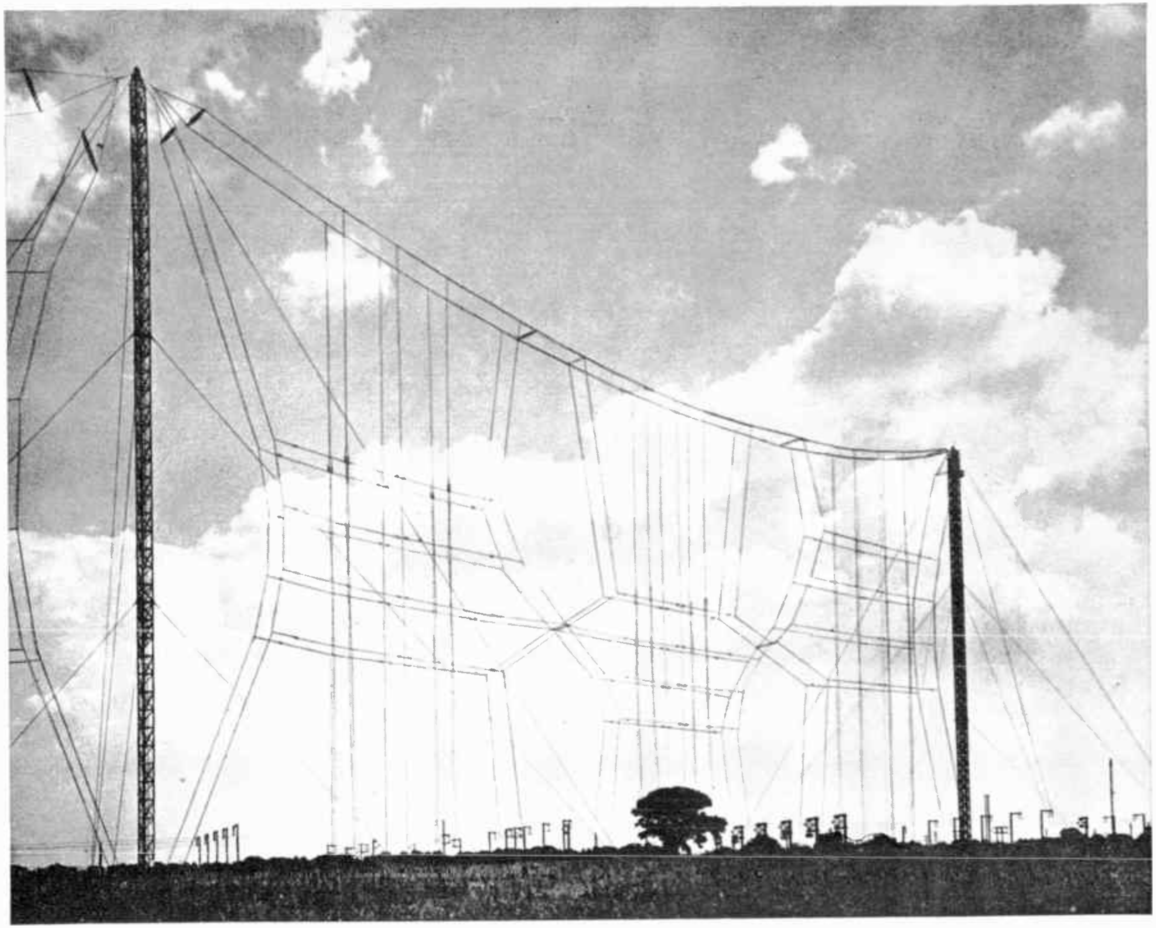
To convert wavelength in metres to frequency in kilocycles divide 300,000 by the number of metres.

Similarly, to convert megacycles to metres divide 300 by the number of megacycles.

To convert metres to megacycles divide 300 by the number of metres.

In this country it is a common practice to refer to medium- and long-wave stations in terms of metres and short waves in terms of megacycles; the new V.H.F. broadcasting stations are also referred to in terms of megacycles. In America it is customary to use kilocycles and megacycles. It is interesting to note that American receivers are not normally fitted to receive the long waveband, as they do not broadcast on this band.

R.T. 1—141



COMMONWEALTH BROADCASTING

A highly directional B.B.C. aerial array comprising 14, 17 and 19 metre systems which serve Western Australia, Malaya, West Indies and also Central America.

CHAPTER 3

WAVES IN FREE SPACE

THIS chapter is devoted to a detailed consideration of radio waves, their peculiarities, behaviour, and the natural obstacles which control the direction of their movement through free space. A radio wave which would normally reach a certain receiving installation may be so affected by influences outside human control that it may never reach its destination, or may be so attenuated as to be useless, or may alternately appear and disappear. It is necessary that these things should be understood in order that the working of devices for minimising their effects may be readily appreciated when reading the appropriate chapter.

It has already been intimated that radio waves are similar in character to those of light and heat and numerous other forms of energy; although these forms of radiation make themselves apparent in widely divergent ways, the characters of their waveforms are similar excepting only their wavelength or frequency. The shortest known wave that travels through free space is termed penetrating radiation, which reaches the earth from some unknown source, presumed to be many millions of miles out in space, and has a wavelength of ·00000000000005 metres,[1] while the longest known waves are those used in radio which extend to above 20,000 metres.

The wavelengths used for broadcasting are divided into four bands, the limits of which, unfortunately, vary owing to the lack of proper standardisation, but for the purposes of this work the four wavebands will be as follows:

Long waves, 900–2,000 metres (333–150 kcs.).
Medium waves, 200–600 metres (1,500–500 kcs).
Short waves, 10–100 metres (30–3 mcs.).
Ultra-short waves, (V.H.F.) below 10 metres (30 mcs.).

Ionised Layers.—The term free space implies that radio waves are free to travel therein but does not imply a freedom from obstacles which beset their path. At varying heights above the earth's surface there are layers or belts of air that have the property of bending waves; these layers are electrically conductive, are termed ionised layers, and are caused by a bombardment of particles which are given off by the sun in streams which strike the earth's atmosphere. These layers are very variable in character, and their height and density in any particular region alter with the rotation of the earth, thus conditions are inclined to recur every 24 hours. Two of these layers are named after their discoverers and are called

[1] A metre is approximately 40 inches.

the Heaviside layer and Appleton layer, the others being referred to alphabetically. The lowest layer is in the region of 5 miles above the earth, while the highest, which concerns radio reception, is about 200 miles high.

Fig. 14.—The ground wave propagated by the transmitter (left) follows the earth's curvature and impinges on the receiving aerial (right).

Radio waves radiate in all directions above the earth's surface. If the receiving aerial is, say, 10 miles away, the waves will arrive at their destination in a substantially straight line, but where the distance is sufficiently great, the horizon will come between the two aerials on account of the earth's curvature. This presents no obstacle, providing the distance is not too great, as the waves will follow the earth's curvature for a distance that decreases with frequency; this is diagrammatically illustrated at Fig. 14.

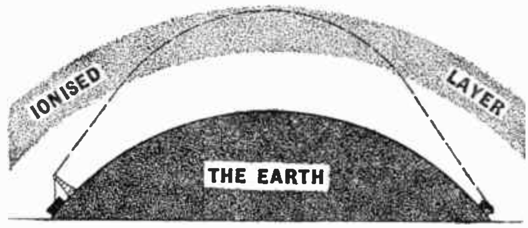


Fig. 15.—The sky wave propagated by the transmitter (left) is bent by an ionised layer many miles above the earth's surface and returns earthwards to impinge on the receiving aerial (right).

A large proportion of the radiated energy travels upwards towards the sky and would be lost in space if it were not for the bending properties of the various ionised layers, which will deflect a wave to an extent dependent on the density of the former and the frequency of the latter. Fig. 15 gives an impression of the manner in which the transmitter "sky wave" is bent so that it returns to earth at a point which would otherwise have been out of range. It is possible that the first layer may exert only a small influence on the direction of a particular wave, so that it continues on a path away from the earth, but upon entering the second layer it may bend so sharply that it returns earthward and, generally speaking, will again suffer a slight change of direction as it passes through the lower layer on its return journey.

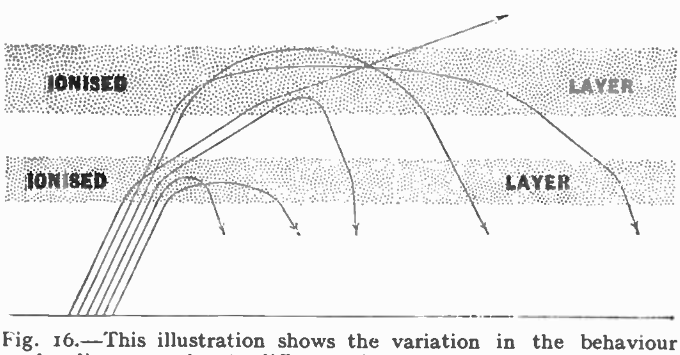


Fig. 16.—This illustration shows the variation in the behaviour of radio waves due to difference in frequency and also the effect of ionised layers of different density.

The illustration, Fig. 16, shows the paths of a number of radio waves which, although propagated into space in the same direction and from the same area, behave differently on entering ionised layers because of their varying frequency ; the waves portrayed in this diagram might be grouped under four headings ; (*a*) those which bend so sharply on striking the lower layer that their path almost forms a triangle ; (*b*) waves which bend so gradually that they travel for a considerable distance before returning earthwards ; (*c*) those which pass through the lower layer but are bent down by the upper layer, and (*d*) those which are but slightly bent by both layers and either travel outwards into space, are bent down by a higher layer, or pass through and along so many layers that they are absorbed.

Skip Distance.—The higher frequencies, *i.e.* those covered by the short and ultra-short wavebands, do not travel along the ground for any great distance, largely due to the fact that they are readily absorbed by material objects that they will normally encounter ; the ground wave radiated by a short wave transmitter working with a frequency of, say, 10 mcs. may die away after travelling only a few miles ; for the purpose of this example this distance may be nominally 20 miles. It is unlikely that the sky wave from the transmitter will bend sufficiently sharply to come down to earth at a distance of less than, say, 300 miles ; thus between 20 and 300 miles reception is impossible. This area is known as the skip distance.

Skip distance may occur in a number of zones ; when the ionised layers of the upper atmosphere are in a suitable condition, reception from a particular transmitter may be obtainable at various distances interspaced by zones where reception is impossible. It is due to the phenomenon of skip distance that the short-wave Commonwealth transmissions from Daventry are difficult to receive in this country although easy to pick up in India, Australia, and the various Dominions which they are intended to serve. Like all phenomena connected with the reflection of radio waves, skip distance varies with the time of day, and to compensate for this the frequency of short-wave broadcasting stations is varied throughout the 24 hours so that it does not affect areas that are intended to be served by the transmitter.

Daytime broadcasting relies almost entirely on the ground wave for the medium and long wavebands, although long-distance short-wave reception relies on the reflected wave during the whole 24 hours. When a receiving aerial picks up the ground wave only the volume of the signal will remain sensibly constant, but when both ground and sky waves are received (the condition that will usually obtain on all wavebands at all times, with the exception of medium and long waves during full daylight), fading will be present. This phenomenon will be familiar to anybody who is in the habit of listening to foreign broadcasting stations, but as the term " fading " is often confused with the term " fade-out " it will be as well to define the former.

Fading.—Fading is a periodic rise and fall in volume, which is sometimes so bad that one minute reception may be uncomfortably loud, and the next, die away to silence; the time interval between successive increases and decreases may be five minutes or more, on the other hand it may only be a fraction of a second. The latter condition will render speech unintelligible and turn music into a farce. Fading is caused by two or more waves which, although originating from the same transmitting aerial, have followed different paths before impinging upon the receiving aerial.

It will be remembered that a radio wave causes a current to flow up and down the receiving aerial in sympathy with its own upward and downward movement; if two waves of equal amplitude arrive by different paths, the current in the aerial will be doubled providing that the two waves rise and fall together; but if, on the other hand, one wave rises to its maximum height at the same instant that the other wave falls to its maximum depth, each will cancel the other and consequently there will be no aerial current and no signal will be heard; there are, of course, intermediate stages between these two extremes. Unless the two waves are of equal amplitude, as cited in the example above, the signal will not entirely disappear. Suppose that a wave A had an amplitude equal to 50 per cent. of a wave B, it is obvious that the limits of fading would be B − A to B + A. When two waves or waveforms are in step, that is to say they rise and fall precisely together, they are said to be in phase, while, if they bear any other relationship, they are out of phase.

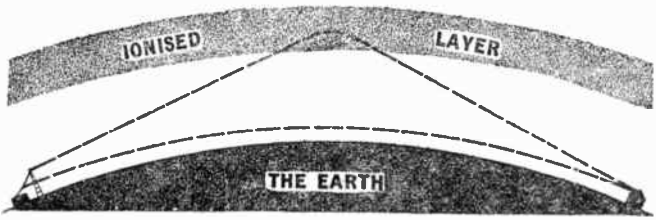


Fig. 17.—Under certain conditions both ground and sky wave will impinge on a receiving aerial and cause the phenomenon known as fading.

A few moments' thought will show that the two waves will be in phase if the difference in the length of their paths is an exact multiple of the wavelength, whereas, on the other hand, if the difference of the distance in metres is an exact multiple of the wavelength plus half a wavelength, then the two waves will be in exactly opposite phase.

Fig. 17 shows a ground wave and sky wave both impinging upon the receiving aerial, a condition which is a common cause of fading; the total length of the ground-wave path remains constant, whereas the length of the sky-wave path continually alters due to random changes in the height or condition of the reflecting layer. The alternative cause is two

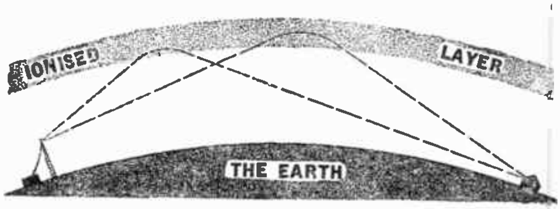


Fig. 18.—Variations in the density of an ionised layer sometimes cause two sky waves to impinge on the receiving aerial, resulting in particularly bad and erratic fading.

sky waves which strike the reflecting layer at different points but, due to varying local density, bend at dissimilar angles and so meet at the receiving aerial, see Fig. 18. Fading caused in this way is usually more erratic, as the length of the path followed by both waves is each undergoing continuous change.

Selective Fading.—If two waves of different frequency are radiated from the same place, one may bend more sharply than the other. It will be remembered that a modulated wave is not radiated as a single frequency but as a narrow band of frequencies. The station working at a frequency of 1,000 kc. will, therefore, cover a band of 993–1,007 kcs. If this wave strikes the ionised layer when it is in a peculiar condition it will bend a 993-kc. wave more sharply than a 1,007-kc. wave, with the result that the receiving aerial will pick up only a portion of the modulated wave, which causes distorted reproduction.

This form of distortion is termed selective fading, and is distinguished by reproduction becoming progressively less intelligible until speech or music is reduced to a meaningless jumble devoid of the higher musical scale. Reproduction then returns to normal, although, when conditions are bad, it may disappear completely for a short time.

Both ordinary and selective fading are peculiar inasmuch as they may have a profound effect on reception for an hour, a day, or a week, while, when conditions improve, these phenomena may be practically non-existent for a considerable period; American stations, for example, may fade so badly and rapidly that they are unintelligible on one evening, while on the next evening reception may be almost as steady as that obtainable from the local B.B.C. station.

Fade-out.—Fade-out is another phenomenon which adversely affects long-distance reception. Unlike fading, which is more or less periodic rise and fall, fade-out is characterised by signals on the short wavebands suddenly becoming unobtainable or else becoming very weak; this period of impaired reception may last for only half a minute or for an hour or more, and then terminate by reception reverting to normal with surprising rapidity. This type of fade-out is known as the Dellinger fade-out; the cause is not fully understood, but sufficient data are available to conclude that it is attributable to the effect of radiation from sun spots on the earth's atmosphere.

There is another type of fade-out which differs from the Dellinger inasmuch as the strength of signals decreases gradually, often taking some hours to reach a minimum level, where it remains for a period that may be several hours, days, or even weeks. This type of fade-out usually appears concurrently with magnetic storms, which have a marked effect on the height and density of the ionised layers in the upper atmosphere.

Those who possess a short-wave receiver will have noticed that long-distance reception is only obtainable on certain wavebands at certain times of day. It has already been explained that reception on the short wavebands (higher frequencies) is dependent on the reflected sky wave; since the density of the reflecting layers varies throughout the 24-hour rotation of the earth, it follows that the wave will only be obtainable at a certain distance if its frequency is such that it bends in the right manner. Thus, when the whole path between the transmitter and the receiver is in daylight, the higher frequencies become effective, while, conversely, when both transmitter and receiver are in total darkness, lower frequencies such as the 49-metre band become usable. The correct choice of short wavebands for receiving distant stations at various times during night and day is given in Appendix 1 (5), with general hints.

Atmospherics.—Reception from a distant station is often marred by extraneous noise arising from sources other than radio transmitters. This background noise, as it is called, may consist of random clicks and bangs which can be so numerous as to resemble the sound associated with the frying of bacon, or alternatively the noise may be of a continually recurring nature suggestive of some electro-mechanical device such as a sewing machine or a motor car. Whatever the source or nature of background noise it is quite properly included under the chapter heading "Waves in Free Space," as it is usually through this medium that noises are conveyed to the receiver.

There are two distinct causes of background noise, the first of which is termed man-made static and, as its name implies, has an earthly origin. It includes waves generated and propagated into space by electrical machinery or appliances, of which the following are typical examples: electric-lift motors, trams, trolley buses, vacuum cleaners, refrigerators, fans, industrial motors, motor-car ignition systems, neon signs, X-ray, ultra-violet, and other electrical medical apparatus. Some television receivers also radiate interference.

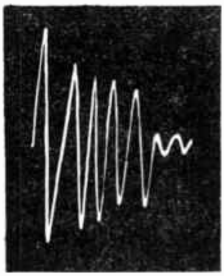


Fig. 19.—An atmospheric recorded by the cathode-ray oscillograph.

The other form of background noise is termed atmospherics, which are of natural origin. This type of interference is most prevalent during thundery weather, and is characterised by a hiss followed by a sharp crack, reminiscent of a damp firework. Atmospherics become louder and more frequent with the approach of a thunderstorm and attain great volume when the storm centre is in the region of the receiving aerial.

Atmospherics are not always attributable to local thunderstorms, but may be due to severe electrical disturbances remote from the receiver, or to electrical storms hundreds of miles above the earth's surface. It has been suggested that this disturbance may, on occasion, originate from the sun, where electrical disturbances of colossal magnitude are not infrequent. Fig. 19 shows the waveform of an atmospheric, photographed by the author; it will be observed that unlike waveforms previously illustrated the amplitude tends to decrease progressively.

CHAPTER 4

ELECTRICITY

THE expression " electric current " is to-day a household word, and is looked upon, by the uninitiated, as something which flows along the wires and illuminates our houses and cities. Few ever pause to wonder how it is that an electric current can flow through a solid wire, while many take refuge behind the assertion that the nature of electricity is still a mystery. In the reign of King George III, electricity and everything to do with it was undoubtedly wrapped in the most profound mystery, for it was at this time that Galvani hung some dead frogs on an iron fence by brass hooks and then set about trying to find out why they kicked (although dead) each time the brass hooks touched the iron railings.

To-day, however, electricity may be considered an exact science, and almost every form of electrical phenomena can be prearranged or accurately predicted. There are many methods of approaching the fundamental principles of electricity, but in the author's opinion the most satisfactory line of approach is through a brief description of the theory of matter; for this purpose the neutron is ignored.

The Basic Electron Theory; Protons and Electrons.—Solids, liquids, and gases are the three broad groups into which matter is divided. The word " solid," although undoubtedly a useful addition to the English language, is somewhat of a misnomer, as the popular conception of a solid is a serious obstacle in the way of understanding the true nature of matter. Whether a piece of copper, steam from a kettle, or a joint of meat is chosen as an example, it is still basically the same thing when reduced to the ultimate two units of which everything is composed.

A road is sometimes made of granite " bricks " : a castle is sometimes made of granite " bricks." The unit (a granite " brick ") is the same in each case, the difference between these two examples is purely the manner in which the " bricks " are arranged.

If, for example, a piece of copper about the size of a pin's head could be divided a million × million × million times, each of the " pieces " would be an atom. The smallest division, therefore, of copper (or any other element) is an atom, because further division would turn the particle from a copper atom into two or more atoms of some other element. The atom, as already intimated, is the unit of any element, and it is necessary to know something about its structure. The simplest atom is that of the gas, hydrogen, as it is made up of only two parts, a proton and an electron; the proton is the larger of the two and is the centre around which the electron revolves in precisely the same way that the earth revolves round the sun. The electron and the proton have a mutual attraction for each other and are dissimilar, and this dissimilarity is referred to by saying that the proton is positive and the electron is negative. The proton may be conveniently looked upon as a fixture, while the electron, which has about $\frac{1}{2000}$ of its mass, may be regarded as being lively, adaptable, fast moving, and often unstable. In plain English, electrons are electricity, and for this reason the electron is often considered as the unit of electrical quantity or charge.

We are more concerned with the electron than the proton, and furthermore a detailed description of the theory of matter has no place in this volume, but before leaving the subject a little further information may be usefully included as it will assist the reader to understand the functioning of electric batteries and valves. As already stated an atom of hydrogen comprises one proton with one electron revolving round it, an arrangement that is diagrammatically illustrated in Fig. 20. The hydrogen atom is obviously the simplest of all atoms ; before going on to investigate the arrangement of more complicated atoms it is necessary to comment upon the relationship that exists between these incredibly minute particles.

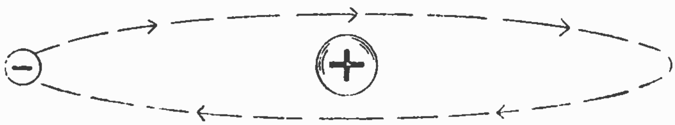


Fig. 20.—A diagrammatic representation of the hydrogen atom which comprises a single proton with one electron revolving round it.

The electron is negative and has a great attraction for the positive proton ; on the other hand, similar charges have an equal repulsion, that is to say, two electrons will repel each other or alternatively two protons will repel each other. This introduces the first fundamental rule which governs all electrical and magnetic phenomena : *like signs repel, unlike signs attract*, the conventional sign for the proton being + and for the electron —. In order that an atom may be a stable, self-contained unit, it is necessary that it shall comprise an equal number of protons and electrons.

The protons must necessarily congregate in the centre, and to make this possible there must be one or more electrons associated with them, as without an opposite sign to attract them they would push away from each other. The central collection of protons and electrons is called a nucleus and the electrons contained therein are called fixed electrons, while the electrons which spin round on an orbit outside the nucleus are called free electrons. The conception of an atom is somewhat difficult to grasp, but the following examples will help to make it more understandable.

The helium atom is illustrated at Fig. 21, the nucleus of which comprises four protons and two electrons, while two free electrons revolve on a common orbit.

An atom of carbon has a nucleus comprising twelve protons and six electrons, and six free electrons ; this atom is diagrammatically illustrated at Fig. 22, from which it may be observed that the free electrons do not share a common orbit but two concentric orbits. It is most important to remember that the electrons on the outside orbits of any system are more readily detached than those on the inside orbits.

Fig. 21.—The helium atom has two free electrons revolving round the nucleus which is made up of four protons and two electrons, and has a positive charge equal to two protons.

It will be unnecessary to deal separately with the atom of each element such as carbon, nitrogen, oxygen, copper, silver, and so on up to one of the most complicated atoms, such as the metal uranium, which has a nucleus comprising

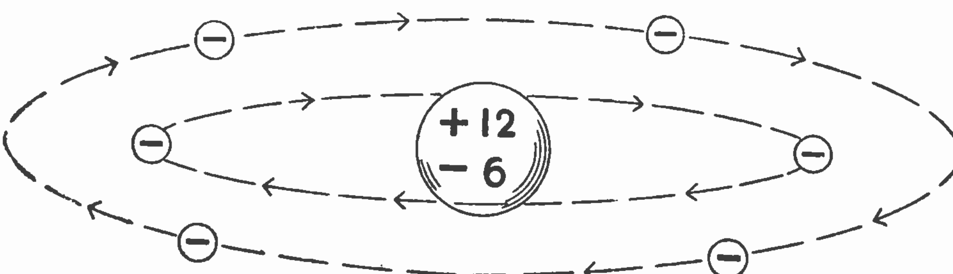


Fig. 22.—The carbon atom has six free electrons revolving on two orbits round the nucleus which is made up of twelve protons and six electrons and has, therefore, a positive charge equal to six protons.

one hundred and eighty-four protons with ninety-two electrons and ninety-two free electrons.

The Electric Current.—The above simplified explanation of atomic structure is included primarily to pave the way for an explanation of that phenomenon which is commonly called an electric current. Imagine a long string of atoms of copper each of which will be, as already explained, a stable and complete family. Suppose that an isolated electron is introduced into atom number one ; this will completely upset the balance between positive and negative charges, as there will be one electron too many and the attraction of the nucleus will be unable to hold this additional burden. Suppose that yet another electron is introduced into atom number one, which will result in such a congestion that an electron is forthwith thrown out from atom one into atom two. Atom two is now unable to stand the burden of the new addition and will eject a surplus electron ; it cannot throw the "outsider" back to atom one as this still has a surplus electron, therefore it must necessarily throw the spare electron into atom three. Provided that spare electrons are continuously introduced into atom one it will continue to pass on a spare electron to atom two, which will in turn pass on a spare electron to atom three, and so on for as long as spare electrons are poured into atom one.

The idea of talking about a single electron is purely for the purpose of simplifying the explanation, as also is the idea of a single string of atoms. The finest piece of copper wire imaginable would be many millions of atoms wide, and similarly a small electric current such as would flow through a flashlamp bulb would represent untold millions of millions of electrons per second.

It has probably taken three minutes to read this explanation of the movement of an electric current, but actually the rate of travel is inconceivable, speeds of the order of tens of thousands of miles per second being perfectly normal.

Insulators and Conductors.—Although the electric current travels at a prodigious pace it does not follow that a particular electron will accomplish the journey from one end of a piece of copper wire to the other at even " walking pace." It will be remembered that it has been stated above that an electron introduced into atom one caused it to pass an electron on to atom two, not necessarily the same electron ; recent experiments have shown that although untold millions of electrons per second may enter one end of a piece of wire, say ten feet long, and similarly untold millions of electrons per second may leave the other end of the wire, it may take an hour or more for a particular electron to complete the journey. The atoms of certain materials are so arranged that they *will not pass* an electron from one atom to the next ; such materials are called insulators, examples of which are ebonite, porcelain, glass, real silk, rubber, paraffin wax, etc. Those materials which *are able to pass* an electric current are called conductors, although their efficiency varies considerably. Typical examples of conductive materials are the majority of metals, carbon, graphite, acids, etc.

A brief outline has been given above showing how electrons can be passed from one atom to another in a conducting material providing that there is a surplus number of electrons at one end. A moment's reflection will show that a current of electrons could not flow along a conductor if there were not an outlet at the far end. This significant fact automatically carries the foregoing explanation to its conclusion in as far as the actual passage of electrons is concerned.

It follows, therefore, that for a stream of electrons to flow along a conductor, the following conditions must be present :

(*a*) There must be a surplus of electrons available ; this is obvious, because an electric current is simply and solely a stream of electrons and it cannot flow if it does not exist ;

(*b*) There must be a means of disposing of the electrons when they reach the end of the conductor, which means that the conductor must be attached to something that is short of electrons.

Polarity.—When something is short of electrons it is positive in respect to something that is not so short of electrons or alternatively has a surplus. Conversely, something which has more electrons is said to be negative in respect of something which has a shortage. When dealing with electricity for the purposes of radio engineering it is absolutely imperative to forget any preconceived ideas that this or that is positive or negative, in the same way that one may say that this is white and that is black. It is incorrect to regard any particular point on a piece of electrical apparatus as intrinsically positive or negative; some particular point may, however, be positive in respect to some other point and in turn may well be negative in respect to some further point. For the sake of convenience, however, it is customary to refer to the most negative point as negative and to refer to other points as being so many volts positive in respect to it.

This relationship may be more readily understood if a simple flashlamp battery is used as an example: one of the projecting tags is colloquially called the positive terminal and the other the negative terminal. It is implied, however, that the positive terminal is positive in respect to the negative terminal and vice versa.

Only half the phenomenon of an electric current has been explained, and in the interests of simplicity the cart has been put before the horse. It has been stated that electrons will flow through a wire providing that there is a surplus at one end of the conductor; no mention has yet been made regarding the source of these electrons, which may be either a battery or some form of generator, such as a dynamo. As the latter can scarcely be considered within the scope of this book the former will serve our purpose very well.

The Simple Cell.—The word "battery" is apt to be misused, it is therefore desirable to mention that strictly speaking this word means two or more cells; thus the ordinary 2-volt accumulator is a cell, but when two of these are joined together, either temporarily or permanently, they become a battery. There are two types of cells: the primary cell, of which the dry cell is a typical example, and the secondary cell, the only example of which is the accumulator.

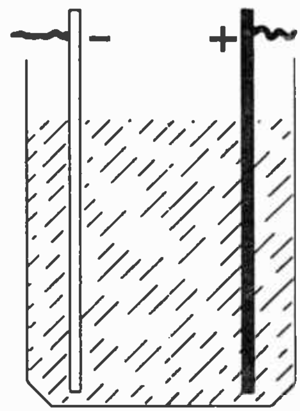


Fig. 23.—A simple cell consisting of a zinc plate (−) and a copper plate (+) partly immersed in a weak solution of sulphuric acid and water.

There are numerous varieties of primary cells, but for the purpose of explaining the principle that shown at Fig. 23 will serve. It consists of a copper plate and a zinc plate partly submerged in a weak solution of sulphuric acid and water. The zinc plate must of necessity be coated with mercury, as otherwise it would be eaten away in a matter of seconds. The action of a primary cell is dependent on positive and negative ions; it will be remembered that a normal atom always has an equal number of electrons and protons. If, however, it has lost one or more electrons it is no longer an atom but an ion, and since the protons outnumber the electrons, it is a positive ion.

If, on the other hand, an atom acquires one or more electrons it becomes a negative ion.

The atoms of certain substances are prone to lose electrons, others are prone to acquire them. In the cell illustrated at Fig. 23, the zinc atoms tend to acquire electrons from the negative ions in the solution, while the copper atoms tend to become short of electrons due to absorbing positive ions from the hydrogen which forms on its surface, and there is a flow of positive ions in one direction and negative ions in the other. In this way the positive terminal is short of electrons and is said to be at high potential, *i.e.* positive in respect to the zinc plate which has a surplus of electrons, which will flow to make up the deficiency at the positive terminal provided that the two terminals are connected together.

As already intimated, the true direction of an electric current is *from negative to positive*; some confusion arises because earlier textbooks refer to the current travelling in the opposite direction. This unfortunate state of affairs is due to early scientists misinterpreting electrical phenomena.

The Accumulator.—The secondary cell, which is variously known as the storage cell and the accumulator, resembles the primary cell in broad principle but differs very considerably in detail. In place of the copper and zinc plates in the simple cell illustrated at Fig. 23, it has plates constructed in the form of lead grids, a typical example being shown at Fig. 24. The positive plate is filled between the mesh of the grid with a mixture of red lead and sulphuric acid, which is forced in under great pressure in the interests of mechanical strength, while the negative plate is filled with litharge and sulphuric acid. The solution, or electrolyte, to use the proper term, consists of sulphuric acid which is mixed with water in such proportions that the specific gravity is about 1·1. Unlike the primary cell the accumulator is not ready for use until it has been "charged"; this is achieved by passing a suitable electric current through the accumulator in the reverse direction, that is to say, in at the negative side and out at the positive side.

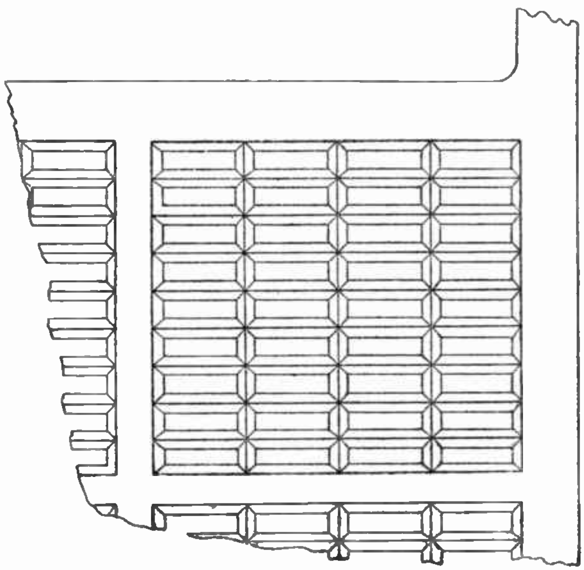


Fig. 24.—A corner of a typical accumulator plate showing the grid formation before it has been filled with lead paste.

The electrons, passing through the electrolyte on their journey from the negative to the positive plate, decompose the water and cause oxygen bubbles to form on and be absorbed by the positive plate and hydrogen[1] to form on and escape from the negative plate. Charging is continued until the plates are incapable of further chemical change, at which time the electrolyte will have attained a specific gravity of about 1·25. An examination of the accumulator will show that the positive plate has become a warm chocolate colour, while the negative plate assumes a very dark grey colour. If a suitable conductor is placed between the terminals of a charged accumulator, current will pass from the negative plate via the conductor to the positive plate; at the same time the positive plate will throw off oxygen and become deficient in electrons, while the negative plate will throw off hydrogen and acquire a surplus of electrons.

If the accumulator is allowed to discharge itself completely it will return to its uncharged state, *i.e.* the specific gravity will have fallen to 1·1, the positive plate will lose its warm colour and the negative plate become light grey in colour.

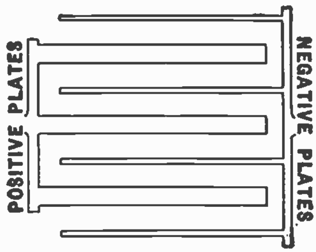


Fig. 25.—The arrangement of a seven-plate accumulator.

The accumulator, as interpreted by various manufacturers, is available in numerous forms designed to suit a diversity of purposes; those used with radio apparatus are too well known to need description. It may be mentioned, however, that the simplest form of accumulator has two plates, while more complicated types may have any odd number of plates. Fig. 25 shows the arrangement of a seven-plate accumulator which is made of three positive plates and four negative plates. In the interests of long life, accumulators require proper care and attention, a subject that is fully dealt with in the appropriate chapter.

Potential Difference.—It has been explained that an electric current flows from a negative to a positive point due to the difference in electron content at the said points; this difference is called "potential difference," the magnitude of which is expressed in terms of a unit called the volt.

Potential difference should not be confused with electromotive force, which is the latent driving force in a battery. Electromotive force is present in the battery whether it is in circuit or disconnected. When the voltage of a battery on open circuit is measured the figure obtained is the e.m.f. If, however, it is measured when connected in circuit the figure obtained may be regarded as potential difference.

A single dry cell, for example, has an e.m.f. of 1·5 volts approximately, which means that this force is available to drive a current through any circuit which may be completed between its terminals. If two such cells are connected in series, *i.e.* + terminal of one is connected to the —

[1] A naked light should never be exposed near an accumulator when on charge as the escaping hydrogen will combine with air and may explode.

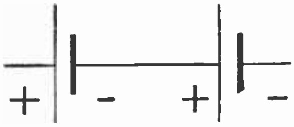


Fig. 26.—The conventional method of showing a cell may be seen from this illustration which shows two cells in series. The long thin line always represents the positive terminal and the short thick line the negative terminal.

terminal of the other, then the e.m.f. across the battery will be 3 volts, and so on, see Fig. 26.

To summarise, electromotive force is the total available voltage of a battery, whereas potential difference is the active difference of voltage in an electrical circuit. p.d. = potential difference. E = electromotive force. V = volt. I = current.

The Ampère.—The next consideration is the measurement of the quantity of current flowing. This may be one thousand or one million or any number of electrons per second. The unit for expressing the quantity of current flowing is called the ampère, which is often written as amp and is symbolised by the letter "A." The measurement of the flow of current through a wire is comparable to the measurement of water flowing through a pipe in terms of gallons per minute; it is important to note that the flow of current is the same throughout its entire journey, whereas potential difference decreases progressively.

Consider the simple circuit shown at Fig. 27, which consists of a loop of wire which, for purposes of reference, is divided into three equal sections. Assume that one ampère is flowing from the negative terminal; it follows that one ampère is flowing right through the whole circuit and back through the positive terminal of the cell.

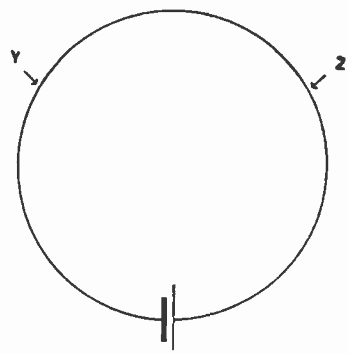


Fig. 27.

If the total voltage across the cell is 1·5 volts, the potential difference between — and Y will be ·5 volt (see Fig. 27); the voltage between Y and Z will be ·5 volt, and the voltage between Z and + will also be ·5 volt. A moment's reflection will show that this must be so because current will flow only to a point of higher potential, and as the current is flowing from — to Y and from Y to Z it follows that Y must be at a higher potential than —, Z higher than Y, and + higher than Z.

Resistance.—It has been implied that current has to be forced through a conductor; it is obvious that if energy is required to bring about a flow of current there must be some opposition to be overcome. This opposition is called resistance which is written "R," and measured in terms of a unit called the ohm which is abbreviated by the symbol Ω which is the Greek letter omega. Every electrical circuit must contain resistance, and if there is current flowing there must be voltage. It is the relationship between voltage, current, and resistance that is so vitally important, as it forms the basis of all simple electrical formulæ, and furthermore it gives an insight into the meaning of these terms that is readily understandable. This relationship is called Ohm's law, and it is impossible to overstate the importance of this law to all who desire to obtain a practical knowledge of radio or electrical engineering.

Ohm's Law.—The original law as put forward by Georg Ohm in 1826 is not very informative, but the following interpretation will better serve the present need.

One volt is the electric pressure necessary to force a current of 1 ampère through a resistance of 1 ohm; this gives the simple equation, volts = ampères × ohms which, written in a conventional and workmanlike way, is—

$$V = IR$$

A slight rearrangement of the preceding paragraph shows that 1 ampère is the amount of current that 1 volt can force through a resistance of 1 ohm; this gives the simple equation, ampères = volts ÷ ohms, which is written—

$$I = \frac{V}{R}$$

Yet another rearrangement shows that 1 ohm is the resistance that permits a current of 1 ampère to flow when the p.d. across the resistance is 1 volt; this gives the equation ohms = volts ÷ ampères, which can be written—

$$R = \frac{V}{I}$$

(in the above equations V = p.d. in volts, I = current in amps, and R = resistance in ohms).

Consider the simple circuit Fig. 28, if the p.d. across the cell be 2 volts and the value of R be 1 ohm the application of Ohm's law will show that the current flowing is 2 ampères. Consider next the more elaborate circuit Fig. 29, which consists of a 3-volt battery and three resistances having value of 1, 2, and 3 ohms respectively. The total resistance, then, is 6 ohms, and the voltage of the battery is stated to be 3 volts, therefore the current must be ·5 amp. It is also interesting to note the varying potential drop at different points in the circuit. As a current of ·5 ampères is flowing in the circuit, the drop across the 1-ohm resistance will be ·5 volt, across the 2-ohm resistance will be 1 volt, and across the 3-ohm resistance 1·5 volts.

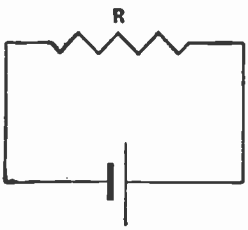


Fig. 28.—A simple circuit.

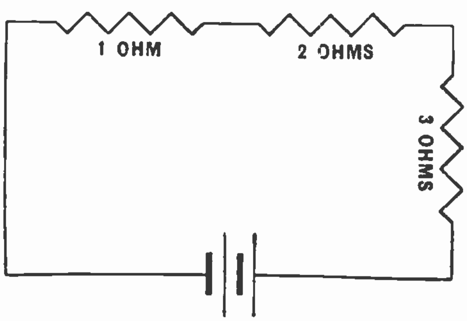


Fig. 29.—A circuit comprising three resistances in series.

The three resistances in Fig. 29 are

said to be in series, which is the term used when they are so connected that the total current has to pass through each in turn; similarly the two cells in this illustration are also in series. Fig. 30 shows three resistances in parallel, which is the term used when they are so connected that the current divides and a portion goes through each, the actual proportion through each resistance being determined by the relative value of each resistance.

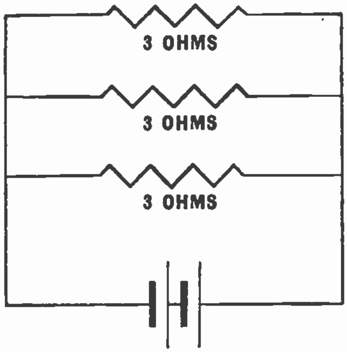


Fig. 30.—Three resistances in parallel.

Assume the p.d. across the resistances to be 3 volts, and each resistance to have a value of 3 ohms; the total resistance will be 1 ohm, which will permit a current of 3 ampères to flow: 1 ampère will flow through each resistance.

The value of *two* resistances in parallel can be found by dividing their product by their sum; for example, suppose two resistances are connected in parallel having a value of 5 ohms and 20 ohms respectively the sum of 5 and 20 = 25, the product of 5 × 20 = 100, therefore, by dividing 25 (the sum) into 100 (the product) gives the answer 4 ohms. The value of any number of resistances in parallel can be determined by

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \text{ etc.}$$

Wattage.—It is apparent that the actual power performed in a circuit is governed by the amount of current flowing and the force which causes it to flow; consequently, to determine the amount of power expended it is necessary to take into account both voltage and ampèrage which is achieved by using a unit called the watt.

Wattage is determined by multiplying together volts and amps. 1 volt × 1 amp = 1 watt; by applying this rule to Fig. 29 it will be found that the total wattage is 1·5, which is arrived at by multiplying the p.d. of 3 volts by the current which is ·5 amp. The arrangement shown at Fig. 30 has, it will be remembered, a p.d. of 3 volts and a current of 3 ampères, therefore the dissipation is 9 watts, 3 watts in each resistance.

The word "dissipation" is used because voltage has been "lost" in the resistance. It is impossible to lose or destroy energy but quite possible to convert it into another form; in the case of resistance the energy represented by the voltage dropped is converted into heat, which is dissipated into the surrounding atmosphere: a typical example is the ordinary electric fire, which converts electricity into heat and dissipates the latter into the room.

Resistances are normally provided with a wattage rating which indicates the maximum wattage that the resistance can dissipate without suffering ill effect due to overheating or complete decomposition.

Ohm's law is equally applicable to the watt and may be interpreted in three variations. The symbol for the watt is "W." Volts × amps = watts, which is conventionally expressed—

$$VI = W$$

When it is desired to determine the wattage without taking voltage directly into the formula, this is achieved by the formula $(\text{amps})^2 \times \text{ohms} = \text{watts}$, which is written—

$$I^2 R = W.$$

When it is desired to determine the wattage without directly taking the ampèrage into consideration, the following formula is used: $(\text{volts})^2 \div \text{ohms} = \text{watts}$, which is expressed—

$$\frac{V^2}{R} = W.$$

(In the equations above, V = p.d. in volts, I = current in ampères, R = resistance in ohms, and W = watts.)

As already stated, the watt is the unit that expresses the power accomplished in an electrical circuit, it is therefore interesting to note that 746 watts is equal to 1 horsepower, a comparison that serves to give some idea of the power represented by 1 watt.

Direct Current.—All electrical phenomena dealt with in this chapter have been confined to that type which has a steady current flowing in a definite direction; this type of current is known as direct current, which broadly speaking may be defined as a current which flows in one definite direction and which never drops below zero. Direct current is usually written D.C., and is sometimes called continuous current.

Alternating Current.—An alternating current is a phenomenon associated with radio signals, microphone currents, and the like. It is a current which alternately flows first in one direction then in the opposite

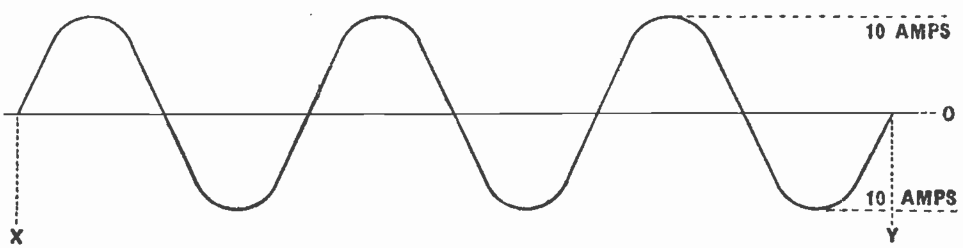


Fig. 31.—An alternating current waveform which has a peak value of 10 amps.

direction. Fig. 31 shows a typical A.C. waveform which, it will be noted, is similar to sound waveforms illustrated in previous chapters. Commencing from the left-hand side it will be seen that the current starts to rise from zero sharply at first and then progressively slower until the maximum is reached, which in this example is 10 amps. The current then starts to decrease until it reaches zero (literally 0 amps), at which point no current is flowing. The current next commences to flow in the opposite direction until it reaches a maximum of 10 amps, after which it dies down until it reaches zero when the cycle of events recommences and continues to repeat. The number of times per second that the current will complete a cycle is known as the periodicity or frequency; in Fig. 31 there are three complete cycles, and if the distance XY is assumed to represent one second, it follows that the frequency is three cycles per second. If the distance XY represented $\frac{1}{100}$ of a second the frequency would be 300 cycles per second.

Alternating currents generally met with in broadcasting range from 16 cycles per second, which is the lowest note of the organ, to about 60,000,000 cycles, which is the frequency that would be used by a transmitter working on a wavelength of 5 metres.

The A.C. waveform shown at Fig. 32 serves to illustrate A.C. voltage. Here again the voltage commences at zero, rises to a maximum, which

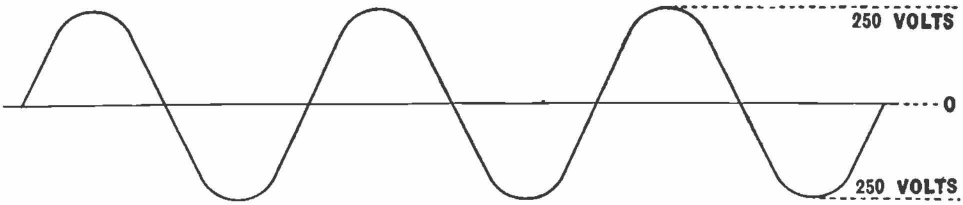


Fig. 32.—An A.C. voltage waveform with a peak value of 250 volts.

in the example chosen is 250 volts, and dies away to zero, after which it again builds up to a maximum but the polarity is reversed.

A pair of wires carrying direct current possess polarity, *i.e.* one is positive and the other is negative, but a pair of wires carrying alternating current do not possess polarity because each is alternately positive and negative. The waveforms chosen as examples in Figs. 31 and 32 show waveforms that are symmetrical, or in other words the two halves are separated by the imaginary zero line and are similar in appearance. Figs. 3–8 are typical examples of unsymmetrical A.C. voltage waveforms and also serve to show the erratic way in which the voltage and consequently the current may vary in a circuit.

Units.—The units referred to above, *i.e.* volt, ampère, ohm, and watt, are the basic units by which electrical phenomena are measured, but for convenience the following units are in general use, the recognised abbreviation being shown in brackets:

kilovolts	= 1,000 volts (kV)
millivolts	= $\frac{1}{1000}$ volt (mV)
microvolts	= $\frac{1}{1000000}$ volt (μV)
milliamp	= $\frac{1}{1000}$ amp. (mA)
microamp	= $\frac{1}{1000000}$ amp (μA)
kilowatt	= 1,000 watts (kW)
milliwatt	= $\frac{1}{1000}$ watt (mW)
megohm	= 1,000,000 ohms (MΩ)

Choice of Units.—Consideration of the above units will suggest that certain values may be expressed by more than one unit. For example 100 millivolts could alternatively be expressed as ·1 volt; then again ·2 megohm could be expressed as 200,000 ohms. Similar remarks may be made about units not mentioned in this chapter, such as farads and microfarads, henrys and microhenrys. Unfortunately, there is no hard and fast rule to indicate the choice of expression and care must be taken, therefore, to avoid confusion. There is a natural tendency when reading casually to gain the impression that ·1 volt is more than 100 millivolts, an oversight that may obviously give rise to a serious misunderstanding.

The author makes a practice of using the smaller denomination when the alternative entails the use of more than one decimal place, an exception being made, of course, when referring to graphs where the use of mixed units would be intolerable.

When values are stamped on small components they are often expressed in a rather objectionable manner. For example, a resistance may be marked ·001 MΩ purely because this expression is shorter than the more conventional "1000Ω."

Voltage, current, resistance, and wattage can all be measured by means of instruments expressly designed for the purpose and provided with calibrated scales permitting direct reading of the appropriate units. Multi-range meters are available with extra scales which become operative when the requisite series or shunt resistances are brought into circuit. These instruments are known as the voltmeter, ammeter or milliammeter, wattmeter, etc., thus clearly indicating the purpose for which the particular meter is intended. There is, however, one exception to this nomenclature since the instrument for measuring resistance in megohms is called a megger.

The construction and the principles governing the action of these meters are described in a later chapter; in the meantime it is merely necessary to become acquainted with their practical application to the various purposes for which they are intended.

There are, however, one or two remarks that will not be out of place regarding the use of the voltmeter. With the exception of one or two specialised types the voltmeter will pass current when a potential is applied across its terminals which will introduce an error when measuring a voltage across a high value of resistance which is fed through another resistance. An example will make this point clear. If two resistances, each having a value of ·1 megohm, are connected in series across a supply having a potential of 300 volts, the application of Ohm's law will show that the potential drop across each resistance will be 150 volts. Assume that the potential across one resistance is to be measured and that the voltmeter to be used has an internal resistance of ·1 megohm. Directly the voltmeter is connected complete rearrangement of potential takes place in the circuit since the voltmeter is in parallel with the resistance to be measured forming a total resistance of 50,000 ohms; the application of

Ohm's law shows that potential difference across 50,000 ohms in series with ·1 megohm will be one-third of the applied potential, *i.e.* 100 volts.

The above example cites an instance where the potential difference across a resistance is 150 volts, but when a voltmeter is connected across it for the purpose of measurement, a serious error is introduced since the current passed by the voltmeter causes the potential difference to fall to 100 volts.

CHAPTER 5

MAGNETISM AND INDUCTANCE

MENTION was made in Chapter 4 of the mistake made by early scientists in determining the true direction of the flow of current. While the actual flow of electrons is from negative to positive, it is convenient to assume the converse. This imaginary direction of flow, *i.e.* from positive to negative, is usually called the conventional current, while many authorities refer to it simply as current.

While in many ways it might be thought desirable to abandon this make-believe, such a course is impracticable, as it would reverse all the laws governing the direction of magnetic fields, render a large amount of apparatus obsolete, and cause the worst possible confusion since the standard textbooks of to-day would differ in almost every paragraph from the books of to-morrow.

The author would very much like to break away from convention and refer exclusively to the electronic current, but, in deference to the best interests of readers who may already possess some electrical knowledge and who have read or may read other books, has adopted the existing standards. It is important to note, therefore, that in this and the following chapters (except where otherwise stated), the direction of flow will be assumed to be from *positive to negative*, i.e. *conventional current.*

Magnetism in some form must be familiar to everyone. In fact, the average person makes the acquaintance of a toy magnet at such an early age that its remarkable properties are taken for granted. The manner in which an ordinary horse-shoe magnet will attract a piece of iron is too well known to need comment, but attention may usefully be drawn to the fact that this force is exerted without any tangible medium between the magnet and the iron ; in brief, magnetic force exists in free space.

The phenomenon of magnetism was well known to the ancients, in fact the Greek philosopher Socrates made mention of the word "magnet," which was the name given to a peculiar mineral found near Magnes in Asia Minor, which had the remarkable property of always coming to rest in the same position when suspended on a thread. This natural compass was used by the Anglo-Saxons, who took advantage of the fact that a suitably shaped piece of this material would come to rest so that its extremities pointed to the north and south. The Anglo-Saxons called this peculiar mineral lodestone, but its modern name is magnetite, or magnetic oxide of iron ; it has no practical value, as the artificial magnet is much more efficient.

The reason why a magnet attracts a piece of iron is not yet fully understood and, furthermore, the theories that have been put forward are too complicated to justify their inclusion in this work and must give way to a consideration of the more practical aspect, namely the nature and effect of magnetism.

The permanent magnet may be defined as a magnet made of steel which is sufficiently refined and hardened to retain its magnetism for a considerable period. It may be shaped in the conventional manner, or it may take the form of a round or square bar or a cube, sphere, half moon, star, or any shape that the mind may devise. The actual magnetism is imparted to a magnet by rubbing it against another magnet or by inserting it in a coil of wire through which a suitable electric current is passed for a few seconds.

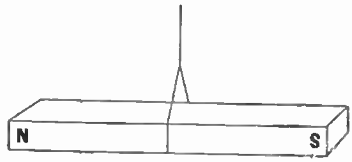


Fig. 33.—If a magnet is freely suspended, it will come to rest on a line due north and south. That end which points to the north is termed the north pole.

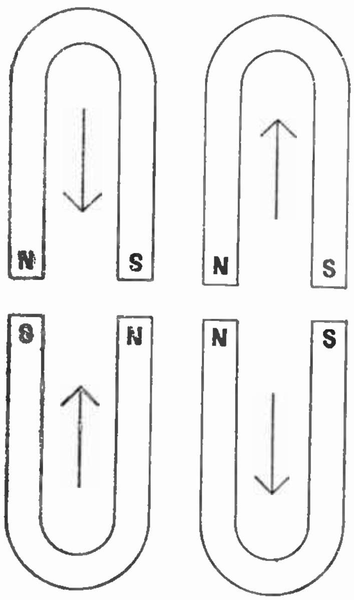


Fig. 34.—When permanent magnets are placed with unlike poles opposite they attract each other.

Fig. 35.—Magnets placed with like poles in opposition repel each other.

Whatever the shape of the magnet it has two "poles," which may be described as the centres of its magnetic energy; one pole is called the north pole and the other the south pole (see Fig. 33). These poles may be likened to the positive and negative charges of electricity because the same law applies, *i.e. unlike signs attract and like signs repel.* If two horse-shoe magnets are placed face to face as shown at Fig. 34, they will attract each other and, providing that the distance is not too great, each will move towards the other. If, on the other hand, they are placed as shown in Fig. 35, so that they are face to face but with like poles opposite, the two magnets will repel each other, and if placed sufficiently close will move away from each other.

If a sheet of glass is placed horizontally over a magnet it will be found that if iron filings are evenly distributed, they will become arranged in a definite formation along the lines of magnetic force emanating from the magnet. Fig. 36 shows the magnetic field of an ordinary horse-shoe magnet determined in this way.

Some magnets are stronger than others, due to a greater or lesser number of lines of force; these lines are usually referred to as the flux, and the number of lines per unit sectional area as the flux density. Quantitative measurements are usually expressed as flux density per square centimetre. A really first-class magnet will have a flux density of the order of 14,000 lines per sq. cm. if the air gap between the poles is short.

The various magnets that have been mentioned above are called permanent magnets because their magnetic properties are always present and remain so until such time as they lose them due to leakage. Permanent magnets are made of very hard steel, such as cobalt or tungsten, because the hardness of the steel largely controls both the flux density and the useful life of the magnet. It is generally thought that a magnet will attract only iron, steel, cobalt, or nickel, but it has a slight attraction for a number of other materials, including aluminium, manganese, and platinum; it is interesting to note that certain substances have a slight repellent action, these include copper, silver, antimony, tin, zinc, and phosphorus.

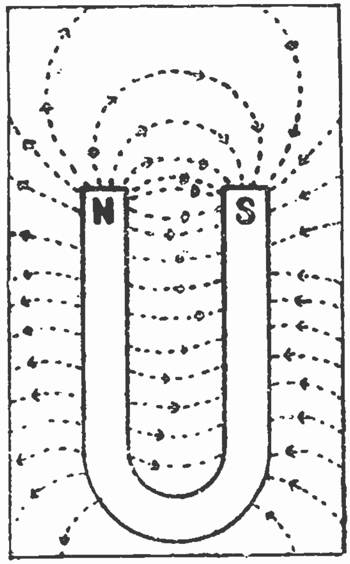


Fig. 36.—The field of a permanent magnet determined by means of iron filings placed on a sheet of glass.

There is an entirely different form of magnet known as the electro-magnet, which consists fundamentally of an iron core around which a coil of wire is wound. When a current is passed through the coil the core becomes magnetised and remains in this condition until the current is switched off; it is important to note that when the current is switched on the core takes a measurable time to become fully magnetised, and when the current is switched off the core takes an appreciable time to become demagnetised. This is known as hysteresis.

The core of an electro-magnet is usually made of very soft iron such as Swedish charcoal iron, because the softer the iron the greater will be the flux density and the lower will be the hysteresis.

Permeability may be defined as the ability of a material to accommodate magnetic flux; iron that will accommodate a large number of lines of force per sq. cm. for a given magnetising force is said to possess high permeability and vice versa. The strength of an electro-magnet is dependent upon the number of turns in the coil and the strength of the current passing through it. One ampère passing through 10 turns produces the same flux density as ·1 amp passing through 100 turns. By multiplying together the number of turns and the number of amps in either of these examples, 10 is the product; this figure is the number of ampère turns, which is the factor which determines the strength of the field. Double the number of ampère turns will give approximately twice the flux density, three times the number will give three times the flux density, and so on, providing that the coil is so designed that all its turns are close to the core and that the core has not become saturated, *i.e.* reached the state when it is unable to accommodate an increase in the number of lines of force.

In order to produce a magnetic field it is not necessary to employ an iron core, as the passage of current through any conductor will set up a magnetic field. Fig. 37 shows a wire that has been passed through a sheet of paper lightly dusted with iron filings which have become arranged along the lines of magnetic force due to a current being passed through the wire.

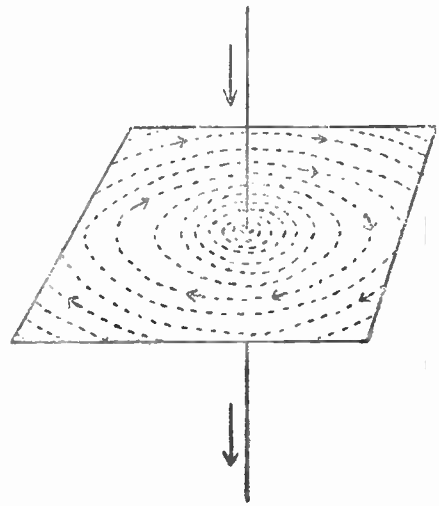


Fig. 37.—The field caused by conventional current; the conductor is passed through a sheet of paper on which iron filings are sprinkled.

Fig. 38 shows the magnetic field set up round a conductor by an electric current which is travelling towards the reader. Fig. 39 shows a diagram that is somewhat similar to Fig. 37, except that the paper is pierced by a loop of wire, the current through which produces two separate fields, the arrows indicating the direction of both conventional current and fields.

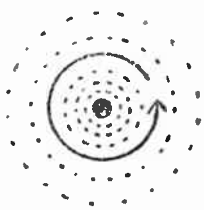


Fig. 38.—This diagram shows the direction of the magnetic field when the conventional current is travelling along the conductor towards the reader.

For a given current the magnetic field set up by a straight wire is very feeble, but by forming the wire into a coil a relatively high flux density will be produced; see Fig. 40, which shows the magnetic field due to a current through a coil. If an iron core were introduced into the coil shown at Fig. 40, an electro-magnet would be formed; if the core were withdrawn from the coil it would continue to be magnetised to a decreasing extent until it was withdrawn to such

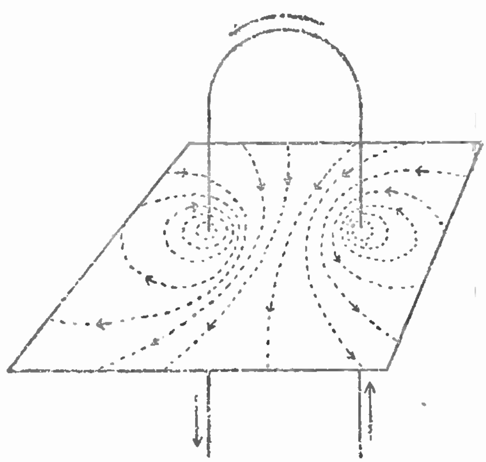


Fig. 39.—Two independent fields due to the flow of current in opposite directions.

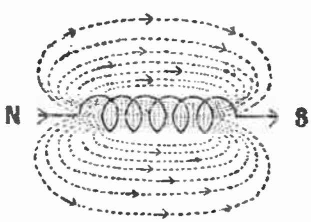


Fig. 40.—The field around a coil through which a current is flowing. The larger arrows indicate direction of conventional current.

a distance that its total mass was outside the field produced by the coil. Unless the core is placed symmetrically within the coil they will be attracted to each other, and if the core is placed just outside the coil and freely suspended, the magnetic field will cause it to move along a path through the centre of the coil until it reaches the centre, when it will come to rest. See Fig. 41.

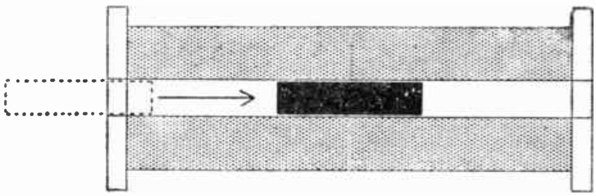


Fig. 41.—Section of a coil showing the position taken up by an iron rod due to action of the magnetic field.

It has been stated that the flow of current through a conductor will set up a magnetic field; conversely a magnetic field will set up a current if it cuts a conductor, provided that there is present either mechanical movement or magnetic variation. Fig. 42 shows a bar magnet, the field of which is cut by a conductor, the ends being connected to a galvanometer, which is an instrument capable of detecting a very minute electric current. If the magnet is at rest the galvanometer will show zero; but if the magnet is moved, a flow of current will be registered and will so continue as long as the magnet is kept moving, but as soon as the magnet is allowed to become stationary the flow of current will cease. This phenomenon is called electro-magnetic induction, and is of great importance to the student of any branch of electrical engineering.

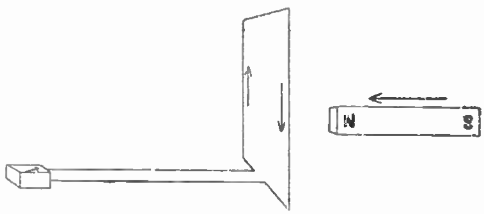


Fig. 42.—A current will be induced in a conductor if a magnet is moved in its vicinity. Small arrows show direction of conventional current when the north pole is moved towards the conductor.

The effect of a magnetic field on a straight wire is limited, but the effect applied to a coil is important. Fig. 43 shows a coil suspended in the field of a magnet and connected to a battery; the flow of current through the coil will set up an independent magnetic field which will cause the coil to be drawn towards the magnet or repelled, according to the direction of the current. If the coil is connected to an alternating-current source (instead of the battery) the coil will move backwards and forwards in sympathy with the change of amplitude and direction of flow of the alternating current. For this experiment the permanent magnet could be changed for an electro-magnet or for a simple coil; the effect would be the same.

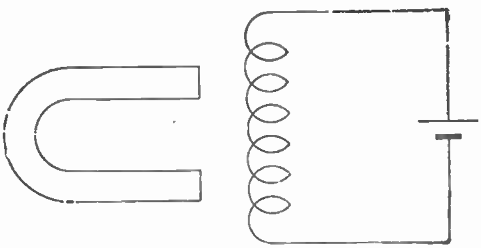


Fig. 43.—The energised coil and permanent magnet will attract or repel each other according to their relative polarity.

Another aspect of magnetic phenomena is mutual induction, which in brief is *the transference of electrical power from one conductor to another by virtue of magnetic coupling.* Fig. 44 shows two coils which for convenience are denoted by the letters P and S respectively. Coil S is connected to a galvanometer to give visual indication of the flow of current. If a cell is connected across the coil P and the switch closed, it will cause the galvanometer needle to move and then immediately come to rest; if the switch is opened a similar movement of the needle will take place in the opposite direction.

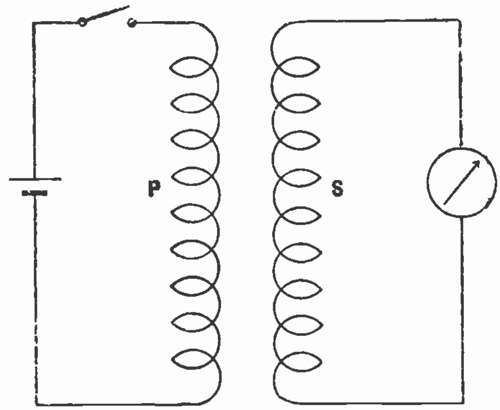


Fig. 44.—When the switch is closed or opened a current will flow in coil "s."

This simple experiment shows that electrical power is conveyed from one coil to the other by mutual induction when an electrical change occurs. When the coil P is passing a steady current, current is *not* induced in coil S.

To carry this experiment to its logical conclusion the ends of the coil P are connected to an alternating-current source, which will result in the galvanometer showing a to-and-fro movement because the direction of flow of current through the coil P is continually changing, therefore a current is constantly induced into the coil S; this induced current will be alternating current having exactly the same characteristics as the current flowing through the coil P, excepting only the amplitude, which will be larger or smaller dependent on the number of turns in each coil and the distance between them.

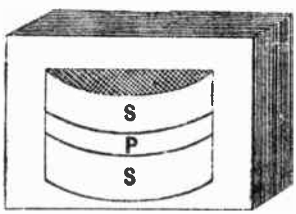


Fig. 45.—A simple transformer; the primary is between the split secondary winding.

The letters P and S are not an arbitrary choice, as P stands for primary, which is the coil where the original or primary current flows, and S stands for secondary, which is the coil in which the induced or secondary current flows.

Two coils used in this manner constitute what is called a transformer, which in practice may comprise any number of primary and secondary windings; the coupling may be entirely due to mutual induction, which may be aided by an iron core which is common to all windings; Fig. 45 shows a simple split secondary transformer.

The transformer has two main applications: (1) to convey power from one part of a circuit to another when a direct metallic connection is inconvenient; and (2) to raise or lower voltage: this application makes the transformer a most valuable piece of apparatus.

If an iron-cored transformer, such as that shown at Fig. 45, has 1,000 turns on the primary and 5,000 turns on the secondary, the voltage available across the secondary will be nearly five times that across the primary. When the secondary is composed of a greater number of turns than the primary it is termed a step-up transformer because it "steps up" the voltage. Conversely, when the smaller number of turns is on the secondary it is known as a step-down transformer.

The relationship between the number of turns on primary and secondary is referred to as the ratio, which is determined by dividing the greater number of turns by the smaller, thus, 5,000 primary turns and 10,000 secondary turns is referred to as 2 : 1 step up while 10,000 primary turns and 5,000 secondary turns is 2 : 1 step down.

When a transformer is well designed the voltage ratio is nearly equal to the turn ratio, *i.e.* when 10 volts is applied across the primary of a 2 : 1 step-up transformer, 20 volts will be available across the secondary. Actually, this perfection is not achieved in practice owing to various losses, which include resistance of windings, leakage of magnetic flux, and what are called eddy current losses.

In order to reduce eddy current losses, the core of a transformer is made up of laminations, *i.e.* thin iron plates separated from each other by paper or some other suitable material. Alternatively, it is sometimes composed of a bundle of iron wire for the same reason. Transformers required to carry speech-frequency currents often use cores made of mu-metal, which is an iron-nickel alloy; while certain types of transformers, that are intended to carry radio-frequency currents, utilise a core of finely powdered iron mixed with some suitable material. In both cases the iron is split up into a great number of parts which are separated from each other by non-magnetic material, resulting in a very great decrease of eddy current loss.

A transformer may be wound to give any ratio of voltage between primary and secondary, but it is important to realise that whatever the ratio, the *wattage* of the primary must always be equal to the wattage of the secondary plus power wasted due to losses, therefore a transformer having a step-up ratio of 5 : 1, and a primary current of 1 amp at an applied voltage of 100 V, will induce a voltage of 500 V across the secondary when the secondary current is ·2 amp. This example assumes that there are no losses, the primary and secondary wattage being 100 watts in each case; in practice, however, the average transformer used in radio receivers has an efficiency of about 80 per cent., *i.e.* the available secondary wattage is 80 per cent. of the wattage taken by the primary.

There are two distinct types of transformer: the double-wound type, which has two separate windings without metallic connection between them; and the auto-transformer, which has virtually a single winding with an appropriately placed tapping. The conventional symbols for a double-wound transformer and auto-transformer are shown at Fig. 46 and Fig. 47 respectively. There are numerous refinements in transformer design and factors determining their performance which are dealt with in the appropriate chapters

The phenomenon of a magnetic field set up by the flow of current introduces a quality known as inductance. Inductance is to electricity what momentum and inertia are to mechanics. Briefly, inductance is that quality which tends to oppose a change in the flow of current. It has already been explained that the passage of current through a wire sets up a magnetic field ; it has also been explained that a changing magnetic field will induce a voltage in a neighbouring conductor. It is, therefore, not surprising that a magnetic field induces a voltage into the conductor around which it originates. This induced voltage opposes the original current and delays the rate at which it may increase. If the original current is D.C., inductance will not influence the flow of current when it has attained a steady level, as a voltage cannot be induced by a steady

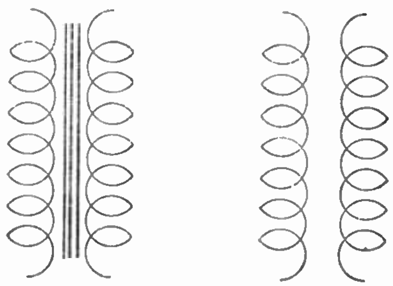


Fig. 46.—Left : the conventional symbol for an iron-core transformer. Right : the symbol for an air-core transformer.

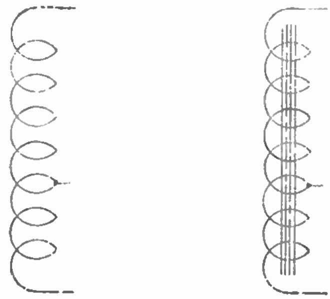


Fig. 47.—Right : the conventional symbol for an iron-core auto-transformer. Left : the symbol for an air-core auto-transformer.

field ; it is apparent that since alternating current is always changing it will be profoundly influenced by inductance.

Inductance also opposes a decrease of current when current decreases, the lines of force decrease and in so doing induce a voltage in the same direction as the original current, which delays the decrease.

To summarise, it may be said that an increasing magnetic field induces a voltage which opposes the current that causes it, while a decreasing field induces a voltage in the same direction as the current that causes it.

In the above explanation reference has been made only to inductance in a straight wire. Actually inductance in a straight wire is very small, but is considerable in a coil, and for a given number of turns it is still further increased if the coil has an iron core.

The henry is the unit of inductance, and may be defined as the inductance necessary to bring about a reverse pressure of 1 volt when the flow of current is increased by 1 amp in 1 second. Large iron-cored coils and transformers have an inductance of many henrys, but when expressing the inductance of small air-cored coils it is convenient to use the microhenry, which is $\frac{1}{1000000}$ of a henry. The recognised abbreviation for inductance is L, the henry H, and the microhenry μH.

CHAPTER 6

CAPACITY

If a conductor is temporarily connected to a source of potential it will continue to hold a charge after disconnection provided that it is insulated from earth and any other conductor; this ability to hold an electric charge is called " capacity."

Capacity may exist as a charge on a single conductor that has no electrical relationship to any other, in which case it is referred to as " self capacity." Capacity may also exist between two conductors: in this case it is simply referred to as " capacity." The existence of self capacity may be easily demonstrated in the following manner.

A suitable object, *e.g.* a brass ball, is carefully insulated by suspending it with non-conducting material; it is then charged by momentarily connecting to it the negative side of a potential source. The brass ball will now hold a negative charge; if one side of a galvanometer is connected to earth, the needle will show a deflection when the other terminal is connected to the brass ball. This is due to the charge of electrons escaping to earth.

The amount of self capacity possessed by any object is dependent on its surface area and the medium surrounding it. Thus a large ball has a greater capacity than a small ball, and as capacity is dependent on *surface* area it follows that the self capacity of a thin sheet of metal is greater than that of a solid metal ball having the same mass. The capacity may be increased if the ball is immediately surrounded by a suitable substance; if, for example, it is surrounded by paraffin wax its self capacity would be about three times greater than when surrounded by air.

The amount of capacity existing between two conductors is controlled by three factors: (1) the surface area of the conductors—the capacity is proportional to the surface area; (2) the distance between the conductors—the *smaller* the distance between the conductors, the *larger* will be the capacity; and (3) the nature of the medium between the conductors, which is called the dielectric. Conditions (2) and (3) are to some extent related; the charge held by virtue of the capacity between two conductors is due to a strain imposed upon the insulating material between them, therefore the closer the conductors are to each other the greater will be the strain. The difference of potential between the two conductors will exert a definite strain, but some substances are more easily affected in this way than others. Thus, by immersing the conductors in paraffin wax the capacity is increased about three times, and by filling the space with selected mica the capacity will be increased by about eight times.

The quality of an insulating material to influence capacity is referred to as the dielectric constant or permittivity, which is usually abbreviated as "s." The dielectric constant for dry air is 1, for paraffin wax 3, for ruby mica 8; the table of dielectric constants is given in the Radio Circuits and Data Volume, where it may be seen that the figure for almost every substance varies with different samples.

The amount of capacity between two wires is very small, therefore when it is deliberately desired to introduce capacity into a circuit it is convenient to use a device called a condenser.

The unit of capacity is the farad, which may be most readily defined in the following terms. A condenser having a capacity of one farad will take a charge of one coulomb of electricity when a p.d. of one volt is applied across it. The coulomb is a unit of quantity, and may be defined as the amount equal to the flow of one ampère for one second.

The symbol for capacity is C and for the farad F.

The Farad.—The farad is too large for convenient reference in radio engineering, therefore two smaller denominations are in general use. The microfarad is $\frac{1}{1000000}$ of a farad, and is variously written as μF, mf., or mfd. The micro-microfarad is $\frac{1}{1000000}$ of a microfarad, and is variously written as μμF, mmf., or mmfd. It should be noted that m. normally stands for $\frac{1}{1000}$; it is therefore unfortunate that mf. has become the colloquial abbreviation for $\frac{1}{1000000}$ of a farad.

There is a Continental rating for capacity which is arrived at by linear measurement. A condenser is spoken of as having a capacity of so many centimetres (which is written cm.); one μμF = ·9 cm. Unfortunately it is quite common to find a small condenser marked with its capacity in cm. in British-made receivers.

It has been stated that capacity is inversely proportional to the distance between condenser plates. It might appear at first sight that capacity could be increased indefinitely by decreasing the spacing, but a limitation is imposed by the danger of the insulation being broken down by the applied voltage, therefore the minimum permissible thickness of dielectric will increase in proportion to the working voltage. Commercially manufactured condensers have a declared working voltage which is usually about two-thirds of the voltage applied to the condenser for testing purposes.

Mention has also been made of the increase in capacity due to the use of a dielectric such as mica; unfortunately it is not practicable to make use of this factor when designing condensers for all purposes, as many insulating materials introduce what is termed dielectric loss, which is most objectionable when dealing with very high frequencies. Therefore for this purpose air dielectric condensers are often insisted upon, although there are on the market condensers, using a type of porcelain dielectric, which are generally satisfactory. Mica is also precluded from use in large condensers on account of the relatively high cost involved; the types of condensers at present available are so diverse that the following brief description of each will prove of interest and also serve to indicate their uses and limitations.

The *air dielectric* condenser has special applications when very high frequencies are to be handled, and otherwise in transmitters where high voltage would accentuate dielectric loss. The main variable condensers used in radio receivers are almost always of the air dielectric type. The variable condenser will be familiar to most readers, but for the sake of completeness a typical example is illustrated at Fig. 48. Those plates which are almost hidden by the framework are stationary and are referred to as the fixed vanes; the other set of plates, the moving vanes, may be rotated so that any portion of their surface is between the fixed vanes. In this way the capacity of the condenser may be varied within wide limits. The moving vanes may be shaped so that any desired rate of capacity change (per degree of rotation) may be obtained, but for reasons that will be apparent in due course a moving vane usually approximates to the shape shown at Fig. 48.

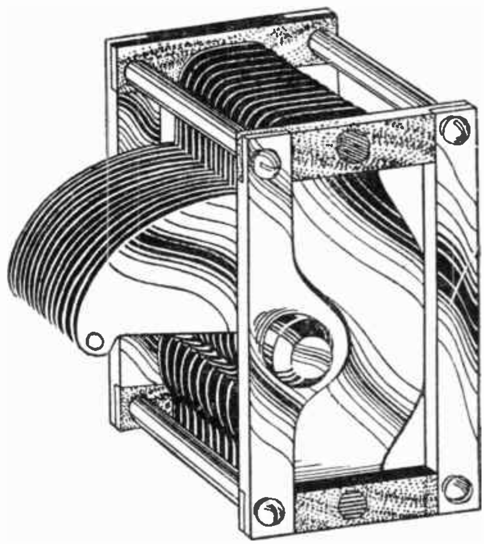


Fig. 48.—A simple variable condenser.

The *paper dielectric* condenser is very widely used for capacities of ·01 μF and upwards, although often used for lower values. The declared capacity of paper condensers is not always very accurate, but the lower values may be obtained accurate to within + or − 5 per cent. Paper condensers are usually tubular in form and provided with short lengths of wire at each end for the purpose of making connection. Those sold to the general public are sometimes housed in rectangular metal containers, and provided with terminals. These condensers are suitable for any purpose in a radio receiver except where the very highest possible insulation is required.

Mica condensers are in general use for capacities below ·01 μF, and usually take the form of a series of copper-foil plates interleaved with mica plates and housed in a moulded container. There are specialised condensers, among which is the silver-deposited type consisting of a mica sheet with a layer of silver, chemically or electrically deposited on each side; the aim of such a condenser is to retain a constant capacity irrespective of temperature change. Small variable condensers often employ mica discs as a dielectric between the vanes.

The *ceramic* condenser uses a special dielectric which closely resembles porcelain and is used where a condenser is required that is practically unaffected by temperature change; it is sometimes rectangular in appearance, although very small values are shaped so that they appear like half of a sphere and are about ⅜ inch in diameter.

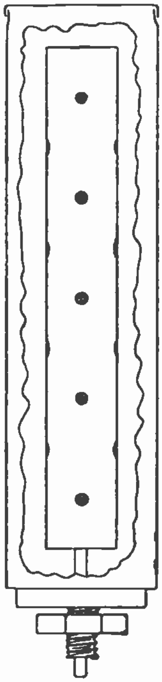


Fig. 49.

The *electrolytic* condenser is used where large capacities are required and a small continuous leak is not detrimental. There are two distinct types of this condenser, the wet electrolytic and the dry electrolytic; the former is illustrated at Fig. 49, the outer case being broken open to show the interior construction. Briefly, the wet electrolytic condenser consists of an aluminium case containing a solution in which an aluminium electrode is placed. This type of condenser should only be charged in one direction, *i.e.* the aluminium "case" must always be joined to the negative pole, and the inner electrode to the positive pole. When voltage is first applied across this type of condenser a heavy current flows through it which breaks up the molecular structure of the solution and causes gas to form on the positive plate; thus the inner electrode is one plate of the condenser, the gas is the dielectric, and the solution is the other plate. The capacity is greatly increased by engraving or sandblasting the inner electrode to increase its surface area; in this way capacity may be increased by twenty times. The great advantage of this type of condenser is the high capacity for a given size; an electrolytic condenser measuring 6 inches by 1½ inches may have a capacity of 32 μF, whereas a paper condenser of the same capacity and diameter would be about 40 inches long.

The *dry electrolytic* condenser is similar to the wet type except that the solution is replaced by a stiff jelly; thus it may be used in any position. whereas the wet type must always be upright.

Condensers connected in parallel have a total capacity equal to the sum of the individual capacities, but in series the capacity is equal to the reciprocal of the sum of the reciprocals, that is to say—

$$C = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} \text{ etc.}} \qquad \text{or} \qquad C = \frac{C_1 \times C_2}{C_1 + C_2}$$

The right-hand formula is applicable when it is desired to find the capacity of *only two* condensers in series. It may be seen from the above formula that the capacity of two or more condensers in series must always be less than the capacity of the smallest condenser.

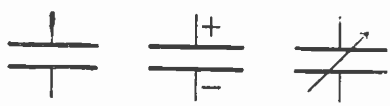
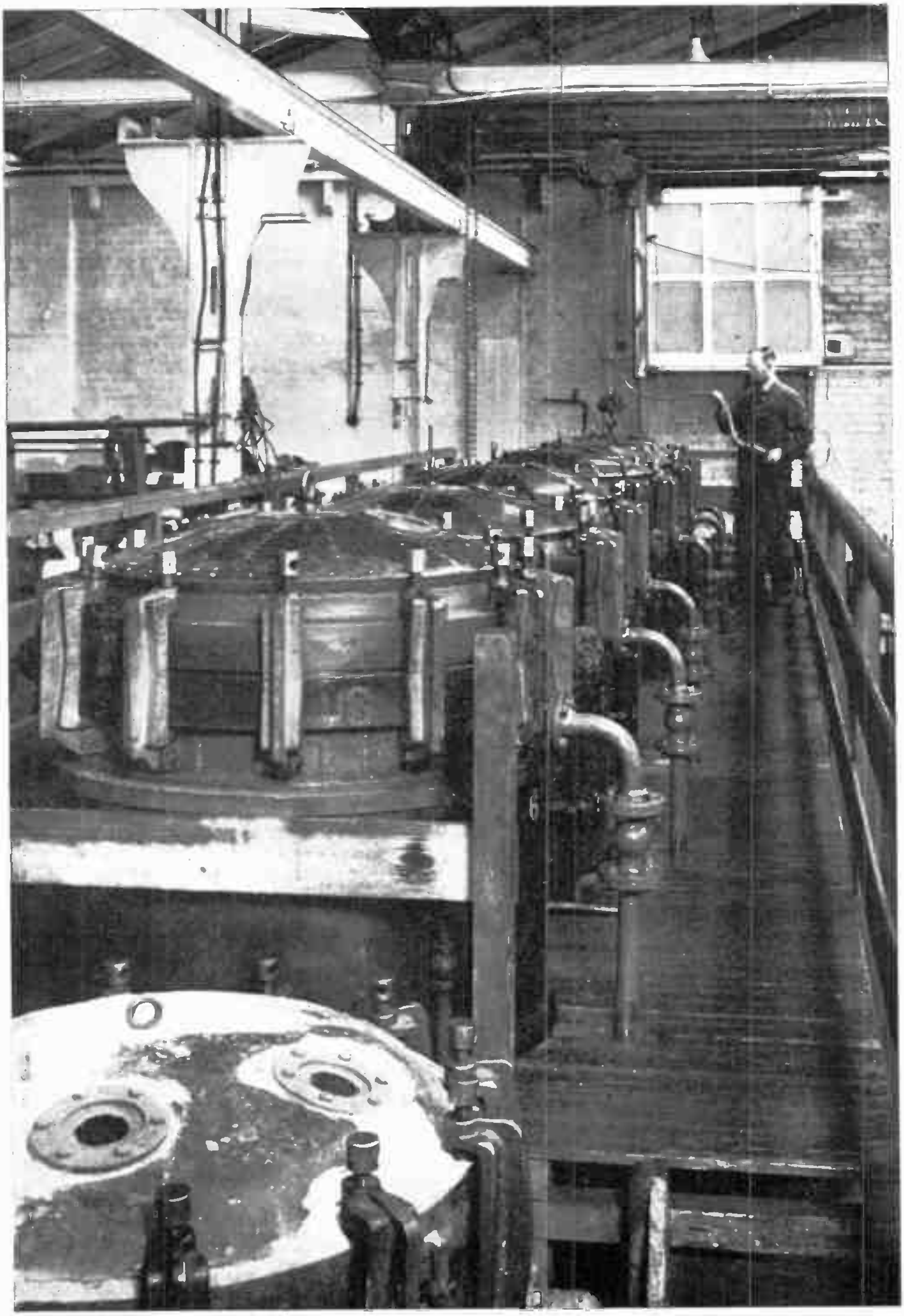


Fig. 50.—Symbols: *Left*, fixed condenser. *Centre*, electrolytic condenser. *Right*, variable condenser.



CONDENSER MANUFACTURE

To-day radio manufacturing requires considerable specialised plant. This photograph shows a battery of condenser impregnation vats at the condenser section of British Insulated Cables, Ltd.

CHAPTER 7

REACTANCE AND IMPEDANCE

RELATIONSHIP between D.C. voltage, D.C. current, and pure resistance as defined by Ohm's law is dealt with in Chapter 4. This law is only applicable for calculations based upon the flow of direct current. Calculations of this nature based on the flow of alternating current must take into account the reactance of the circuit. Reactance, which is written " X," may be defined as the opposition to the flow of current due to inductance or capacity or both

When potential is applied across a pure resistance, *e.g.* a piece of carbon rod, the opposition offered to the flow of current will not vary with the nature of the applied potential; if the carbon rod has a resistance of, say, ten ohms, this factor will remain constant irrespective of all other considerations and it is immaterial whether the applied potential is alternating or continuous.

Phase.—Fig. 51 shows a circuit consisting of an inductance in series with a hot-wire ammeter, which is an instrument that will measure the flow of either alternating or direct current. If a D.C. potential is applied across XY the meter will register the current flowing, which will be dependent upon the applied voltage and the pure resistance of the circuit due to the resistance of the wire of which the inductance is composed. If an A.C. potential of the same value as the D.C. is applied across XY, it will be found that the current is much less and, further, an increase of frequency will cause the current to be still smaller. This is due to the reactance of the coil which opposes the flow of alternating current.

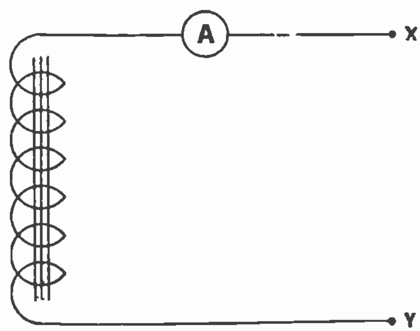


Fig. 51.—This illustration shows diagrammatically an iron-cored coil in series with an ammeter.

When an A.C. potential is applied across a circuit which comprises a pure resistance, the alternating current flowing will rise and fall in exact sympathy with the rise and fall of the applied voltage; in other words, maximum current will occur simultaneously with maximum voltage (in each direction) and voltage and current are said to be in phase.

When inductance is introduced into the circuit, current and voltage are no longer in phase; the rise and fall of voltage will not be affected, but maximum current will occur later than maximum voltage, due to the delay caused by inductance. If the inductance of a circuit is so high compared to the resistance of the circuit that the latter may be neglected, the rise and fall of current will be a quarter of a cycle behind the voltage which is referred to as a current lag of 90°. Since the current is lagging behind the voltage the significance of the term "lag" is obvious, while the representation of a quarter of a cycle by the expression 90° is conventional, as a complete cycle is regarded as 360°.

Reactance.—The inductive reactance in ohms is equal to $2\pi f$ L where $\pi = 3{\cdot}141$, f = frequency in cycles per second, and L = inductance in henrys. It is important to note that no power is consumed in overcoming the opposition due to inductance, as the energy expended in building up the magnetic field which opposes an increase of current is given back to the circuit when the field collapses due to the decrease of current.

Fig. 52 shows diagrammatically the relationship between voltage and current due to pure inductance. It can be clearly seen from this illustration[1] that the current lags by 90°. Current related in this manner to voltage is termed reactive, or wattless current, because the average power is zero for each complete cycle.

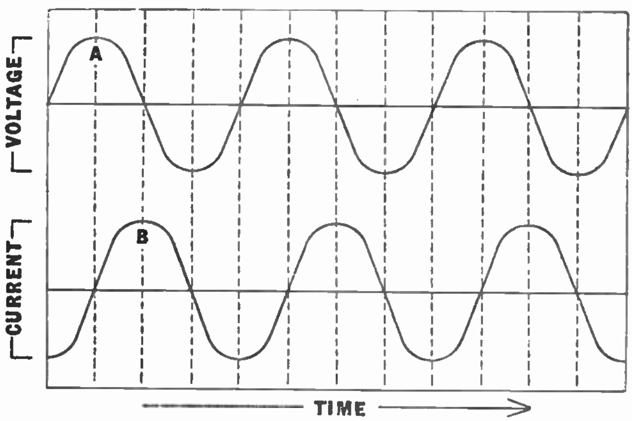


Fig. 52.—Each vertical division represents 90°, *i.e.* ¼ cycle. This illustration show the 90° current lag in a purely inductive circuit. As time is depicted as moving from left to right the current reaches its maximum at B *after* the voltage reaches its maximum at A.

When resistance and inductance are both present in a circuit the current lag will be less than 90°, but since the exact phase-angle relationship between voltage and current is unimportant when studying the more practical aspects of radio engineering, it is not within the scope of this work to go into the subject very fully, although further reference is made in appropriate chapters.

Attention may now be drawn to the effects resulting from the introduction of capacity into a simple circuit. Fig. 53 shows a lamp in series with a condenser; if D.C. potential is applied across the ends of this circuit XY, the lamp will not light, as the condenser forms a complete break in the circuit and prevents the current from flowing. It is important to note, however, that current will flow momentarily until the condenser has become completely charged. If the capacity of the condenser is sufficiently high, the charging current will cause the lamp to light momentarily.

[1] Readers finding difficulty in interpreting this illustration should read Appendix 1 (2).

Substitution of A.C. for D.C. will result in the lamp lighting in a normal manner providing that the condenser has a suitable capacity. If the capacity is increased, the lamp will light more brilliantly, and vice versa. The fact that the lamp lights might be interpreted as proof that alternating current can flow through a condenser; it is convenient to assume that this is the case because the effect is often similar, but it is desirable to understand what actually takes place. As the terminals X and Y are connected to a source of A.C. potential, each will become alternately positive and negative. Consequently, each plate of the condenser will become alternately positive and negative, which in turn will result in electrons flowing to and away from each plate in turn; in other words, the condenser will be charged, first in one direction and then in the other. Reference to Fig. 53 will show that the charging current on the way to plate A and the discharging current from A must necessarily pass through the lamp, which will light in the normal manner. To summarise, a lamp may be made to light when in series with a condenser, although electrons do not flow from one end of the circuit to the other.

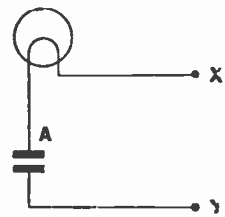


Fig. 53.—A lamp in series with a condenser. In suitable circumstances the lamp will light if an A.C potential is applied across XY.

The opposition to the flow of current due to capacity is called capacitive reactance and, in order to assess the opposition, it is convenient to refer to the reactance of a condenser as being equal to so many ohms. The reactance of a condenser will vary with frequency and may be determined by the following simple equation:

$$\text{Reactance} = \frac{1}{2\pi f C}$$

where $\pi = 3.141$, f = frequency, and C = capacity in farads.

It has been explained above that reactance due to pure inductance does not absorb any power from the circuit. This is equally true of reactance due to pure capacity, assuming the condenser to be theoretically perfect. In practice, however, the condenser will not give out a charge equal to that which it has taken in, due to dielectric and other losses.

It will be remembered that inductance causes the current to lag 90° behind the voltage; the converse is true of capacity which causes the current to lead the voltage by 90°.

It has already been explained that a phase difference of 90° between voltage and current is a condition of zero power; the latter is therefore wattless current.

Impedance.—It is impossible to have a circuit comprising either pure inductance or pure capacity, as pure resistance must also be present due to the resistance of the connecting wires used, the resistance of the wire comprising the choke, and the resistance of the actual condenser plates. Occasions will arise, however, when the reactance of a circuit is so high compared to the resistance that the latter may be neglected; in such circumstances the current may be taken as being proportional to the applied voltage and inversely proportional to the reactance of the circuit. The majority of circuits will possess both reactance and resistance, which will both influence the flow of current ; the combined effect of reactance and resistance is called impedance, the symbol for which is " Z," and is determined by the following simple equation :

$$\text{Impedance} = \sqrt{(\text{Reactance})^2 + (\text{Resistance})^2}$$

If both inductive and capacitive reactance are present in the circuit the total reactance is the *difference* of these two reactances, a detail that is fully discussed in Chapter 9.

The reader will not grasp the practical significance of lagging and leading current at this juncture, but the next chapter deals with the distribution of potential in circuits containing resistance, inductance, and capacity, and also explains the modification of Ohm's law to alternating current and potential.

CHAPTER 8

ALTERNATING CURRENT

MANY textbooks attempt to draw a dividing line between alternating and high-frequency currents, a procedure that must inevitably cause a certain amount of confusion inasmuch as it implies that there is some fundamental difference between the two.

The nature of alternating current has already been described; what are colloquially termed high-frequency currents are simply alternating currents of very high frequency, there is no other difference or distinction whatever. This chapter deals with alternating current in general and its association with inductance, resistance, and capacity; phenomena peculiar to alternating currents of very high frequency are dealt with in subsequent chapters, where such considerations are appropriate. It will be remembered that alternating current is built up by a current that rises and falls rhythmically in each direction; it follows, therefore, that maximum current is only maintained for a fractional portion of the duration of each cycle.

R.M.S.—The maximum current attained is called the "peak" value of the current, similarly the maximum voltage attained is called "peak" voltage. Since the duration of the actual *peak* value is relatively short, it would be unreasonable to expect that it could accomplish the same effect as a continuous current of equal magnitude; in other words, an alternating current of 10 amps (peak) flowing through a resistance of 10 ohms would not dissipate as much heat as a continuous current of 10 amps flowing through the same resistance.

It can be shown mathematically that the value of alternating current producing the same heating effect as a continuous current is equal to the peak current divided by the square root of 2 (*i.e.* divided by 1·414 or multiplied by ·707). The value thus obtained is called the R.M.S. value. R.M.S. is the accepted abbreviation for root mean square, and it is both interesting and instructive to pursue the meaning of this expression and to see why the behaviour of an alternating current waveform should be affected by square root. It will be remembered that power (*e.g.* heating) is proportional to the square of the current.[1] Fig. 54 shows a curve obtained by plotting the squares of an alternating-current waveform. It will be noted that the zero line is shown at the bottom of the curve, because Fig. 54 is solely concerned with the magnitude of the current squared and not with its direction. The height of the line AB represents

[1] See Ohm's law, Chapter 4.

the mean or average value of the square of the current, inasmuch as the rectangle ABCD is equal in area to the area of the waveform ; this is quite obvious when it is realised that a rectangle can be formed by cutting off the peaks above the line AB and inverting them into the troughs below this line.

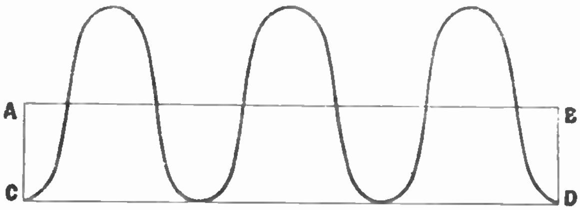


Fig. 54.—This diagram shows how the expression root mean square is derived.

A glance at Fig. 54 will now show the meaning of root mean square, which may be expressed in the following way. The root mean square is the square root of the mean or average value of the current squared, and is comparable with the same value of continuous current.

It may be seen from Fig. 54 that the curve must have a particular shape in order that the upper half will fit exactly into the lower half. It must, in fact, be derived from what is termed a "sine wave," an example of which is shown at Fig. 55, which is an actual oscillograph recording of the waveform developed by a very good A.C. generator. A moment's thought will show that a waveform such as that shown at Fig. 56 would be equal to a continuous current that is considerably smaller than ·707 of the peak value, while it is equally apparent that the converse applies to Fig. 57.

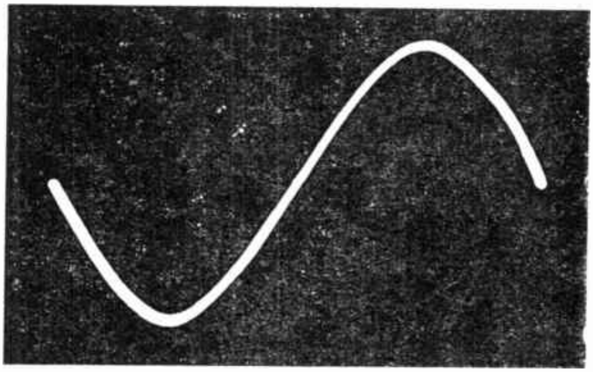


Fig. 55.—An oscillogram of a sine wave ; the illustration shows one complete cycle.

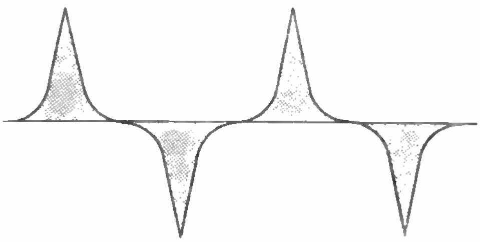


Fig. 56.—A waveform which has a low mean value ; note the comparatively small tinted area. This illustration, like Fig. 57, has been drawn to accentuate the explanation in the text ; the shape is rather improbable.

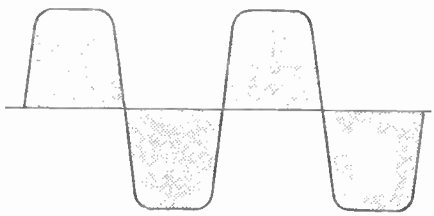


Fig. 57.—A waveform where the mean and peak values are nearly equal ; note the large tinted area.

(As already intimated in Chapter 1, the most complex waveform must necessarily be capable of being resolved into a number of sine waves.)

The Sine Wave.—The exact nature of a sine wave is difficult to define except in pure mathematical terms; the following description of the manner in which a sine wave may be plotted by projecting a circle should be studied carefully. It is not assumed that the reader will ever have occasion to plot a sine wave in this manner, the description being included solely as a convenient means of defining its shape. Fig. 58

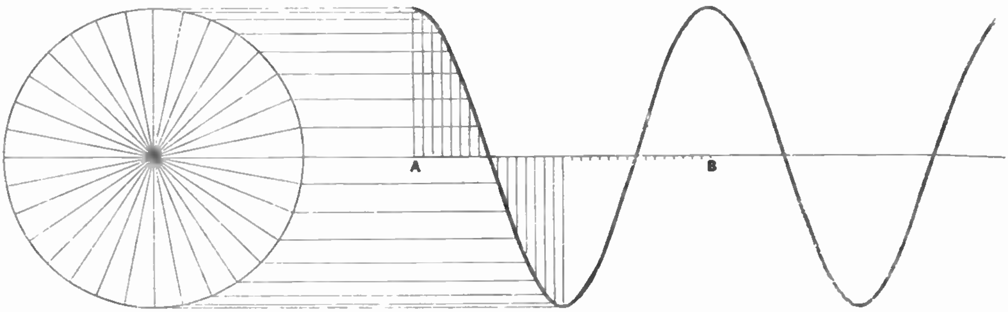


Fig. 58.—The relationship between a sine wave and a circle can readily be seen from this illustration in conjunction with the text.

shows a circle which has been divided into thirty-two parts, the line AB is also divided into thirty-two parts; it is intended that the distance AB shall represent one cycle, the actual length in terms of inches is quite arbitrary. To plot a sine wave lines are projected horizontally from each point on the circle until they meet the corresponding vertical lines formed by the divisions on the line AB. When this procedure has been completed for one half-circle, the points thus plotted may be joined up, the resulting curve being one half-cycle of a pure sine wave. In the illustration, Fig. 58, the curve has been plotted for a further one and a half cycles, in order to accentuate the shape of a pure sine wave.

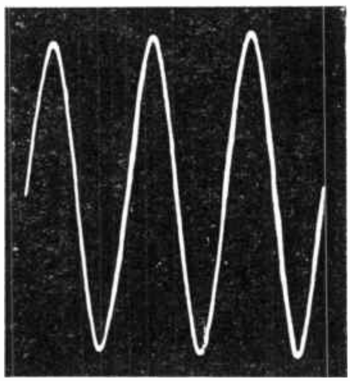


Fig. 59.—An A.C. waveform taken with the same generator as that used for taking Fig. 55; the horizontal axis has been shortened, but the rate of change remains the same.

It must be particularly stressed that a sine wave curve represents a particular law governing the *rate of change* in amplitude compared with horizontal displacement (time). It will be remembered that the length of the line AB was arbitrary; by making this line half or double the length the curve could have been made to *appear* different. Figs. 55 and 59 are oscillograms of the same A.C. generator, no change whatever having been made except to shorten the horizontal axis (*i.e.* the length of the line AB in Fig. 58). The important point to note is that in Figs. 55, 58, and 59, the *rate of change* in amplitude for each corresponding degree of each cycle is the same in each case and furthermore follows a true sinusoidal law.

Ohm's Law.—The application of Ohm's law to alternating current is very easily expressed by the simple equation, volts = ampères × impedance (in ohms), which expressed in the usual way and with the usual abbreviation is—

$$V = IZ$$

It will be remembered that Ohm's law could be rearranged so that the unknown quantity could be readily determined. In the same way the simple equation above may be expressed as—

$$I = \frac{V}{Z} \quad \text{or} \quad Z = \frac{V}{I}$$

These equations apply equally well for peak values or R.M.S. values but they may not be mixed in any one equation, that is to say, that if V is expressed as an R.M.S. value, I must also be expressed as an R.M.S. value.

If Z happens to be made up of pure resistance, the wattage dissipated in the circuit is determined by the same expression as that used for continuous current, namely, V × A = W where V = volts (R.M.S.), A = amps (R.M.S.), and W = watts. Wattage, it will be remembered, is an expression of power inasmuch as it may be regarded as directly representing rate of doing work. It is apparent, therefore, that V and A must be in terms of R.M.S. values because, as already explained, the peak value does not represent the true value of voltage or current in terms of its ability to perform work or dissipate heat.

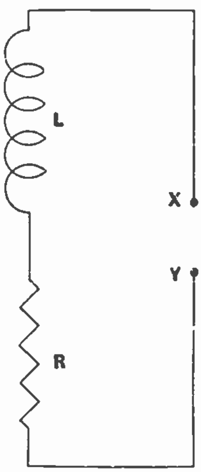


Fig. 60.—Resistance and inductance in series.

If the simple application of Ohm's law constituted the whole story, calculations of alternating-current electricity would, indeed, be simple. As already stressed, the direct application of Ohm's law is only possible when the impedance of the circuit is made up of pure resistance; when reactance is present, considerable complications arise. Consider, for a moment, the circuit, Fig. 60, which shows a resistance R in series with an inductance L (which for the present purpose is assumed to be a pure inductance with negligible resistance). Assume that R has a resistance of 5Ω and that L has a reactance ($2\pi fL$) of 5Ω, and that 100 volts peak A.C. is applied across XY.

R and L in Series.—If L and R were both pure resistances they could simply be added together and Ohm's law applied, which would show that a current of 10 ampères would flow through the circuit; furthermore, it could be determined that the p.d. across each section of the circuit would be 50 volts. It will be remembered that when current flows through an inductance, voltage and current are 90° out of phase, but that when current flows through a resistance it is in phase with the voltage. Since the current flowing through the circuit must have the same value and the same phase sense at any point, it follows that the voltage across R will reach its maximum coincident with maximum current, but the voltage across L will not.

It is obvious that the voltage across R plus the voltage across L must at all times equal the applied voltage; it also follows that the sum of the individual maxima must be greater than the applied voltage. It will be interesting, therefore, to work out the current flowing through this circuit and the maximum p.d. across L and R. The obvious method of approach is to determine the current flowing by the application of Ohm's law, $I = \frac{V}{Z}$. The first step is to determine the value of Z (impedance) which is arrived at by adding R and X vectorially, that is to say taking the square root of $R^2 + X^2$, which for the values shown in Fig. 60 may be written—

$$Z = \sqrt{R^2 + X^2} \qquad \text{or} \qquad Z = \sqrt{25 + 25} = 7{\cdot}07\Omega$$

The impedance of the circuit is now known, therefore the peak value of current flowing may be determined by the simple application of Ohm's law as follows:

$$I = \frac{V}{Z} = I = \frac{100}{7{\cdot}07} = 14{\cdot}14\text{A}$$

It is interesting to note that the current is approximately 40 per cent. greater than would have been the case if a pure resistance had been substituted for L. Now that the current is known it is a simple matter to determine the *maximum* p.d. across L and R, which will be the same in each case, the actual calculation being as follows—

$$V = I \times R = 14{\cdot}14 \times 5 = 70{\cdot}7\text{V}$$

It is stressed that the p.d. across R does not reach 70·7 volts at the *same time* as the maximum p.d. across L; *when* the p.d. across R is at maximum, *i.e.* 70·7, the p.d. across L will be zero,[1] and vice versa.

The power dissipated in the whole circuit will be only that dissipated in the resistance R, which may be determined by applying the now familiar $I^2 \times R = W$. It must be remembered that the current here is the R.M.S. value, *i.e.* $\frac{14{\cdot}14}{1{\cdot}414} = 10$ A, so that the power is $10^2 \times 5 = 500$ watts. The current flowing through and the p.d. across L may be ignored when calculating the power dissipated in the circuit, because, as already explained, energy is not expended in this portion of the circuit the voltage being 90° out of phase with the current.

R and C in Series.—It will be noted that in the preceding calculation, L has been represented solely by its reactance (5Ω), therefore all the figures would hold good if a condenser having a reactance $\left(\frac{1}{2\pi f C}\right)$ of 5Ω were substituted for the inductance. The simple calculations given in this chapter are included as a convenient means of giving the reader an insight into the behaviour of alternating current in a circuit containing

[1] Since the current through the circuit will be out of phase with the applied voltage, maximum current will be reached when the applied voltage has fallen to 70·7 volts.

resistance and reactance. It will be appreciated that, in practice, an inductance will possess pure resistance due to the actual wire from which it is made; it is, however, generally satisfactory to regard such a component as a pure inductance in series with a pure resistance (*i.e.* the resistance of the winding).

R in Parallel with L or C.—Fig. 61 shows the circuit rearranged so that R and L are in parallel, having values of 5Ω resistance and 5Ω reactance respectively; in this arrangement, current from the source of supply will flow directly to each component, consequently each will pass a current quite independently of the other. It is easy to see, therefore, that if the applied p.d. is 100 volts A.C., R (having a resistance of 5Ω) will pass 20 amps, and L (having a reactance of 5Ω) will also pass 20 amps. It must not be assumed, however, that the total current flowing is 40 amps; if both R and L were pure resistances this would be true, but since L is an inductance, the current flowing through it will be 90° out of phase with the current flowing through R, consequently the maximum peak current through each component will not occur at the same time, and the total peak current can never be as great as the sum of the individual peak currents. It is scarcely within the scope of this work to elaborate upon these matters, but it will be of passing interest to conclude the consideration of Fig. 61. The total current flowing may be determined by adding the two currents vectorially:

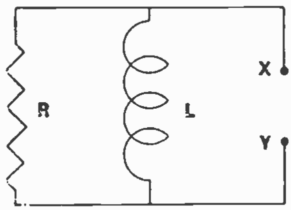


Fig. 61.—Resistance and inductance in parallel.

$$\text{total current} = \sqrt{I_1^2 + I_2^2} = \sqrt{400 + 400} = 28{\cdot}3\text{A (approx.)}$$

As an alternative method of determining the current, the joint impedance of the circuit could be calculated, and with the knowledge of this value and the applied p.d., Ohm's law could be applied and the current determined by the familiar formula $I = \frac{V}{Z}$ The total impedance of resistance and reactance in parallel can be determined by combining them in the following formula—

$$Z = \frac{1}{\sqrt{\left(\frac{1}{R}\right)^2 + \left(\frac{1}{X}\right)^2}}$$

In both the above formulæ it is assumed that L is a pure reactance, and all remarks would apply if L were replaced by a condenser having the same reactance, the circuit for such an arrangement being shown at Fig. 62.

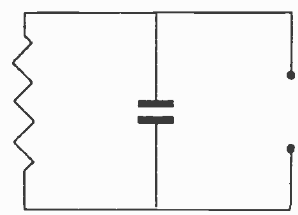


Fig. 62.—Resistance and capacity in parallel.

Some readers will no doubt notice that this formula can be simplified in the mathematical sense, but this is not shown as it would tend to confuse rather than clarify the point at issue.

CHAPTER 9

THE TUNED CIRCUIT

CHAPTER 8 explained the effect of capacity and inductance when associated with resistance. The association of capacity and inductance in the same circuit will, under suitable conditions, bring about the phenomenon of resonance which is the quality that makes it possible for a wireless receiver to select a particular station from among a number of others. It is apparent, therefore, that the subject dealt with in this chapter is of major importance in radio engineering.

L and C in Series.—The simple circuit (Fig. 63) shows an inductance having a reactance of 10Ω at, say, 50 cycles in series with a condenser having a reactance of 5Ω at 50 cycles ; it will be remembered that inductance causes the voltage to lead with respect to the current, whereas capacity causes the voltage to lag, the total reactance therefore is equal to the difference between the inductive and capacitive reactance which in Fig. 63 will be 5Ω at 50 cycles. The simple application of Ohm's law will show that if a 50-cycle A.C. potential of 5 volts is applied, a current of one ampère will flow; the important point to note is that the same current will flow if the two components in Fig. 63 were replaced by either an inductance or condenser having a reactance of 5Ω. It is apparent that the condition represented by Fig. 63 must be entirely imaginary, as it is impossible for a circuit to be without some pure resistance.

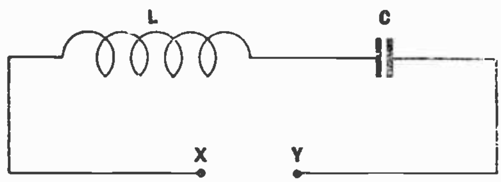


Fig. 63.—Inductance and capacity in series.

It will be remembered that the reactance of a condenser equals $\frac{1}{2\pi f C}$, consequently the greater the frequency the lower the reactance. It will also be recalled that the reactance of an inductance equals $2\pi f L$, therefore an increase of frequency will bring about an increase of reactance.

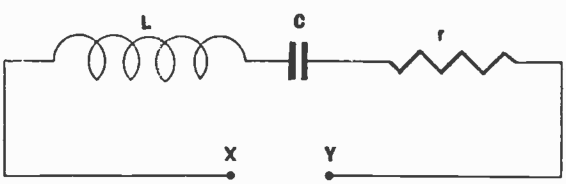


Fig. 64.—Inductance and capacity in series: the high-frequency resistance of the complete circuit is symbolised by a series resistance.

Fig. 64 is a modification of Fig. 63, inasmuch as resistance is included in the circuit ; it is not, in this instance, intended to represent a separate component, but represents the high-frequency resistance of L and C. In this way it is possible to regard L as pure inductance, C as pure capacity, and r as resistance, which may be given an arbitrary value of, say, 20Ω at 800 kilocycles per second.

Reference to Fig. 65 will show the reactance of one value of capacity and three values of inductance over a range of frequencies; for example, it may be seen that the reactance of a 200 μH inductance at 800 kilocycles (375 metres) is 1,000Ω approx. It may also be seen that the reactance of a 200 μμ F condenser is also 1,000Ω approx. at the same frequency; it will be interesting to apply these values to L and C in Fig. 64.

Resonance.—Assuming that an A.C. potential of 100 millivolts is applied across the terminals XY at the above-mentioned frequency of 800 kilocycles per second, it will be easy to determine the current flowing in the circuit when the total impedance is known. The total reactance of L and C will be zero, since, under the conditions chosen they both have a value of 1,000Ω; as already stated the total reactance of inductance and capacity in series is equal to the difference of their individual reactances. The reactance of L and C having cancelled each other the impedance of the circuit will be equal to the resistance, " r," and the condition of resonance will be obtained; the application of Ohm's law will show that the applied pressure, *i.e.* 100 millivolts, will cause a current of 5 milliampères to flow.

Magnification.—The simple circuit under review and the values chosen will now serve to introduce what is perhaps the most extraordinary set of circumstances that can be found in the study of electricity. As explained above the impedance of the circuit in question is only 20Ω because the reactance of L and C cancel each other, but when L is reviewed separately it is an indisputable fact that it has a reactance of 1,000Ω and 5 milliampères is flowing through it, and to determine the potential difference across this inductance Ohm's law may be applied, which will reveal the surprising value of 5,000 millivolts, notwithstanding that the total applied potential is only 100 millivolts.

In other words, the potential difference across the ends of the inductance L is fifty times the applied potential; thus the circuit is said to have a magnification factor of fifty. The accepted abbreviation for coil magnification is " Q," although the old abbreviation " m " is sometimes used.

The particular method used above to determine the magnification of the circuit shown at Fig. 64 was chosen in order to explain as fully as possible what takes place when a circuit is at resonance; there is a more direct method of determining this factor, as the magnification of a circuit at resonance is equal to the ratio of reactance to high-frequency resistance, which may be written as follows:

$$\text{Coil magnification} = \frac{\text{Inductive reactance}}{\text{H.F. resistance}} \text{ or } Q = \frac{X}{r} \text{ or}$$

$$Q = \frac{2\pi f L}{r}$$

Selectivity.—Returning to a further consideration of Fig. 64 it will be interesting to study the effect of applying two different frequencies across the terminals XY, a condition closely resembling that set up in a wireless receiver within the range of two broadcasting stations; one frequency may be the resonant frequency for the values chosen, *i.e.* 800 kilocycles, and the other 700 kilocycles, the applied voltage being 100 millivolts in each case. The total reactance of the circuit at 700 kilocycles may be ascertained in the manner already described, and is 260Ω, which, when added vectorially to the high-frequency resistance, gives the total impedance of the circuit as 261Ω approx.

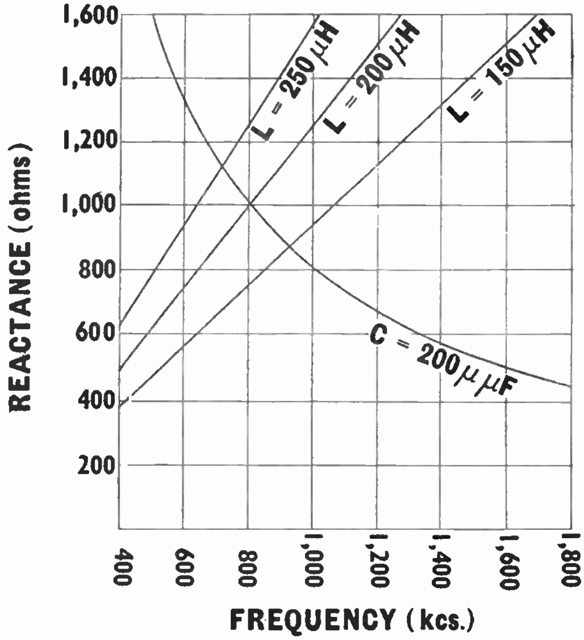


Fig. 65.—The reactance over a range of frequencies of three values of inductance and one value of capacity can be read from this graph.

The applied voltage of 100 millivolts will cause a current of ·38 milliampère to flow. Reference to Fig. 65 will show that the reactance of L at a frequency of 700 kilocycles is 880Ω, and ·38 × 880 gives a voltage across L of 334 millivolts. It will be remembered that the voltage developed across L at 800 kilocycles per second is 5,000 millivolts (5 volts). 334 is approximately one-fifteenth of 5,000; it is therefore apparent that the circuit has a discrimination of fifteen times to a frequency 100 kilocycles per second off resonance. It is doubtless apparent to the reader that this is the manner in which a wireless set is enabled to select a particular station from among many that may be transmitting at the same time. The discrimination of the particular circuit and values mentioned above is inadequate, but, as will be seen later, discrimination may be increased by additional circuits and by other means. It is, perhaps, desirable to mention that when a circuit is in resonance at a particular frequency it is said to be tuned to that frequency, and that the word "discrimination" may now be more appropriately replaced by the term "selectivity."

The behaviour of the tuned circuit under discussion has been noted under the condition of a fixed applied voltage at two different frequencies. It is a comparatively simple matter to determine the voltage developed across the inductance for any number of different frequencies and to show the results in the form of a curve or graph. Fig. 66 shows a curve (Q = 50), determined in this manner from the values taken from Fig. 64. The upper curve in Fig. 66 shows the curve derived from a tuned circuit, the magnification of which is 125; in other words, the value of r in Fig. 64 has been reduced to 8Ω.

Frequency Response.—The curve shown at Fig. 66 is usually termed a response curve, because it shows the extent to which a tuned circuit will respond to various frequencies compared to its response at resonant frequency. A glance at Fig. 66 will show that the higher the magnification the greater the efficiency in terms of both voltage developed and selectivity.

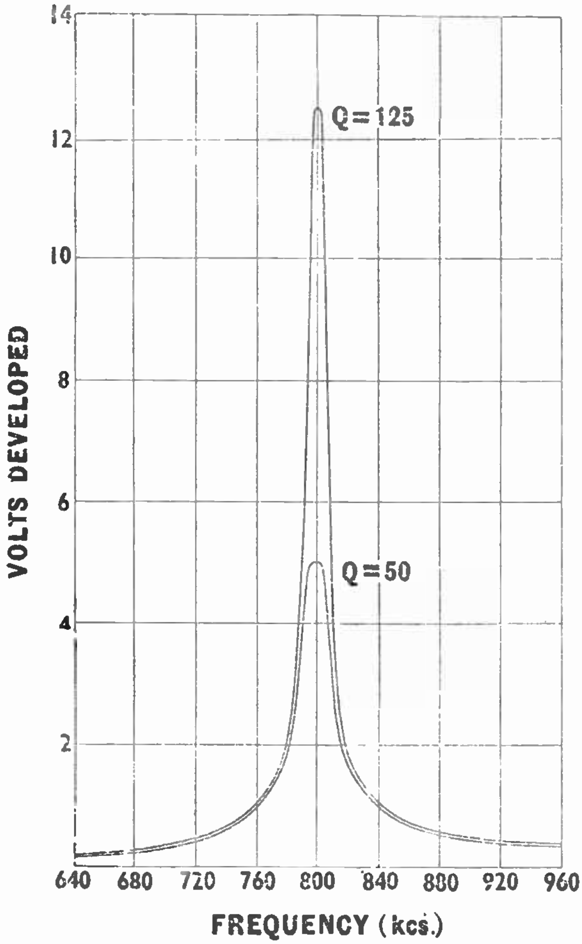


Fig. 66.—The response curve of two inductances having a magnification of 50 and 125 respectively.

It will be noted that r has been used throughout this chapter to denote resistance in preference to R; this is because it is used to represent high-frequency resistance, and must be clearly distinguished from the normal resistance to a direct current. High-frequency resistance is characterised by the fact that it varies with frequency and is somewhat of a paradox inasmuch as the high-frequency resistance of a coil may *increase* if thicker wire is used.

Since the magnification factor of a tuned circuit is inversely proportional to the high-frequency resistance of the circuit, it follows that the magnification factor (Q) will vary with frequency, although when designing a tuned circuit for incorporation in a radio receiver it is desirable to make the Q factor as constant as possible, an aspect that is dealt with in a later chapter. It is perhaps of interest to mention that, in the early days of broadcasting, coils were sold to the general public having "blind spots," that is to say Q varied with frequency to such an extent that its value was almost negligible at certain frequencies.

Parallel-tuned Circuits.—All the foregoing considerations have been limited to the series-tuned circuit, and attention may now be directed to the parallel-tuned circuit. Fig. 67 shows L, C, and *r* rearranged to form a parallel-tuned circuit; it will be noted that *r* has been split up into two portions representing the *high-frequency* resistance of L and C respectively. The value of *r* in the condenser branch is usually so small that its effect may be neglected.

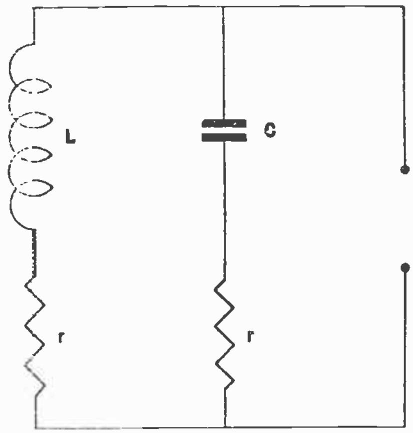


Fig. 67.—A symbolic representation of a parallel-tuned circuit.

Dynamic Resistance.—Assuming for the moment that L and C (Fig. 67) are pure inductance and capacity, it follows that when the circuit is tuned the current flowing in one branch of the circuit will be equal to the current flowing in the other branch of the circuit, and as these will be exactly 180° out of phase the total current will be zero. In practice, however, a small current will flow, as the presence of high-frequency resistance will not permit the two currents to be exactly 180° out of phase. Since an applied voltage causes a current to flow, the circuit must possess as a whole some factor of impedance; this value of impedance is termed dynamic resistance, and is distinguished by the fact that it varies inversely with high-frequency resistance.

The magnification of a parallel-tuned circuit is the same as that of a series-tuned circuit, and everything which has been said about the latter is applicable to the former except in one particular. The series-tuned circuit at resonance permits a large current to flow, which is limited only by the high-frequency resistance of the circuit; on the other hand, the parallel-tuned circuit imposes an almost complete barrier to the flow of current, in fact if it were not for the presence of high-frequency resistance the impedance to the flow of current would be infinitely great and the current would be zero.

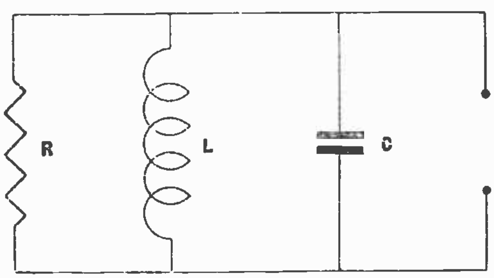


Fig. 68.—In this diagram L and C represent pure inductance and capacity and R symbolises the dynamic resistance.

Fig. 68 shows a parallel-tuned circuit consisting of inductance and capacity and a parallel resistance, R, which symbolises the dynamic resistance of the circuit. In this purely theoretical circuit, L and C are assumed to be pure inductance and capacity, and therefore present an infinite impedance at resonance; the symbolic resistance therefore is unaffected by their presence, and for the purpose of considering dynamic resistance L and C may be ignored, but of course only at the resonant frequency.

It will be noted that R is used instead of r as dynamic resistance behaves as a pure resistance once again, providing that it is only so regarded when the circuit is in resonance. Dynamic resistance is important, as it is required when calculating the over-all magnification of a high-frequency amplifier. It is, however, somewhat difficult to calculate, and can only be reliably determined by measurement, the method of which is dealt with in various textbooks devoted to this subject. A reasonably accurate figure may, however, be obtained by the following formula, but unfortunately the true value of r can only be accurately determined by practical measurement. It is possible to calculate r from dimensions and other coil data, but this does not take into account dielectric and other losses.

$$\text{Dynamic resistance} = \frac{L}{Cr} \text{ approx.}$$

Units are farads, henrys, and ohms respectively, and r is the resistance of the coil.

When actual high-frequency measurements are made to determine the high-frequency resistance of a tuned circuit, a disproportionate figure is obtained ; this is due to losses imposed by the insulating material associated with the circuit, the insulating material to which the ends of the windings are attached, the insulation supporting the vanes of the condenser, and the insulated covering of the wire itself. In addition to this the high-frequency resistance of a coil of wire is always greater than its D.C. resistance, due to the effect of one turn upon the next, and at the higher frequencies to skin effect, which is the term used to describe the behaviour of these currents which travel on the surface of the wire and do not therefore make use of its total cross-section area.

Dielectric losses of this nature may be expressed as a resistance which, shunted across the coil, would bring about the same loss ; it should be noted particularly, however, that the *effect* of a given dielectric loss is proportional to frequency.

A terminal strip which introduces dielectric losses equivalent to a parallel resistance of 1 MΩ at 800 kcs. per second will introduce a loss equivalent to a shunt resistance of ½ MΩ at 1,600 kcs.

Note particularly that the losses of a series-tuned circuit may be regarded as an imaginary resistance in *series*, and that the *lower* this value the *greater* will be the efficiency. In a parallel-tuned circuit losses may be regarded as an imaginary resistance in *parallel*, and the *lower* this value the *lower* will be the efficiency.

The general appearance of an ordinary air-cored coil is too well known to need illustrating. A dust-iron-cored coil is illustrated at Fig. 69; due to the use of the iron core an inductance of 185 μH is obtained with only twenty-three turns of Litz wire on a former half an inch square; the Litz wire used consists of ten strands of forty-five gauge. The high-frequency resistance of such a coil is extremely low, measurements show the example illustrated has the low figure at 4·7Ω at 1,000 kcs.

For the sake of simplicity in the above explanations capacity has been fixed arbitrarily at 200 $\mu\mu$F, but for the purpose of tuning a wireless receiver over a range of frequencies it is necessary that either the inductance or capacity shall be continuously variable. Variation of capacity is usually employed when continuous variation is required, the conventional variable condenser being used, a simple form of which is shown at Fig. 48; modern sets, however, usually employ more than one continuously variable tuned circuit and, to facilitate operation, two or more variable condensers are manufactured as a single unit, and rotated by a single knob.

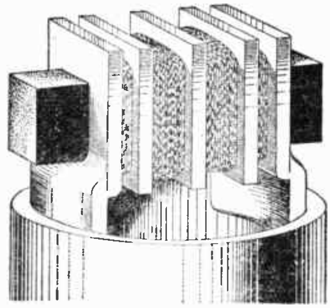


Fig. 69.—An example of a dust-iron-cored coil. The former is moulded from a special synthetic material having very low dielectric loss. The secondary has an inductance of 185 μH with a high-frequency resistance of 4·7 Ω at 1,000 kilocycles.

Capacity Tuning.—The usual type of modern tuning condenser has a minimum capacity of about 30$\mu\mu$F, to which must be added stray capacities due to wiring, etc., while the maximum capacity is approximately 510$\mu\mu$F. Assuming that stray capacities amount to 30$\mu\mu$F, a variation is obtained from 60 to 540$\mu\mu$F; the ratio of maximum to minimum *frequency* is equal to the square root of the maximum to minimum capacity ratio, which for the example chosen will equal 3. It follows that for any given inductance the maximum frequency will be three times the minimum frequency, and in order to select the inductance required means must be found to determine the frequency of various combinations of inductance and capacity.

Permeability Tuning.—When iron cored coils are used the inductance can be varied by withdrawing or inserting the iron core into the coil. This system is known as permeability tuning and is generally used when inductance is pre-set; it is also used for variable tuning at very high frequencies, the aerial tuning of V.H.F. and television receivers being examples.

Relationship between L, C, and f.—It will be remembered that when a tuned circuit is in resonance the capacitive reactance must equal the inductive reactance; it follows, therefore, that

$$2\pi f L = \frac{1}{2\pi f C}.$$

The above equation is somewhat inconvenient to handle, and either of the following equations will be found more suitable:

$$f = \frac{1}{2\pi\sqrt{L \times C}} \text{ or } f^2 = \frac{1}{38{\cdot}5 \times L \times C} \text{ (approx.)}$$

where f is the frequency in cycles per second, L the inductance in henrys, C the capacity in farads, and π equals 3·14 approx.

When it is desired to know the wavelength instead of the frequency the following formula will be found convenient, as microhenrys and microfarads may be used for L and C.

$$\lambda = 1{,}885 \sqrt{L \times C}$$

where λ is the wavelength in metres, L the inductance in microhenrys, and C the capacity in microfarads.

Single inductances are rarely used for tuned circuits in modern receivers, their place being taken by the high-frequency transformer, which usually consists of a tuned secondary coil and an untuned primary; such an arrangement is shown diagrammatically at Fig. 70. Specialised forms of coils are dealt with in the appropriate chapters, and in the meantime it will be sufficient to mention that the characteristics of the primary are imposed upon the secondary and vice versa, to an extent dependent upon the ratio of one winding to the other, the separating distance, and their angular relationship. As an example, losses present in the secondary circuit due to various causes are also present in the primary to an extent dependent upon the above-mentioned factors.

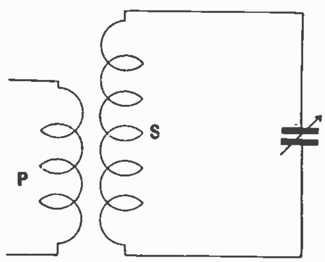


Fig. 70.—A tuned high-frequency transformer.

A step-up high-frequency transformer steps up the primary voltage so that a greater voltage appears across the secondary; unfortunately the permissible step-up ratio is limited by a number of factors, one of which is the falling off of primary impedance when the number of primary turns is decreased.

Sideband Cutting.—As explained in an earlier chapter, the radiated wave from a broadcasting station occupies a definite band width. Reference to Fig. 66 will show that maximum voltage is only obtained at resonance; when a number of coils are used, or other means are taken to improve selectivity, the curve becomes much sharper, with the result that the response is considerably reduced at a frequency only 1 or 2 kcs. off resonance, resulting in distortion, which takes the form of high-note attenuation due to the reduction in the response of the tuned circuit to those frequencies which, although off resonance, are nevertheless within the band width of the transmission being received. This form of distortion is referred to as sideband cutting.

The Bandpass Filter.—It is apparent that the ideal tuned circuit should have a level response to a band width of about 4 kcs. each side of the resonant frequency and a negligible response outside it. In other words, if Fig. 66 were the curve of an ideal tuned circuit its sides would be parallel, spaced about 8 kcs. apart, and with a flat top. In modern practice the coil designer strives to produce response curves as near as possible to the ideal; special high-frequency transformers are used, having both the primary and secondary tuned and carefully arranged coupling. Such an arrangement is called a bandpass coupling, or a bandpass filter, for the obvious reason that it is designed to pass a band of frequencies and attenuate all others.

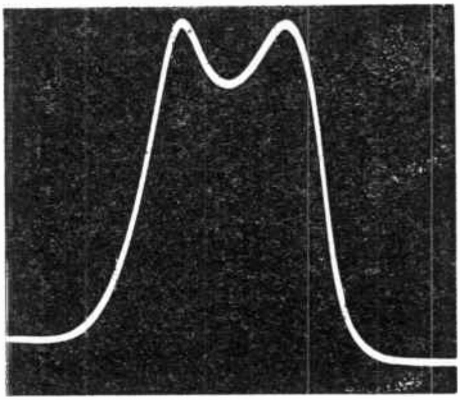


Fig. 71.—An oscillogram showing the frequency response of a bandpass filter.

There are various forms of couplings used in bandpass filters. As a single example will serve the present need, mention may be made of the over-coupled type. This takes the form of two coils of equal inductance mounted side by side so that their characteristics have a profound influence on each other. Each coil is tuned to the resonant frequency by a condenser connected in parallel. Fig. 71 shows the actual response curve of an amplifier using two complete bandpass couplings of this type; being an actual photograph of a response curve it is an honest illustration even though it may fall short of the claims made for such circuits. It should, however, be clearly understood that when producing an oscillogram the vertical and horizontal scales may be varied at will, and this particular illustration could have been made a foot high and an inch wide. In order, therefore, that it may be presented in its true perspective, Fig. 72 is included, which is taken to exactly the same scale as Fig. 71, the only difference being that the two coils were moved farther apart so that the coupling between them was very small and in consequence the bandpass qualities of the coupling were destroyed. As a further aid to the appreciation of these oscillograms it may be mentioned that the frequency difference between the two peaks shown at Fig. 71 is approximately 5 kcs., and the amplitude of the whole oscillogram approximately 15 volts. As the two oscillograms are taken to the same scale, it is apparent that the sharply tuned circuit shown at Fig. 72 will cut sidebands to a very serious extent.

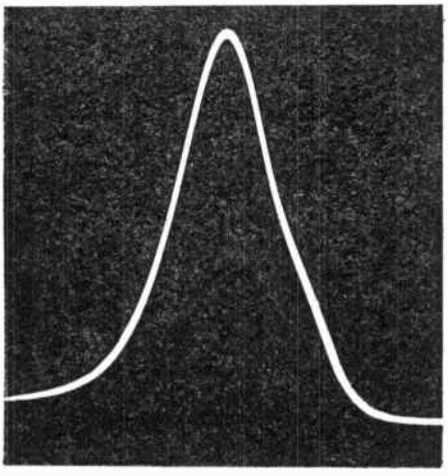


Fig. 72.—An oscillogram showing the frequency response obtained with the same coils as used for Fig. 71, but differently adjusted, as described in the text.

Oscillograph instruments suitable for taking these oscillograms are described in some detail; nevertheless, it may be desirable to define briefly the principle of the instrument, so that the true nature of these oscillograms will be apparent.

The cathode-ray tube utilises a beam of electrons which may be made to move by the application of the voltage or current to be examined. The extremity of this beam impinges on a chemical screen which becomes fluorescent under bombardment, permitting an accurate photograph to be taken of the trace so formed. Figs. 71 and 72 are photographs obtained in this manner.

CHAPTER 10

THE PRINCIPLES OF THE THERMIONIC VALVE

TOWARDS the end of the last century Professor J. A. Fleming made a discovery of far-reaching importance. In the course of experiment he discovered that certain substances, particularly metals, when heated to a suitable temperature in a vacuum possessed the peculiar property of emitting what were then thought to be charged particles. Further experiment disclosed that these "particles" could be attracted by a metal plate, provided that it was held at a positive potential relative to the emitting substance; on the other hand, no attraction occurred if the metal plate was held at a negative potential. It was therefore concluded, and with good reason, that these mysterious "particles" must hold a negative charge. It is now known that these "particles" were in fact electrons, about which so much has already been said that no introduction is necessary.

Those who are interested in these historic discoveries of Professor Fleming may readily find them described in books devoted to the historical development of electrical engineering. It may, however, be said that the modern valve of to-day, which is available in so many specialised forms, is a direct development of these early discoveries.

The Diode.—The simplest form of thermionic valve is the diode, which is so called because it consists of two electrodes, the filament or cathode and the anode. The filament may be made of some unaided metal such as tungsten; such a valve is known as a bright emitter, as it is necessary for the filament to be run at a temperature of some 2,200° C., *i.e.* approaching white heat, to obtain any appreciable emission of electrons. Owing to the necessity of running a tungsten filament at such a high temperature its life is necessarily short, and such filaments are not now in general use.

The modern coated filament consists of a fine wire made of tungsten or nickel forming a core which can conveniently be heated to a temperature of some 800° C., which is a dull red heat. This core is coated either virtually or literally with chemicals that have the property of emitting prolific quantities of electrons at a relatively low temperature. The exact formula used to compound these coatings and the methods of making them adhere to the core are still somewhat guarded secrets of the valve manufacturer, but the basis is almost invariably barium or strontium oxides or both.

The anode may consist of any piece of metal situated reasonably close to the filament, but in practice it takes the form of a small open-ended cylinder symmetrically surrounding a straight wire filament. It is of interest to mention that valve electrodes are usually made of nickel or molybdenum, both of which are readily obtainable in a high degree of purity; the former possesses the additional advantage that it is easily freed from natural gas, while molybdenum has the advantage of an extremely high melting-point. For specialised purposes other metals are used, notably nicrome for grids, while copper is sometimes used to support electrodes which are liable to become hot owing to the high heat conductivity of this metal.

Vacuum.—For reasons which will be apparent later in the chapter it is necessary that the valve bulb should be pumped to a very high degree of vacuum and that the metal parts, and even the inside of the bulb that contains them, must be freed from surface gas which might otherwise be freed by the action of electrons and impair the efficiency of the valve. To achieve these objects the most extravagant precautions are taken by modern valve manufacturers.

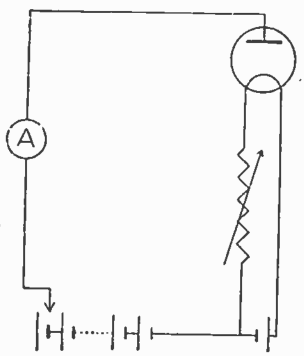


Fig. 73.—A diode valve arranged for plotting its characteristic curve.

The above brief introduction has served to outline the structure of valves in general and the diode in particular, and attention may now be directed to the circuit shown at Fig. 73, which shows a convenient circuit arrangement for investigating the characteristics of a diode valve. It will be noted that a variable resistance is included in the filament circuit to control the current passing through it, and consequently its temperature. A suitable milliammeter is included in the anode circuit. Since it is intended to liberate electrons from the filament and collect them by means of the anode a battery is included in the anode circuit to hold the anode at a positive potential to attract the electrons away from the filament.

Emission.—Fig. 74 shows a curve obtained by this means, showing emission in the vertical direction plotted against anode voltage in the horizontal direction. Emission does not commence until a certain filament temperature is reached; if the filament is of the non-coated type, a point is reached where further increase of anode voltage does not increase emission. This is known as saturation point. Saturation does not occur with a coated filament, as an increase in anode voltage will always bring about an increase of emission, although it may be very small. The curve of such a valve cannot be taken to finality, as the filament coating is destroyed when its emission is increased too far above normal.

It should be clearly understood that the flow of electrons is simply an electric current and that there is no difference between the flow of electrons from filament to anode the and flow of electrons from the anode via the anode circuit to the filament; it is simply the electronic current, although the medium is different in each case, *i.e.* free space between filament and anode and a metallic conductor for the rest of the journey.

The electrons travel from the filament to the anode, which is held at a positive potential. It will be remembered that this direction, namely negative to positive, is the true direction of an electric current, but that the converse is assumed for reasons that are clearly stated in the opening paragraphs of Chapter 5.

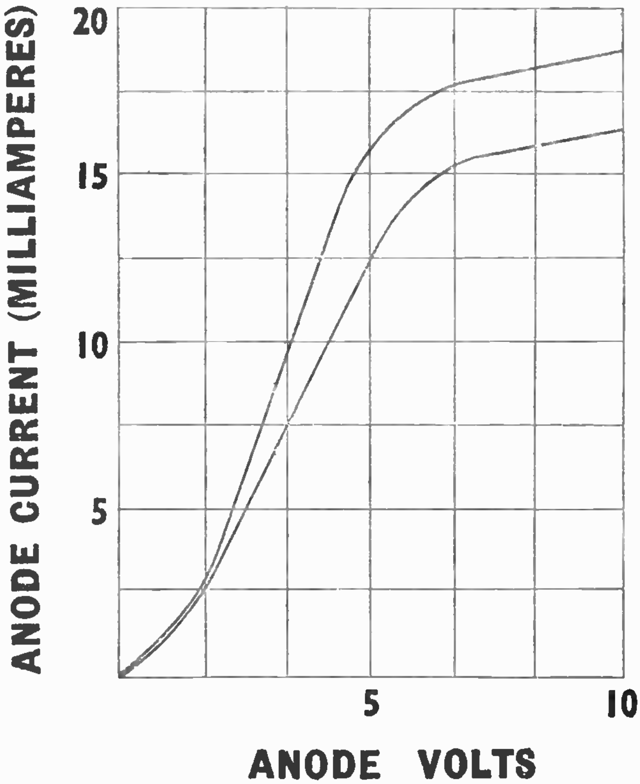


Fig. 74.—The characteristic curve of a diode valve showing the effect of filament temperature. The upper curve was taken with a potential difference of 4 volts across the filament, and the lower curve with 3·5 volts across the filament.

Rectification.—The diode, like all thermionic valves, has a most useful function, inasmuch as it will permit the flow of current in one direction only, and it is apparent, therefore, that it will have a marked effect if suitably introduced into the path of an alternating current. Fig. 75 shows a convenient circuit for applying an alternating potential across a diode valve. It will be interesting to follow the behaviour of both voltage and current for a period of one complete cycle (commencing with the zero point immediately before the positive half-cycle). Since, at this point, voltage is zero, current will also be zero, but as the voltage rises towards maximum positive, current will flow through the valve and will continue to do so as long as the anode remains positive, the actual amplitude of the current being determined by the applied A.C. voltage and the internal A.C. resistance of the valve.

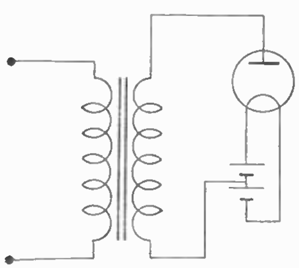


Fig. 75.—A simple circuit to illustrate the uni-directional properties of a diode.

At the completion of the positive half-cycle the current will fall to zero, and will remain at zero during the entire negative half-cycle, since the electrons cannot flow from anode to filament because the anode is incapable of emission. Fig. 76 shows (left) an alternating potential which when applied to a diode will cause a current to flow, having a waveform as shown at Fig. 76 (right). It should be noted that the relative amplitudes have no significance, as one diagram represents voltage and the other current.

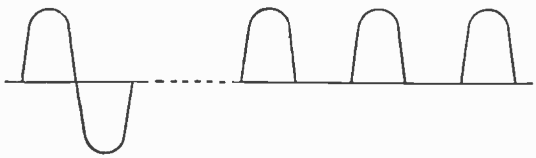


Fig. 76.—(*Left*) An alternating current waveform, and (*Right*) after rectification.

The conversion of alternating current (A.C.) to continuous current (D.C.) by means of a valve is termed rectification, and a valve specially designed for this purpose is referred to as a rectifier. The diode may also be used for detection, which is a subject dealt with in detail in the next two chapters.

The Grid.—Although useful for detection and rectification the diode is incapable of amplifying, that is to say the output from a diode circuit can never exceed the input. Fortunately, this difficulty was overcome by Lee de Forest, an American, who in 1907 discovered that a valve could be made to amplify by means of a third electrode made of wire gauze (now called the grid) placed between filament and anode in the path of the electrons. He found that small changes of potential between grid and filament brought about a relatively large change of potential across a resistance in the anode circuit and amplification was achieved.

The Triode.—Fig. 77 shows a basic circuit that will serve to illustrate the function of a triode valve. It will be convenient to assume that the input consists of an alternating voltage having a value of one volt peak, and to follow the functions of the valve over one complete cycle of the input. In order that the grid will not become positive, a fixed potential of 3 volts negative is applied by means of a 3-volt battery; a battery used for this purpose is called a grid-bias battery, and the actual potential applied is termed the grid bias.

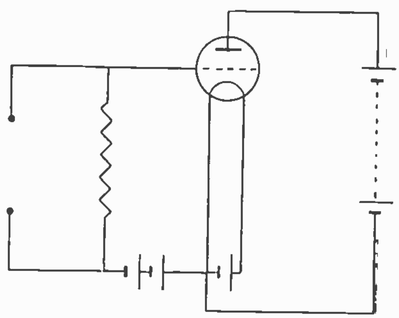


Fig. 77.—A skeleton circuit to illustrate the text.

When the grid is held at the same potential as the filament, a good proportion of the electrons emitted by the filament are drawn towards the anode by its positive field and pass through the mesh of the grid. When a small negative potential is applied to the grid it opposes the free passage of electrons and the flow to the anode is reduced. A further increase of negative potential brings about a further decrease in anode current, and so on, until the grid becomes so negative that the flow of electrons ceases and produces a cloud round the filament forming what is termed a space charge. In the interest of strict accuracy it is desirable to mention that although the flow of electrons ceases for all practical

A GIANT TRANSMITTING VALVE

Differing in size but not in principle this large transmitting valve requires a special trolley when replacement is necessary; this picture shows the final amplifier at a B.B.C. transmitting station. Note the doors which instantly disconnect the H.T. supply when opened.

purposes, a few stray ones will find their way from filament to anode by some roundabout route outside the controlling influence of the grid.

Fig. 78 shows diagrammatically the effect of negative grid potential on the electron stream. Left shows the condition obtaining when the grid is held at a potential equal to the mean filament potential, centre illustrates the effect of normal negative grid bias, while right represents the stoppage of anode current due to the application of a relatively high negative value of grid bias.

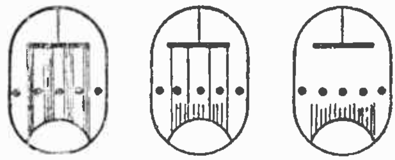


Fig. 78.—A purely imaginary sketch, showing the influence of the grid on the electron stream. (*Left*) Indicates no grid bias; (*middle*) shows the effect of moderate grid bias, while (*right*) shows that excessive grid bias will completely stop the flow of electrons to the anode.

When the small alternating potential already referred to is applied between grid and filament it will in effect decrease and increase the standing bias as the input becomes positive and negative respectively. When the input reaches the peak of the positive half-cycle, *i.e.* 1 volt positive, the grid voltage will be reduced to 2 volts negative (-3 and $+1 = -2$). The grid under this condition will permit an increase of anode current. When the input reaches its maximum negative value the potential difference between grid and filament will be 4 volts (-3 and $-1 = -4$) and the flow of electrons will decrease correspondingly.

To summarise, it is apparent that a change of potential applied between grid and filament will cause a *proportionate* change of anode current, so that the waveform of the alternating voltage applied to the grid will be faithfully reproduced as a fluctuating current in the anode circuit. By inserting a suitable resistance in the anode circuit the current passing through it will produce a voltage drop across its ends and convert the changes of anode current to changes of voltage. Thus changes of voltage applied to the grid will bring about changes of voltage across the anode resistance which are identical in every respect except amplitude, which will be greater in proportion to the amplification of the stage, *i.e.* the valve and its attendant anode resistance.

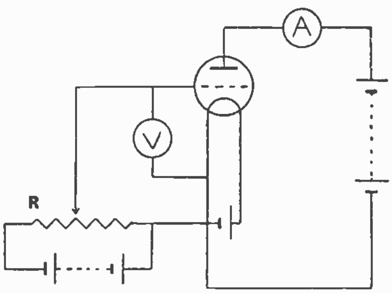


Fig. 79.—This circuit permits grid-volt characteristics to be plotted.

Characteristics.—Fig. 79 shows a circuit which will enable certain characteristics to be taken from a triode valve; the present intention being to ascertain the influence that a change in grid potential will have upon the anode current. It will be observed that a milliammeter is connected in the anode circuit to give direct reading of the anode current. A voltmeter is connected between grid and filament, so that a direct reading is obtained of the voltage difference between filament and grid which may be varied by means of a potentiometer, R. A series of figures taken from this circuit are plotted in the form of a graph, shown at Fig. 80; it will be observed that the graph is plotted between anode current in the vertical direction and grid voltage in the horizontal direction. Such a curve is described as a grid-volts/anode-current curve.

The anode current of any valve is influenced by the anode voltage, consequently it is necessary to state the potential difference between anode and filament obtaining when a curve is plotted. The family of curves shown at Fig. 80 were each plotted with different anode potentials of 75, 100, 125, and 150 volts respectively, each being indicated on the curve by the conventional abbreviation V*a* = 100, etc. It will be noted that the variation of grid voltage at Fig. 80 is from − 7 volts, where emission is entirely absent to zero. Such a curve could be extended in the right-hand direction to show the effect of applying a positive grid voltage, but such a procedure is not normally adopted, as the average valve does not perform normally under such conditions owing to the presence of grid current.

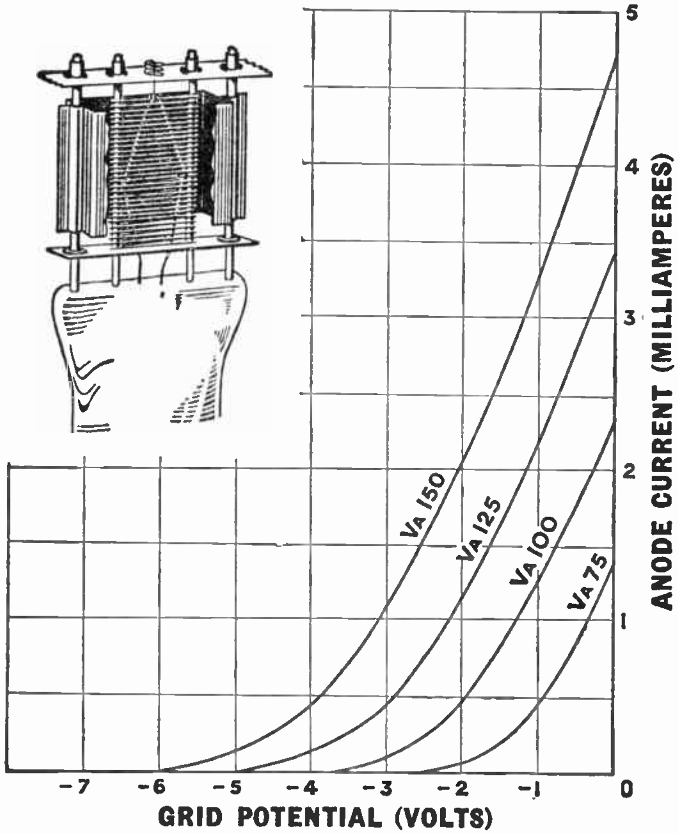


Fig. 80.—Characteristic curves of a typical triode valve. The valve from which they were taken is illustrated in the inset.

Grid Current.—Grid current is a term applied to a flow of electrons from filament to grid due to the positive potential of the latter drawing a certain proportion of the electrons off the main stream to the anode. In other words, the filament and grid behave as though they constituted a diode valve. When a triode is used as a detector the grid is deliberately made positive to encourage grid current—this aspect, however, is dealt with separately in the following two chapters.

It is desirable to mention that it is impracticable to plot a curve with any appreciable positive grid voltage applied, as under conditions of normal anode voltage the anode current would be so high that the filament coating would rapidly break up.

Operating Conditions.—Fig. 81 shows diagrammatically the application of a small alternating voltage to the grid of a valve and the resulting change of anode current. This anode current passed through a suitable resistance will bring about a relatively large change of anode voltage. It has been stated that the voltage output will be a faithful replica of the input in every respect except amplitude; this is only true because certain important conditions have been observed. Reference to Fig. 81 will show that the input is applied about the centre of the *straight* portion of the curve. If the grid bias had been excessive the positive half-cycle would have worked on a sensibly straight portion of the curve, but the negative half-cycle would work on a curved portion, which would result in a decreased and non-linear change of anode current, producing a distorted waveform similar to that shown at Fig. 82. Taking the converse case, the absence of grid bias would result in the negative half-cycle being faithfully reproduced in the anode circuit, but the positive half-cycle would cross the zero line, the grid would become positive, grid current would flow and cause a waveform to be distorted. Fig. 83 shows (*a*) an undistorted A.C. waveform, (*b*) the same waveform distorted by underbiasing, and (*c*) distortion due to overbiasing.

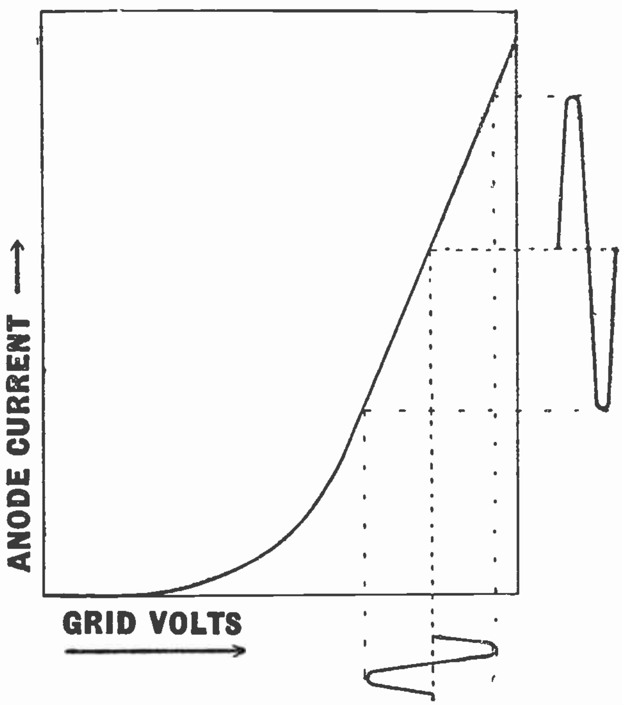


Fig. 81.—Showing an alternating voltage input and resulting alternating current output when valve is correctly biased.

Distortion.—It is apparent that similar distortion would result if the amplitude of the input is so large that its swing is greater than the straight portion of the curve. This causes a combination of the distortion shown at Fig. 83 (*b*) and (*c*), and has the appearance shown at Fig. 83 (*d*). When a valve is in the condition shown at (*c*) it is said to be bottom bending, while condition (*b*) is referred to as running into grid current, although both these conditions are also referred to as partial rectification. The condition (*d*) is referred to as overloading, the reason underlying this nomenclature being obvious.

Since grid potential has such an effect upon the electron stream, it is not surprising that the general dimensions and position of the grid should have an equally profound influence. Fig. 84 illustrates two grids taken from triode valves of widely different characteristics, and it is apparent that some means is required for expressing the ratio of control effected by the grid in various types of valve. A review of this and other characteristics will throw considerable light on the function of a valve, and the manner in which they are related to such components that may be used to form a complete circuit. The method of measuring these characteristics is also explained below, as it permits ready appreciation of their significance.

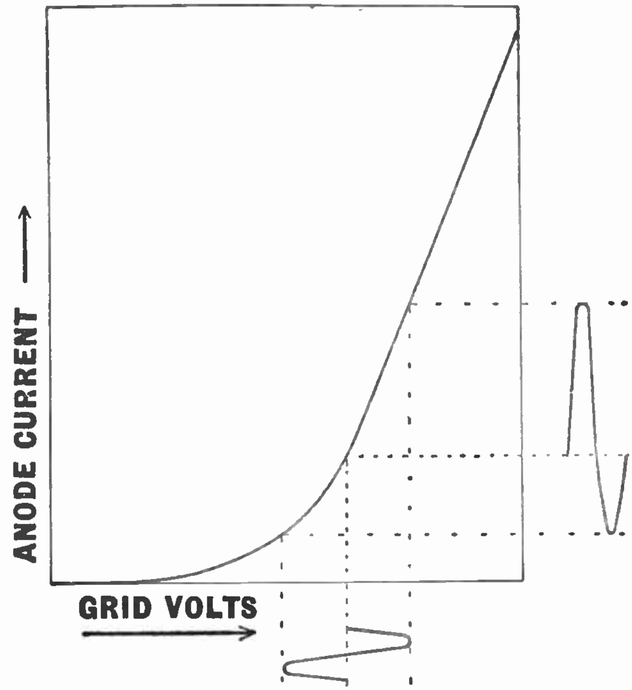


Fig. 82.—Showing an alternating voltage input and resulting alternating current output when valve is overbiased.

Impedance.—The first characteristic is termed anode A.C. resistance or impedance, and is the internal A.C. resistance between filament and anode, the value of which varies considerably with operating conditions. The term "impedance" is deprecated by the British Standards Institution, who recommend the use of the term "anode A.C. resistance." This expression, however, is unwieldy and, furthermore, the term "impedance" is generally used in valve catalogues and most textbooks; the author therefore adopts the term "impedance" throughout this work. Valve impedance, which is written r_a, depends primarily on anode voltage, and an increase of anode voltage will normally bring about a decrease of impedance. In certain types of valves it is desirable to reduce the impedance to a very low value, but limitations are imposed by the consequential large increase in anode current. Impedance is

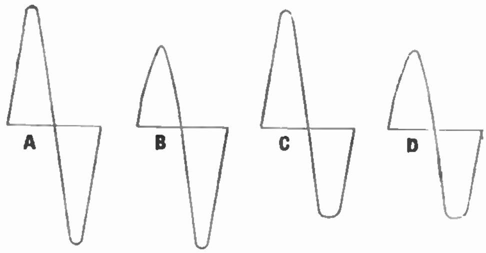


Fig. 83.—(A) A normal undistorted A.C. waveform. (B) The effect of underbiasing. (C) The effect of overbiasing, and (D) Overloading.

also affected by grid voltage, and an increase of the latter in a negative direction will bring about an increase of the former.

Since impedance varies with operating conditions, *i.e.* anode and grid voltages, it is necessary to state these figures when quoting a value of impedance. Impedance of a triode valve is usually quoted for an anode potential of 100 volts and zero grid volts, which is expressed as $Va = 100$, $Vg = 0$.

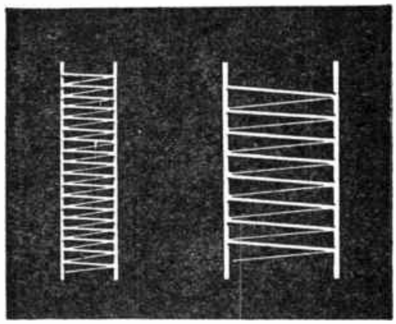


Fig. 84.—Sketch showing two grids taken from normal triode valves. Note the wide difference in mesh and width.

Impedance is measured by noting the change of anode current resulting from a change of anode voltage, the variation being small, and is actually determined as follows:

$$\text{Impedance} = \frac{\text{Change in anode volts}}{\text{Change in anode current}}.$$

The change in anode voltage must be relatively small, and grid volts must be kept constant. Units are volts and ampères.

Suppose that a triode valve passes an anode current of 6 milliampères at 90 volts and 8 milliampères at 110 volts, it is apparent that a change of 20 volts has brought about a change of 2 milliampères. To avoid converting milliampères to ampères the current may be divided into the voltage straight away, when the answer will be in thousands of ohms, since there are a thousand milliampères to an ampère; in the present example, 20 volts divided by 2 milliampères equals 10, and since the answer is in thousands of ohms, the impedance is 10,000 ohms.

Amplification Factor.—As already explained, a triode valve possesses the ability to amplify, and the quality of the particular valve to perform this function is the amplification factor. It should be noted that the amplification factor is the inherent ability of the valve, but when incorporated into a circuit the effective amplification must necessarily be less, for reasons which will be apparent in due course. Amplification factor may be described as the ratio of the anode voltage to the grid voltage as a means of controlling anode current. In the example quoted above, to explain impedance it was necessary to raise the anode potential by 20 volts to change the anode current by 2 milliampères; if a change of 1 volt on the grid brings about a similar change of anode current, it is apparent that the grid has twenty times the influence of the anode, and the valve, therefore, has an amplification factor of twenty.

The amplification factor, which is written μ (pronounced "mu"), is measured by noting the anode current at $Va = 90$, $Vg = 0$; the anode potential is then increased to $Va = 110$, and negative grid voltage increased until the anode current falls back to the original reading.

value of grid voltage necessary to bring this about is then divided into the change of anode voltage. Expressed conventionally:

$$\text{Amplification factor} = \frac{\text{Change in anode volts}}{\text{Change in grid volts}}.$$

It should be noted that μ also means one millionth of, and care should be taken to avoid confusion as μ may appear twice in a formula and mean amplification factor at one appearance and the alternative at another.

By changing the structure of a valve, impedance and amplification factor can be increased or decreased within certain limits. By moving the anode farther from the filament both these factors will be increased, but the efficiency of the valve will very probably be reduced, since it is difficult to realise in practice the amplification factor of a high-impedance valve. Consequently some factor is required that will take into account both impedance and amplification factor, and act as an indication of valve efficiency quite independently of any other consideration. Such a factor is available and is termed "mutual conductance" or, colloquially speaking, "slope."

Mutual Conductance (Slope).—Mutual conductance signifies the change of anode current brought about by a change of grid voltage. It is usually denoted by the letter g_m and expressed as "the change of anode current in milliampères per volt change of grid potential," and is expressed as *m*A/V, or in other words:

$$\text{Mutual conductance} = \frac{\text{Change in anode current}}{\text{Change in grid volts}}.$$

When actually measuring mutual conductance, it is usual to increase the grid voltage from zero to -1 and note the change in anode current. If this is 3 milliampères then the mutual conductance is 3*m*A/V.

Mutual conductance, amplification factor, and impedance are all related, and if any two are known the third can be found by application of the appropriate formula:

$$g_m = \frac{\mu \times 1{,}000}{r_a} \qquad \mu = \frac{r_a \times g_m}{1{,}000} \qquad r_a = \frac{\mu \times 1{,}000}{g_m}$$

where g_m is in *m*A/V, and r_a is in ohms.

The Interpretation of Curves.—Valve manufacturers publish characteristic curves for each type of the thousand-odd types of valves available on the British market. A typical example of the characteristic curves is shown at Fig. 80. These curves are in very great demand by constructors, amateurs, service engineers, many of whom limit their usefulness to determining the grid bias appropriate for any given set of conditions; characteristic curves, however, are capable of wider interpretation, as they form a fairly complete specification of the valve and much information may be obtained from them.

Curves such as those shown at Fig. 80 will yield the following information with a reasonable degree of accuracy:

(1) Nominal valve impedance.
(2) Valve impedance at various grid voltages.
(3) Amplification factor.
(4) Anode current under various conditions of grid and anode potential.
(5) Correct grid bias for four different anode voltages.
(6) Maximum permissible input, *i.e.* grid swing.

Reading Impedance.—For calculating nominal impedance it is necessary to know the change in anode current due to a known change of anode voltage. If the valve is a triode, the nominal impedance is usually quoted as $Va = 100$, $Vg = 0$, and anode current is usually measured at $Va = 90$ and $Va = 110$. This precise information is not available in Fig. 80, but the anode current can be read for anode potentials 25 volts above and below the nominal potential of 100 volts.

The anode current for $Va = 75$, $Vg = 0$ is 1·4 milliampères, while the anode current for $Va = 125$, $Vg = 0$ is 3·4 milliampères; thus it can be seen that a change of 50 volts in anode potential brings about a change of 2 milliampères in anode current. Application of the formula for impedance, *i.e.* $50 \div 2$, gives 25. Since the anode current is in milliampères the answer will be in thousands of ohms; the valve, therefore, has an impedance of 25,000 ohms at $Va = 100$, $Vg = 0$. (This rating being the mean potential.) It will be interesting to use the same method for calculating the impedance at a set of conditions likely to be met with in practice, say, $Va = 125$, $Vg = 1·5$. The curve for $Va = 125$ is mid-way between the curves for $Va = 150$ and $Va = 100$, so the latter may be used to give the necessary change in anode voltage. Since the required condition is $Vg = 1·5$, the current change must be read where the curves intersect an imaginary vertical line drawn between 1 and 2 on the grid-volts scale. The change of current is 1·8 milliampères and the change of anode potential is 50 volts; $50 \div 1·8 = 27·7$ approx., thus the impedance of the valve at $Va = 125$, $Vg = 1·5$ is 28,000 ohms approx.

Reading Amplification Factor.—To calculate amplification factor it is necessary to know the grid voltage required to keep the anode current constant when anode voltage is increased; employing the same curves as used above it is simply necessary to find that bias which must be applied to the $Va = 125$ curve so that the anode current is the same as that passed when $Va = 75$, $Vg = 0$.

Reference to Fig. 80 will show that the anode current flowing when $Va = 125$, $Vg = 1·75$, is the same as when $Va = 75$, $Vg = 0$. The amplification factor is equal to change in anode volts divided by change in grid volts, thus $50 \div 1·75 = 28·5$ approx., the amplification factor. If this method of approach is pursued a step farther, it is possible to calculate the amplification factor of the valve when operating under working conditions, for example at $Va = 125$, $Vg = 1·5$, the amplification factor is 27·5.

Reading Slope.—Slope is the easiest characteristic to calculate from a curve, as it is simply necessary to note the fall in anode current for a particular anode voltage when 1 volt is applied to the grid. When reading the $Va = 100$ curve it will be found that the change in anode current for a change of one grid volt is 1·1 milliampères, while from the impedance and amplification factor in the manner already described, it will be found to be 1·15 *m*A/V. This slight discrepancy is to be expected when reading figures from a small-scale drawing, it is also partly due to slight inaccuracies inevitable with freehand curves.

It is obviously a simple matter to read the slope for the four values of anode potential plotted and to tabulate them as follows:

Slope at $Va = 150 = 1{\cdot}45$ *m*A/V.
,, $Va = 125 = 1{\cdot}25$ *m*A/V.
,, $Va = 100 = 1{\cdot}15$ *m*A/V.
,, $Va = 75 = {\cdot}95$ *m*A/V.

The measurement of slope may be carried out under any conditions of grid voltage in relation to any of the four anode voltages for which curves are drawn: one further example will suffice, taken at the suggested practical operating conditions used for previous examples, *i.e.* $Va = 125$, $Vg = 1{\cdot}5$. Under these conditions slope $= 1{\cdot}05$ *m*A/V. It should be noted that the necessary 1-volt variation is made up taking a reading at ·5 volt above and below the specified condition of $Vg = 1{\cdot}5$; this is convenient, and also tends towards greater accuracy; unfortunately the same procedure cannot be adopted at $Vg = 0$, since this would entail taking readings at $Vg = -{\cdot}5$ and $Vg = +{\cdot}5$. Under the latter condition the majority of valves will run into grid current.

Correct Grid Bias.—The correct value for grid bias that should be applied to a particular valve when working at a stated anode potential can be obtained most conveniently from inspection of the curves. The correct value will be the highest negative value that will permit the input to work on a sensibly straight portion of the characteristic curve; the expression sensibly straight is chosen deliberately, as the perfectly straight portion of the grid-volts/anode-current curve of a high impedance valve is so short that it is useless for practical purposes. The portion of a curve that may be considered usable is necessarily somewhat arbitrary, unless it is considered worth while to carry out a detailed analysis to ascertain the actual distortion that will result from using a selected portion of the curve; such a procedure is worth while when determining the correct operating conditions for an output valve, for reasons that will be apparent in due course. Such an elaborate procedure is not normally undertaken for valves in the other stages for various reasons, important among which are: (1) the considerable difference between the actual working curve and the published static curve due to the influence of high impedance in the anode circuit, and (2) the variation between different specimens of the same make and type of valve. The following suggestions will serve as a guide to correct biasing, using once again the curves shown at Fig. 80 as an example. The $Va = 150$ curve may be considered as usably straight between zero and − 3 volts, and in order that it may take the maximum input without distortion the appropriate grid bias will be − 1·5, which is the mid-point of the straight portion of the characteristic. If, for any reason, the valve is not expected to receive the maximum permissible input, the value of grid bias may be somewhat higher. The $Va = 75$ curve has very little straight portion, but bearing in mind that the external anode impedance will tend to straighten it, the portion zero to − 1·2 volts may be considered usable, the appropriate bias being − ·6 volt.

Stage Gain.—It has already been intimated that the voltage-amplification factor of the valve will not be the actual signal amplification when the valve is working as part of a complete circuit. Fig. 85 shows a triode valve arranged as an amplifier. It will be noted that grid bias is applied to the grid through a resistance, R_1. There will not be any voltage drop across this resistance, since current will not flow through it; unless, of course, the valve becomes overloaded and runs into grid current. The resistance R_2 is included in the anode circuit to convert change of anode current into voltage change. The voltage output will be available across V_2, which will be an alternating potential, the D.C. voltage component in the anode circuit being isolated by the condenser C_2, similarly, any D.C. voltage that may be present in the input circuit is isolated by condenser C_1.

The A.C. input is equal to V_1, and the amplified A.C. output is equal to V_2, consequently the stage gain will be the ratio of V_2 to V_1. The stage gain will be dependent upon the impedance of the valve, the impedance of the anode circuit, which in this case is the value of the resistance R_2, and the amplification factor of the valve. It is very important to note that both the impedance and amplification factor must be the values obtaining under working conditions. The nominal impedance and amplification factor, as quoted by the valve manufacturers, are measured at $Va = 100$, $Vg = 0$, but in the circuit shown at Fig. 85 the valve is working under other conditions, as the application of negative grid voltage will increase both the amplification factor and impedance and decrease the slope. On the other hand, the converse will result if the anode potential is greater than 100 volts. It should be noted that the anode potential is the actual potential difference between anode and filament, which will be less than the voltage of the high-tension battery, due to the voltage drop across R_2 caused by the flow of anode current.

Stage gain, *i.e.* the ratio alternating voltage output to alternating voltage input, is determined by

$$\text{Stage gain} = \frac{\mu \times R_2}{R_2 + r_a}$$

when μ equal the amplification factor of the valve under working conditions, R_2 equals the resistance in the anode circuit, and r_a equals valve impedance under working conditions.

The necessity for using the operating value of μ and r_a is stressed to throw further light upon the behaviour of a valve; when calculating stage gain for practical purposes the nominal values of μ and r_a can generally be used with perfect safety, as other factors, including variations between valves of the same type, are liable to introduce considerable error, and there is little to be gained by being pedantic about a small error when relatively large errors cannot easily be avoided. The only satisfactory method of determining stage gain is by actually measuring the input and output and dividing the value of the former into the value of the latter.

This brief introduction to valve amplification is necessarily expressed in general terms, since conditions vary with the type of valve and the nature of the input to be handled, which may be at high or low frequency and of small or large amplitude. This important subject is, however, dealt with in detail under the appropriate headings in succeeding chapters.

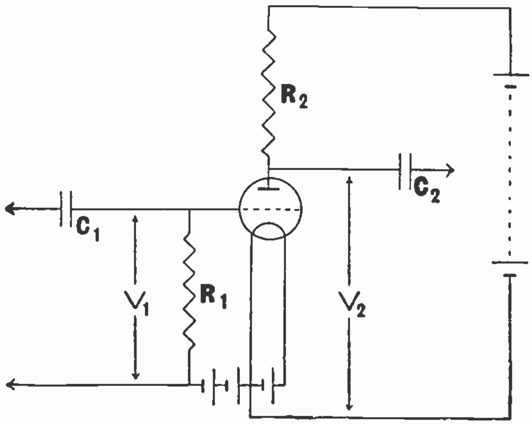


Fig. 85.—A skeleton diagram to illustrate the principles of voltage amplification.

High-frequency Amplification.—The triode valve has fallen into disuse as a high-frequency amplifier, but mention must be made of its behaviour in this capacity, as it has a bearing on the more elaborate types of valves specially designed to perform this function. Fig. 86 shows a triode valve with tuned input and output, which forms the basic circuit of a high-frequency amplifier. Both circuits will contribute to the over-all selectivity, the tuned anode coil taking the place of the resistance used in the circuit shown at Fig. 85, since it is desired to build up a potential across V_2 when the anode circuit is tuned to resonance with the voltage V_1. If the efficiency of the two tuned circuits is sufficiently high, the valve will oscillate if the anode coupling is tuned to resonance with the grid circuit, that is to say, the valve will generate an alternating potential across V_2, even though there is no input across V_1 due to external sources. This phenomenon will occur even if the two tuned circuits are totally screened from each other by enclosing them in suitable metal boxes.

A valve will oscillate only when a variation of potential in the anode circuit is fed back into the grid circuit, and, furthermore, with sufficient amplitude to overcome losses present in the latter. Since the phenomenon will occur in the absence of both magnetic coupling and metallic connection, it is apparent that the actual feed-back must occur through the valve itself. This feed-back is unavoidable in a triode, owing to the capacity existing between the anode grid and which is represented by the condenser shown dotted in Fig. 86. Due to this capacity, the characteristics of the anode circuit, *e.g.* dielectric losses, are present in the grid circuit and vice versa to an extent determined by the actual value of the grid/anode capacity.

Ionisation.—The brief notes on valve construction touched upon the exacting method used to produce a high degree of vacuum within the valve bulb. When the degree of vacuum is sufficiently high for normal purposes a valve is said to be "hard," but when the degree of vacuum is inadequate, and its efficiency consequently impaired, it is said to be "soft." The presence of gas within the valve bulb causes the phenomenon of ionisation, which is colloquially called blue glow on account of a blue light, the centre of which is situated round the filament. The offending gas atoms may have entered the bulb through some indescribably minute crack or may have become liberated due to excessive anode or filament current, and a certain proportion of them are located around the filament. Electrons travelling outwards from the filament collide with the gas atoms with such great velocity that the latter become ionised; that is to say, they lose one or more electrons, with the result that they have a surplus positive charge and form a partially conductive path between grid and filament, with the result that current flows in the grid circuit, even though the grid may be held at a high negative potential, and distortion results similar to that shown at Fig. 83 (*b*).

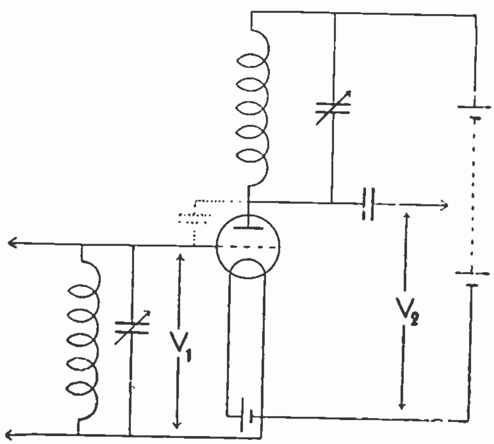


Fig. 86.—A skeleton circuit using a tuned circuit as input and output.

Ionisation reduces the control of the grid over the electron stream, with the result that the slope is proportionately decreased. The presence of ionisation is easily detected by means of the backlash test, which is effected by applying an adequate negative grid potential through a high resistance, say, 1 megohm. The anode current is noted and the resistance short circuited; if the valve is "hard," the anode current will remain unchanged. If the valve is "soft," the anode current will fall. As a measure of "softness" the valve is deemed to be 1 microampère "soft" per milliampère change of anode current. This direct ratio is only present when the suggested value of grid resistance is employed, namely, 1 megohm.

The degree of "softness" which can be tolerated is dependent upon the type of valve and the purpose for which it is employed. Generally speaking, however, the valve may be considered adequately "hard" when not more than 1 microampère "soft."

Fluorescent Phenomenon.—Ionisation should not be confused with fluorescence, which is also identified by the presence of a blue light but, curiously enough usually indicates a particularly high degree of vacuum. Unlike ionisation, which causes a blue light around the filament, fluorescence causes a blue flicker to appear as a small patch upon the inside of the bulb or the pieces of mica used to strengthen the electrode assembly. Except in the most rare circumstances fluorescence does not remain stationary, but shifts from one place to another in completely haphazard fashion.

Mains Valves.—The valve symbols previously illustrated have been drawn with a filament, indicating that a directly heated type is portrayed. An entirely different class exists—the indirectly heated valve. These valves are usually, but not invariably, intended for use in mains receivers. Their construction differs, inasmuch as the filament is replaced by a heater and cathode. The former consists of a bent wire insulated from the cathode in which it rests. The cathode is a long thin metal tube coated with electron-emitting material which is raised to the appropriate temperature by the heater.

Mains-Battery Valves.—There is a special range of valves for use in portable radio receivers that are designed to work from household electric mains or self-contained batteries at the will of the user. These special valves are so constructed that they have the necessary low filament consumption for economic battery working and also suitable heat-emission characteristics to avoid mains hum when operated from A.C. mains.

CHAPTER 11

THE AMPLITUDE MODULATED SIGNAL ANALYSED

SEVERAL following chapters are devoted to detection and amplification. In order that these may be readily appreciated it is necessary that the nature and peculiarities of an amplitude modulated carrier be defined. The frequency modulated carrier is dealt with in Chapter 29.

In order that a speech frequency can be radiated by a transmitter, it must be imposed upon a carrier wave, for reasons that are fully explained in Chapter 3. The modulation of a carrier wave by an audio wave is not accomplished by adding the two together, as mere addition would mean that the aerial would virtually have to radiate the two frequencies, one of which it cannot handle with any appreciable degree of efficiency. The problem is to so impose the audio frequency wave upon the carrier wave that the former is lost in terms of frequency, although capable of being recreated at the receiving end. An aerial is unable to radiate a low frequency, but it can radiate a high-frequency wave of varying amplitude; the solution, then, is to arrange for the aerial to be fed by the steady carrier wave and to vary its amplitude in sympathy with the audio frequency.

The Amplitude Modulated Carrier Wave.—The carrier wave is symmetrical, and variations of amplitude will affect both positive and negative half-cycles, with the result that the modulated wave is also symmetrical (see Fig. 87). A word of warning is necessary regarding the interpretation of this illustration, since there is an inadequate difference in terms of broadcast wavelengths. A single cycle at 5,000 cycles per second would be equal in length to 240 cycles of a carrier wave working on a wavelength of 250 metres, while a single cycle at 50 cycles per second would be equal to 24,000 cycles of the same carrier wave. Fig. 88 is an oscillogram of a 1,000-kilocycle carrier wave modulated by an audio frequency of 400 cycles. It will be observed that the individual cycles of the carrier wave cannot be distinguished as separate entities, although the variation in amplitude due to the modulating frequency, *i.e.* 400 cycles, is very apparent.

Reference to either Fig. 87 or Fig. 88 will show that the mean amplitude of the wave is always zero, and is consequently incapable of actuating any device that responds to low frequencies. It will, however, actuate any device working at high frequency.

A modulated carrier may be amplified by a suitable valve or valves working as high-frequency amplifiers, but it is apparent from the above remarks that some drastic changes must take place before the signal can be made audible by means of headphones or loudspeaker. This change is called " detection," although the term " rectification " is sometimes used, but is to be deprecated, as it is liable to give rise to a misleading conception of the process of detection.

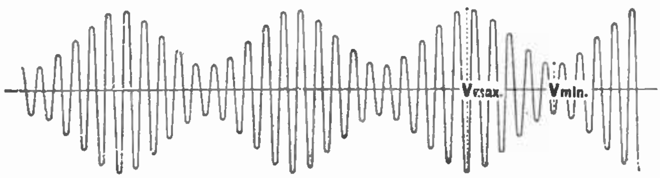


Fig. 87.—An amplitude modulated carrier. Each peak is offset by a trough, with the result that the mean amplitude is zero.

Detection.—Fig. 89 shows Fig. 87 with the lower half removed; in other words, the negative half-cycles of the carrier wave are absent, which has brought about a great change, inasmuch as the mean amplitude of the waveform is no longer zero, and rises and falls in sympathy with the original audio-frequency current flowing in the microphone circuit at the transmitter studio. For reasons which will be clear in due course, the output from the detector valve will resemble the form shown in Fig. 90, since the detector circuit will be incapable of responding to the rapid changes of the carrier frequency but will be obedient to the slower changes of the audio frequency.

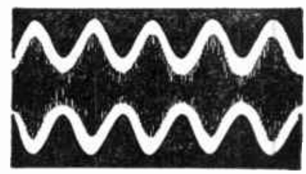


Fig. 88.—A drawing from an oscillogram of an amplitude modulated carrier wave. The individual cycles of the carrier have become merged owing to the small space between them.

The amplitude of the modulated wave may vary within wide limits, and may, therefore, bear a varying relationship to the amplitude of the depth wave; this relationship is referred to as the carrier of modulation, and when the modulated amplitude is double the amplitude of the carrier, 100 per cent. modulation is present.

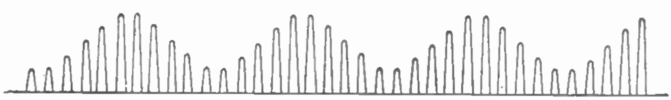


Fig. 89.—This illustration shows the waveform Fig. 87 with the lower half removed. The mean amplitude is no longer zero.

Percentage Modulation.—Percentage modulation, which is symbolised by the letter " K," is usually determined by the ratio between the amplitude of the modulated wave to the amplitude of the carrier wave, the former being expressed as a percentage of the latter. Thus, a rise from 10 millivolts to 12·5 millivolts is 25 per cent., a rise from 10 millivolts to 15 millivolts is expressed as 50 per cent., and so on. The method of determining modulation depth may be more readily understood when expressed in the following manner. In Fig. 87 the maximum peak amplitude of the envelope is denoted by $V_{max.}$ and the minimum amplitude

Fig. 90.—A diagrammatic representation showing the effective audio-frequency component of the waveform at Fig. 89.

is denoted by $V_{min.}$; using these two quantities percentage modulation (K) may be determined by the following equation:

$$K = \frac{V_{max.} - V_{min.}}{V_{max.} + V_{min.}} \times 100.$$

It should be clearly understood that variations in volume are conveyed by variations in modulation depth. It is immaterial whether there be an interval or a full orchestra playing at its loudest, the amplitude of the carrier, before modulation, remains constant; it is only the depth of modulation which varies. In the former case percentage modulation will be zero, while in the latter circumstance it will be perhaps 80 to 90 per cent., which is approximately the maximum modulation depth permitted by the B.B.C. The illustrations of modulated high-frequency currents at Figs. 87 and 88 represent the combining of two waves, both of which approximate to sine waves. During a normal broadcasting item the shape of the envelope is indescribably erratic, although it must at all times remain symmetrical, *i.e.* the lower edge is a precise inverted replica of the upper edge, and the depth of modulation is kept within its prescribed limits.

Sidebands.—A considerable change in the carrier waveform due to modulation brings about a slight variation in frequency. When the carrier wave is modulated by a single note it may be regarded as virtually three separate frequencies, the additional frequencies being spaced equidistantly above and below the original frequency. In more precise terms a carrier frequency f_c, modulated by an audio frequency f_a, may be regarded as three frequencies which are equal to f_c (the fundamental), $f_c + f_a$ (the upper sideband), and $f_c - f_a$ (the lower sideband).

If the steady carrier frequency be 1,000 *kilo*cycles per second and the modulating frequency be 5,000 cycles per second, it is apparent that the sidebands will be 995 and 1,005 kilocycles per second. If the modulating frequency is lower in the musical scale, say 2,000 cycles per second, then the sidebands must be 998 and 1,002 kilocycles per second.

It is apparent that when a normal musical programme is being transmitted, sidebands will occur variously between the carrier frequency and the outermost sidebands, the frequency of which will be determined by the highest audio frequency that is permitted to reach the modulator. If the highest audio frequency is 5,000 cycles, then the outermost sidebands will be 995 and 1,005 kilocycles per second, as already stated; the band of frequencies between these two extremes will be monopolised by the transmitter, which will be said to have a band width of 10 kilocycles per second.

The band widths used by various transmitters differ somewhat, but 12 to 16 kilocycles per second is in general use. This limitation is necessary owing to the high state of congestion of the available broadcasting bands; a notable exception, however, is the B.B.C. television sound transmitter, which has a band width of some 20 kilocycles per second, made possible by the absence of stations around the frequency in question.

It is extremely important that the reader should be thoroughly familiar with the characteristics of a modulated waveform, since the full understanding of the following chapters is only possible when these principles are known.

Frequency Modulation.—The method of imposing speech frequencies upon a carrier wave in the system known as frequency modulation is fundamentally different from the amplitude system and is dealt with later in this volume as other principles must be explained before this alternative system of modulation can be readily understood. Because frequency modulation broadcasting, usually termed FM, is radiated by the B.B.C., on the very high frequency band, it is often referred to as V.H.F. in the lay press, and the radio trade.

CHAPTER 12

AMPLITUDE MODULATION DETECTION

THE previous chapter has explained the need for detection, or, to use the rather apt American term, demodulation, and the next step is to examine the functioning of the several types of detectors

The Crystal Detector.—The simplest form of detector is the crystal, such as galena, with the familiar cat's whisker, carborundum and steel, or two suitable crystals such as borite and zincite. The crystal detector is rapidly falling into disuse, but its action is so free from complications that it will well serve as an introduction to the principle of detection.

Fig. 91 shows the characteristic curve of a crystal detector which is somewhat reminiscent of the characteristic of a valve; it will be observed that the A.C. resistance of a crystal varies with the voltage applied, that is to say, the change in voltage at one part of the curve does not bring about the same change in current as the same voltage change at another part of the curve. Reference to Fig. 91 will show that the application of ·4 volt positive will cause 36 microampères to flow, whereas the application of ·4 volt negative will cause 9 microampères to flow, thus it is apparent that a crystal detector permits the flow of current in one direction far more readily than in the opposite direction and exhibits, therefore, properties similar to the diode valve.

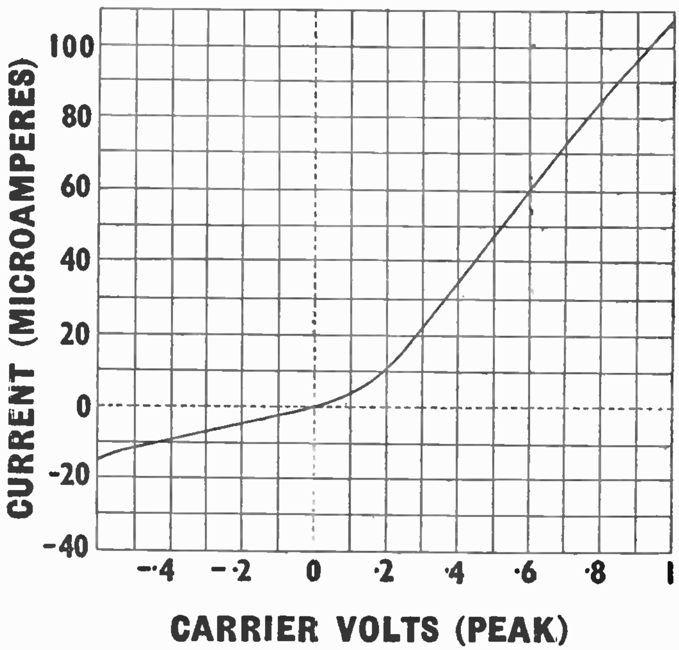


Fig. 91.—Characteristic curve of a crystal detector, showing the relationship between voltage and current.

If an A.C. potential, having a value of ·4 volt peak, is applied across the crystal as shown in Fig. 91, the positive half-cycle will bring about a current waveform which rises to a value of 36 microampères, whereas the negative half-cycle will bring about a flow of only 9 microampères, with the result that the current waveform is nearly uni-directional, as the flow of current is four times greater in one direction than in the other.

Fig. 92 shows the basic circuit of a crystal receiver which comprises an inductance and variable condenser forming a tuned circuit to select the required station, a crystal detector, and a pair of headphones; the aerial and earth are connected to each end of the inductance, so that the energy picked up by the aerial will appear as a potential difference across it.

When an unmodulated wave is "picked up" by the aerial it is rectified by the crystal in the manner explained above, but the rectified current will fluctuate so rapidly that the comparatively heavy diaphragm will be unable to respond to the individual changes and no sound will emanate from the headphones.

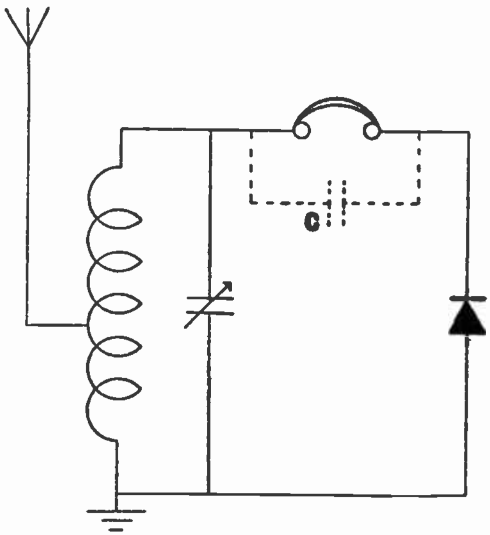


Fig. 92.—The circuit of a simple crystal detector.

Fig. 93 shows the current that will flow in the circuit when the incoming carrier wave is modulated; each positive cycle brings about a change in current, the amplitude of which is determined by the instantaneous depth of modulation, while each negative cycle brings about a comparatively small change in current; thus the lower half of the modulation envelope has, virtually, been dispensed with, and the headphones will respond to the mean change of current at audio frequency since they are incapable of responding to the very rapid changes of the high-frequency component. The mean change is the difference between the value of current flowing due to the application of successive positive and negative voltage peaks, *i.e.* if the peak value is ·5 volt and the depth of modulation is 50 per cent., the audio-peak-frequency current will be 40 microampères, due to the positive half of the carrier, and 7 microampères due to the negative half, so the mean current change available to operate the headphones is 33 microampères. The condenser shown dotted in Fig. 92 is usually included to offer a lower impedance path for the passage of high-frequency currents, since the impedance of the headphones may be extremely high at such frequencies and, furthermore, the presence of high-frequency currents in the headphones is apt to cause practical difficulties.

In Fig. 93 the rectified current output is shown as a series of half-cycles of the modulated carrier frequency, the equivalent audio-frequency current being emphasised by joining the extremities with a thick line; the carrier-frequency component has not usually any significance and, furthermore, is usually sensibly absent due to the presence of the condenser, C, in Fig. 92. In future, therefore, the carrier frequency will be omitted when diagrammatically illustrating the audio-frequency output of a detector.

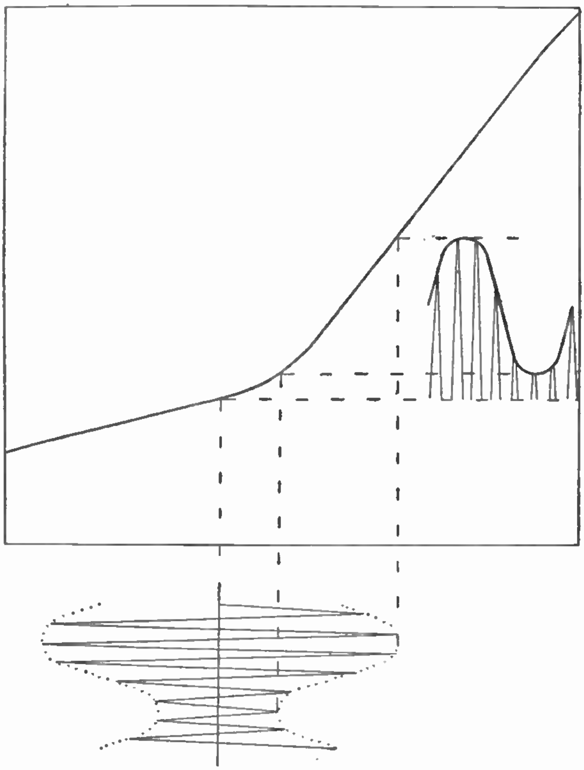


Fig. 93.—The same curve as at Fig. 91, showing the application of an amplitude modulated carrier and resulting audio-frequency waveform. The values of voltage and current are omitted in the interest of clarity, but may be obtained by reference to Fig. 91. The comparatively small audio waveform resulting from the negative half-cycle of the modulated carrier is omitted for the same reason.

The Diode.—It has already been intimated that the behaviour of a crystal detector is similar to that of a diode valve. It would seem, therefore, that the substitution of a diode for the crystal detector (in Fig. 92) would be expected to give the same results; this substitution is effected in Fig. 94. It will be observed that the headphones have been replaced by a resistance, R, since it is unlikely that anyone would desire to use headphones with a diode valve. A diode detector is usually followed by a valve amplifier, which, being a voltage-operated device, will require a voltage output to operate it. (Headphones are current-operated devices.)

Although the action of the diode detector in Fig. 94 is similar to the action of the crystal detector in Fig. 92 it is not identical; the presence of the resistance, R, introduces complications which make the functioning of the circuit rather difficult to follow.

Fig. 95 is the characteristic curve of a typical diode and shows the anode current resulting from the application of various anode potentials; it will be noted that the curve is plotted from 2·5 volts positive through zero to 2·5 volts negative; observe, also, that the flow of anode current does not stop at zero anode potential but at a point just above 1 volt negative. In view of remarks in previous chapters regarding the behaviour of electrons and negatively charged bodies, it will be necessary to interrupt the present logical train to explain why electrons should flow

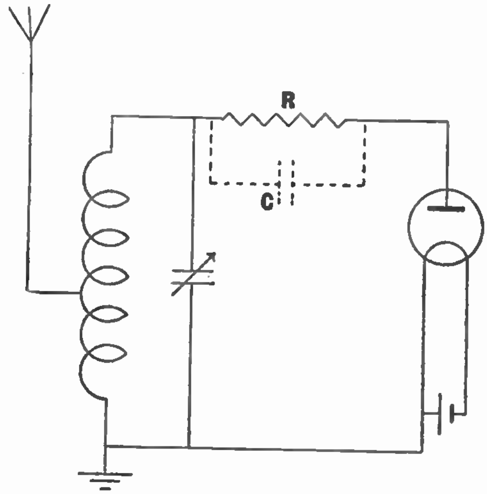


Fig. 94.—A simple circuit showing a diode as amplitude modulation detector.

to the anode when the curve shows that the latter is 1 volt negative in respect to the filament.

It is unnecessary to go deeply into the matter, but briefly this seeming paradox is due to the initial velocity of the electrons leaving the filament, which is such that an effective anode potential of 1 volt negative is necessary to prevent electrons reaching the anode.

Returning to the consideration of Fig. 94, it will be seen that the anode is connected through the resistance, R, to the filament; the small standing anode current will have to pass through this resistance, and will cause a voltage drop across it which will drive the anode negative. In order to study fully the working of the diode it will be necessary to ascertain the exact value of negative potential at the diode, due to the voltage drop across the resistance, R. This voltage drop will obviously be largely controlled by the value of the resistance, R, which for the present purposes may be given a value of ·5 megohm.

In order to discover the meeting-point between the characteristic curve of the valve and the effect of the anode resistance it is necessary to draw on the same scale a line representing the behaviour of a ·5 megohm resistance; Ohm's law shows that when the potential difference across a resistance is zero, the current flowing is zero, thus where zero voltage and zero current meet will serve as one point to determine the position of

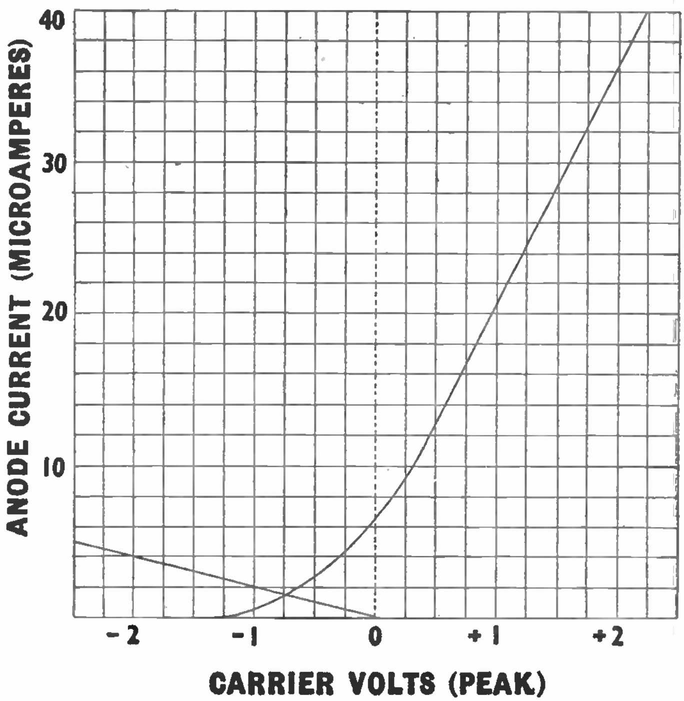


Fig. 95.—Emission curve of a diode.

the line, the second point may conveniently be where 2·5 volts negative meets 5 microampères, since a potential difference of 2·5 volts will drive a current of this value through a resistance of ·5 megohm. The operating point will be where the valve curve crosses the load line, *i.e.* ·75 volt negative approximately.

The application of an alternating voltage due to the reception of an unmodulated carrier will cause the anode voltage to swing equidistantly above and below the operating point. Reference to Fig. 95 will show that the positive half-cycle will bring about a much larger change in anode current than that caused by the negative half-cycle, consequently the average anode current will increase. This increase in current will bring about an increase in the voltage drop across the resistance, R, which will make the anode more negative. The next cycle will make the anode still more negative, until the anode finally settles down at a new operating voltage; in practice this voltage will be such that the positive peaks of the applied high frequency will enable the valve to pass anode current momentarily, say, for about 5 degrees of the cycle, no current flowing during the remaining 355 degrees. This condition will remain while the carrier amplitude is constant; the next step, therefore, will be to ascertain the behaviour of the diode when the carrier is modulated. In order to do this, however, it will be necessary to plot a curve showing the actual anode voltage of the diode due to various alternating voltages caused by varying carrier amplitudes; such a curve is shown at Fig. 96.

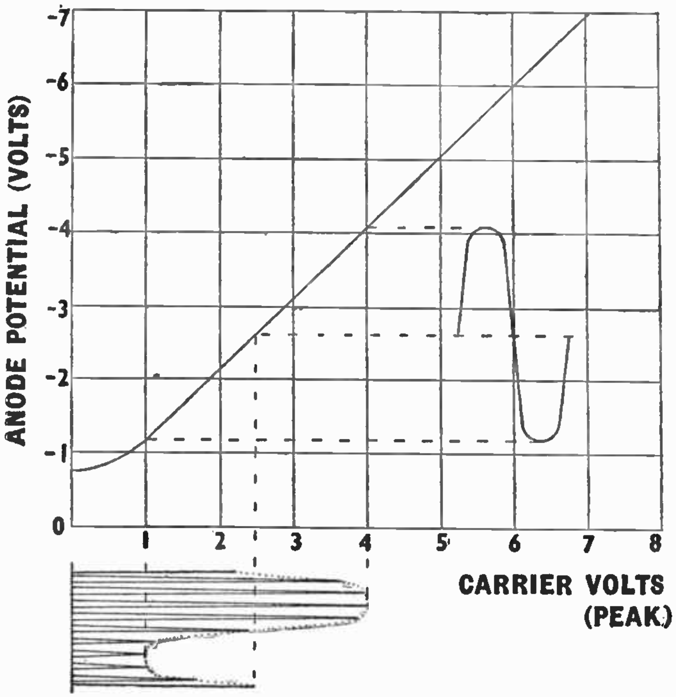


Fig. 96.—Detection curve of a diode. Note that the negative half of the amplitude modulated carrier is omitted.

The positive half of the carrier will rise and fall on the working portion of the characteristic, and with the input shown will vary from 1 to 4 volts of high-frequency input, which will bring about a change in anode potential of 1·2 to 4·1 volts negative. This voltage will appear as a potential difference across the diode which may be used to bring about a change of grid potential in the following amplifying valve.

It will be observed that the changes referred to above take place on the straight portion of the curve; it follows, therefore, that the voltage developed will be directly proportional to the voltage applied, consequently no distortion will be introduced. Reference to Fig. 96 will show that this state of affairs will not always obtain. Two examples will make this point clear. If the carrier has a value of 1 volt peak and is modulated at, say, 50 per cent., it is apparent that the change in applied voltage due to modulation will be from ·5 volt to 1·5 volts. Reference to the curve will show that the swing in the upward direction will bring about a larger change in anode voltage than the swing in the downward direction, which will result in harmonic distortion. Harmonic distortion may be defined as a departure from faithful reproduction due to the presence of frequencies not present in the received waveform. Distortion will also be introduced if the received signal is more deeply modulated than indicated at Fig. 96; an inspection of the curve will show that a modulation depth of 70 per cent. will just encroach on a non-linear portion of the curve. Such distortion, however, need not be considered seriously, since such deep modulation will seldom occur, and then only for extremely short periods. It is, however, interesting to note that detection will be linear for any depth of modulation up to about 95 per cent. if the peak voltage of the carrier be increased to 6 volts.

Detector Damping.—In the above explanation R was given the arbitrary value of ·5 megohm. Since any reasonable resistance will be very much larger than the impedance of the valve, it will not materially influence the constants of the detector; it will, however, have a marked influence on the tuned circuit. For all practical purposes the effect of the resistance, R, upon the tuned circuit is equal to connecting a resistance of half the value straight across the tuned circuit, *i.e.* the damping introduced by an anode resistance having a value of ·5 megohm will be equal to connecting ·25 megohm across the tuned circuit, which will bring about a marked decrease in efficiency; it is apparent, therefore, that ·5 megohm will usually be considered the minimum value. There is also a limitation in the other direction which is explained below.

Values of R and C.—Reference to Fig. 94 will show that the resistance, R, has a condenser, C, connected across it. This is necessary to permit the high frequencies to develop a potential across the diode without the serious loss which would occur if the resistance, R, provided the only path. A close study of Fig. 94 will show that since the inductance has negligible impedance to audio frequencies, the condenser, C, is in parallel with the diode, the resistance, R, and the input to the following valve, and is capable, therefore, of attenuating audio frequencies. The degree of attenuation will be determined by the ratio between the reactance of the condenser (at audio frequencies) and the resistance of R. Since the reactance of a condenser is inversely proportional to frequency, the low notes will not suffer, but the high notes must unavoidably suffer some loss. The percentage attenuation of a given frequency compared to a very low frequency due to connecting a condenser across a resistance may be determined from the following formula :

$$\text{Percentage of frequency, } f, \text{ compared to very low frequency} = 100\left(1 - \frac{1}{\sqrt{1 + \omega^2 C^2 R^2}}\right)$$

when R equals resistance in ohms, C equals capacity in farads, and ω equals $2\pi f$.

It may be seen by applying the above formula that if R equals

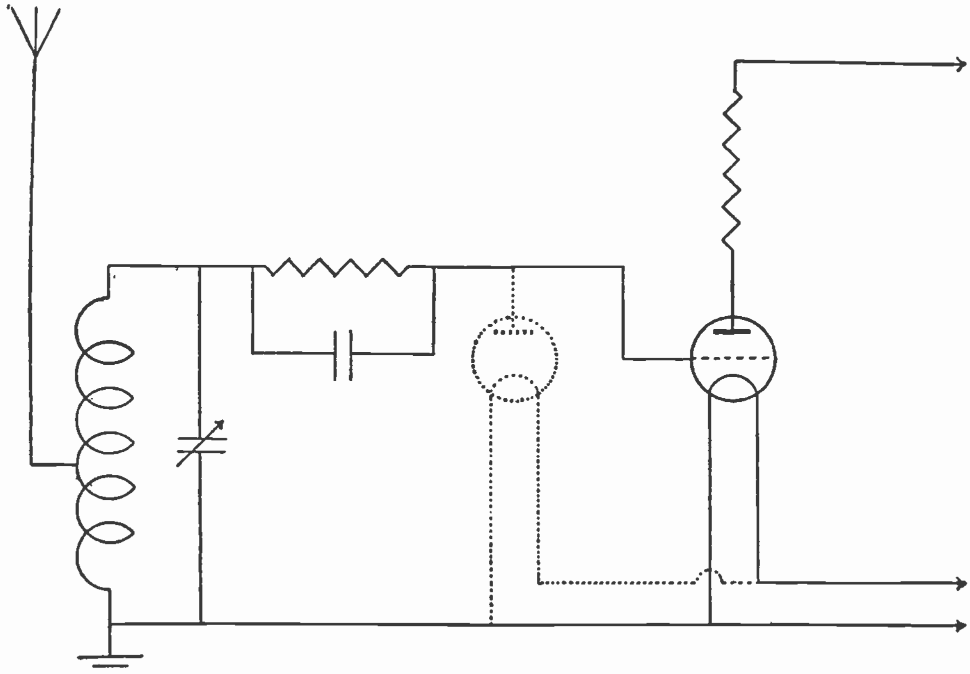


Fig. 97.—This circuit illustrates the function of a leaky grid detector.

·5 megohm, C must not exceed about ·00003 microfarad approx. if the attenuation of 5,000 cycles per second is to be limited to 10 per cent. ; the diode detector is usually employed in a type of receiver where attenuation of the higher audio frequencies is inevitable. Since no useful purpose is served by cutting the higher frequencies in one part of the circuit and taking undue precautions to preserve them in another, it will usually be found that a capacity of about ·00005 microfarad is associated with 5· megohm to form the load of a diode detector.

The Grid Detector.—Another popular type of detector is variously called the grid detector, the leaky grid detector, and the cumulative grid detector. It can best be described as a diode and amplifier combined in a single valve. Fig. 97 shows the circuit of a diode detector (Fig. 94) with the addition of an amplifier ; it will be noted that the filaments of the two valves are joined together, likewise the anode of the diode and the grid of the triode. Both the latter-mentioned electrodes are immediate neighbours of their respective filaments; if, therefore, the anode of the triode is ignored, it is apparent that there are two diodes in parallel, which suggest that one could be dispensed with. In Fig. 97 the diode is shown dotted to emphasise the fact that the circuit will continue to function as both detector and amplifier if the diode is removed. Since the resistance, R, and condenser, C, are no longer associated with an anode they are renamed grid leak and grid condenser respectively.

It has been stated that the removal of the diode from Fig. 97 will permit the circuit to function as both detector and amplifier. This statement is not intended to imply that the efficiency of the circuit remains unchanged. Assume that when working at some predetermined anode potential, a triode has a characteristic curve that is straight from zero to − 5 volts. It would appear that such a valve would permit an audio-frequency voltage of 2·5 volts peak; this would be true if the valve were acting as a pure amplifier. When working as a detector amplifier, however, the available grid swing is restricted by the carrier-frequency voltage which will be present on the grid.

When the combined amplitude of carrier-frequency and audio-frequency voltage is too high, the former encroaches on the curved portion of the characteristic and drives the anode current towards a lower value when the audio-frequency component is trying to drive it to a higher value, resulting in a particularly unpleasant form of distortion. In practice, therefore, a suitable filter is included between the diode anode and the triode grid to attenuate high frequencies to negligible proportions.

The Power Grid Detector.—The power grid detector is simply a variation of the leaky grid detector and differs inasmuch as the anode voltage is higher, the grid leak has a lower value of resistance, and the grid condenser a somewhat higher value of capacity. These modifications result in the valve being capable of handling deeply modulated signals without encroaching on the curved portion of the valve characteristic. The advantages of such an arrangement are only manifest when the high-frequency input voltage is relatively large; when this condition obtains it is almost always advantageous to use a diode, consequently the so-called power grid detector is of very little use and virtually obsolete.

The Anode Bend Detector.—There is yet another system of detection which is known as anode bend detection. This type of detector enjoyed considerable popularity some years ago, until its alleged advantages were found to be offset by surprising disadvantages; a short description is, however, included below for the sake of completeness.

Fig. 98 shows the grid-volts/anode-current curve of a high-slope triode; if the valve is biased at the point where anode current ceases to flow (called the cut-off point), it will detect by virtue of the fact that the negative half of the applied carrier will not change the anode current, which will remain at zero since the applied signal voltage will drive the grid more negative ; the positive half of the signal voltage will, in effect, reduce the standing bias and anode current will flow. Fig. 98 shows the resulting change in anode current due to the application of a deeply modulated signal of relatively high amplitude. A glance at the illustration will show the serious distortion caused by the deep modulation encroaching on the curved portion of the characteristic.

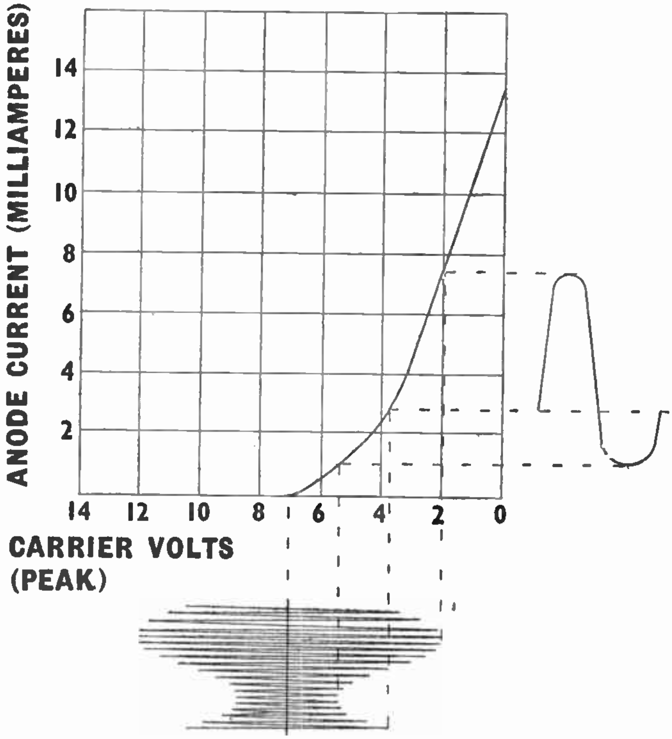


Fig. 98.—The principle of anode-bend detection.

Further consideration of Fig. 98 will show that sensibly undistorted detection is only possible when the applied signal is so large that modulation up to 80 or 90 per cent. does not encroach upon the curved portion of the valve characteristic. It is admitted that undistorted detection of relatively small inputs is possible providing that the signal is not deeply modulated. Since, however, the carrier waves transmitted by broadcasting stations *are* deeply modulated, this aspect is irrelevant.

Accentuated Fading.—The sensitivity of an anode bend detector tends to increase with an increase of signal voltage, consequently the gain of the detector stage tends to be higher when receiving a strong signal than when receiving a weak signal. This unfortunate tendency aggravates the effect of fading to a very noticeable extent when the valve used has a gently sloping grid-volts/anode-current characteristic.

The Germanium Diode.—A somewhat radical device was introduced during the Second World War for the detection of very high frequency currents, and following improvements in reliability it is now in general use. It is called a germanium diode and is only about a quarter of a cubic inch in size. This device relies on the fact that the resistance of a union between the metal germanium and a suitable contact possesses much greater resistance in one direction than the other. Forms of this device are available with more than two "electrodes" and are able to amplify and perform other functions hitherto only possible with valves; they are called transistors and are having a profound effect on radio receiver design, especially portables.

The Metal Oxide Detector.—An entirely different type of detector is available, known as the metal oxide detector, can only perform the functions of detection and rectification, and is quite incapable of amplifying. The device consists of a metal plate chemically treated on one side and held in contact with each other so that the chemical face of one presses upon the metal face of the other.

The metal oxide detector functions by virtue of the fact that it offers much greater resistance in one direction than in the other direction, and therefore behaves like a diode.

CHAPTER 13

REACTION AND DAMPING

THE damping on the tuned circuit due to the anode resistance of a diode detector was dealt with in the last chapter. Bearing in mind the similarity between the functioning of a diode detector and a leaky grid detector, it might be expected that the same remarks would apply; it is true that the damping imposed by the anode resistance of a diode detector is similar to the damping imposed by the grid leak of a grid detector. There is, however, a very much more serious source of damping due to what is termed the "Miller effect."

Detector Damping.—Fig. 99 shows a skeleton circuit of a grid detector, the presence of capacity between anode and grid being emphasised by the condenser, C, which is intended to represent it. It will be remembered that both high and audio-frequency potentials are present in the grid circuit, consequently they are also present in the anode circuit. The capacity between grid and anode of an average triode will be of the order of 10 $\mu\mu$F and will, therefore, be too small to allow an appreciable flow of audio-frequency current but large enough to permit the flow of high-frequency current, the amplitude of which will be sufficient to have a profound influence on the effective magnification of the tuned circuit unless it is 90 degrees out of phase.

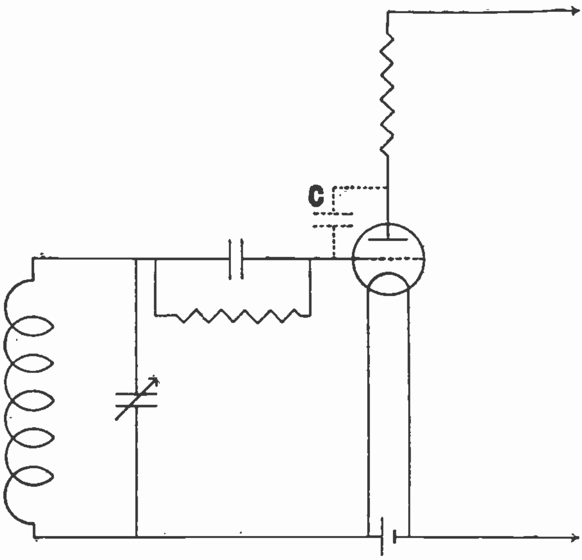


Fig. 99.—A simple detector circuit to emphasise the capacity between anode and grid of a triode valve.

If the anode load is inductive the current fed back to the tuned circuit will develop a potential in phase with the original voltage and will increase the total voltage developed across the tuned circuit; if the additional voltage thus developed is large enough, the valve will oscillate. It is impracticable to have a purely inductive load in the anode circuit of a detector, as the capacity between the anode and all other electrodes will be an important factor if the inductance is large enough to offer a reasonable impedance to audio-frequency currents.

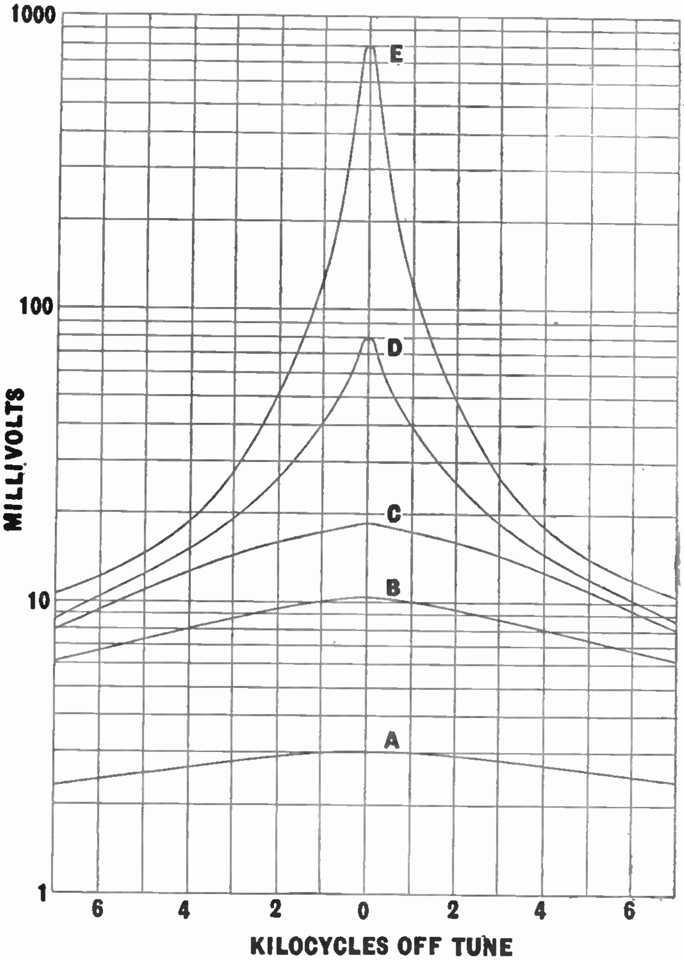


Fig. 100.—Curves showing reaction and damping, expressed as millivolts, developed for an input of ·1 millivolt. (C) shows the natural response of a tuned circuit having a Q factor of 175. (A) shows response with total detector damping, Q = 20. (B) shows reduction of damping due to anode bypass condenser, Q = 105. (D and E) show the effect of varying degrees of reaction: Q = 800 and 8,000, respectively. The curves are drawn on logarithmic paper to reduce the illustration to practical proportions. This method is fully described in Appendix I (2).

If the anode load could be purely resistive the voltage developed across the tuned circuit would be 90 degrees out of phase with the original voltage, but, again, if the value of resistance is high enough to permit the circuit to function, the load can be regarded as capacitive due to the parallel effect of the capacity between the anode and other bodies.

A capacitive load will cause the voltage set up across the tuned circuit, due to the current flowing through C, to be out of phase with the original voltage, and will in effect damp the tuned circuit to an extent that may well reduce its magnification from, say, 200 to 20. The damping introduced in this manner may be equivalent to connecting across the tuned circuit a resistance of low value, in certain circumstances having a value of only a few thousand ohms. Fig. 100 shows the response curves of a tuned circuit comprising an inductance of 200 μH, capacity of 200 μμF, and high-frequency resistance of 5·7Ω; it will resonate, therefore, at approximately 800 kilocycles per second and have a magnification of 175. Curve (A) shows the response with the detector damping, while curve (C) shows the response of the same tuned circuit relieved of detector damping; *i.e.* with the detector valve simply pulled out of its holder.

Since the grid/anode capacity of an average triode is seldom more than 10 $\mu\mu$F, it may seem surprising that its influence should be so profound. If the valve indicated in the circuit at Fig. 99 is so designed that it has an amplification factor of 1, the damping due to the presence of the capacity, C, will be normal. If, on the other hand, the amplification factor is, say, 50, it follows that the high-frequency voltage between anode and filament will be fifty times the voltage between grid and filament, and consequently the current flowing to the grid circuit will be fifty times greater. Expressed in the slang of the radio industry the capacity, C, "looks like" μ times its actual value. (Where μ represents the amplification factor of the valve.)

Anode Bypass.—It will be apparent that the damping of the tuned circuit due to the Miller effect is determined by several factors, one of which is the high-frequency potential of the anode; it follows, therefore, that damping will be reduced if this potential can be decreased. Fig. 101 shows the circuit, Fig. 99, with the addition of a condenser C_1, which is connected between anode and filament; this will act as a bypass to high-frequency currents and reduce the high-frequency potential of the anode to an extent dependent upon its reactance. If this condenser could have a capacity of ·1 μF the high-frequency potential of the anode would be negligible, but a capacity of this order would offer a relatively low reactance to the higher audio-frequency currents and introduce frequency distortion. The value of C_1 must be a compromise and must be as large as possible without attenuating the higher audio frequencies to an objectionable extent. If the anode resistance has a value of 50,000 ohms the value of C_1 will not usually exceed about ·003 μF.

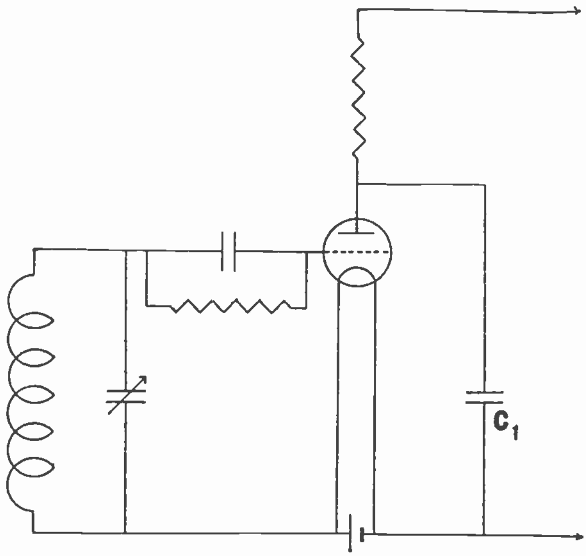


Fig. 101.—Amplitude modulation detector circuit showing the connection of a bypass condenser.

The response curve (B) in Fig. 100 is intended to suggest the condition when detector damping has been reduced as much as possible by making the value of C_1 as high as practicable. The magnification of the tuned circuit is still considerably lower than the natural value, as shown by curve (C).

Reference to any of the curves shown at Fig. 100 will suggest that some means must be adopted to sharpen the curve to obtain a higher degree of selectivity, since even curve (C) has only a selectivity ratio of about 2 : 1 for an input 7 kilocycles per second off tune, whereas a ratio of about 500 : 1 is about the minimum ratio that can be tolerated unless reception is limited to a local transmitter situated at a distance of a few miles. For foreign reception a ratio of 500 : 1 is totally inadequate.

Reaction.—Fig. 100 shows response curves marked (D and E) which show the response of the same tuned circuit when different degrees of reaction are introduced, the principle of which is described below.

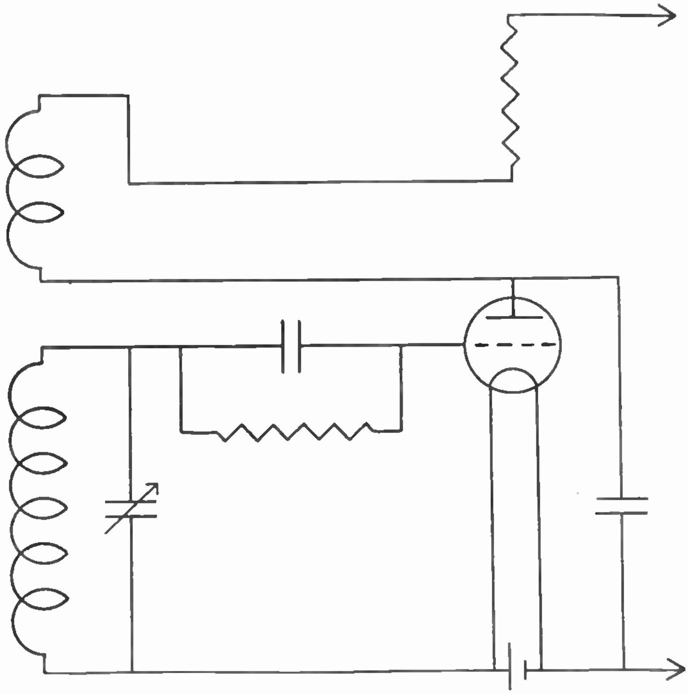


Fig. 102.—A typical amplitude detector circuit with magnetic reaction. The degree of reaction is varied by the coupling between the reaction and grid coils.

Fig. 102 shows a detector circuit with the addition of a reaction coil, which in practice is so arranged that the coupling between the two coils can be varied at will and so connected that the voltage induced across the tuned circuit due to the magnetic field of the reaction coil will be in phase with the signal voltage.

Since reaction coupling is variable it will be possible to control the amount fed back, but only within certain limits; with the careful use of the reaction adjustment it will be possible to exactly offset detector damping, but closer coupling will raise the magnification of the tuned circuit above its natural value.

When the magnification of a tuned circuit is increased by means of reaction the resonance curve becomes sharper and selectivity is increased. With ordinary care and standard components, reaction can be increased until the magnification of the tuned circuit is about 5,000, but with precision apparatus reaction may be increased until the magnification is approaching 8,000, at which point the effective high-frequency resistance of the entire tuned circuit will be about ·13 ohm. Such high values of Q, brought about by the application of reaction, are of purely academic interest, since quality of reproduction is ruined by excessive use of reaction. Reference to the curve (E) at Fig. 100 will show that the response at 2,000 cycles off tune (2 kcs.) is only about 6 per cent. of the response at resonance; this severe top cut would render speech unintelligible and music horribly distorted.

The extent to which reaction may be used is necessarily arbitrary, but it is obvious that it may safely be used to an extent that offsets damping due to the detector valve.

The arrangement shown at Fig. 102 is one of many suitable for introducing reaction, but is seldom used in modern practice since it is inconvenient to arrange a movable coil. The modified circuit shown at Fig. 103 is a very popular arrangement; the reaction coil is fixed in relation to the grid coil and adjustment of reaction is achieved by varying the condenser C_R which controls the amount of high-frequency current flowing through the reaction coil, and consequently its magnetic field. The condenser C_R could be placed at the anode end of the reaction coil, but renders adjustment difficult, as hand capacity is liable to be introduced. With the arrangement shown at Fig. 103 one set of plates is at earth potential, and these undesirable effects are obviated.

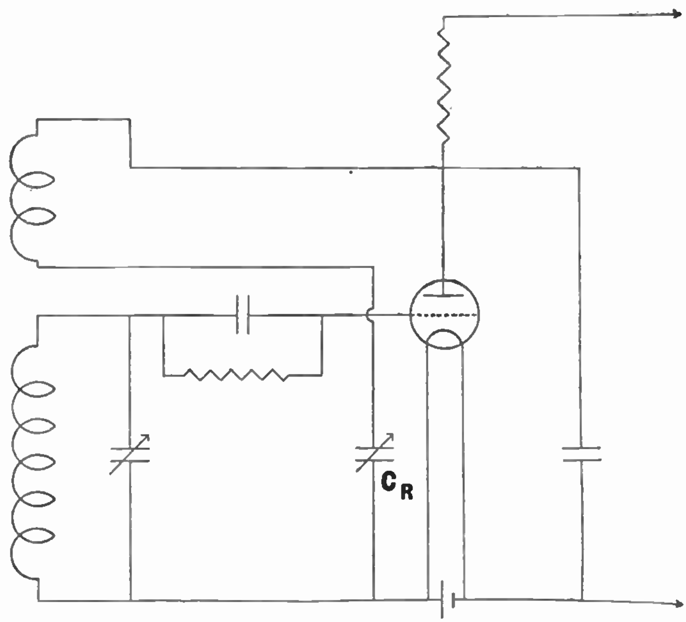


Fig. 103.—Detector circuit showing capacity-controlled magnetic reaction. A high-frequency choke is desirable between the anode resistance and reaction coil but is seldom used in practice.

Backlash.—When designing a reaction circuit some experiment is usually necessary to determine the best value of grid leak, grid condenser, and anode voltage to avoid undue backlash. Backlash is the name given to the difference in setting of reaction where oscillation starts and stops; a badly designed circuit will start oscillating when the reaction condenser is rotated, say, 80 degrees, but on the return journey does not cease at the same point, the valve continuing to oscillate until the setting is reduced to, say, 70 degrees, making critical adjustment very difficult.

Reaction Chasing.—The design of the reaction coil is not limited to consideration of inductance, since the spacing between the actual reaction coil and the coil to which it has been coupled is somewhat critical.

Unduly tight coupling will produce the phenomenon of reaction chasing, which may be defined as a fault in a reaction circuit, the adjustment of which unreasonably mis-tunes the circuit to which it is coupled. It is possible to design a reaction circuit so improperly that a station near the end of the waveband is pushed completely off the waveband when reaction is increased for the purpose of boosting signal strength.

CHAPTER 14

THE R.F. PENTODE AND TETRODE

THE chapter that was devoted to the principle of detection showed that distortion was inevitable with small inputs. It is possible to go a step farther and say that if the input is small enough detection is impracticable. It is apparent, therefore, that some means must be found to amplify signals of small amplitude *before* detection, so that the detector may function in an efficient manner. Pre-detector amplification is achieved by the use of a "radio-frequency amplifier," otherwise called a high frequency amplifier, which is important since it is in the radio-frequency stage, or stages, that the selectivity of the receiver will be determined and, to a large extent, the sensitivity and quality of reproduction.

Triode R.F. Amplifier.—Some years ago the triode valve was used for this function, since there was no alternative type available; but it was replaced some thirty years ago by a valve specially developed for the purpose called a screened-grid valve or screened-grid tetrode. Although the triode has fallen into complete disuse as a high-frequency amplifier, it is desirable to know something of its performance in order that the advantages of screened-grid valves may be fully appreciated.

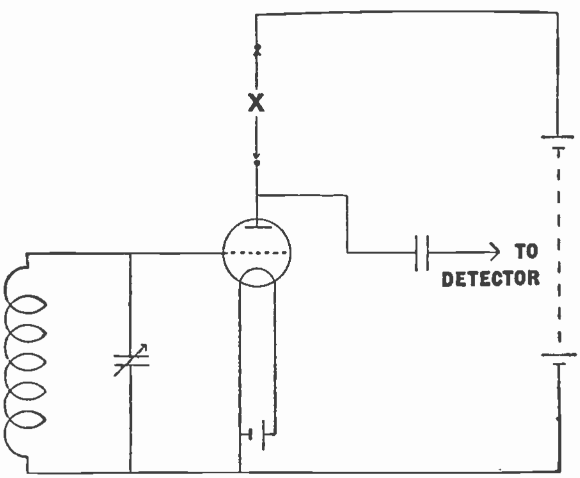


Fig. 104.—Basic circuit of a high-frequency amplifier using a triode valve.

The chief reason for the unsuitability of the triode for high-frequency amplification lies in its relatively high grid/anode capacity, certain effects of which were mentioned in the last chapter. Fig. 104 shows the basic circuit of a high-frequency amplifier using a triode valve; the anode load is represented by "X," so that alternative forms of coupling may be discussed conveniently. The simplest form of coupling is obtained by making "X" a resistance which at first sight would seem satisfactory, since by using a fairly high value reasonable amplification might be expected. Unfortunately this arrangement is doomed to failure, since the anode resistance will be shunted by the grid/anode capacity of the valve and sundry stray capacities which at, say, 1,000 kcs. per second, will amount to only a few thousand ohms, with the result that the stage gain will be very poor, usually only about three or four. It is apparent, therefore, that this method, although simple, is practically useless on the count of gain alone, without going into the loss of selectivity due to the unavoidably heavy damping on the grid circuit due to the Miller effect.

The Screening Grid.—The obvious method of preventing the grid/anode capacity from reducing the impedance of the anode load is to use a parallel-tuned circuit (" X " in Fig. 104), so that the grid/anode and stray capacities form part of the total capacity, and have no effect other than reducing the capacity of the tuning condenser for any given frequency, which is of no importance whatever. With this arrangement the grid-anode capacity limits stage-gain in another way, since the valve will oscillate if the energy fed back through this capacity is greater than the energy used up by the losses in the grid circuit, a condition which will obtain if the gain is considerable. Thus, in order to stop the valve from oscillating, the gain must be reduced by deliberately introducing losses, and once again it is apparent that the triode cannot be regarded as an efficient high-frequency amplifier.

Circuits are available where a high-frequency voltage is introduced across the grid circuit in opposite phase to the voltage caused by feedback. Such an arrangement is called a neutralised circuit, or neutrodyne, but has fallen into disuse for a number of reasons, among which is the introduction of a valve having a *very* low grid/anode capacity, the screened-grid valve.

If a metal plate of adequate dimensions is interposed between the plates of a two-plate condenser and connected to a point that is at zero potential in respect to them, capacity will cease to exist between the original plates. This principle is applied in the screened-grid valve, a fourth electrode being interposed between anode and grid which is appropriately called the screening grid.[1] This electrode cannot take the form of a solid metal sheet, since it would prevent the electrons from reaching the anode, so use is made of a grid gauze or lattice structure.

Some thought may now be given to the drawing of a multi-grid valve on the facing page ; if an actual valve of the type indicated is available for breaking up it will be useful to do so as the position, pitch and spacing of the electrodes will be more apparent and the position and coverage of the shielding structure more readily appreciated.

The vital point of this illustration, for the purpose of this chapter, is the screening grid which is interposed between control grid and anode, also the elaborate shielding to screen the electrode assembly from the components which will surround the valve in a receiver ; among other

[1] When speaking about a multi-grid it is usual to call the grid "the control grid" to avoid confusion.

advantages the use of internal shielding in modern H.F. valves has made it possible to lead the anode and grid out by way of the base.

Other points of interest are the rigid locking of the electrodes by mica discs and the use of a cooling fin on the control grid supports to avoid the possibility of the grid reaching a temperature at which it could emit electrons (grid emission); the shield which surrounds the actual operative assembly is perforated with holes as a further means of keeping the electrodes at a safe temperature.

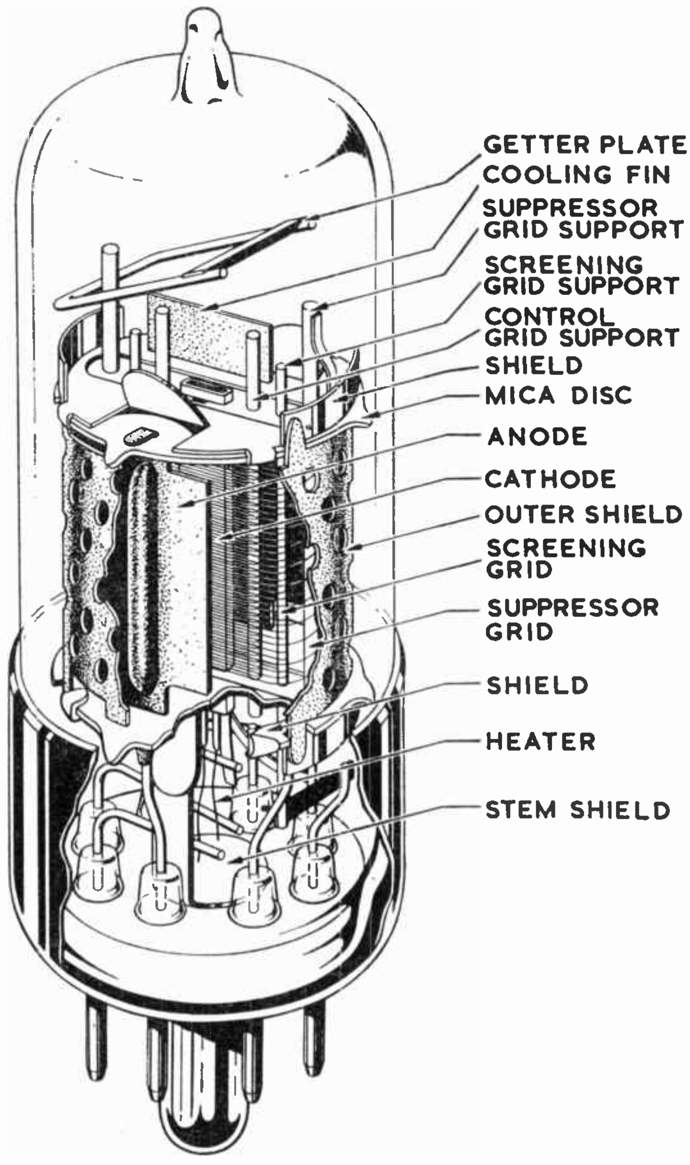


Fig. 105.—The construction of a modern valve; the example shown is a Mazda 6F1 screened pentode.

The Screened Tetrode.—The valve discussed above is a screened pentode and is so called because it has an additional grid between screening grid and anode, this refinement must be forgotten for the moment as the special behaviour of the screened tetrode must be understood before the reason for this extra grid can be appreciated.

In common with all valves, the characteristics of a screened-grid tetrode vary with operating voltages; it is important to note that screen plus anode current (*i.e. total* space current) is influenced to a great extent by the potential applied to the control grid and screening grid, but to a very small extent by the anode potential. Fig. 106 shows the basic circuit of a high-frequency amplifier, from which it may be seen that the screening grid is held at a positive potential (in the D.C. sense), a

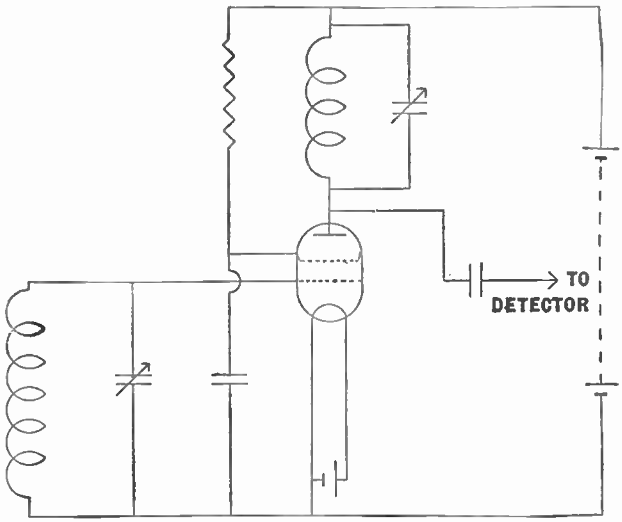


Fig. 106.—Basic circuit of a high-frequency amplifier using a screened-grid tetrode.

condenser being connected between this electrode and filament to hold it at zero high-frequency potential or, to be strictly accurate, as near to zero as the reactance of the condenser will allow. It is necessary that the screening grid be held at a suitable positive potential, because it exerts such a profound influence on the characteristics of the valve—which is not surprising when it is realised that the electrons must pass through this grid on their way to the anode; only a proportion do, in fact, reach the anode, the remainder being "collected" by the screen

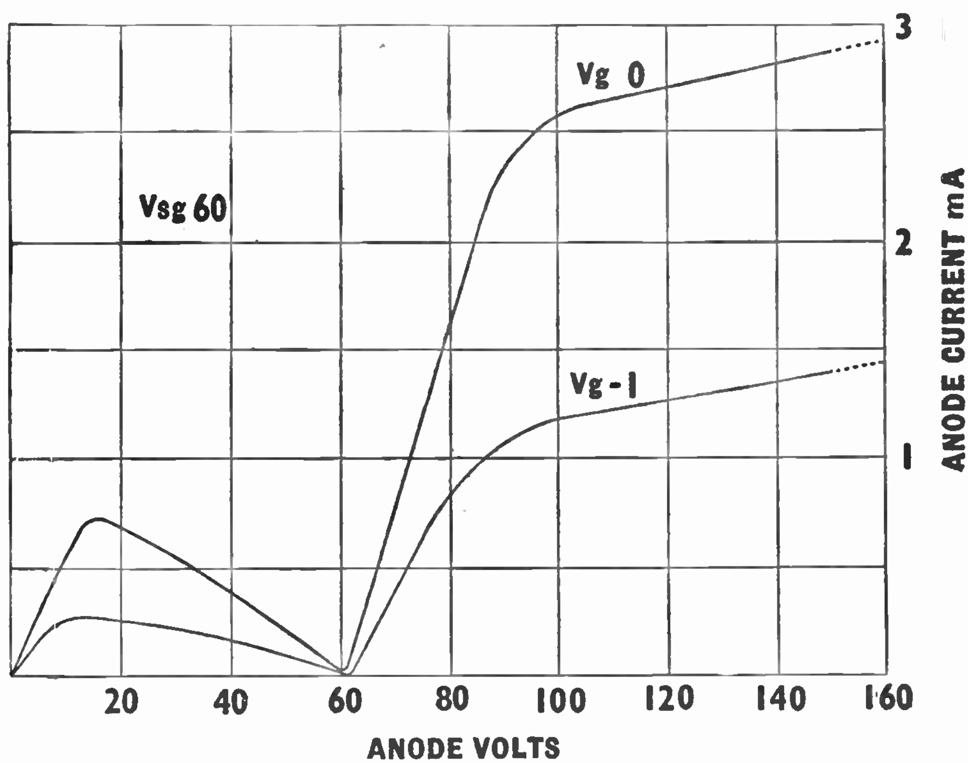


Fig. 107.—Characteristic curve of a screened-grid tetrode. Note that the straight portion (105–150 volts) is restricted by the negative resistance kink.

and forming a current in the screen circuit which is referred to as the screen current.

Negative Resistance.—Fig. 107 shows a typical anode-volts/anode-current curve of a screened-grid valve. It will be noted that its shape differs radically from curves already shown, inasmuch as it changes its direction, indicating that a change of anode voltage does not result in a progressive change of anode current ; it will be both interesting and instructive to study this curve by making a " tour " starting from the low-potential end.

Starting from zero anode volts, and ignoring the Vg = 0 curve, it will be seen that an increase of anode potential brings about an increase of anode current up to 15 volts, after which an increase of potential brings about a decrease in current until, at 60 volts, the anode current has dropped to zero. The portion between 15 volts and 60 volts is appropriately named the negative resistance kink of the characteristic, since an *increase* of voltage brings about a *decrease* in current.

Continuing the " tour," a small increase of a potential above 60 volts brings about an enormous change of current, after which the curve flattens out and is sensibly straight from 90 to 150 volts and beyond ; but the curve is not taken far enough for this to be apparent. It will also be observed that the anode current is greatly affected by grid voltage when a relatively high anode voltage is applied, but that when the anode voltage falls below the screen voltage grid potential has little effect. The caption on the curve Vsg = 60 denotes that the curves were taken with 60 volts positive applied to the screening grid.

Observations made in earlier chapters have established the fact that a serious change of direction in the characteristic curve of a valve means that it will rectify if the incoming signal is permitted to encroach on the non-linear portion ; it is evident, therefore, that the valve portrayed at Fig. 107 should be worked with an anode potential as high as permissible, *i.e.* 120–150 volts. Mains types are designed to operate with higher anode voltages, and 150–200 volts may be applied.

Secondary Emission.—The irregular form of a curve associated with a screened-grid tetrode is due to a phenomenon called " secondary emission," which may be described in the following manner : When an electron strikes a metal surface with sufficient velocity it will knock out one or more electrons, which will remain suspended in space until a positive body takes possession of them. Returning once again to Fig. 107, it will be possible to trace the effects of secondary emission by studying the curve more closely.

It is apparent from Fig. 107 that when the applied anode voltage is greater than 15 volts the velocity of the electrons impinging upon it is sufficient to cause secondary emission. The electrons thus " knocked off " the anode are pulled to the screening grid, due to its higher positive potential. A glance at the curve will show that as the anode potential is increased up to 60 volts the velocity of the electrons increases to such an extent that the flow of primary electrons is off-set by secondary electrons, so that the mean flow of electrons in the anode circuit is zero. When the anode potential is raised above the screen potential, so that it can overcome the pull of the screen, it will collect the electrons temporarily lost through secondary emission, with the result that the anode current is not affected by this phenomenon.

It should be noted that the actual flow of electrons from the filament is not materially affected by secondary emission, since the anode current lost in this way appears as an increase of screen current ; it is apparent,

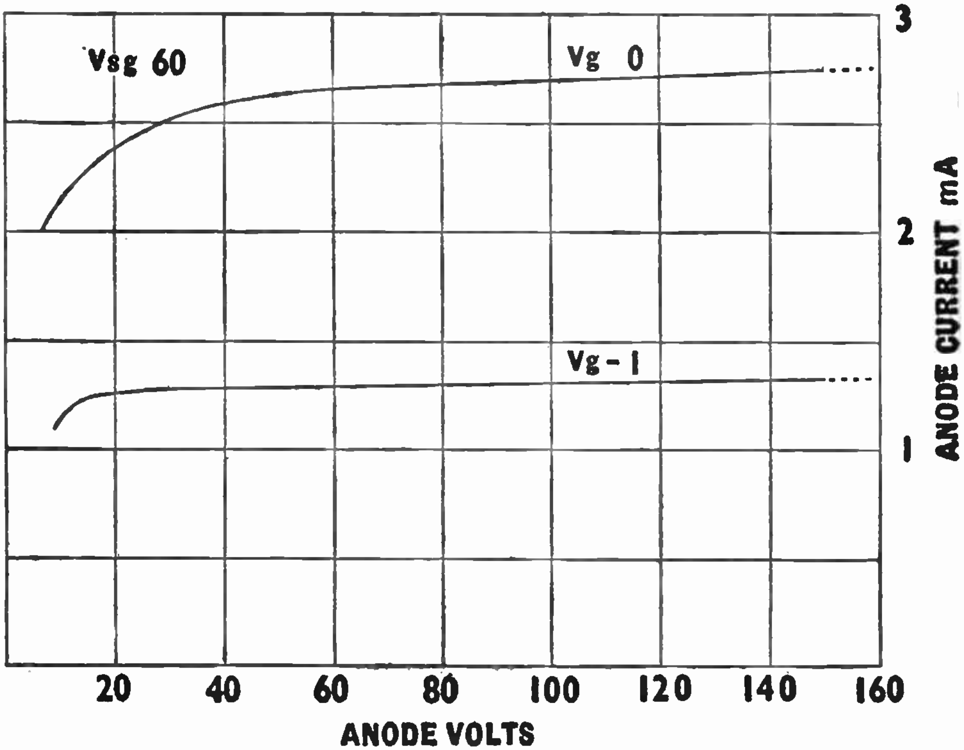


Fig. 108.—Characteristic curve of a screened-grid pentode. Note the increased linearity due to the suppression of secondary emission.

therefore, that the characteristic curve of a screened-grid tetrode could be flattened out and the negative resistance kink removed if secondary electrons could be prevented from reaching the screening grid ; this possibility will be referred to below.

Typical Characteristics.—Inspection of Fig. 107 will show that the impedance of the valve chosen as an example is 200,000 ohms at Vg = 0, while it rises to about 250,000 when Vg = — 1. This increase is not remarkable, since high-slope mains valves often suffer an increase of impedance to an extent of four or five times when the grid potential is varied from zero to — 1. A few years ago valve manufacturers quoted the impedance of screened-grid valves when measured under conditions that could not be used in practice, making the choice of a valve a matter for luck rather than discretion ; but to-day their catalogues are more enlightened, and impedance is quoted for working conditions, and is usually between 150,000 and 750,000 ohms ; values of mutual conductance being between 1·0 and 1·5 mA/V for battery valves, and 2·0 and 5·0 mA/V for A.C. mains types. The amplification factor of a screened tetrode may be anything between 200 and 1,000, or even more, but the resulting stage gain is not so high as might be expected, for reasons that will be apparent after reading the next chapter.

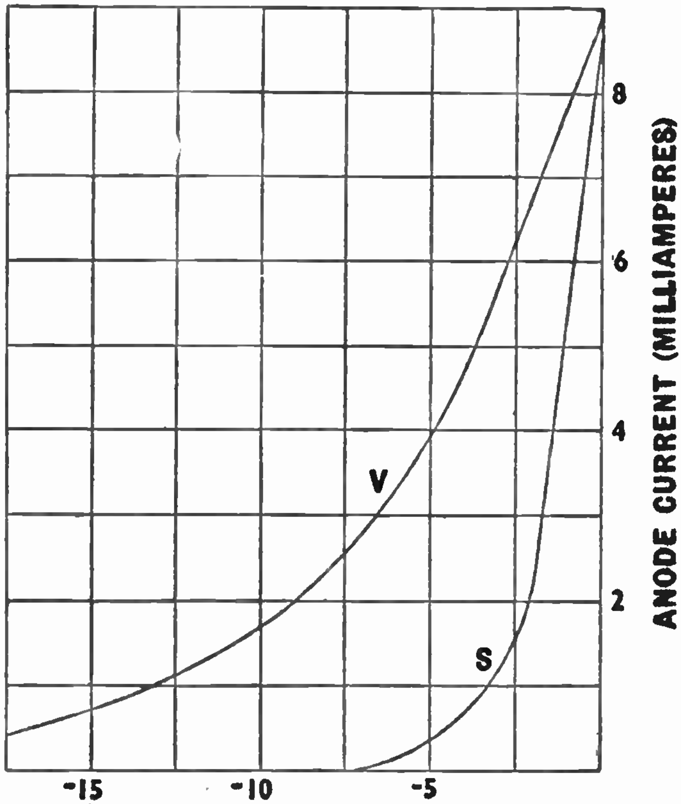


Fig. 109.—Comparison between a variable-mu valve and a "straight" valve.

The R.F. Pentode.—The screened-grid tetrode is not the ultimate answer to the problem of high-frequency amplification, since its non-linearity gives rise to certain difficulties and it has been superseded by the screened-grid pentode. It will be remembered that the kink in the curve of a screened-grid tetrode is due to the flow of secondary electrons from anode to screening grid. In the screened-grid pentode this has been prevented by the introduction of yet another grid, which is placed *between* the screening grid and the anode. This additional electrode is called the suppressor grid, since it suppresses secondary emission.

The suppressor grid is usually very open in construction, and is connected to filament or cathode so that it is held at a potential that is negative in respect to the screening grid. When the electrons flow from the filament to the anode their velocity is very considerable, and they are thus able to overcome the repelling effect of the negative suppressor grid and pass onwards to the anode. When secondary electrons leave the anode they are moving at comparatively slow speed and are unable to make their way through the suppressor grid, since the comparatively distant screening grid is unable to give them the necessary velocity, with the result that the electrons are collected by the anode and the negative resistance kink is absent.

The anode-volt/anode-current curve of a screened-grid or R.F. pentode is shown at Fig. 108; a valve has been chosen with similar anode-current characteristics as the screened tetrode already referred to, so that comparison is assisted; it will be observed that the screened pentode has much greater linearity. The impedance of the screened-grid pentode is usually somewhat higher than the tetrode which assists selectivity, since the impedance of the valve may be regarded as being in shunt with its own anode coupling. This point is, however, insignificant compared to the advantages accruing from greater linearity.

Variable-mu.—There is a modified form of the two basic types that have formed the subject of this chapter, called respectively the variable-mu screened-grid tetrode and the variable-mu screened-grid pentode; these valves have modified control grids permitting the mutual conductance and amplification of the valve to be controlled within wide limits by variation of grid bias. The methods of using the valve in this way are described in the next chapter, but a curve is shown at Fig. 109 which serves to compare the straight with the variable-mu type. The curves are taken showing the anode current plotted against grid potential, the curve "S" representing a typical straight valve, while curve "V" is typical of a variable-mu type. It will be seen that the undue application of bias to the curve "S" will result in rectification owing to the sharp bend, but that bias may be applied up to the cut-off point of curve "V" without introducing serious rectification, the curve being a gradual sweep devoid of the sharp bend that is characteristic of curve "S."

CHAPTER 15

RADIO-FREQUENCY AMPLIFICATION

THE previous chapter dealt with screened-grid valves especially designed for radio or high-frequency amplification. Attention can now be directed to the application of these special valves to the intended purpose. As already intimated, radio-frequency amplification has a profound influence upon sensitivity and selectivity, and consequently upon the quality of reproduction; it is obvious that the radio-frequency amplifier should be so designed that it maintains within reasonable limits the degree of these qualities present over the range of each waveband. The radio-frequency amplifier can conveniently be divided into two sections, the aerial coupling and the anode coupling.

The Aerial Coupling.—The aerial coupling may consist of any number of tuned circuits; for present purposes, however, it is only necessary to consider those couplings which employ one or two tuned circuits. The most simple form of aerial coupling is a single coil connected between the grid and cathode (or filament) of the amplifier, the aerial and earth being connected to either end respectively. This arrangement, however, is so unselective that it may be considered useless for present-day conditions. The most simple coupling that is likely to prove useful is shown at Fig. 110, which shows the grid coil arranged as an auto-transformer, since the aerial and earth system is tapped across only a portion of the grid coil; this arrangement gives some control over selectivity, since this quality is increased by reducing the number of turns between earth and the point where the aerial is tapped into the grid coil. This gain can be accomplished without loss of sensitivity within certain limits, since there is an optimum point for maximum stage gain which is not the top of the coil unless the aerial is extremely short. If the aerial is tapped in at a point lower than the optimum point, some loss of sensitivity may be expected.

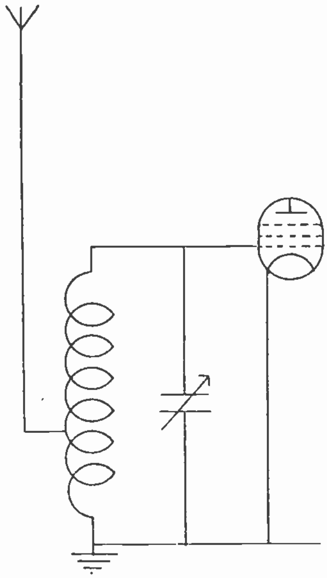


Fig. 110.—Auto-transformer aerial coupling.

A slight modification of the arrangement shown at Fig. 110 is shown at Fig. 111, where the aerial tapping is replaced by a small inductance coupled to the grid coil. This coil is sometimes referred to as an aperiodic aerial coil, which is a misnomer, since the aerial coil is tuned by virtue of the coupling existing between it and the tuned grid coil. By suitably proportioning the number of turns in the aerial coil to the number of turns in the grid coil, and by carefully regulating the coupling between them, some effort can be made towards securing a uniform response-curve over the waveband in question. This illustration also shows the optional inclusion of a small condenser, usually of the order of 10 μμF, which may be included to raise the efficiency at the high-frequency end of the waveband which is liable to suffer due to a number of causes, including the effect of dielectric losses and the high-frequency resistance of the coil; this condenser is usually omitted on the long waveband, the suggested value of 10 μμF being suitable for the normal medium waveband.

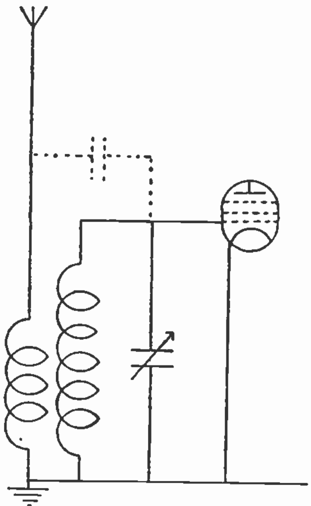


Fig. 111.—Aerial transformer coupling.

Cross Modulation.—Additional selectivity may be obtained by suitably designing the anode coupling or couplings of the high-frequency amplifier valve or valves, but even if the over-all selectivity is sufficiently high, it is nevertheless necessary that the aerial coupling itself shall possess an adequate degree of selectivity in order to avoid the phenomenon known as cross modulation. When the selectivity of the aerial coupling is inadequate, the first valve may become overloaded by energy received from a powerful station when actually tuned to some other station; the condition of overload causes a screened tetrode and, to a lesser extent, a screened pentode to rectify and impose the modulation of the unwanted station on to the carrier of the wanted station; thus the carrier wave of the wanted station appears in the anode circuit of the valve carrying the modulation of both stations. Since both modulations are imposed upon a single carrier, it is impossible for successive tuned circuits to remove the interference. It is interesting to note that when a station is being received with interference due to cross modulation the unwanted station will disappear when the wanted station closes down. This is of course due to the inability of the unwanted station to break through the tuned circuits of the receiver without the assistance of the carrier wave to which the receiver is tuned.

It must be made clear that cross modulation is much more prevalent when utilising the screened-grid tetrode than when using the screened-grid pentode. Nevertheless the latter can produce this phenomenon, and therefore it is necessary that adequate selectivity be provided in the aerial coupling; the use of high selectivity in the aerial coupling is sometimes referred to as "pre-selection."

Bandpass Coupling.—Adequate selectivity can be obtained by a single tuned circuit in the aerial coupling, but only at the expense of cutting sidebands resulting in a more or less serious loss of the high audio-frequencies. To obtain a high degree of selectivity without serious loss of quality it is convenient to employ a double-circuit tuner of the type known as a bandpass filter. Reference has already been made to this type of circuit, and the response-curve of a typical bandpass coupling is shown at Fig. 71 on page 65. Figs. 112, 113, and 114 show the basic circuits of band-pass tuners in general use. That shown at Fig. 112 is probably the most popular of the three types shown, and consists of two separate tuned circuits coupled together by the re-actance of the fixed condenser which is common to both circuits; the coils themselves are screened to prevent mutual coupling or, alternatively, mounted at right angles to accomplish the same purpose. With this arrangement the band width of the response-curve may be varied by varying the capacity of the coupling condenser and the variation of band width over any one waveband is not intolerable.

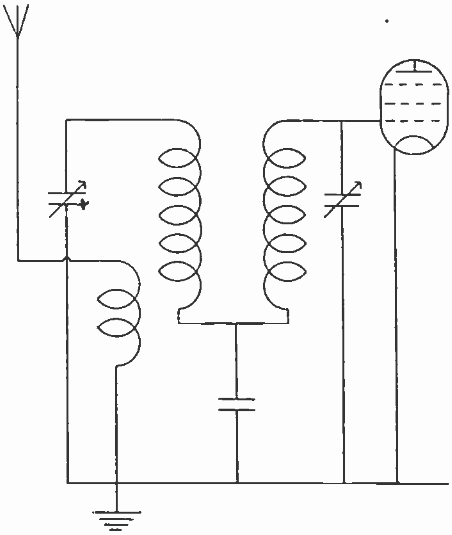


Fig. 112.—Capacity-coupled bandpass aerial coupling.

The arrangement shown at Fig. 113 relies upon mutual coupling to determine the band width and is very efficient when used as a filter on a particular frequency, but for general purposes, where reception is required within the limits of, say, the broadcast waveband, it has a disadvantage that the characteristic of the response-curve shows very considerable variation. All simple bandpass circuits tend to give low response at the high-frequency end of the waveband and inconstancy of band width, troubles that are overcome in modern receivers by the use of mixed couplings; the most simple form of mixed coupling will be obtained by connecting a small condenser of the order of 10 $\mu\mu$F between the top ends of the two tuned circuits shown at Fig. 112. This type of coupling is used by many of the radio receiver manufacturers.

Where extreme selectivity is required and some loss of sidebands is not regarded as a serious drawback, it is convenient to use a circuit shown at Fig. 113, the two coils being loosely coupled instead of over coupled. With this arrangement any degree of selectivity may be obtained within reasonable limits by loosening the coupling, which will be accom-panied by a more or less proportionate loss of sidebands and sensitivity. It is, however, possible to overcome the loss of sidebands to some extent

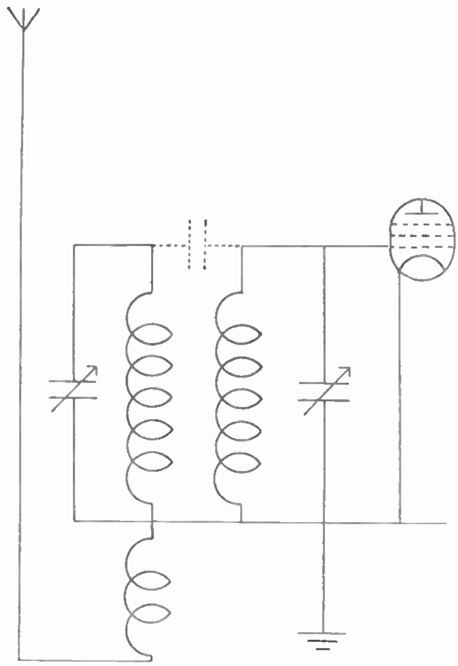


Fig. 113.—Aerial coupling which relies on over coupling between the two tuned circuits to obtain bandpass characteristics.

by employing subsequent tuned circuits of the over-coupled bandpass type so adjusted that the middle frequencies are attenuated and the sideband frequencies accentuated. This arrangement is sometimes used in superheterodyne receivers (the principle of which is dealt with in a later chapter), but there are several examples of its application in straight receivers, some of which may be found among contemporary receivers.

A complete book might well be devoted to the subject of aerial coupling, but the numerous possible variations are all based upon circuits mentioned above. It should, however, be borne in mind that the efficiency of any tuned circuit is very greatly influenced by the actual design of the coils used, since the response-curve of any coupling must be to a greater or lesser extent determined by the magnification of the tuned circuits used.

Intervalve Coupling.—The anode coupling may consist of a resistance, high-frequency choke, or a tuned circuit. For reasons that have already been elaborated only the last-named needs consideration, and for convenience may be divided into three broad groups, tuned anode, tuned grid, and tuned radio-frequency transformer. It is true that the tuned anode and tuned grid are merely modifications of each other. It is nevertheless convenient to consider them separately.

Tuned Anode Coupling.—The tuned anode arrangement is shown at Fig. 115 and represents the simplest possible form of tuned coupling, since it is made up of the bare necessities of a tuned circuit. Where the production of maximum stage gain is the only consideration use may be made of this coupling, but it presents considerable difficulties, since it is probably more difficult to achieve stability when using tuned anode couplings of

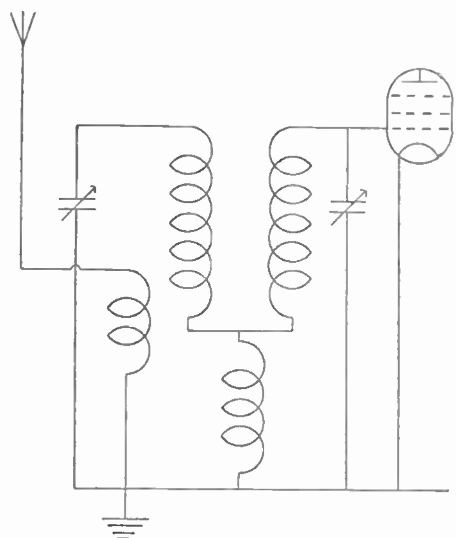


Fig. 114.—Inductively coupled bandpass aerial coupling.

high effective dynamic resistance than when using any other tuned couplings having similar characteristics. This difficulty is partly due to difficulties encountered in adequately screening the tuned circuits from each other, and also partly due to the large high-frequency voltage developed at the anode.

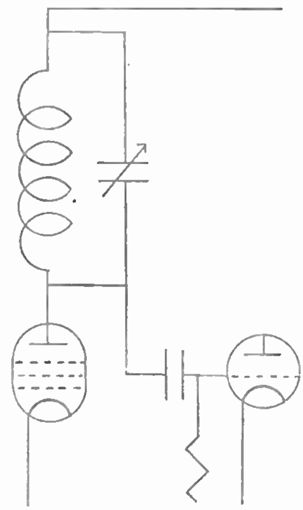


Fig. 115.—Tuned anode intervalve coupling.

Tuned Grid.—The tuned grid coupling (Fig. 116) has the advantage that stability is comparatively easy to achieve since the dynamic resistance of the anode coupling is limited by the shunting effect of the choke or the anode resistance, which from the point of view of high-frequency voltages may be considered as being in parallel with the tuned circuit. It will be noted that one side of the tuning condenser is at earth potential, which minimises feed back to the grid circuit when using the conventional type of ganged condenser. It is apparent that this circuit cannot give the maximum gain of which the valve and coil are capable, since the impedance of a tuned circuit must be reduced when shunted by a pure resistance or another impedance. By varying the value of this resistance, the dynamic resistance of the tuned circuit may be varied and some control obtained over the stability of the stage. It should be noted, however, that the value of the anode resistance may not be unduly low, since it will have the effect of damping the tuned circuit and reducing selectivity. Some such damping, however, is desirable in the interests of good quality if the magnification is high enough to attenuate the sidebands seriously. The anode resistance may be replaced by a high-frequency choke which has low D.C. resistance and relatively high impedance. It is therefore an advantage when the total high-tension voltage is limited, but is otherwise to be avoided, since its impedance is liable to vary with frequency.

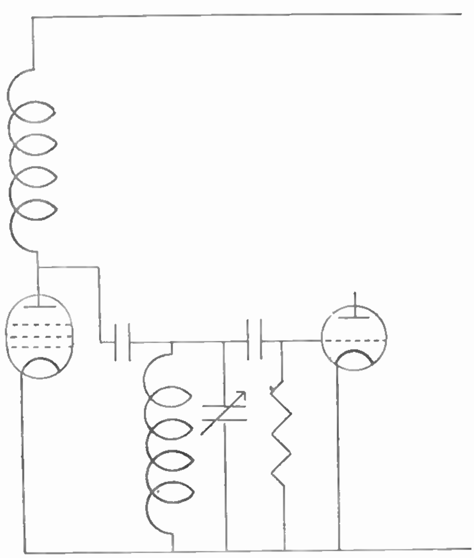


Fig. 116.—Tuned grid intervalve coupling.

The Tuned Inter-valve Transformer.—The usual type of tuned transformer is shown at Fig. 117, and may be considered to be the most desirable form of coupling unless considerations of cost or convenience suggest the use of the couplings already mentioned; the most useful feature of the high-frequency transformer is its ability to step up or step down voltage by adjusting the number of turns in the primary in relation to the number of turns in the secondary, thus permitting the control of both stability and selectivity. It also permits maximum stage gain to be obtained in a multi-stage amplifier where instability may be a limiting factor; this important aspect is again referred to later in the chapter.

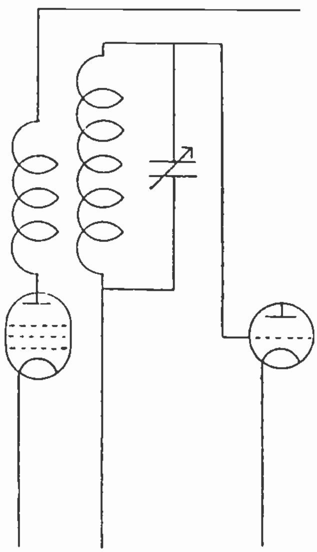


Fig. 117.—Tuned inter-valve transformer coupling.

Stage Gain.—The stage gain of a radio-frequency amplifier may be obtained from the following simple equation:

$$\text{Stage gain} = \frac{\mu \times R}{R + r_a}$$

when r_a is anode impedance, R is dynamic resistance of anode circuit, and μ is the amplification factor of the valve.

Thus a screened-grid valve having an amplification factor of 750 and an impedance of 500,000 ohms under working conditions associated with an anode coupling having an effective dynamic resistance of 200,000 ohms will have a stage gain of 300 times. The expression "effective dynamic resistance" is used, since the nominal value will be decreased by grid current damping if it is followed by a grid detector or, alternatively, will be increased by feed back if it is followed by another stage of high-frequency amplification. The effective dynamic resistance of a tuned circuit is often small when compared with impedance of the valve. In these circumstances the formula may be simplified as follows:

$$\text{Stage gain} = \frac{\mu R}{r_a} \text{ or } g_m \times R$$

when r_a equals the impedance of the valve under working conditions, R equals the effective dynamic resistance of the tuned circuit, μ equals the amplification factor of the valve, and g_m equals the mutual conductance of the valve in ampères per volt.

Stability.—When visualising the use of modern high-gain valves and iron-cored "Litz" wound coils having high dynamic resistance it is easy to obtain high stage gain on paper, but it is quite another matter to obtain high gain with stability in an actual receiver. Instability will arise from one of two causes, energy fed back from anode circuit to grid circuit due to accidental magnetic or capacity coupling arising through insufficient screening between one circuit and the other, and to energy fed from anode to grid circuit through the capacity existing between the anode and grid of the valve. It has already been stressed that the grid anode capacity of the screened-grid valve is of a very low order. It is nevertheless significant, since it will determine the maximum stage gain that may be developed without the valve bursting into oscillation ; assuming that the screening between the anode circuit and grid circuit is perfect, the permissible stage gain may be calculated from the following formula. The stage is stable when the undermentioned expression produces an answer that is less than 2 :

$$g_m \times R_a \times R_g \times C \times f \times 2 \times \pi$$

when R_a equals the effective dynamic resistance of the grid circuit, R equals the effective dynamic resistance of the anode circuit, C equals the inter-electrode capacity of the valve in farads, f equals frequency in cycles per second, and π equals 3·141.

The above formula is included rather to show the effect of the various constants upon stability, since its actual application is very seriously limited by the inability of obtaining by simple methods the values of R_a and R_g. Also the assumption that screening is perfect represents a degree of optimism that is quickly modified by a little practical experience.

If constants are chosen for a high-frequency amplifier using a single valve in such a manner that the maximum gain is obtained, that is to say the valve is approaching the point of self-oscillation, it cannot be assumed that the constants can be duplicated for the second stage, since the energy fed back from the anode of the second valve will increase the effective dynamic resistance in the anode circuit of the first valve and cause it to break into oscillation. Unless gain and selectivity are to be deliberately decimated by damping the tuned circuits, recourse must be made to the use of a high-frequency transformer of suitable ratio. To obtain stability it is necessary in effect to reduce the high-frequency voltage at each anode, since this will proportionately decrease the energy fed back through the grid anode capacity of the valve. The use of a step-up transformer will reduce the anode voltage out of proportion to the loss of stage gain, since the voltage across the secondary of the transformer will be proportional to the square of the voltage across the primary. For an example, if it is necessary in a multi-stage amplifier to use a transformer having a ratio of 4 : 1, the high-frequency potential at the anode will be reduced to $\frac{1}{16}$th and the gain will be divided by 4 ; the use of such a high ratio would not normally be contemplated in practice, but serves to accentuate the principle, and illustrates clearly the desirability of achieving stability in this way compared to a wasteful alternative of reducing gain by other means, such as damping the tuned circuits or reducing the amplification factor of the valve by lowering the screen voltage. It is possible to substitute an auto-transformer for the tuned high-frequency transformer, that is to say, to use tapped tuned anode or tapped tuned grid. There are, however, several drawbacks to this method, which is fast becoming obsolete.

Volume Control.—The question of maximum gain naturally gives rise to the thought that means must be available for reducing the stage gain at will when powerful stations are being received; several systems of gain control are available, some for use in front of the detector, some for use after the detector. Among the former may be mentioned the following: variation of screen voltage will control stage gain, since the reduction of screen voltage will bring about reduction of the amplification of the valve. This method is to be deprecated, however, since it increases the tendency of the valve to overload and consequently may be expected to give the worst quality from the most powerful signal, which will normally be the local station, from which the best quality is usually expected.

A variable resistance may be associated with the aerial coupling either as variable damping on the tuned circuit or as variable input to the aerial coil. Both methods have the disadvantage that although the signal strength is controlled the valves are working at maximum gain and consequently noises inherent to the working of valves, e.g. valve hiss, will remain at a maximum.

The only really satisfactory form of volume control is the utilisation of variable-mu valves for the first or, preferably, all high-frequency stages. It will be recalled that control of amplification is made possible by varying the grid voltage of a variable-mu valve.

It cannot be said that the variable-mu valve offers the perfect solution to the problem of gain control, since relatively large signals will unavoidably operate on a curved portion of the characteristic. There is, however, no other system available that offers less disadvantages. The variable-mu valve, though not perfect, is nevertheless satisfactory, and fortunately gives negligible distortion on powerful signals because the grid-volts/anode-current characteristic is sensibly straight when high values of negative voltage are applied. By the use of variable-mu valves it is possible to obtain automatic control of gain regulated by the amplitude of the received signal; this arrangement is known as automatic volume control, and is of such importance that a subsequent chapter is devoted entirely to this subject.

CHAPTER 16

THE PRINCIPLE OF THE SUPERHETERODYNE

It has already been stated that selectivity may be increased by the use of additional tuned circuits; when two or three, tuned circuits are sufficient to give some predetermined degree of selectivity, there is much to commend the use of the so-called " straight " receiver.

The design of a receiver using four or more variably tuned circuits presents certain practical problems inasmuch as the ganged condenser assembly must possess a degree of accuracy that can only be obtained at considerable expense; furthermore, such a receiver must necessarily be somewhat unwieldy, and serious difficulties will be encountered due to the inconsistency of the response curve, for reasons that have been explained in an earlier chapter, and inaccuracies in the matching of the ganged condenser at various degrees of its rotation.

Three tuned circuits are inadequate for present-day conditions, while the selectivity obtainable from four tuned circuits is only adequate when the individual circuits are so sharply tuned that sideband cutting is serious. The broadcast bands are so congested that six efficient tuned circuits may be regarded as the workable minimum if it is desired to receive weak stations working on frequencies close to powerful transmitters situated at relatively short distances from the receiver. Since there is need for a very high degree of selectivity, and it appears impracticable to employ sufficient variably tuned circuits to obtain it, other means must be found; such means are available in the form of the supersonic heterodyne receiver, which is colloquially called the superheterodyne or, even more briefly, the superhet.

Frequency Changing.—Expressed in a nutshell, the superheterodyne principle permits the use of any number of tuned circuits, all permanently tuned to a specific fixed frequency; the incoming signal having its frequency " changed " to this predetermined frequency irrespective of its original frequency. By these means only two tuned circuits are essential, although three tuned circuits are desirable for reasons which will be apparent in due course.

Before proceeding with the detailed description of this important principle, it will be as well to take a bird's-eye view of a typical circuit, to become familiar with the order in which the several functions occur. Fig. 118 shows a block diagram of a superhet circuit.

Although, in principle, a single tuned circuit is cited, it is desirable to use two tuned circuits or, as a refinement, a stage of ordinary radio-frequency amplification preceded by bandpass aerial coupling, for reasons which will be made clear in due course ; it is, however, sufficient for the moment to visualise the single tuned circuit aerial coupling. The next box in the diagram is the " mixer," the purpose of which is to *combine* the incoming signal with the output from the oscillator ; note that the incoming frequency must be *combined* with the output from the oscillator and not merely co-exist. In a manner which will be described shortly the combined signal output from the mixer can be made to take the form of a new

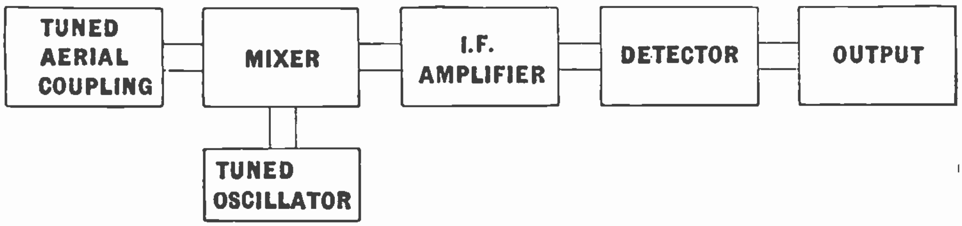


Fig. 118.—A block diagram showing the various sections of a superheterodyne receiver.

frequency that will be constant irrespective of the frequency of the incoming signal, and is known as the intermediate frequency, abbreviated as I.F. It should be noted that the intermediate frequency will be modulated in sympathy with the modulation imposed on the carrier wave of the incoming signal.

The Oscillator.—Some mention has been made of the basic purpose of the oscillator ; this portion of the circuit is basically a valve, usually a triode, the anode circuit of which is so tightly coupled to the grid circuit that continuous oscillation is maintained, the frequency of which is controlled by tuning either the grid or anode circuit, almost invariably the former.

The next box represents the intermediate-frequency amplifier, which will comprise one or more screen valves arranged as high-frequency amplifiers, with the exception that they are only required to deal with one fixed frequency, *i.e.* the intermediate frequency. The frequency chosen may vary, but will usually be low enough to permit the use of really efficient coils with complete stability so that high gain is achieved.

The output of the intermediate-frequency amplifier is fed to the detector, which functions in a normal manner since the wave form, handled by the intermediate-frequency amplifier, has all the characteristics of a modulated carrier ; the output from the detector being passed to the output stage in the conventional manner. The detector stage usually employs a diode, which is followed by a stage of amplification before the signal is ultimately fed to the output stage. This detector is sometimes called the second detector because the mixer is sometimes also regarded as a detector. No useful purpose will be achieved by raising the controversy regarding the necessity for detection in the mixer stage, since it is an argument which may cause considerable confusion.

Intermediate Frequency.—This brief survey will have served to identify the various sections of the superheterodyne, which makes it possible to discuss conveniently the manner in which the frequency of the incoming signal is changed to the predetermined intermediate frequency. Assume that the aerial circuit is tuned to resonance with a transmitter radiating at a frequency of 1,000 kcs. per second, and that the oscillator is tuned to 1,465 kcs. per second; if these circuits are arranged in conjunction with a valve so that both the incoming signal and the oscillator can vary its anode current, a complicated set of frequencies will appear in the anode circuit. Ignoring for the time being the various odd frequencies due to harmonics, there will be four predominant frequencies, (*a*) the signal frequency, which it will be remembered is 1,000 kcs.; (*b*) the oscillator frequency, 1,465 kcs.; (*c*) a frequency which is equal to the difference between the signal and oscillator frequencies, *i.e.* 465 kcs., and a frequency which is equal to the sum of the signal and oscillator frequencies.

It is apparent that, since the frequency of the combined wave form is equal to the sum and difference between the signal and oscillator frequencies, an oscillator frequency of 535 kcs. will also produce a 465 kcs. component, since the difference between 1,000 kcs. and 535 kcs. is equal to 465 kcs. In practice, however, the oscillator frequency is almost invariably higher than the signal frequency.

A moment's reflection will show that the 465 kcs. component can be kept constant for any signal frequency if the oscillator frequency is maintained at 465 kcs. higher. To carry the point a step farther, the oscillator circuit and aerial circuit can be so designed that the rotation of a ganged condenser will tune the aerial circuit and the oscillator circuit, the essential difference in frequency being maintained by using specially shaped vanes for the oscillator condenser, or by other means which will be described in due course.

No doubt the reader will have already concluded that the 465 kcs. is the intermediate frequency; obviously the oscillator frequency could be varied to produce any intermediate frequency; 465 kcs. is, however, in general use, although 128 kcs. and 110 kcs. are among the intermediate frequencies that are, or have been, used in this country. In America 456 kcs. is standardised; there are reasons for governing the choice of the intermediate frequency which are discussed during a later chapter, but 465 kcs. will serve very well for the present explanation.

As already mentioned, there will be a variety of frequencies present in the anode circuit of the mixer valve; only one of these, the intermediate frequency, must be passed on to the intermediate-frequency amplifier, and all others must be rigorously eliminated. This necessary selection is accomplished by means of a tuned circuit, which invariably takes the form of a transformer having both primary and secondary tuning, since it is desirable to introduce as many tuned circuits as possible in the interests of selectivity, while in the interests of quality the primary and secondary can be over-coupled to give bandpass characteristics. It should be noted that each intermediate-frequency amplifier stage may introduce a further two tuned circuits.

As already explained, all the tuned circuits associated with the intermediate frequency are adjusted to 465 kcs. This gives great scope for designing transformers capable of giving really good bandpass characteristics, since they are intended to work at one predetermined frequency and, furthermore, the frequency chosen is usually sufficiently low to permit high coil magnification to be used without impairing stability.

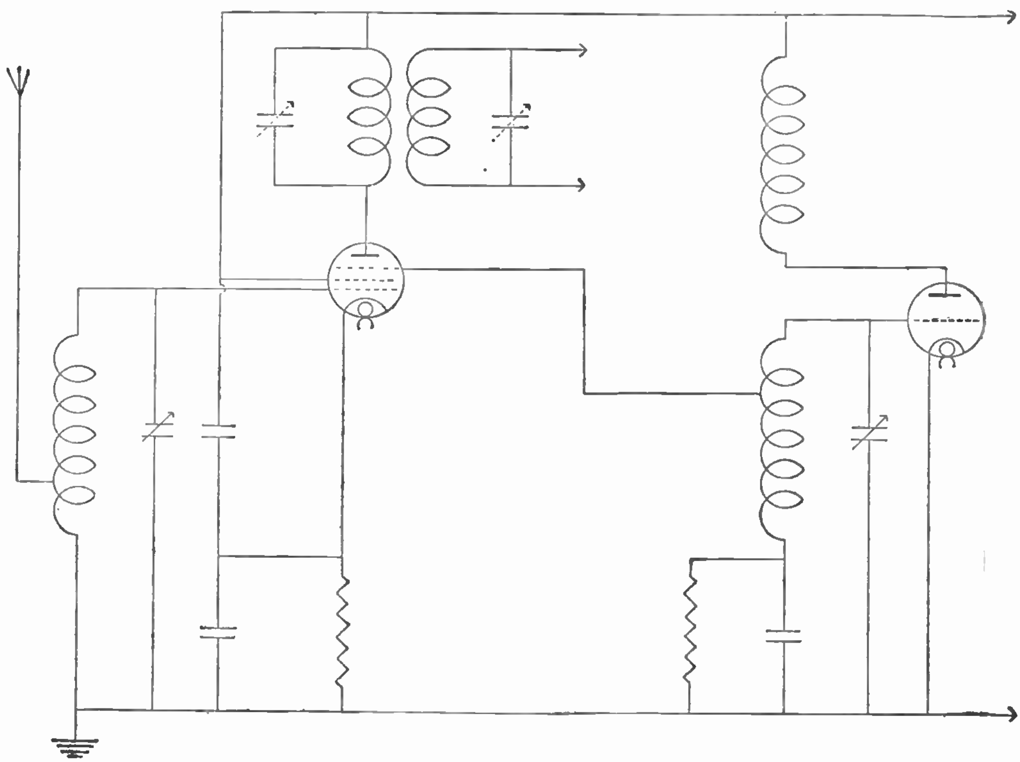


Fig. 119.—Basic circuit showing the use of an ordinary triode and pentode valve to form a frequency-changing stage. This circuit is not recommended, but is included to illustrate the text.

A Simple Frequency Changer.—Fig. 119 shows the basic circuit of a frequency-changing stage using a triode as oscillator and a screened pentode as mixer; this circuit, in fact, constitutes the first stage of a simple superheterodyne, but is scarcely of the type that could be recommended, since much more efficient arrangements could be evolved around modern specialised valves, the several types of which are dealt with separately in the next chapter, together with suitable circuits in which to use them. The circuit shown at Fig. 119 is included since it employs valves with which the reader has already been made familiar, and this permits the principle to be discussed without the complication of simultaneously introducing a new type of valve. The signal is introduced by connecting a tuned grid coil between the grid and cathode of the valve in the conventional manner. The oscillator consists of a tuned grid coil so arranged that its frequency is always higher than the frequency to which the aerial coil is tuned by an amount equal to the intermediate frequency. Oscillation is maintained by the close coupling between the oscillator anode and grid circuits, the principle involved being similar to the coupling existing in detector circuits for the purpose of introducing reaction. It will be observed that the grid circuit is completed from the H.F. point of view by a fixed condenser, and completed from the D.C. point of view by a resistance. This resistance and condenser act in conjunction with each other and cause the valve to bias itself by grid current; when the grid becomes positive, grid current flows which sets up a potential difference across the resistance, which in turn charges the condenser which tends to maintain the bias when grid current is not actually flowing. In this way the valve will bias itself so that the grid only just runs into grid current on the occasion of each positive half-cycle.

The pentode is usually worked under a condition of relatively high negative grid bias, which is derived from the resistance in its cathode lead. The parallel condenser in this case is intended merely as an H.F. by-pass, a similar purpose being served by the condenser shown immediately above it, and connected between screen and cathode. The signal is introduced on the ordinary control grid as already described, while the output from the oscillator is fed directly to the suppressor grid, resulting in the oscillator output having a measure of control over the anode current of the pentode. Thus both oscillator and the incoming signal control the anode current. A suitable tuned circuit is included in the anode circuit of the pentode to select the intermediate frequency, which will be either the sum of or the difference between the signal and oscillator frequencies as described above.

The circuit in question, Fig. 119, cannot be recommended, since it requires a very large output from the oscillator owing to the relatively small control exercised by the suppressor grid; the average type of pentode requiring between 20 and 30 volts swing from the oscillator. The circuit is, however, included as it forms, in the author's opinion, the simplest possible circuit capable of illustrating the principle of the frequency changer. Modern specialised valves designed expressly for this purpose are described in the next chapter.

The arrangement shown at Fig. 119 is capable of considerable modification, since the principle involved is the generation of local oscillation which is made to exercise some control over the anode current of the mixer valve, the essential feature being that the incoming signal also exercises a measure of control. There is no reason why the oscillator valve should be a triode, it could equally well be a screened-grid or high-frequency pentode valve. In the illustration the frequency of the oscillator is determined by the grid circuit, which is tuned by means of a variable condenser ; the same purpose could be achieved by tuning the anode circuit, a practice that is carried out in a number of commercial receivers.

In order to simplify the function of a frequency-changing stage the oscillator output is connected to the suppressor grid of the mixer valve; another possible arrangement is connection to the screening grid, which necessitates the use of a fixed condenser to prevent the voltage on the latter from appearing as a grid potential on the oscillator valve. Yet another possible arrangement is a coupling between the oscillator circuit and the cathode circuit of the mixer valve. Various methods of frequency changing with specialised valves designed expressly for this purpose are described in the next chapter.

CHAPTER 17

FREQUENCY-CHANGING VALVES

THERE are a number of specialised types of valves designed specifically for frequency changing or mixing. In the inevitable fashion of nomenclature adopted in this country considerable confusion exists, since the names of two of these valves have been reversed by some manufacturers—as will be seen below. Since the functioning and, in some cases, the purpose of these specialised valves show considerable differences, it will be convenient to deal with each type as a separate entity, presenting them in an order chosen for its convenience, and without consideration of their date of introduction.

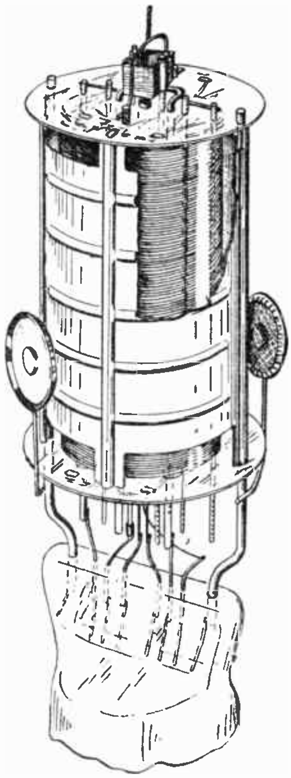


Fig. 120.—The electrode assembly of a typical pentagrid valve. The external appearance of the octode is similar.

The Pentagrid.—Some frequency-changing valves are definitely two separate valves mounted into one bulb. The pentagrid, however, is an example of the truly single-valve frequency changer, and in consequence is somewhat elaborate in structure. The writer has before him a typical example of a well-designed pentagrid, and it will be interesting to recount the details of its construction as being a typical example of valves of the class under discussion. The external appearance of the assembly may be seen at Fig. 120, while certain of its component parts are shown in the illustration, Fig. 121. Starting from the innermost electrode, and working outwards, the first electrode to receive attention will be the heater and cathode assembly, which consists of an M-shaped heater-wire porcelain coated and inserted in a metal cathode, the active coating of which is basically the usual mixture of barium and strontium oxides. The cathode is surrounded by a narrow grid, marked 1 in the illustration. This grid is made of nickel-chrome wire, wound on copper supports in order to prevent the grid wires from becoming heated, which would cause the grid to emit electrons, since its proximity to cathode causes it to collect a certain amount of active material. When the assembly is completed the grid is terminated by blackened metal fins, further to assist in the dissipation of the unwanted heat.

The next electrode, 2 in the illustration, is what is sometimes called a phantom grid, due to its exceptional open construction. It is, in fact, simply a piece of bent wire. Next come three grids of more normal appearance, marked 3, 4, and 5 in the illustration, and, finally, the anode, which may be clearly seen in Fig. 120. All the electrodes are connected with separate pins in the base, with the exception of the grids marked 3 and 5, which are connected internally and therefore are brought out to a common pin. The grid marked 4 is not connected to a pin in the base but to a terminal situated on the top of the bulb. The relative positioning of these grids is kept constant by the use of mica discs, which serve to lock the assembly in permanent alignment.

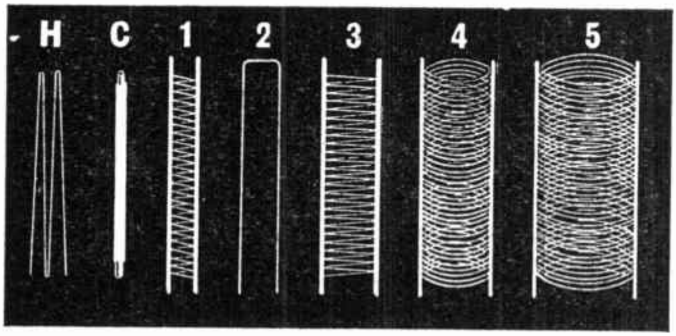


Fig. 121.—The electrodes of a pentagrid valve. The anode is not shown, since it may readily be seen at Fig. 120. Those shown are, from left to right: heater, cathode, oscillator grid, oscillator anode (phantom grid), inner screening grid, signal grid, and outer screening grid.

The above brief introduction will have served to give a mental picture of the pentagrid, and attention may now be directed to the purpose fulfilled by each of the several electrodes.

The following explanation should be read in conjunction with the illustration at Fig. 122. Electrons are duly emitted from the cathode and are accelerated by the potentials on grids 2 and 3, which are positive in respect to the cathode; the bulk of the electron stream is checked by grid 4, which is held at a negative potential in respect to the cathode, with the result that an electron cloud will form between grids 3 and 4, and the subsequent movement towards the anode will be controlled by the potential of grid 4, which it will be noted is varied by the received signal. It will be observed that grid 1 constitutes a normal tuned-grid circuit, and that grid 2, the phantom grid, is in series with an inductance that is tightly coupled to the grid coil; thus the cathode with grid 1 and grid 2 form a triode which will oscillate under the conditions outlined above, and in so doing will control the number of electrons passing to form the electron cloud.

It may be seen from the above brief explanation that the main anode current of the valve is controlled by grids 1 and 4 of the oscillator and signal grid respectively. The result of this dual control is the production of beat notes in the anode circuit, one of which will be the intermediate frequency. As already intimated, this frequency may be selected by placing a suitable tuned circuit in the anode circuit which will not only separate the intermediate frequency by virtue of its selective properties, but will attenuate the other frequencies, as it will offer to them a relatively low impedance. The above explanation is abridged to such an extent that it is not quite complete, but it is hoped that it will serve as an introduction to the rather complicated process of frequency changing within the stream of electrons without going into the matter mathematically or devoting undue space to what is purely a matter of interest, since the

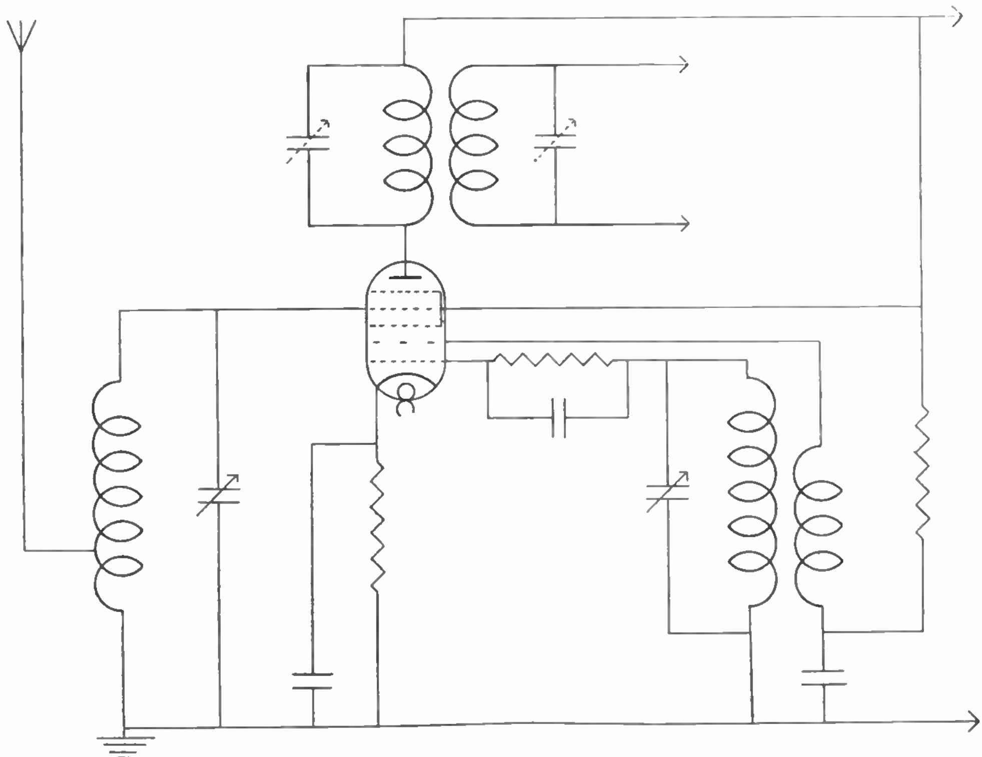


Fig. 122.—The basic circuit of a pentagrid frequency changer. Like all circuits in this chapter it is a skeleton circuit, and lacks certain necessary refinements.

important aspect is the feat that the valve accomplishes rather than the method of its internal working.

Fig. 122 needs some further explanation. It will be observed that no values are given for the components, since these vary widely with valves of different manufacture. The aerial coupling is arranged as a single-tuned circuit and develops a potential between the signal grid and cathode, negative bias for this grid being provided by the bias resistance in the cathode circuit. The signal grid, which is sometimes called the modulator grid, usually has variable-mu characteristics, and control of volume may therefore be obtained by using a variable resistance in place of the fixed resistance in the cathode circuit. The signal grid is sandwiched between grids 3 and 5, which serve the same purpose as the screening grid of an ordinary H.F. valve. In this case, however, the signal grid is screened from everything to prevent coupling between this circuit and the oscillator circuit, which would result in the oscillator frequency being re-radiated by the aerial and the tendency for one tuned circuit to mistune the other.

Grids 1 and 2 form with the cathode a triode oscillator in the manner already described, but attention may be directed to the grid leak and condenser associated with grid 1, which is not intended to produce grid rectification, but is intended to hold the grid at the required potential, which is obtained by the voltage drop across this resistance due to grid current which flows when the grid swings to maximum positive. This circuit, like all circuits shown in this chapter, is stripped of refinements that would be necessary under working conditions, since they are intended to illustrate the principle; full circuits are illustrated and described in a later chapter.

The pentagrid may be described as a most efficient frequency changer when used at the relatively low frequencies, that is to say below 1,500 kcs. (200 metres), but its efficiency begins to fall off at the higher frequencies, and at frequencies around 20,000 kcs. (15 metres) it is difficult or impossible to make the oscillator section function. The pentagrid may be regarded as a tetrode when considering the behaviour of the anode circuit, since the electron cloud, signal grid, outer screening grid, and anode form and operate as a screened tetrode. The valve has a comparatively low anode impedance, and consequently somewhat severely damps the tuned circuits which form the intermediate frequency transformer.

The Octode.—As explained above, the pentagrid introduces severe damping in its anode circuit, which is common to all valves which bear resemblance to the tetrode. The octode is an attempt to overcome the difficulty by introducing a suppressor grid between the outer screening grid and the anode which raises the impedance in the same manner that the suppressor grid functions in the H.F. pentode. In this way damping of the intermediate-frequency tuned circuit is reduced. Unfortunately, however, certain drawbacks are also introduced, particularly in the direction of increased total space current, which is presumably the reason why this valve does not enjoy the popularity that might be expected.

The Heptode.—The heptode somewhat resembles the pentagrid, inasmuch as it utilises 5 grids. It is not, necessarily, a complete frequency changer, but very often is a mixer or modulator valve, making essential the assistance of a separate oscillator to form a complete frequency-changing stage. The basic circuit arrangement for this valve is shown at Fig. 123, from which it may be seen that it bears some resemblance to the octode, since the outermost electrode is connected to the cathode and forms a suppressor grid. In other words, the oscillator and heptode may be considered as forming an octode, but with the essential difference that the signal grid is the innermost grid, a modification that permits the valve to oscillate readily at relatively high frequencies; thus, with careful design, it can be used for frequency changing up to 60 mcs. (5 metres) or perhaps even a little higher. Unfortunately certain manufacturers market a pentagrid valve under the name of heptode; consequently, when a valve is described as a heptode, some doubt must necessarily arise regarding the exact function that it is intended to perform. As will be seen later the position is still further confused by the nomenclature adopted for certain other types.

Triode Heptode.—So far the valves described have been types that may be considered as single structures; at least from the mechanical aspect.

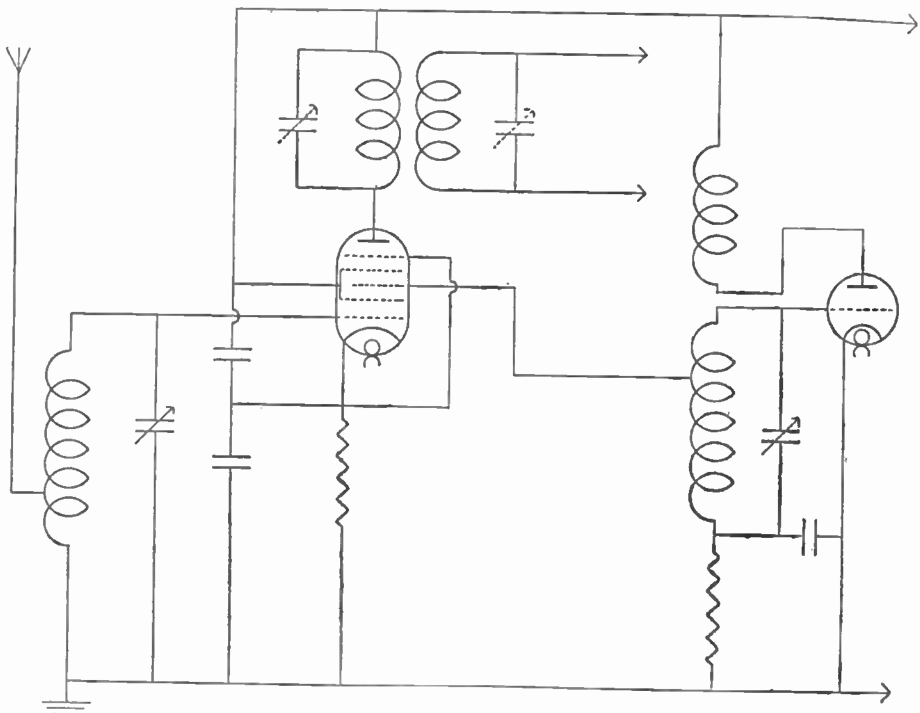


Fig. 123.—Basic circuit of a heptode mixer-valve with separate triode oscillator.

The triode heptode serves to introduce a class of valve that is becoming increasingly popular, and comprises two mechanically distinct assemblies mounted in one bulb. The external appearance of the electrode assembly of a triode heptode is shown at Fig. 124. The example chosen is arranged with the assemblies mounted one above the other, the lower being the triode section, which is separated by a screen from the upper section, which is purely and simply a heptode. No electrical connection exists between the two, with the exception of an internal connection between the oscillator grid and grid 3 of the heptode. This connection may be seen by reference to Fig. 125; the cathodes are of course connected together, but, as these may be regarded as zero potential in respect to all other electrodes, this connection will not influence the relationship between the two valves. It is interesting to note that some manufacturers mount the two assemblies side by side when a high value of mutual conductance is required from the triode, since this arrangement lends itself to increasing the dimension of the latter section. Fig. 125 shows the basic circuit of a triode heptode frequency-changing stage, and it can be seen by comparing it with the circuit at Fig. 123 that there is no basic difference between these two circuits. The only difference is a practical one, inasmuch as the valve under discussion incorporates the two necessary valve assemblies in a single bulb. This arrangement is slightly advantageous when working at very high frequencies, due to the shortness of the lead coupling the two valves together. Bearing in mind that an electron cloud will form between grids 2 and 3, it is possible to visualise this valve as behaving like a pentode: consequently the damping of the anode circuit is relatively low.

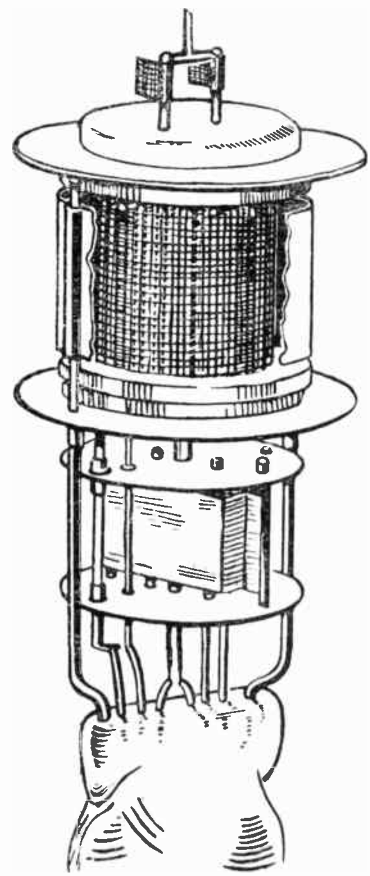


Fig. 124.—The electrode assembly of a typical triode heptode; the lower section is the triode, while the upper section is the heptode, with anode partly cut away to show the outer screening grid.

Triode Hexode.—The triode hexode is exactly similar to the triode heptode, except that it does not employ a suppressor grid; consequently the damping of the anode circuit is somewhat higher. Generally speaking, the term triode hexode is reserved for this type of valve, which has four grids in the hexode section. Unfortunately at least one manufacturer has seen fit to include a suppressor grid, but retained the term hexode, whereas the valve should, strictly speaking, be designated heptode. Fortunately the method of using both valves is precisely similar, and the pin connections are the same. Nevertheless such reversal of nomenclature is unfortunate.

Triode Pentode.—It will be noted that the frequency-changing valves so far described have utilised direct metallic connection between the oscillator and the mixer. The triode pentode, however, differs radically from this arrangement, and the method of using it is fundamentally different. The basic circuit for using the triode pentode is shown at Fig. 126. It will be observed that the valve comprises a normal screened pentode and a normal triode; the aerial circuit is arranged to produce potential difference between the inner or control grid and the cathode; the screening grid is taken to a source of positive potential, and the suppressor grid is normally connected to cathode. This connection is not made internally, but the suppressor grid is brought out to a separate pin, permitting an alternative connection to be made. The triode section is arranged to work in a somewhat unusual manner—the anode circuit is not coupled to the grid circuit—the grid being taken to a point at zero potential through a resistance which is associated with a condenser to provide grid bias, due to the potential set up across the resistance when grid current flows. The anode circuit incorporates a tuned inductance which is coupled to an inductance in the cathode lead. This will cause the valve to oscillate, and, since both cathodes are common, the variation in cathode potential will be imparted to the pentode section. In this way the anode current of the pentode will be controlled by both the oscillator valve and the potential applied to the control grid, thus producing the two beat notes in the anode circuit in a manner similar to that already described.

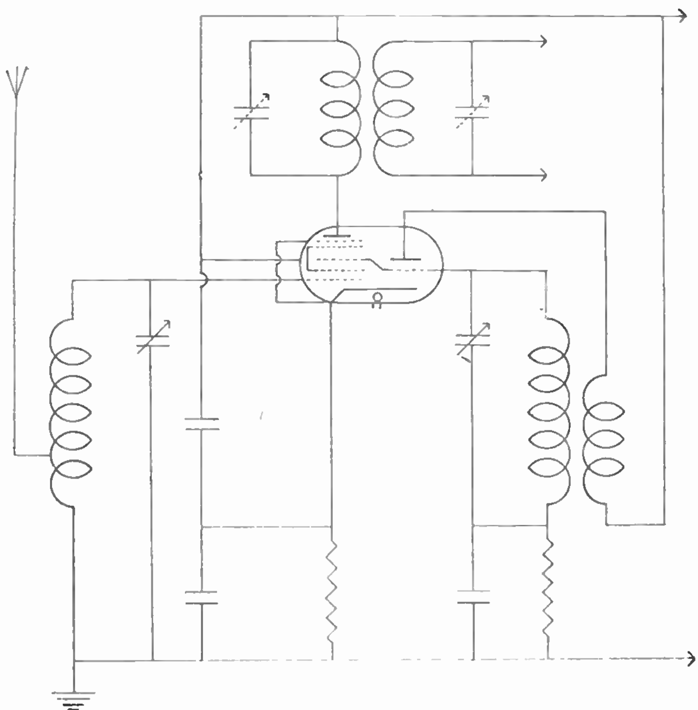


Fig. 125.—A basic circuit using a triode heptode for frequency changing.

The coupling of the anode circuit to the cathode circuit as a means of producing oscillation is so unusual that some explanation is called for. It has been explained in an earlier chapter that the anode current of a valve may be controlled by the difference in potential between grid and cathode, the conventional interpretation being to hold the cathode at a fixed potential and vary the grid in respect to it. The arrangement at Fig. 126 is an exact reversal of the conventional arrangement, since the grid is held at a fixed potential and the cathode potential varied in respect to the grid. In either case variation is achieved between grid and cathode, and the valve will oscillate.

It is doubtful whether the triode pentode has any advantage that would suggest its selection in preference to the triode heptode, although its efficiency may be improved by the use of a relatively complicated circuit which uses both cathode and suppressor-grid injection. The arrangement has, however, found favour with some designers, which alone is sufficient to justify its inclusion in this brief survey of frequency-changing valves.

Conversion Conductance.—When considering the performance of frequency-changing valves it is necessary to find some factor for measuring performance, since mutual conductance does not give the information required. It will be appreciated that the mutual conductance of a frequency changer would be a measure of the control of any one grid over anode current ; the performance of a frequency changer is determined by the characteristics of the signal section and the oscillator section, and is

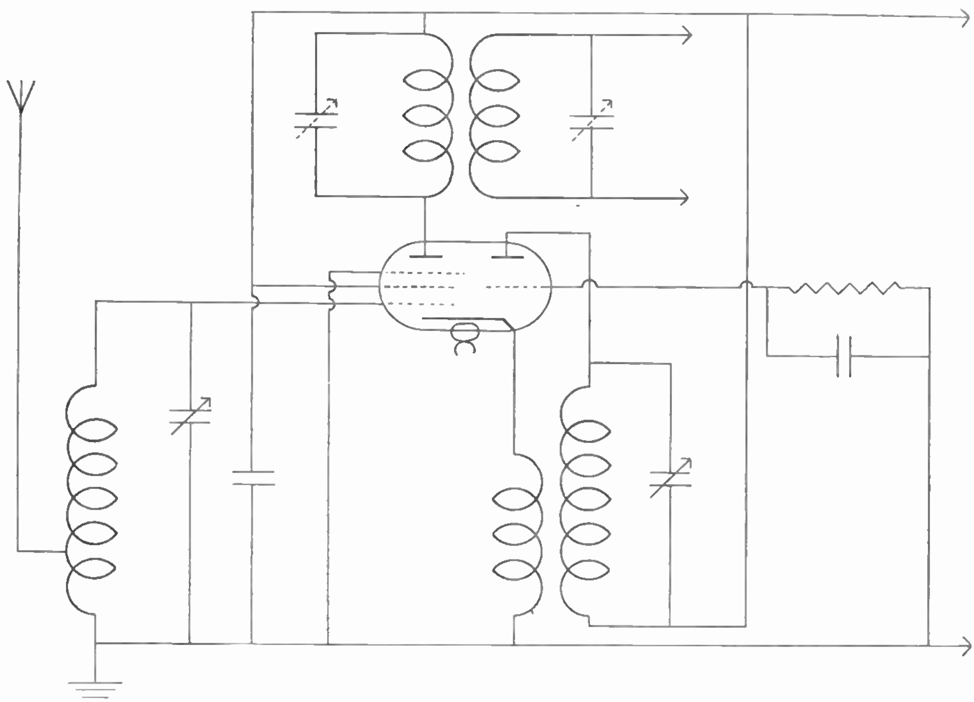


Fig. 126.—Basic circuit of a triode pentode frequency changer. That shown is an indirectly heated valve. Considerable modification is necessary when using a battery type.

measured in terms of conversion conductance. Conversion conductance may be defined as the factor of merit of a frequency-changing valve. It is defined as the rate of change of intermediate-frequency current brought about by a change of alternating signal voltage applied to the signal grid, and is expressed as milliamps per volt (ma/V). Since conversion conductance is partly dependent upon the behaviour of the oscillator section, it is not surprising that this section must be controlled if maximum results are to be obtained ; in other words, the circuit must be so arranged that the oscillator grid swing is maintained at an optimum value.

Fig. 127 shows a curve plotted to show the conversion conductance obtained from a typical pentagrid when various oscillator voltages are employed; the voltage developed by the oscillator section of a frequency changer is usually called the heterodyne voltage. Reference to Fig. 127 will show that efficiency is greatly diminished if the heterodyne voltage is permitted to fall below about 6 volts, though an increase of heterodyne voltage brings about a negligible increase. The valve in question should therefore be worked at about 9 volts R.M.S., which will ensure high conversion conductance with a reasonable safety margin. Excessive heterodyne voltage should be avoided, since it is likely to bring about an increase in the harmonic content of the anode current, which may beat with other frequencies and produce whistles. In practice, care is required so to design the oscillator circuit that the heterodyne voltage will remain constant within reasonable limits over all sections of the wavebands to be covered.

The suggested value of 9 volts for the valve portrayed at Fig. 127 will permit of some variation without bringing about a noticeable change in conversion conductance.

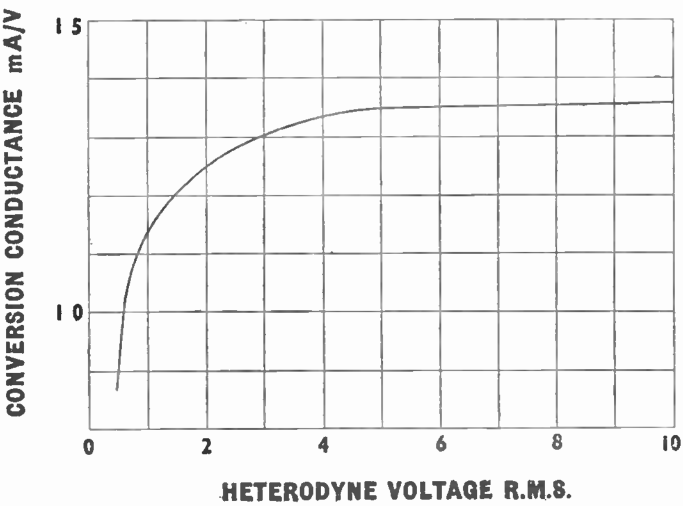


Fig. 127.—Curve showing the effect of heterodyne voltage (oscillator output) on the conversion conductance of the frequency-changing stage. The actual valve used to plot this curve was an indirectly heated triode hexode.

The previous chapter outlined the principle of the superheterodyne, and after this introduction to the basic types of valves in general use it is possible to devote the next chapter to a detailed consideration of the finer points governing the design and behaviour of the superheterodyne receiver.

Background Noise.—Several references have been made to background noise due to random variation of the emission from the cathode or filament; this effect is particularly apparent in the frequency changer. The high level of valve noise in this stage is largely due to the design of the valve and some attempt has been made to lessen the effect by careful attention to valve geometry. There is, however, a way of reducing valve noise in this stage by using a high-frequency amplifier in front of it. As already stated, valve noise reaches a relatively high level in the frequency-changing valve, but it is practically unaffected by the amplitude of the incoming signal. The effect of valve noise on reproduction can only be measured in terms of the signal to noise ratio. Since the amplitude of valve noise is sensibly constant, it is apparent that the signal to noise ratio can be improved by increasing signal amplitude, which can be most easily accomplished by the use of a high-frequency amplifier in front of the frequency changer.

The high-frequency amplifier will contribute to the level of general valve noise, but the signal to noise ratio of this stage is very much more favourable than that obtaining in the frequency-changing stage; consequently its use brings about an improvement in the over-all noise-level. In order to avoid confusion the stage in front of the frequency-changing stage is often referred to as a *radio*-frequency amplifier.

CHAPTER 18

DESIGN OF THE SUPERHETERODYNE

THE preceding two chapters have served to introduce the principle of the superheterodyne and valves peculiar to frequency changing. It might be thought from the brief outline given that the superheterodyne is simplicity itself and the ideal solution to many of the problems of modern radio. Actually, this type of circuit is prone to a number of difficulties, the minimisation of which calls for special care. It is undoubtedly the only known solution to the congested state of the broadcast waveband, and the best modern interpretation of this type of receiver indicates that the early drawbacks have almost entirely disappeared. In all probability the average reader of this book has an incomplete idea of the astonishing difference in the number and power of stations operating to-day compared to those of, say, 1928. To give some mental picture of the great change that has come

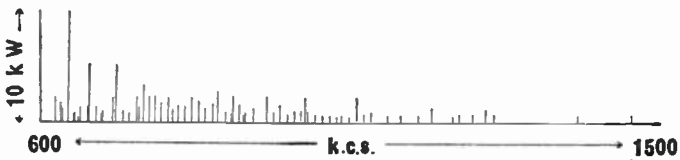


Fig. 128.—The number and power of European broadcasting stations working in 1928. Height of lines represent power, and position in the horizontal direction shows frequency.

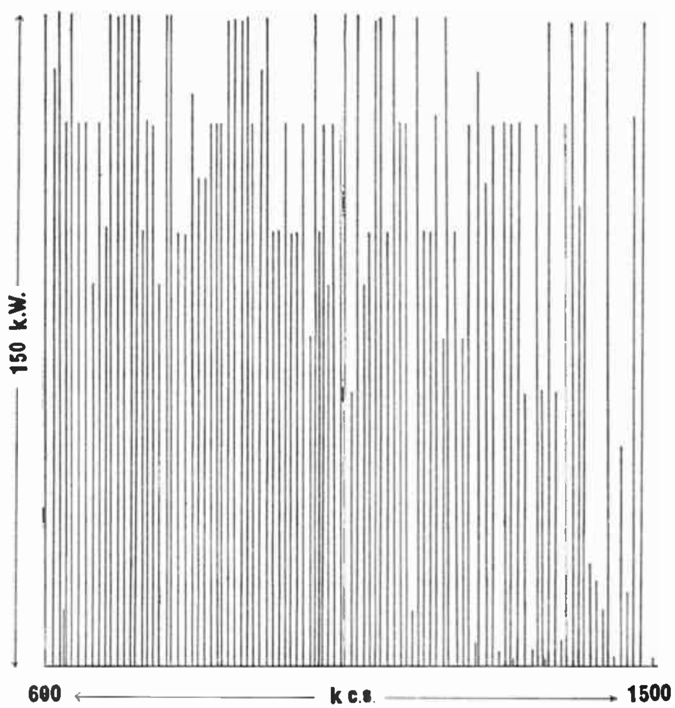


Fig. 129.—This diagram was prepared in exactly the same way as Fig. 128, but shows the situation to-day; a few stations actually are powered at 300 and even 500 kW and some have been omitted as they are too close to be drawn as separate lines, one line may represent as many as a dozen stations all working on the same wavelength.

about a diagrammatic representation is shown in Fig. 128 and Fig. 129 respectively. Fig. 128 shows the number and power of stations operating in 1928; each line represents a station, the length of the line indicating the power in kilowatts in accordance with the scale shown. Fig. 129 shows the number and power of stations operating at the present time. Purely as a matter of interest it may be noted that the total number of kilowatts radiated when all stations as shown at Fig. 128 are working amounts to about 142 kW, while the same figure derived from Fig. 129 amounts to about 20,000 ignoring all under 10 kW.

The above brief statement of the position has shown the task that a modern receiver is expected to perform, and attention may now be devoted to consideration of the various aspects of the superheterodyne, the difficulties that must be overcome, and various other relevant details.

Adjacent-channel Selectivity.—Questions governing consideration of selectivity can be divided into two classes. Adjacent-channel interference and second-channel interference. It will be convenient to consider the former first. Adjacent-channel selectivity may be defined as the ability of the receiver to eliminate interference from stations working *immediately* above and below the station that it is desired to receive. If the wanted station is working at a frequency of 1,000 kcs. per second, it may well have stations working at frequencies of 991 and 1,009 kcs., respectively, as possible sources of interference. Assuming the intermediate frequency to be 465 kcs. per second, the oscillator frequency will usually be 1,465 kcs. per second when receiving a station working at a freqency of 1,000 kcs.; this frequency, beating with the three signal frequencies mentioned above, will produce the following frequencies in the anode circuit: 465 kcs. per second—the wanted frequency; and 474 and 456 kcs. per second—the unwanted frequencies. It is therefore apparent that the intermediate-frequency amplifier must be capable of attenuating the unwanted frequencies to such an extent that they will be inaudible. It should be noted that the wanted station may be received at a strength inferior to the unwanted stations. The aerial coupling may be expected to make some contribution towards the necessary attenuation of the unwanted station, but the major selectivity must be provided in the intermediate-frequency amplifier, which must employ the requisite number of tuned circuits. These will normally be of the bandpass type, and, since they will work at a fixed frequency, considerable scope is offered to the designer to produce a series of coils, the total response of which will show some close approach to the ideal bandpass curve, which, it will be remembered, has a flat top and vertical sides.

The high selectivity necessary in the intermediate-frequency amplifier must result in a considerable loss of the high audio-frequencies, but, fortunately, a certain amount of "faking" is possible—to "replace" this loss. Fig. 130 shows an oscillograph of the combined high- and intermediate-frequency response-curve of a modern superheterodyne employing bandpass aerial coupling and two over-coupled bandpass transformers in the intermediate-frequency amplifier. This curve represents a fairly serious loss of top, since the width at half the height is equal to a band width of 7 kcs. per second. Nevertheless, with the aid of a certain amount of "faking" introduced into the latter end of the receiver, the quality of reproduction can be made equal to that obtained from the average commercial superheterodyne. This is perhaps a rather loose method of expression, but it is one which readily conveys the type of intermediate-frequency response-curve that can be tolerated on the grounds of quality.

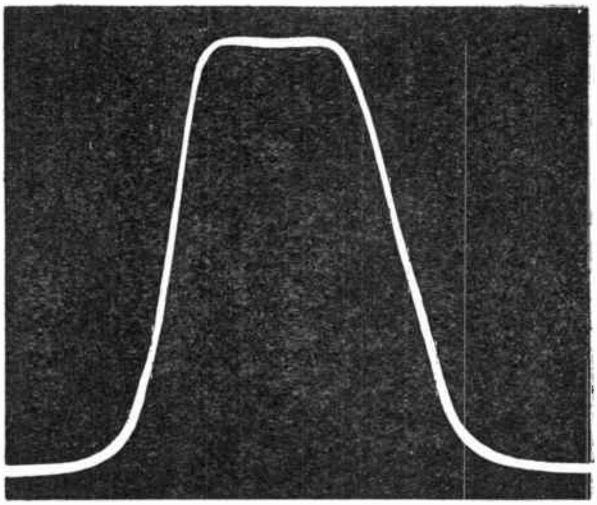


Fig. 130.—The combined high- and intermediate-frequency response-curve of a modern superheterodyne.

Second-channel Selectivity.—It will be remembered that two beat notes are produced, being the sum of and the difference between the oscillator and signal frequency. Using once again 1,000 kcs. per second for the wanted station, and 1,465 kcs. per second for the oscillator, it will be possible to explore the possibilities of second-channel interference. As an introduction, suppose that there is a station working on 1,928 kcs. per second, and that the aerial tuning is so flat that it permits a measurable potential to be developed across the grid-cathode circuit of the frequency changer. It will be remembered that the difference between a signal frequency and the oscillator frequency will produce a beat note. The difference between 1,928 and 1,465 is 463 kcs. per second; thus we have a beat note appearing having a frequency of 463 kcs. per second, which will appear as an interfering frequency to the 465 intermediate frequency, and give rise to a whistle, the frequency of which will once again be the difference, or 2,000 cycles per second.

A tuned circuit must necessarily be extremely inefficient to permit a transmission on a frequency of 1,928 kcs. per second to interfere with the station working at a frequency of 1,000 kcs. per second, but a very different state of affairs exists if a lower intermediate frequency is used. For example, if 128 kcs. per second is chosen for the intermediate frequency, it is apparent that similar interference will arise from a station working on a frequency of 1,591 kcs. per second when the receiver is tuned to a station working on a frequency of 1,000 kcs. per second, and it is well within the bounds of possibility for such interference to be caused when using a single tuned circuit in the aerial coupling. It will be remembered that the selectivity of a single tuned circuit is very low, and is made even lower by the damping imposed by the aerial system, since it is quite impracticable to use any form of reaction to off-set this damping.

It is apparent from the above two examples that the selectivity of the aerial coupling, or, if a stage of high-frequency amplification is used, the selectivity of the stage, must be capable of adequately eliminating those frequencies which can give rise to second-channel interference. It is equally apparent that a relatively high intermediate frequency calls for less selectivity in the aerial coupling. For this reason 465 kcs. per second has become almost standard in this country; the advantage of a lower intermediate frequency is the ability to produce higher stage gain per valve in the intermediate-frequency amplifier, but this advantage is off-set by the necessity for high selectivity in the aerial coupling. The position can perhaps be summarised by saying that a minimum of two tuned circuits is necessary in front of the frequency changer when the intermediate frequency is about 128 kcs., while one tuned circuit can be made to suffice if the intermediate frequency is about 465 kcs. per second.

The possibility of using some frequency between 128 and 465 kcs. may perhaps have occurred to the reader, but such a choice is impracticable, since these frequencies are those associated with the long wavebands, and difficulty will arise due to the grid circuit of the frequency changer being tuned to a frequency close to the intermediate frequency, and under this condition the valve is liable to oscillate. In addition, there is danger of the intermediate-frequency wiring picking up interference direct from a powerful long-wave broadcasting station. Another disadvantage of using intermediate frequencies between 128 and 465 kcs. per second will manifest itself in a comparatively large number of whistles arising from oscillator harmonics beating with various powerful broadcasting stations. Second-channel interference is sometimes called image interference.

Sideband Splash.—When using a superheterodyne receiver having a reasonably good audio response-curve adjacent-channel interference may appear in the form of strange noises intermittently accompanying the required programme. These noises often resemble the sound that might be expected when hearing a strange language by way of a very crude telephone. This interference is usually termed sideband splash, though the Americans refer to it rather aptly as " monkey chatter." It is caused by the high audio-frequencies of the station working on the adjacent channel encroaching on the band width passed by the intermediate-frequency amplifier. It will be realised that this phenomenon is difficult to avoid when the adjacent-channel signal is received at a strength comparable with the wanted signal, when it is remembered that the majority of stations are spaced from their neighbours by 9 kcs. per second, and are modulated to about 7 kcs. each side of the fundamental frequency, giving a definite overlap between those frequencies above

4·5 kcs. per second (4,500 cycles per second)—an audio-frequency that is just above the top note of the piano and comfortably within the harmonic range required for the true reproduction of music.

Variable Selectivity.—It has been implied that sideband splash will be apparent if the intermediate-frequency amplifier has a band width that is sufficient to allow a reasonably good quality of reproduction ; it is necessary that such high selectivity be employed if it is desired to receive those stations that have powerful stations working on adjacent channels. On the other hand, it seems unreasonable to spoil the quality of reproduction on all stations in the interests of receiving a few, free from sideband splash. Unless a compromise is to be effected, it is apparent that the band width of the intermediate-frequency amplifier must be varied at will by some suitable control. Variable selectivity in the intermediate-frequency amplifier is often referred to as variable band width or variable band spread, and can be accomplished in a number of ways; the simplest method is to make provision for varying the coupling between the coils comprising the first intermediate-frequency transformer. This method has the advantage of simplicity from the mechanical point of view, but is difficult to accomplish successfully from the electrical point of view, since variation of coupling will inevitably cause a variation in the resonance frequency of the circuit so that adjustment of band width is accompanied by mis-tuning. With care, however, such arrangements can be used without the mis-tuning becoming objectionable, providing such mis-tuning occurs when the band width is broadened, and not when it is narrowed.

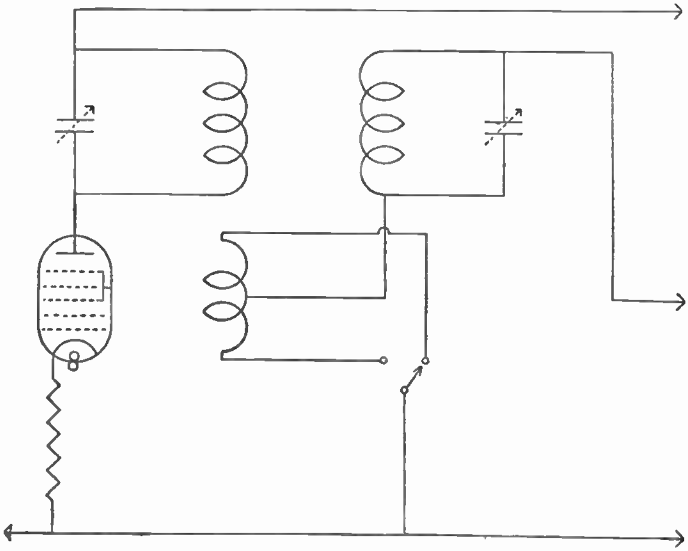


Fig. 131.—A method of obtaining two band widths.

An alternative method of obtaining variable selectivity is shown at Fig. 131, which is an arrangement permitting two alternative band widths to be obtained by means of a switch ; the primary and secondary coils are coupled to an extent that will give a band width equal to the average band width of the alternatives. In addition, extra coupling is provided by means of a *small* coil in series with the secondary and *closely* coupled with the primary. By means of the selectivity switch the small coil may be made to increase or diminish the coupling, thus giving the choice of band width; by suitably proportioning and spacing the small coil and the primary coil very little mis-tuning is introduced.

Before leaving the question of variable band-width control some mention may be made of the simplest possible form, which entails the use of a variable resistance across the primary or secondary. While this arrangement certainly gives variation of selectivity, it cannot be recommended, since it affects the gain to an intolerable extent, and also introduces considerable mis-tuning.

Ganging the Oscillator.—Every modern commercially built superheterodyne receiver is tuned by rotation of a single knob, and it is necessary, therefore, to find means of keeping the oscillator circuit spaced from the signal circuit by the intermediate frequency; it has already been mentioned that the oscillator may be less than, or in excess of, the signal frequency by an amount equal to the intermediate frequency, and that the latter alternative is invariably chosen. Another reason for this is apparent when the alternatives are considered. Assume that the receiver is required to tune from 200—550 metres (1,500 to 545 kcs. per second). If the intermediate frequency is 465 kcs. per second, then the oscillator circuit must tune from 1,965—1,010 kcs. per second, which is a ratio of 1·9 : 1 approximately. If the oscillator frequency is to be less than the signal frequency the ratio is approximately 30 : 1, which is impossible, since it will be recalled from an earlier chapter that careful design is required to enable a tuned circuit to have a maximum to minimum frequency ratio of 3 : 1. If a lower intermediate frequency is used, the difference in ratio between the alternative oscillator frequencies is somewhat diminished, but the difference is nevertheless somewhat formidable.

When a figure is decided upon for the intermediate frequency, means must be found for ensuring that the oscillator circuit will differ in frequency by this amount from the signal-frequency circuit, which is not as simple as might be supposed, since no relationship of inductance or maximum condenser capacity will keep these circuits at their correct relationship over the signal-frequency bands to be covered. One method of accomplishing the required relationship is to utilise a special oscillator condenser, the vanes of which are so shaped that the required change of capacity is obtained at any setting of the condenser. This method is entirely satisfactory and is in general use, but unfortunately it can only hold good for any one waveband, since a change of the associated inductance necessitates a change in shape of the condenser vanes, and recourse must be made to the system of padding for the second and subsequent wavebands used; in order to avoid serious complications the vanes are shaped to give the necessary effect when working on the highest frequency band incorporated in the receiver, and the lower frequency band or bands are corrected by means of padding.

It will be convenient to deal first of all with circuits that do not use a specially shaped condenser and use, therefore, padding on all wavebands

A moment's reflection will show that the use of fixed capacity can be made to correct the frequency at minimum and maximum, that is to say, a fixed condenser in parallel with the variable condenser can correct the minimum capacity of the circuit, or, alternatively, a fixed condenser can be placed in series with either the variable condenser or the coil to correct the maximum capacity. These alternatives, however, will result in deviation from the desired frequency at the middle of the scale; recourse is made, therefore, to a carefully chosen combination of the two, which results in the relationship between the signal and oscillator circuits being very satisfactorily maintained over each waveband. In practice, the fixed series condenser is invariably placed in series with the coil, since a different value will be required for each of the frequency bands covered by the receiver, and the requisite condenser can be brought into circuit without any additional complication to switching. The relationship between the signal and oscillator circuits is called tracking; the series condenser above referred to is called the padding condenser and is usually, although not necessarily, of the pre-set type, to permit of adjustment when the receiver is manufactured; the small parallel capacity above referred to is called the trimming condenser, and is invariably of the pre-set type, for similar reasons.

The correct values of padding and trimming condensers and the inductance with which they should be associated are left to a later chapter, since these can be more readily discussed when a complete superheterodyne receiver circuit is considered in detail. When the oscillator and signal-frequency condensers have similarly shaped vanes, padding and trimming condensers will normally be used on all wavebands. When a shaped vane condenser is used to correct the highest frequency band in use, the auxiliary pre-set condensers will be required on the other band, or bands, and their capacity will necessarily require some modification.

The Intermediate-frequency Amplifier.—The superheterodyne receiver need not necessarily include an intermediate-frequency amplifier, in fact there are a number of commercially built receivers which are so designed. The superheterodyne principle is used solely to obtain additional selectivity, no extra amplification being sought. In such arrangements the detector is usually provided with reaction as a means of obtaining sufficient sensitivity for normal purposes. When it is required to design a receiver having a high degree of selectivity, and employing only three valves, this arrangement has much to commend it, and its performance may be considered entirely satisfactory as long as it is visualised as a highly selective three-valve set rather than as a superheterodyne; such a circuit is described in detail in a later chapter.

The intermediate-frequency amplifier usually employs a single valve, although two are sometimes used in battery receivers, owing to the lower mutual conductance of battery valves; there are examples of mains receivers using two, or even three stages of intermediate-frequency amplification, but these are rare. Fig. 132 shows the circuit of a typical intermediate-frequency amplifier from the anode of the frequency-changing valve to the anode of the detector. It will be observed that four tuned circuits are introduced, and consequently a high degree of selectivity may be expected. The response-curve of such an amplifier may be seen from the illustration at Fig. 134, which is an oscillograph taken from a commercial superheterodyne receiver using an indirectly heated mains valve of the screened-pentode type and bandpass intermediate-frequency transformers over-coupled to give the desired response-curve. It should be understood that Fig. 134 shows the response-curve of the intermediate-frequency amplifier only. Fig. 130 shows the response-curve of the same receiver from the aerial coupling to the detector, and includes, therefore,

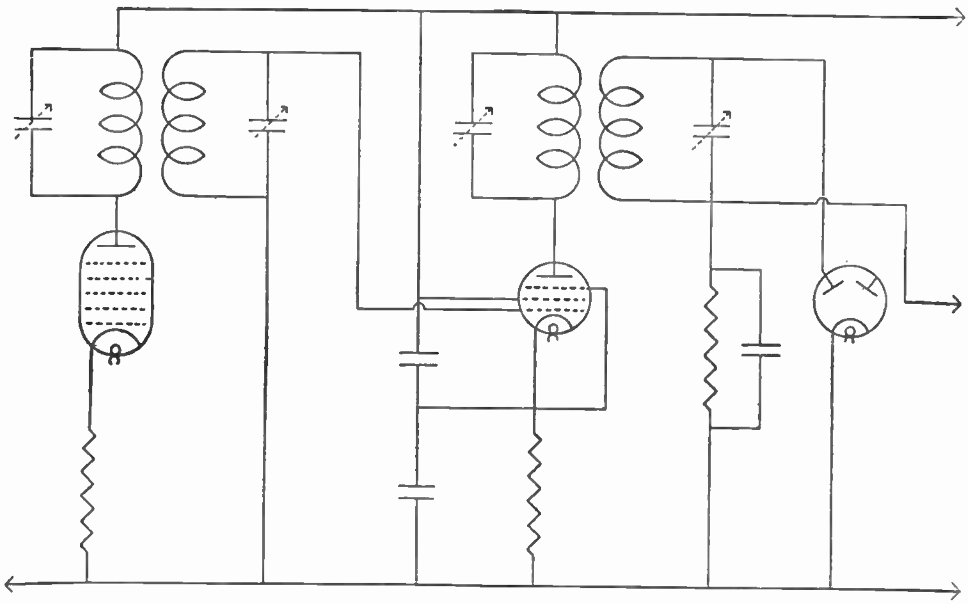
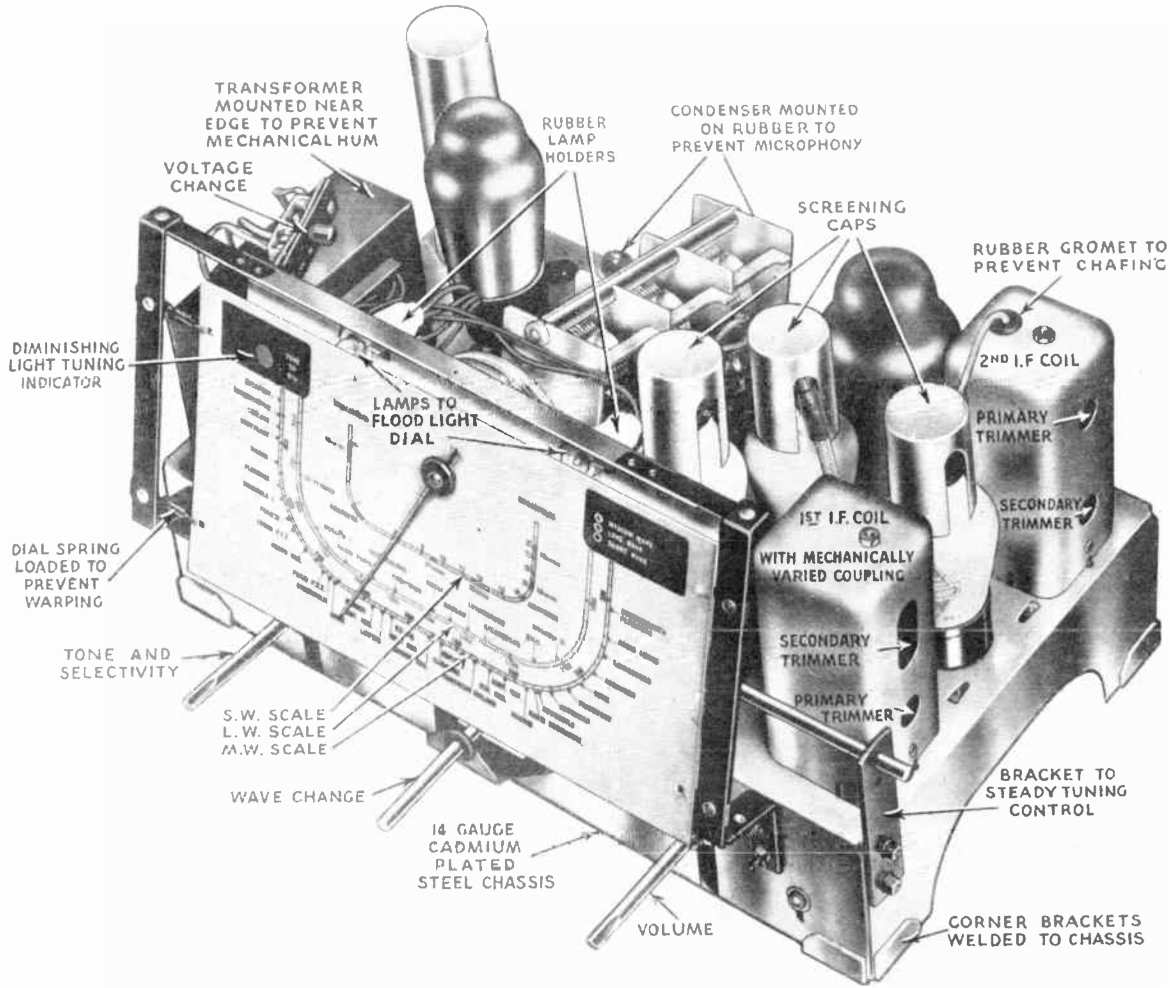


Fig. 132.—A complete circuit of an intermediate-frequency amplifier. The dotted arrows indicate that the associated condensers are of the variable pre-set type. The resistance shown on the right forms the diode load.

the selectivity of the aerial coupling, which is also of the bandpass type. When recording Fig. 130 the receiver was deliberately tuned to a point where the response-curve of the aerial circuit left something to be desired, and it is intended to illustrate that in practice it is virtually impossible to preserve the ganging of variably tuned circuits so that the response-curve is constant at all frequencies.

Fig. 133 was obtained by incorrectly adjusting the trimming condensers across the intermediate-frequency transformers. Actually, the two primaries were correctly tuned, but the secondaries were sufficiently off tune to render completely absent the bandpass characteristics that are apparent in Fig. 134. It should be understood that in this condition the sensitivity of the receiver remained normal, and quality alone suffered.



A SUPERHETERODYNE CHASSIS

The chief details of this Cossor chassis are clearly seen in this illustration, which reveals a number of interesting design points of both electrical and mechanical significance.

Fig. 135 shows the condition where the secondaries were slightly off tune and have produced a second hump, but of insufficient amplitude to cause

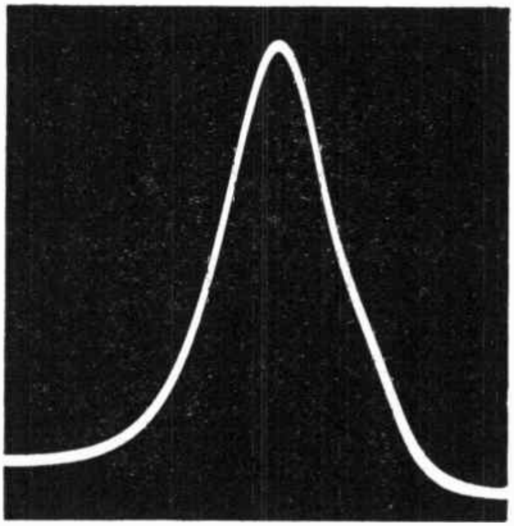


Fig. 133.—The response-curve of an over-coupled bandpass intermediate-frequency transformer. To obtain this illustration the secondaries were so badly mis-tuned that the bandpass characteristics have been lost.

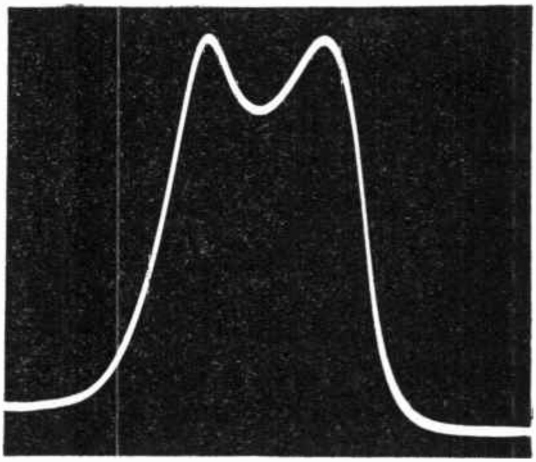


Fig. 134.—The intermediate-frequency response-curve using two tuned intermediate-frequency transformers slightly over-coupled.

the merging of the two humps to produce the desired shape of response-curve. Examination of Fig. 134 will show that the top of the curve dips somewhat in the middle, which indicates that the coils are over-coupled, resulting in accentuation of the higher frequencies and some attenuation of the middle and low frequencies.

When coils are so coupled that the characteristic bandpass dip is barely apparent, the coils are said to be critically coupled. Coupling that is less than critical coupling will result in the response-curve taking the form of a single peak; this condition is illustrated at Fig. 133.

It is sometimes convenient to couple deliberately the

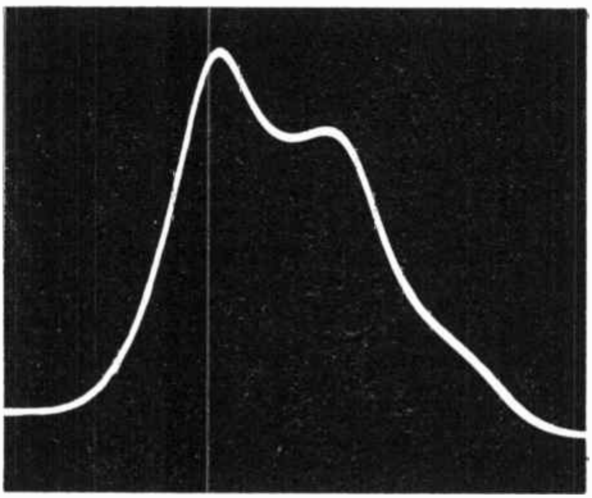


Fig. 135.—A response-curve taken from the same intermediate-frequency amplifier as that used for taking Fig. 134, but with the secondary of the first transformer slightly mis-tuned.

intermediate-frequency transformers tighter than critical coupling with a view to accentuating the higher audio-frequencies; this allows the aerial coupling to be sharply tuned, and the frequency characteristics of the one can be made to compensate for the frequency characteristics of the other, so that the total response-curve of the receiver is not intolerable. As an alternative arrangement, it is possible to introduce deliberately three entirely different response-curves for the aerial and the two intermediate-frequency transformers. The usual procedure adopted utilises sharply tuned aerial and first intermediate-frequency coils to obtain the maximum possible selectivity in the earlier stages, and to correct the audio-frequency response of the complete receiver by using a very much over-coupled transformer in the second position. This arrangement is employed partly with a view to giving special characteristics to the primary circuit of the second intermediate-frequency transformer in order to provide means of avoiding the unpleasant sound that may arise when a superheterodyne is being tuned from one station to the next, since this arrangement entails a special automatic volume-control circuit. Further reference will be made when this principle is dealt with in Chapter 27.

The tuned transformer has been referred to exclusively as the means of coupling the intermediate-frequency amplifier; transformer coupling has everything to commend it, but it is nevertheless possible to employ tuned anode coupling, and, in fact, this alternative is often adopted for receivers designed to operate only on the short wavebands. All things being equal, the tuned anode coupling will give greater stage gain but impaired quality of reproduction, a compromise that is sometimes preferred on the grounds that good quality is unobtainable on the short waves, and that no useful purpose is served by sacrificing gain in order to achieve the impossible. Such philosophy is to be greatly deprecated, since quite good quality can be obtained on these wavebands, and, in fact, many commercial receivers are capable of giving very excellent reproduction from short-wave broadcasting stations. Admittedly reception of far-distant stations is often rendered horrible by atmospherics, but it seems unreasonable to permit the reception of these distant stations to dominate the design of the receiver when excellent entertainment is available on these wavebands from many Continental transmitters.

It is obviously impossible to design a single-tuned anode coupling to have bandpass characteristics, particularly when high magnification will be required in the interests of sensitivity. It is, however, possible to design the amplifier as a whole so that it has a response-curve which approaches that illustrated at Fig. 134. This feat is accomplished by tuning the first and second intermediate-frequency tuned anode coils to slightly different frequencies, usually 463 and 467 kcs. per second, respectively, or 126 and 130 kcs. per second, respectively, according to the intermediate frequency used. This arrangement gives an intermediate-frequency response-curve of the double-hump type, which, when associated with a sharply tuned aerial coupling, gives quite tolerable quality of reproduction.

It is well within the bounds of possibility to use staggered intermediate frequencies for transformer coupling, the principle involved being exactly the same as that outlined above for tuned anode coupling, the only difference being that the tuned anode coils are replaced by tuned transformers, which are designed or adjusted so that their response-curves approximate to the shape shown at Fig. 134. No useful purpose is served, however, other than some small increase in gain and a trifling reduction in cost, since the manufacturing tolerances permitted for coil inductance are not so stringent as those necessary for coils intended for bandpass coupling.

Certain American receivers use intermediate-frequency transformers comprising three tuned circuits; there is at least one example of this arrangement to be found amongst receivers of British manufacture. However, it is not likely to become a general favourite in this country, since it is a means of obtaining a little extra selectivity at the expense of a relatively large reduction of quality. Although the broadcasting band is terribly congested from the point of view of reception in this country, it is not as bad as the state of affairs obtaining in America, consequently the more normal intermediate-frequency transformer employing two tuned circuits may be designed to give adequate selectivity for reception in this country.

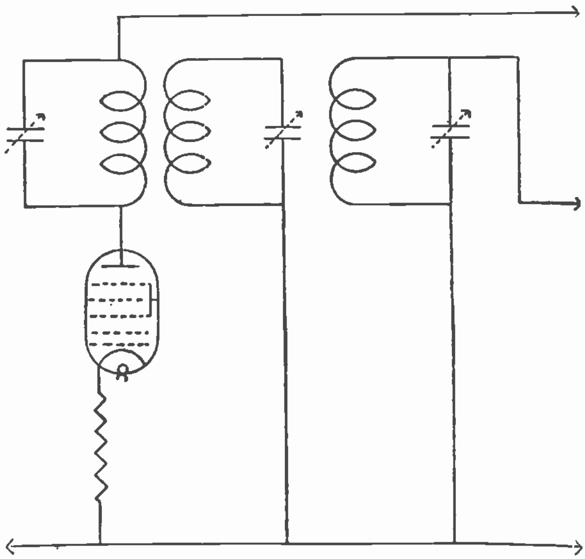


Fig. 136.—A triple-tuned circuit intermediate-frequency coupling.

A short description of the triple-tuned intermediate-frequency transformer is given below, partly for the sake of completeness, and partly because it is finding favour in this country for use in receivers designed for commercial and other radio-telephony. The circuit is given at Fig. 136, from which it may be seen that the arrangement is quite normal, with the exception that an additional tuned circuit is included, which, it will be observed, has no metallic connection with the receiver, except that one side is earthed to give a measure of stability. From the purely theoretical standpoint this connection may be omitted.

The functioning of the triple-tuned intermediate-frequency transformer is dependent upon its construction. The three coils are arranged on a common former with the extra coil in the middle, and are so spaced that the direct coupling existing between the primary and secondary is fairly small, the major portion of the coupling being due to the mutual coupling existing between the primary and secondary with the middle coil. It will be remembered that damping of the secondary of a transformer is transferred to the primary, and vice versa, to an extent dependent on ratio and coupling; the presence of the middle coil reduces this transference of damping, which, together with the inherent selective properties of the third tuned circuit, brings about a marked increase of selectivity.

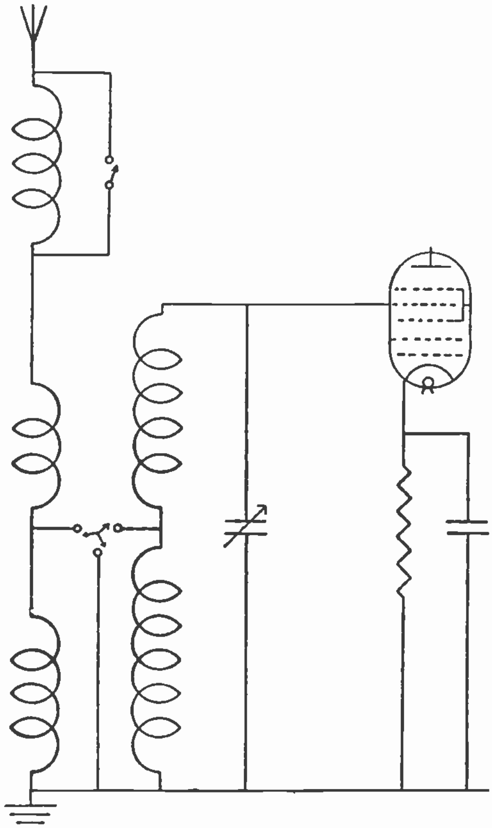


Fig. 137.—Input coupling using a choke in the aerial lead to suppress whistles on the long waveband.

Whistle Suppression.—Whistles often appear on the long waveband of a superheterodyne receiver, due to stations on the medium waveband which are not effectively rejected by the aerial coupling, owing to certain of the former being harmonics of certain frequencies on the long waveband. This phenomenon appears as a whistle interfering with the reception of a long-wave station, due to interference from a medium-wave station in the manner described. To overcome this trouble the arrangement shown at Fig. 137 is often used. It consists of a small high-frequency choke in the aerial lead, which is designed so that it offers as little impedance as possible to frequencies on the long waveband, but as much impedance as possible to frequencies on the medium waveband. It is, of course, necessary to arrange for this choke to be short-circuited, or in other ways put out of circuit when receiving medium waves. This device is unnecessary when using bandpass coupling, or when using a stage of high-frequency amplification in front of the frequency changer, but its incorporation is desirable when only one tuned circuit precedes the frequency changer.

Signal to Noise Ratio.—The reception of distant stations must unavoidably be accompanied by at least some background noise, which can be conveniently classed under two headings: noise picked up by the aerial, and valve hiss. It will be convenient to deal with the former first. The amount of noise picked up by the aerial cannot be considered in terms of the actual voltage developed across the aerial coil from this source, since the actual amount of noise which will appear as a background to the programme received must necessarily be considered in terms of its volume relative to the required programme. It is thus usual to refer to the signal to noise ratio, which is the relative amplitude of the one to the other. It might be thought that the signal to noise ratio would invariably be the actual ratio of energy picked up by the aerial. This is not so, as noise will be generated by the receiver itself, and by the frequency-changer valve in particular which introduces more noise for a given stage gain than any other valve. Bearing this in mind it will not be surprising that improvement can be effected by introducing a stage of ordinary tuned high-frequency amplification in front of the frequency changer, and thereby reducing the intermediate frequency amplifier gain necessary for a given overall stage gain. The introduction of the high-frequency amplifier will have other beneficial effects, notably the elimination of second-channel interference.

Valve Hiss.—Valve hiss, which is sometimes called valve noise, is due to a phenomenon known as the Schrot effect, which may be described as the inherent property of a filament or cathode to give small instantaneous variations of emission which cannot be controlled by any outside influence. The noise caused by this effect tends to be constant irrespective of the amplitude of the received signal and, furthermore, the noise introduced in the frequency changer is more marked than in any other portion of the circuit. When the frequency-changing valve is the first valve in the receiver, the ratio between the incoming signal and valve hiss will tend to be unfavourable, and this ratio will be preserved after they have both been duly amplified by the various following stages. If a stage of high-frequency amplification precedes the frequency changer, it follows that the signal delivered to the frequency changer will be proportionately larger, and amplification following the frequency changer proportionately smaller, and a corresponding gain in signal to noise ratio is thereby obtained. Admittedly the high-frequency amplifier will add its quota of noise, but this will be less than that of a frequency changer, with the result that the improvement is still maintained, and, as already intimated, a gain in selectivity is achieved.

Background noise will appear as a combination of noise picked up by the aerial and valve hiss, and in the interests of the over-all reduction of this unwanted noise it is desirable that the first valve should give maximum amplification, and that the subsequent valves should give the gain required to raise the signal to the required volume-level. This suggests that the first valve should work at the maximum gain and that the remaining predetector valves should be provided with volume control. Unfortunately this is impracticable on the medium and long wavebands, as many stations would be received at strength sufficient to overload the first valve when working under conditions appropriate for maximum gain. It is, however, possible to permit the first valve to function at maximum gain on the short waveband, where it is unusual to receive signals capable of overloading a high-frequency pentode valve in the first stage. A compromise is usually effected by applying volume control to all pre-detector valves on medium and long waves, but so arranging the waveband switching that volume control is omitted on the first valve when receiving short waves.

CHAPTER 19

PRACTICAL COIL DESIGN

ANY casual observer who has had occasion to notice the coils used in modern radio receivers may have quite reasonably formed the opinion that there are no rules governing their construction and that their shape is determined by spinning a coin or by mere personal preference. Actually, coil design is probably the most exacting section of a modern receiver. The almost bewildering variation in outward form is due partly to the diverse purposes which coils are employed to fulfil, and also because there are sometimes alternative ways of performing a task equally well.

Mechanical Consideration.—In the majority of cases a coil will form part of a tuned circuit, and consequently it must fulfil certain rigid mechanical requirements in order that its inductance will not change during its period of service due to such a cause as vibration. The first consideration is rigidity, which means that every turn of wire must be held in such a manner that movement is impossible. The obvious method to this end is the complete immersion of the coil in some adhesive material, but such a procedure is rightly frowned upon, since it will increase the losses inherent in the coil by increasing the capacity between the turns; it will be recalled from earlier chapters that the presence of insulating material between conductors increases the capacity to a greater or lesser extent. Rigidity is usually obtained by using coils that are inherently strong. A number of examples are detailed below.

Coils which form part of a tuned circuit must be protected from the effects of humidity and dampness, since moisture permeating the insulated covering will cause leakage in addition to other dangers, such as corrosion. The coil is invariably supported on some former which is usually of the laminated paper type, made in the form of a tube, and protected against damp by means of varnish or wax. These substances often contain chemicals which are capable of doing serious damage if they become dissolved in moisture lying on the wire due to atmospheric conditions. The chemical may be harmless in itself, but when a minute electric current is passed through it electrolysis takes place, which is capable of eating through fine copper wire, even though it may take a term of months to reach the point where the wire becomes electrically severed. A few years ago the great bugbear of transformer and coil manufacturers was free chemical impurities in insulating material. Research has done much to minimise this danger, and materials are available from reputable manufacturers which may be classed as entirely safe. Nevertheless, when opening up a defective coil for the purpose of examination, it is found all too frequently that the broken wire is accompanied by a tiny speck of green, showing that the cause of failure may be attributed to chemical causes, due, not necessarily to unsuitable insulating material, but possibly to a minute splash of soldering flux or any foreign matter with which the wire may have come into contact.

The actual wire used for coil winding may be covered with enamel, silk, cotton, or any two of these substances. Enamelled wire has the great advantage that it offers protection from corrosion, but has the disadvantage that it is thin, resulting in turns being spaced too close together, a difficulty that is aggravated by the comparatively high dielectric constant of enamel. When expense does not prohibit its use, silk-covered wire has much to commend it, either one or two layers being used, spun in opposite directions. Cotton-covered wire has the advantage of cheapness, but the unavoidable thickness of the covering takes the wire to the other extreme and makes the coil bulky, and by preventing the turns from being sufficiently near to each other may result in loss of efficiency; from these apparently contradictory remarks the reader will have gathered that there is an optimum spacing between turns which must be observed when designing highly efficient coils. A compromise is sometimes effected by combining silk and enamel, the wire being coated first of all with enamel, which is in turn covered with a layer of silk. Single and double cotton-covered wire is known as S.C.C. and D.C.C. wire respectively, while single and double silk-covered wire are abbreviated as S.S.C. and D.S.C. respectively.

Litzendraht Wire.—The actual wire used for coils is made from high-conductivity copper or, in plain English, soft copper having an adequate degree of purity, since in this condition the metal has the lowest possible resistance per unit area. It should be noted, however, that the resistance offered by a wire is greater to high-frequency currents than to direct currents, due to the phenomenon called skin effect. This effect may be readily understood when it is remembered that current flowing through a wire produces lines of magnetic force in and around the wire in the form of concentric circles. These circles are denser in the centre and offer greater reactance to the passage of high-frequency current, resulting in the current density in the wire being at a maximum on the outside. When the wire forms in fact a coil, skin effect becomes more apparent, since each turn produces lines of force in all other turns; this alone shows that the spacing and shape of a coil have a marked influence on high-frequency resistance.

The skin effect may be reduced by the use of stranded wire, providing the strands are insulated from each other, and that they are twisted in order that each strand shall pass through each part of the magnetic field encircling it, and consequently carrying the same current. Such wire is termed Litzendraht, which is invariably called Litz. This wire may comprise any number of strands of any gauge wire, the following being

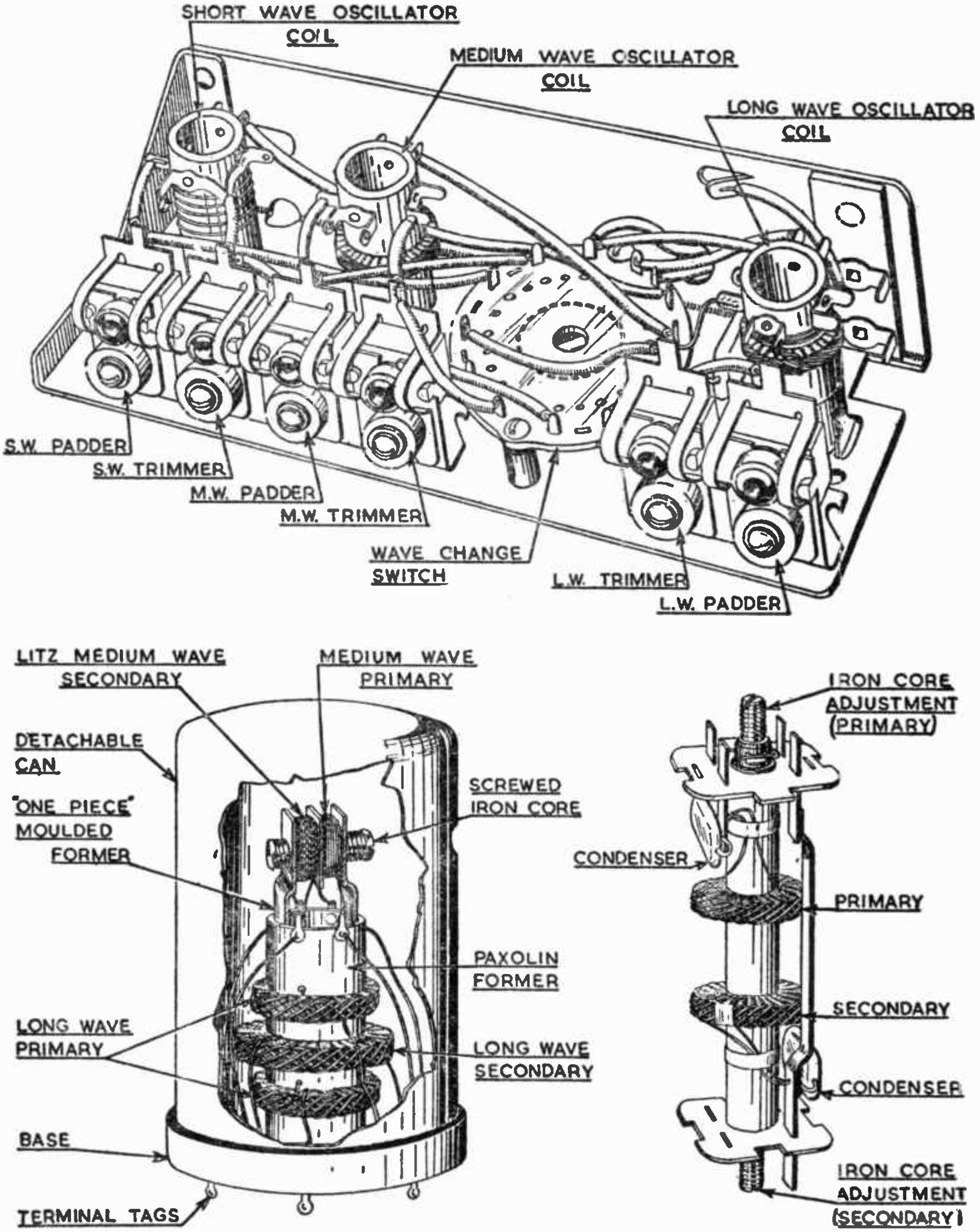


FIG. 138.—Typical coil assemblies. (Top) A compact oscillator coil unit. (Bottom, left) An older type 2 waveband H.F. transformer. (Bottom right) Modern I.F. transformer with screening can removed.

examples in general use, the first figure denoting the number of strands and the second figure the gauge of wire expressed in standard wire gauge: 9/45, 27/48, 30/47, etc.

When using Litz wire the greatest care is required to strip the numerous fine strands and subsequently to ensure that each makes good connection, since discontinuity in a single strand will often increase the high-frequency resistance by several hundred times.

Single-layer Coils.—The accompanying full-page plate shows a variety of coils, the type and purpose of which can be readily seen by studying the caption. For convenience, however, individual examples are illustrated and attention is directed to Fig. 139, which shows a typical example of a single-layer coil which is sometimes termed a solenoid, though the term is strictly applicable to a coil having more than one layer. This type of coil probably represents, in principle, the earliest conception of a coil intended for tuning a radio receiver. It is nevertheless in use to-day since, when properly proportioned, it represents a highly efficient arrangement for coils comprising a limited number of turns, permitting relatively wide spacing with consequent reduction of self-capacity.

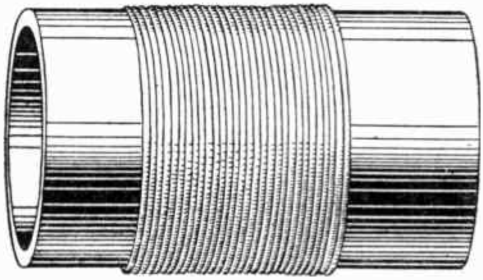


Fig. 139.—A typical single-layer coil.

Self-capacity.—A coil must unavoidably possess self-capacity, since there is insulating material, even although it may be only air, between turns which have a potential difference relative to each other. This condenser effect will be made up by capacity between turns which are adjacent to each other, capacity between all turns with all other turns, and capacity between the coil as a whole and earth, which in general will normally be the chassis, screen, or other metal object, and not the earth connection. This self-capacity has the usual property of storing energy which increases the high-frequency resistance of the coil and reduces its efficiency. It will be remembered from remarks made in the chapter devoted to the tuned circuit, that low high-frequency resistance is synonymous with efficiency.

Coil design may be summarised as an effort to reduce self-capacity, high-frequency resistance, and dielectric loss, in addition to which may be added the mechanical considerations which have been briefly outlined above. Further means towards the achievement of this end are described below.

The Wave-wound Coil.—Fig. 140 shows a typical example of a wave-wound coil which in principle resembles the so-called honeycomb coil which was familiar some ten years ago, though the modern version has less abrupt changes of direction of the winding than its predecessor. Some idea of the formation of these coils may be obtained from the illustration, though the following description may be helpful to those who have not actually had the opportunity of seeing one. A wave-wound coil is made by rotating a cylindrical former and feeding the wire over a finger which moves from side to side for a short distance in a manner determined by the action of a cam. In this way the wire is laid on in a wave formation, the actual length of each "wave" being determined in such a manner that second and subsequent layers are not formed immediately over the layer beneath. Wave-wound coils owe their efficiency to the fact that the maximum air spacing is obtained between adjacent turns, thus keeping the self-capacity to a minimum. Owing to the distribution of the magnetic field, it is necessary to use a slightly longer length of wire than would be the case if the turns were laid side by side, but the increase in high-frequency resistance brought about in this manner is considerably less than the reduction brought about by the decrease of self-capacity. The wave-wound coil is usually chosen for coils of relatively high inductance, since it offers the means of obtaining high efficiency with economy of space. This type of coil may also be chosen where tight coupling is required; the very shape of the coil gives opportunities for tight coupling, since when two are placed close together the remotest turns are necessarily comparatively close.

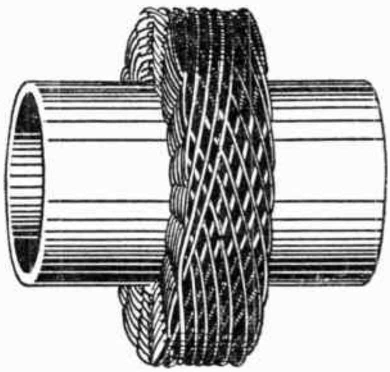


Fig. 140.—A wave-wound coil.

A wave-wound coil is surprisingly strong and, although unsupported, shows no tendency to fall apart or become unwound; it is nevertheless necessary to cover it lightly with some suitable varnish, usually of the amyl-acetate celluloid type although, when great consistency of inductance is required, the coil is sometimes completely immersed in paraffin wax. Such a coil is illustrated in the accompanying plate (extreme left, front row).

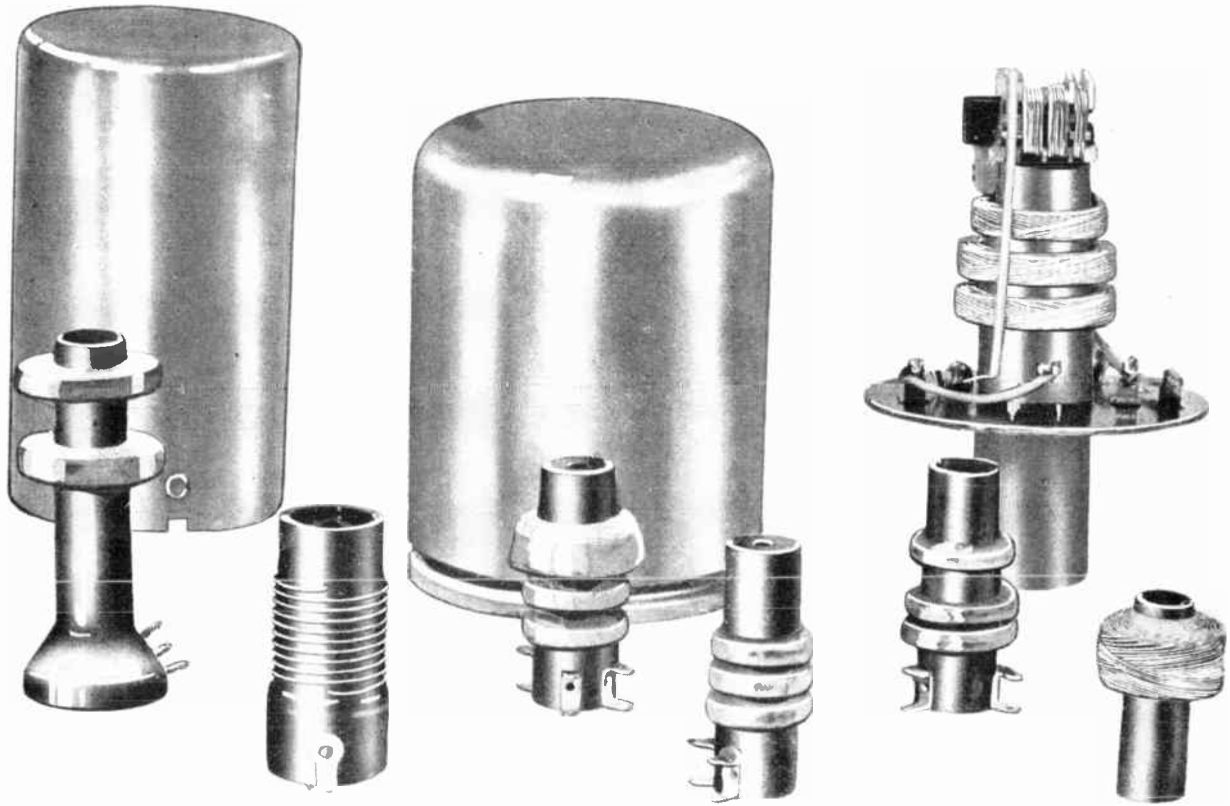
Iron-cored Coils.—It has been realised for many years that coils of extremely high dynamic resistance could be made with the assistance of some form of magnetic core; the presence of such core would result in a given inductance being obtained with a greatly reduced length of wire, but until comparatively recently the necessary material was lacking, since the thinnest iron sheet would give rise to excessive eddy currents at the high frequencies. The problem has been solved by the introduction of dust-iron cores. The manufacture of these cores calls for iron in the form of an extremely fine powder, so fine, in fact, that it cannot be obtained by mechanical means, but is made by depositing iron chemically in the form of an exceedingly fine precipitate. The finely powdered iron is mixed with a suitable insulating and non-magnetic substance so that each particle of powder is separated from its neighbour. For this purpose mica dust is commonly employed, and bound by "cement" or the iron dust may be compounded with a ceramic; the former are moulded under considerable pressure in order to impart the necessary mechanical strength, and also to obtain a degree of uniformity between them.

The most common type of iron core is a round section, moulded with a thread permitting it to be screwed in and out of the coil for the purpose of adjusting its inductance; another type takes the form of a section of square rod about an inch and a half long and a quarter of an inch thick. Owing to the concentrated magnetic field that will surround the core it is almost imperative that the coil should be made of Litz wire, otherwise the skin effect is so high that it is better to dispense with the core and use a normal coil. By good design it is possible to manufacture an iron-cored coil having an inductance of, say, 160μH with a dynamic resistance of 200,000 to 250,000 ohms, even though the whole coil need only be about one and a half inches long and one inch in diameter.

Permeability Tuning.—It has already been mentioned that the inductance of iron-cored coils may be varied by the position of the core. The practice of deliberately tuning by sliding or screwing the core in and out is called permeability tuning. When the core is withdrawn, the frequency will be the maximum for the particular value of inductance, the frequency being decreased as the core is moved farther towards the centre. Unfortunately the rate of change of frequency is not constant, the effect of the core being very rapid when it is just entering the field of the coil, but having little effect when it is approaching the central position. Due to this uneven rate of change permeability tuning has never achieved popularity except in tuning selectors having fixed positions such as television. It is, however, quite satisfactory for pre-set circuits such as intermediate frequency transformers, since values can be so arranged that resonance will occur at a point where the rate of change of inductance is convenient for accurate and easy manipulation. For this purpose the screwed iron core is to be preferred duly provided with a wide slot permitting rotation to be effected by means of a non-metallic screwdriver.

Permeability tuning has the advantage of being very free from variation due to temperature, providing that the material from which the core is made is chosen to avoid expansion and contraction. Because permeability tuning is used it does not follow that capacity can be dispensed with, for two reasons. Firstly, the correct value of capacity is necessary to produce the right shape response-curve, and secondly, some parallel capacity is desirable which should preferably be large compared to the self-capacity, in order that small variations of the latter due to temperature changes shall not bring about an appreciable change in the resonance frequency.

It is obvious that the stable nature of permeability tuning will be lost if the shunt capacity is liable to variation; it is, therefore, necessary to use fixed condensers of a type that will not suffer from capacity drift. Such a condenser is known as the anodically sprayed type; it consists of



TYPICAL EXAMPLES OF TUNING COILS AND SCREENING CANS.

Back row (*left to right*) : coil can, coil can, two-band H.F. transformer with reaction. Middle row (*left to right*) : two-band anode coil, two-band oscillator coil, two-band aerial coil. Front row (*left to right*) : short-wave aerial coil, iron-cored R.F. transformer, filter coil.

a sheet of specially selected mica with silver deposited on each side to form the plates; these condensers can be obtained accurate within very close limits, and are very free from the effects of changing temperature.

Coil Screening.—Attention has been drawn to the necessity for preventing coupling between the anode and grid circuit of a high- or intermediate-frequency amplifier; some means must therefore be found to prevent magnetic coupling between the coils. Certain receivers have separate metal-lined compartments enclosing each tuned circuit and relevant components, but such a method is cumbersome, and modern receivers use individually screened coils. The screened coil is contained in a metal can or box which may be of any convenient shape and of adequate dimensions to enclose the coil without the metal coming unduly close to the windings or the core, if one is employed. These screening cans, as they are usually called, should preferably be made of copper, but on the grounds of expense other metals are used, aluminium or iron being probably the most popular.

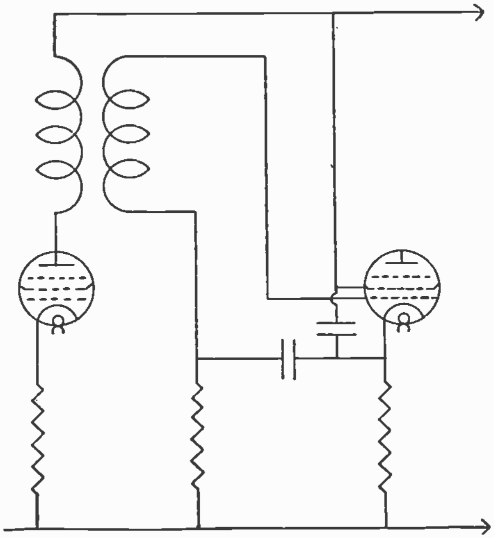


Fig. 141.—A circuit illustrating a point discussed in the text.

The efficiency of the coil is somewhat reduced by the relatively close proximity of the can, partly due to the effects of damping and partly due to the necessity for increasing the length of the wire used to compensate for the reduction of inductance caused by the proximity of the metal. It should be clearly understood that an unscreened coil is more efficient when regarded purely as an inductance than when it is enclosed in a can. It is, however, necessary so to enclose it to preserve stability if it is to be used as one of the tuned circuits associated with an amplifier.

Insulation.—From the purely high-frequency point of view, ordinary precautions will suffice for obtaining the necessary insulation between coils. There are, however, certain conditions where exceptionally high insulation is necessary. The illustration at Fig. 141 will serve as an example; assume that the anode voltage is 255 volts, and that the resistance connected between the secondary of the transformer and the earth line has a value of 2MΩ. Normally, insulation resistance between coils reaching the high value of 100MΩ would be considered quite satisfactory, in fact many service engineers would be unable to test such a high value owing to the lack of a suitable instrument. Consideration of the circuit (Fig. 141) will show that the resistance between the primary and secondary of the transformer forms with the 2MΩ resistance a potentiometer with the grid-cathode of the valve tapped across the 2MΩ portion. The application of Ohm's law will show that the high-tension voltage of 255 volts is so distributed that a positive voltage of about 5 volts is applied to the grid of the valve, which will cause it to function in a most improper manner, or cease to function altogether. In the interests of accuracy it must be mentioned that the voltage mentioned, namely 5 volts, will be modified by the flow of grid current to some considerable extent. This example serves to indicate the type of conditions that call for exceptional insulation between coils; other similar situations may be found in seemingly quite normal circuits. It is perhaps worthy of mention that the example illustrated is not an imaginary set of conditions chosen to explain the points under discussion, but is actually taken from a very popular receiver, the manufacturers of which took adequate precautions to secure the necessary high degree of insulation.

CHAPTER 20

SWITCHES AND SWITCHING

THE term switch covers such a variety that some sub-division seems desirable; but, unfortunately, no such classification exists, and some arbitrary division must necessarily be made in order to present this subject in a readable manner. The most simple form of switch may consist of a device that is little more than a paper clip, while other switches used in radio engineering are so elaborate that they present difficulty in describing them or illustrating them. The modern wafer switch, for example, is capable of being formed into an assembly for switching an almost unlimited number of series, each of which may consist of half a dozen alternative ways of switching half a dozen different circuits.

The Single-pole Switch.—The performance of a switch is designated by the terms " pole " and " way." The term " pole " is intended to mean an electrically isolated portion of the switch, while the term " way " indicates the number of alternative connections that may be made; thus an ordinary electric-lighting switch is described as single-pole, single-way, inasmuch as it will break one lead only and offers but one alternative—on and off. On the other hand, the type of electric-light switch which may be thrown into two different positions for controlling lighting on stairways is designated as single-pole, two-way, since it provides two alternative connections for a single lead.

The simple on-off switch, such as that used for switching on and off the battery receiver, is so well known that illustration is superfluous. Its requirements are merely that it shall make good contact when in the " on " position. On-off switches intended for controlling mains receivers are necessarily more complicated; since they must be capable of carrying a relatively high current when in the " on " position, and be so insulated that electric shock is impossible and, furthermore, the moving portion should preferably be so designed that some spring action hastens the making and breaking of the circuit, so that the contacts are not burned if the switch is operated in a leisurely manner. Switches used for this purpose show considerable variation in their external appearance, consequently no useful purpose will be served by including an illustration. It may, however, be mentioned that the two most popular types used by set manufacturers are, respectively, miniature rotary types and tumbler types; the latter term embraces those patterns which are operated by the movement of a small dolly which responds to the touch with a snap action; the conventional electric-light switch is an example.

Three-point Switches.—The three-point switch forms a very useful contribution to the wide range of available switches, since its special arrangement of contacts permits a fairly elaborate change to be made in the circuit with which it is associated, while the switch itself is exceedingly simple. Three contacts are incorporated in this type of switch, all of which are entirely insulated when the device is in the " open " position; when the switch is closed all three contacts are joined together, but still remain insulated from anything on which the switch may be mounted.

Waveband Switches.—The most exacting switches are those that are specially intended for use in conjunction with tuned circuits. Their main requirements are low capacity, so that no transference of energy is effected when the switch is in the " open " position, and an absolute minimum of dielectric loss. In addition to these requirements, it is imperative that the switch shall be so designed that separate sections may be ganged together, permitting control of several circuits to be effected by a single external knob, or lever, while at the same time the several sections are screened from each other in such a manner that all danger of feed back is eliminated.

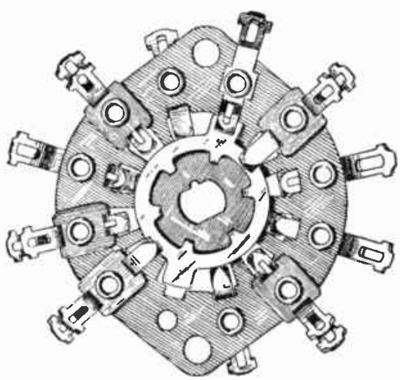


Fig. 142.—A wafer switch; the example illustrated is typical of modern switch technique.

The most efficient waveband switch in general use to-day is the wafer switch, which is available in innumerable modifications, but since the principle remains unchanged, a detailed description of a single example will serve to introduce them all. Fig. 142 illustrates a typical wafer switch; that shown being of two-pole, four-way type, that is to say it is capable of switching two leads each to four different contacts. It could, for example, be used for selecting four wavebands, and is capable of changing three wavebands plus a gramophone position. Fig. 142 shows what may be considered as the under side of the switch. The outer section is the fixed portion, while the central circular section is the rotary portion. These switches often have subsidiary switching on the under side as in the case of the one illustrated, to short out coils when not in use, to connect the grid to earth when in the gramophone position, or to perform other necessary services. It is intended that one, two, or more of these wafers be mounted behind each other and separated where necessary by a suitable screen to prevent coupling, all switches being turned by a flat-section rod, the slot for which may be clearly seen in the exact centre of the rotating portion. A complete control spindle is shown at Fig. 143.

The switch as shown at Fig. 142 is not complete in itself, since it requires means whereby the centre portion may be held in the correct

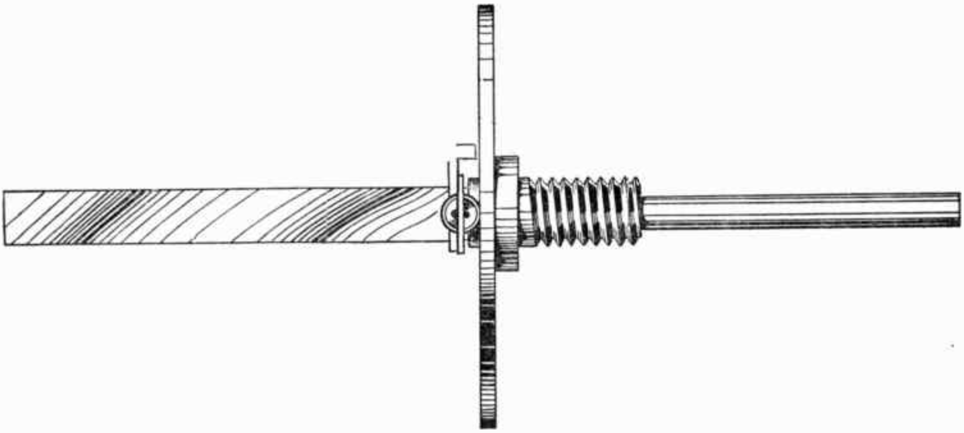


Fig. 143.—The control spindle and locating plate; the switch wafers are threaded on the flat "blade." Illustration three-quarters full size.

relationship to the fixed portion, which is rendered somewhat difficult by the fact that the nature of the spring contact used tends to make the centre portion take up a position which is incorrect. The usual means of obtaining the necessary control is shown at Fig. 144, which consists of a metal plate with depressions or slots into which the rotating arm will fit in such a manner that movement is impossible, excepting, of course, when the switch is deliberately operated; the example shown is provided with small wheels rotating in the arm to provide free deliberate movement combined with very positive locking. A plate intended for locking a rotating arm in various positions is known among engineers as a locating plate.

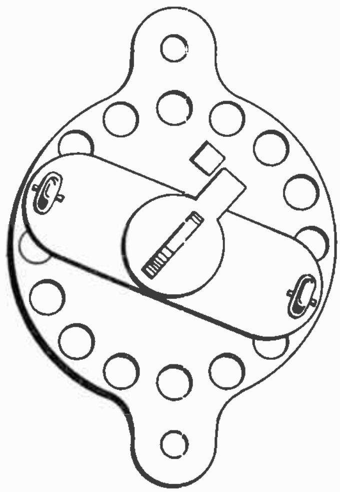


Fig. 144.—The locating plate of a wafer-switch assembly.

The wafer switch is reliable and efficient, qualities which are easily forfeited if the contacts are allowed to become dirty or greasy. It is imperative, therefore, that the greatest care should be exercised when making a soldered connection to see that soldering flux is not splashed or dropped on to the body of the switch. Similarly, some care is required to obtain sufficiently good alignment when two or more wafers are used, in order that the switch is not bent when the control spindle is rotated.

A Typical Circuit.—The remainder of this chapter and accompanying illustrations is devoted to typical circuit arrangements to illustrate the use of switching. Further and more elaborate examples will be found in a later chapter, where several complete receiver circuits are discussed in

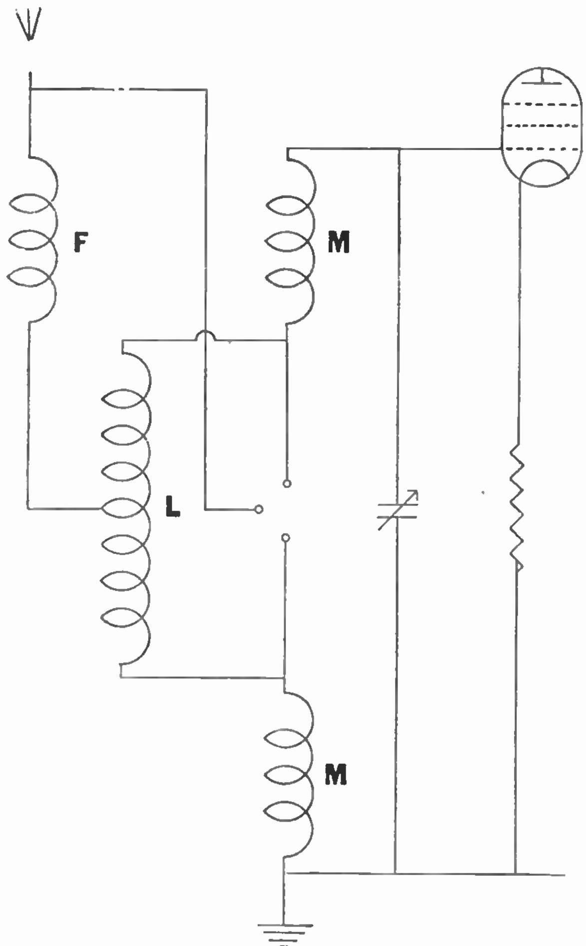


Fig. 145.—Wave-change and filter switched by means of a simple three-point switch.

detail. The reader will appreciate that the combinations and permutations are literally without limit, and that it is often possible to use three or four alternative arrangements, the chcice being dependent upon convenience, or merely by the fact that one arrangement has to be adopted for some particular reason.

Three-point Switching.—Fig. 145 shows the use of a three-point switch to give alternative selection of medium and long wavebands and at the same time to short out the filter when in the medium-wave position. To make this possible the medium-wave coils have to be split into two sections and the long-wave coil centre-tapped. It will be observed that the aerial is connected to the centre of the tuned circuit in either position; the filter coil is marked "F," the long-wave coil "L," and the medium-wave coils "M."

Fig. 146 shows the use of a three-point switch for an entirely different purpose, and is arranged to disconnect the positive terminal of the grid-bias battery when the low-tension circuit is broken. This arrangement is commonly used in battery receivers to prevent the grid-bias battery from passing current through the volume control potentiometer when the receiver is not in use. The possibilities of the three-point

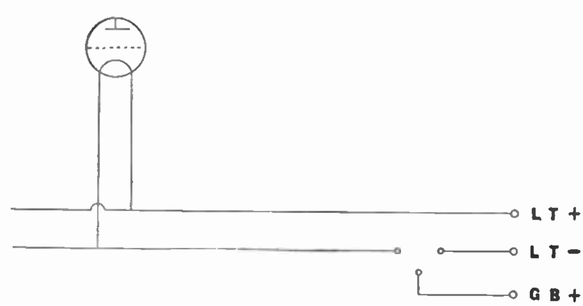


Fig. 146.—A three-point switch arranged to break the filament and grid-bias battery circuits simultaneously.

switch are very numerous, but the above two examples will serve to illustrate that it is surprisingly versatile. The illustration, Fig. 145, also suggests that a little thought will often result in a simple switch being found adequate for carrying out duties which would otherwise be assigned to one of more elaborate construction.

Waveband Switching.—The wafer switch permits really elaborate switching to be accomplished with the minimum waste of space and loss of efficiency. By using such elaborate types as that shown at Fig. 142, it is possible to effect really complicated circuit changes. For the present purpose, however, quite simple switching will suffice. Fig. 147 shows the application of a wafer switch for selecting three aerial couplings, and is therefore a very typical example, since the tuned circuits might well cover long, medium, and short wavebands. The method of diagrammatically representing this switch requires some explanation, since at first sight it may appear to have no relationship with the actual switch. In principle each dot represents a contact tag on the perimeter of the switch and each arc represents a portion of the central contact ring while the black dot is used to show the actual connection effected by the rotation of the centre portion. It is implied that each corresponding dot has equivalent relationship on the switch or, in other words, each black dot at the 12 o'clock position is so placed on the switch that the rotor portion makes contact with each simultaneously.

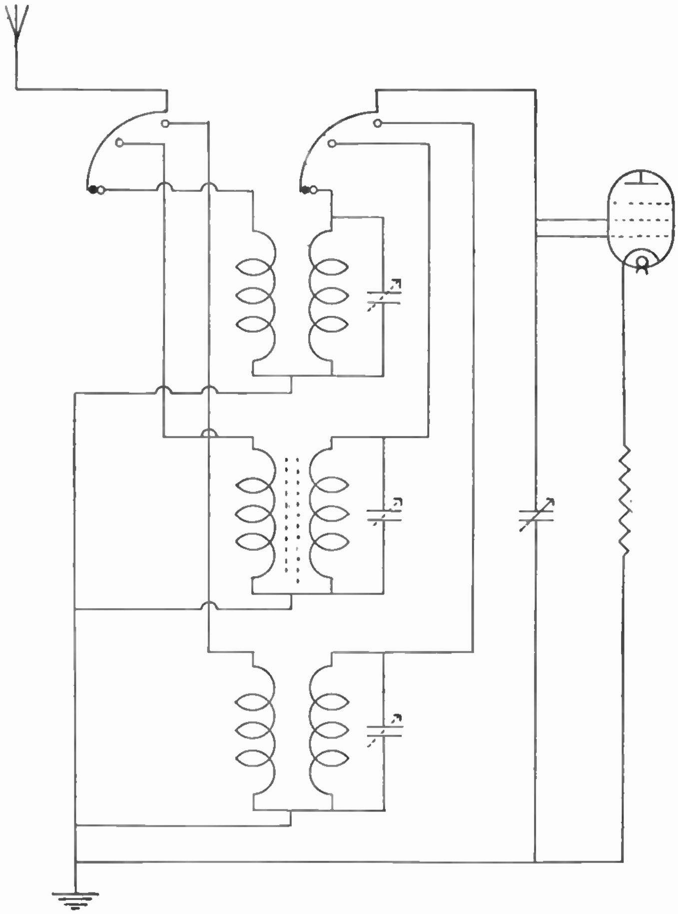


Fig. 147.—Three-band aerial circuit switched by means of a two-pole, three-way wafer switch.

The black dots may be considered superfluous in Fig. 147, since it is reasonably obvious that the rotation of the switch will be 12 o'clock, 1.30 o'clock, and 3 o'clock in each case; their use is, however, important when illustrating circuits where two or more wafers are used, resulting in some doubt regarding the sequence of the several component sections.

The wafer switch is extremely difficult to describe, and the reader is advised, therefore, to study an actual sample switch in conjunction with these notes, when the manner of its working will be readily understood.

Some receivers employ a wafer switch to control all switching requirements, and for this purpose the five-way variety is not uncommon, the following sequence of positions being a typical example:

1. Off.
2. Short waves.
3. Medium waves.
4. Long waves.
5. Gramophone.

In the above list it is, of course, assumed that the receiver is switched on automatically when the switch is turned to position 2, 3, 4, or 5. It is, perhaps, desirable to mention that when turned to the fifth position the receiver is connected for the reproduction of gramophone records, but the actual switching on of the electric turn-table motor is accomplished by means of an automatic switch, since the ordinary wafer switch is not intended for such purposes. It is, however, perfectly feasible to gang a suitable switch on the same spindle for this special purpose.

CHAPTER 21

LOW-FREQUENCY AMPLIFICATION

THE several chapters that have touched upon the stages of a receiver have always shown the output stage directly following the detector; while this sequence is quite possible, and is, in fact, often used, the need usually arises for some additional low-frequency amplification when the detector is a diode. The signal-handling capacity of the diode detector is such that it can easily deliver sufficient output to load the output stage, but as the diode does not amplify it is obviously necessary to provide adequate high-frequency amplification. Generally speaking, it is more economical to obtain low-frequency amplification than high-frequency amplification and, in addition, the low-frequency stage is less bulky and does not present any problems, such as ganging, which are inherent to the high-frequency amplifier.

When large output valves are used, the need for a stage of audio or low-frequency amplification is very apparent, as the usual screened pentode will not handle an anode swing large enough to load up an output stage requiring a large input. Whatever the reason for using a low-frequency stage the principle remains unchanged, and use is made of one of the basic arrangements described below.

Distortion.—Before describing the various basic circuits, it is convenient to review the requirements of a low-frequency amplifier. Apart from the obvious aim to achieve the highest possible gain, the most important requirement is freedom from distortion and, in the case of a battery receiver, economy of high-tension current. There are two main types of distortion: amplitude distortion and frequency distortion; the former arises from a condition of overload, or the application of incorrect bias. Amplitude distortion can be most readily described by the use of an example: assume that an output valve requires a grid swing of 50 volts to load it fully, and that the low-frequency stage has a stage gain of 10; it is apparent that the input to the latter must be a swing of 5 volts.

For the above-mentioned conditions it is necessary to employ a valve in the low-frequency stage that has an adequate straight portion to its characteristic curve *under working conditions*, or, in other words, the valve when operating at the chosen anode voltage must have a straight grid-volts/anode-current characteristic from the point where grid current commences to a point that is 5 volts negative in respect to it; furthermore, it is imperative that the valve be biased at the exact centre of this straight portion, so that the incoming signal can swing in either direction without running into curvature or grid current. If the length of the straight portion is inadequate, or incorrect bias is employed, amplitude distortion will result due to the signal encroaching upon curvature or causing the valve to run into grid current. All voltages relating to signal input used to illustrate the above example are peak volts, not the root mean square value.

It should not be assumed from the above example that a low-frequency amplifying valve must necessarily be biased at the mid-point, since it may be somewhat over-biased if the input is relatively small, a condition that will obtain when the low-frequency amplifier is capable of delivering a voltage output considerably in excess of that required to load the grid circuit of the output stage fully. This practice is normally confined to battery receivers, where it is desired to effect economy in high-tension battery consumption. In mains receivers it is usual to reduce the gain of a low-frequency amplifier by lowering the value of the anode resistance and thus decreasing the loss of the higher audio-frequencies caused by the effect of the valve capacity which is shunted across the anode circuit.

Stage Gain.—The gain of the low-frequency amplifier is determined by a formula which is now familiar, but is repeated for convenience :

$$\frac{\mu \times R}{R + r_a}$$

when μ equals the amplification factor of the valve under working conditions, r_a equals the impedance of the valve under working conditions, and R the effective resistance of the anode circuit. When the anode load is purely inductive, *i.e.* a choke, the formula for the amplification becomes

$$\frac{\mu \times \omega L}{\sqrt{r_a^2 + \omega^2 L^2}}$$

where L equals inductance of choke, and ω equals $2\pi f$.

It will be understood that the amplification of the stage must necessarily be less than the amplification-factor of the valve, unless a transformer is included, since it is necessary for the impedance of the anode circuit to be infinity in order to realise the full amplification of the valve, a condition which is, of course, impossible. The stage gain of a transformer-coupled low-frequency stage is determined by the following equation :

$$\frac{N \times \mu \times \omega L}{\sqrt{r_a^2 + \omega^2 L^2}}$$

when N equals the effective turns ratio of the transformer, and ωL equals the reactance of the primary of the transformer. The resistance of the primary may be neglected.

Resistance-capacity Coupling.—The simplest form of coupling is effected by means of resistances and a condenser, and is shown at Fig. 148. The value of the anode resistance is determined by a number of considerations ; a high value will give high gain, but will limit the voltage-handling capacity of the valve if the total high-tension voltage available is insufficient to give sufficient potential difference between anode and cathode after allowing for the drop across the resistance, and, furthermore, the use of a high-value anode resistance will result in some attenuation of the higher audio-frequencies, due to the shunting effect of the capacity between the anode and all other electrodes, which is, in effect, in parallel. It is apparent, therefore, that some compromise must be effected, and a reasonable value is three times the anode impedance of the valve.

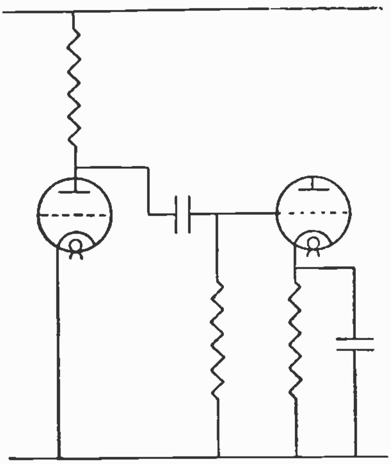


Fig. 148.—Resistance-capacity coupling.

The next consideration is the grid leak, which is virtually in parallel with the anode resistance, and must be kept reasonably high if stage gain is not to be sacrificed. The actual value will be determined by various considerations, but, generally speaking, the grid leak may have a value equal to five times the anode resistance.

The value of the coupling condenser is extremely important, since attenuation of the lower frequencies will result if the capacity is too small, while distortion will result if the capacity is too large. Consideration of Fig. 148 will show that the resistance and grid leak may be considered as a potential dividing device, the mid-point being connected to the grid of the output valve. Since the reactance of the condenser will vary with frequency, it is apparent that the two " arms " of the potentiometer will bear a relationship to each other which will vary with frequency. It can be shown, for example, that if the reactance of the condenser at 100 cycles is equal to the resistance of the grid leak, the attenuation at this frequency will be approximately 30 per cent. For general purposes, however, the relationship between grid leak and condenser will be found satisfactory when the reactance of the grid condenser at 25 cycles per second is equal to the resistance of the grid leak.

Transformer Coupling.—The basic circuit of a transformer-coupled low-frequency stage is shown at Fig. 149, which is in itself sufficiently explanatory to need little comment ; the advantage of this type of coupling is the additional gain due the voltage step-up of the transformer, but the corresponding disadvantage is the difficulty in avoiding frequency distortion, an aspect of the question which belongs to the consideration of transformer design. Frequency distortion in a low-frequency transformer takes the form of high-note attenuation due to the self-capacity of the winding, and bass attenuation consequent upon the difficulty of obtaining sufficiently high inductance to give adequate impedance at low frequencies. There are, however, transformers using special high-per-

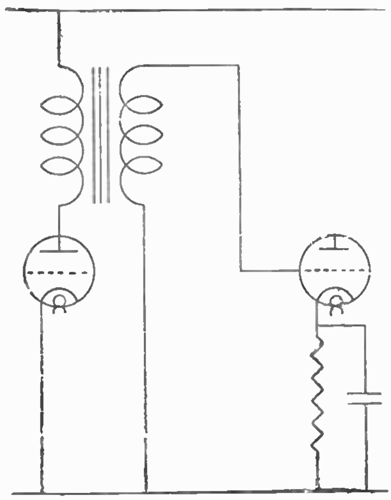


Fig. 149.—Transformer coupling with indirectly heated mains valves.

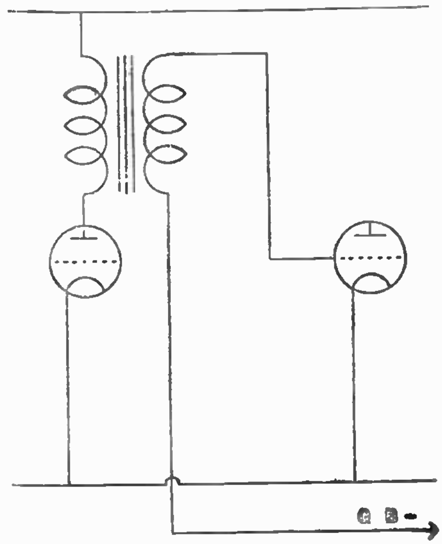


Fig. 150.—Transformer coupling for directly heated battery valves using battery grid bias.

meability iron cores which give adequate values of primary inductance, but the core is so easily saturated that it is necessary to resistance feed the primary in order to prevent the anode current of the valve from passing through the primary winding.

Resistance Transformer Coupling.—The basic circuit for resistance-fed transformer coupling is shown at Fig. 151. It will be observed that the valve is fed from the high-tension line through an anode resistance, while the speech frequency circuit is completed through a condenser. Normally, the value of anode resistance will be the maximum that will permit adequate potential difference between the anode and cathode of the valve. Occasions arise, however, when a lower value may be chosen as a means of improving the response-curve of the transformer.

The coupling condenser is not critical, and requires little consideration other than to ensure that it is large enough, values from ·1 to 1 μF being in general use. Since the D.C. resistance of the transformer primary will be quite low, this condenser may be made fairly large. Here, again, occasions may arise where it is desirable to deliberately attenuate the lower frequencies as a means of accentuating the higher frequencies which may have been attenuated in the tuned circuits employed in the earlier stages of the receiver ; when it is desired to attenuate the lower frequencies, the value of the condenser is decreased until the desired percentage of attenuation is arrived at. The various circuit-diagrams in this chapter are deliberately drawn so that the left-hand valve can represent the low-frequency amplifier and the right-hand valve the output valve. On the other hand, the left-hand valve may represent the detector valve, and the right-hand valve the low-frequency amplifying valve. In this way it is possible to visualise two of the circuits as being part of the same receiver; for example Fig. 151 may represent the coupling between the detector stage and the low-frequency stage, and Fig. 148 the coupling between the low-frequency valve and the output valve. In other words, the right-hand valve in Fig. 151 may be regarded as one and the same valve as the left-hand valve in Fig. 148.

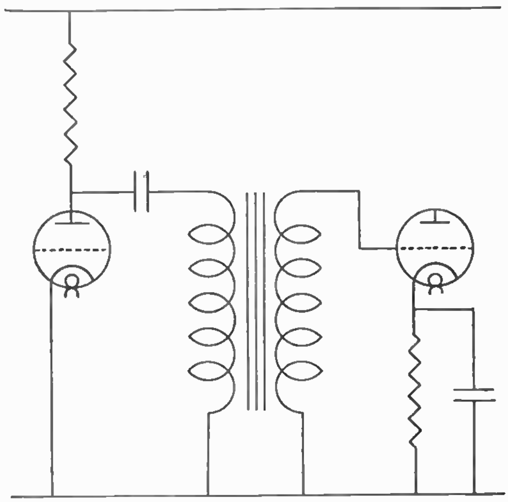


Fig. 151.—Resistance-fed transformer coupling.

The circuit arrangement shown at Fig. 151 is liable to modification to give a different effective transformer ratio. Taking a transformer with the nominal ratio of 3 : 1, it is apparent that this figure is realised in the arrangement shown at Fig. 151. A different set of conditions obtains in the arrangement shown at Fig. 152, since the winding shown on the left-hand side (the normal primary winding) will function in the ordinary way, whereas the secondary is made up of both windings, the G.B.—terminal being connected to the A terminal. In this way the nominal 3 : 1 ratio becomes 4 : 1. A further variation is possible by utilising an arrangement where the primary turns are in effect deducted from the secondary, giving a ratio of 2 : 1. The circuit is, however, omitted, since this method of connection is undesirable owing to the intolerable frequency-response curve which results.

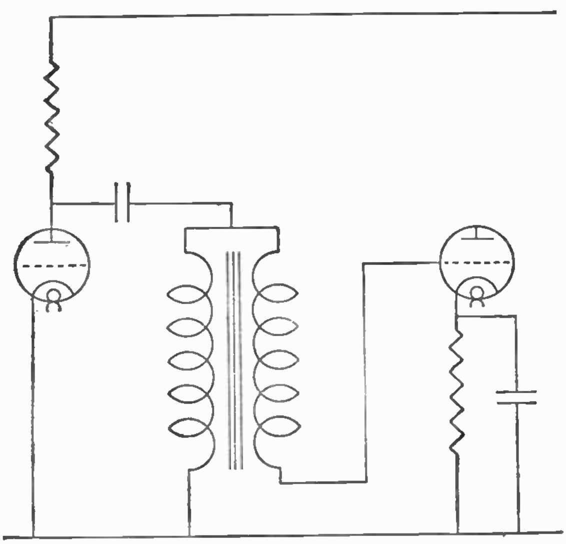


Fig. 152.—The circuit shown at Fig. 151 rearranged to give increased gain.

For convenience, a further arrangement is shown at Fig. 153, which may be described as resistance-fed auto-transformer coupling; by reference to the diagram it will be seen that a true auto-transformer is used; actually this circuit is similar to that shown at Fig. 152, with the exception that in the former case an auto-transformer is used to perform its normal function, whereas in the latter case an ordinary double-wound transformer is employed, but is so connected that it functions as an auto-transformer. In practice, the auto-transformer is provided with only three connecting points, whereas the double-wound transformer is provided with four connecting points, the primary and secondary windings being insulated from each other.

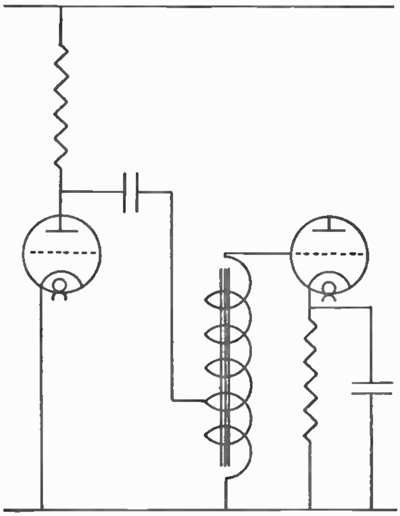


Fig. 153.—Resistance-fed auto-transformer coupling.

Fig. 153 is useful inasmuch as it shows rather clearly that the lower portion of the winding forms the primary, whereas the whole winding forms the secondary. The same remarks apply to Fig. 152, but the point is not so apparent owing to the manner in which this circuit is drawn.

Diode to Triode Coupling.—Reference has already been made to the desirability of following the diode detector by a stage of low-frequency amplification. As a convenient means of achieving this aim it is usual to use the double diode triode, or alternatively the double diode tetrode, which consists of a normal valve assembly and two diodes contained in a single bulb. The method of connecting the signal diode to the triode is shown at Fig. 154. The pentode valve is intended to represent the final intermediate-frequency amplifier which

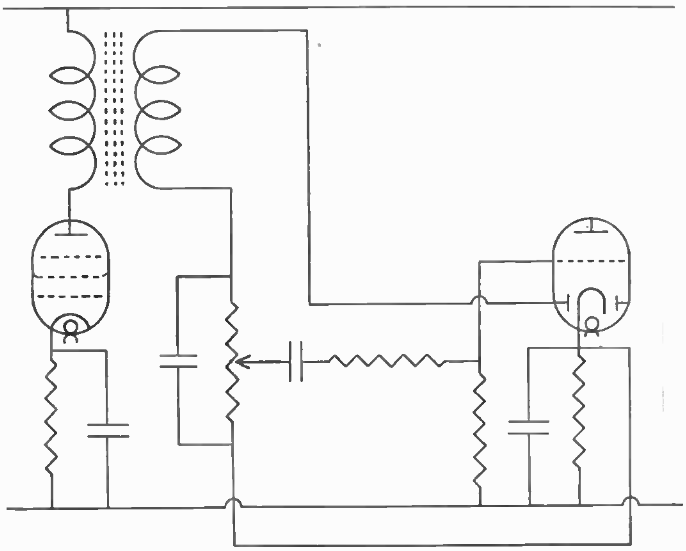


Fig. 154.—A double diode triode used as detector and low-frequency amplifier in a superheterodyne.

is coupled by means of an iron-cored intermediate-frequency transformer to one of the diodes of the double diode triode. It will be observed that the diode load and accompanying bypass condenser is connected in series with the secondary of the intermediate-frequency transformer, and that its low-potential end is returned to cathode. The diode load takes the form of a potentiometer in order to permit control of volume. It will be noted that the moving arm of the potentiometer is connected through a condenser and resistance to the grid of the triode valve, which is tied down to the high-tension line by a further resistance in order that the grid may be biased by the potential drop across the bias resistance in the cathode circuit. The condenser is included to prevent the bias on the grid from being short-circuited, since the lower end of the potentiometer is returned to the cathode. The resistance in series with the condenser prevents the high-frequency component of the diode circuit from appearing on the grid of the triode section at sufficient amplitude to cause instability and other undesirable effects. When volume control is not required the connection is taken to the high-potential end of the diode-load resistance, which then takes the form of a normal fixed resistance.

Mains Hum.—The amplification of the triode section of the double diode triode plus the amplification of the output stage is usually very considerable and special care is necessary to prevent the introduction of mains hum into the grid circuit of the triode section. Quite apart from the actual gain, it will be realised that the coupling between the valves in question will be favourable to the transference of mains hum, which on 50-cycle mains will have a frequency of 100 cycles per second if the rectifier valve is of the full-wave type.

The actual disposition of the components included in the grid and diode circuits of the double diode triode are inclined to be scattered and consequently considerable care is required in positioning the components and wiring. When the diode load resistance takes the form of a potentiometer, this component will usually be mounted on the front of the chassis, so that it is available for the manual control of volume; the detector diode is connected to the secondary of the intermediate-frequency transformer, with the result that the designer is usually faced with the alternative of a long detector diode lead or a long grid lead. The usual way out of the difficulty is to make the diode lead short and screen the grid lead. The screening of the grid lead requires some care, owing to the danger of attempting the higher audio frequencies, and recourse is usually made to some form of low-capacity coaxial cable.

The Choice of Valves.—The triode valve has been used in the various circuits which show a low-frequency amplifier. This should not be taken as an indication that the triode valve is the only suitable type. Both the tetrode and pentode may be used in this stage and, in fact, several types of double diode tetrodes are available. The tetrode valve is usually employed when the input is small enough not to cause overloading and has the advantage of a high amplification factor. The pentode is employed as a low-frequency amplifier when it is desired to introduce a special form of tone correction or when it is desired to take advantage of the suppressor grid for rendering the loudspeaker silent while tuning from one station to another. The subject of inter-station noise suppression is dealt with in a later chapter.

CHAPTER 22

THE OUTPUT STAGE

THE term output stage may be broadly defined as the ultimate valve of a receiver. There is, however, an implication that the output stage is intended to drive a loudspeaker as distinct from headphones, since the latter may well be driven by the detector valve, and it is something of a paradox to refer to the detector valve as the output valve, since their normal functions differ so widely. The output valve is different from all other valves in one important particular; it is required to deliver power, as distinct from voltage. It will be remembered that a valve is a purely voltage-operated device, and when one valve is used to drive another which follows it the former is only required to deliver voltage output. A loudspeaker is not a voltage-operated device, but is essentially a current-operated device, and will, therefore, require a power output, since voltage will also be required to bring about the flow of the current through the winding of the loudspeaker. The requirements of a valve intended to deliver a power output are almost fundamentally different from a valve required for purely voltage amplification, and, consequently, output valves not only differ in construction, but require different operating conditions.

The output stage comprises the output valve, the loudspeaker and its attendant components; loudspeakers are dealt with in a separate chapter, and for the time being attention is directed solely to the output valve, and the method of its application. An output valve may be a triode, tetrode, or pentode, but the measure of its efficiency is in all cases determined by three factors: sensitivity, limitation of distortion, and speech output; it being understood that the latter term is intended to imply the actual signal output available for operating the loudspeaker, and is variously referred to as power output, A.C. output, speech output, and undistorted output.

Undistorted Output.—The actual speech output obtainable from an output valve is determined by the anode dissipation of the valve, which is in turn determined by multiplying the mean anode current by the voltage difference between anode and cathode or filament. It is not possible, however, to permit an output valve to deliver its maximum possible output, since, under this condition, distortion would be quite intolerable. Consequently the output of the valve must be limited to some smaller value, which is called the undistorted output; a term which is a most unfortunate misnomer, since the extreme condition required for output without distortion would result in the output being negligible. It is apparent, therefore, that some compromise is necessary. This compromise is a purely conventional one, and allows the valve to be rated for the speech output that it may deliver without introducing more than 5 per cent. distortion. The term undistorted output, therefore, may be defined as the maximum speech output that the valve can deliver without introducing distortion to a greater extent than 5 per cent. The method of determining undistorted output and the calculation of distortion is dealt with in the next chapter, since the procedure differs somewhat with various types of output valves.

Second Harmonic Distortion.—Distortion introduced in the output stage is brought about by the valve generating spurious harmonics, which naturally alter the characteristic of the music to a greater or lesser extent. The unwanted harmonic content is caused by the non-linearity of the grid-voltage/anode-current characteristic. It has been convenient in the preceding chapters to refer to the straight portion of this characteristic, but the simple expedient of laying a straight-edge along a selected portion of an honestly-drawn curve will show that the term " straight " is a relative one, since slight curvature begins almost from $Vg = 0$.

The exact meaning of second harmonic distortion needs some explanation, in order that the phenomenon may be understood readily. Assume that a single fundamental musical note is being broadcast, the pitch of which is equivalent to middle " C " on the piano, which has a frequency of 256 cycles per second, and that the receiver is so designed and adjusted that the output valve delivers one watt to the loudspeaker. It is apparent that if distortion is entirely absent the fundamental note of middle " C " will be heard at the volume indicated. If the output valve is working under such conditions that it introduces 5 per cent. second harmonic distortion, then the valve will introduce a spurious frequency of 512 cycles per second, which is a second harmonic of 256 cycles per second, and is the musical note " C," but one octave higher than middle "C," and since the distortion is equal to 5 per cent., the spurious frequency can be rated at 5 per cent. of 1 watt, which is 50 milliwatts. Second harmonic distortion will always consist of the introduction of a frequency one octave higher than the initial frequency. It should be understood that this harmonic distortion will appear not only on the fundamental note or notes, but also on the harmonics which are themselves introduced by the instruments of the orchestra. The introduction of a spurious frequency that is always separated from the initial frequency by an octave is not particularly distressing to the ear, and its effect is rather in the nature of tending to alter the character of the sound; that is to say, it tends to make a musical instrument sound a little unreal.

Third Harmonic Distortion.—The non-linearity of a triode valve is in one direction; that is to say, the curvature consists of a deviation to one side only of a straight line drawn between the extremities of the grid swing (see Fig. 155).

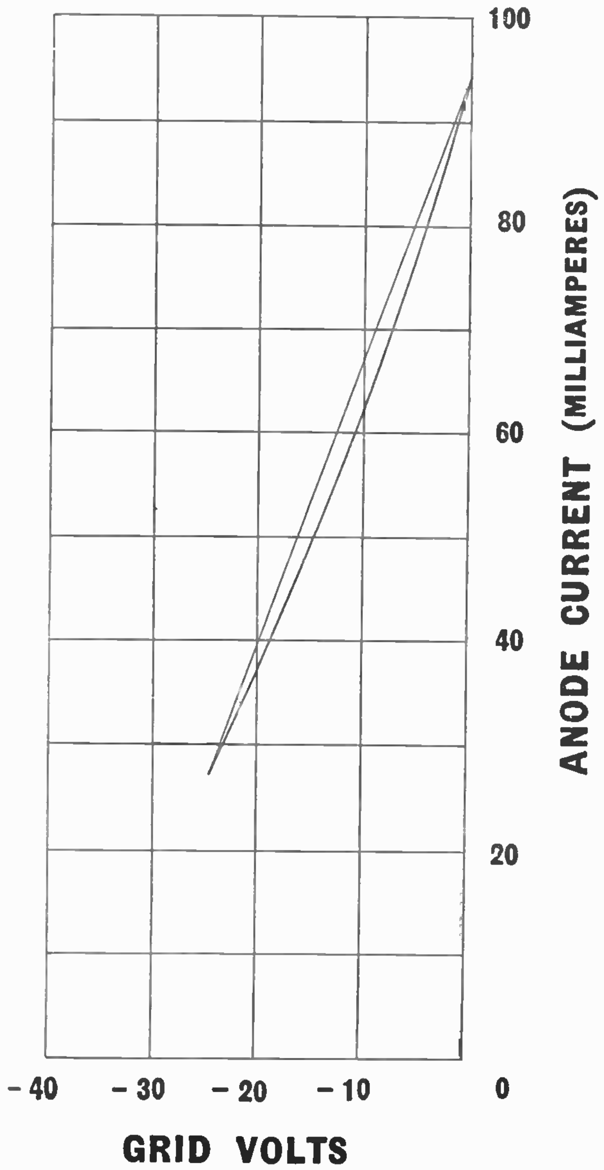


Fig. 155.—Dynamic curve of a triode output valve. Since this curve is taken from the valve under working conditions, it is limited to the portion actually operated by the input voltage. The straight line shows the theoretical condition of zero distortion.

Fig. 156 shows the dynamic grid-volts/anode-current characteristics of a pentode valve. It should be understood that a dynamic characteristic is obtained from a valve when operating under working conditions, *i.e.* with correct grid bias applied and with a load in the anode circuit. Reference to Fig. 156 will show that the pentode differs from the triode inasmuch as the departure from the imaginary straight line occurs on both sides, with the result that third harmonic distortion is introduced in addition to second harmonic distortion. Generally speaking, the percentage of third harmonic distortion is so much greater than the percentage of second harmonic distortion that the latter may be neglected when the valve is used under certain conditions. There are, however, a limited number of pentode valves available on the British market which prove an exception, since they are so constructed that second harmonic distortion is greater than third harmonic distortion.

To illustrate third harmonic distortion it will be convenient to investigate the behaviour of a pentode which is operating under such conditions that it introduces 5 per cent. of third harmonic distortion. Once again assume that a fundamental note of 256 cycles is being broadcast. It will be remembered that this frequency is known to musicians as middle "C." The third harmonic of 256 cycles per second is 768 cycles per second, which no longer differs from the fundamental note in terms of octaves, but is the higher "G"; thus an entirely alien note has been introduced. It is, perhaps, unnecessary to remark that the introduction of an alien note may be regarded as more serious than the introduction of the higher octave, particularly when it is remembered that a fundamental note emanating from a musical instrument will be attended by various harmonics, which will, in turn, give rise to alien notes in the reproduction.

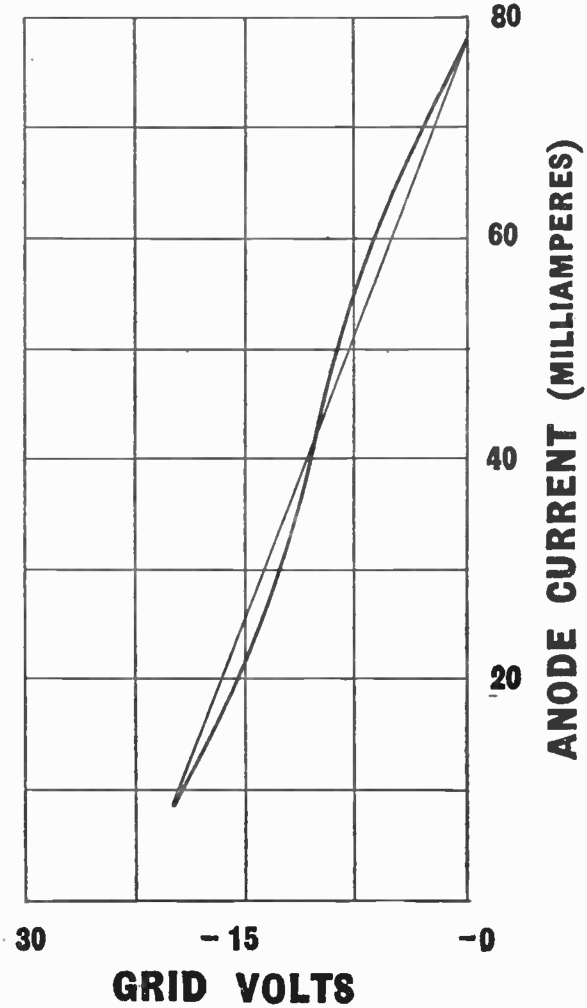


Fig. 156.—Dynamic curve of a pentode output valve; the curve deviates on both sides of the imaginary straight line, indicating the presence of third harmonic distortion.

The effect of harmonic distortion upon the listener will vary with different individuals, but, if the author may strike a personal note, it may be of some guidance to mention that he is prepared to tolerate 5 per cent. of second harmonic distortion more readily than 2 per cent. of third harmonic distortion. It may also be mentioned that the presence of third harmonic distortion causes reproduction to appear both harsh and shrill, and is of such a character that it continues to appear to the ear as shrill, even if the higher frequencies are attenuated by artificial means. The same remarks apply equally to both the pentode and the output tetrode.

Optimum Load.—In order that the valve may deliver its maximum output with limited distortion, it is necessary that the anode load should have an optimum impedance—which is termed the optimum load. It is apparent, without going into the question deeply, that the presence of a very small impedance in the anode circuit must result in the available power being developed in the valve instead of in the load where it is wanted. On the other hand, the presence of a ridiculously high load will result in the functioning of the valve being so impaired that its efficiency is proportionately low; the actual figure for the optimum load can usually be conveniently obtained by consulting the data supplied with the valve. It is, however, obtainable by various other means, the most convenient of which is the graphical method, which is described in the next chapter. The term optimum load may be defined as the external anode impedance which will permit an output valve to deliver the maximum speech output without exceeding 5 per cent. harmonic distortion. When using a triode valve the optimum load is invariably adhered to, but when using a pentode or output tetrode, some modification may be considered desirable, when a considerable reduction in third harmonic distortion will result, without unduly reducing the speech output and second harmonic distortion.

Fig. 157 illustrates the importance of using the correct load for a triode valve. The curve shows the relationship between the anode load and the speech output and second harmonic. It will be observed that the effect of using an excessive impedance is less serious than using an inadequate impedance. It may also be seen that reasonable latitude is given by the triode valve, since deviation from the optimum load to the extent of a few hundred ohms does not bring about a profound change in available output.

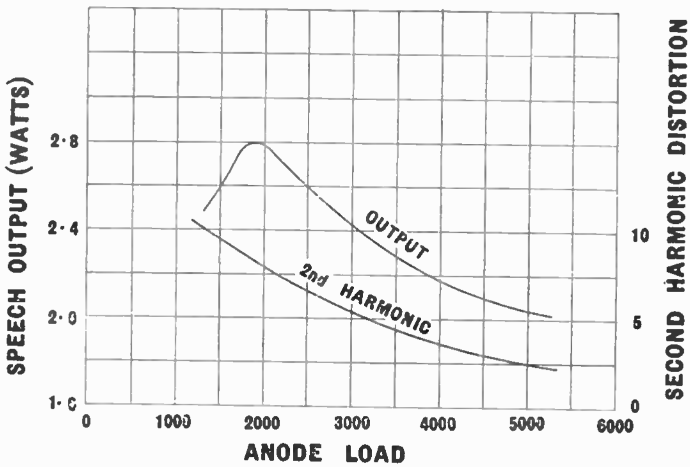


Fig. 157.—This illustration shows the speech output and second harmonic distortion plotted against anode load. The valve used for these curves was a triode having an anode dissipation of 12 watts.

Fig. 158 shows the relationship between the anode load, harmonic distortion, and available output of a pentode valve. It will be observed that the output curve is reasonably level, and that small change of optimum load does not materially affect the available output. On the other hand, the variation in the harmonic distortion is considerable for a relatively small change of anode load. A load of 5,500 ohms will give zero second harmonic distortion, but about 4·5 per cent. of third harmonic distortion; the conventional interpretation of this curve would result in the valve being used with a load of 5,750 ohms, since this gives the greatest output without exceeding 5 per cent. third harmonic distortion. The author considers this conventional interpretation to be capable of improvement and, bearing in mind the unpleasant nature of third harmonic distortion, would prefer to use an anode load of 5,000 ohms, which will increase the second harmonic distortion to 2 per cent., but will reduce the third harmonic distortion to about 3·3 per cent. Admittedly the available output is sacrificed to the extent of about 2 per cent., but this sacrifice is a trifling matter compared with the reduction in third harmonic distortion.

It is apparent from a cursory glance at Fig. 158 that the anode load for a pentode is very much more critical than for a triode, and, furthermore, that under-loading is preferable to over-loading, since the former causes a relatively small reduction in output, whereas the latter causes a really serious increase of third harmonic distortion.

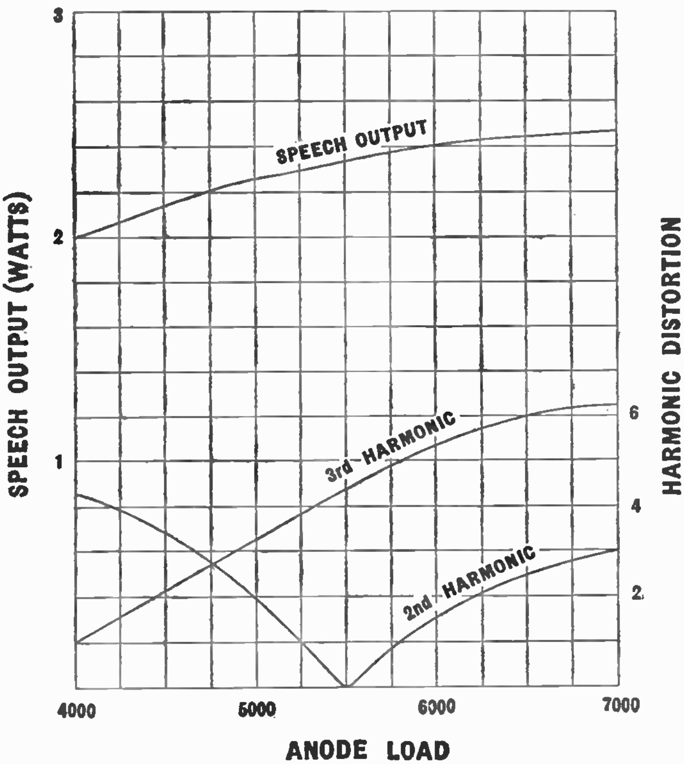


Fig. 158.—Curves showing the relationship between anode load and speech output, second harmonic distortion and third harmonic distortion. The valve used was a pentode having an anode dissipation of 8 watts.

Impedance Limitation.—In order to eliminate as far as possible disproportionate amplification of certain frequencies, it is apparent that the anode load should be constant at all frequencies which the output valve is required to handle. The modern moving-coil speaker is usually sufficiently well designed to give approximately uniform impedance from 50–5,000 cycles, or more. Nevertheless, it is often desirable to introduce some means of limiting the impedance, particularly when using high-impedance speakers, with which there is a tendency for impedance to increase with frequency. The most obvious arrangement is the use of a fixed condenser across the anode load, which will effectively limit the impedance at the higher frequencies to an extent dependent upon its capacity, but is liable to attenuate unduly the very high audio-frequencies. It is, therefore, usual to use a resistance and condenser in series across the anode load, so that the impedance at very high audio-frequencies cannot fall below a predetermined value, namely, the value of the resistance. This arrangement is shown at Fig. 159.

Tone Control.—The fact that the impedance of the anode load can cause the top end of the frequency scale to be attenuated suggests that this phenomenon may be used to effect tone control, which could take the form of the filter, C_1, R_1, shown at Fig. 159, the condenser having sufficient capacity to attenuate the higher frequencies to a desired extent, and the resistance made variable and of a value capable of practically offsetting the bypassing effect of the condenser. This arrangement is often used to provide tone control, but is considered undesirable, since manipulation of the variable resistance will not only affect the frequency response but the total impedance of the anode load to such an extent that serious increase in harmonic distortion may result. It is, therefore, preferable to use a fixed condenser and resistance when necessary to limit the impedance of the anode load, and to introduce tone control in front of the output valve (RC in Fig. 159), in the form of a fixed condenser in series with a variable resistance connected between grid and cathode of the low-frequency amplifying valve, where such a valve is employed.

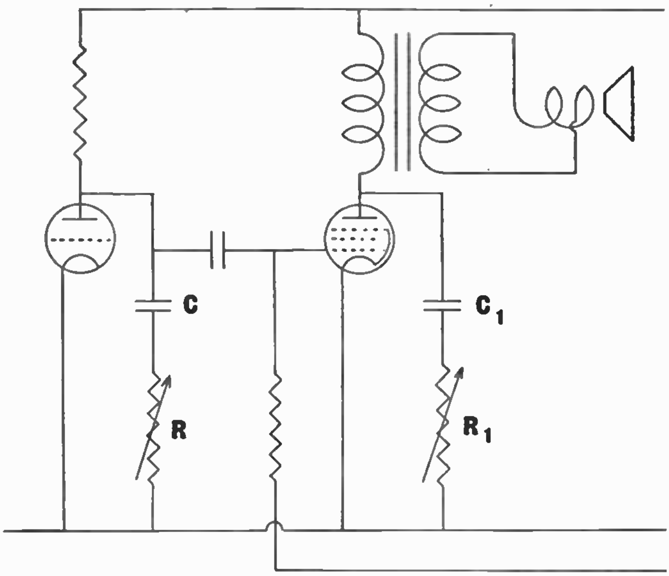


Fig. 159.—Alternative positions for variable tone control; R and C is preferable to R1 and C1.

The variable tone control is used by many listeners to attenuate the higher frequencies so that reproduction is rendered "mellow," a term which cannot be too strongly deprecated by the musically minded, since it means deliberate frequency distortion introduced to make musical reproduction less faithful.

Valves in Parallel.—When it is desired to increase the speech output, and it is inconvenient to use a larger valve, it is possible to use two or more valves connected either in parallel or push-pull; the latter alternative may, under certain circumstances, give additional advantages. Valves connected in parallel are illustrated at Fig. 160, from which it may be seen that corresponding electrodes are joined together, *i.e.* anode to anode, etc. It will be noted that the suppressor grids are not joined together, since these electrodes are connected to the cathode internally, the actual connection usually being made between the appropriate wires on the foot of the valve. This connection is shown internally in the illustration. Slight variations are possible, notably the connection of heaters in series instead of parallel, as a matter of convenience. Also, the grid circuit may be modified, permitting grid bias to be applied separately to each valve by means of separate bias resistances, a feature which prevents damage to one valve when its partner becomes defective, and, incidentally, permitting the stage to continue functioning with partial efficiency when one valve has suffered complete failure.

Two valves in parallel will deliver twice the output of which one valve is capable, and, since the output increase is in the nature of a current increase, the anode load must be halved. In addition to doubling the output, this system of connecting valves doubles the sensitivity, since the doubled output is delivered, though the input voltage remains unchanged. It will be remembered that a valve is a voltage-operated device, consequently a given input will drive any reasonable number of valves, providing they are so biased that grid current is completely avoided.

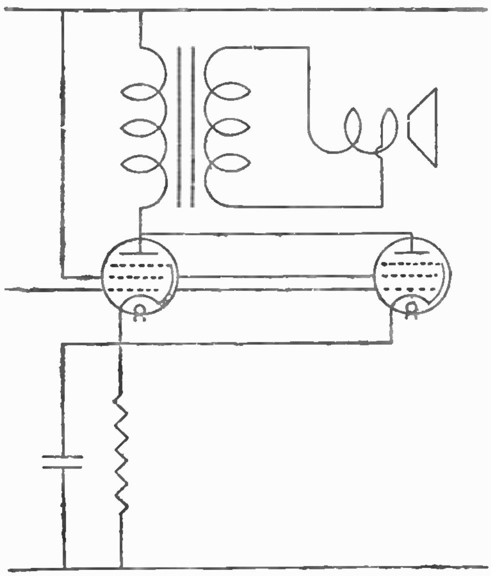


Fig. 160.—Output valves in parallel.

It is undesirable that the total D.C. resistance between grid and cathode of an output valve should be of a high order, 1 megohm being considered the maximum figure while with really large output valves a considerably lower value is desirable. This limitation is imposed because an output valve will almost invariably work under such conditions that exceptional peak values will drive the valve into grid current, and the effect of this will be to decrease the effective bias in proportion to the total D.C. resistance through which it must flow.

Push-pull Output.—One of the most valuable contributions to the technique of the output stage takes the form of push-pull amplification, the basic circuit of which is shown at Fig. 161, where a typical circuit is given for two triodes in push-pull. It will be noted that the input is delivered by means of a centre-tapped transformer, the centre of which is connected to cathode, so that the opposite ends are in opposite phase. Since the extremities of the secondary are in opposite phase, the output valves will be driven in opposite directions; thus the anode current of one will increase, while the anode current of the other decreases, hence the term push-pull.

The most outstanding advantage of push-pull amplification is the automatic cancellation of second and all even harmonic distortion. It is thus possible to design a triode output stage by the utilisation of this principle, which is practically free from harmonic distortion. It should be understood that valves in push-pull cancel out even harmonic distortion only, but do not cancel odd harmonic distortion ; consequently the advantages of this system are more easily realised when using triode valves,

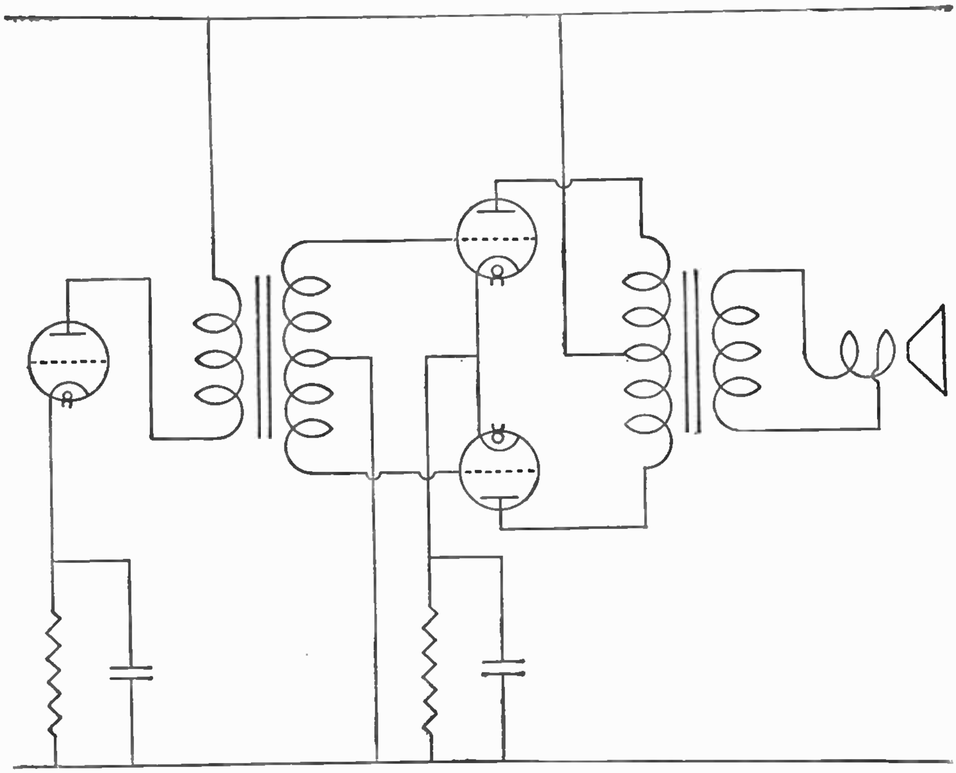


Fig. 161.—Basic circuit of a push-pull output stage using indirectly heated valves.

which only generate even harmonics at significant amplitude. It is, however, possible to utilise the principle for pentode valves, the even harmonic distortion being cancelled out in the manner already described, and third harmonic distortion being considerably reduced by the application of a principle known as negative feed-back, which is described in detail at the end of this chapter.

Class A Push-pull.—Class A output may be defined as an output valve running under conditions of normal bias, that is to say, the valve is biased at the middle of the " straight " portion of the characteristic. The term may be applied to a single valve, valves in parallel, or valves in push-pull, though the term has little significance, except when applied to push-pull, as it is scarcely conceivable that a single valve or valves in parallel could be operated at a condition sensibly different from that of normal bias. It is, however, most significant when applied to push-pull valves, since these may be operated under widely differing conditions. Generally speaking, the optimum load for the two valves, *i.e.* the anode to anode load, will be double the value that is correct for one valve when the stage is working as Class A output. It is, however, often practicable to vary the load slightly, and, in consequence, obtain a larger output; a liberty that may be taken, since the increase will merely result in increasing second harmonic distortion in each valve, which is unimportant, since the even harmonics are cancelled.

Quiescent Output.—Quiescent output is an important development applied to the battery receiver, since it brings about a very considerable saving in high-tension current consumption.

Special pentodes biased almost to cut-off and Class B push-pull may be described by the common title of quiescent push-pull output, and it is necessary to define the meaning of the latter term before describing the alternative methods of its application.

Class A output stage consumes a fixed average high-tension current irrespective of the work accomplished. If the valve is so designed that when correctly biased it passes, say, 20 milliamps, then it will pass 20 milliamps when reproducing a full orchestra; it will also consume 20 milliamps when reproducing a single voice; and, what is more wasteful still, it will consume 20 milliamps during a programme interval. A quiescent output stage is biased so that its standing anode current is very small, and valves capable of giving the same output as that quoted in the examples above will pass only one or two milliamps when quiescent, *i.e.* during a programme interval. The incoming signal will drive each valve alternatively, so that its anode current increases to an extent determined by the amplitude of the signal, thus the stage passes only sufficient current at any instant to enable it to handle the signal that is driving it; the actual waste of high-tension current is of the order of only 10 per cent., which represents a considerable economy.

It is impossible to compute the wastage of anode current occurring in a Class A stage, since the waste is dependent upon the type of programme; but a test carried out by the author gave the following results, measurement being effected by the use of silver plates in a solution placed in series with the high-tension supply, the total current being determined by the gain in weight of one plate, due to the silver deposited by the total current passing through the cell. The test was carried out between two pentodes in quiescent push-pull (that is an ordinary QPP pentode), and compared with two pentodes in Class A push-pull, the input to each being so adjusted that both stages delivered the same output, measured by means of an output meter. The valves were switched on at 10.15 a.m., and switched off at midnight automatically, and the receiving stages tuned to a British broadcasting programme. This test was continued for six days, and the valves in Class A push-pull consumed 1,450 milliampère-hours, whereas the quiescent push-pull consumed only 675 milliampère-hours. It will be noted that the saving in high-tension consumption was more than 50 per cent. Both stages delivered the same output, and, at times no doubt took the same current, but the QPP stage effected the economy during the period when the programme material was such that the stages were not called upon to deliver their maximum output.

It must be admitted that the quality of reproduction of a QPP output stage is inferior to that available from a Class A output stage, all things being equal. Nevertheless, it is of great advantage when used in battery-operated receivers. When high-tension consumption is of primary importance, the QPP stage may be considered to give the best quality, as, when the matter is viewed broadly, the alternatives are a QPP output stage giving slightly indifferent quality compared with a single valve, which will be badly over-loaded, and therefore give worse quality. This comparison, of course, only applies to receivers where high-tension consumption is necessarily limited by economic consideration.

Class C Output.—Class C output is a form of quiescent push-pull output, and may be defined as two valves working in push-pull and biased at a point where anode current practically ceases, *i.e.* the cut-off point. The actual point chosen is of some importance, since it determines the linking up of the two valves or, in other words, the accuracy with which one valve will commence to function when the other one has ceased. The application of incorrect bias will cause serious distortion when handling small inputs, but is not so important when handling large inputs. It must be remembered, however, that the output stage is dealing with a low-frequency wave form, and consequently will be called upon to handle small inputs and large inputs at the direction of the programme material being reproduced. Class C amplification is sometimes used for very large amplifiers, particularly of the portable type, since problems of heat distribution are brought about when really heavy anode currents are in use ; otherwise the system is almost entirely confined to domestic battery receivers, the actual valve chosen being usually of the pentode type in order to obtain high sensitivity. Special valves are available which comprise two pentodes mounted within a single bulb ; this development is purely one of convenience, and has no theoretical significance.

It should be particularly noted that a Class C output stage may work with an input which will drive it from approximately zero anode current to a point where the grid swing approaches, but does not reach, the value at which grid current will flow.

Class B Output.—Class B output is a form of quiescent push-pull which fulfils the same advantages of economical high-tension current consumption, but achieves the desired result in a somewhat different manner. The typical Class B valve comprises two triodes mounted in a single bulb and having relatively high impedance. A typical circuit is shown at Fig. 162, from which it may be seen that the valve is working without grid bias, although certain types actually use a small value of negative bias. It is, however, more convenient to use for an example the type of valve which works at 0 bias, under which condition each anode will pass something less than 1 milliamp. It is apparent that when positive signal voltage is applied to the grid the valve will make an excursion in the positive grid region, *i.e.* the grid will become more and more positive in accordance with the amplitude of the applied signal. The valve is in all respects a triode, and will pass grid current when the grid is made positive to a material extent, which would normally result in severe distortion due to the load imposed on the preceding valve. The valve immediately preceding the output valve at Fig. 162 is not a low-frequency amplifier in the generally accepted sense of the term, since

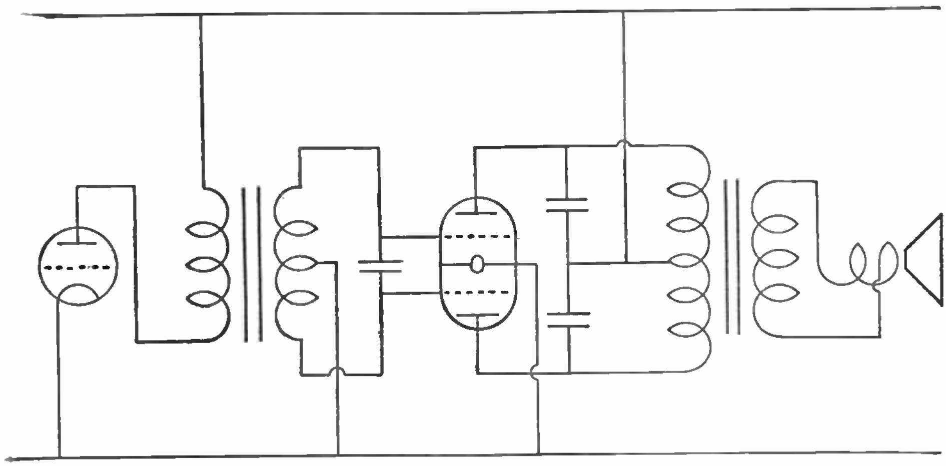


Fig. 162.—Basic circuit of a Class B output stage; special reference is made in the text to the condenser connected between the grids of the Class B valve.

it performs the unusual function of delivering not only a voltage output to drive the output stage, but a current output, so that the energy consumed in the grid circuit of the output valve can be provided for without adversely affecting the performance of either stage.

This special valve, which supplies the requirements of a Class B output valve, is somewhat aptly termed the driver valve, and usually takes the form of a small power valve over-biased to an extent which will permit it to deliver some 30 milliwatts for an anode current of about 1·5 milliamps. Under certain circumstances, however, it is possible to use a valve of what is colloquially termed the low-frequency type; this arrangement, however, tends to increase anode current to some small extent, though it effects a useful saving in filament current.

It will be noted that the coupling between the driver and Class B output valve takes the form of a transformer; this component differs from the usual type of low-frequency transformer inasmuch as it has a small step-down ratio instead of a step-up ratio, a detail made necessary by the desirability of reducing the loading imposed in the driver valve anode circuit by the heavy flow of grid current in the grid circuit of the output valve. It is also necessary that the secondary of the driver transformer shall have a low D.C. resistance, usually not more than about 200 ohms, in order that the grid current flowing through the winding will not cause an appreciable voltage drop across the winding, which would result in variable grid bias being applied to the valve, and consequent distortion.

It will be noted that the outer terminals of the driver transformer secondary are connected together by means of a fixed condenser. At first sight this might be assumed to be some form of tone control, a function which it does actually perform, but it has far greater significance. As already stated, the anode current is dependent on the amplitude of the signal input which will normally be made up by the modulation from the programme that it is desired to hear, but considerable danger arises from the possibility of the presence of a supersonic frequency, which may have a steady amplitude capable of driving the Class B valve to a pointwhere it passes very heavy anode current, under which condition, of course, the life of a quite large high-tension battery may be measured almost in days. A supersonic frequency may be roughly described for the present purpose as a whistle above audible frequency, so that its presence is not detected by ear. It could arise from the heterodyning of two stations 18 kilocycles per second apart, or from other causes. The danger of excessive anode current, due to the presence of a supersonic frequency, is rendered negligible by the condenser connected across the secondary terminals of the driver transformer, since the capacity will attenuate any frequency above audibility to such an extent that for all practical purposes it assumes negligible proportions. It is apparent that this condenser or some similar device must be included in front of the Class B valve and not in the anode circuit, as it is necessary to remove the unwanted frequency *before* it reaches the grid. It will be observed that each half of the primary of the output transformer is shunted by a condenser which will in effect limit the impedance of the anode load. It is important that the function of this condenser should not be confused with the condenser in the grid circuit.

The output transformer must have a ratio suitable to raise the impedance of the loudspeaker to the optimum load required by the valve. It must, however, be so designed that the D.C. primary resistance is of a low order, usually about 150–200 ohms. This is necessary to avoid material changes of applied D.C. anode voltage arising from the considerable change in anode current, which will usually be from 1–30 milliamps, or more.

It is found in practice that distortion may be very easily introduced into receivers using Class B output. This may be due to failure to observe the special requirements detailed above or to the presence of high frequencies introduced into the driver valve anode circuit and elsewhere,

R.T. I—13

and also to spurious frequencies arising in the Class B output stage finding their way back into the preceding stages. It is necessary, therefore, that rigid precautions should be taken to prevent coupling between the anodes of the valves, an aspect of receiver design that is dealt with separately in the chapter devoted to de-coupling.

The driver valve and Class B output valve are usually looked upon as a single stage, since the function of one is dependent upon the other, and, furthermore, the driver valve must necessarily work under such conditions that its signal amplification is small; in fact, the stage gain of the complete output system is very low, often less than one-tenth of that obtainable from two pentodes working in quiescent push-pull. To compensate for this it is generally considered that the Class B arrangement is capable of more faithful reproduction than that available from quiescent push-pull pentodes. It may be added that both systems have their own peculiar forms of distortion, which cannot be defined mathematically by any of the usual methods which are applied to normal Class A output systems.

Negative Feed-back.—It has already been intimated that means are available for reducing the third harmonic content of a pentode output stage. This is achieved by means of a principle known as negative feed-back, and is applicable when using a single pentode valve, or when two pentode valves are used in push-pull. In the latter case, however, the second harmonic distortion is cancelled out, so that with negative feed-back the total harmonic content is very small. Negative feed-back may be defined as a method of reducing third harmonic distortion in a pentode valve by feeding a small part of the speech-frequency voltage in the anode circuit back into the grid circuit.

It is necessary that the energy fed back from the anode circuit should be in series with the normal signal voltage, since the alternative method would introduce undesirable secondary effects. A suitable circuit is shown at Fig. 163. It will be observed that the output stage is normal, except that the anode load of the low frequency amplifier is not connected to the high tension supply in the normal manner but to a potentiometer arrangement connected across the anode load of the output valve. The resistances, R and R_1, form a simple potentiometer to divide up the anode speech potential so that the necessary portion of it may be fed back to the grid circuit. The combined value of the two resistances should be about ten times the value of the anode load, since the former is in effect in parallel with the latter, while the value of R will normally be between five and ten times the value of R_1, so that the voltage fed back is between one-sixth and one-eleventh of the speech-frequency voltage across the output anode load.

The voltage fed back in this manner reduces the sensitivity of the output stage very considerably, normally to the extent of about a fifth. It is thus necessary that the preceding valve shall be capable of delivering about five times the output, in order to preserve the same speech output from the pentode. It should be understood that though the sensitivity is considerably reduced, the maximum speech output is not affected, and, furthermore, the third harmonic distortion is reduced by approximately the same factor as the reduction in gain. It is thus possible to reduce serious third harmonic distortion to a very low percentage.

The introduction of negative feed-back has an effect that is synonymous with a reduction of working impedance, resulting in a further improvement in the quality of reproduction, since the low anode impedance will considerably reduce loudspeaker resonance, which is normally noticeable with a pentode valve owing to its relatively high dynamic impedance. It should not be assumed from these remarks that the anode load should be deliberately reduced, although some variation is permissible. Some manufacturers quote a value as the optimum load which gives zero second harmonic distortion, in which case the figure can be adhered to, since negative feed-back will take care of third harmonic distortion. When, however, a pentode valve is working under conditions other than zero second harmonic distortion, it may be desirable to modify the load.

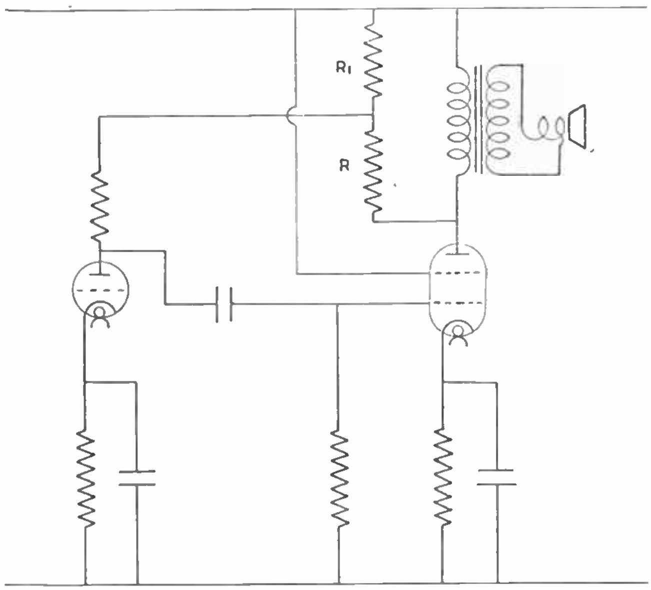


Fig. 163.—A satisfactory method of applying negative voltage feed-back to a tetrode or pentode output valve.

Negative feed-back may be applied to pentode valves in push-pull, but it is necessary that the transformer shall have two separate secondary windings, so that the low-potential ends can be returned to the potential divider across their respective anode circuits. When working pentodes in push-pull with negative feed-back, both third and even harmonic distortion is taken care of. It is thus possible to increase the anode load of each valve in order to obtain a little more output, making the total anode to anode load, say, two-and-a-half times, instead of twice the optimum load for a single valve.

Numerous methods of applying negative feed-back can be employed and are divisible into two classes. When the feed-back is so arranged that the *voltage* fed back is proportional to the *current* flowing through the output load, the arrangement is known as negative current feed-back, and while often convenient it has the disadvantage that it increases the effective internal resistance of the amplifier. When feed-back is arranged so that the *voltage* fed back is proportional to the *voltage* across the output load the arrangement is known as negative voltage feed-back and is preferable since it reduces the effective internal resistance of the amplifier.

Negative feed-back is quite applicable to a battery pentode, but its use in a battery receiver is usually rendered impracticable by the reduction in sensitivity.

Paraphase Push-pull.—The push-pull output stage shown at Fig. 161 uses transformer coupling between it and the preceding stage. It is possible to use resistance-capacity coupling by employing a special circuit arrangement; the normal anode resistance in the low-frequency amplifier stage is divided into two sections, one occupying its usual place in the anode circuit and the other being placed in the cathode lead. The cathode and anode are 180° out of phase; thus the anode is coupled through the usual coupling condenser and associated grid leak to the grid of one output valve, the grid of the other output valve is coupled in a similar manner to the cathode of the low-frequency amplifier.

An alternative method necessitates the use of an additional valve in the low-frequency stage. The low-frequency amplifying valve is coupled by means of a coupling condenser and associated grid leak to one of the output valves, the extra low-frequency valve being similarly coupled to the other output valve. The normal low-frequency valve is driven by the preceding stage, but the extra valve derives its operating voltage from a tap on the anode resistance of the low-frequency valve. In this way the anodes of the valves are exactly 180° out of phase and, by varying the tap on the anode resistance, the voltage output of the two valves can be made equal; in practice the tap is formed by means of a potentiometer across the anode resistance, which is so adjusted that no sound is heard from a pair of headphones inserted in the high-tension lead of the *output* valves. The headphones must necessarily be of relatively low resistance, as the high-resistance type would probably be burnt out by the heavy anode current.

CHAPTER 23

OUTPUT VALVES

OUTPUT valves may be broadly divided into three classes: the triode, pentode, and tetrode; such specialised types as the Class B output valve being modifications which, from the constructional point of view, may be considered as of a minor order. The construction of the triode, pentode, and tetrode shows considerable variation, while their characteristics are widely diverse, and the method of interpreting the characteristic curves to obtain such information as the optimum load is different in each case.

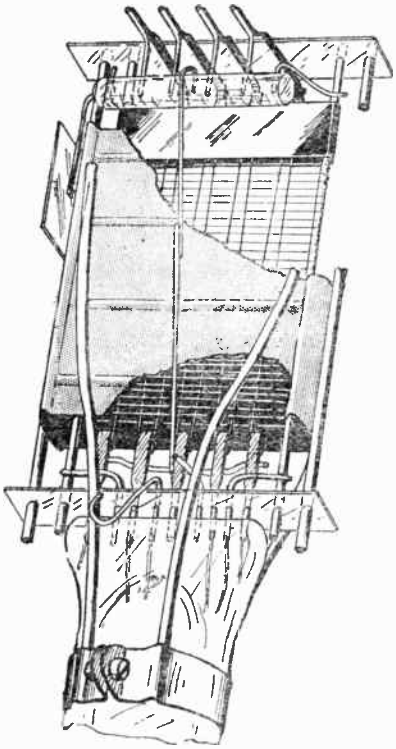


Fig. 164.—A typical directly heated output triode.

The Triode.—The triode valve has been described in an earlier chapter, but some remarks are called for regarding the output triode, which shows considerable modification when compared with triodes intended for use in earlier stages of the receiver. The illustration (Fig. 164) shows a typical mains output triode, points of interest being the carbonised anode to facilitate the dissipation of heat and the grid which is constructed to prevent its temperature rising to a point which would make grid emission possible. The copper supporting-wires, on which the grid is wound, give the necessary heat distribution. It should be noted that the example chosen is of the type intended for use in receivers capable of working off either alternating or direct current mains supply. This type of receiver is prone to introduce mains hum and, as a means of helping to combat this tendency, the valve in question has the grid connected to a terminal mounted on top of the bulb, so that it is well away from its heater terminals. The normal output triode, however, has all four connections taken to the pins on the base.

The anode of the valve illustrated at Fig. 164 has been treated by carbonisation, a process which imparts to the anode a very thin coating of carbon to prevent secondary emission, and for similar purposes approximately three-quarters of the inside of the bulb is treated with a form of carbon which is so finely powdered that it may be conveniently mixed with water. The phenomenon of secondary emission has been described in an earlier chapter ; it will be remembered that it takes the form of electrons emitted from a substance as a result of an electronic bombardment. Most metals will emit secondary electrons comparatively easily, but carbon will not emit secondary electrons under conditions that are likely to obtain in a normal output valve. The output triode, like all other valves, is prone to considerable modification when interpreted by various manufacturers ; one example departs from convention to the extent of having a grid placed between the control grid and anode. This valve is, nevertheless, a triode, since the extra grid is internally strapped to the anode, an arrangement which reduces the internal impedance without placing the anode so close to the control grid that the latter might suffer from grid emission through over-heating.

The Class B Triode.—The principle of Class B amplification requires valves having special characteristics ; these special characteristics do not result in the actual triode assembly possessing a distinctive appearance, although the valve as a whole is distinguished by the fact that the two necessary triode assemblies are mounted side by side in the same bulb. The mounting of the two electrode assemblies as one valve is due solely to considerations of economy and convenience. The valve is usually capped with a seven-pin base, the two anodes and two grids being brought out to separate pins. It is not necessary that the correct grid and anode should be associated together, since it is immaterial, as the input and output circuits are completely symmetrical.

The Quiescent Pentode.—The superficial appearance of a Q.P.P. output valve is similar to that of a Class B triode, inasmuch as two assemblies are mounted in a single bulb. The difference in construction lies in the addition of the auxiliary and suppressor grids ; the latter are connected together and strapped internally to the filament, while the former are usually connected together and brought out to a single pin. There is at least one type of quiescent pentode with the auxiliary grids brought out to separate pins, permitting slightly different potentials to be applied for the purpose of matching the anode current of the two sections.

The Pentode.—As its name implies, the pentode has five electrodes: the cathode, or filament, the control grid, auxiliary grid, suppressor grid, and anode. The term auxiliary grid is used in place of the term screening grid when referring to an output pentode ; although this grid has the same electronic action as the screening grid of an H.F. pentode, it is not constructed in a manner that allows it to be regarded as a screen for the purpose of reducing grid/anode capacity.

The battery-type pentode usually employs a circular inner grid and rectangular auxiliary grid, suppressor grid, and anode. The mains pentode, however, is a very much more elaborate affair, as precautions have to be taken to eliminate the possibility of secondary emission and grid emission. Fig. 165 shows a typical output pentode which may be regarded as a good example of valve design, and, consequently, a few remarks regarding its construction may be of interest.

The pentode shown at Fig. 165 has a flat cathode containing an M filament rated at 4 volts, 2 amps; the high heater wattage being necessary

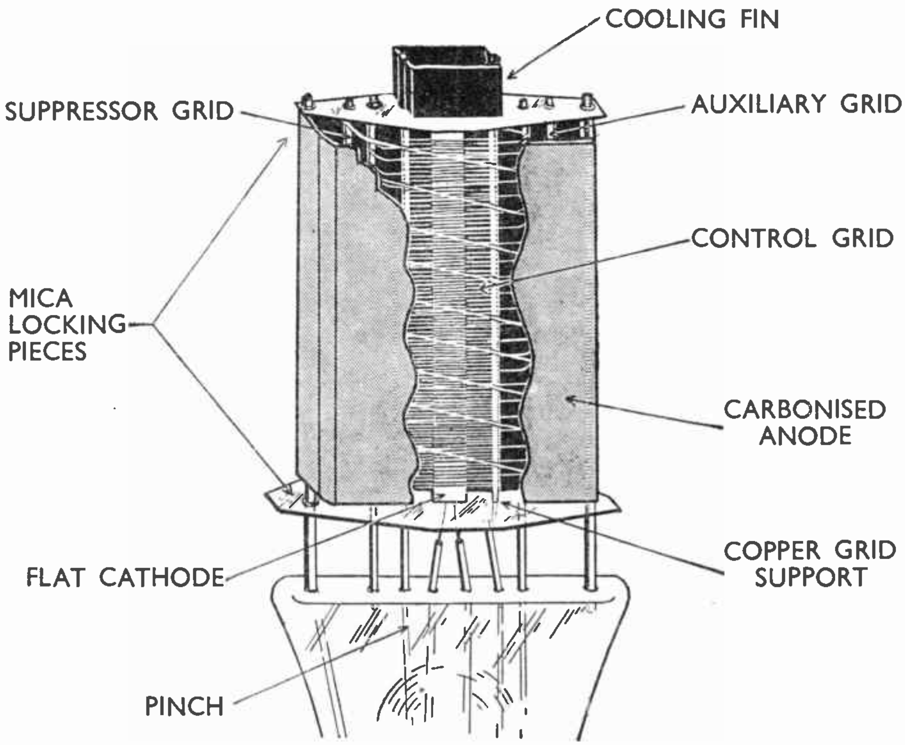


Fig. 165.—A high-slope output pentode rated to dissipate 20 watts.

to bring about the high value of mutual conductance, which is about 8 mA/V. The control grid is made of nickel-chrome alloy wire, and has copper supporting-wires of exceptionally thick gauge which terminate in cooling-fins; both precautions being intended to maintain the grid at a sufficiently low temperature to preclude the possibility of grid emission. These precautions are very necessary, since the valve has a total dissipation of nearly 20 watts: 8 watts for the heater, 8 for the anode, and over 2 for the screen. The auxiliary grid is of normal construction, the same remark being applicable to the suppressor grid, which is of very open spacing. The anode is carbonised, to improve its radiation properties as a further contribution towards maintaining the whole structure at a low operating temperature.

Almost the whole of the interior of the glass bulb is covered with a fine carbon deposit to prevent the emission of secondary electrons. The inner wall of the bulb is continually bombarded by electrons which have missed the auxiliary grid and anode and ultimately impinged on the bulb. This continuous bombardment would normally cause secondary emission from the glass to the highest positively charged electrode, namely, the anode. This unwanted contribution to the anode current would be of a random nature, since it would not necessarily be proportional to the instantaneous grid voltage ; in this way a portion of the anode current would be outside the control of the grid, a set of conditions which will introduce distortion.

The output pentode as interpreted by various manufacturers shows wide diversity of design. The remarks made about the example at Fig. 165 may, nevertheless, be regarded as being of a general nature.

The Output Tetrode.—The possibility of employing a tetrode valve was realised at about the same time as official broadcasting was commenced in this country, but until comparatively recently the characteristic of a tetrode was thought to be inseparable from the negative resistance kink which was fully explained in Chapter 14. This non-linearity of characteristic rendered the valve quite unsuitable for use in the output stage, where large anode swings are necessary in the interests of large output.

It has been found that suitable modifications of the tetrode assembly will almost entirely remove the negative resistance kink, although careful examination of the anode current curve of an output tetrode will show that a slight trace still remains. The necessary modification consists of placing the anode at an adequate distance from the other electrodes, so that its immediate vicinity is not greatly influenced by the voltage-field of the auxiliary grid. Furthermore, the anode is provided with fins which effectively prevent slow-moving electrons from returning to the auxiliary grid.

Relative Advantages.—The normal broad types of output valves have been briefly outlined above. It is now necessary that some remarks should be made regarding their relative advantages. It will not be necessary to dwell upon the application of the Class B and quiescent pentode valves, since their peculiar advantages are apparent.

The triode valve is inefficient from the point of view of speech-output available from a given anode dissipation. The usual type of triode seldom exceeds an efficiency of 25 per cent. On the other hand, the triode is entirely free from third harmonic distortion, and, for this reason alone, it is rapidly effecting a return to popularity. The sensitivity of a triode valve is also low, and consequently a relatively large input is required for a given output ; a disadvantage that may perhaps be off-set by the tolerance of the valve towards the condition of over-load which allows the valve to be run at a relatively high mean speech-output, since the occasional over-load due to very heavy orchestration may be considered tolerable when compared with a pentode working under similar conditions. The triode is also tolerant to incorrect anode load, but this cannot be considered as a true advantage, since there is no reason why the optimum load should be seriously modified.

The pentode is identified by its higher efficiency—examples being not uncommon which permit speech-output equal to 40 per cent. of the anode dissipation, and, slope for slope, the sensitivity of the pentode is higher than the triode. Against this it is necessary to weigh the disadvantages, which are the presence of third harmonic distortion, the tendency to permit loudspeaker resonance owing to high internal impedance, a very noticeable intolerance towards over-loading, and the tendency to attenuate the higher audio-frequencies owing to high output capacity, *i.e.* the capacity existing between the anode and all other electrodes

The output tetrode may be regarded as a modified pentode, and all the remarks made about the latter are applicable to the former, with the exception of those relating to loudspeaker resonance and high-note attenuation. The impedance of an output tetrode tends to be lower than that of a pentode, and provides a certain amount of damping which reduces loudspeaker resonance. Since a characteristic of the tetrode is the somewhat remote placing of the anode, it follows that the output capacity of this class of valve is relatively low. It would appear, therefore, that the tetrode may be regarded as a pentode capable of giving a superior quality of reproduction ; there is, however, some doubt in the author's mind, as practice does not seem to completely substantiate this claim.

Detector Output Valves.—Output pentodes and tetrodes are available with assemblies that are modified to include one or two small anodes which, with the cathode, form small diodes. This arrangement is intended to allow the output stage to perform the dual function of detector and output, and is made possible by the high sensitivity of such valves, since they may be easily loaded direct from the diode detector without demanding an excessive output from the intermediate-frequency amplifier.

Optimum Load.—The method of determining the optimum load is usually by means of a set of anode-volts/anode-current curves. Fig. 166 shows a typical family of curves taken from a directly heated triode having an anode dissipation of 12 watts, and rated for a maximum anode voltage of 250 volts. The first step is to find the operating-point which will normally be the maximum permissible. Since the valve is rated for 250 volts, 12 watts, the application of Ohm's law will show that the operating-point is 250 volts, 48 milliampères, which may be marked on the curve where these two lines intercept, marked I_0 in the illustration. Since the valve is directly heated, it may be allowed to swing from $Vg = 0$ to twice the grid bias, which is 57 volts (curve shown dotted). It may be

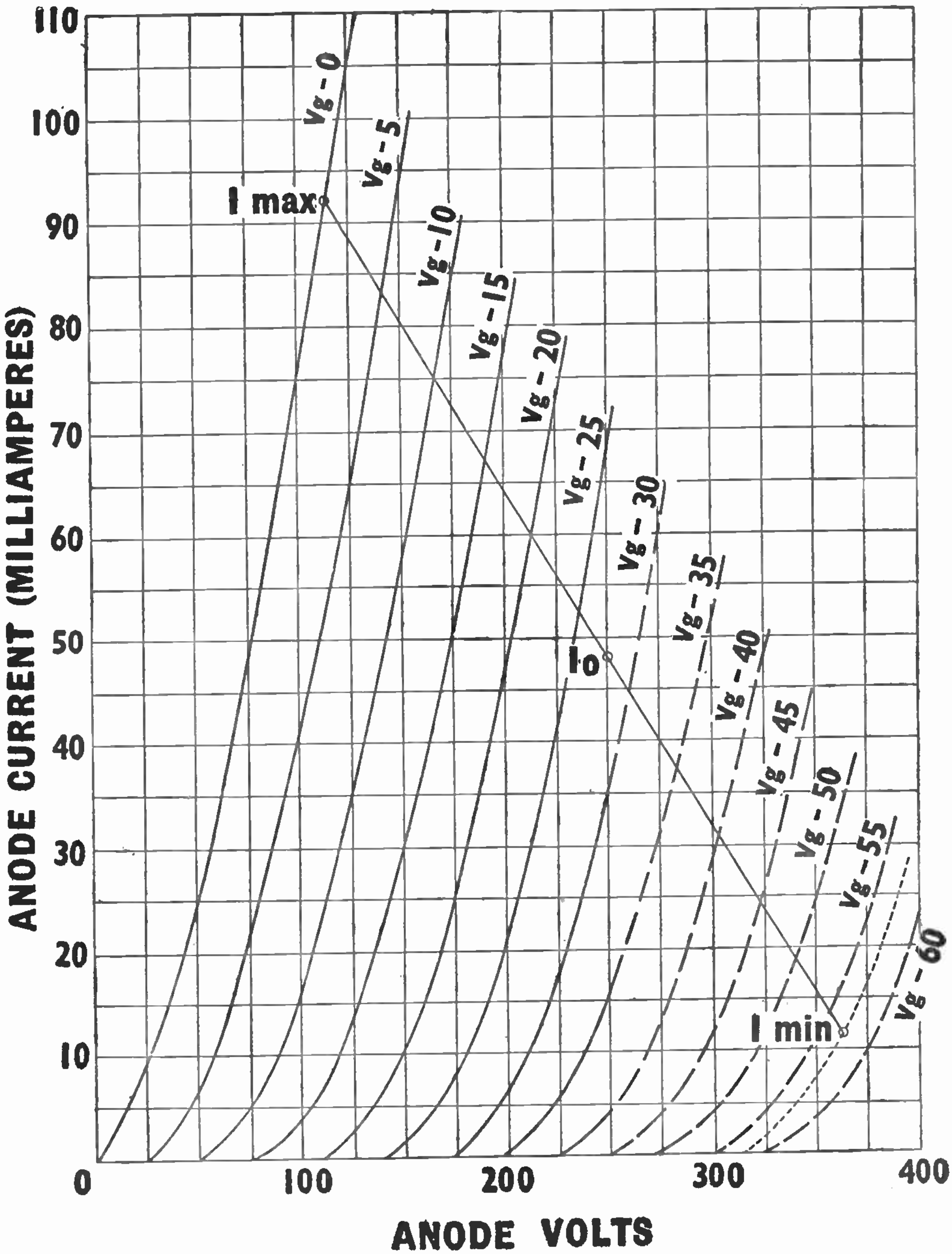


Fig. 166.—Anode-volt/anode-current curves of a directly heated output triode. The dotted curve is drawn in to show the position of Vg — 57, which is double the operating voltage of 28·5 volts.

observed by drawing an imaginary line through I_0 parallel to Vg — 30 that the grid bias is 28·5 volts. It is now necessary to draw a line between Vg = 0 and Vg — 57 at such an angle that the distance I max. to I_0 is equal to the distance I_0 to I min. multiplied by $\frac{11}{9}$, since this relationship will introduce 5 per cent. second harmonic distortion. The use of a ruler graded in millimetres will show that the distance I_0 to I min. is 63 millimetres, which multiplied by $\frac{11}{9}$ = 77 millimetres. The distance I_0 to I max. is also 77 millimetres, thus the line I max., I min. fulfils the required condition.

A celluloid ruler is available, which is so graded that the divisions on one side of the centre zero are equal in length to $\frac{11}{9}$ of the divisions on the other side. When such a ruler is available, it is merely necessary to place the centre zero on the operating-point and revolve it until the division nearest to Vg — 0 bears the same numbers as the division nearest to Vg — 57.

The next step is to determine the impedance represented by the load line. It will be noticed that it shows a change in current of 80 milliampères, *i.e.* a swing from 12 to 92 milliampères and a change in voltage of 250 volts, *i.e.* a swing from 115 to 365 volts. To obtain impedance it is necessary to divide the voltage by the current, bearing in mind that the former must be expressed in millivolts, since the current is in milliampères. 250,000 divided by 80 = 3,125 ohms or, in round figures, 3,000 ohms.

Undistorted Output.—The same values required to determine the optimum load may be used to determine the speech-output by means of the following formula :

$$\frac{1}{8}\,(\text{I max.} - \text{I min.})\,(\text{V max.} - \text{V min.})$$

the various factors being determined from Fig. 166. It will be remembered that the voltage change from the points marked I max. and I min. was 250 volts, and the current change, I max. — I min., was 80 milliampères, which is ·08 ampère. 250 × ·08 is 20, which multiplied by $\frac{1}{8}$ = 2·5 watts.

It is possible to calculate the optimum load and undistorted output by means of Brain's formula, which will be found in "The Radio Circuits and Data Volume," but this formula, although extremely useful, is not always reliable and is sometimes capable of considerable error, particularly when applied to indirectly heated triodes. Nowadays valve manufacturers publish this figure which may be accepted with confidence.

The Optimum Load (Pentode).—The calculation of the optimum load for a pentode valve presents certain difficulties, since there is no ready method of determining the angle of the load line, and several experimental load lines must be drawn and further curves plotted from the information thus obtained. Fig. 167 shows a dynamic grid-volts characteristic, which is arrived at by plotting the anode current for various grid voltages read from the points where the load line intercepts the grid voltage curves.

From the curve thus obtained the third harmonic distortion can be determined by the following formula:

$$\text{Third Harmonic Distortion (per cent.)} = \frac{X - Y}{I\ max. - I_0} \times 100$$

when I max. — I_0 is the swing between the operating-point and I max., and X — Y is the deviation between the actual anode current at the mid-point between I_0 and I max., and the ideal condition, which is a straight line joining I max., I_0, and I min. There are other methods of determining both optimum load and harmonic distortion for a pentode or tetrode valve, but the simplest is that described above.

It should be understood that the total harmonic distortion of a pentode valve cannot be obtained by the mere addition of the figures for each type of distortion, but must be combined by adding them vectorially.

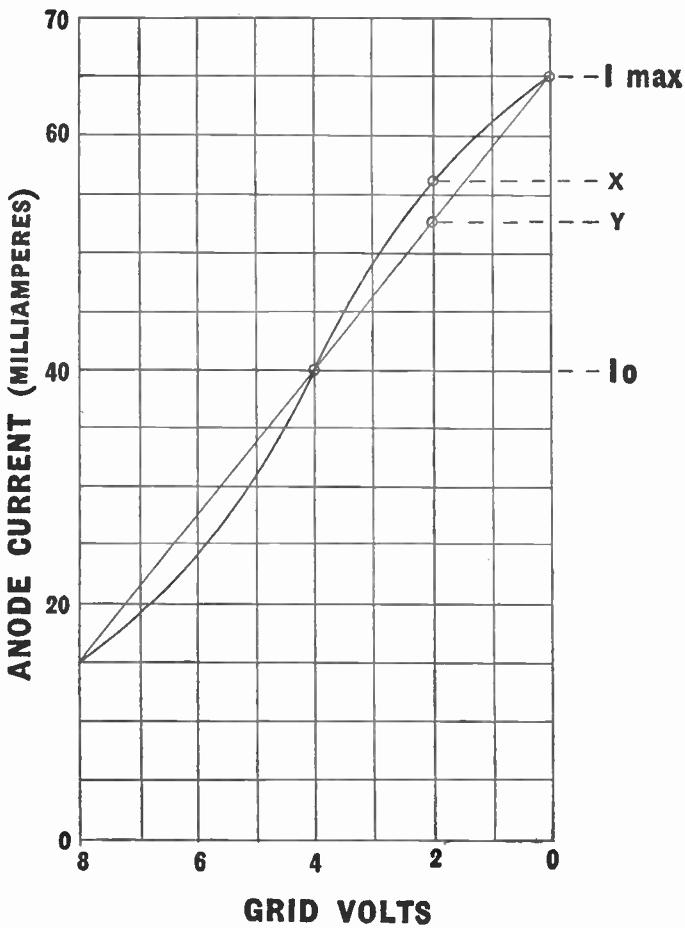


Fig. 167.—The text describes how the third harmonic distortion can be calculated from data obtained from the above drawing.

Harmonic Distortion, Class B.—Reference was made in the previous chapter to the performance of the Class B output system, and the manner in which the plate current varied with input. It is therefore interesting to study the set of curves shown at Fig. 168, which shows the grid current, harmonic distortion, plate current, and power output plotted against various input voltages. It should be noted that the driver and Class B valve have been considered as a single stage, and the curves in question show the combined performance of the two valves, that is to say, the input volts are the R.M.S. value of the signal fed to the driver, the plate current is the combined current for both valves, and the harmonic curve shows the combined distortion of all harmonics for both valves; the power output curve naturally relates to the Class B valve only. It is interesting to note that the harmonic content rises rather abruptly when

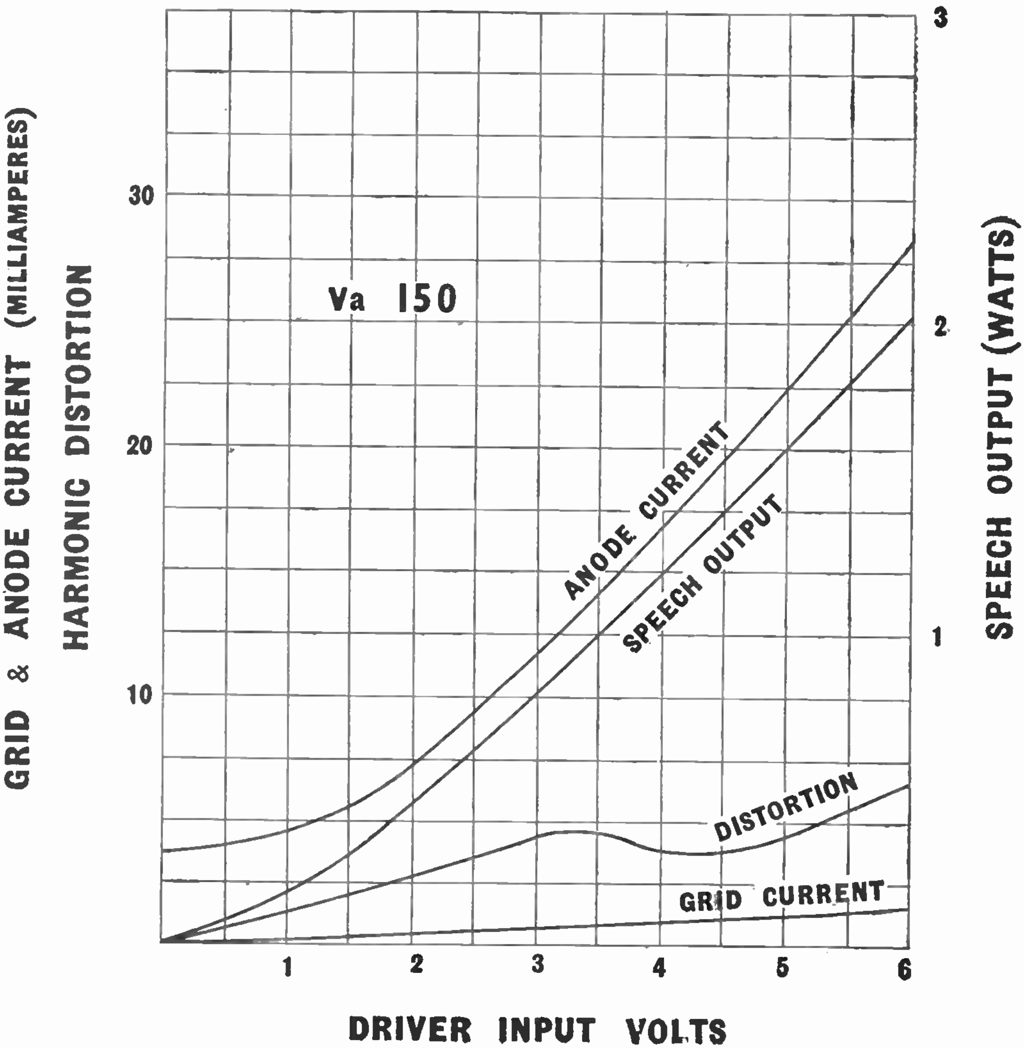


Fig. 168.—Performance curves of a Class B output stage. The curves show the combined performance of driver and output valves.

the input exceeds 5 volts; it is therefore reasonable to conclude that the maximum permissible input to the driver valve is in the region of 6 volts R.M.S. This illustration is interesting, since the whole question of Class B harmonic distortion seems to have been wrapped in mystery. The curve shown at Fig. 168 was taken from a typical small power valve as driver and a typical Class B valve, and, since an output of 2 watts is obtainable without exceeding 6 per cent. total harmonic distortion, there appears to be no reason for this reticence.

Automatic Bias.—In all stages other than the output stage the bias resistance bypass condenser may be regarded as a means of holding the cathode at earth potential from the A.C. standpoint, and, generally speaking, a relatively small capacity is adequate. The bypass condenser across the bias resistance of the output stage must necessarily be rather large to avoid the attenuation of the lowest frequency. The bias resistor is virtually in series with the anode load, and, when the latter takes the form of a loudspeaker transformer, its impedance at the lowest audible frequencies is comparable with the resistance; a condition which will cause considerable loss of bass. To overcome this possibility it is necessary to use a large condenser, usually 25 or 50 microfarads, so that the reactance is low compared with the anode load. For this purpose the electrolytic condenser will normally be used for the sake of economy and compactness.

CHAPTER 24

THE LOUDSPEAKER

Before describing the more important types of loudspeakers it will be advantageous to outline the requirements for ordinary domestic purposes. It is desirable, but not essential, that a loudspeaker should possess reasonable sensitivity, judged on the basis of apparent volume for a given input of energy from the output stage of a radio receiver or amplifier. It is important that the loudspeaker should have reasonably even frequency response over the audio range associated with broadcasting, which will generally be 25–7,000 cycles per second, or 25–12,000 cycles per second for FM broadcasting, and not introduce spurious frequencies. In order to eliminate the possibility of audible distress, *i.e.* rattling and buzzing, the loudspeaker must have adequate power-handling capacity; it is generally accepted that the power-handling capacity should be 50 per cent. greater than the maximum power that it will be called upon to handle.

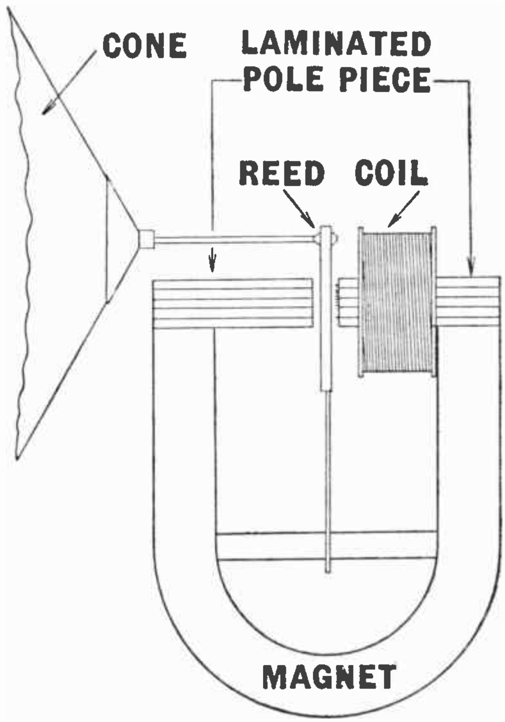


Fig. 169.—A reed-type loudspeaker; some examples have a coil on both pole pieces

Reed Types.—The most simple type of loudspeaker, ignoring the metal diaphragm horn type, which can be considered as obsolete, is the reed type which is shown at Fig. 169; these are still sometimes used in small low-priced midget receivers, but reference is made primarily to serve as a basic introduction to loudspeaker technique. The driving mechanism comprises a permanent magnet, around the poles of which are placed two coils which will have a D.C. resistance in the neighbourhood of 1,000 ohms. Unless adversely influenced by price considerations, the magnet will have a fair cross-section area, and will be perhaps half an inch by one inch and made of tungsten or cobalt steel. The moving element consists of an iron reed firmly anchored to the apex of the diaphragm ; it is important that the total mass should be as light as possible consistent with the necessary rigidity. It is equally important that the reed should be incapable of even small movement without the diaphragm, and vice versa. The reed must possess sufficient length to permit of the necessary flexibility, while, on the other hand, it must be sufficiently springy to prevent the magnetism of the pole pieces from drawing it into contact. These requirements call for some care in design, since, in the interests of sensitivity, the gap between the pole piece and reed must be relatively small, as the strength of the magnetic field will vary in inverse proportion to the length of the gap.

The reed is generally connected to the diaphragm by a short, stiff bar fixed to the latter by fairly large conical washers to achieve rigidity. The diaphragm, which is colloquially referred to as the cone, must be both light and rigid, and is usually made of suitable paper which is specially manufactured for the purpose. The cone is connected to the edge of some fixed surround by means of flexible material, which is intended to isolate the front from the back while allowing free movement. It is probable that the very best substance for this purpose is thin chamois leather, but preference is given to light, flexible, densely woven cloth when expense prohibits the use of leather.

The "fixed support," referred to above, usually takes the form of a suitable circular hole in a flat wooden board or cabinet which is of such dimension that the shortest distance between one side of the cone and the other is not less than some 18 inches. This barrier is known as the baffle, and is made necessary by the fact that the displacement of air on one side of the cone is out of phase with the displacement on the other side, which would cause acoustic interference in the absence of an adequate baffle.

The mechanism shown at Fig. 169 is actuated by the audio-frequency current in the output stage passing through the coils and automatically increasing and decreasing the strength of the magnet and, consequently, the pull on the reed. The latter, being under tension from its own springiness, will move backwards and forwards in sympathy with the instantaneous pull of the magnet, and, in so doing, will move the cone backwards and forwards. It is practically essential that some adjustment be provided to vary the relative positions of magnet and reed to permit a suitable compromise between sensitivity and power-handling capacity.

The simple reed speaker abounds with disadvantages ; it has been mentioned that the D.C. resistance of the coils will be in the neighbourhood of 1,000 ohms, but this figure is quite unrelated to the speech-frequency impedance, which varies widely at different frequencies, and, by offering an inconstant load to the output valve, results in uneven output. The impedance variation is quite remarkable, and there are many types in existence which have an impedance of less than 50 ohms at 60 cycles and more than 500,000 ohms at 5,000 cycles. They have, nevertheless, proved acceptable to thousands of people, with no aid other than a condenser connected across the winding to limit impedance at the higher frequencies.

As the reed moves towards and away from the magnet the pull of the latter will vary, not in a linear manner, but in proportion to the square of the distance; consequently the movement of the cone is not directly proportional to the current, since the movement in one direction will be different from the movement in the other direction, and if the input is sinusoidal the acoustic wave form of the output will exhibit distortion similar to second harmonic distortion. The percentage of distortion introduced in this manner is obviously proportional to the movement of the reed, and will, for this reason, be most noticeable on the lower frequencies. Some slight improvement can be effected by so arranging the reed that it approaches the pole piece at a suitable angle, but it is doubtful whether any worthwhile improvement can be achieved. Other spurious frequencies are introduced by various resonances, particularly those associated with the coupling bar and the cabinet or baffle.

Balanced Armature Mechanism.—The mechanism shown at Fig. 170 is a modification of the simple reed movement designed to overcome non-linear relationship between current and armature movement. It will be observed that the armature is pivoted at the centre and free to move for a short distance in either direction; it is held at rest midway between the magnets by means of a flexible suspension which will be provided with some form of adjustment for centring purposes. The relationship between current and cone movement is sensibly linear over a small range, but departs from linearity when the output is increased, resulting in the introduction of spurious harmonics. This type of mechanism suffers from the disadvantage that the natural frequency of the moving member is rather high, resulting in serious attenuation of the lower frequencies. The natural frequency may be lowered by the introduction of mechanical damping, but this results in considerable loss of sensitivity. The balanced armature loudspeaker enjoyed a certain popularity at the

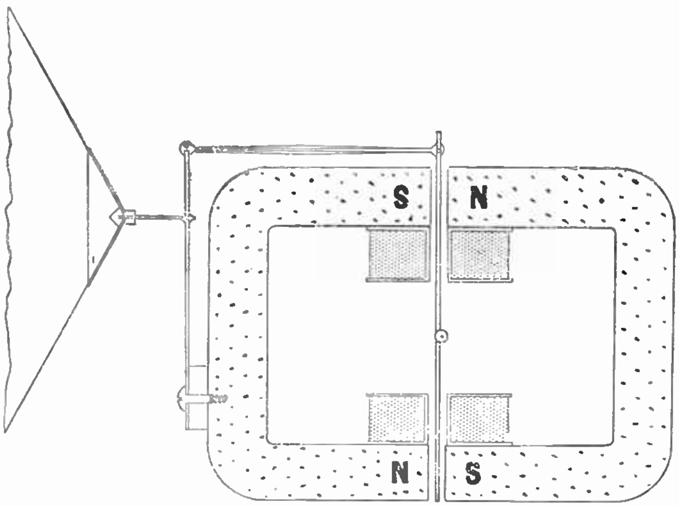


Fig. 170.—Section of a balanced armature loudspeaker.

time of its introduction ; it is, however, relatively costly, and has, therefore, been completely superseded by the moving-coil loudspeaker, which is very much more efficient.

The Inductor Dynamic Loudspeaker.—The inductor dynamic loudspeaker was introduced some ten years ago—when it was hailed as a great discovery, since it was able to handle quite considerable output and avoided many of the disadvantages of the moving-reed and balanced armature types. Owing to the considerable available movement of the cone, it was able to handle the lower frequencies with comparative ease, but, owing to the weight of the moving member, suffered from very bad high-note attenuation. As the result of these two features, reproduction was of a deep and somewhat sepulchral tone, which some listeners mistook for bass reproduction. Admittedly, at least one interpretation of the inductor dynamic speaker was capable of reasonably good reproduction, but once again the moving-coil loudspeaker offered at a popular price became the principal type of loudspeaker.

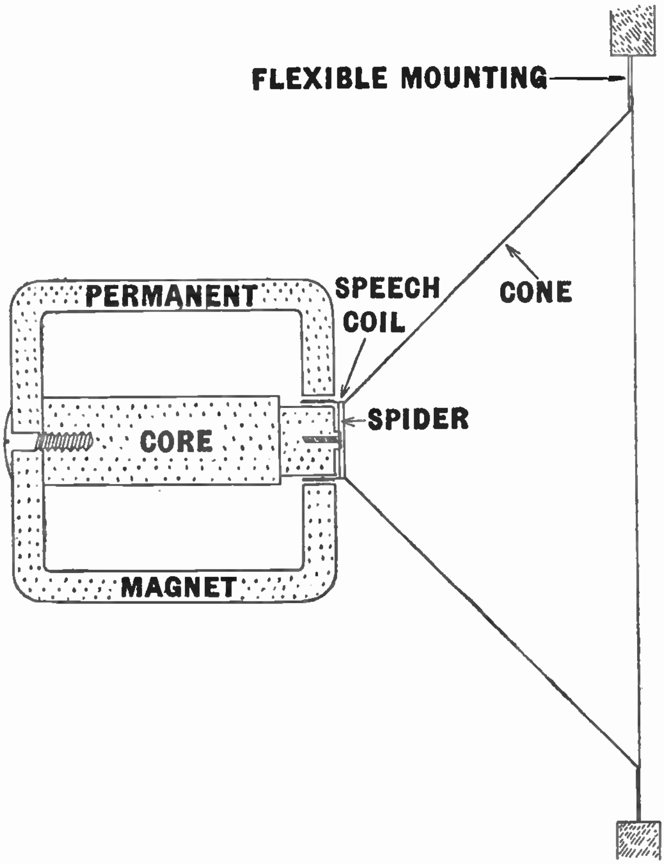


Fig. 171.—Simplified section of a permanent-magnet moving-coil loudspeaker; the chassis has been omitted for simplicity but may be seen in Fig. 174.

The Moving-coil Loudspeaker.—Fig. 171 shows the cross-sectional area of a permanent-magnet moving-coil loudspeaker. It consists of a relatively massive magnet of high flux density provided with a very small circular air gap—which is often no more than ·03 inch.

The moving portion consists of a coil of light but strong construction fixed to the apex of a cone which is freely suspended by chamois leather or other supple material. The coil usually consists of an impregnated paper or aluminium-foil former, wound with some 20–50 turns of fine wire, and having an impedance in the neighbourhood of 2 ohms. Since this coil must be capable of moving backwards and forwards between the pole pieces with very little clearance, some means must be available for flexibly anchoring the coil to prevent side movement. This is usually accomplished by means of a flexible paper centring device, which is permanently secured to the coil and anchored at its centre by a screw which is tapped into the centre of the magnet. Such a device is termed the spider, a typical example of which is shown at Fig. 172. Generally speaking, the hole in the centre of the spider will be somewhat larger than the screw, allowing a slight adjustment for the purpose of accurately centring the coil.

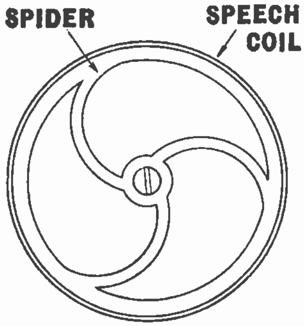


Fig. 172.—A typical "spider."

It is apparent from the illustration that the moving section of a moving-coil speaker can be extremely light, and can be capable of considerable backward and forward movement, providing that the spider is suitably designed and the annular surround sufficiently flexible.

The impedance of the coil, which is usually termed the speech-coil, will be somewhat similar to its D.C. resistance, and must be fed by a transformer in order to provide the output valve with a load of adequate impedance. Low-impedance coils are almost entirely independent of frequency, the usual variation being from, say, 2 to 2·1 ohms at 25,000 and 7,000 cycles per second, respectively. When current is passed through the coil it is caused to move inwards or outwards according to the direction of flow and the polarity of the magnet. Movement of the order of a ¼ inch is not unusual with the larger type of domestic moving-coil speaker. Since the impedance of the coil is sensibly constant for the audible range, it might be expected that the input to output ratio might be equally constant, and, in fact, is nearly so. Some frequency discrimination, however, arises from losses in the iron of the magnet and phase shift between coil current and the resultant magnetic flux. It is interesting to note that the radial field of the magnet is at right angles to the coil, with the result that interaction between the magnetic field and the field from the coil is of negligible proportions.

The moving-coil loudspeaker undoubtedly represents the most efficient form of sound reproducer for normal purposes, but it should not be considered as nearing perfection. A stress has been laid upon the level frequency characteristics of the coil, but the acoustic response is subject to certain irregularities which are due to spurious frequencies introduced at low frequencies by the spider and the annular suspension offering mechanical resistance towards the termination of the comparatively large movement of the cone at these frequencies. Furthermore, the cone itself cannot be considered as a rigid structure, since limitations of rigidity are imposed by the necessity of reducing weight to a minimum.

The entire moving assembly will undoubtedly possess resonance, and so will the baffle. With good design, however, the former is very small when compared with the latter. When the loudspeaker forms an integral part of a radio receiver, and has components, valves, and other obstructions placed immediately behind it, undesirable frequencies are introduced by the resonance of these varying objects. This distortion often reaches such large proportions that an obvious improvement can be effected by removing the loudspeaker from the receiver and fitting it on a separate baffle-board.

In the interests of minimising baffle or cabinet resonance, some care should be given to the design of these accessories. The modern tendency of using ply-wood is to be deprecated, as this material is prone to resonance. Soft pine wood of adequate thickness is a convenient and efficient material and, when made in the form of a cabinet, the depth of the structure should be as small as possible; but where consideration of con-

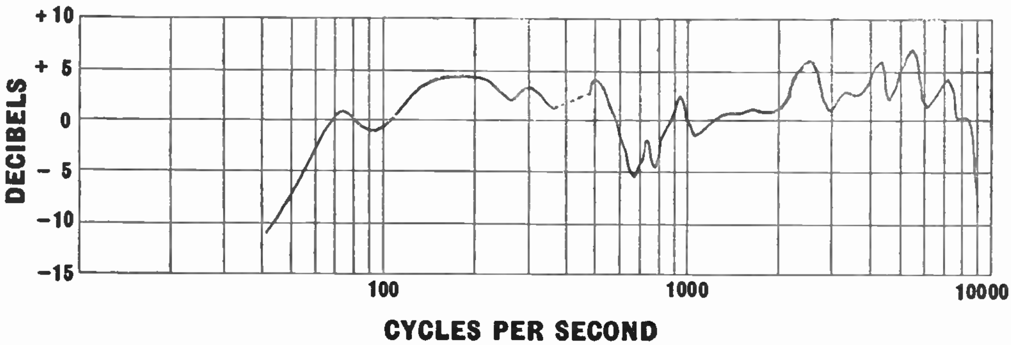


Fig. 173.—A typical response-curve.

venience calls for the cabinet to be deep in comparison to the width some improvement may be effected by lining the loudspeaker compartment with sound-absorbing material.

Fig. 173 shows the response-curve of a typical low-impedance coil loudspeaker having a cone diameter of approximately 10 inches. It will be observed that a small section is shown dotted, since the considerable deviation at this point is due to the resonance of the baffle on which it is mounted, and cannot be fairly considered as a defect in the loudspeaker. Some readers may be surprised at the irregularities in response when comparing them with certain published curves of loudspeakers which show a practically straight line. It is necessary to point out that the curve shown at Fig. 173 represents the actual response determined by means of a microphone of excellent characteristics placed in a room with a loudspeaker, the room being completely lined with many layers of sound-absorbing material. The almost straight-line characteristics are response-curves showing the actual impedance of the speaker at various frequencies, as distinct from its acoustic output.

Energised Moving-coil Speakers.—The loudspeaker shown at Fig. 171 is of the permanent-magnet type, that is to say, the magnet is of hard steel and magnetised during the process of manufacture. There is an alternative type known as the energised moving-coil speaker which differs inasmuch as the permanent magnet is replaced by an electro-magnet ; the hard steel inner and outer poles being replaced by soft iron or mild steel, which is magnetised by means of a coil placed round the pole piece, the whole arrangement being shown at Fig. 174. A few years ago the energised speaker was very much more efficient than the permanent-magnet speaker, but the difference in efficiency has narrowed considerably due to recent improvements, with the result that the superiority of one type over the other is not very marked, but, nevertheless, the mains-energised type still retains sufficient superiority to bring about slightly improved bass response.

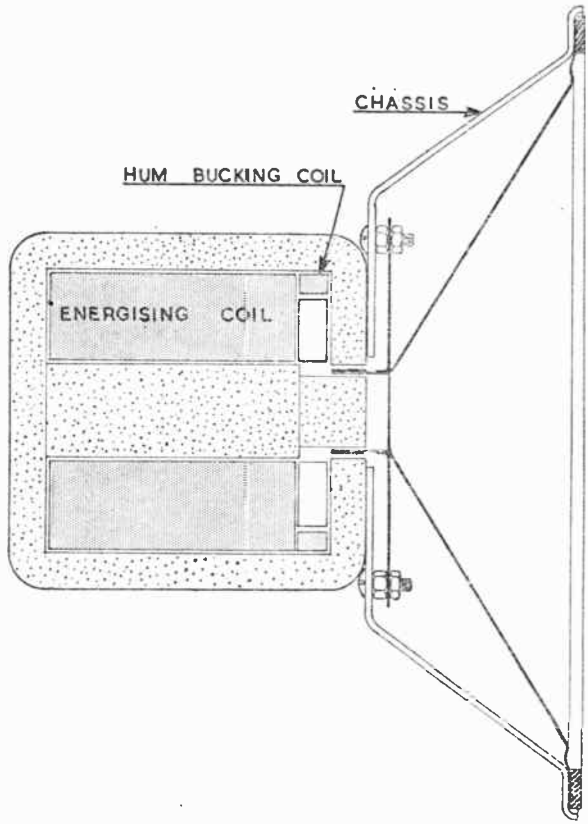


Fig. 174.—Section of an energised loudspeaker with hum bucking coil.

The mains-energised type has two minor advantages ; the permanent-magnet type is apt to deteriorate both with use and age, although it retains its magnetic properties long enough to outlast the average life of a modern receiver. It sometimes occurs in the course of ordinary usage that a particle of some ferrous material, *i.e.* a fragment of iron, becomes drawn into the gap, and, by lightly touching both coil and magnet, causes an unpleasant jarring noise which will be most noticeable when the speaker is reproducing some particular frequency. Once this particle has become lodged it cannot be easily removed, as it is held in the grip of a powerful magnet. This criticism does not apply to the energised type, since the magnets are practically demagnetised when the energising current is switched off.

The energising current must be D.C. current, and may be supplied in several ways. As mentioned in an earlier chapter, the flux density of an energised magnet is dependent upon ampère turns; it is apparent, therefore, that the coil may consist of a relatively small number of turns of thick wire through which a considerable current is passed or, alternatively, a large number of turns of thin wire through which a small current is passed. It is equally apparent that a low voltage will drive the current through the former type of coil, since the resistance of the wire will be relatively low, but the converse applies in the latter case, assuming, of course, that the weight of wire is approximately the same in each case.

The most obvious method of energising the speaker is direct from the same supply that is used to provide high-tension current for the various valves. The gauge of wire and number of turns are so proportioned that the required flux density is achieved by the current which will flow when the total available voltage is applied across the ends of the energising coil. This arrangement is not usually employed, except in receivers intended to work from D.C. current mains.

When an energised speaker is used in a receiver working from A.C. mains, it is convenient to energise it by allowing the total anode current of the valves to pass through it or, alternatively, the current to the last valve. When the magnet is energised by the total anode current, it is convenient to allow the energising coil to serve the dual purpose of energising the magnet and assisting in the suppression of mains hum, a subject which is dealt with separately in the appropriate chapter.

When it is convenient to energise the speaker by the anode current of the output valve, it is again possible to serve a dual purpose, since the coil can act as an output choke permitting the speech-coil to be fed through a suitable condenser so that D.C. is excluded, which will result in increased bass response, since the inductance of the loudspeaker transformer will be increased owing to the absence of D.C. passing through the primary winding.

The Loudspeaker Magnet.—It is impossible to generalise on magnets associated with reed, balanced armature, and inductor dynamic mechanisms, but some observations may be made regarding the magnets of moving-coil types. The flux density across the gap of a permanent-magnet speaker is dependent upon the quality of the magnet and the dimension of the gap. As an example, however, it will be convenient to refer to a magnet where the gap has a mean diameter of 1 inch, a depth of ·3 inch, and an actual gap-width of ·04 inch. Magnets of approximately these dimensions have a flux density of more than 8,000 lines per square centimetre; greater density is possible, and speakers are available with magnets having a flux density of some 15,000 lines per square centimetre, but their use is limited, since the gap-width is reduced to such an extent that the speaker is liable to show signs of mechanical distress when the output exceeds that associated with battery receivers.

The energised speaker usually has a slightly larger gap-width, since it will be used in a high power amplifier, and will normally be called up to handle a very large output. Assuming, however, that the gap-width and other dimensions are as given above, it will be possible to realise a flux density of the order of 10,000 lines per square centimetre when the magnetising force is 3,000 ampère turns. It is interesting to note that under these conditions less than 75 per cent. of the total lines of force will pass across the gap, the remainder forming a field outside it which is referred to as the flux leakage. It should be understood that this figure is only a vague generalisation, as it is influenced by a number of factors, including actual shape of the magnet and the material from which it is made.

Efficiency.—Comment has already been made on moving-coil loudspeaker efficiency from the point of view of quality of reproduction, and some mention may usefully be made regarding the power efficiency. Here, again, it is only possible to attempt a vague generalisation. A high flux density loudspeaker conforming to the specification already referred to will be capable of handling an input of about 4 watts, and will give an acoustic output of ·75 watt; while at half the input, namely 2 watts, it will give an acoustic output of ·5 watt. These figures are quoted from tests made on a popular commercial speaker employing an 8-inch cone having a total weight of 2 grammes, including the speech-coil and employing very light suspension.

Output Transformers.—It has been suggested that 2 ohms is a reasonable impedance for the speech-coil of a moving-coil speaker, although examples of commercially manufactured speakers show variation between 1 and 5 ohms. It will, however, be convenient to continue to use 2 ohms as an example. It is apparent from the previous chapter that the anode load required by an output valve is some thousands of ohms, and means must be found to reconcile the anode load required by the valve with the impedance of the speech-coil; this is accomplished by the use of an output transformer, the ratio of which will be such that the impedance of the coil is raised to the required value. The ratio of an output transformer may be determined by the following simple equation:

$$\text{Ratio} \sqrt{\frac{\text{Required impedance}}{\text{Speech-coil impedance}}}$$

This formula shows the true ratio that is required, but may be used to determine the turns ratio, for which purpose it is accurate when the ratio does not exceed about 50 : 1; above this figure the inaccuracy is appreciable, due to losses which cause the turns ratio to be different from the true ratio as obtained by measurement.

The output transformer may have a profound influence on the response-curve of the output stage as a whole. In order to preserve the lower frequencies it is necessary to have high primary inductance, which means a large number of turns; and a large number of turns is apt to mean high self-capacity, which will attenuate the higher frequencies. The average well-designed transformer is generally satisfactory, due to the use of interleaved windings to reduce the self-capacity. There is, however, a tendency for the average output transformer to fall off below 100 cycles per second, but an improvement can be made by parallel feeding the primary to relieve it of the D.C. component of the output valve anode circuit.

Hum Bucking.—When the energising current of a mains-energised speaker is derived from rectified A.C., there is a considerable possibility of hum arising from ripple, particularly when the energising coil is used for smoothing purposes. This is overcome by means of a hum-bucking coil, which consists of some twenty or thirty turns of wire tightly coupled to the energising coil, and connected in series with the speech-coil. The hum-bucking coil is so connected to the speech-coil that it deliberately introduces a ripple voltage which is out of phase with the directly introduced ripple voltage and, if the proportions are correct, the ripple is cancelled out.

The Crystal Tweeter.—The piezo-electric loud speaker, which is almost invariably referred to by its colloquial name of crystal tweeter or, in America, simply as the tweeter, is intended to be used in conjunction with a moving-coil speaker for the purpose of increasing the frequency response at the top end of the audible scale. This type of speaker has a response that is relatively small around 2,000 cycles per second, rising rapidly as the frequency is increased. It may be used to overcome the shortcomings of a moving-coil speaker, or to extend the range into regions well above 6,000 cycles per second—where the response of a moving-coil speaker begins to fall off rather rapidly. The piezo-electric tweeter is also used deliberately to accentuate the response of the upper half of the normal audio-frequency range to overcome high-note loss in cinemas and similar buildings ; it will be remembered that the higher frequencies are easily absorbed by soft material, *i.e.* drapings and furnishings.

The functioning of this speaker is dependent upon the fact that a suitable section of a Rochelle salt crystal will vibrate in sympathy with an alternating potential connected across it.

Directional Loudspeakers.—The most familiar type of directional speaker is probably the horn type that was in general use at the inception of broadcasting. Many readers will recollect that it consisted of little more than a telephone earpiece provided with a horn forming an air column to provide a load for the diaphragm. The modern horn speaker uses a moving-coil movement, and is intended for use when directional properties are advantageous. Such a loudspeaker is illustrated diagrammatically at Fig. 175. This type of speaker is capable of giving extremely faithful reproduction when the horn is suitably shaped, that is to say, when its diameter increases according to an exponential law and its length is sufficient to provide a sensibly constant load on the diaphragm over the whole audio-frequency range. An excellent example of this loudspeaker was built for the Science Museum, the horn having a length of approximately 22·5 feet.

Another type of directional speaker is substantially an ordinary moving-coil speaker with a directional baffle; this type of speaker is in general use for addressing crowds in the open, where directional properties are necessary to avoid the serious loss which would result if the sound were broadcast in all directions.

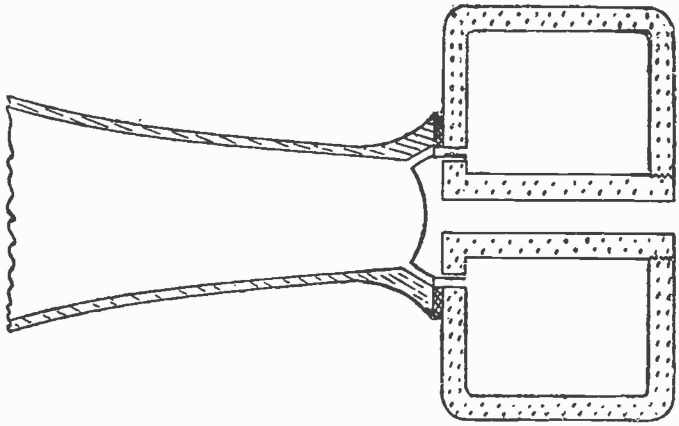


Fig. 175.—Section of a horn-type moving-coil loudspeaker; the shape of the horn usually follows an exponential law. Note the concave diaphragm.

Nomenclature.—In order to avoid confusion certain terms have been omitted from this chapter but are given below:

The magnet is made up of two sections, the cylindrical inner portion and the outer piece. The former is usually referred to as the core or pole piece, while the latter is referred to as the magnet.

The speech-coil is often referred to as the voice-coil or, occasionally, as the driving-coil or moving-coil.

Permanent-magnet moving-coil loudspeaker is often abbreviated as P.M. speaker. The energised loudspeaker is sometimes called mains-energised speaker.

The term diaphragm is strictly applicable to that part of the speaker which actually produces sound waves. It is, however, usual to reserve this term for the appropriate portion of a horn speaker, and to refer to the diaphragm of a moving-coil speaker as the cone.

The energising coil is often referred to as the field-coil or, simply, as the field, or pot.

The term moving-coil loudspeaker invariable refers to the loudspeaker complete with output transformer, which may or may not have tappings to give alternate ratios.

The metal structure which holds the magnet and the edge of the diaphragm is known as the loudspeaker chassis.

The term baffle normally implies a flat sheet of wood or other material surrounding the diaphragm, but the term is sometimes intended to be interpreted as a box-like structure, *i.e.* the cabinet in which the loudspeaker is housed.

The centring device for holding the speech-coil in correct relationship with the pole pieces is alternatively referred to as the spider and centring ring.

Lesser-known Types.—There are in existence a surprising number of loudspeakers using little-known principles: a noteworthy example was developed in the early days of broadcasting and was capable of giving excellent reproduction direct from a crystal receiver without any additional amplification. The instrument comprised a horn, which was terminated by a small metal diaphragm the centre of which was fixed to a long but very light stilus, the other end of which was held rigidly. Just beneath the stilus a disc revolved slowly, driven by a clockwork motor; a cork pad rested lightly on the disc and was firmly fixed to the stilus. A telephone earpiece was placed above the cork pad, to which it was attached by a reed. This delicate instrument functioned by the movement of the earpiece diaphragm varying the pressure between the cork pad and the rotating disc, the disc "dragged" the cork pad in proportion to the mutual pressure which in turn pulled the loudspeaker diaphragm to an extent many times the movement of the earpiece diaphragm. This superbly delicate instrument gave excellent quality of reproduction and represented a remarkable and original achievement.

CHAPTER 25

AUTOMATIC VOLUME CONTROL

THE phenomenon of fading has been dealt with in an earlier chapter, from which it will be remembered that signals from certain stations are received at varying amplitudes. It is apparent that the trouble can be overcome within certain limits by varying the gain of the receiver manually. Such a procedure, however, is inconvenient and impracticable when the fading is relatively rapid, and means must be found to vary the gain of the receiver automatically, so that the strength of the incoming signal determines the gain of the receiver in such a manner that the volume of output is as constant as possible. This principle is known as automatic volume control (A.V.C.).

The principle of automatic volume control is, briefly, the rectification of the amplified input, which is used to produce a negative voltage which can be applied to all the pre-detector valves for the purpose of controlling the gain of the several stages. The valves controlled in this manner must have variable-mu characteristics, and must together give sufficient gain to over-load the output valve when the incoming signal is relatively weak. It is possible to use a single diode to perform the functions of detector and automatic control valve, but the practice has fallen into disuse, and attention is directed therefore to the use of a double diode valve, which permits the functions of detection and automatic bias control to be separated.

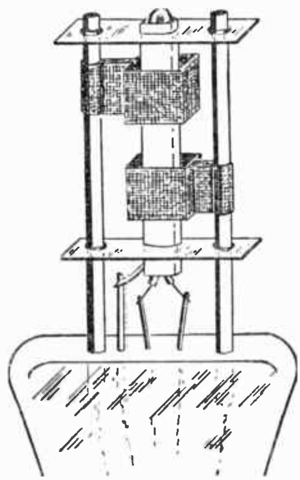


Fig. 176.—The electrode assembly of an indirectly heated double diode valve.

Fig. 177 shows a typical automatic volume control circuit arranged as part of a superheterodyne receiver. It will be observed that the secondary of the intermediate-frequency transformer is connected in series with the usual diode load and is across the cathode and one anode for the purpose of detecting the signal in the conventional manner; the diode load resistance can take the form of a potentiometer to provide manual volume control, the moving contact being taken to the L.F. amplifier or output valve as required. The detector anode is connected to the automatic volume control anode, through a condenser, in order that the signal appears across the cathode and anode respectively; the latter is provided with a separate load, R, and the negative voltage appearing at the junction between the anode and the resistance, R, is led away through a resistance, R_1, to the grids of as many valves as possible, connection being made to the low-potential end of the various tuned circuits. R_1 has an associated capacity, C, which will serve three purposes: firstly, it will act as a bypass to complete the several H.F. circuits, which will have been disconnected from the earth line; secondly, it will prevent the various frequencies present in the several tuned circuits from being fed back to the detector; and thirdly, it will ensure that the negative bias applied to the pre-detector valves will remain sensibly unaffected by depth of modulation, since the time-constant of R_1 and C will not permit the rectified voltage to vary appreciably at audio frequencies.

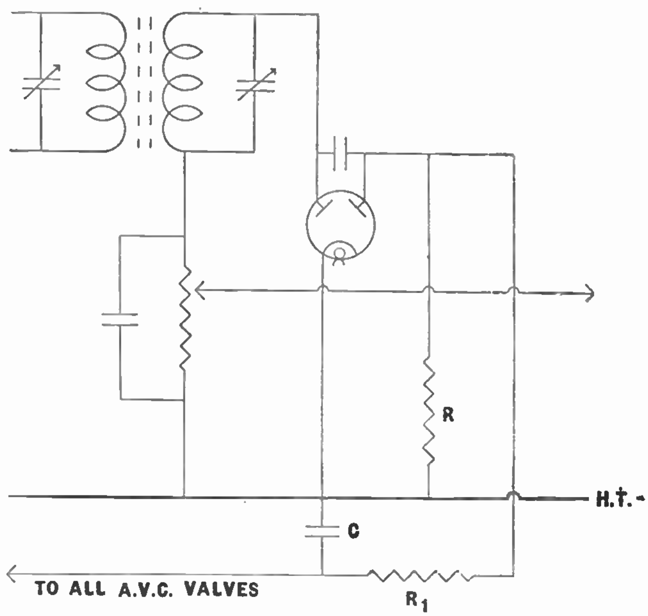


Fig. 177.—The circuit arrangement for simple automatic volume control. The H.T.— (earth) line is emphasised to indicate that the leads shown below it are negative in respect to H.T.—

The arrangement described above will result in the reactance of the condenser, C, being common to the several tuned circuits through which the automatic bias is supplied; this common coupling will often cause instability, which is avoided by taking a separate resistance from the junction of R and the diode to each valve, and associating each resistance with its own condenser. This arrangement and other possible variations are dealt with in a subsequent chapter which is devoted to decoupling.

Fig. 178 shows the performance of various automatic volume control systems, and attention is directed to curve B, which shows the performance to be expected from the circuit shown at Fig. 177. Inspection of this curve will show that the application of automatic volume control considerably reduces the sensitivity of the receiver on signals that are of insufficient amplitude to load the output valve. This is due to the fact that the smallest input will produce some negative voltage which will lower the gain of the receiver; it is apparent that the ideal arrangement would be a circuit where automatic volume control would only start to function when the input is large enough just to load the output valve, and to prevent signals of greater amplitude from over-loading the output

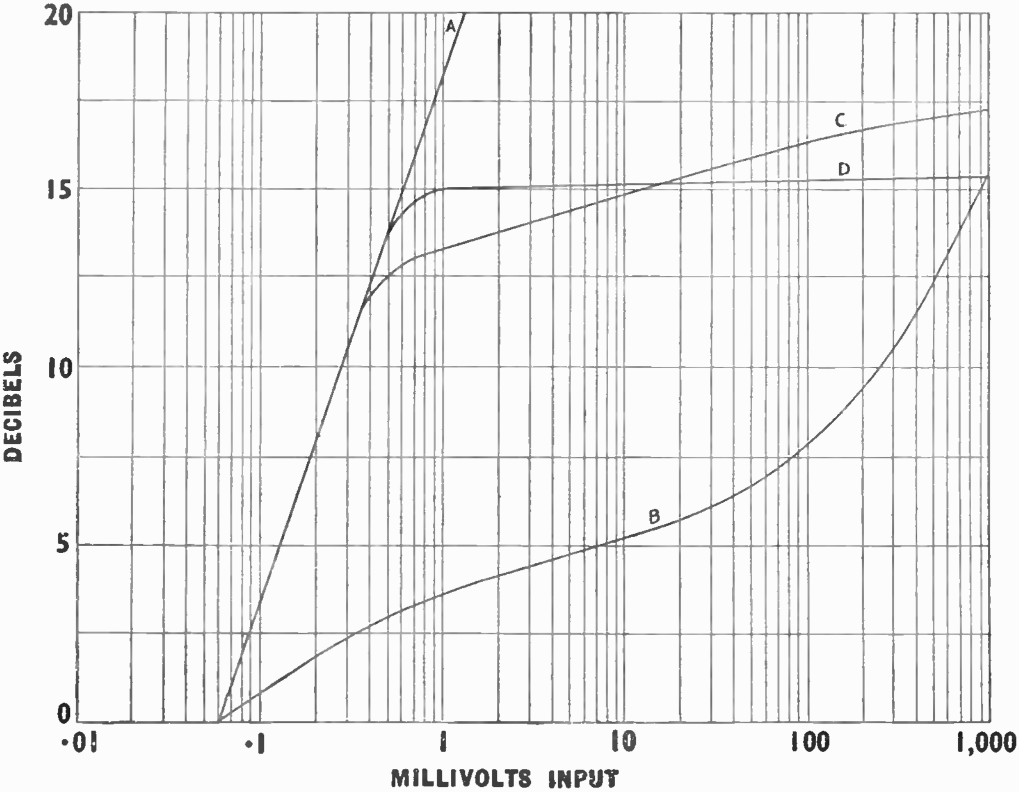


Fig. 178.—Performance curves of various automatic volume control systems.
A = Receiver without A.V.C. C = Receiver with delayed A.V.C.
B = Receiver with simple A.V.C. D = Receiver with delayed and amplified A.V.C.
The 5 db. line can represent ·3 watt and the 15 db. line 3 watts (approx.). The maximum output of the receiver may be assumed to be 3·25 watts.

valve by adequate control of gain. This ideal is to some extent realised by the system of delayed automatic volume control, which is in general use in modern receivers.

Delayed Automatic Volume Control.—Fig. 179 shows a double diode triode arranged for delayed automatic volume control; the simple diode shown at Fig. 177 has been replaced by a double diode triode, since it is necessary that D.C. flows through the bias resistance, R_1. When it is desired to dispense with L.F. amplification the ordinary double diode may be used, and a suitable resistance connected between positive H.T. and the cathode to permit the necessary few milliampères to flow through R_1. Reference to Fig. 179 will show that the arrangement of the detector anode circuit is unchanged, but that the automatic control diode is returned through R_2 to the negative side of the automatic bias resistance. With this arrangement the voltage drop across R_1 will appear as a negative voltage on the automatic control diode, which will not pass current until the signal amplitude exceeds the negative bias. In this way the action is delayed. As an example suppose that an input of 5 volts in the detector anode will result in output valves being nearly fully loaded. If the resistance, R_1, is such that the negative voltage appearing on the control diode is 5 volts, then the latter will start to pass current when the signal input rises above 5 volts, and so endeavour to prevent the increased signal amplitude from overloading the output stage. Reference to Fig. 178, Curve C, will show that the action of delayed automatic volume control cannot entirely prevent

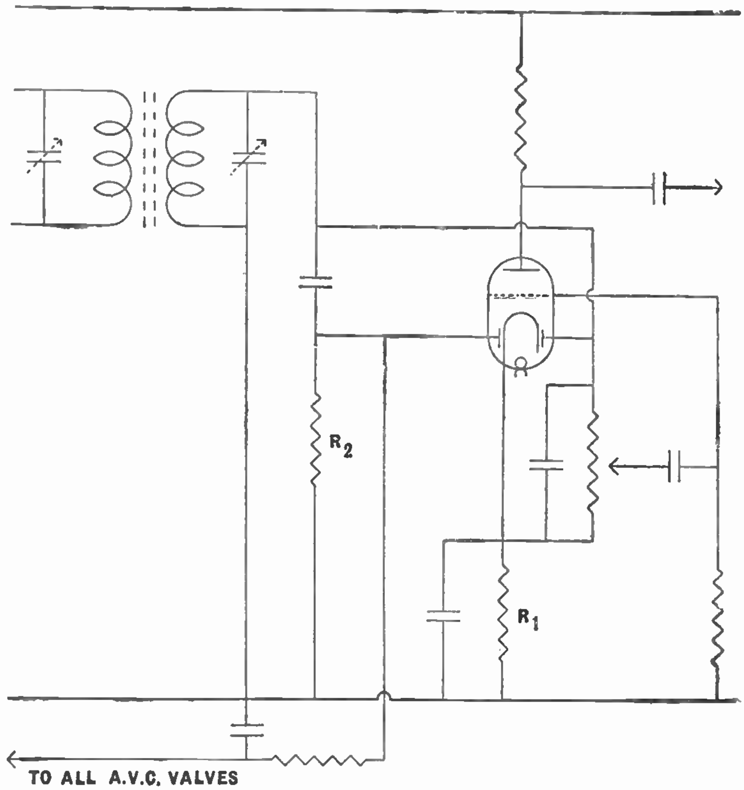


Fig. 179.—Circuit arrangement for delayed automatic volume control, using a double diode triode valve.

a condition of over-load, although it shows a vast improvement over the performance of the set with ordinary control, and without control. (See Curves B and A respectively.) As a compromise, the delay voltage may be, say, half of the signal voltage for the conditions set out above.

Distortion.—Ordinary or delayed automatic volume control can introduce various forms of distortion, both directly and indirectly, the most important of which is the tendency for the last pre-detector valve to overload on the local station, when the voltage output will be very large, and will be working under conditions that are not favourable, as there is danger of unwanted anode bend detection due to the grid swing being forced beyond the cut-off point by the large value of automatic bias. This difficulty may be minimised by tapping the automatic volume control load resistance, and so feeding the last pre-detector valve with only a portion of the controlling bias. This modification is not a solution, and can barely be considered a compromise, since it materially reduces the efficiency of the automatic control; nevertheless delayed automatic volume control is in general use, although most of the troubles can be overcome by a system of amplified control.

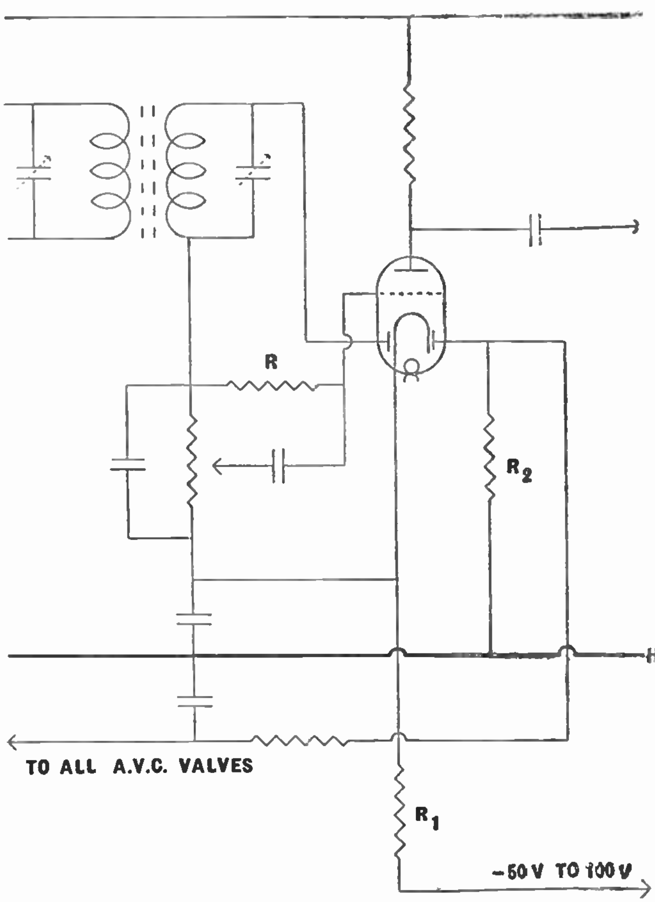


Fig. 180.—Basic circuit for delayed and amplified automatic volume control.

Amplified Automatic Volume Control.—The system of amplified and delayed automatic volume control provides an almost ideal solution to the many problems involved, judged by the efficiency of control and absence of undesirable secondary effects. There are, however, one or two practical disadvantages arising from the necessity of producing a potential that is negative in respect to the main earth line, which will usually be the chassis of the receiver. This potential, which will be 50 or 100 volts negative, can only be produced by inserting a suitable resistance in the common H.T. negative lead across which the necessary voltage will appear. This means raising the H.T. voltage by, say, 100 volts, and arranging for the circuits from which the power is derived to supply a further 5 or 10 watts, according to the total H.T. current of the receiver. Perhaps the most awkward difficulty to overcome is the fact that the chassis is not at zero potential, and all sorts of precautions have to be taken to provide the necessary insulation in the power supply circuit; furthermore, a considerable voltage will appear between the heater and cathode of an indirectly heated valve, unless it is provided with a heater supply which is isolated from the other heaters. Valves are not normally designed to withstand such a potential difference between heater and cathode, and are consequently liable to give trouble.

The arrangement for delayed and amplified automatic volume control is shown at Fig. 180, where it may be seen that the signal detector circuit remains unchanged. Once again the signal anode load takes the form of a potentiometer, so that the required volume may be determined manually, and the automatic control allowed to maintain all incoming signals at this predetermined value, excepting, of course, those which are received at insufficient amplitude to overcome the delay. Reference to Fig. 180 will show that the grid of the triode section is returned to cathode, and that when no signal is being received grid current will flow through R and the diode load; the cathode will be held at a potential of some 25 volts above earth by a suitable choice of values for R_1 and R_2. A comparatively small signal on the detector anode will drive the grid negative and reduce the anode current flowing through R_2, which will drive the cathode in a negative direction. The automatic control diode is connected to earth through the load resistance, R_2, and will pass current when the cathode falls below earth potential, a condition which will obtain when only a volt or so is applied to the signal anode. When the incoming signals exceed the delay by a very small value the current flowing through R_2 will cause a voltage drop which may be many times the voltage applied to the signal diode. The values are usually so arranged that current will flow through R_2 when the signal voltage exceeds about 2 volts, and the value of R_2 can be such that when the signal voltage reaches, say, 2·5 volts a bias of, say, 20 volts is available for operating the automatic volume control system. The Curve D at Fig. 178 shows the performance which may be expected from delayed and amplified automatic volume control where the several resistance values are carefully chosen. It should be observed that the values of resistances are somewhat critical, and that the action of the automatic control is affected by the amplification-factor of the valve. It is apparent, therefore, that considerable consistency is necessary between various specimens of the valve used in order that eventual replacement will not upset the characteristics of the system. Unfortunately the double diode triode is a type of valve which cannot be classed among the types that are prone to consistent characteristics, due, presumably, to the nature of the structure which divides the length of the cathode between the diode and triode sections. It is reasonable to conclude that amplified automatic volume control is an ideal arrangement when incorporated in a receiver built for individual construction, but undoubtedly presents difficulties for quantity production, owing to the critical tolerance of valve characteristics.

Special Valves.—Double diode valves are available for both battery and mains working. The latter is naturally indirectly heated, while the former proves an exception to battery valves, inasmuch as it is also indirectly heated, a modification that is rendered necessary by the difficulty of preventing a slender filament from shorting to the anodes. It also provides means for applying delay by the use of a cathode bias resistance, which is sometimes preferable to battery bias when the valve is used for certain special purposes.

The double diode triode consists of a normal triode assembly with a somewhat short anode and grid, so that about a third of the filament is available to be associated with the two diode anodes which usually form a tiny cylinder around the ends of the filament. Both mains and battery types are available, and special care is necessary in using the latter, since the two diode anodes are at a different potential to the mean filament potential ; one is at the positive end, and one at the negative end of the filament, consequently the diode at the positive end of the filament is normally used as the detector, and the other anode for automatic volume control—which will provide 1 volt delay, since this anode works in conjunction with a portion of the filament that is 1 volt negative in respect to the mean filament potential.

When tuning a receiver which is equipped with automatic volume control the background noise between stations may rise to objectionable limits because, in the absence of a signal, the pre-detector valves will work at maximum gain ; furthermore, when a station is approached a somewhat raucous noise may be emitted from the loudspeaker, due to the accentuation of the sideband, which will appear at volume above normal owing to the slight time-delay of the automatic volume control system. Means are available for overcoming both these objections, and are dealt with in a subsequent chapter devoted to inter-station noise suppression.

Corrected Automatic Volume Control.—Some years ago considerable interest was aroused by the possibility of correcting automatic volume control by applying the control voltage to the low-frequency amplifier. The idea underlying the arrangement was brought about by the realisation of the fact that ordinary automatic volume control applied to the pre-detector valves could not achieve anything approaching constant output. It will be realised that pre-detector control cannot give truly constant volume of output, since the actual bias voltage is derived from the signal itself and in order to obtain a large negative voltage the signal must rise above the required level ; if it did not it would follow that various values of bias were derived from the same signal amplitude, which is absurd.

The application of automatic bias to the low-frequency amplifier renders the ultimate sound-level independent of the automatic volume control curve of the pre-detector. In other words, it will be possible to design a low-frequency amplifying valve the gain of which would actually decrease with the application of negative bias to such an extent that the output volume would be reduced instead of increasing to the point where over-loading occurs. The essence of the arrangement lies in the fact that the application of variable bias on the low-frequency amplifier does not reduce the signal voltage, which, in fact, produces the variable bias.

In order that bias may be applied to the low-frequency amplifier it is essential that the valve should have variable-mu characteristics in order that distortion is not introduced, and for the same reason the input to the valve must be kept reasonably small, making the use of a high-gain valve desirable. A special valve was designed to fulfil these requirements and took the form of a double diode low-frequency pentode; the diodes are used for detection and automatic volume control respectively, and the pentode section for low-frequency amplification. This system has fallen into disuse, but the description is included on account of its intrinsic interest.

CHAPTER 26

TUNING INDICATORS

THE high selectivity of a modern superheterodyne makes tuning somewhat difficult, since slight mis-tuning causes accentuation of one sideband, and consequent distortion. Inconvenience is also caused on extremely selective receivers due to certain items being unsuitable to facilitate correct adjustment, with the result that the receiver when apparently correctly tuned sounds unpleasant on a following item containing heavy bass orchestration. A tuning indicator is very desirable with FM receivers.

To facilitate tuning many receivers are fitted with some device which gives visual indication of the correct tuning-point. Such a device permits quick and easy tuning, and also allows the unmusical to tune correctly. Furthermore, correct tuning may be achieved even though the required station is tuned in during a programme interval.

In order that some visual indicator can function it must be actuated by some potential or current which varies in proportion to the strength of the carrier, and for this reason tuning indicators are usually fitted only to those receivers which employ automatic volume control, although at least one type, the "magic eye," may be used with receivers not so equipped. For the sake of completeness, mention must be made of the earliest type of indicator, which took the form of a milliammeter connected in the anode circuit of a leaky grid detector. When the signal input to a leaky grid detector is increased the anode current falls, and when the signal is accurately tuned the meter will show the lowest reading. This arrangement cannot be considered satisfactory, as the change in current is small when compared with the standing anode current, with the result that the indicating movement is also small and, furthermore, the deflection of the needle is scarcely noticeable between correct tuning and, say, 1 kilocycle per second off tune. Since the disadvantages of this arrangement render it unsuitable for modern requirements, attention may be directed to representative examples of specialised devices.

Mechanical Indicators.—Mechanical tuning indicators are developments of the system described above, but are intended to rely on the large change of anode current present in the anode circuit of the valve, or valves controlled by an automatic volume control circuit. The most modest superheterodyne usually has two such valves, the frequency changer and the intermediate-frequency amplifier, which together may take 10 milliampères under conditions of no signal and 4 milliampères when receiving a local transmission. This change of anode current, which represents a ratio of 5 : 2, is sufficient to actuate a comparatively insensitive device.

Mechanical indicators invariably consist of a coil which influences an iron armature or a small moving coil in the field of a permanent magnet. In the former case the anode current flowing to the appropriate valve causes the armature to move, while in the latter case the flow of current causes the coil to move; it will be convenient to refer to the moving armature, or moving coil, as the moving member. The moving member will be provided with a hair-spring to maintain it at the zero position and offer the necessary slight mechanical resistance to its movement which will be determined by the current flowing through the coil. It will be remembered that the anode current of valves controlled by the automatic volume control circuit will reach a low value when the incoming signal is at a maximum. It is necessary, therefore, so to arrange matters that the standing anode current will cause the moving member to make the maximum permissible movement, which will appear as zero to the user. In this condition the action of the automatic volume control will allow the spring to shift the moving member an appropriate amount.

From the above description it can be seen that the indicator would show a deflection due to a change of current flowing through the coil, the change of current being controlled by the action of the automatic volume control circuit, and the influence of the automatic volume control circuit being controlled by the amplitude of the incoming signal. The amplitude of the incoming signal should be at maximum when the receiver is correctly tuned.

It will be noted that the word "should" is used, since it is impossible for any visual tuning indicator to function correctly if the receiver is so designed that the response-curve shows a double hump, as this would result in maximum indication when the receiver is off tune, a condition which the device is intended to avoid; it is extremely difficult to design a receiver that will give good quality and yet have a response-curve where the maximum height coincides with correct tuning. A compromise is usually effected by making one of the valves control the indicator, and providing this valve with a tuned circuit, the response of which takes the shape of a peak, the total response of the receiver being corrected by over-coupling some other tuned circuit. It should be understood that this paragraph is equally applicable to the several types of indicators described below.

The two alternative types of movement have been described above, and some general remarks may be made regarding the manner in which this movement is presented to the eye. The most simple arrangement is probably a pointer equipped with a scale permitting the maximum deflection to be easily recognised, but, to make the device more attractive, the pointer could be geared and provided with a small clock-face or, in fact, with any type of dial calculated to make the receiver more attractive to those who are apt to place novelty before efficiency. Alternatively, the pointer can be dispensed with, and use made of a rotating disc which could be, say, half white and half red and provided with a small escutcheon so that correct tuning is achieved when the maximum amount of red is showing ; obviously there is no limit to the manner of presentation.

Mechanical indicators tend to suffer from mechanical inertia, so that the visible indication is a fraction of a second out of step with the electrical change taking place. This is no disadvantage when the tuning condenser is rotated slowly, but when rotated quickly the indicator fails to respond in the required manner. For this reason preference is often given to purely electrical indicators, which have the additional advantage of being more reliable from the service point of view.

The Diminishing Light Indicator.—Fig. 181 shows the circuit of a simple indicator which can be very satisfactory but has never enjoyed the popularity it deserves. Reference to this diagram shows that the anode current of a suitable valve flows through the primary of a transformer which is so designed that the core is almost saturated by the anode current under conditions of no signal. The secondary consists of two sections which are connected in opposite phase, and a small lamp in series with the secondary is illuminated at considerable brilliancy by A.C. which can be derived from the heater supply. It should be particularly noted that the D.C. resistance of the secondary will be approximately equal to the A.C. impedance when the core is saturated. When a station is tuned in and the automatic volume control brings about a reduction in the anode current, the core will recede from saturation-point, with the result that the secondary winding A.C. impedance will increase and the brilliance of the lamp diminish. With this arrangement the tuning control is manipulated so that the lamp is as dim as possible.

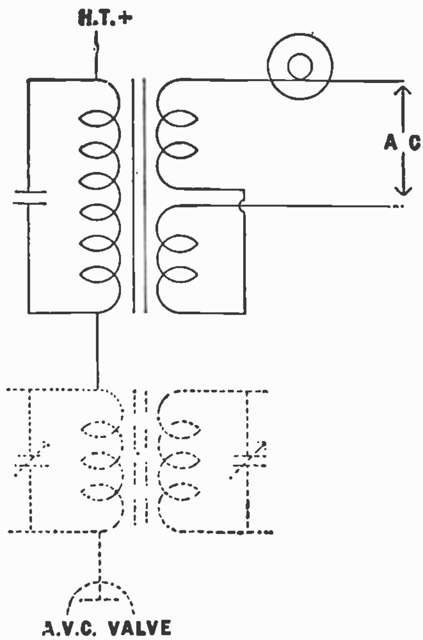


Fig. 181.—Circuit of the diminishing light indicator. A special transformer is necessary, as described in the text.

The success of the diminishing light indicator is dependent upon the careful choice of constants. The core must be so proportioned that it is just saturated or nearly saturated by the standing anode current of the valve which actuates the device, usually the intermediate-frequency amplifier. The lamp must be so chosen that it responds quickly to a change in current, and so that the change in impedance of the secondary winding is the maximum possible. The A.C. supply of the secondary can be taken from the valve heater supply, and will therefore be 4 volts, and, to comply with the required conditions, it is suggested that a 2-volt lamp be used, passing about ·2 ampère, working with a secondary D.C. resistance of about 12 ohms. These values allow the lamp to work just below normal brilliancy, so that a further reduction in current will bring about a very apparent change of brilliancy. Reference to Fig. 181 clearly shows the arrangement, and also shows that a condenser is connected across the primary so that its impedance at radio frequencies is sensibly zero. This condenser should have a capacity of 4 μF, or more.

Fig. 182.—Sectional drawing of the neon tuning indicator. The long electrode is the cathode; the short electrodes are primer and anode.

The Neon Tuning Indicator.—Fig. 182 shows the neon tuning indicator, which consists of a small glass tube filled with rarefied neon gas and equipped with one long electrode called the cathode, and two very small electrodes called the anode and primer respectively. The basic circuit is shown at Fig. 183, from which it will be seen that the primer is held at a voltage of approximately 40 volts below the cathode, and that the anode is held at a steady voltage of between 145 and 160 volts, the value of R being appropriately adjusted. Under these conditions a potential difference of 145 to 160 volts is maintained between the anode and primer, which will cause the neon gas to ionise in the vicinity of these electrodes and appear as a small orange glow at the bottom of the tube. When the anode current falls, due to the action of the automatic volume control, the potential drop across R_1 will be reduced, with the result that the potential difference between the anode and cathode will increase and reach a value where ionisation takes place between the anode and the bottom of the cathode. A further decrease of current through R_1 will bring about a proportionately increased potential difference between the anode and cathode, causing ionisation to take place farther up the cathode; thus in use the device appears as a column of orange light, the length of which increases in proportion to the signal, and

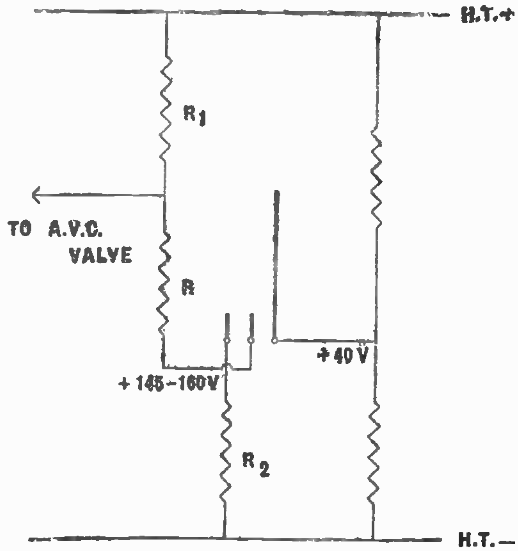


Fig. 183.—Basic circuit of the neon tuning indicator

correct tuning is indicated when the column of light is as long as possible. The value of R_1 should be such that the column of light starts to rise when a reasonably weak station is correctly tuned, but does not quite reach the top when the local station is correctly tuned.

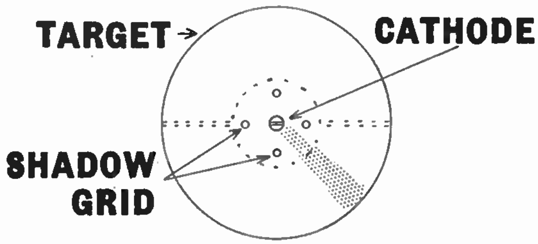
The primer is necessary owing to the backlash present in a neon tube, which causes the ionisation to cease at a lower potential difference from that required to restart it. The primer maintains slight ionisation so that the device is responsive to a small change of potential. Without the primer ionisation would not take place until the striking voltage attained a value corresponding to ionisation approaching the top of the tube. The neon indicator is usually provided with an escutcheon which just hides the anode and primer, but permits the remainder of the cathode to be seen. It is, however, sometimes presented end-on through a small circular escutcheon. This indicator is not in general use.

The " Magic Eye."—The " magic eye " is a comparatively elaborate indicating device, and is almost the modern standard. It actually contains an ordinary triode in addition to the actual indicating electrodes. The device is presented with the top of the bulb showing through an escutcheon, so that the whole of a circular electrode may be seen; under conditions of no signal a cross of green light appears as represented at Fig. 184, but under conditions of maximum signal the cross broadens out like a Maltese cross until the aperture is nearly filled with light, see Fig. 185. In practice the device is entirely satisfactory, and without inertia, since the light is obtained by bombarding the circular electrode by a stream of electrons, the electrode being covered by a substance, usually zinc silicate, which has the property of becoming fluorescent when bombarded by electrons.

Fig. 184.—Appearance of the " magic eye " under conditions of no signal.

Fig. 185.—Appearance of the " magic eye " under conditions of maximum signal.

Fig. 186 shows a sectional drawing of the " magic eye " while Fig. 187 shows a plan view of the device seen from the top. Reference to Fig. 186 will show that the lower portion of the assembly consists of a normal triode made up by cathode, control grid, and anode. The cathode is extended so that it forms the centre of the upper section. The upper section consists of the top of the cathode, around which are placed four thin vertical wires forming shadow grids, the whole being surrounded by a cone-shaped electrode called the target, the inner side of which is coated with zinc silicate or some other suitable substance. The shadow grid is internally connected to the triode anode, the assembly being completed by a small circular cap masking the shadow grid from view and connected to the target; in Fig. 187 this cap is omitted, but its position is indicated by a dotted circle.



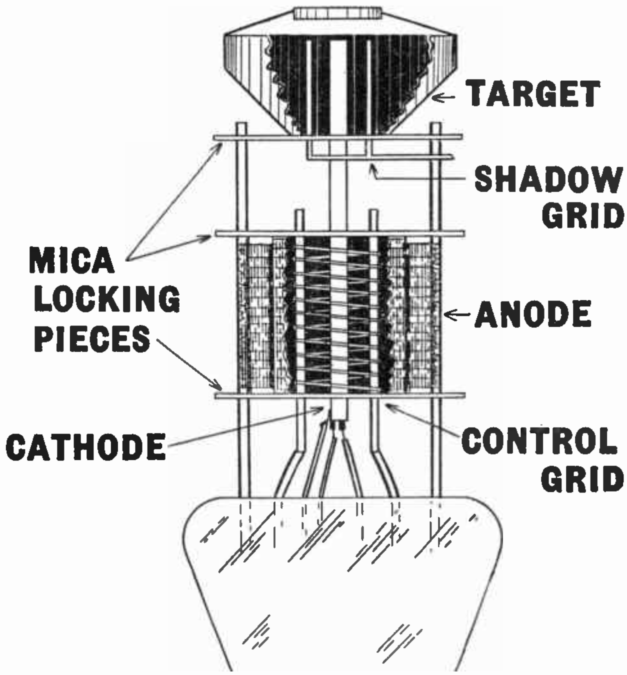


Fig. 186 (*Lower drawing*).—A broadside view of the "magic eye," with target and anode cut away to show the shadow grid and control grid respectively.

Fig. 187 (*Upper drawing*).—Plan view of "magic eye"; the small cap is shown dotted. One of the four electron beams is represented diagrammatically.

Fig. 188 shows the conventional symbol of the "magic eye," and identifies the different electrodes. Fig. 189 shows the basic circuit of the "magic eye," and requires description, since it is difficult to follow the action from the diagram. Under conditions of no signal the control grid is held at cathode potential, and the anode current will be relatively large, resulting in a potential drop across R of, say, 100 volts; thus the triode anode, and consequently the shadow grid, will be 100 volts negative in respect to the target, which will resist the passage of electrons from cathode to target and also marshal the electrons into a narrow beam which, impinging upon the inclined surface of the target, will cause a narrow strip of fluorescent light to appear; since there are four spaces between the shadow grid wires, there will be four arms of light, as shown at Fig. 184. When a signal is received the circuit is so arranged that the control grid is driven negative to an extent determined by the amplitude of the signal. This will decrease the anode current of the triode, and consequently the potential drop across R, with the result that the shadow grid will be driven in a positive direction and permit more electrons to flow,

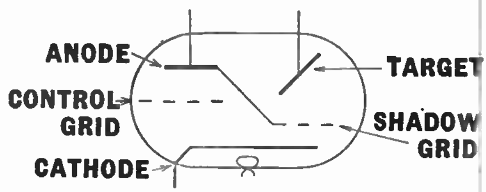


Fig. 188.—The conventional symbol of the "magic eye."

producing an increased and wider electron beam, see Fig. 185. It should be understood that Fig. 184 and Fig. 185 represent maximum and minimum visible change, intermediate changes are brought about by the application of intermediate voltages to the control grid. The device is relatively sensitive, several types being available which will bring about the visual change represented by Fig. 184 and Fig. 185 for a voltage change on the control grid of Vg = 0 to Vg = − 5.

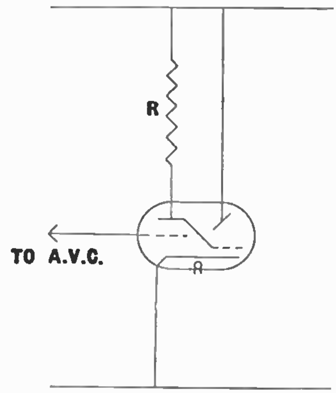


Fig. 189.—Basic circuit of the "magic eye."

It will be noted that the control grid of the "magic eye" must be connected to a point which is zero in respect to the cathode under conditions of no signal, and which comes progressively negative as signal input increases; only two such points present themselves, the signal and automatic volume control diode. The former suggests itself, since it is unlikely that the addition of the "magic eye" will upset the circuit, but, unfortunately, when so connected the indicator will only work on those stations which are received at sufficient strength to overcome the delay applied to the diode. It may be argued that visual indication is not required on the weakest stations, when this arrangement can be considered as the better

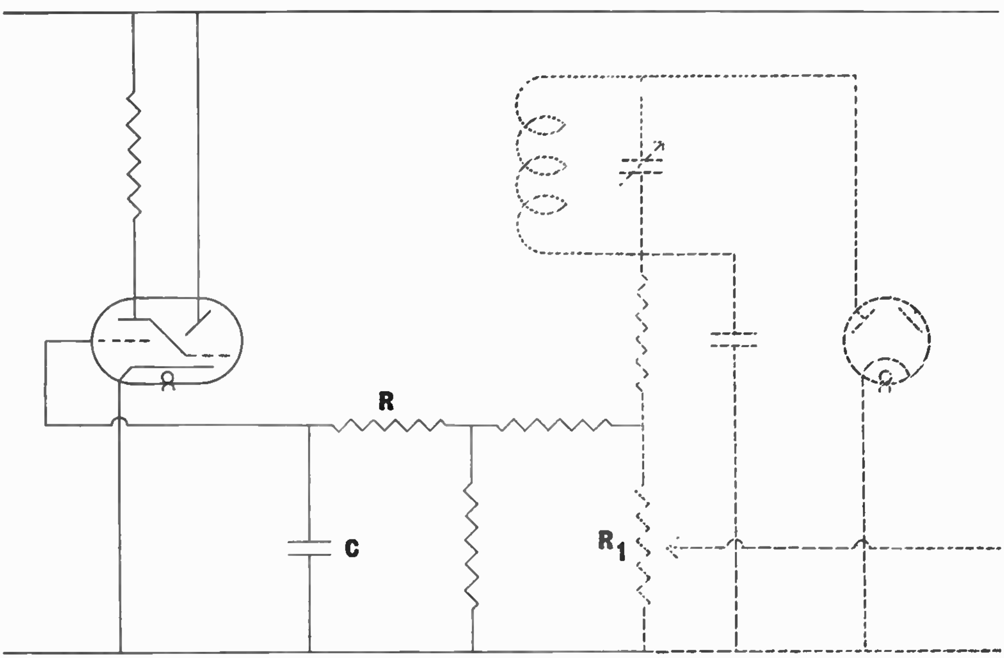


Fig. 190.—The complete circuit suggested for the "magic eye" fed from the anode of a diode detector.

choice. When the indicator must work on all stations, connection must be made to the signal diode, as shown at Fig. 190.

The resistance, R, and condenser, C, form a circuit having a time-constant such that the potential between the control grid and cathode is not varied by modulation. The diode load, R_1, is shunted by two resistances in series to form a potentiometer, so that R is fed by only a portion of the total potential across R_1, since the latter will often be greater than the voltage required to actuate the "magic eye"; the values of these resistances are determined by the maximum voltage experienced across R_1, but together they must always be equal to a value that is several times greater than R_1, so that the value of the diode load is not materially affected. When the maximum voltage experienced across R_1 does not exceed the maximum voltage required to actuate the "magic eye," R may be connected direct to the top of R_1, but the value of R will have to be increased so that it is equal to a value several times greater than R_1 for the reason described above.

The potentiometer arrangement across R_1 will be even more necessary if control is taken from the automatic volume control diode, as the voltage at this point will be at least 15 volts negative.

Several modern versions of the "magic eye" differ from that shown at Fig. 186, inasmuch as a suppressor grid is placed round the upper end of the cathode and connected to the latter. This forms a space charge grid, so that the sensitivity is not greatly dependent upon the emissivity of the valve, which will be affected by temperature and age, and thus sensitivity is constant throughout its useful life.

CHAPTER 27

INTER-STATION NOISE SUPPRESSION

THE maximum possible gain of a superheterodyne normally reaches a very high figure and when tuning from one station to another considerable background noise is heard. This increase of background noise is due to the absence of negative bias on the pre-detector valves consequent upon the automatic volume control ceasing to function owing to the lack of a steady incoming signal. Another unpleasant inter-station noise is experienced when tuning off one station and when tuning on to the next, and occurs when the tuning condenser is rotated to that position when the tuned circuit is about 3 kcs. per second off-tune, with the result that the higher frequencies are reproduced considerably above normal volume, the middle frequencies are attenuated, and the bass frequencies virtually absent; this characteristic sound is known as sideband shriek.

It is apparent that background noise and sideband shriek must be suppressed if it is desired to rotate the dial without experiencing unpleasant noise between each station. It will be convenient to deal with the suppression of sideband shriek before noise suppression, since many receivers have provision for eliminating the former but not the latter; but the converse does not apply. Sideband shriek is more noticeable when tuning on to a station than when tuning off a station, as the time constant of the automatic volume control circuit will not permit the circuit to function sufficiently quickly to prevent the sideband shriek from rising to abnormal amplitude: which results in this unpleasant noise attaining a volume several times that expected from the station which is about to be tuned in. It is apparent that for the virtual suppression of sideband shriek some arrangement is required whereby the automatic volume control is brought into action before the tuning condenser gets sufficiently close to resonance to permit the edge of the sideband from being reproduced. Fig. 191 shows a simple modification of the typical automatic volume control circuit which was shown in Chapter 25. It will be noticed, however, that while the detector anode is fed from the secondary of the intermediate-frequency transformer in the usual manner, the automatic volume control anode is fed from the primary; this modification, although extremely simple, is very effective in reducing sideband shriek to limits which are not objectionable. The response-curve of the primary will be wider than that of the secondary. Assume that the response of the secondary is 7 kcs. per second wide at some fixed amplitude, and that the primary is 9 kcs. per second wide at the same level; then it follows that the automatic volume control anode will receive the incoming carrier wave 1 kc. per second before the detector anode, which is sufficient to permit the pre-detector valve to be adequately biased by the time that the tuned circuit has reached the point where the signal potential is rising rapidly at the detector anode.

The elimination of all sound between station may involve very elaborate arrangements, and numerous circuits have been used and suggested for providing quiet automatic volume control (Q.A.V.C.), all of which endeavour to overcome various disadvantages that are liable to manifest themselves. It is perhaps desirable to outline the requirements of such a system. Firstly, the basic requirement is some means of rendering the receiver inoperative while the tuning condenser is rotating from one station to the next. Secondly, it is desirable that this muting action shall be so arranged that the receiver mutes and unmutes suddenly, otherwise distortion must result; and thirdly, it must not hamper the normal automatic volume control action or cause distortion on deeply modulated but relatively weak stations. In addition, it may be desirable to have some pre-set control so that weak stations having no entertainment value are treated by the circuit as background noise and passed over in silence, the pre-set control determining the amplitude required to unlock the muting arrangements. So numerous are the circuit variations that it is only practicable to give a representative selection.

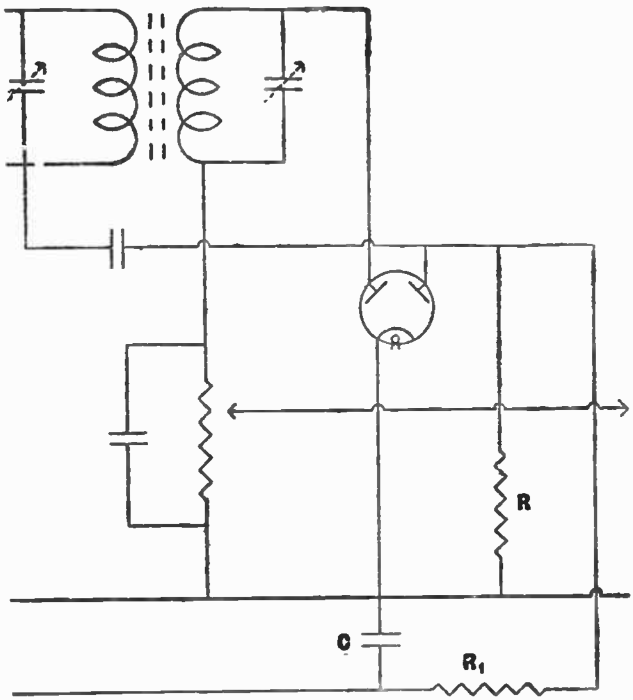


Fig. 191.—A modified automatic volume control circuit where the diode is fed from the primary of the intermediate-frequency transformer to minimise sideband shriek.

Fig. 192 shows one of the most simple arrangements for inter-station noise suppression. It will be seen that the signal diode is negatively biased, so that it does not function until the incoming signal reaches an amplitude greater than the value of bias. For simplicity the diagram shows a simple double diode valve; bias is obtained by the current flowing through the bias resistance and the feed resistance from high-tension positive. This simple suppression circuit has the advantage that it requires practically no additional components, as it is even possible to omit the resistances by returning the diode cathode to some suitable positive point, such as the cathode of the output valve. On the other hand, it possesses practically all the possible disadvantages, the most serious of which is the distortion of signals received at an amplitude sufficient to unlock the muting, but insufficient to permit the detector to swing without encroaching on the negative bias.

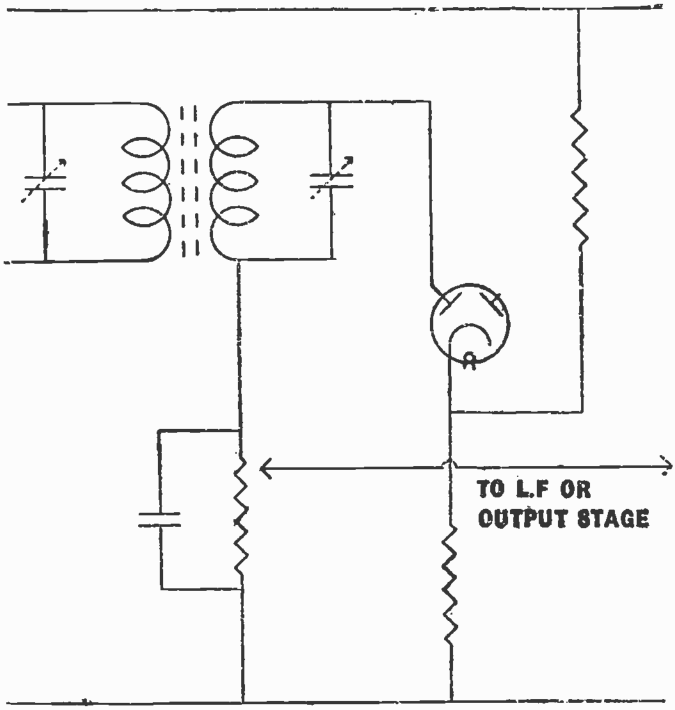


Fig. 192.—A very simple form of inter-station noise suppression achieved by placing a negative bias on the detector anode.

Fig. 193 shows a more ambitious circuit that may be considered generally satisfactory and yet does not require unduly elaborate equipment. It should be particularly noted that the double diode triode performs the functions of detection, suppression, and automatic volume control; there is no low-frequency amplification, since the triode portion is not used as an amplifier. The bias resistor is of exceptional value, *i.e.* about 2,000 ohms, a quarter of which is used to bias the grid of the valve. Assuming the anode voltage to be about 250 volts, a normal valve will settle down with an anode current of about 5 milliampères, giving a bias of 2·5 volts approx. The incoming signal is applied between the detector anode and a tap on the bias resistance, and also to the grid. The other diode is also fed by the signal, but is returned to a point that is 10 volts negative in respect to the cathode; thus it is normally inoperative and, being the detector, the receiver will be muted. The muting is unlocked when the incoming signal is sufficient to overcome the bias on D_1. When D_1 passes current it will drive the grid negative and reduce the anode current to a point where the potential across R_1 and R_2 has dropped to sensibly zero, permitting the detector to function in a normal manner.

It will be observed that the diode D_2 performs the dual function of detection and automatic volume control and is without adequate delay. This difficulty can be overcome where necessary by using a separate diode or by replacing the valve shown by a treble diode triode. In either case the modification is the same, the new diode being fed direct from the primary of the intermediate-frequency transformer and provided with a separate load resistance and delay voltage. The modified circuit is shown at Fig. 194, where it will be seen that the delay voltage is obtained by the usual bias resistance, or by returning the control anode to the cathode end of the output bias resistance or, if the voltage so obtained is excessive, to a suitable tap. It will be noted that the control diode is fed from the primary of the intermediate-frequency transformer, and consequently sideband shriek will be reduced to unimportant proportions.

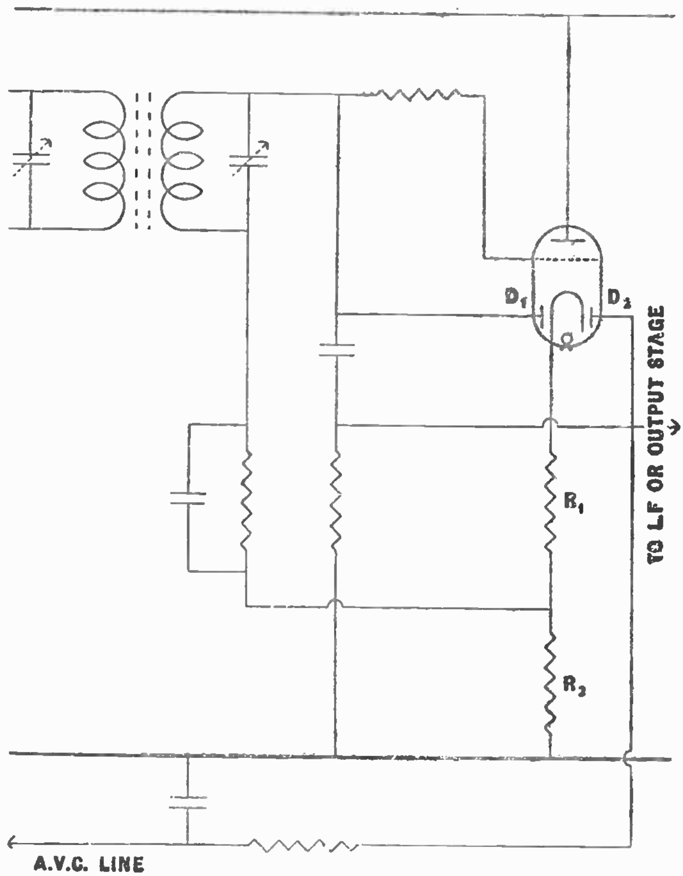


Fig. 193.—An improved Q.A.V.C. circuit. Note particularly that the valve performs the function of detection, noise suppression, and automatic control. The triode section does not amplify.

Another System.—Fig. 195 shows an unusual method of inter-station noise suppression that has been used by the writer for experimental purposes, with considerable success. The muting device consists of a triode valve. No particular novelty is claimed for the system, but inclusion is justified by the clear manner in which it shows the operation of Q.A.V.C. systems employing a separate muting valve.

It will be noted that the cathodes of both detector valve and muting valve are joined together and returned through a single bias resistance to high-tension negative. The grid of the muting valve is controlled directly from the automatic volume control. Under conditions of no signal there will be no voltage imposed on the triode grid from the automatic volume control and the valve will settle down to an anode current determined by the resistance R. If a low impedance output type of valve is used and R has a value of 1,000 ohms, the anode current would settle down at about 10 milliampères. The drop across R will be 10 volts and consequently the detector anode, which is returned to high-

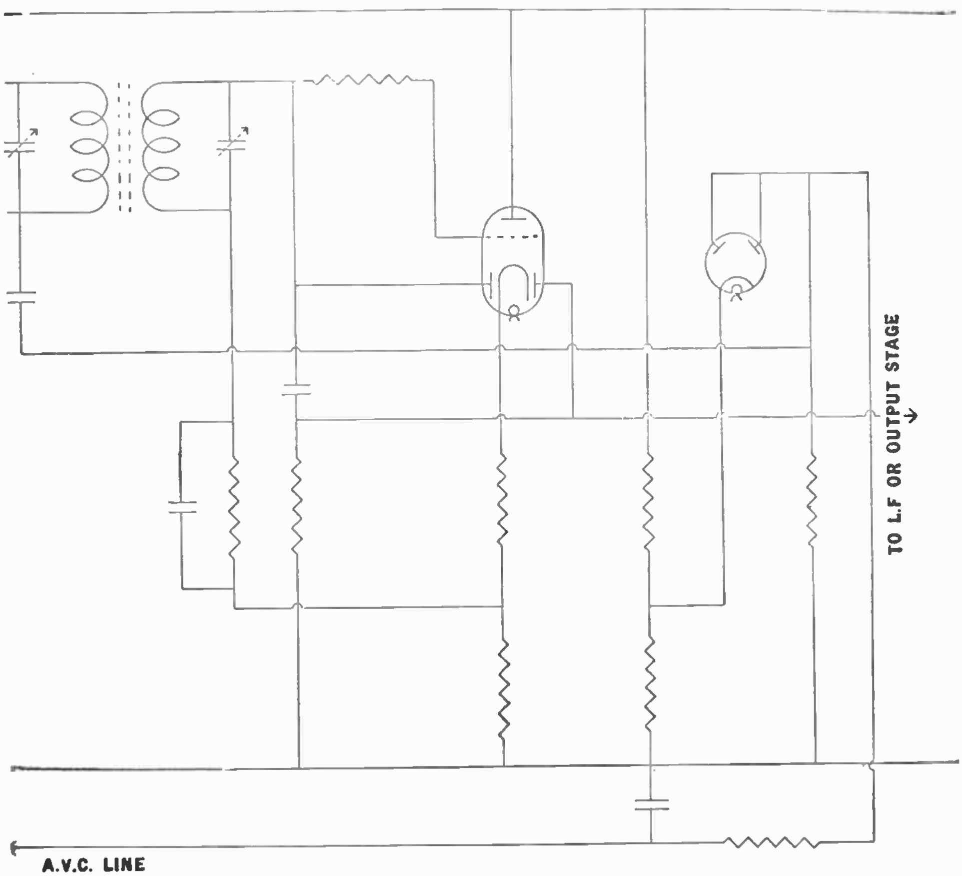


Fig. 194.—An improved version of Fig. 193, a separate diode being used to separate the automatic volume control circuit and to permit the application of delay.

tension negative, will be 10 volts negative in respect to its cathode and consequently quite inoperative.

When an adequate signal is tuned in the automatic volume control will drive the triode grid negative and reduce the anode current, and consequently the voltage drop across R, to proportions which will not interfere with the action of the detector. By returning the control diode to a tapping on R delay is obtained, which will control the muting circuit so that it may be made to unmute on a signal of predetermined amplitude.

Automatically Discriminating Circuits.—There is no limit to the complications possible to achieve the ideal of suppressing every unwanted form of noise, so that rotation of the tuning dial tunes in a succession of stations of real entertainment value, all others being eliminated automatically. To accomplish this ideal it is obviously necessary to provide means for eliminating sideband shriek and inter-station background noise, but, in addition, it is necessary to devise some means of rejecting stations with an unacceptable signal noise ratio.

The principle calls for the use of two very sharply tuned circuits peaked at, say, 3 kcs. per second above and below the intermediate frequency. These feed the diode anodes of an entirely separate suppressor valve, which is so arranged that it will only unmute the circuit when the input to this valve is equal to, or nearly equal to, the input to the detector. Consequently, when a station is tuned in plus extraneous noises the system will not unlock because the amplitude off-tune will be considerably less than the amplitude at resonance.

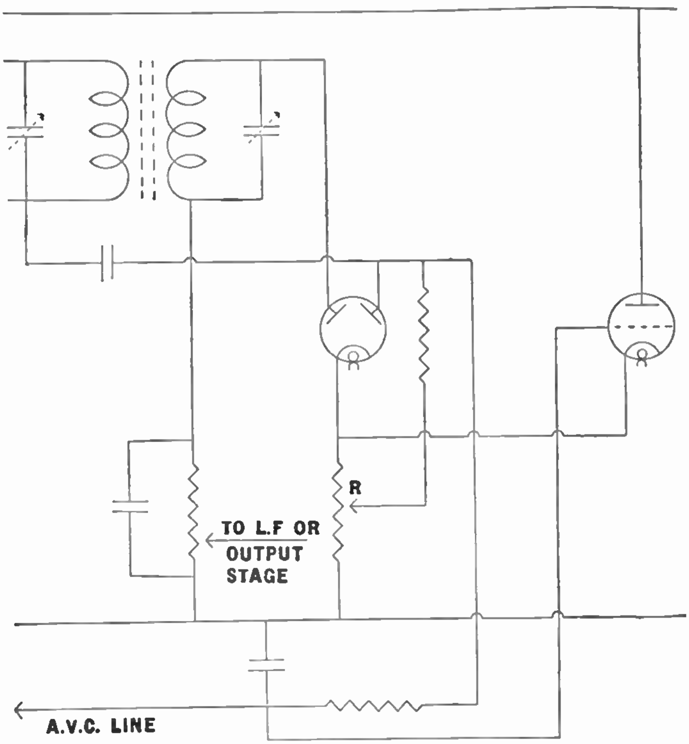


Fig. 195.—A simple inter-station noise-suppressor circuit using a triode valve for muting.

Mechanical Suppression.—The most efficient form of suppression consists of a relay which definitely shorts out a suitable grid circuit. The arrangement is simple, and consists of a sensitive relay, the coils of which are connected in series with the high-tension line feeding the anode circuits of all valves controlled by the automatic volume control. The device is adjusted so that when the current passing through its coils reaches a predetermined value the moving armature is pulled down towards the coils and at the same time closes a circuit which can conveniently be the grid and cathode of the output valve, which will positively prevent the receiver from functioning. There are various mechanical systems applicable to motor-driven and push-button self-tuning receivers.

CHAPTER 28

AUTOMATIC TUNING

THE subject covered in this chapter is necessarily rather wide, since it covers automatic tuning arrangements which vary from simple switch types to complicated motor-driven systems. Broadly speaking, automatic tuning may be defined as a means of accomplishing a precise adjustment without the necessity of expending either skill or care ; in other words, a receiver incorporating automatic tuning will accurately tune a number of stations merely by depressing a button or moving a lever.

Automatic tuning can be conveniently subdivided into three groups : (1) purely mechanical arrangements, whereby the ganged tuning condenser can be made to stop at a definite point by, say, the depression of a knob ; (2) pre-selector systems, where a choice is made from a number of previously tuned circuits by the depression of an appropriate switch ; and (3) motor-driven systems, where the tuning condenser is rotated by a small electric motor ; this group is complicated by the addition of circuit arrangements to make final adjustments to the tuning automatically, as it is normally impracticable to provide a motor drive that will stop at an accurately determined point, since inaccuracy tends to be introduced due to wear of moving parts. It will be convenient to deal with the three groups in the order set out above. It will be appreciated that the pre-adjustment may call for some skill in setting up, but the manual device for selecting the station must be simple, reliable, and certain in action.

The Teledial.—An extremely simple and practical system is shown at Fig. 196. It consists essentially of a skeleton plate, the arms of which terminate in buttons which are marked A in the illustration ; the skeleton plate may be rotated on a centre boss, and each button may be rotated on its independent axis. Each button is provided with a small tapered peg, B, on its perimeter, which may engage in the slot marked C when the skeleton plate is rotated to the appropriate position. The skeleton plate is normally covered by a dial with holes corresponding to the ten buttons. In use the finger is placed on the appropriate button, which is depressed and, by maintaining pressure on the button, the whole assembly may be rotated until the tapered peg on the button being depressed falls into the slot and further movement is impossible. In this manner the tuning condenser can be made to stop positively at any one of ten positions, merely by depressing the appropriate button and rotating until it engages in the slot.

Mention has been made of the fact that each button may be rotated on its own axis : since the peg is on the rim of the button, rotation will cause it to assume a position to the left or right of the centre of the button ; in other words, it controls the precise point where the rotating member will stop, the spacing between buttons being such that each may be set to stop at any point on its own section of the dial, which will be equal to some 30 degrees of rotation. It will be understood that the dial must be geared to the condenser by such a reduction ratio that will result in the condenser turning through its maximum of 180 degrees, while the dial is rotated through some 300 degrees.

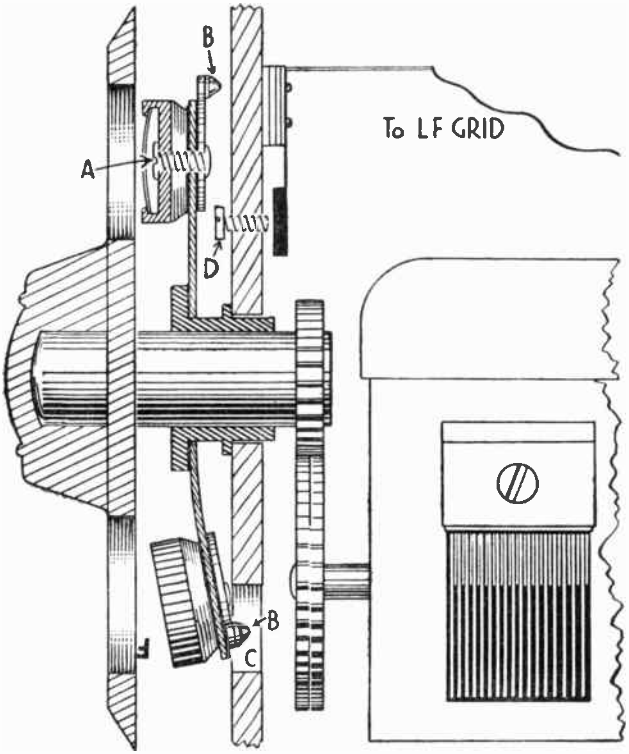


Fig. 196.—Semi-section of the teledial automatic tuning system. Note that the pegs on the perimeter of the buttons do not touch the back-plate until depressed.

The buttons are set for ten suitable stations in the following manner: The desired station is tuned in manually in the ordinary manner, since the whole dial may be treated as though it were an ordinary tuning-knob. Next, the button nearest to the slot is depressed and a special key or broad screwdriver inserted in the slots in the button so that it may be rotated until the whole of the skeleton plate assumes the position appropriate for precisely tuning the required station ; the name of the station is inserted in the button and the procedure is complete and is repeated for the additional buttons. It will be noted that reference is made to ten *suitable* stations ; this qualification is imposed, since each button can only be adjusted over a portion of the waveband, consequently the stations selected must be fairly evenly distributed.

Reference to Fig. 196 will show that contact is made between the appropriate tapered peg and the metal back-plate when any button is depressed, and contact is maintained until the button is released at the completion of the rotation ; the skeleton plate is connected to earth and the circular plate is connected to an appropriate valve grid-circuit, preferably the output. In this manner complete inter-station noise suppression is achieved, since the set will be inoperative when the dial is rotated by means of a button ; when the dial is rotated for normal manual tuning the suppression does not function and the receiver works in a normal manner. The metal back-plate is appropriately termed the muting plate, and to facilitate the operation of pre-setting the buttons this plate is not connected directly to a grid-circuit, but through a screw marked D in the illustration. This screw may be loosened so that contact between the muting plate and grid-circuit is broken; in this way the set is not muted when the button is rotated by means of the key, as described above.

It will be understood that each button may normally be pre-set for one particular station and relies on the wave-change switch to select the correct waveband, since the teledial has no influence over waveband switching. The necessity for independent waveband switching makes possible the selection of an additional station. The long waveband may be trimmed in such a manner that the condenser setting, for a worth while long-wave station coincides with the setting for a popular medium-wave station ; thus a long-wave and a medium-wave station may be tuned in with the same button, the choice being determined by the position of the wave-change switch.

Reference to the illustration will show that the individual buttons are hollow, to accommodate replaceable discs which are made of celluloid and serve to protect the paper discs bearing the names of the appropriate stations. Fig. 196 reveals an interesting refinement in the form of a split gear-wheel, and although it is in no way peculiar to the teledial it warrants an explanation. It will be observed that the larger of the two gear-wheels is split and is, in fact, two thin gear wheels, only one of which is fixed to the spindle ; the free member is attached to the fixed member by a small but powerful spring which would cause it to rotate if it were not checked by being in mesh with the smaller gear-wheel. This arrangement causes the two members of the large wheel to mesh with the small wheel under tension, and thus obviates the backlash which would otherwise be present or would occur through wear.

Button-operated Selector.—The number of possible arrangements for rotating a condenser to a predetermined position is practically without limitation, and manufacturers are frequently devising new principles or modifications of existing ones. The example given above is operated by what is virtually a rotary movement, and below an example is given of a device which functions by merely depressing an appropriate button, and these two systems must suffice to illustrate the principle of the pure mechanical systems. Whatever arrangement is adopted, it is equally important that due care be taken to obviate the possibility of frequency variation through a change in temperature.

The accompanying plate shows that the unit consists of four buttons, each of which terminates with a type of cam. Reference to the button shown depressed will reveal that both edges of the cam are engaged upon two flat bars which are connected by a link pivoted through the centre. A moment's thought will reveal that this bar assembly may rotate a condenser if connected by a link. The position of the cam is locked in relation to the button, so that when it is depressed it will move the bars into such a position that the edges of the cam rest on both. It follows, therefore, that the angle at which the cam is set will determine the position of the two bars and, consequently, the position to which the condenser is turned; in this way mechanical press-button tuning is accomplished. The operation of this device is shown diagrammatically at Fig. 197.

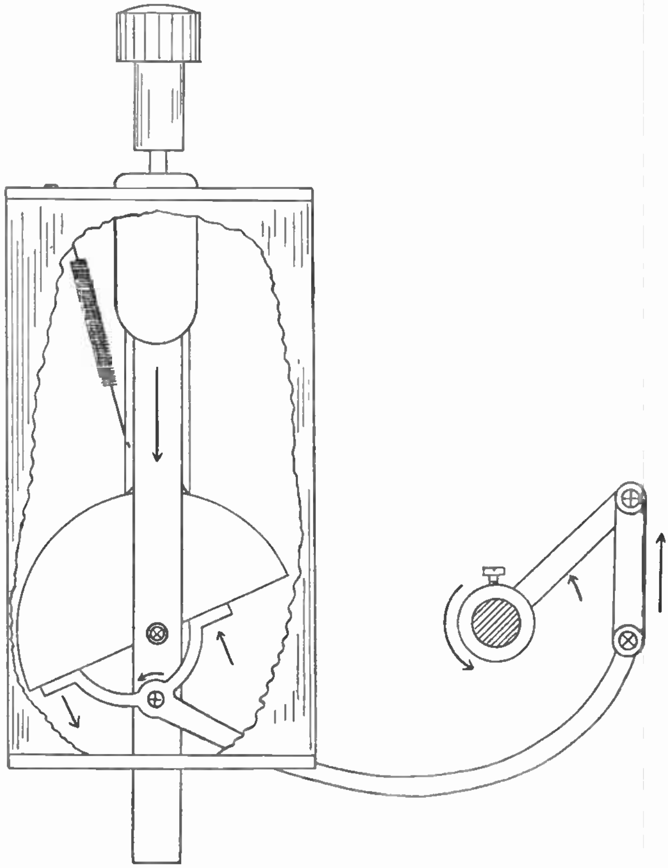


Fig. 197.—A diagrammatic drawing showing the operation of a push-button unit.

The method of pre-setting the buttons is extremely simple; the required station is tuned in by the manual control provided. The button intended to be used for this station is turned anti-clockwise, when it releases the cam; the button is then gently depressed, when the cam (which is now free to move) will take up a position resting on the two tuning bars. The operation is completed by rotating the knob in a clockwise direction, which locks the cam rigidly in its correct position.

These illustrations do not reveal a further refinement of this unit, which takes the form of an arrangement for giving a reduction gear between the manual-tuning knob and the condenser spindle, to facilitate adjustment.

Switch-operated Selector.—Attention may now be directed to an alternative system, whereby a number of tuned circuits are pre-tuned to a selection of stations and the appropriate circuit brought into operation by depressing one of a series of switches. This system presents two aspects, namely, the switch-gear and the tuned circuit. It will be convenient to deal firstly with the former, since this is unchanged in principle by consideration of the latter.

The push-button switch-gear is, in principle, a series of switches, one for each station to be tuned automatically; provision is usually made for between six and ten stations. The author has refrained from illustrating a switch unit, since it is impossible to select one that may be considered as being typical, as their method of construction shows astonishing variation. It is sufficient to mention that push-button switch-gear is fundamentally the same as any other switch-gear, types being available to make contact with the necessary number of points demanded by the circuit in use. Generally speaking, each switch is electrically independent but mechanically linked, so that it stays in the depressed position but is released when another switch is depressed. Various refinements are available, one of which is a mechanical link between each switch and a shutter permitting the name of the station to be illuminated when the appropriate switch is depressed.

The most obvious form of circuit arrangement for use with the switch selector is a tuning coil of appropriate inductance shunted with the ordinary tuning condenser for manual tuning and a series of pre-set condensers, each of which is brought into circuit when the corresponding button is depressed. With this simple arrangement the pre-setting for each button is accomplished by the appropriate adjustment of the pre-set condenser. There are many examples of push-button receivers which employ this system, which is just as satisfactory as the pre-set condenser is constant. Pre-set condensers are inclined to suffer from capacity drift due to various causes, the most prominent of which is expansion and contraction of the metal plates when influenced by heat; there are, however, special condensers constructed in a manner to overcome drift. Many manufacturers have chosen to dispense with pre-set condensers altogether and use permeability tuning.

Permeability-tuned coils for push-button use are usually wound with Litz wire for the coils intended for use on medium waves, and single-strand wire for the long-wave coils. They may be about $\frac{3}{4}$ inch in diameter and provided with a dust-iron core moulded in the form of a screw, the coil formers being appropriately threaded. Tuning is, of course, accomplished by screwing the core in or out, which will vary the inductance of the coil; and by the careful choice of dimensions each coil may cover a fairly wide band, so that there is considerable over-lap between successive coils, permitting reasonable choice of stations.

Motor-driven Systems.—Relatively elaborate receivers are fitted with motor-driven tuning, the greatest advantage of which is the ease with which remote control can be provided, since the actual switches control the motor and are not an electrical connection with the tuned circuit. Another important advantage is the absence of pre-set condensers, or equivalent devices, since tuning is accomplished by the rotation of a normal ganged condenser. Fig. 198 shows a diagrammatic layout of a relatively simple motor-tuning system. It will, perhaps, be desirable to identify the various sections before proceeding with a description of the arrangement. The transformer marked (1) is intended to step the mains voltage down to the voltage required by the motor, usually 25 volts, which is used to drive a 12-volt motor. This considerable over-load is permissible, since the motor will not only run for very short periods and it increases the starting torque of the motor by about five times; a thermal delay-switch is usually incorporated to switch the motor off if it is caused to run for an excessive period should, for example, some uninformed person be disposed continuously to press buttons to watch the mechanism working. Item (2) is a reversible electric motor which, when intended for A.C. working, is of a highly specialised type, since such a motor is not normally reversible. Item (3) is, of course,

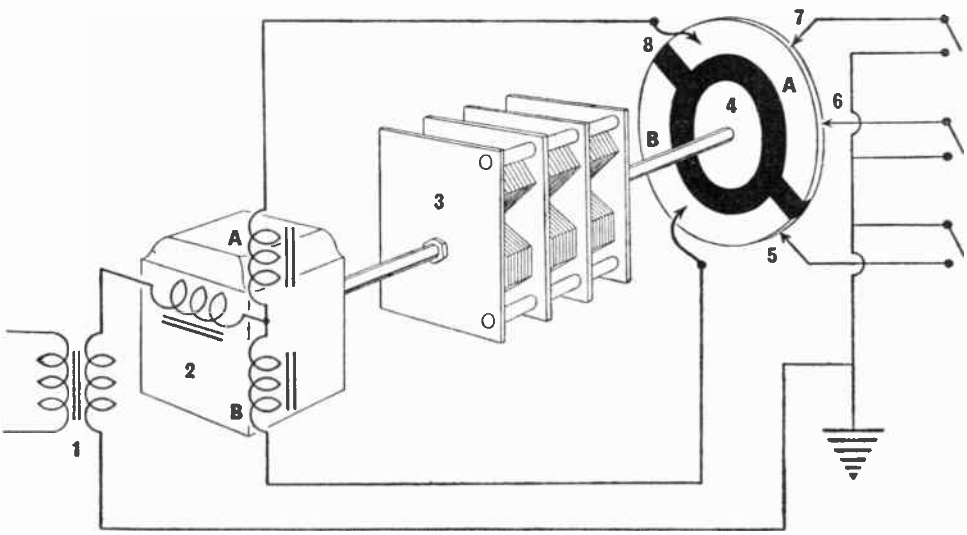
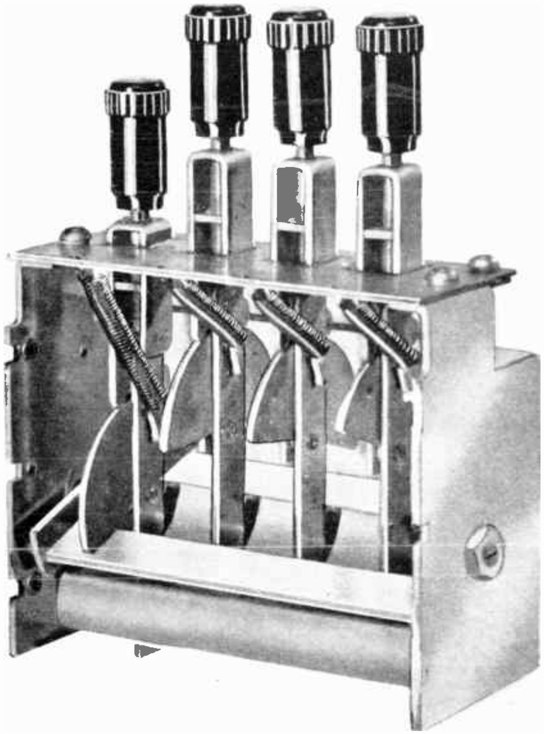
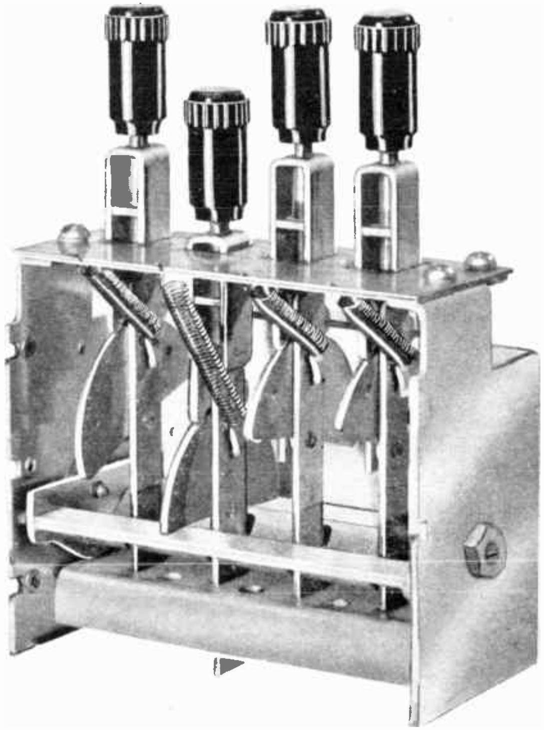


Fig. 198.—A composite illustration showing the principle of motor tuning using the direct-homing method.

a normal ganged tuning condenser, while item (4) is a single selector disc of the *direct-homing* type.

(5), (6), and (7) are the pre-selector contacts, any reasonable number of which may be provided. They will normally be arranged to slide round some form of frame, to position them so that they make contact with the rim of the control disc at the point necessary to tune the required station. They will be provided with some arrangement whereby they may be released and moved to the appropriate position, ultimate adjustment being achieved by some vernier device to facilitate accurate adjustment. In order to follow the working of the arrangement it will be convenient to assume that button No. 7 is depressed, which will complete the circuit from earth through section 4A of the control disc, through





A TYPICAL FORM OF MECHANICAL PRESS-BUTTON TUNING.

Mechanically operated press-button tuning; note position of the tuning bars when the end button is depressed. The tuning bars are directly connected to the spindle of the tuning condenser by means of a link.

The same mechanism as that shown on the left; note the different position of the tuning bars due to the position of the cam brought into action by depressing the second button. The angle of each cam is easily adjustable.

coil 2A of the motor, thence through the armature to the secondary of the transformer, the other terminal of which is earthed and completes the circuit. The motor will then start and rotate the disc in a clockwise direction until the circuit is broken by the insulated segment of the disc, marked 8 in the illustration, coming opposite to contact No. 7, which will break the current and stop the motor; if the position of No. 7 switch contact is correct the condenser will have stopped at the proper position for tuning the appropriate station.

In order to avoid confusing the reader it will be convenient to assume that the moving section is again in the position shown at Fig. 198, and that on this occasion button No. 5 is depressed. Reference to the illustration will show that the contact thus made will cause the current to flow to the motor via section 4B of the control disc, and thence through coil 2B of the motor, which will cause the motor to rotate in an anti-clockwise direction until the insulated segment stops it in the correct position. At first sight this reversal of direction might seem unnecessary, but by splitting the control disc in half the disc automatically rotates in a direction which will give the insulated section the shorter journey to the contact, thus avoiding irritating delay.

Once again, possible arrangements for motor driving are too numerous to be described in detail, but the one explained above and illustrated at Fig. 198 serves to illustrate the principle excellently. It is known as the direct-homing type, since by means of a split disc the condenser always rotates in the right direction. Where this principle is not employed a switched circuit is included so that the motor reverses when the condenser reaches maximum or minimum. This system has the disadvantage that considerable delay is experienced when the motor switch is set for, say, the clockwise direction and the required station is a few degrees anti-clockwise of the condenser setting, resulting in the condenser making a complete traverse in the clockwise direction, reversing and returning to the required tuning-point.

In Fig. 198 a single disc is shown around which the pre-selector contacts are placed. An alternative arrangement consists of a separate disc for each station and a row of contacts in line, preadjustment being accomplished by correctly positioning the disc on the spindle. This method appears unnecessarily cumbersome, and for this reason is unlikely to achieve great popularity.

Muting.—Motor-driven tuning is usually provided with some device to mute the receiver for the purpose of inter-station noise suppression while the motor and ganged condenser are revolving. Several muting systems are possible, one of which consists of deliberately arranging end-play for the motor armature and arranging a spring so that the armature is pushed out of the exact centre of the pole pieces; when the motor is switched on the armature will centre itself, and this small movement may be made to close a pair of contacts situated at the end of the motor shaft. When this arrangement is used, the coupling between condenser and motor must be such that this movement may take place without moving the condenser spindle.

Automatic-frequency Control.—Unless very special arrangements are incorporated, it is impossible to make the motor stop at the precise position required for the accurate tuning of a station, consequently means are usually employed to correct this slight mis-adjustment by purely electrical means. The circuit for accomplishing this correction is known as an automatic-frequency control circuit, usually abbreviated as A.F.C., which has the additional advantage that it will correct frequency drift in the oscillator circuit; it is, of course, assumed that the circuit employed is of the superheterodyne type, since motor tuning would not normally be employed with a straight receiver.

Fig. 199 shows a block diagram of a superheterodyne receiver with automatic-frequency control. It will be realised that if the ganged condenser is slightly mis-tuned, two or more circuits will be out of alignment, but the circuit that really matters is the oscillator circuit which will control the intermediate frequency.

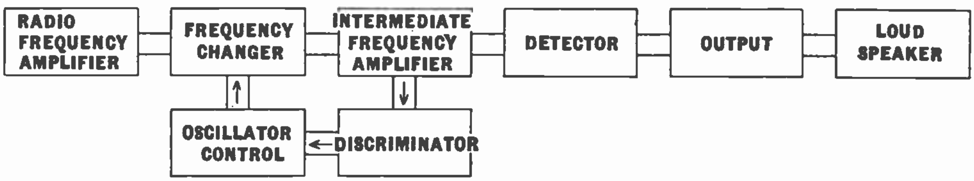


Fig. 199.—Block diagram of a superheterodyne with automatic-frequency control.

Assume that the mis-adjustment is such that the intermediate frequency is actually 463 kcs. per second, whereas the intermediate-frequency transformers are tuned to 465 kcs. per second. Reference to Fig. 199 will show that the voltage developed across the intermediate-frequency transformer is led to the discriminating circuit, which may consist of a special double diode valve having a separate cathode associated with each anode, the resistive load connected between the cathode and centre tap resulting in a voltage being developed in a negative direction if the intermediate frequency is too high, or in the positive direction if it is too low. In this manner a potential is produced which varies in direction and amplitude in proportion to the intermediate-frequency drift; this voltage may be used in several ways to correct the frequency of the oscillator and in consequence the intermediate frequency.

The voltage output of the discriminating circuit is usually fed to an oscillator control-valve. It may appear as a potential between grid and cathode of a triode valve, so that the latter becomes, in effect, a variable impedance which is virtually connected across the oscillator coil, so that it increases or decreases the impedance and consequently the frequency to which the oscillator coil is tuned.

CHAPTER 29

FREQUENCY MODULATION

ALL previous reference to modulation has referred to amplitude modulation, which is a system whereby audible sound frequencies are imposed on carrier waves by varying the amplitude. In this system the fundamental frequency of the carrier waves remains constant although side bands above and below the carrier frequency are introduced in the process of modulation ; thus the pitch of the audible sound to be transmitted varies the amplitude and forms what it will be remembered is termed the modulation envelope, and the intensity of the audible sound being transmitted varies the extent or depth of modulation. There are, however, other systems of modulation, all of which are of a semi-experimental or restricted nature, with the exception of frequency modulation, a system which forms the subject-matter of this chapter.

Frequency modulation is not new, and the basic idea was suggested by authorities in the early days ; in fact this form of transmission was used experimentally in the United States of America before the World War. It is not, however, intended that this remark should convey either the impression or otherwise that the United States are in front of Great Britain in this development, but it is obvious that a system which has greater freedom from noise has fundamentally greater advantage in that country where atmospheric interference is more serious than in the British Isles. It would be unfair, however, to end this historical note without tribute to Major E. H. Armstrong who, in the author's view, is the chief pioneer of this system.

The British Broadcasting Corporation commenced experimental FM transmissions in 1944 and opened a regular service on 2nd May, 1955, at Wrotham in Kent to serve London and South-east England and then started to cover the whole country with a network of stations; the service uses the V.H.F. band and occupies from 87·5 to 100 mcs.

Frequency modulation has certain material advantages over amplitude modulation and is likely to gain in popularity, although its use is restricted to the higher frequency bands, since its advantages are only apparent when it occupies a wide band width which would not be tolerated on the lower frequency bands. A special type of receiver is necessary to receive frequency modulation, and while the system soon became popular in coastal areas when interference is bad, its adoption inland was somewhat disappointing. It has, however, unique possibilities in connection with television or where it is desired to establish a broadcasting system under conditions where atmospheric disturbance would render the amplitude modulation system impracticable.

It is not intended to go into the advantages and disadvantages of frequency modulation in any great detail, since there are so many circumstances which may attend a communication requirement when the various features of the two systems have varying advantages and drawbacks. It is, however, desirable to stress three important advantages, namely, greatly increased signal-to-noise ratio, which is probably the over-ruling advantage; less interference between stations on adjacent channels or from A.M. transmitters; the audio modulation may be subject to less amplitude compression. The signal-to-noise ratio improvement of frequency modulation over amplitude modulation is between 250 : 1 and 750 : 1 according to the extent to which the possible advantages are used.

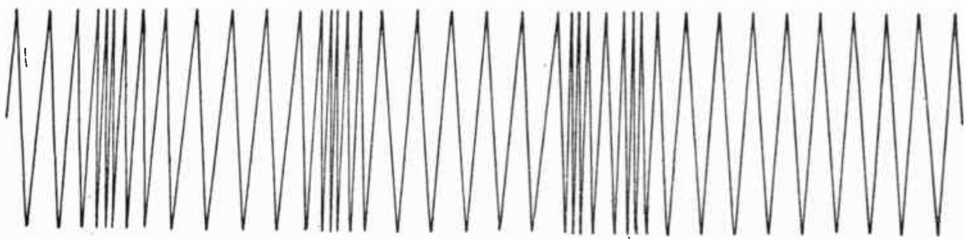


Fig. 200.—A diagrammatic representation of frequency modulation. (For ease in drawing and general clarity straight lines have been used instead of curved lines of sinusoidal character.)

The Basic System.—Any system of modulation used to transmit sound must be capable of conveying two quantities, frequency and amplitude. In frequency modulation the carrier frequency is varied by the modulation frequency, that is to say the carrier frequency is speeded up and slowed down at a rate equal to the modulation frequency. For example, if the modulation frequency is 500 cycles per second, then the carrier frequency must be varied 500 times per second. It is important to note that the modulation frequency corresponds to the rate that the carrier frequency is varied and not to the amount of variation which is controlled by the amplitude of the modulation frequency.

To recapitulate, frequency modulation is a system by which audio pitch controls the rate of frequency variation of the carrier, audio amplitude controls the extent of carrier frequency variation while the carrier amplitude itself remains unchanged. In conformity with amplitude modulation, frequency modulation occupies a definite band in the frequency spectrum the limits of which will be determined by the change in amplitude of the modulation and not by the modulation frequency. The extent of the deviation of the carrier frequency may be set within any reasonable limits, but for practical purposes the deviation of plus and minus 50 to 150 kilocycles per second may be taken as indicative of the band width occupied by the system.

The Frequency-modulation Receiver.—Fig. 201 is a block diagram of a frequency-modulation receiver from which it will be seen that the

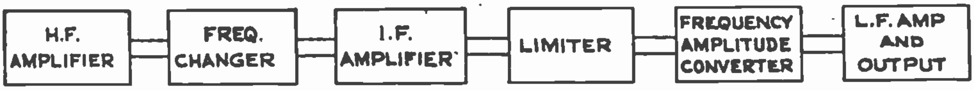


Fig. 201.—Block diagram of a frequency-modulated superheterodyne receiver.

first three stages and the last correspond to the orthodox receiver, but that the second detector and automatic volume control system are replaced by a frequency-amplitude converter stage and limiter stage respectively. These two stages are dealt with below, and before leaving the other stages of the receiver it is necessary to emphasise that the frequency changer stage calls for special care in design, since greater frequency stability is required from the local oscillator. De-tuning of the oscillator in amplitude modulation merely results in accentuating the higher audio-frequencies, but in a frequency-modulation system it causes amplitude distortion by flattening the upper or lower half of the wave-form. It is also necessary to provide the oscillator stage with adequate smoothing to prevent any trace of modulation due to mains hum, a state of affairs that is most serious in a frequency-modulated receiver, as the converter stage will change such frequency modulation into an audible signal.

The Limiter Stage.—The function of the limiter stage is to reduce to the smallest possible proportions any amplitude modulation of the carrier wave form due to static, electrical interference, valve noise, or interference from unwanted stations. It is apparent from the previous paragraphs that the amplitude of a frequency-modulated transmission remains constant; it is desirable, therefore, that the same condition should obtain before the received signal is converted to audio-frequency. It is also fairly obvious that such an arrangement will greatly increase signal-to-noise ratio, an aspect which is again referred to in a later paragraph. There are numerous possible forms of limiter, but only one is considered below, the saturated amplifier, which is the most suitable for general purposes.

The circuit diagram of a saturated amplifier limiter circuit is given at Fig. 202, while its performance curve is shown at Fig. 203. Reference to Fig 202 will show that the valve is arranged somewhat like a leaky grid detector. The carrier input is rectified by the valve and automatic bias is produced across R_1, and if the working conditions are so arranged that the gain of the valve is inversely proportional to the bias across R_1, then amplitude modulation will be substantially absent across the output circuit providing that the voltage across R_1 faithfully follows any

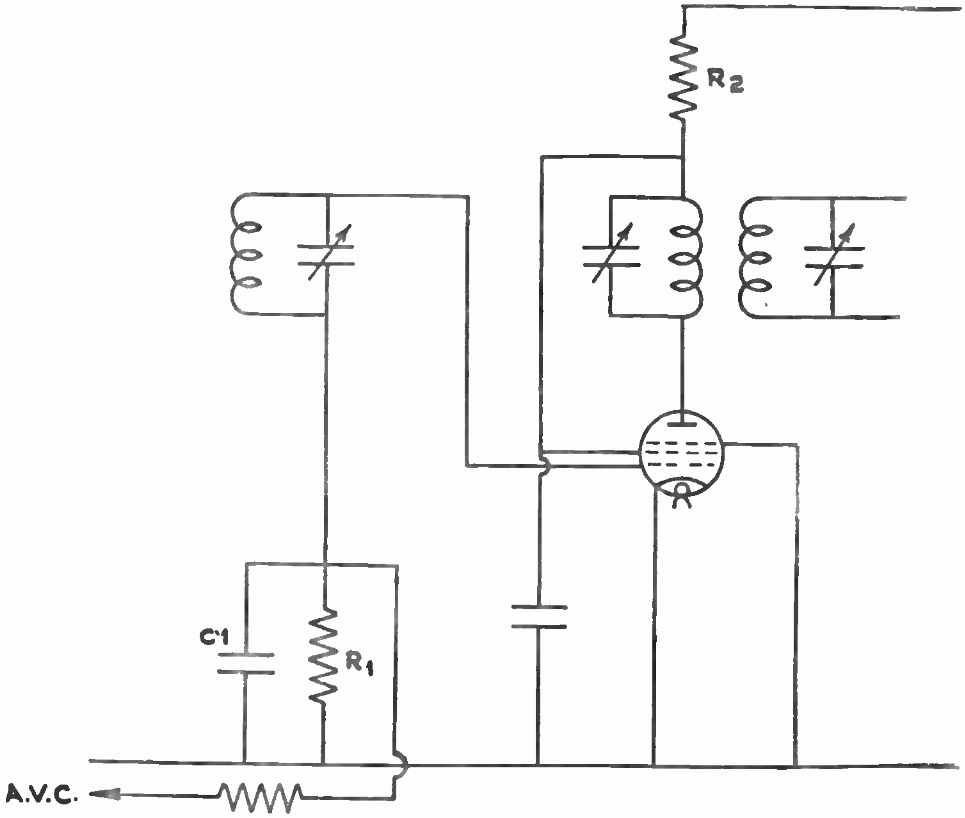


Fig. 202.—The limiter valve; Fig. 203 shows the performance of a typical stage.

changes of amplitude fed from the I.F. amplifier. In order to fulfil these requirements a pentode having a short grid base is essential, that is to say, it should be what is colloquially known as a straight pentode and should not be of the variable mu type; other requirements are suitable anode and screen voltages and correct values for R_1, C_1.

The correct value of anode and screen voltage must, of course, vary with different valves, but normal examples require an anode and screen voltage between 35 and 45 volts. The values of R_1, C_1 must be chosen so that adequate voltage is produced across R_1 for proper control of I.F. and H.F. stages, while at the same time the voltage produced faithfully follows any amplitude modulation which, it will be remembered, it is desired to eliminate. Generally speaking, R_1 may be 0·1 to 0·15 megohm and C_1 100 μμF. Reference to Fig. 203 will show the performance of a typical limiter stage and illustrates that the output of the device remains substantially constant irrespective of input, providing, of course, the input is big enough to produce the necessary condition of saturation. The upper of the two curves fulfils the requirements as well as can be expected in practice, while the lower curve is included to emphasise the point that undue overlimiting is produced by R_1 having too high a value.

Frequency-amplitude Converter.—Before describing in detail the frequency converter stage it will be useful to define the meaning of the term " frequency converter," since this will reveal the precise function that it is desired to accomplish. It will be remembered that the frequency converter stage replaces the detector stage of the normal receiver, although the frequency converter stage in itself incorporates a normal detector arrangement. In fact the frequency converter stage is in essence a frequency-modulation to amplitude-modulation converter plus a comparatively normal amplitude-modulation detector. The requirements of the frequency-amplitude converter are linearity and high conversion efficiency ; linearity is essential, that is to say, the resultant amplitude modulation developed in the anode circuit must be directly proportional to the frequency modulation applied to the grid circuit, otherwise untrue rendering of the original audio modulation must obviously result. High conversion efficiency is necessary, otherwise the advantages of frequency modulation are correspondingly offset.

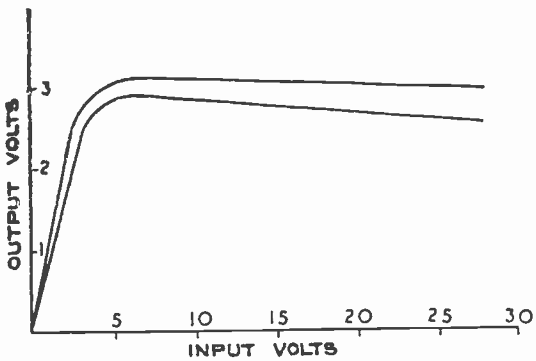


Fig. 203.—Action of the limiter valve ; typical input-voltage, output-voltage curves.

Perhaps the most obvious way of converting frequency to amplitude modulation is to apply the frequency-modulated carrier to the grid cathode circuit of a suitable valve, the anode load of which is a tuned circuit tuned off resonance either above or below the unmodulated carrier frequency ; with this arrangement the voltage developed across the anode load will vary in proportion to the frequency change across the grid cathode circuit, the function of the stage being completed by detecting the amplitude-modulated carrier thus obtained by means of a diode or other detector in the normal manner. This single arrangement, unfortunately, has two serious drawbacks, the desired linearity of conversion is only preserved if the input is very small and the conversion efficiency is very low, as the anode load is seriously off resonance and must be heavily damped to accommodate the necessary band width of the modulation. In practice there are two basic circuits in general use, usually referred to as the detector and the phase ratio detector, typical arrangements of which are described below.

The Ratio Detector.—Unfortunately, it is not possible to go deeply into the functioning of this system or that of the phase detector, which follows, without the use of a purely mathematical approach which would be inconsistent with this work as a whole, the author hopes, however, that the following brief details will be sufficient for most purposes. Fig. 204 shows the basic circuit of a frequency amplitude converter which is known as a ratio detector and is the system in most general use. Other methods exist, most noticeable among which is the phase detector which has merits that are sometimes overlooked. It is described on page 245.

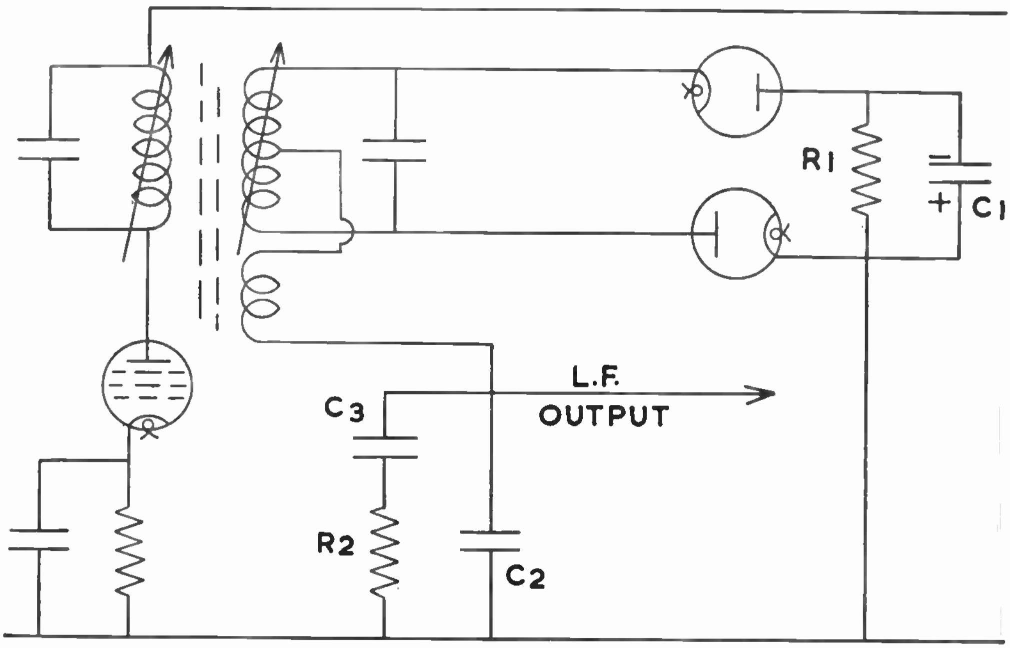


Fig. 204.—The ratio detector.

The screened pentode in this illustration is the limiter valve and is coupled to the ratio detector diodes by a special type of transformer which has a coupling coil connected between the centre tapped secondary and L.F. lead. The system relies on the fact that the voltage induced in the transformer secondary, due to its coupling with the primary, is out of phase with the voltage injected into the circuit by the coupling coil. This injected voltage is 90° out of phase with the voltage at either end of the secondary when the carrier frequency is the same as the resonant frequency to which the transformer is tuned. When, due to frequency modulation, the incoming frequency varies, this balance is upset and the current flowing through the two diodes will be unequal depending on the ratio between this current and the current arising purely from the primary-secondary coupling. On successive half cycles an audio-frequency voltage is developed across C2. The filter, C3, R2 across C2, is a special form of tone compensation known as de-emphasis; it is referred to on page 247.

The Phase Detector.—This circuit, which is also known as the Foster-Seeley Detector, is shown at Fig. 205. Briefly, the phase detector makes use of the fact that the tuned primary of the high-frequency transformer is 90° or 270° out of phase with its tuned secondary at resonant frequency.

In the arrangement of Fig 205 the secondary winding is centre tapped and one half is in series with the primary. Thus the *effective* sum of the

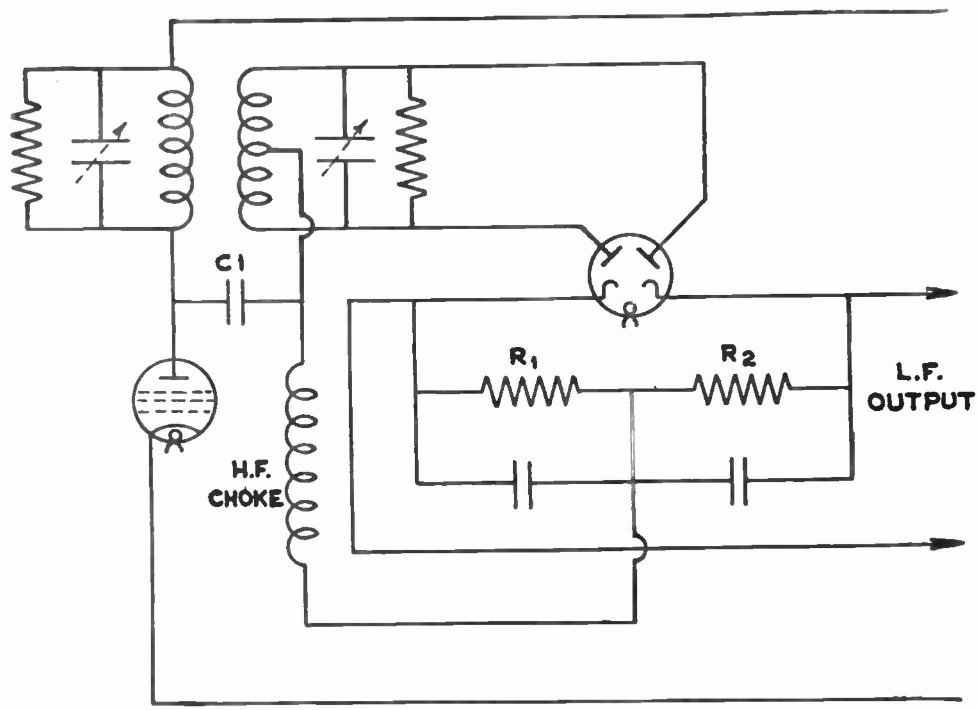


Fig. 205.—The phase detector frequency-amplitude converter.

two voltages developed is applied to one diode detector, the other half of the secondary being similarly arranged in series with the primary and applied to the other diode. The diode loads R_1 and R_2 are arranged in opposition as in the amplitude converter circuit so that the voltage developed across R_1 and R_2 will be the sum of that developed across each and proportional to the frequency change applied across the grid-cathode circuit.

Correct functioning of the phase detector is controlled, largely, by the tuning of the primary and secondary windings and the coupling existing between them. In general terms the correct tuning of the primary so balances the circuit that its response to a given change of frequency above the mean carrier frequency has the same effect as an equal change in the opposite direction; correct secondary tuning produces the required state of zero voltage across R_1 and R_2 when the carrier is unmodulated, while the degree of coupling, in conjunction with the magnification of the inductances, gives the desired conversion linearity.

In preceding paragraphs the inductive coupling has been referred to as a high-frequency transformer in order to avoid any possible confusion in the mind of the reader between the subject under discussion and the functions of the ordinary superheterodyne frequency changer. In practice, however, it will normally be a special form of intermediate frequency transformer, since it is most unlikely that a frequency-modulated receiver would employ other than the superheterodyne principle, though there is probably no fundamental reason why the straight high-frequency amplification could not be used other than the ridiculously low efficiency that would result inherent with tuned circuits designed to handle a wide band width at high frequency. To prevent any possibility of misunderstanding, the block diagram at Fig. 201 should be studied, which shows the sequence of operations of a typical superheterodyne frequency-modulated receiver. It will be noted that both frequency changers and frequency amplitude converter stages are used, both performing their separate special functions.

It should be particularly noted that in Figs. 202, 204, and 205 a limiter valve circuit is shown separately from the frequency-amplitude converter circuit. This course has been adopted to simplify explanation, but in practice a single valve usually performs both functions. Reference to Fig. 202 will show that the function of the limiter valve is largely carried out by the grid-cathode and merely requires that the anode load operates over the band width to be handled ; reference to Figs. 204 and 205 and the explanation given above will show that the function of conversion is accomplished entirely in the anode circuit and merely requires the frequency-modulated input to be developed between the grid and cathode; thus the requirements for both functions are compatible and a single valve will perform both ; in other words, the limiter valve for Fig. 202 should be regarded as the same valve as that illustrated at Fig. 204 or 205. As already stated, the limiter valve and the amplitude frequency conversion valve may be in fact a single valve ; conversely, if desired they may be separate valves coupled by a normal transformer, and this practice is employed in some receivers.

The Combined Limiter and Frequency Converter.—The function of limiter and frequency amplitude converter may be combined and a possible arrangement is shown at Fig. 206, which has the advantage of enormous stage gain. The circuit is, essentially, a pair of leaky grid detectors with fixed reaction arranged for push-pull working, the input circuit being a transformer made up of three coils which will be the last intermediate frequency transformer or tuned signal frequency transformer depending upon whether the receiver is of the superhet type or otherwise, one secondary is tuned above and the other below the carrier frequency. Sufficient reaction is introduced to cause the valves to oscillate violently but such action is prevented however, by a system of rapid interruption known as quenching, that is the periodic choking of the valve by grid current at a frequency pre-determined by the value of the grid leaks and condensers.

The chosen quenching frequency is normally well above audio frequency and is not, therefore, audible although some distortion is introduced; 100,000 and 250,000 times per second is normally used. The lower frequency gives greater gain but introduces distortion apparent to a critical listener whereas the higher frequency gives lower gain with apparent freedom from distortion. The limiter action is quite automatic and relies on the fact that the grid swings from cut off to saturation due to the super-regenerative action and any increase of grid swing caused by variation in the incoming signal swings beyond cut off and saturation and consequently has no effect on the output.

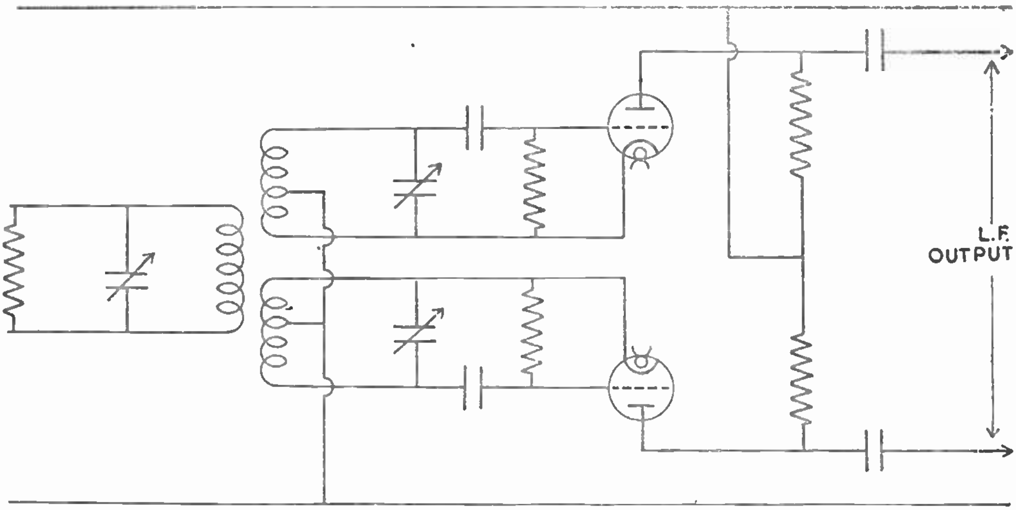


Fig. 206.—An interesting circuit which combines the functions of limiter and frequency-amplitude converter; using the super-regenerative principle this arrangement has very high stage gain.

Pre-emphasis.—The signal-to-noise ratio, already greatly improved by the use of the frequency-modulation system, can still further be increased by the introduction of pre-emphasis, a system whereby the higher audio-frequencies are transmitted at disproportionately high amplitude and can be restored at the receiver end by the de-emphasis which is achieved by reducing the amplification of the high audio-frequency to an extent equal to the increase imposed in the transmission; de-emphasis is accomplished in Fig. 204 by the condenser C2 and resistance R2.

The Frequency-modulated Transmitter.—Frequency-modulation transmitter technique is complicated in its advanced form but the following notes will illustrate the basic principle. The simplest form of F.M. transmitter is a single valve oscillator with a condenser microphone connected across the tuned circuit. If a sound wave is directed to the microphone it will cause a change of capacity proportional to the intensity of the note. The *higher* the pitch the *more rapid* the change; the *lower* the pitch the *slower* the change. The *louder* the note the *greater* the change; the *softer* the note the *smaller* the change. Since the microphone is connected across the tuned circuit these changes of capacity will affect the oscillator frequency and its output will be frequency modulated.

The more usual arrangement is a most ingenious device known as the reactance modulator but sometimes referred to as the phantom inductance for reasons which will become apparent. Its action cannot be explained precisely, or even adequately, without recourse to mathematics but it is hoped that the following broad outline will be found useful. The fundamental requirement is that the audio frequency input shall change the frequency of the oscillator V2 which is dependent on the inductance and capacity of its oscillatory circuit; the reactance modulator, shown at

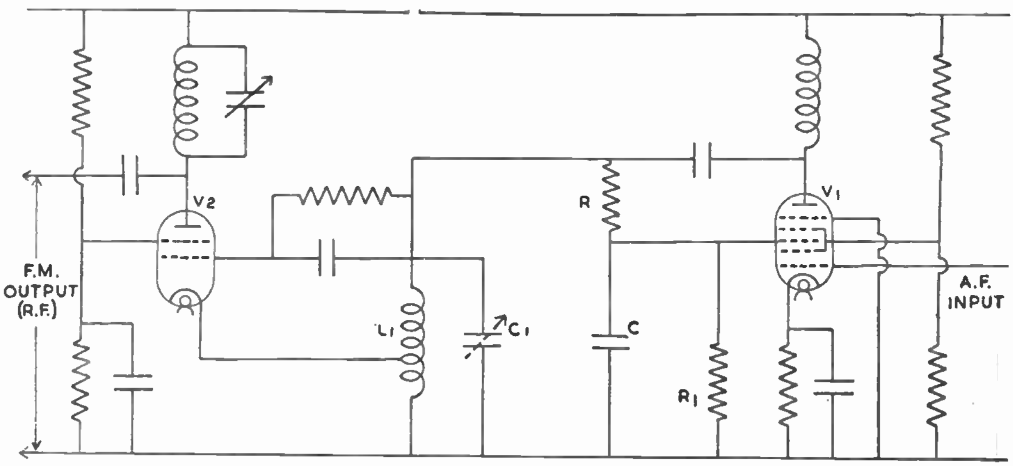


Fig. 207.—A typical reactance modulator circuit coupled to a simple oscillator.

Fig. 207, in effect, converts a change in audio frequency current into a change of inductance. Providing that the reactance of C is small compared with the resistance of R the voltage developed across the former will cause the anode current of the reactance modulator V1 (which flows through the oscillator inductance) to lag a quarter of a cycle behind the oscillator current. Since inductance causes the current flowing through it to lag a quarter of a cycle behind the voltage across it, the lagging current introduced by the reactance modulator valve will have the same effect as though an inductance were connected across the oscillator inductance L1. The effective value of the phantom inductance on the oscillator frequency is determined by the audio frequency input to the reactance modulator valve; thus, frequency modulation is achieved.

The oscillator will normally function at a sub-multiple of the ultimate frequency to be broadcast and will be followed by the necessary number of frequency multipliers which will multiply the deviation frequency as well as the carrier frequency of the oscillator thus reducing the deviation necessary in the oscillator-reactance modulator circuit. Frequency multiplication is described in Chapter 8, Volume II.

Advantages and Disadvantages of Frequency Modulation.— It is desirable to summarise the advantages and disadvantages of the system under discussion and analyse the several factors which produce the very favourable signal-to-noise ratio that is a feature of the system. As stated earlier in the chapter, the three principal advantages are increased signal-to-noise ratio, less interference between stations on adjacent channels, freedom from A.M. jamming, and audio-modulation may be subject to less amplitude compression. To these may be added greater output at the receiving end for a given transmitter power, although this feature is rather one of economic than purely fundamental advantage. The principal disadvantage of the system is the very adverse effect of selective fading, which produces much more unpleasant results than when using the amplitude-modulation system. This disadvantage is mainly due to the fact that low audio-frequency produces a very large number of side bands and selective fading makes any audio output based on these frequencies quite unintelligible even under conditions that would be tolerable when using amplitude modulation on the same frequency at the same time and in the same place. The cause of selective fading is dealt with in an earlier chapter and need not be further discussed. Since selective fading is so objectionable, it follows that the use of the system is restricted to a service area where the receiver receives substantially only the direct transmitter ray and no reflected rays from the upper atmosphere. The B.B.C. employ a number of limited range transmitters; even so, multi-path distortion can be serious.

The increased signal-to-noise ratio is tabulated below under four main headings, the last of which has a gain of two, due to the greater transmission efficiency of the system; but, as already explained, this is to some extent purely an economic advantage, since the same gain could be achieved with any system by building a transmitter having twice the power. The figures quoted are in round terms.

IMPROVEMENT OF SIGNAL-TO-NOISE RATIO FREQUENCY MODULATION COMPARED TO AMPLITUDE MODULATION

Due to action of limiter valve	3 times
Due to wide band width (deviation 75 kcs each side of carrier)	25 ,,
Use of pre-emphasis	5 ,,
Due to efficiency of transmission	2 ,,

The above summary shows an increased signal-to-noise ratio of 750 : 1 under the conditions quoted; if the gain due to transmission efficiency is ignored for reasons already stated and pre-emphasis is not employed, the gain is 75 : 1, a factor which shows the fundamental advantage of the system and at the same time draws sharp attention to the advantage of pre-emphasis, which converts the gain of 75 : 1 to 375 : 1.

Aerial Arrangements.—For receiving B.B.C. broadcasting using the frequency-modulation system, special aerial arrangements are highly desirable, not because of the special type of modulation employed, but because the transmissions are on very high frequency (V.H.F.) or, to be precise, on a band extending from 87·5 to 100 mcs. It is, therefore, convenient to deal with the point in this chapter and not as part of general aerial considerations in Volume II.

For the proper functioning of the F.M. system the signal supplied by the aerial must reach a certain level so that the input to the limiter valve is large enough to allow it to perform its function efficiently. Failure to produce this condition due to an inadequate aerial will make the receiver liable to interference from electrical apparatus, particularly the ignition systems of motor vehicles ; it may also allow some fading when the receiver is situated towards the limit of the transmitter service area.

When the receiver is situated 10 miles or so from the transmitter, or even 20 miles in favourable circumstances, good reception is usually possible when using a compressioned dipole aerial inside the receiver cabinet. If a better aerial is required but an outside aerial is unnecessary, a simple indoor aerial can be made by taking a length of 60–80 ohm twin television feeder and splitting the top end for a distance of 32 inches and bending the two arms thus formed to a " T " shape. If possible, the top arms of the " T " should be at right-angles to the direction of the transmitter. The receiver will be fitted with twin aerial sockets, since whatever form of aerial is used it will be connected to the receiver by twin feeder cable ; always use proper low loss feeder of 60–80 ohms impedance as it has special characteristics that permit reasonable matching between aerial and receiver.

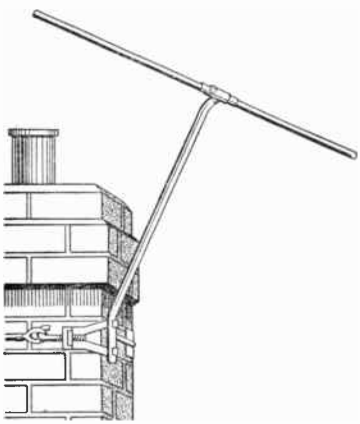


Fig. 208.—A Simple dipole for V.H.F. reception.

The theory of the dipole aerial is dealt with at length in the section devoted to television aerials which commences on page 178 of Volume II, but it must be remembered that B.B.C. transmitters on V.H.F. use horizontally polarised aerials, consequently the receiving dipole must also be horizontal. Fig. 208 shows a simple dipole aerial which, when fixed to the chimney stack of a normal two-storey house, is usually adequate up to the outer limit of the B.B.C. service area. Difficult locations or distances beyond the service area may require more efficient aerials which are obtainable with two or more elements, suitable for chimney fixing.

MODERN PRACTICAL RADIO AND TELEVISION

A PRACTICAL AND COMPREHENSIVE TREATISE DEALING WITH EVERY PHASE OF RADIO ENGINEERING, INCLUDING DESIGN, CONSTRUCTION AND MAINTENANCE, WITH SPECIAL CHAPTERS ON TELEVISION, ETC.

BY

C. A. QUARRINGTON, A.M.Brit.I.R.E.

AND EDITED BY

W. H. DATE, B.Sc., A.M.I.E.E.

VOLUME II

THE CAXTON PUBLISHING COMPANY LIMITED
LONDON · NEW YORK · MELBOURNE
TORONTO · WELLINGTON

First published	. *January*	1946
Second Edition	. *June*	1948
Reprinted	. *May*	1949
Reprinted	. *April*	1950
Reprinted	. *November*	1950
Reprinted	. *March*	1951
Reprinted	. *June*	1951
Reprinted	. *November*	1951
Reprinted	. *May*	1952
Reprinted	. *September*	1952
Reprinted	. *December*	1955
Reprinted	. *May*	1957

PRINTED AND BOUND IN ENGLAND BY
HAZELL WATSON AND VINEY LTD
AYLESBURY AND LONDON

CONTENTS OF VOL. II

CHAPTER 1

THE POWER PACK

CHAPTER 2

DECOUPLING

CHAPTER 3

THE GRAMOPHONE PICK-UP

CHAPTER 4

GENERAL MECHANICAL AND ELECTRICAL CONSIDERATIONS

CHAPTER 5

FIVE CIRCUITS ANALYSED

CHAPTER 6

AERIALS, EARTHS, AND NOISE SUPPRESSION

CHAPTER 7

CAR RADIO

CHAPTER 8

PRINCIPLES OF LOW-POWER TRANSMISSION

CHAPTER 9

THE HIGH-VACUUM CATHODE-RAY TUBE AND ITS APPLICATION TO TELEVISION

CHAPTER 10

THE TIME BASE

CHAPTER 11

AN OUTLINE OF TELEVISION TECHNIQUE

CHAPTER 12

TELEVISION-RECEIVER DESIGN

CHAPTER 13

ADJUSTMENTS AND FAULTS OF A TELEVISION RECEIVER

FULL-PAGE PLATES
and
FOLDING DIAGRAMS

VOL. II

FULL-PAGE PLATES

FOLDING DIAGRAMS

Various circuits, devices and principles described in this volume form the subject matter of letters-patent or provisional protection.

MODERN PRACTICAL RADIO AND TELEVISION

VOL. II

CHAPTER 1

THE POWER PACK

NUMEROUS diagrams in the preceding chapters have been shown with high-tension positive and negative rails, and it has been understood that these are fed from some source providing the high-tension supply. In the case of battery-operated receivers power will be derived for heating the filaments from some such source as an accumulator, while the high-tension current will normally be supplied by a battery having an E.M.F. of 65–100 volts; such a battery will contain about 45–65 cells of the so-called dry type and of dimensions commensurate with the current to be drawn. The average battery receiver employing four valves will take an anode current of about 6–9 milliampères while a six- or seven-valve superheterodyne may take upwards of 15 milliampères.

Class B Working.—Some care is required when selecting a high-tension battery for use with a receiver employing quiescent output. A receiver with quiescent output may take an average anode current of, say, 14 milliampères, and a battery rated to deliver a maximum current of 15 milliampères might appear suitable. Such a receiver will take peak currents up to about 30 milliampères for fairly long periods, such as during an organ recital, with the result that the high-tension battery develops a certain amount of internal heat—sufficient to dry up the paste electrolyte—resulting in uneconomic life. Such receivers should work with a battery rated to deliver about 50 per cent. more current than the average current consumption of the receiver.

Mains Operation.—The question of high- and low-tension supply for a mains-operated receiver cannot be dealt with in the brief manner adopted for battery-operated receivers. Mains receivers may be divided into two classes, *i.e.* those intended for working from alternating-current mains, and those for working on either alternating-current or direct-current mains; receivers designed for working on direct current *only* are virtually obsolete, and can therefore be ignored, but some explanation is called for regarding the necessity of employing receivers for use on alternating current only when there is an alternative system available which functions on either type of supply. Receivers intended for use on either alternating or direct current are known as *universal* or A.C./D.C. *receivers*, and are preferable for those likely to move to a different supply or have their existing supply changed, and are fundamentally inferior, since it is impossible to raise the high-tension voltage supplied to the valves above the mains voltage; consequently, such a receiver would not be chosen unless it was likely to be used on direct-current mains.

Either type of mains receiver is required to work from alternating current, and means must be found for converting to direct current for the high-tension supply; although the heaters may be fed with alternating current, since they will be of the indirectly heated type with the possible exception of the output valve. The conversion from alternating to direct current is known as rectification, and is accomplished by means of a valve or metal oxide rectifier; the former will first receive consideration.

The Rectifier Valve.—A rectifier valve is in principle a diode, but differs from the detector diode inasmuch as it is more heavily constructed to enable it to pass the heavy anode current required and dissipate a considerable amount of heat without distress. Fig. 1 shows a full-wave mains rectifier, although it is difficult to convey a true mental picture with an illustration. It may be mentioned, however, that a rectifier is more heavily constructed than those types of valves previously mentioned, and employs a heavy filament, or heater usually rated at 4 or 6·3 volts for A.C. working, while a current rating of ·2 amp. is practically standard for A.C./D.C. receivers, the voltage rating being 20–80 volts or even more depending on the demands on the valve. It may be observed from Fig. 1 that the valve is a dual assembly comprising two anodes and two filaments; such a valve is known as a full-wave rectifier, whereas a single assembly is known as a half-wave rectifier.

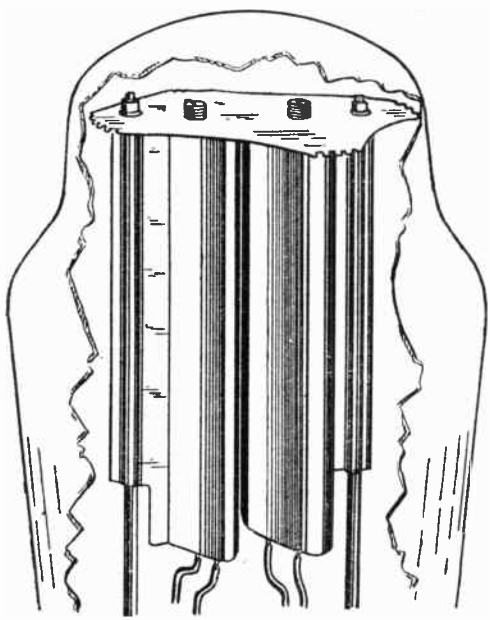


Fig. 1.—A full-wave rectifying valve.

Fig. 2 shows the basic circuit of a full-wave rectifier arranged for use in an alternating-current mains receiver. The mains are connected direct or through a fuse to the primary of the transformer. Three secondary windings are usually provided for supplying the heaters of the receiving valves, the heater, or filament of the rectifier, and the anodes of the rectifier; the first-mentioned winding is not shown in the illustration. It will be noted that the windings are centre-tapped. The alternating potential across AB will cause electrons to flow from the cathode, or filament to each anode in turn during successive half-cycles, so that the

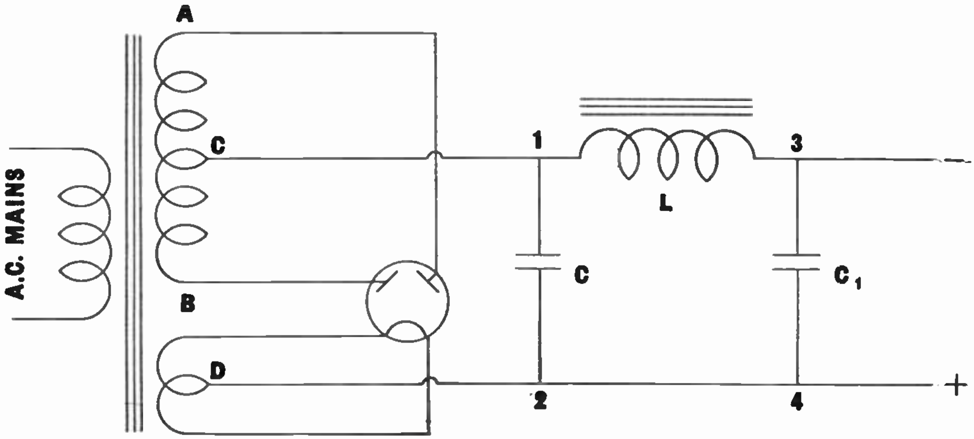


Fig. 2.—Basic circuit using a full-wave valve rectifier.

flow of current is uni-directional in relation to the points CD, from which may be taken rectified current to supply the receiver.

The condenser C is usually called the reservoir condenser, although the Americans sometimes rather appropriately call it the tank condenser or, if the whole expression is to be Americanised, "tank capacitor." The

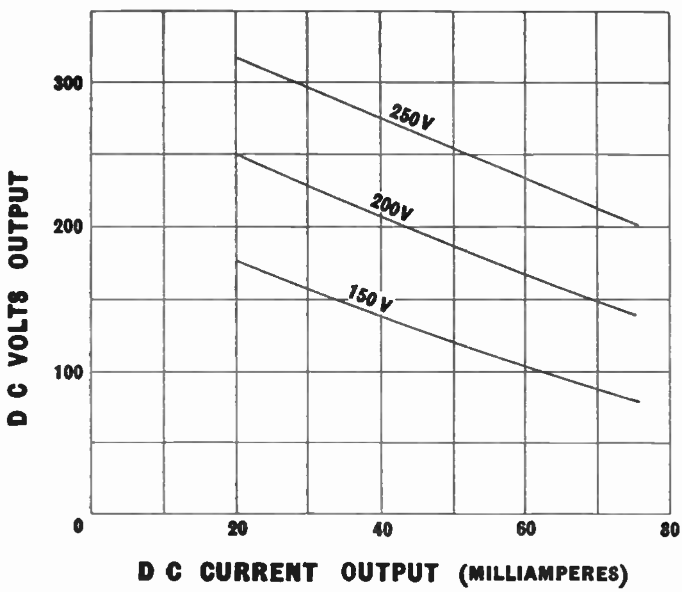


Fig. 3.—Performance curves for full-wave rectifier.

capacity of this component will influence the voltage across the points CD, but it will also assist in removing the ripple which will be superimposed on the direct-current output. Fig. 3 shows a typical performance curve taken with a full-wave rectifier with a 4 μF condenser across the load; each curve shows the performance for a stated applied alternating voltage and permits the rectified voltage to be determined for various values of rectified current. As would be expected, the voltage is greater for a small value of output current, and *vice versa*. The extent of the change in voltage resulting from a change in current is referred to as the voltage regulation, and should be as small as possible, since it is obviously desirable that the voltage between the high-tension positive and negative rails should remain as constant as possible, although the current taken by the various receiving valves may vary.

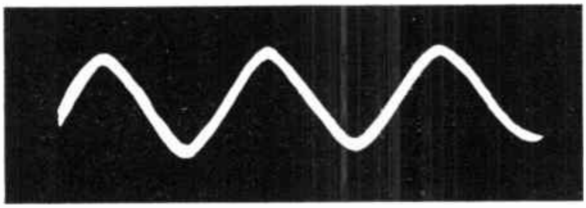


Fig. 4.—Oscillogram showing mains ripple appearing across the points 1 and 2 in the circuit arrangement shown at Fig. 2.

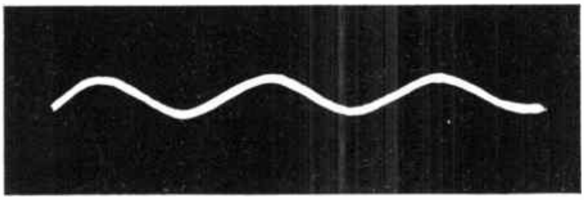


Fig. 5.—Oscillogram showing mains ripple appearing at points 3 and 4 when C_1 has a capacity of 2 μF.

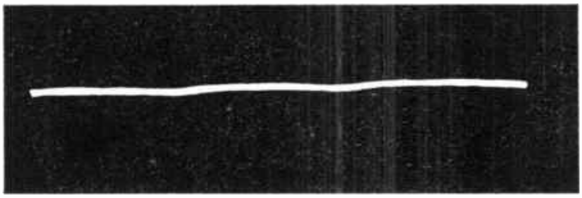


Fig. 6.—Oscillogram taken under the same conditions as Fig. 5, except that the capacity of C_1 is 16 μF.

Figs. 4, 5, and 6 show oscillograms taken from the circuit shown at Fig. 2. Fig. 4 shows the residual ripple taken across the points 1, 2 when the choke L and condenser C1 are removed. This illustration may therefore represent the efficiency of the rectifier with its attendant reservoir condenser to perform the function of rectification without additional aid.

Fig. 5 shows the potential across the points 3, 4 when the choke L is connected as shown and C1 is 2 μF. It will be observed that the alternating component is reduced. Fig. 6 is taken across the points 3, 4 with the condenser C1 raised to 16 μF; due to the small size of the illustration it may appear that the alternating component has been entirely eliminated; actually, it has been greatly reduced. Some small residual alternating component will be present, but this is unimportant if it has been reduced to limits which do not result in the loudspeaker emitting an audible note due to this ripple. A humming noise emitting from the loudspeaker, due to inadequate smoothing, is known as mains hum. When a full-wave rectifier is used the mains hum will take the form of a note having a frequency of 100 cycles per second, if the periodicity of the mains is 50 cycles per second; if a half-wave rectifier is employed, the hum will have a frequency of 50 cycles per second.

Reference to Fig. 2 will show that the rectified current must pass through the high-tension winding, and it is apparent, therefore, that the resistance of this winding will influence the potential difference across the points 1 and 2. It is desirable that the resistance of this winding should be relatively low, as it will adversely affect the voltage regulation of the complete unit. If a really badly designed transformer is used with a good rectifying valve, the voltage regulation is largely determined by the resistance of the high-tension secondary, since under these conditions the impedance of the valve will be unimportant. Bad transformer design will adversely affect voltage regulation for reasons other than those described above, the most important being the change of alternating-current voltage across the points A and B due to partial saturation of the core.

It is impossible to lay down any definite values for C, L, and C_1. since it will be influenced by the design of the actual receiver. Generally speaking, C will not be less than 4 μF, and will often be 8 μF, particularly if the condenser used is of the electrolytic type. The inductance of the choke L may have a value of, perhaps, 20 henrys, this rating being the inductance obtaining when the required value of current is flowing through it. This proviso is important, as a choke rated at 20 henrys may only have an inductance of, say, 5 henrys when passing a relatively heavy current. The condenser C_1 will have a relatively large capacity, 8 μF and 16 μF condensers being often used for the position.

The Metal Rectifier.—The metal rectifier is fundamentally a series of metal plates, each of which is either oxidised or coated with selenium on one face and held in firm contact with its neighbour, this has the peculiar property of offering high resistance to the flow of current in one direction and low resistance to the flow of current in the opposite direction. Fig. 7 shows the basic circuit of a metal type rectifier arranged for voltage doubling, since this may be considered the most popular circuit arrangement. The term "voltage doubling" is intended to indicate an arrangement whereby the rectified output voltage is approximately double the alternating-current input voltage, when the latter is expressed as an R.M.S. value. Reference to the illustration will show that one side of the secondary is

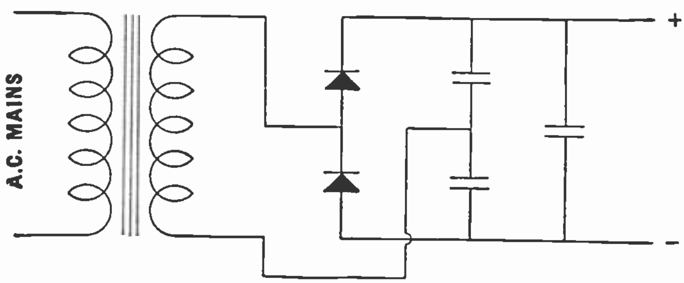


Fig. 7.—Basic circuit of metal rectifiers arranged for voltage doubling.

taken to the centre of two condensers connected in series across the output. The capacity of these condensers exercises remarkable influence over the rectified voltage developed. It is usual to make each of these condensers 4 μF, although special types of rectifiers call for larger values. The electrolytic condenser is unsuitable for use in this position.

Heat Dissipation.—When designing a mains pack considerable care must be taken to provide adequate ventilation, since the mains transformer and rectifying valve or metal oxide rectifier will dissipate a considerable amount of heat. If ventilation is inadequate, the temperature inside the receiver cabinet will rise—with serious results. The effect of heat may appear at a number of points in the circuit, but a frequent cause of trouble is distortion of the loudspeaker cone due to warping, which in turn causes the voice-coil to touch the pole pieces. Another trouble is the tendency for capacity drift in trimming and padding condensers due to rise in temperature. Other unfortunate effects of undue temperature rise include failure of electrolytic condensers and ultimate breakdown of the mains transformer, particularly if its windings are impregnated with wax.

Universal Mains Pack.—Fig. 8 shows the basic circuit of a universal mains pack. It will be noted that the mains are connected direct to the

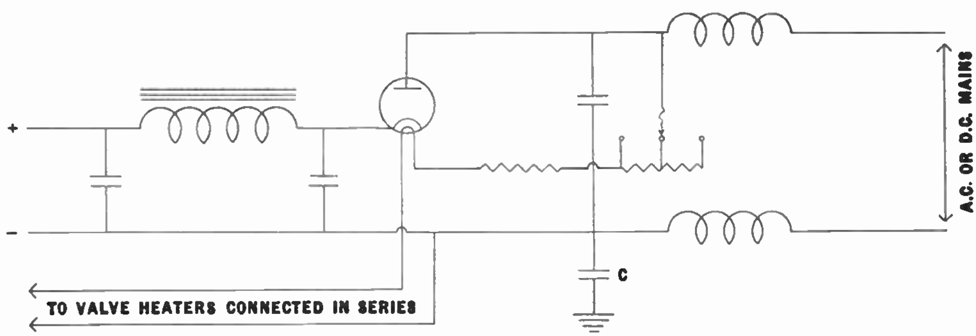


Fig. 8.—Basic circuit of a universal receiver mains pack; the tapped resistance permits adjustment to suit various mains voltages. It will be noted that the rectifier must be of the indirectly heated type.

anode of the rectifier on the one side, and direct to the high-tension negative rail on the other side. The heater of the rectifier valve and the heaters of the receiving valves are connected in series, a suitable resistance being included, to limit the flow of current; it is necessary that a team of valves for universal working have similar heater *current* rating, although the heater *voltage* rating may be different for various stages. In this way each valve functions at its correct temperature when the proper current is flowing through the circuit. It will be observed that the resistance in series with the heaters is tapped to permit alternative tappings for various mains voltages.

When the mains pack is connected to direct current, the anode of the rectifier valve is held at a positive potential and electrons flow from cathode to anode. Under these conditions the rectifier valve may be regarded as a low resistance. When the mains pack is connected to alternating current, the valve functions as a half-wave rectifier, the residual ripple being smoothed by the condensers and choke. Fig. 8 is described as a basic circuit. Nevertheless, a refinement is shown which takes the form of an air-cored choke in each mains lead associated with a condenser. These components are intended to attenuate static and other electrical disturbances which are picked up by the electric-light mains, and which would otherwise find their way into the receiving circuit. The interference with reception is so great when these precautions are omitted that they may be considered as an essential part of the equipment.

Special Precautions on Direct-current Mains.—Many districts are wired on the three-wire system, and the electric-light cables taken down the road are three in number, the outer ones having a potential difference equal to double the voltage supplied to the consumer, the middle cable being earthed. Each alternate house or each side of the road is fed from one of the outer cables and the centre cable; consequently, 50 per cent. of the consumers are supplied with mains that are earthed on the positive side. It is therefore absolutely essential that there should be no direct connection between a universal receiver and the earth lead, since this would constitute a short circuit on the mains when the positive main is earthed. The difficulty is overcome by connecting a condenser between the receiver and its earth terminal, while for similar reasons a condenser is connected between the aerial coil and the aerial terminal, as without this modification the aerial would be live and capable of imparting an electric shock if touched. It is important that the condenser in both the aerial and earth lead should be capable of withstanding the mains voltage on which the receiver is used plus an adequate safety-margin.

Almost all modern receivers are constructed on a metal baseboard, or chassis, which is invariably connected to negative high tension and, in fact, constitutes the negative high-tension rail, so that all cathode circuits and earth returns can be connected to a convenient point. It is apparent from these and the above remarks that the chassis will be live in respect to earth when used on direct-current mains which are earthed on the positive side. It is therefore necessary that precautions be taken to prevent the chassis from being touched accidentally. A similar precaution obviously applies to any metal-work that is in metallic connection with the chassis, and care is necessary to avoid overlooking some trifling component, such as the grub-screw which holds the tuning-knob to the condenser spindle.

Mains Hum.—It has been stated that the inductance of the smoothing choke and the capacity of the associated condensers will be determined by the characteristics of the receiver, but some further remarks are necessary. The most important characteristic will be the sensitivity of the receiver, since it will amplify any alternating-current voltage which appears as a potential between the grid and cathode of the receiving valves. It does not necessarily follow, however, that this potential will be introduced into the first valve. The grid of the first valve should be quite free from alternating-current ripple, since it has no metallic connection to high-tension positive. If the coupling between the first and second valves takes the form of a tuned anode, a ripple voltage will appear between grid and cathode of the second valve If, on the other hand, transformer coupling is used, there will be no ripple in the grid-circuit of the second valve, as the coupling between the anode of the first valve and the grid-circuit of the second valve will be purely magnetic. It is apparent than the smoothing arrangements must be very much more thorough when using tuned anode or tuned grid coupling than when using high-frequency transformer coupling ; all other characteristics being equal.

Modulation Hum.—A peculiar phenomenon may be observed in certain receivers, inasmuch as mains hum is entirely absent when the receiver is tuned to a frequency that is not occupied by a transmitter, but when the receiver is tuned to receive any station mains hum is immediately audible. This phenomenon is known as modulation hum, and arises through the signal frequency being present in the mains pack, or through cross modulation. Assume that the first two stages of a receiver are coupled by means of high-frequency transformers and that the smoothing is such that the sensitivity of the third and subsequent stages will not result in audible mains hum. If the second valve is working under conditions that permit cross modulation to occur, the ripple voltage will modulate the carrier frequency and consequently appear across the grid and cathode of the third valve after being amplified perhaps 200 times. In the absence of cross modulation the ripple voltage would not appear before the anode circuit of the third valve, and the hum-level would consequently be $\frac{1}{200}$ of the level obtained when cross modulation is present in the second valve. The same remarks apply if a ripple voltage is picked up by the grid of the first valve, but this is unlikely, although it may happen in a universal receiver working on alternating-current mains.

Heater Sequence for A.C./D.C. Working.—In order to reduce mains hum in universal receivers it is desirable to choose the sequence of the valve heaters carefully. Here again it is not possible to suggest any hard-and-fast rule, but the following suggested sequence will serve as a guide :

Detector.
Frequency changer.
Intermediate-frequency amplifier.
Output.
Rectifier.

It should be understood that the above sequence is from negative to positive, that is to say the detector is connected direct to the negative end of the supply ; the actual connections for such a sequence are shown at Fig. 9.

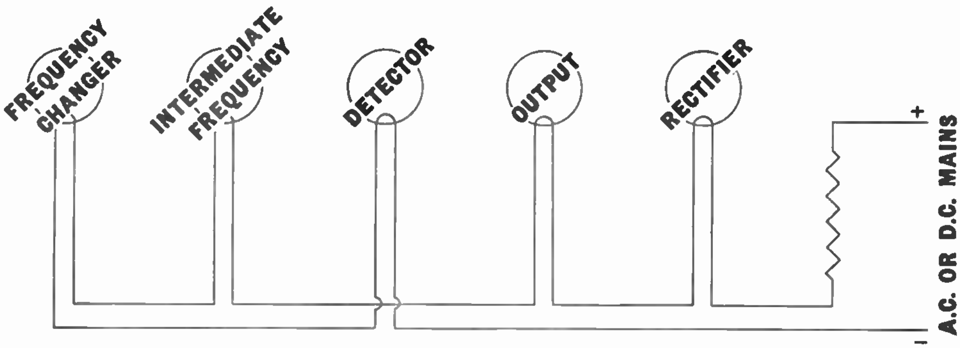


Fig. 9.—Suggested sequence for connecting heaters in a universal receiver.

Indirectly Heated Rectifiers.—Reference to Fig. 8 will show that a big potential difference exists between the heater and cathode of the rectifier valve used in a universal power pack. It is therefore essential that the valve shall have an indirectly heated cathode. The use of a directly or indirectly heated rectifier is optional in an alternating-current mains receiver, but the indirectly heated type is usually preferable, as it prevents excessive voltage being applied to the anodes of the receiving valves and the several condensers associated with the anode circuits while the cathodes are warming up. Indirectly heated rectifiers are designed so that they take longer to reach working temperature than the receiving valves, consequently voltage rise is avoided.

Mains Suppression.—As already explained, mains suppression is highly desirable in receivers designed for universal working. Some similar arrangement is not so essential, but desirable for receivers designed for use on alternating-current mains; the most simple form of suppression is a static shield between the primary and secondary of the mains transformer, which may take the form of a copper, brass, or aluminium sheet placed between the two windings and connected to earth, the core of the transformer being also connected to earth. This arrangement is usually sufficient but may be supplemented by air-cored chokes and conden-

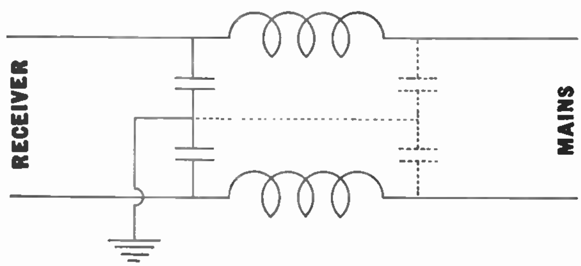


Fig. 10.—A simple mains filter. The dotted section indicates alternative or additional connections.

sers, in highly sensitive receivers as shown at Fig. 10; the condensers must be constructed to withstand the mains voltage.

Voltage Doubling.—The circuit, Fig. 7, shows the metal type rectifier arranged for voltage doubling, and was chosen as the basic circuit for describing the principle, as this type of rectifier is often used in this manner. The basic circuit for valve rectification shown at Fig. 2 is once again typical of general practice. It is, however, possible to use a special form of rectifier valve for voltage doubling.

Fig. 11 shows a circuit arranged for voltage doubling using valves. It will be observed that each anode is associated with a separate

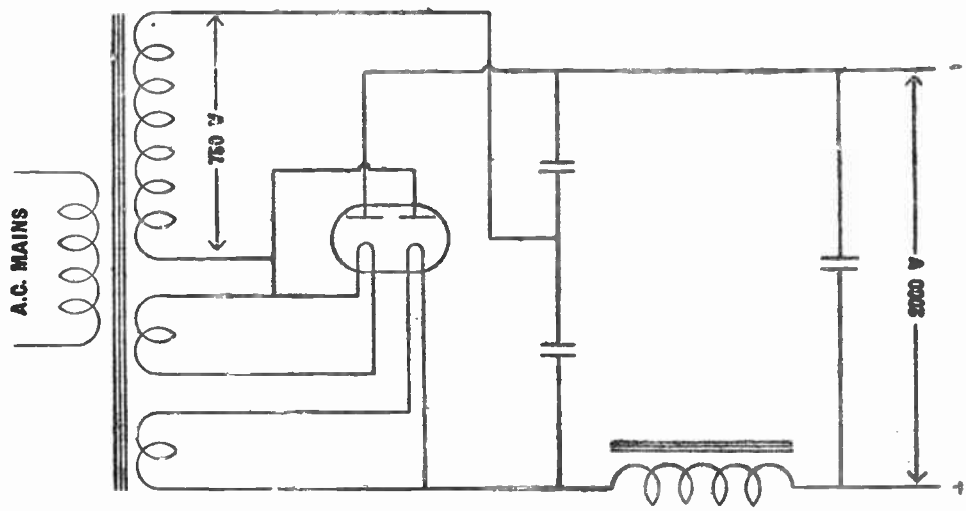


Fig. 11.—Voltage doubler circuit employing valve rectification; note that the filaments must be led out separately and not connected together inside the valve.

filament and that the two filaments are not directly connected. It is therefore necessary that the valve used should be specially designed so that the two filaments are led out to separate pins and not connected together internally.

It is difficult to suggest a use for the voltage doubler circuit shown, unless for the purpose of supplying a relatively high voltage with a measure of economy, since transformers developing a relatively low voltage are inclined to be disproportionately cheaper than those rated to deliver a voltage of 1,500 volts or more. The circuit shown at Fig. 11 can be modified by the use of indirectly heated rectifiers, so that voltage doubling can be accomplished without the use of a transformer (*see* Fig. 12). In this way it is possible to produce a voltage approximately double that of the supply voltage. It will be observed that a minimum of equipment is required, and no disadvantages arise, except those of a purely legal nature, since a few "local" regulations insist that apparatus such as radio receivers and transmitters shall be isolated from the mains by a double-wound transformer. Voltage doubling without a transformer is, therefore, restricted for use on what might be termed private sources of supply and the scheme is often used to double the voltage

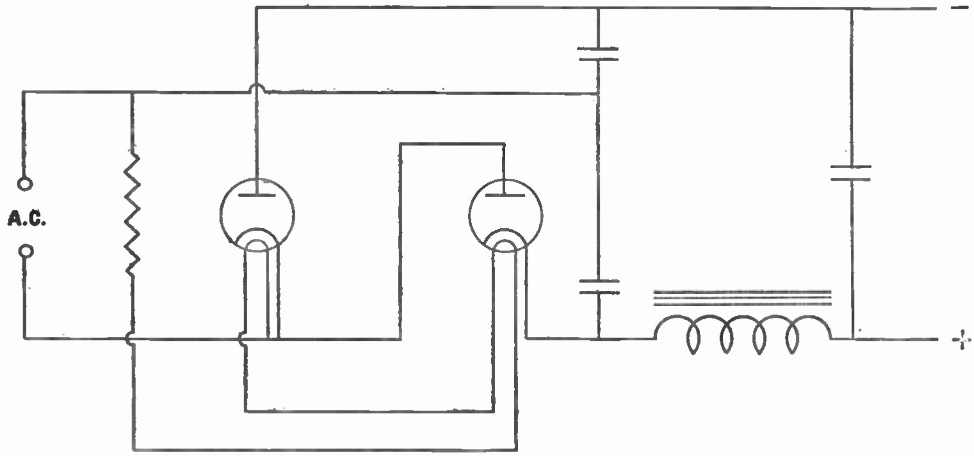


Fig. 12.—Voltage-doubling circuit arranged for direct connection to alternating-current supply.

delivered by small alternators, which may be driven from internal combustion engines or from direct-current motors as a means of obtaining alternating current from direct-current mains.

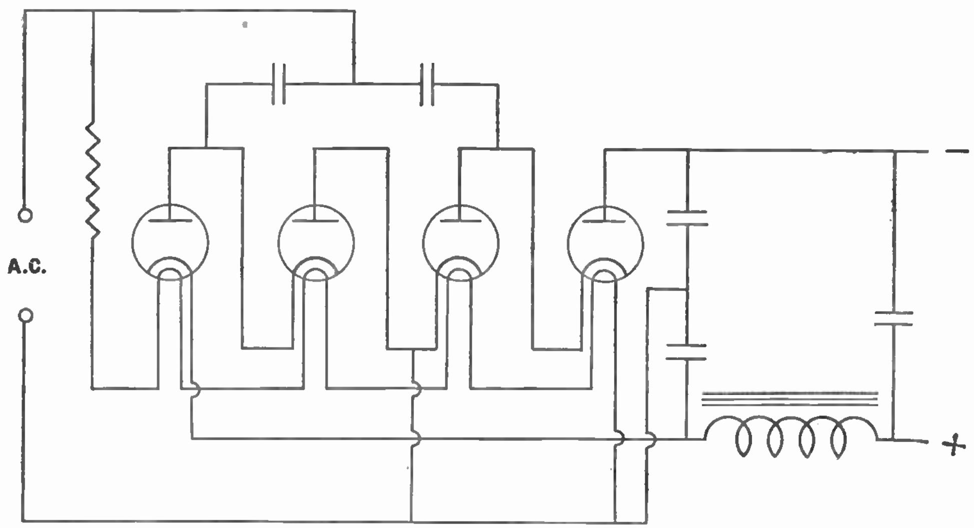


Fig. 13.—Voltage-quadrupling circuit arranged for direct connection to alternating-current supply.

Voltage Quadrupling.—The principle of the voltage doubler can be extended to voltage quadrupling, a suitable circuit for which is shown at Fig. 13. It will be observed that the circuit is arranged for use without the transformer, and consequently indirectly heated valves are necessary. The condensers can be of the order of 10 μF each and the valves must be so constructed that the heater insulation is sufficient to withstand the total voltage developed plus the peak alternating-current voltage supply. So far as the author is aware, there are no valves generally available at the time of writing capable of being used with an input of the order of 200 volts, since such a condition would require a heater to cathode insulation sufficient to withstand a potential difference of more than 1,000 volts. This difficulty does not arise, however, if the arrangement is transformer fed, since each heater can be supplied by a separate secondary winding, heater and cathode being tied together; in fact, when each valve is fed from a separate winding it is possible to use directly heated valves if these are more convenient for any reason.

The circuit as shown at Fig. 13 is convenient for producing a normal voltage from a 50-volt alternating-current supply. The author had occasion to employ this principle to raise the output voltage from a small alternator; with an input voltage from the alternator of 50 volts a direct-current output of 220 volts was obtained with a load of 50 milliampères.

Gaseous Rectifiers.—The valves used as examples for the several circuits included in this chapter have all been of the high-vacuum type, and some mention must be made of the gas-filled rectifier. The modern gas-filled rectifier should not be confused with the cold-cathode type, such as employed for accumulator charging, the use of which presents various difficulties if used as an integral part of a power pack. The type of gas-filled rectifier in general use is not dissimilar in construction to the high-vacuum type and employs a hot cathode, although it should be clearly understood that this is to bring about the initial ionisation, and does not emit an electron stream, as in the case of the high-vacuum type; in this class of rectifier, rectification is dependent upon the action of the ionised gas within the bulb, which provides a very low impedance path in one direction but a very high impedance path in the opposite direction.

Gas-filled rectifiers are usually employed when high values of rectified current are required at a relatively moderate potential. Their use is not actually restricted to this condition, but for reasons of general convenience the valves are usually employed in this manner. Certain specialised types are available capable of passing really high current, very much higher than could be obtained from high-vacuum rectifiers of similar dimensions. Among their other advantages they have low internal impedance, wide cathode to anode spacing, and are therefore not likely to cause serious damage through mechanical failure.

Multi-stage Smoothing.—The several circuits shown in the foregoing portion of this chapter have employed a single inductance to provide the necessary smoothing, and occasions often arise when very low hum ripple is required, which would require a very large value of inductance and/or capacity. When a low hum ripple is desired it may be more economical to use two stages of smoothing, particularly if the low hum level is required to feed the earlier stages of the receiver, a normal level being deemed sufficient for the later stages. As an example, the output stage of a receiver may have a relatively high mains ripple in the anode supply without producing audible hum from a loudspeaker, while, on the other hand, the earlier stages, particularly the detector and frequency changer, may require very much more efficient smoothing. These factors can be employed to advantage, since the output valve will pass a

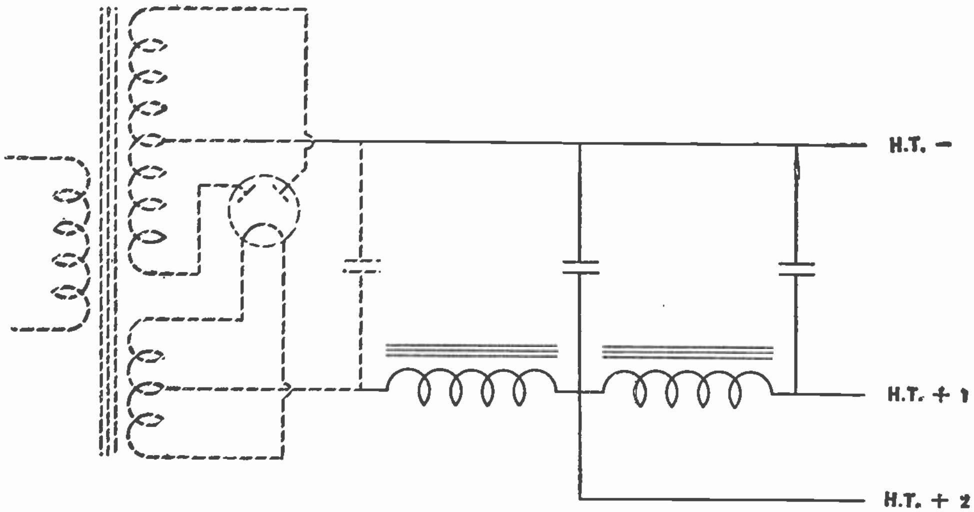


Fig. 14.—Two-stage mains filter arranged to give additional smoothing to the earlier stages of the receiver.

relatively high anode current, making a large value of smoothing inductance somewhat uneconomic.

The percentage ripple after a single inductance and condenser is given by the following simple formula :

$$\text{Percentage ripple} = \frac{100}{LC}$$

when C equals capacity in μF and L equals inductance in henries.

It should be understood that the above formula and the one given immediately below express the percentage relationship between the ripple appearing across the smoothing condenser when compared with the ripple appearing across the reservoir condenser. In other words, the reservoir condenser is not considered as part of the smoothing system for the purpose of making comparisons. The illustration at Fig. 14 shows a two-stage filter or, to use an alternative term, cascade filter. There is no reason why the inductances should bear any numerical relationship to each other, and if the first inductance only is included in the supply to the output valve it will normally have a very much lower value than the second inductance, the current flowing through which will be relatively low. For all practical purposes the ultimate choke and condenser can be ignored when calculating the percentage ripple of the high-current line, while the following formula may be used for calculating the percentage ripple of the low-current line or, in other words, the percentage ripple of the two filter stages :

$$\text{Percentage Ripple} = \frac{650}{L_1 L_2 (C_1 + C_2)^2}$$

when C equals capacity in μF and L equals inductance in henries.

A glance at the above formula will show that the expression $L_1 L_2 (C_1 + C_2)^2$ must total 650 if the percentage ripple is to be reduced to 1 per cent., 1,300 if the ripple is to be reduced to ½ per cent., and so on. In a really high-gain superheterodyne it may be necessary to reduce the ripple to ·1 per cent., or even less.

Voltage Stabilisation.—Certain points of voltage distribution in a radio receiver are required to remain sensibly constant irrespective of current variation within certain limits. These requirements are usually met with by the use of potentiometer feed, but when exceptional voltage regulation is required there is an electronic device available, known by the general name of the voltage stabiliser. It consists of a structure generally resembling that of a thermionic valve, and has a number of grids accurately interposed between cathode and anode. The geometry and functioning of the device is such that the voltage on any intermediate electrode bears a relationship to the total voltage that is determined solely by geometrical relationship and is virtually independent of the current drawn from the electrode in question. A voltage stabiliser of the type under discussion cannot be regarded as a normal component of a radio receiver, but the device has very definite uses in the laboratory, while it certainly has applications in specialised types of receivers for use on ultra-high frequencies.

The Neon Voltage Stabiliser.—There is a simplified type of voltage stabiliser available, the cost of which is only a fraction of that referred to above, but which is very much more limited in its application. It consists essentially of two electrodes, anode and cathode, in a bulb containing a low pressure of neon gas mixed with certain other rare gases. When used in conjunction with a standard circuit arrangement, which is shown at Fig. 15, it has natural stabilising voltage in the neighbourhood of 130 volts, which figure cannot be varied, as it is inherent with the construction of the device.

The neon voltage stabiliser in intended to achieve a constant voltage when the load is varying within wide limits. When used in conjunction with a standard circuit, shown at Fig. 15, it is capable of limiting the change of voltage to 7 volts, with a change of load from 5 to 70 milliampères. Alternatively, it will limit the change of voltage to less than 1 volt with a change of load from 30 to 70 milliampères. The device functions in a very simple manner and relies upon the fact that its impedance falls very rapidly as the potential across it increases; thus, if the current drawn by the load and by the stabiliser is fed through a common resistance, the tube tends to keep the flow of current constant, maintaining the voltage within the narrow limits indicated above. The value of the resistance has a profound effect on the functioning of the device, the current value for a variety of conditions being easily determined from the table supplied with the tube. It should be understood that the various factors controlling potential must be such that the potential across the stabiliser does not drop below the figure necessary to maintain ionisation and also must rise at the instant of switching on to the striking voltage of the tube, which is in the neighbourhood of 175 volts.

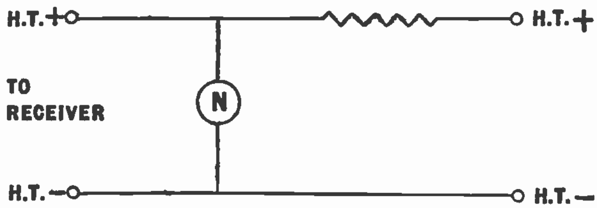


Fig. 15.—Basic circuit of a neon voltage stabiliser.

It is quite practicable to use two neon stabiliser tubes in series to produce a natural stabilising voltage in the neighbourhood of 260 volts. It is usually necessary to connect a resistance across one of the tubes, which may have a value of 10 megohms, in order that both tubes have a potential across them to bring about the initial ionisation. Without this resistance each tube would be isolated by the other from the applied potential, and unless a leak is present neither will strike. Theoretically, it should be possible to use more than two in series, but the author has had little success when using more than two in this manner. Under certain conditions a neon voltage stabiliser will introduce an effect which causes the apparent presence of self-oscillation and brings about a small but rhythmic rise and fall of the stabilised voltage. This phenomenon is rare and is instantly cured by the connection of a condenser in parallel having a capacity of some 2 μF or more. It is interesting to note that if this device is used as part of a smoothing system its A.C. impedance is such that it has an effect equivalent to some 5 μF.

Safety Factors.—Fundamentally the power pack should be at least as reliable as any other section of the receiver. In actual practice, however, a considerable percentage of receiver failures are attributable to breakdown in this section. A rectifying valve is fundamentally robust, due to the heavy gauge of its filament and the relatively wide spacing between the electrodes; in practice 95 per cent. of breakdowns in the power pack are caused by premature failure of electrolytic condensers or defective insulation developing in the high-tension secondary winding of the mains transformer. It should not be concluded from these remarks that electrolytic condensers are less satisfactory than those using a solid dielectric, or that mains transformers are inherently unreliable.

It is probably true to say that 90 per cent. of power-pack faults are avoidable inasmuch as they are due to an inadequate margin of safety.

Dealing, first of all, with the mains transformer, it is not unusual to find a power pack so designed that the mains transformer is subject to a very considerable temperature rise with the result that a relatively small overload raises the temperature to the danger point. Premature failure of electrolytic condensers may also be attributed to an inadequate safety margin in almost every instance ; the manufacturers of these components state clearly the permissible working conditions, but these are often exceeded in the interests of initial economy or alternatively exceeded through lack of appreciation of the fact that the maximum voltage developed across the condenser is considerably greater than the normal D.C. working.

The allowance of an adequate safety factor is particularly desirable in the case of a condenser since the resultant cost of a breakdown is out of all proportion to the initial economy, owing to consequential damage to the mains transformer or rectifying valve or both, in addition, of course, to the condenser itself.

CHAPTER 2

DECOUPLING

MENTION has been made in the appropriate chapters of the necessity for screening various stages and of preventing energy in one circuit from being fed to another due to unwanted capacity and magnetic coupling; there is yet another means by which energy may pass from one stage to another due to the presence of certain impedances which are common to two or more stages. A simple example will serve to illustrate this possibility. The anode circuit of each stage in a battery receiver is ultimately connected to the high-tension battery, which will possess resistance forming a coupling common to all stages, and the voltage developed across it will appear at various points unless precautions are taken.

The most simple means of reducing the coupling of the high-tension battery takes the form of a relatively large condenser connected from high-tension positive to high-tension negative, when the impedance common to all anode circuits will be approximately equal to the reactance of the condenser; such a condenser is known as a bypass condenser, and is a very necessary refinement, since the resistance of the battery will rise very sharply as the voltage of the battery falls in the course of service. The bypass condenser is an elementary refinement, but is usually insufficient, particularly as the reactance of the condenser may be fairly large at the lower audio-frequencies.

Fig. 16 shows two valves coupled by the familiar resistance-capacity method, and would be similar to a circuit shown in a previous chapter if it were not for the fact that each anode circuit is decoupled. Decoupling may be defined as the practice of preventing coupling between stages due to the presence of common impedances. Reference to Fig. 16 will show that a resistance R has been inserted in each anode circuit, the lower end being connected through a condenser C to a point of zero potential, usually high-tension negative. Reference to the illustration will show that R and C form a potentiometer from the alternating current point of view. The resistance of R is very great compared with the reactance of C, consequently the anode is tapped into the junction which is a point of low alternating current potential; it is apparent, for example, that if R has a value of 10,000 ohms, and C has a reactance of 50 ohms, only a fraction of any alternating current potential existing between high-tension positive and negative will appear across C. This reduction is, in effect, enormously increased by the fact that any alternating current potential existing between the anode of the valve and its cathode is

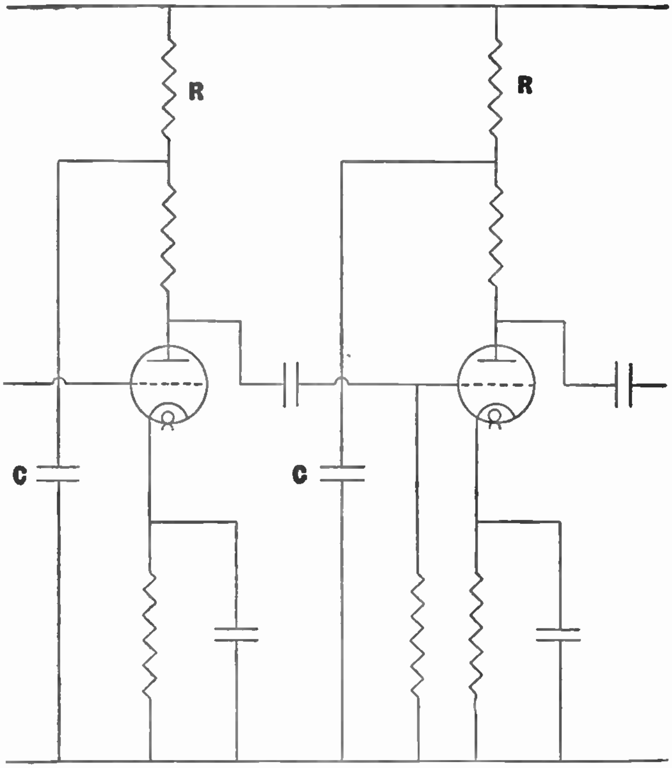


Fig. 16.—Two stages with anode decoupling, which is effected by means of resistances and condensers.

directly across the condenser C, and, due to its relationship with the resistance R, only a fraction of the voltage will appear between high-tension positive and negative. In other words, the decoupling resistance R and the decoupling condenser C prevent the valve from producing a big alternating current potential difference between high-tension positive and negative, and also prevent any appreciable part of such potential from appearing across the grid-circuit of another stage. This ideal condition only holds good if every stage is decoupled; in practice it is not usually necessary to decouple every stage.

Grid Decoupling.—Fig. 17 shows an example of grid decoupling, R and C being used to decouple the grid-circuit from the A.V.C. line, which may be necessary in certain cases, since the time-constant resistance in the A.V.C. line forms a resistance that is common to all grid-circuits that are returned to the A.V.C. line.

Fig. 18 shows another variation of grid decoupling which is necessary where there is an impedance common to several grid-circuits. Since R forms the grid leak which may have a low value, it is possible to make R_1 relatively large, since its effect on the audio-frequency response of the circuit will be insignificant if the value of

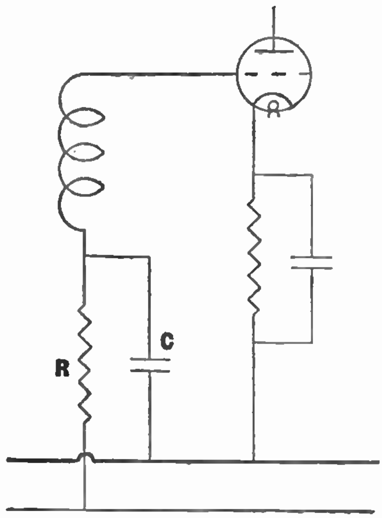


Fig. 17.—Arrangement for decoupling a grid circuit from the common impedance of the A.V.C.

the decoupling condenser C is sufficiently high. It should be borne in mind, however, that any grid current flowing in the circuit will pass through both resistances, and their total value must not be so great that grid current will produce a potential capable of seriously altering the grid potential.

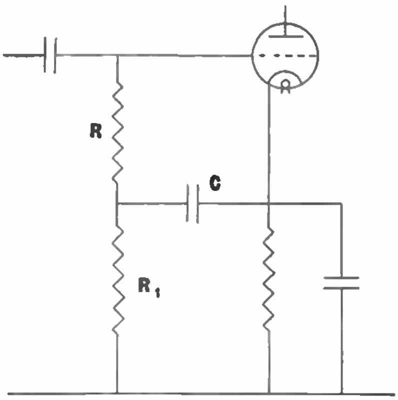


Fig. 18.—Grid decoupling.

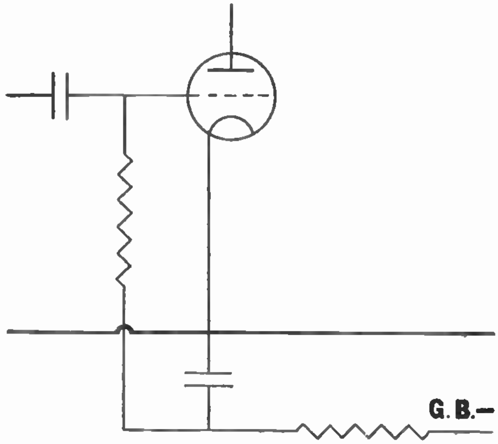


Fig. 19.—Grid-bias decoupling.

Fig. 19 shows a modification of Fig. 18 arranged for grid-bias decoupling in a battery receiver; this precaution is not generally required when a grid-bias battery is used, since the impedance of such a device will be relatively low. When automatic grid bias is employed it is generally necessary to decouple at least one of the grid-bias leads.

Grid Stoppers.—Strictly speaking, the use of grid stoppers should not be included under the heading of decoupling, but they are included for convenience. A grid stopper may consist of a resistance connected in the grid-circuit of a low-frequency valve to attenuate high frequencies which may be present in the circuit. Reference to Fig. 20 will show that the grid stopper is placed immediately next to the grid; the condenser shown dotted represents the input capacity of the valve, *i.e.* the capacity between the valve-grid and everything else. The stopper resistance acts as a potentiometer in conjunction with the input capacity of the valve; the reactance of this capacity is small compared to the resistance of the stopper at high frequencies, consequently a very small proportion of the unwanted

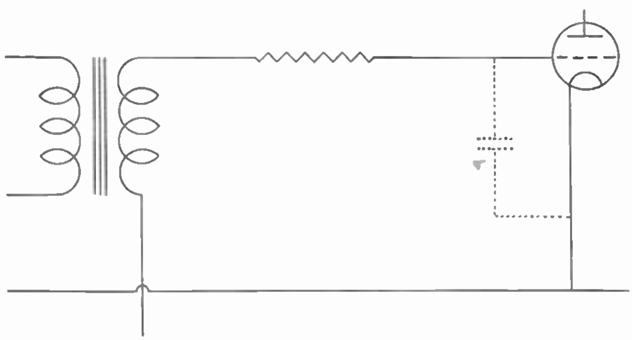


Fig. 20.—Circuit to illustrate the function of a grid stopper.

high-frequency potential across the secondary of the transformer will appear across the grid/cathode circuit of the valve.

The reactance of the input capacity will be very great at audio-frequencies, and the attenuation of these frequencies will be very small; it is often possible, therefore, to make the resistance of the stopper 100,000 ohms, or more, before attenuation of the higher audio-frequencies becomes apparent.

The resistance of the grid stopper does not appreciably reduce the gain of the receiver, as there will be no potential drop across it unless grid current is flowing, a condition which should not obtain in the low-frequency or output stage.

Parasitic Stoppers.—High-slope valves sometimes cause trouble, owing to self-oscillation at very high frequencies due to resonance between the *immediate* anode- and grid-circuits; that is to say, the actual electrode plus the short length of wire connecting it to the appropriate component. To prevent this some small resistance or impedance is inserted in the anode or grid lead, which may take the form of, say, 100 ohms resistance or a small high-frequency choke having perhaps twenty turns on a ½-inch former. To make such a device effective it must be connected immediately against the valve-holder, so that no appreciable length of lead is between the parasitic stopper and the valve itself.

Small chokes are used as stoppers for preventing parasitic oscillation in various grid-circuits—notably in the frequency-changing stage, where this trouble is particularly prevalent.

Tuned Stoppers.—Occasions may arise when a particular frequency which appears at considerable amplitude must be prevented from reaching a particular grid-circuit; the necessity for taking elaborate precautions is somewhat rare, but nevertheless examples may be found in a number of commercial receivers. As an example, a possibility may be cited of the oscillator frequency in a superheterodyne appearing in the discriminating circuit and causing trouble. The use of a grid stopper is impossible, as the wanted and unwanted frequencies are somewhat similar, and recourse may be made to a tuned circuit to act as rejector. It is probable that this tuned stopper will be in series with the normal tuned circuit and will inevitably cause some attenuation of the wanted frequency, but by making the value of the inductance large and the capacity relatively small its impedance to the wanted frequency may be made low.

General Remarks.—The values of decoupling resistances and condensers must be chosen to comply with the requirements of the circuit. It will be realised that an anode decoupling resistance will drop a proportion of the high-tension voltage, and this consideration alone will place a limit on its value. For a given efficiency, reduction in the value of anode resistance must be compensated by an increase in the value of the decoupling condenser; as an extremely rough guide the value of the decoupling resistance in thousands of ohms multiplied by the value of the condenser in μF may equal 20, thus 10,000 ohms may be associated with 2 μF and 20,000 ohms may be associated with 1 μF. The limitation of condenser capacity is purely one of economy, since it may be increased to any extent.

When instability is a major problem and limitations are imposed on the value of decoupling resistances, recourse may be made to high- or low-frequency chokes. Such circumstances often arise in short-wave receivers intended for battery working where limited high-tension voltage is available, anode currents are high, and stability difficult of achievement. The use of a high-frequency choke will often offer a solution, as its impedance is high and its direct-current resistance is low. It is usual, however, to use a limited value of decoupling resistance augmented by a choke.

Receivers capable of delivering really large volume usually employ a low-frequency amplifier to load the output valve ; the anode current of the former may be relatively large and render resistance decoupling inconvenient when the use of a low-frequency choke will often solve the difficulty. Here again considerable impedance at low frequencies may be obtained with low direct-current resistance.

The practical application of decoupling will receive further consideration in the chapter devoted to circuits of complete receivers.

Inductive and Non-inductive Condensers.—Attention has been drawn to the fact that the capacity of a decoupling condenser may be increased to any extent. While this statement is perfectly correct, there is a factor which must not be overlooked. Certain types of condensers are inductive to such an extent that their impedance is considerable at radio frequencies. The effect of inductance may not prove objectionable when the condenser is used for certain purposes, such as low-frequency coupling or as a reservoir condenser connected across a potentiometer to prevent noise due to bad contact between slider and element, but inductance can be very detrimental if the condenser is used for decoupling.

Non-inductive condensers are available, and these should always be used for decoupling ; paper dielectric condensers of this type may be considered entirely suitable for all but the highest frequencies for use, say, below 20 megacycles per second.

Decoupling at Very High Frequencies.—For the very high frequencies, *e.g.* the television bands, very considerable care must be taken when choosing decoupling condensers, as the impedance of an ordinary, non-inductive condenser may be very considerable. For example, a ·1 μF condenser might have an inductive reactance of only ·01 ohm at 1,000 kilocycles per second and an inductive reactance of 25 ohms at 45 megacycles per second, and recourse is made to condensers of relatively small capacity, since their low inductive reactance results in decreased impedance, notwithstanding the fact that capacitive reactance is increased.

For working at 45 megacycles, condensers of the order of 100 μμF are commonly used and may be of the flat-plate mica type or the ceramic type. The former are usually about half an inch by three-quarters of an inch, and extremely thin, due to the necessity for reducing the dielectric material to a minimum; these condensers are colloquially known as "stamp"-type condensers. The ceramic-type condenser is usually cup-shaped and employs the dielectric from which it takes its name.

Occasions may arise when a low impedance must be provided for normal and very high frequencies, in which case it is convenient to use two condensers in parallel, *e.g.* a ceramic condenser having a capacity of 100 μμF and a non-inductive paper condenser having a capacity of ·1 μF.

CHAPTER 3

THE GRAMOPHONE PICK-UP

THE practice of using a gramophone pick-up for the purpose of reproducing records needs no introduction, but attention may be directed to the construction of the several types of pick-up and their electrical consideration. The purpose of normal pick-ups is to convert mechanical movement into audio-frequency voltage which may be amplified by the audio-frequency section of the receiver and reproduced by the loudspeaker at adequate volume. Fig. 21 is a drawing of a typical pick-up with the ornamental cover removed. It consists, essentially, of a clamping device to hold an ordinary gramophone needle, which is free to move from side to side for a limited distance. The moving section is provided with an armature which takes the form of a flat iron strip and may be seen immediately above the needle-screw in the illustration. This armature occupies the central position between two pole pieces which are associated with a U-type permanent magnet, and each is provided with a coil which may have a direct-current resistance of about 500 ohms.

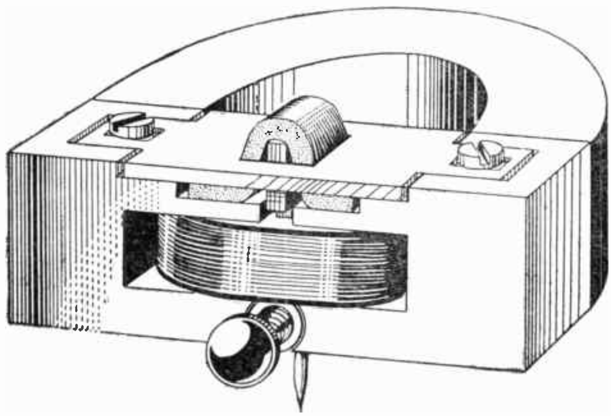


Fig. 21.—Movement of a simple gramophone pick-up shown to illustrate the principle (cover removed).

When the armature moves from side to side in sympathy with the sound-grooves on the record, variations of magnetic flux are brought about which set up a voltage in the coils, the frequency of which will be determined by the sound-grooves on the record: thus the operation is accomplished of converting mechanical movement into electrical change. Some means is necessary to stop the armature from becoming fixed to one pole piece, and also to re-centre it. Innumerable arrangements are possible, but the pick-up shown in the illustration employs a small piece of "live" rubber, which is affixed to the plate, and may be seen immediately above the pole pieces, and presses sufficiently heavily on the top of the armature to hold it in correct alignment. It also exerts sufficient downward pressure to take up any wear in the needle pivots which may occur after long service. The rubber and its attendant fixing-plate are known as the damping element; the latter is fixed to the pole pieces by two screws which pass through slots permitting the plate to be moved sideways to provide adjustment for accurate centring. It should be understood that this adjustment is carried out by the manufacturers, and is not intended for readjustment by the user.

The foregoing description may suggest that the design of a gramophone pick-up is a comparatively simple matter, but this is far from the truth, since very great care is necessary if the output of the pick-up is to be reasonably constant throughout its frequency range. The weight of the moving element must be carefully calculated in relation to the width of the gap between the pole pieces and the effective weight of the pick-up at the needle-point. The question of weight is important, since it must be a compromise between minimum record wear and reasonable output at the lower frequencies.

In order to avoid unduly wearing the side of the record-groove the pick-up must be mounted on an arm which swivels very freely on its mounting, as any mechanical resistance will appear as friction on the side of the groove; the majority of pick-up arms rotate on ball bearings.

Reference to the response-curve of any commercial pick-up will show that the curve is extremely erratic, but nevertheless has a fairly constant response over the middle frequencies. When such a pick-up is associated with a gramophone record the response falls off rapidly at both ends of the musical scale. The attenuation of the lower frequencies is due to the standard record-groove being too narrow to permit the swing necessary to maintain the lower frequencies at the same amplitude as the middle frequencies.

The higher frequencies are attenuated by the response of the actual pick-up and also by mechanical inertia which prevents the needle from changing its direction sufficiently rapidly to follow the impression for the full width of the groove. Various attempts have been made to lighten the armature and attendant accessories, but level response is most readily obtained by the use of correction circuits.

The Needle-armature Pick-up.—Mention has already been made of the desirability of reducing to a minimum the weight of the moving element in gramophone pick-ups. At least one manufacturer has produced a pick-up where this weight is reduced to seemingly minimum proportions, since the moving element consists solely of a gramophone needle. In brief, the principle involved is the use of a gramophone needle as the actual armature; the space between the pole pieces of the magnet is filled with rubber into which the needle is pushed, so that a reasonable proportion of it is held between the pole pieces and varies the flux in the magnetic circuit in sympathy with the vibrations imposed on the needle by the sound-track on the record.

The needle-armature pick-up has the advantage of low armature weight, but unfortunately has rather a small voltage output, with the result that adequate acoustic output cannot be obtained by means of the amplification available in the low-frequency section of many receivers. It is also questionable whether record wear is materially reduced, as the needle tends to wander to some extent and presents the worn edge in a direction where it can cause a certain amount of damage.

The Moving-coil Pick-up.—Among the various forms of gramophone pick-up that have been introduced from time to time there are two further examples which appear worthy of mention. The moving-coil pick-up was introduced to provide really excellent frequency characteristics with low record wear at the expense of voltage output. Admittedly the actual recording falls off rapidly at the higher and lower audio-frequencies, but this is a deficiency that can be fairly easily corrected by means of suitable circuits and presents no difficulties if the response of the pick-up is free from serious peaks. The moving-coil pick-up consists of a light coil, mechanically coupled to the needle, placed in the field of a permanent magnet; the principle is somewhat similar to the moving-coil speaker, except that it works in the reverse manner, that is to say the coil is moved mechanically in the field of the magnet, which induces a voltage in the former in sympathy with the movement of the needle. The moving coil is of the low-resistance type, and a step-up transformer is usually employed to raise the voltage output available.

The moving-coil pick-up is usually associated with cinema work, as it is difficult to justify such a piece of apparatus for normal domestic purposes; the modern cinema uses a sound-track printed on the film in place of the old records, and consequently this type of pick-up is probably used somewhat infrequently. It is interesting to mention that the records used in conjunction with films to produce moving pictures are very much larger than the ordinary domestic record, and are intended to revolve at thirty-three revolutions per minute and commence in the middle and play outwards towards the edge.

The Crystal Pick-up.—Probably the greatest advance in the design of gramophone reproducers takes the form of the crystal or piezo-electric pick-up, which is fundamentally different from the various types described above, since it is without any form of coil and relies on the property of Rochelle salt crystals of producing a potential difference when subjected to change of pressure. Basically it consists of a Rochelle salt crystal cut from a big crystal at a critical angle and placed between two metallic plates so arranged that the pressure on the crystal is varied in sympathy with the vibration of the needle.

The modern crystal pick-up is characterised by high sensitivity, wide frequency response, a natural lift at the lower frequencies, and ability to deal with musical attack in a manner that is probably unequalled by any other principle. Record wear is very low, since high output may be obtained with less than one ounce pressure on the record. The pick-up may have a capacity of about ·001 μF and an impedance of about

100,000 ohms at 60 cycles, more or less progressively decreasing as frequency increases. In this manner the natural bass attenuation of the record is more than offset, and reasonably level response is obtained by means of a top-note lift circuit, details of which are given below.

From a direct-current point of view the crystal type pick-up may be regarded as a condenser and cannot be placed directly into a circuit where direct-current continuity is required. It is important to note that this type of pick-up may be damaged if appreciable direct-current potential difference exists between the two plates, and it is sometimes necessary to isolate it by means of a condenser, when it is essential to complete the direct-current path across the pick-up by a resistance or other means. Fig. 22 shows the normal isolating circuit. The value of the shunting resistance must be very high to avoid attenuation of the lower frequencies. A parallel resistance of ·1 megohm will produce noticeable attenuation, and this or a lower value may be used when it is desired to give less prominence to the lower frequencies. On the other hand, this end of the musical scale can, if desired, be emphasised by connecting a condenser across the pick-up. Bearing in mind that the capacity of the pick-up is of the order of ·001 μF, capacities of similar order and above may be used as required.

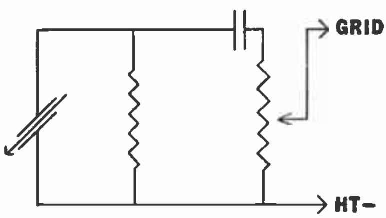


Fig. 22.—A circuit to isolate a crystal pick-up. This illustration shows the conventional symbol for this type of pick-up.

Volume Control.—Generally speaking, the control of volume should be effected between the pick-up and the valve into which it works, in order that distortion is not introduced by working the valve over too large a portion of its grid swing; in the case of the superheterodyne receiver the pick-up will generally be connected across the diode load resistance, which usually takes the form of a potentiometer, so that the volume control on both radio and gramophone is effected by the same component. By slightly modifying this arrangement it is possible to provide the volume control with a central zero position, and to increase volume on radio by rotating the knob in one direction and on gramophone by rotation in the opposite direction. This arrangement is shown at Fig. 23.

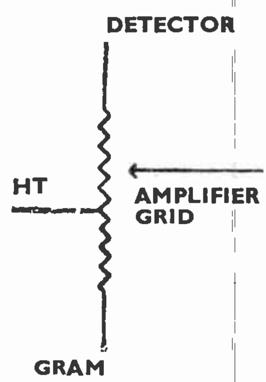


Fig. 23.—A volume control arrangement which is described in the text.

The resistance of the volume control is fairly important, and should be chosen so that it is not so low that it attenuates the higher frequencies, nor so high that it attenuates the lower frequencies; reference to Fig. 24 will show that the total resistance of the volume control is in parallel with the pick-up, but that an appropriate section of it is in series with the load when the control is at a position other than maximum. For the average type of pick-up a volume control having a resistance of 50,000 ohms is suitable, but, as already intimated, the piezo-electric pick-up must not normally be shunted by such a low value, and 500,000 ohms is usually selected.

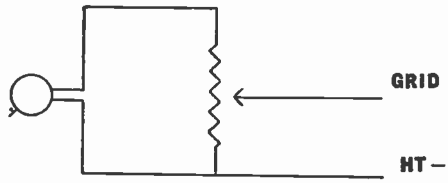


Fig. 24.—The normal connections for gramophone pick-up and volume control.

Gramophone Needles.—With a really bad pick-up it is perhaps unnecessary to trouble unduly about the needle used, but the effect of using an unsuitable needle is very marked with a well-designed radio-gramophone. Speaking quite candidly, there is a tendency to use soft-tone needles; which is unfortunate, since they cause attenuation of the higher frequencies, which are often already inadequate. It would appear that this tendency is due to the fact that a box of soft-tone needles contains several times the quantity of the extra-loud type. The needle to be chosen differs with various pick-ups, but it is inconceivable that any type of pick-up exists that calls for a soft-tone needle. The average moving-armature pick-up may be used with a loud-tone steel needle or, alternatively, with a fibre needle of the round-shank variety. The normal crystal pick-up is usually used with a half-tone needle or fibre needle. An exception must be made in the case of pick-ups working with an automatic record-changer, when a needle must be used of the type intended to play an adequate number of records without being changed.

Response Correction.—Response correction circuits may be used for the purpose that the term implies or they may be used to produce a sharp cut-off at the scratch frequencies for eliminating needle-scratch. Fig. 25 shows an inductance and condenser arranged to produce the necessary band cut, but actually it is unusual to use such an arrangement, as the higher musical frequencies must necessarily suffer. It is, in fact, usual to accentuate the higher frequencies in order to obtain high-fidelity reproduction.

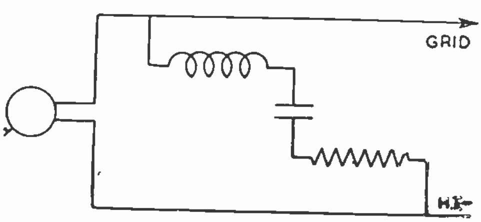


Fig. 25.—A typical top cut or scratch-filter circuit.

As already intimated, the moving-iron type of pick-up plus the natural deficiencies of a record produce attenuation of the higher and lower frequencies, and top-lift and bass-lift circuits can be introduced to level out the over-all response. Fig. 26 shows a typical bass-lift arrangement, the values shown being suitable for a low-impedance pick-up, *i.e.* an impedance of about 600 ohms. The condenser C and resistance R may be considered as a potentiometer, one half of which—the resistance—is independent of frequency, while the other half—the condenser—will vary with frequency. As the reactance of the condenser will fall as frequency increases, it follows that the output of the lower frequencies will be at maximum and will fall off as frequency increases. The resistance R_1 is included to prevent the higher frequencies from being seriously attenuated. It is apparent that the response of the pick-up can be raised at the low-frequency end by using suitable constants in the manner shown in Fig. 26, but that the higher frequencies would unavoidably suffer some attenuation from the circuit in addition to that introduced by the other causes already mentioned. Some method must, therefore, be found to increase the higher frequencies.

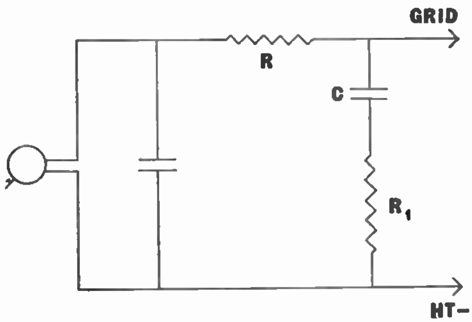


Fig. 26.—A bass-lift circuit for a 600-ohm pick-up; the parallel condenser may be ·004 μF., R. 50,000 ohms, C. ·03 μF., and R_1 15,000 ohms.

It is inconvenient to introduce top lift in the pick-up circuit, but it may be introduced in the anode circuit of the valve amplifier, a typical arrangement being shown at Fig. 27, which takes the form of a tuned circuit resonating at about 6,000 cycles, the relationship between inductance and capacity being chosen so that the circuit has a fairly flat response. The inductance is often wound with resistance wire or shunted with the resistance to further level response. The actual resonant frequency of such a circuit must be determined in conjunction with the response-curve of the pick-up, and innumerable refinements are possible. For example, two tuned circuits could be used in series, one tuned to, say, 5,000 cycles and arranged to have relatively flat response, and one tuned to, say, 6,000 cycles rather more sharply tuned. In this manner the high-frequency end of the response-curve can be sensibly flattened, terminating in a very sudden drop at about 6,000 cycles, so that the response is considerably attenuated at those frequencies associated with needle-scratch. The frequency band covered by needle-scratch is fairly wide, due to the fact that the speed of the record relative to the needle is greater at the edge of the disc than at the centre.

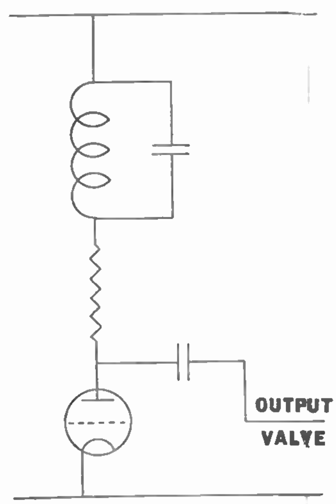


Fig. 27.—A top-lift circuit using an inductance tuned by a condenser as part of the anode load. Typical values are ·006 μF. and ·1 henry and 3,000 ohms.

The circuits shown at Fig. 26 and Fig. 27 were used by the author in conjunction with a 600-ohms pick-up, and the values shown proved satisfactory. The arrangement has now been replaced by a modern crystal pick-up, without correction at the lower frequencies, but with a top-lift circuit consisting of two tuned circuits forming part of the anode load of the amplifying valve. Admittedly a suitable resistance across the pick-up would produce almost equally good response characteristics, but the top-lift method was chosen in order to reduce needle-scratch to acceptable limits. This arrangement also results in maximum voltage output.

Electric Turn-tables.—It is customary to drive the record turn-table by means of an electric motor of a somewhat specialised type. The design and construction of electric motors is not within the scope of this work, but a few remarks on the general requirements will not be out of place. In order to prevent electrical interference the motor is usually of the induction type or, less frequently, of the repulsion type—two systems which obviate the use of commutators or split-rings, and consequently automatically eliminate sparking, which would cause interference. The mechanical load on the motor varies considerably with the recording, and consequently a mechanical governor is employed to regulate the speed, or more frequently the motor is of synchronous type. In either case the turntable is driven via two or more wheels with friction bands and so arranged that a wheel or wheels of appropriate size is brought into the driving sequence by the operation of a lever. In this way the modern turntable may be driven at 33⅓, 45 or 78 revolutions per minute to accommodate long playing and standard records. As a means of reducing possible mains hum, it is customary to earth the motor frame and, in fact, every piece of metal that can be earthed without introducing a short circuit.

Most modern gramophone motors are provided with some form of automatic stop, which is arranged to apply the brake and trip the motor switch by a frictional arrangement which is actuated by the sudden inward movement of the pick-up consequent upon the needle entering the run-off groove which terminates the sound-track of a standard record.

There are numerous ingenious forms of automatic record-changers which provide for the automatic playing of a number of selected records without manual attention. These are purely mechanical devices, and are far too elaborate and intricate to be dealt with here. To appreciate the method by which the automatic record-changer functions it is necessary to observe the mechanism in action.

Pick-up Microphony.—A gramophone pick-up, it will be remembered, is a device for converting mechanical movement into electrical change and should unwanted vibration reach the needle it will appear in the loudspeaker in the form of a howl or humming. Such a vibration may be caused by cabinet resonance, which will convey the sound output to the pick-up via the framework, motor, spindle, turn-table, and record, which causes a most unpleasant droning background noise. Alternatively, motor vibration may be conveyed to the pick-up in the same way.

Pick-up microphony can be prevented by increasing the pick-up damping if the trouble is slight, otherwise the only effective cure is to prevent the vibration from reaching the pick-up, which can be accomplished conveniently by floating the whole gramophone motor-unit on springs or a rubber mounting. Microphony due to motor vibration normally suggests a fault or bad design in the motor and must be dealt with accordingly.

The term "microphony" has been used in the foregoing chapters as a matter of convenience, but it should be noted that the term is not strictly applicable to a device that is deliberately designed to bring about an electrical change consequent upon vibration, and should be reserved to describe a howl set up by mechanical vibration bringing about an electrical change in a component where such an effect is not intended.

CHAPTER 4

GENERAL MECHANICAL AND ELECTRICAL CONSIDERATIONS

THOSE who constructed receivers in the early days of radio will remember that little consideration was given to the positioning of components or to considerations of the mechanical suitability of variable condensers and other units. The introduction of one-knob tuning brought new standards of engineering into the radio industry, since condensers and coils had to be made to fine limits and be so constructed that these limits would not vary through age, wear, or rough treatment.

In the early days components were usually mounted on the underneath of the insulating panel or on a wooden baseboard, the sole purpose of which was to hold the components in position. The increasing complexity of circuits and the numerous wires requiring ultimate connection to high-tension negative became so great that the baseboard was covered with metal foil which was connected to high-tension negative, and acted as a general return for all leads to be connected to the same point. It also ensured the adequate bonding of metal coil cans and other screening, and at the time this arrangement proved satisfactory.

When radio became less of a novelty and more of a domestic appliance, thought was given to the question of making a receiver more compact, and the use of a metal chassis became general. It consisted of an aluminium base-plate with the edges turned down to give it height, permitting the smaller components and the majority of the wiring to be underneath and the larger items, such as ganged condenser, coils, and valves to be mounted on the top. Aluminium was chosen largely for convenience, but proved somewhat unsatisfactory, as it is inherently soft, resulting in warping of the chassis, which caused electrical change in certain components; the soft metal raised other difficulties, including its inability to withstand the weight of a mains transformer at any point other than the corner. Plated iron or mild steel is now generally used.

The extremely high gain in the stages of a modern receiver calls for very great care in disposing the components so that capacity and inductive coupling is reduced to a minimum. High-gain short-wave receivers have innumerable stray fields, and the chassis carries a multitude of alternating currents of varying frequencies. Commercial examples of such receivers are often so critically arranged that instability results if the earth wire is connected to the chassis only an inch from the earth terminal; similar effects are obtained by moving certain other components or varying slightly the position of wires which make direct contact with the base-plate. Obviously the modern chassis must be strong enough to permit the placing of components to the best advantage from the electrical point of view, unhampered by considerations of the strength or weakness of the chassis.

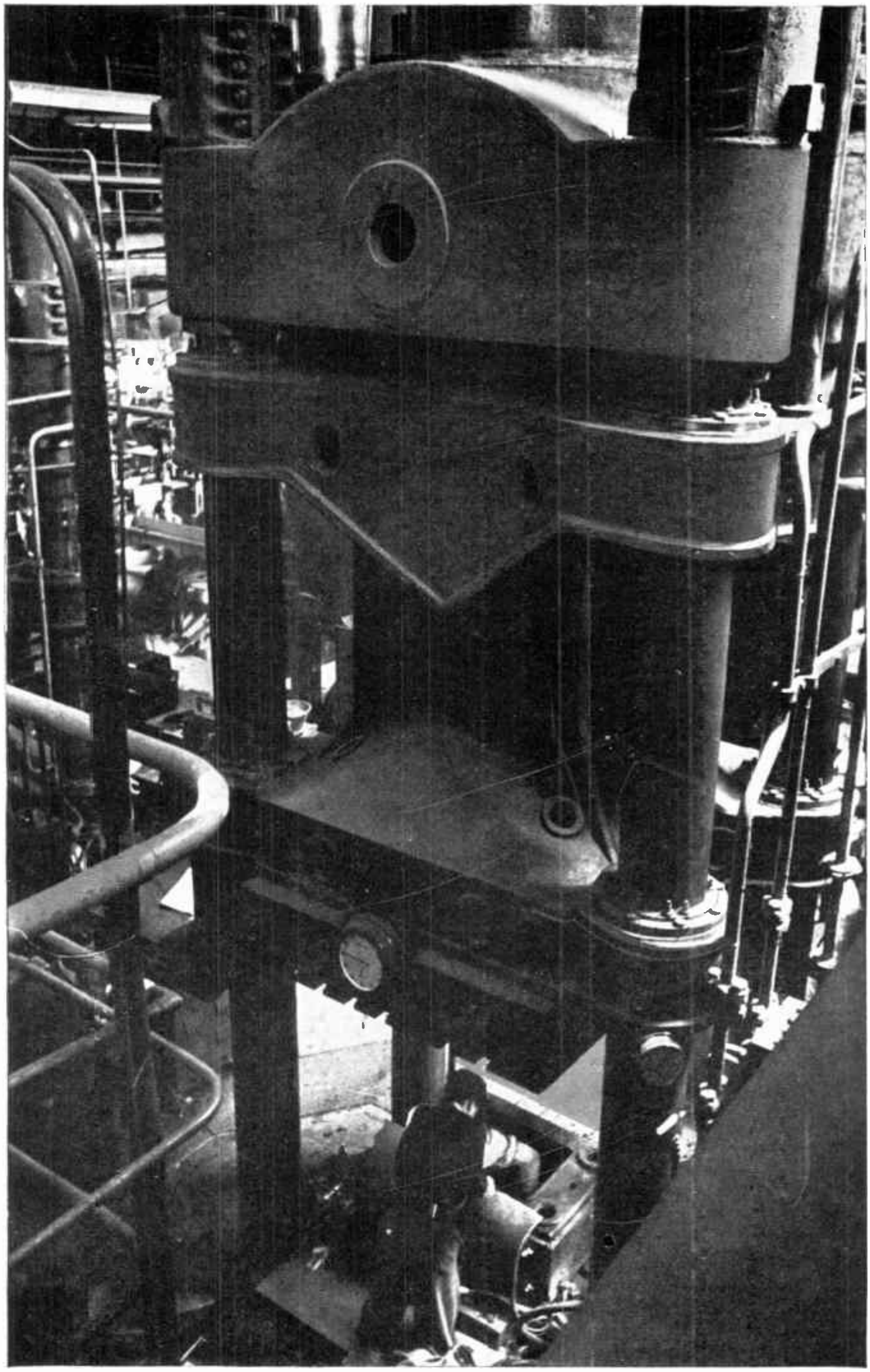
The thickness of the metal used for a chassis is determined by the weight that it has to carry, but it is also influenced by one or two less-obvious considerations. The average mains transformer will have an appreciable field which is capable of causing the top of a chassis to vibrate in the manner of a loudspeaker diaphragm, the remedy being thicker metal. Another consideration is the necessity for the top of the chassis to remain perfectly flat, as bending might distort the tuning condenser or one of the coil cans to an extent capable of producing misalignment of a tuned circuit. When trimming condensers are constructed with a single movable plate and so mounted that the chassis forms the other plate, the necessity for rigidity becomes a real one; this practice is, fortunately, rapidly becoming obsolete.

The surface of iron or steel is liable to rust and the surface resistance is too high to permit efficient bonding, so the entire chassis is plated with cadmium or other suitable metal which gives reasonably high conductivity, coupled with the convenience of using a plating material that may be deposited directly on to iron. Cadmium plating is by no means universal, some manufacturers preferring tin plating, others employ copper plating on the under side and a rust-proof spray on the upper side.

When it is necessary for a wire to pass through the chassis it is customary to protect the wire from abrasion by means of a rubber or plastic bush so shaped that it automatically retains its position in the chassis; these bushes are known as grommets.

Plastics.—Perhaps the greatest modern trend in radio design is the increased use of plastics. The influence of this group of materials has been noticeable from about 1930 onwards in the form of moulded cabinets and such accessories as tag panels. In these early days plastic cabinets were almost invariably brown with the notable exception of a dark green plastic cabinet introduced in 1933. The postwar era has witnessed the introduction of plastic cabinets in a variety of brilliant and pastel colours, and the increasing use of moulded plastics in the internal construction of the receiver, even to the extent of the chassis.

Coil Cans.—As explained in the appropriate chapter, some or all of the tuning coils are screened by means of metal boxes, which usually take the form of a one-piece container with base. These screening cans, or coil cans as they are sometimes called, may be made of aluminium or tin-plate, and do not call for special mention except when employed in receivers working at very high frequencies, when screening is so difficult to achieve that it is sometimes necessary to solder the can on to its lid, since connection relying on a tight fit may prove inadequate. At these frequencies some difficulty is sometimes experienced if the can is made of metal electrically dissimilar from the chassis, which results in certain



MODERN PLASTICS

Plastics play an ever-increasing part in radio design; the photograph shows a 1,650-ton press used for thermo-setting moulding in the Plastics Division of the Southend-on-Sea works of Messrs. E. K. Cole, Ltd.; this type of press is used for making radio cabinets and other large-scale mouldings.

rectification phenomena existing when the metal has become oxidised through the action of the atmosphere over a relatively long period.

The most urgent consideration of the coil can is the problem of mounting the coil so that its position cannot change, since such variation will cause a change of inductance, the effect being almost invariably to decrease inductance—assuming that the coil was originally mounted in the exact centre. Coils intended for direct connection to the top terminal of a valve usually employ a screened lead projecting from the top, while similar arrangements are sometimes made through side apertures for connection to the tuning condenser. The design of coil cans is further complicated by the necessity of arranging for their easy removal—which may be necessary to effect repairs.

Mains Transformers.—The general appearance of a mains transformer is well known. The core consists of the usual laminations, which are separated by thin paper for the purpose of reducing eddy-current losses. The laminations are held firmly together by a cast or pressed metal framework of girder construction secured by four bolts. The necessity for clamping the laminations is a very real one, since they are liable to vibrate and cause an audible sound, which may take the form of a hum determined by the frequency of the mains, or a hum plus a noise produced by the clatter of the laminations against each other. Lamination hum is surprisingly persistent and may appear, when the core is apparently rigidly clamped, due to the middle section bulging slightly unless the winding bobbin is a really tight fit. Similar remarks apply to smoothing chokes if so positioned in the circuit that the winding carries an appreciable alternating-current component.

Low-frequency Transformers.—The remarks made about mains transformers apply, in limited degree, to low-frequency transformers; it is necessary that the laminations of the core be reasonably tightly clamped, as they will otherwise tend to vibrate in sympathy with the speech-current flowing through the windings. The older type of transformers would occasionally permit the programme to be heard within a radius of a few feet without the assistance of the loudspeaker. There are many instances on record where listeners have disconnected the loudspeaker and have been frightened or otherwise perturbed by their ability to hear traces of the programme.

Tuning Condensers.—The general appearance of a modern ganged condenser is no doubt familiar; the framework is die-cast as a solid piece of metal and is braced and strengthened to make twisting impossible. Special attention is directed to the moving- and fixed-vane elements, which are each a solid die-casting and are not built up of separate vanes. This method of construction ensures that the greatest bugbear of condenser design is absent, namely, capacity variation due to movement of a vane in relation to its neighbour. In condensers of orthodox design the fixed vane unit is provided with means of attaching it to insulators supported by the main framework so that the unit is fixed with complete rigidity and insulated from the framework by the minimum mass of insulating material.

For use as a means of tuning several circuits it is obvious that the capacity of each section shall be correct at any degree of rotation; the acceptable tolerance is such that the most accurate manufacture and assembly may not produce accuracy at every degree of rotation. To overcome this difficulty the outer plates of the moving section are sometimes slit radially, so that they may be slightly bent to adjust the capacity at various degrees of rotation. Such adjustment is carried out in conjunction with suitable apparatus for measuring capacity. Trimming condensers are sometimes embodied in the tuning condenser and are usually mounted on the side.

A flexible plaited-wire pigtail is usually employed to make positive connection between the moving-vane element and the condenser framework, as a mere pressure contact of the bearings will usually cause irritating noises to be emitted from the loudspeaker when the condenser is turned; condensers specially designed for use in short-wave receivers sometimes employ non-metallic bearings, as a metal-to-metal bearing will cause noises even when the two elements are bonded together by a pigtail.

Tuning condensers sometimes take highly specialised forms when incorporated in receivers designed for the very short wavelengths, and when cost is not a prime consideration, the vanes are often silver-plated to prevent high frequency surface resistance from reaching serious proportions. Since the capacity of such condensers is relatively small a three-ganged unit may be no larger than a matchbox, and be very attractive from a purely mechanical standpoint.

Condenser Microphony.—Tuning condensers for short-wave receivers are usually made with rather thick vanes or, alternatively, the vanes are bonded together to give extra rigidity, as at these high frequencies microphony is often introduced by changes in a tuned circuit arising from changes of capacity due to the vanes vibrating in sympathy with the sound emitted from the loudspeaker. The tendency towards condenser microphony is aggravated in short-wave receivers by the tuned circuits which are often designed so that the response-curve is shaped as a peak in place of the flat-top response-curve used in receivers intended for operation on the broadcast wavelengths; the effect of the peak response-curve is to bring about an increased change of stage-gain for a given variation of the associated capacity.

Rubber Suspension.—As suggested above, the tuning condenser may be so designed that it will remain unaffected by vibration due to the sound from the loudspeaker impinging upon it. The average modern receiver has the loudspeaker mounted directly on the cabinet, and consequently vibration will reach the chassis and tuning condenser by direct means and at sufficient amplitude to cause almost any tuning condenser to be microphonic when working on the higher frequencies. To prevent this direct transmission of vibration it is customary to mount the tuning condenser on rubber bushes, which are placed above and below the condenser-mounting lugs, so that no direct metallic connection is present. The rubber used for this purpose is far more resilient than that usually met with and is capable of absorbing a surprising amount of vibration. It is useless to mount the condenser on rubber if the tuning-knob or spindle is to touch the cabinet, and several manufacturers break the spindle between the tuning-knob and the condenser by means of a rubber coupling in preference to the alternative arrangement of bringing the rod through a large hole and ensuring that the knob is free from the cabinet. The dial and slow-motion gear, if any, is also in direct contact with the condenser, but these are usually arranged to float free from contact with the cabinet or, alternatively, the dial is anchored to the cabinet or ornamental escutcheon by means of springs or elastic.

The rubber mounting of the tuning condenser is usually insufficient to prevent microphony in high-gain superheterodyne receivers, and it is usual to suspend the chassis on rubber as an additional precaution. The chassis may rest on rubber bushes, as described above, or, alternatively, the chassis may be held at the side by special rubber mouldings fixed to the side of the cabinet. Apart from preventing microphony rubber mounting also prevents irritating rattling noises which may be heard on some receivers emanating from valve electrodes, insulating washers, or any other small accessory which is free to move.

Slow-motion Tuning.—The high selectivity of the modern superheterodyne is such that some form of gearing is desirable between the tuning-knob and the condenser. The large change in frequency per degree of rotation when working on the V.H.F. waveband renders some form of gearing almost imperative, as without such an aid for tuning, correct adjustment can be extremely difficult. The most obvious slow-motion arrangement consists of a pair of gear-wheels; but this simple mechanism will normally suffer from back-lash, which prevents critical tuning, since it will be possible to move the knob a small amount without moving the condenser. This may be overcome by making one of the gear-wheels as two thin wheels with a spring so arranged that the wheels would tend to revolve in opposite directions, which they are prevented from doing by the other gear-wheel with which they engage. The split gear-wheels will expand as much as the companion gear will allow, and effectively take up back-lash.

A popular slow-motion drive consists of a small pulley-wheel working on the inside edge of a large circular disc. Such an arrangement is cheap and effective, permits of large reduction ratio, and is almost unaffected by wear if the pulley is made of two flat discs held together by a spring. Some form of drive is necessary to actuate the pointer, which usually moves horizontally and is often driven by means of a cord which is wrapped round the large disc, the perimeter of which is turned over to form a drum. Obviously, innumerable possibilities offer themselves for actuating the various types of pointers and scales with which manufacturers decorate or endeavour to make their receivers attractive.

It is unnecessary to detail the numerous types of slow-motion gear, but mention may be made of the planetary gear, which consists of a spindle, a few ball bearings, and a ball-cage. The spindle is, in fact, the rod to which the tuning-knob is attached, and revolves in the centre of the cage, which is attached to the spindle of the tuning condenser, the space between them being occupied by a few ball bearings. When the spindle is rotated the ball bearings also rotate, but rather slower than the spindle, and in turn travel round the stationary outer ring much more slowly; the ratio of movement in revolutions is, of course, determined by the size of the components, but a ratio of 5 : 1 is easily accomplished.

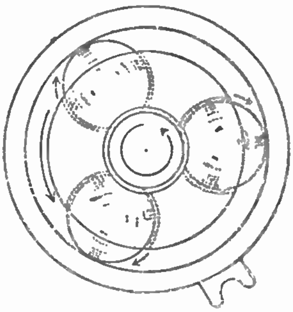


Fig. 28.—A diagrammatic illustration of a planetary gear. The arrows show the relative direction of rotation of the three main units; the outer ring is stationary.

Fig. 28 shows a planetary gear; the illustration is full-size. This type of gear has the advantage of small size, and requires only sufficient anchorage to prevent the outer ring from rotating; it also acts as a very easy-working clutch, preventing the ganged condensers from being forced when the tuning-knob is turned beyond the maximum or minimum dial setting.

Printed Circuits.—A comparatively new technique has started to influence the design of domestic radio and television, this is the printed circuit. Briefly the system is the use of "metal lines" printed on a plastic chassis, each "line" taking the place of the conventional wire. The advantages are less weight, compactness and lower cost. The most obvious disadvantage is when component replacement is necessary, but this can be minimised by care in design.

It should be possible to fill a complete volume with the mechanical considerations affecting the design of a radio receiver and its components. The few considerations detailed above will serve to show that considerable engineering experience is necessary to interpret the electrical requirements of components. This work is not intended to touch on the problems of the manufacturers, except as a means of giving an insight into those aspects of radio engineering which are nearly always ignored in radio textbooks. Certain components, such as switches, volume controls, trimming condensers, loudspeakers, and even cabinets, call for great care from the mechanical point of view if they are to prove reliable in service.

CHAPTER 5

FIVE CIRCUITS ANALYSED

THE early chapters are devoted to principles relevant to radio engineering, and consequently, with but few exceptions, each stage or principle has been considered separately. This chapter is included to present an opportunity for considering a selection of components, couplings, and various refinements incorporated into the circuit of complete receivers; which serves the purpose of showing the team-work of the various stages in a manner that may readily be understood.

The following discussion on five circuits presents an opportunity for arguing the various merits and possibilities of sundry details which has been impossible in previous chapters, since the advantages of various possible refinements and combinations are somewhat meaningless unless they are considered as part of a complete circuit and have, therefore, some very definite object in view.

Perhaps some warning is necessary: with the exception of the five-valve A.C. receiver, these circuits are rather over-elaborate, since they have been arranged with a view to illustrating as many principles as possible, but emphasis is laid on the fact that the author has handled all the receivers described. Certain remarks which are included in the text refer to points of design which cannot be perceived by examining the circuit diagram, but are derived from an inspection of the actual receiver. The author feels confident, however, that the reader will have no difficulty in recognising the comments which are derived in this manner, and consequently it is not anticipated that these extra details will cause confusion.

A Four-valve Class B Battery Receiver.—The circuit diagram facing page 40 shows a four-valve straight receiver, class B output, and may be considered as being a compromise between exemplary design and commercial practice. It is unlikely that such circuits would be found as a commercial entity, as the modern tendency is to provide a super-heterodyne receiver stripped of all refinements, rather than a straight receiver incorporating refinements which are relatively costly. The several circuits have been drawn slightly differently to illustrate the general practice of expression.

When designing a receiver it is usual to draw up a preliminary specification by starting at the loudspeaker and working backwards, but for the present purpose the reverse procedure will be more convenient, and attention may be directed forthwith to the aerial coupling. The aerial coupling consists, essentially, of a two-circuit filter tuned by the variable condensers C_1 and C_2; the medium-wave section consists of the primary L_1, and the secondary L_2, which form a bandpass circuit; it will be noted that the coils are of the iron-cored type. The long-wave coils L_3 and L_4 are air cored. Each coil is provided with a simple shorting switch to short circuit the coil when the receiver is used for medium waves. When switched for long waves, L_1 and L_3 will be in series, and so will be L_2 and L_4. It is apparent, therefore, that the inductance of the long-wave windings must be such that it will cover the required wave-range with the condenser used when in series with the medium-wave winding. The design of the long-wave coils will require considerable care, as otherwise they might act as an absorption circuit and considerably lower the efficiency of the receiver on the medium waveband.

The aerial is not directly connected with the bandpass filter, and is so arranged that a different type of coupling is effected on each waveband without the use of switching. When the tuned circuits are switched to long waves the actual aerial is coupled by mutual coupling between L_5 and L_3. Admittedly, it is also coupled through C_3, but the capacity of this condenser is so small that its effects are negligible; the series aerial condenser C_4 is provided to limit the effective aerial capacity, so that the tuned circuits are not thrown out of alignment when the receiver is used with an aerial having unexpected characteristics. When the receiver is switched for medium waves L_5 ceases to act as a coupling device, since it is associated with the coil that is now short circuited, and coupling is effected solely through C_3, the capacity of which is significant at frequencies associated with the medium waveband. Some care must be taken regarding the characteristics of the coil L_5, as it must offer reasonably high impedance to the frequencies associated with the medium waveband, otherwise the attenuation of signal strength would be serious.

The High-frequency Amplifier.—The first stage employs a variable-mu screened pentode, variable bias being obtained by manual control of the potentiometer R_1. It will be noted that the circuit is completed from the high-frequency point of view by the condenser C_5. The anode load takes the form of a high-frequency transformer using iron-cored coils for the medium-wave winding, and air-cored coils for the additional long-wave section. Once again the latter are provided with simple switches to short circuit the unwanted windings when working on the medium waveband. It will be noted that the long-wave coils are placed on the high-tension positive side, since this rail is sensibly at earth potential from the high-frequency point of view, although it is some 120 volts positive from the direct-current point of view. It will be observed that the high-frequency path back to the filament is completed through the condenser C_7, which also serves another purpose, which will be discussed later. The secondary of the high-frequency transformer is tuned by the variable condenser C_8, and it is assumed that the variable condensers C_1, C_2, and C_8 will be ganged together, and are consequently each provided with a trimmer for the purpose of equalising the stray capacities.

It will be noted that the anode circuit of the first valve is not decoupled, such precaution usually being unnecessary when using transformer coupling, although it is probable that decoupling would be necessary if the coupling shown were replaced by the tuned-anode or tuned-grid system.

The screened potential is applied through the resistance R_2, the value of which is determined by the required screen voltage and the screen current. If the total high-tension voltage is 120 volts, and a screen potential of 60 volts is required, it follows that if the screen current is ·5 milliampère, then the resistance of R_2 must be 120,000 ohms. For any required condition the value of R_2 may be easily determined by the application of Ohm's law. The condenser C_9 is connected between the screen and low-tension negative for the purpose of reducing the high-frequency potential of the former to zero or as near to zero as possible. It is important that this condenser should be so constructed that its inductance is very low, otherwise its function will be to some extent defeated.

Bearing in mind that the screen current of the variable-mu valve will be affected by the control grid potential, it might be thought that the screen should be fed by a potentiometer, so that variation of current will not affect the screen potential unduly. This arrangement is ideal from the theoretical standpoint, but may be rejected on the grounds of economy, since the potentiometer would pass a certain amount of high-tension current, which would be two or three times greater than the screen current if the voltage regulation obtained is worth while. The obvious solution is direct connection to a suitable tapping on the high-tension battery; this would necessitate the use of a third high-tension lead, and the general public or the manufacturers, or both, seem to insist that the number of high-tension leads shall be limited to two.

The Detector Stage.—The detector stage is designed round a screened pentode and works on the leaky grid principle. Here again the desired screen potential is obtained by breaking down the voltage across the resistance R_3, the screen being tied down from the high-frequency point of view by the condenser C_{10}. It is interesting to note that the series feed to the screen is actually preferable to a potentiometer in this stage, as it minimises overloading when the receiver is tuned across a powerful station when the gain control is in a sensitive position. This refinement is achieved by so arranging the circuit that the detector overloads just, but only just, before the output valve; when the input from the aerial rises above that required to fully load the output valve the detector overloads, the screen current rises abruptly, with the result that the screen voltage falls, which decreases the gain of the detector and *tends* to prevent the input of the next valve from rising beyond the required amplitude.

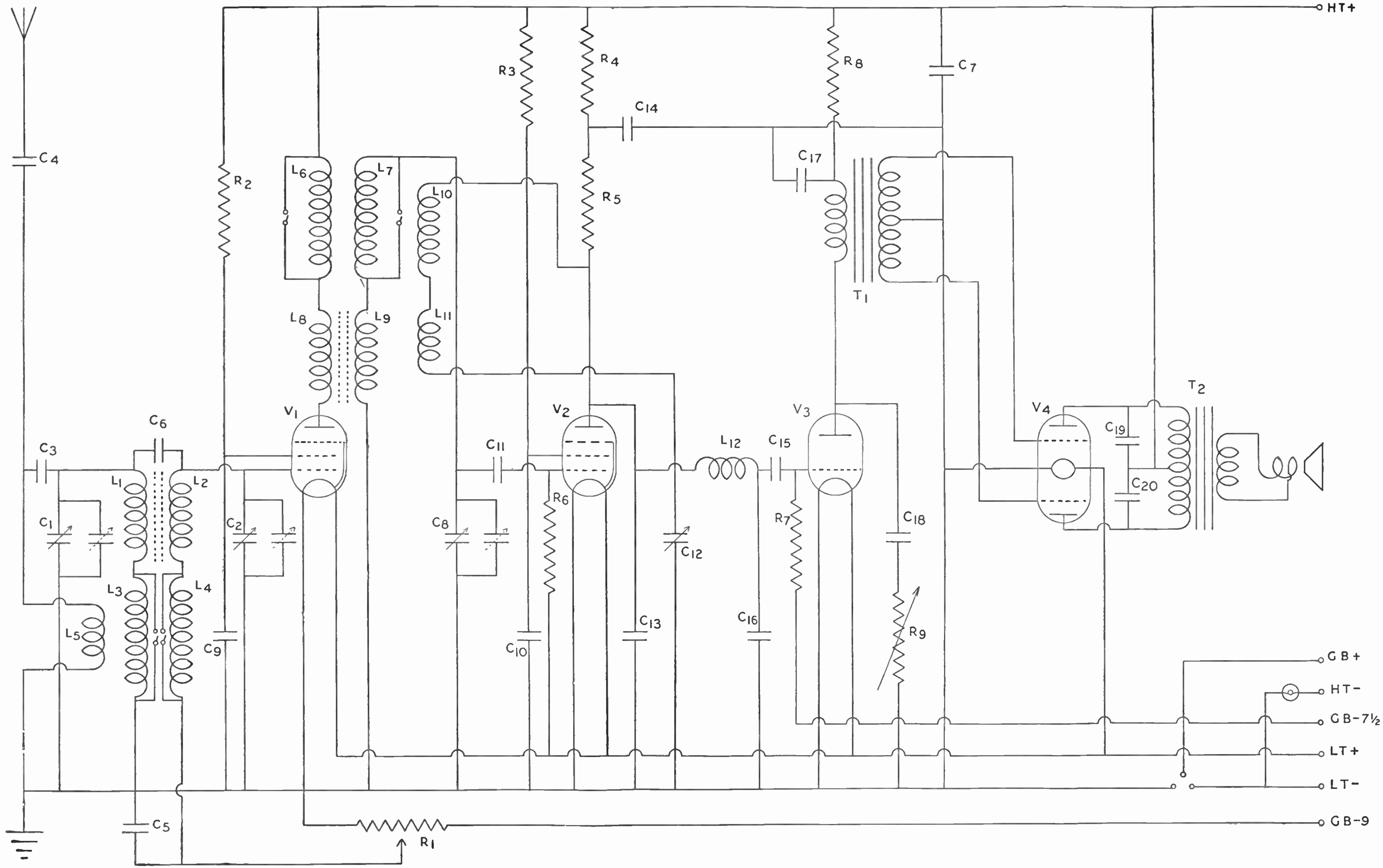
The detector anode circuit includes reaction, which is controlled by the variable reaction condenser C_{12}. Two reaction coils are provided, one coupled to the medium-wave coils and one to the long-wave coils; in this way proper control of reaction can be obtained on both wavebands.

It will be noted that C_{13} is the detector anode bypass condenser and that R_4 and C_{14} are included to effect decoupling.

R_5 forms the detector anode load and is associated with the coupling condenser C_{15} and grid leak R_7. It will be remembered that it is imperative to keep supersonic frequencies from reaching the grid of a class B output valve; in the chapter dealing with class B amplification mention was made of a condenser connected across the driver transformer secondary for the purpose of attenuating such frequencies. In the circuit under discussion this arrangement is avoided, preference being given to the use of a high-note filter made up by the inductance L_{12} and the condenser C_{16}. The use of the filter will preserve the higher audio frequencies, since the response can be made to fall off far more sharply in this way than by a condenser across the driver transformer secondary, consequently the higher audio frequencies can be preserved, while frequencies above are adequately attenuated.

The Driver Stage.—It may be seen that the driver valve is a triode and could be of so-called L.F. type or, alternatively, it could be a small output valve. As the grid bias applied is $7\frac{1}{2}$ volts, it can be assumed that the latter is intended. The anode load takes the form of a driver transformer T_1, which will have a step-down ratio commensurate with the maximum grid current of the class B valve. This stage is decoupled by means of R_8 and C_{17}; no further remarks regarding this stage are called for, except to draw attention to R_9 and C_{18}, which form a tone control for the purpose of providing means of reducing heterodyne whistles or for attenuating the higher audio frequencies to meet the personal taste of the user. It is worth while mentioning that the tone control has been placed in the driver circuit in preference to connecting it in the anode circuit of the class B valve, partly because both sides would be above earth potential and connection would be inconvenient, and partly because it is desirable that the impedance of the Class B output circuit should be optimum, so that the maximum output available is not in any way determined by the tone control. Another reason for including the tone control in the position shown is in the interests of battery economy; it will be remembered that the high-tension current drawn by a class B valve is more or less proportional to the input, consequently there is no point in using high-tension current to handle frequencies which are not to appear in the loudspeaker.

The Output Stage.—The output stage is perfectly conventional; it will be noted that the centre tap on the driver transformer secondary is returned to low-tension negative; obviously, therefore, the class B valve must be of the type intended to work with zero bias; some class B valves are so designed that they require a small negative bias, although they still run into grid current except when handling very small inputs. It will be observed that a condenser is connected across each half of the output transformer to limit the impedance. The transformer will have a ratio appropriate to raise the impedance of the speech-coil to the load required



R.T. II—40]

Circuit diagram of a four-valve battery receiver with a class B output. This type of receiver is popular in export markets.

by the valve; the primary must have relatively low resistance, as the peak anode currents are very high, and distortion must result if the voltage at the anode varies appreciably through voltage drop due to D.C. resistance in the anode circuit.

General Remarks.—It will be noted that the high-tension battery tappings are limited to two, but that there are three grid-bias tappings. Attention is directed to the three-point switch which disconnects the grid-bias positive lead when the set is switched off. This is necessary to prevent current flowing continuously from the grid-bias battery through R_1 when the receiver is not in use. The high-tension negative lead is connected to low-tension negative, in line with general practice, since connection to low-tension positive is unsafe, as it renders the filaments of the valves liable to damage in the event of accidental short circuit. As an additional precaution a fuse is included in the high-tension negative lead; a fuse bulb will give a measure of protection to the valve filament, but is not an infallible safeguard and is, of course, quite useless if an accidental short circuit is made in such a manner that the fuse bulb is not included in the path of the resulting flow of current.

Mention must be made of the condenser C_7, which is connected directly across the high-tension battery. As already stated, it serves to complete one of the tuned circuits from the high-frequency point of view, but its chief purpose is to limit the impedance offered by the high-tension battery, which may reach a high value when the battery is becoming used through service. It also has a reservoir action and makes possible the use of a battery which has become " noisy " with age, and which would otherwise have to be replaced.

C_8 will normally have a capacity of about ·1 μF, which is adequate for the purpose of completing the circuit between the lower end of L_3 and low-tension negative. It is sometimes desirable to use a much larger condenser as a means of preventing noise when R_1 is rotated, should the moving contact become imperfect. For this purpose 2 μF is usually employed, and since the average condenser of this capacity has relatively high inductance, it is desirable to use it with a ·1 μF non-inductive condenser in parallel.

A Five-valve Four-band Superheterodyne Receiver.—The inset facing page 44 shows the circuit of a five-valve four-band superheterodyne. Once again it will be convenient to commence with the aerial and work progressively through the circuit.

The Aerial Coupling.—The aerial coupling takes the form of a single tuned circuit with separate aerial coupling coil. It will be noted that each waveband has its own coils, and in no case are two or more coils used at the same time in the same circuit. Switching is accomplished by a wafer-type switch which connects the grid and the aerial to the appropriate pair of coils.

It will be noted that the low-potential ends of the secondaries of the long, medium, and short band (SW_2), are connected to the automatic volume control line, but the low-potential end of the short-wave coil SW_1 is taken directly to high-tension negative, in order that the first valve shall work at maximum gain, with a view to improving signal to noise ratio, which is liable to be bad on this waveband.

Tuning is accomplished by means of the variable condenser C_1, which automatically appears across the appropriate coil. Each secondary is provided with a separate trimmer, permitting the stray capacities of the circuit and the self capacity of the coil to be equalised on each waveband. Once again it will be observed the medium-wave coils are provided with iron cores, and it will perhaps be desirable to mention that there is no fundamental reason why all four wavebands should not use this type of coil.

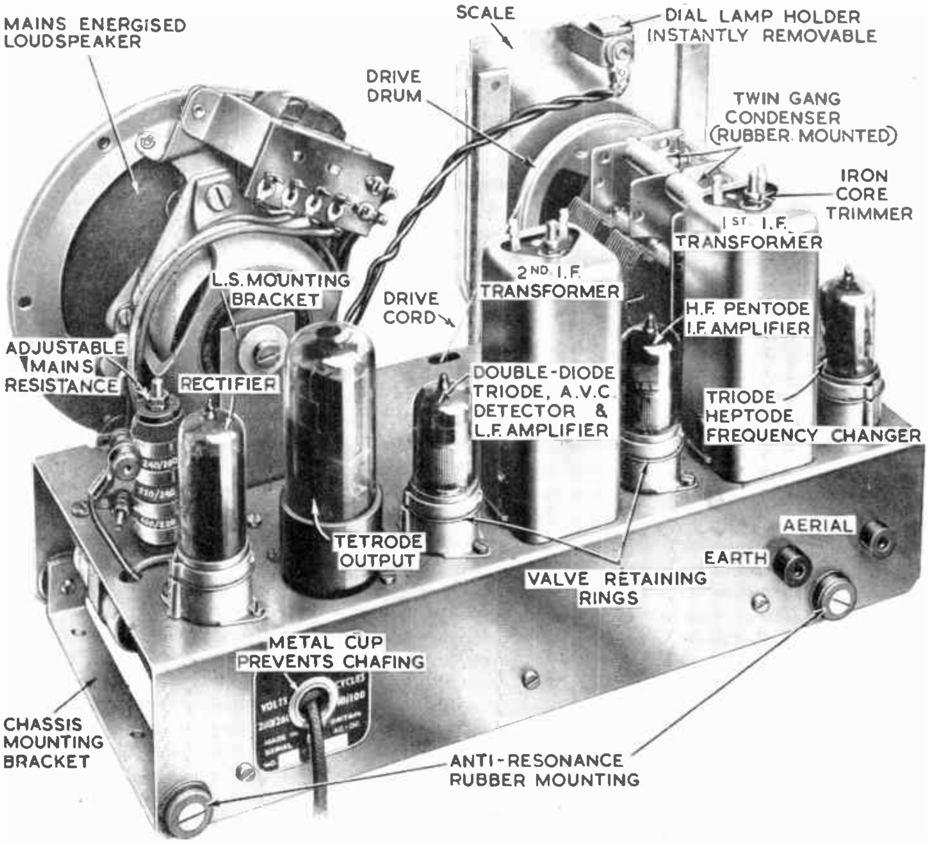
It will be observed that the primary of the aerial coupling SW_1 is connected to the aerial at both ends, one directly and one through the switch; this may be taken to mean that a doublet aerial may be used for the short wavebands, which is a special type of aerial dealt with in a subsequent chapter. When the use of such an aerial is not desirable, the aerial terminal connected to the lower end of the coil will be connected to the earth terminal by means of a piece of wire, or by other device.

The High-frequency Amplifier.—The first valve is obviously a high-frequency pentode, and may be presumed to be of the variable-mu type, since its grid is returned to the automatic volume control line. It will be observed that the screen potential is broken down by means of a trailer resistance R_1, and that the screen is held at filament potential from the high-frequency point of view by means of the usual condenser C_2.

The anode coupling consists of four sets of high-frequency transformers, each having inductances appropriate for the waveband to be covered. The switching arrangement is somewhat similar to that used for the aerial, since the primary and secondary are switched for each waveband. Again, the medium-wave coil is iron cored and the others are air cored, each coil being provided with a separate trimmer for the same reason as that applied to the aerial coupling. Tuning is accomplished by means of C_3, which is permanently connected to the grid of the frequency changer and will be automatically connected across whichever coil is switched into circuit.

The Frequency-changing Stage.—The frequency-changer valve is a triode heptode. It will be remembered that this valve has variable-mu characteristics in the heptode section and would normally be returned to the A.V.C. line via the frequency changer grid coils to the junction of C_{11}, R_9; since, however, this circuit is intended purely for discussion these coils are grounded to show usual practice when A.V.C. is not used, thus making an interesting comparison between the grid circuits of V_1 and V_2. The oscillator employs separate reaction and grid windings for each wave-band, the appropriate coils being selected by the third wave-change switch.

Following the principle adopted with the previous sets of coils, each



ANOTHER EXAMPLE OF RECEIVER DESIGN

This Ultra chassis, which is a superheterodyne of compact proportions, reveals a number of interesting details; this receiver is arranged for A.C./D.C. working, the coils, which cover three wavebands, are underneath the chassis.

oscillator secondary is provided with a separate trimmer, the main tuning being accomplished by the variable condenser C_4. It will be observed that the reaction coils are isolated from high-tension positive and are, in fact, resistance-fed by R_2 and isolated by the condenser C_5. This arrangement makes little difference from the high-frequency point of view, and is adopted so that high D.C. potential is excluded from the switching; the wafer type of switch is quite capable of withstanding any difference of potential that will be met with in a battery receiver, but it is sometimes considered desirable to isolate the high tension, as dust settling on the switch might produce noises through leakage. Another way, of course, is to seal up the under side of the chassis so that dust cannot penetrate, but it is more convenient to adopt the former arrangement.

The secondary of the oscillator coils is tuned by the variable condenser C_4; the secondary is not returned directly to the oscillator grid, since a condenser C_6 is interposed, allowing the grid to be returned to high-tension negative through a resistance R_3, so that the triode section of the valve may bias itself by grid current. The advantage of obtaining bias in this manner is that the valve will work with approximately optimum bias even if replaced by a valve having somewhat different characteristics.

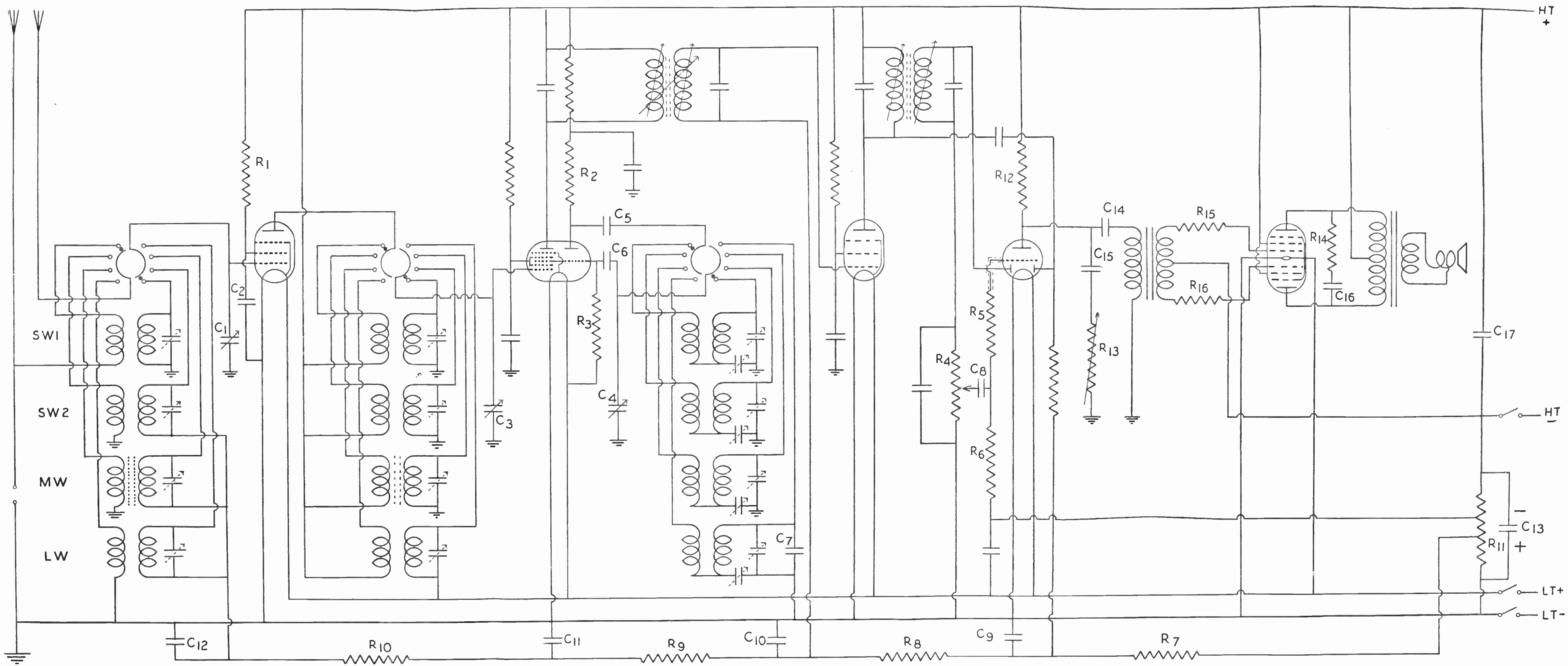
It will be observed that the low-potential end of the oscillator secondary is not connected to high-tension negative directly, but through pre-set condensers which are, in fact, the padding condensers; these are sometimes distinguished from trimmers by a dot on the end of the arrow, a convention that seems to be more often omitted than used. The use of the padding condenser to correct the oscillator tracking has been previously described, but it is interesting to note that all four wavebands are equipped with a padding condenser. It is therefore reasonable to assume that the ganged condenser does not use specially shaped vanes for the oscillator section. It is also worthy of note that the long-wave trimming condenser has a fixed condenser C_7 in parallel; this is to permit the trimming condenser to be of relatively low value and consequently less liable to oscillator drift.

The anode of the heptode is coupled to the following valve by means of an iron-cored intermediate-frequency transformer which may be tuned to one of several frequencies, but, as already mentioned in an earlier chapter, a choice is usually made between 128 and 465 kcs. per second. It will be noted that the parallel condensers are not variable, but there is an arrow through each coil in addition to the larger arrow through both coils. The smaller arrows indicate that the inductance of the coil is variable, and since no other means is indicated, the inductance is obviously varied by permeability tuning, *i.e.* the iron cores are arranged so that they may be screwed in and out. The large arrow indicates that the coupling between the two coils is variable, which will permit manual control of selectivity.

The Intermediate-frequency Amplifier.—The intermediate-frequency amplifying valve is again a variable-mu high-frequency pentode, the grid potential of which is controlled by the automatic volume control line. The screen is fed in a similar manner to the first valve. The anode coupling takes the form of another intermediate-frequency transformer working with fixed parallel capacity and tuned by varying the inductance of the coils by adjustment of the appropriate iron cores. Normally, this transformer will be considerably over-coupled in an attempt to keep the response-curve flat, when the first intermediate-frequency transformer is in the least selective position and therefore considerably over-coupled. It will be realised that it is in this position that the best-quality reproduction will be obtained. The capacities associated with the coils of the second intermediate-frequency transformer will be chosen so that the response of the primary is wider than the secondary, to assist in the elimination of sideband shriek, since the automatic volume control circuit is fed from the primary.

The Detector.—The fourth stage performs the function of detection, low-frequency amplification, and automatic volume control and employs a double diode triode. The signal anode is fed directly from the transformer secondary, the other end of which is connected to high-tension negative through the diode load. The diode load consists of a potentiometer R_4, providing manual volume control, and is connected to the triode section through a direct-current isolating condenser C_8 and a high-frequency stopping resistance R_5, the other resistance R_6 providing a direct-current connection to the automatic grid bias circuit. It will be understood that the stopping resistance must be low in value in comparison with the grid-bias return lead, in order that the potentiometer effect of the two resistances does not seriously attenuate signal strength. It will be noted that the lead from the grid stopper to the grid is encased by dotted lines, the conventional manner of indicating a screened lead. Normally, the use of such a lead is not shown on the theoretical diagram, but it is included at this point, since it has special significance, inasmuch as it will effectively increase the input capacity of the valve and, in conjunction with the grid stopper R_5, will increase the attenuation of the unwanted radio and intermediate frequencies. The automatic volume control anode is fed from the intermediate transformer primary, and is provided with delay voltage from the automatic grid bias circuit ; the delay obtained from this source will be increased by 1 volt if the anode nearest the positive end of the filament is used.

Automatic Volume Control Decoupling.—It will be observed that the automatic volume control circuit is elaborately decoupled. The delay voltage lead is decoupled by C_9 and the diode load R_7, and then progressively each of the control leads is decoupled, the intermediate-frequency amplifier by R_8, C_{10}, the frequency changer by R_9, C_{11}, and the radio-frequency amplifier by R_{10}, C_{12}. The only grid return lead that is not completely decoupled is the output grid return, although the



R.T. II—44

Circuit diagram of a four-band battery receiver with quiescent push-pull pentode output. In common with all circuits in this chapter, this diagram is intended purely to illustrate various points made in the accompanying text.

several sections of the bias resistance R_{11} is shunted by a condenser C_{13}, which will normally be of the electrolytic type, having a capacity of some 20μF, and rated at about 12 volts. Such a condenser is extremely compact, owing to the low voltage rating.

The triode anode load takes the form of a resistance R_{12}, the primary of the low-frequency transformer being capacity fed, C_{14}. Manual tone control is provided by a variable resistance R_{13} in series with a fixed condenser C_{15}, connected between the triode anode and high-tension negative. The resistance will be one so constructed that the moving member does not lift off the resistance element at the minimum position, so that the impedance of the circuit is always limited at the higher audio frequencies. If the resistance is not so constructed, a condenser will be connected across the primary to prevent supersonic frequencies reaching the quiescent output stage.

The Output Stage.—In this receiver a quiescent push-pull double pentode is used, which has the advantage over class B triodes that greater sensitivity is obtained. Once again the two sections of the output primary are shunted by a resistance R_{14} and condenser C_{16} in series to limit the impedance at the higher audio frequencies. Quiescent push-pull is, in other words, class C output, which requires low resistance windings for the output transformer primary, since it will be required to pass large peak current. The secondary of the input transformer does not require to be of low resistance, as grid current does not flow; consequently it is possible to include the grid stoppers R_{15}, R_{16}. It will be remembered that precisely converse considerations apply with class B output. As grid current does not flow, it is unnecessary to use a step-down input transformer, and the low-frequency gain may be increased by using a step-up ratio.

Grid Bias.—It will be observed that there are no grid-bias battery tappings, all grid-bias return leads being taken to the automatic bias resistance R_{11}, the value of which will be such that the total high-tension current flowing through it will bring about the voltage drop required by the output valve, which will, of course, vary with the type of valve used, but will generally be about 9 volts. The resistance is appropriately tapped to supply the delay voltage and the grid potential for the triode. Quite apart from the convenience of dispensing with the grid-bias battery, it has the great advantage that the grid-bias voltage will fall more or less in proportion to the high-tension voltage; consequently the output valve and, incidentally, the other valves, will work with decreased negative bias as the high-tension battery voltage falls, which is most important, since a quiescent output stage produces the most horrible distortion if over-biased, a condition which would obtain if the grid bias remained constant when the high-tension battery voltage decreased with age.

General Remarks.—It will be noted that the high-tension rails have the usual reservoir condenser C_{17} connected across them, and that the oscillator anode circuit is decoupled. Attention is also drawn to the battery switch, which is of the three-pole type, the extra point being used to completely disconnect high-tension negative. It should be understood that although the appropriate end of the high-tension battery is connected to the terminal marked HT—, the true high-tension negative is the earth rail, since the difference in potential between these two points is employed as grid bias.

A Three-valve A.C./D.C. Mains Receiver.—The inset facing page 48 is a three-valve plus rectifier receiver for working on either A.C. or D.C. mains. A cursory glance will show that four valves are employed, but since one of these is included solely for the purpose of rectifying the high-tension supply when the receiver is used on A.C. mains, it may be considered more reasonable to refer to it as a three-valve receiver, a point of view that is adopted by the majority of manufacturers. Since the circuit is primarily included to introduce the principle of the A.C./D.C. receiver, it will be unnecessary to dwell at great length on the rest of the circuit. It is, however, the first mains receiver that has been presented, and some consideration may therefore be directed to the biasing arrangements. It will, however, be convenient to vary the previous procedure, and describe the mains rectifier circuit and then to proceed to the aerial coupling and work through progressively to the output valve.

The mains, whether they are on the A.C. or D.C. system, are connected to the points indicated, and are separated from the receiver by the mains filter L_1, L_2, and C_1. That side which is intended to be connected to the positive main when working on D.C. is connected straight to the anode of the indirectly heated rectifier. An alternative route from the positive main passes through the three resistances R_1, R_2, and R_3. The first two are intended to be interposed as necessary to permit the receiver to work on voltages varying between 200 volts and 250 volts, while the resistance R_3 is intended to limit the heater current of the four valves to the rated value. It will be noted that the four heaters are in series, the heaters being shown in a vertical array for convenience, the order being indicated. As the heaters are in series they must all have the same current rating, usually ·2 or ·3 ampère. The voltage rating, however, may be mixed indiscriminately, such ratings as 13, 20, 30, and 40 volts being quite common; in this way the appropriate heaters may have increased *wattage dissipation*, although the *current* is constant. The value of R_3 will be determined, therefore, by the total voltage rating of the several valves in series, the current rating, and the applied voltage. If, however, a dial light is to be included as shown in the circuit diagram, its resistance and the shunt resistance must be taken into account. The shunt resistance R_4 is necessary, since the average small bulb is quite incapable of standing the initial surge of current which occurs when the heaters are cold. It will be appreciated that the resistance of a filament increases with temperature, consequently the initial heating current will be considerably in excess of the rated working current. The problem of arranging dial lights to give adequate illumination and reasonably long life is so acute that at least one manufacturer has thought it necessary to arrange a thermal delay switch.

The Mains Rectifier.—It will be seen that the rectifier cathode (which is high-tension positive) has a reservoir condenser C_2 and smoothing condenser C_3; the usual smoothing choke being replaced by the field winding of the loudspeaker, an arrangement that has the merit of economy only. Obviously, the total current taken by the valves must be very considerable if the loudspeaker field is to be adequately energised without serious voltage drop. To make this point clear, it must be remembered that the flux density of the speaker is proportional to ampère-turns, and in the present circumstances the number of turns will be limited in the interests of using fairly thick wire to keep the resistance to allow value; consequently the current must be relatively high. Since the valves do not, in the present instance, pass sufficient current, it is increased by the resistance R_5, so that the total current passing through the field winding reaches an adequate value. It will be noted that the reservoir and mains-smoothing condensers are indicated with polarity, showing that they are of the electrolytic type. The above remarks conclude the description of the power pack, with the exception of an observation on the rectifier, to draw attention to the fact that the insulation between cathode and heater must be capable of standing the total high-tension voltage of the receiver *plus* the applied peak voltage of the mains when used on alternating current. It is perhaps desirable to mention that the receiver will function on A.C. mains with the wall plug either way round, but on D.C. mains will only function when the plug is the correct way round, giving the desired polarity.

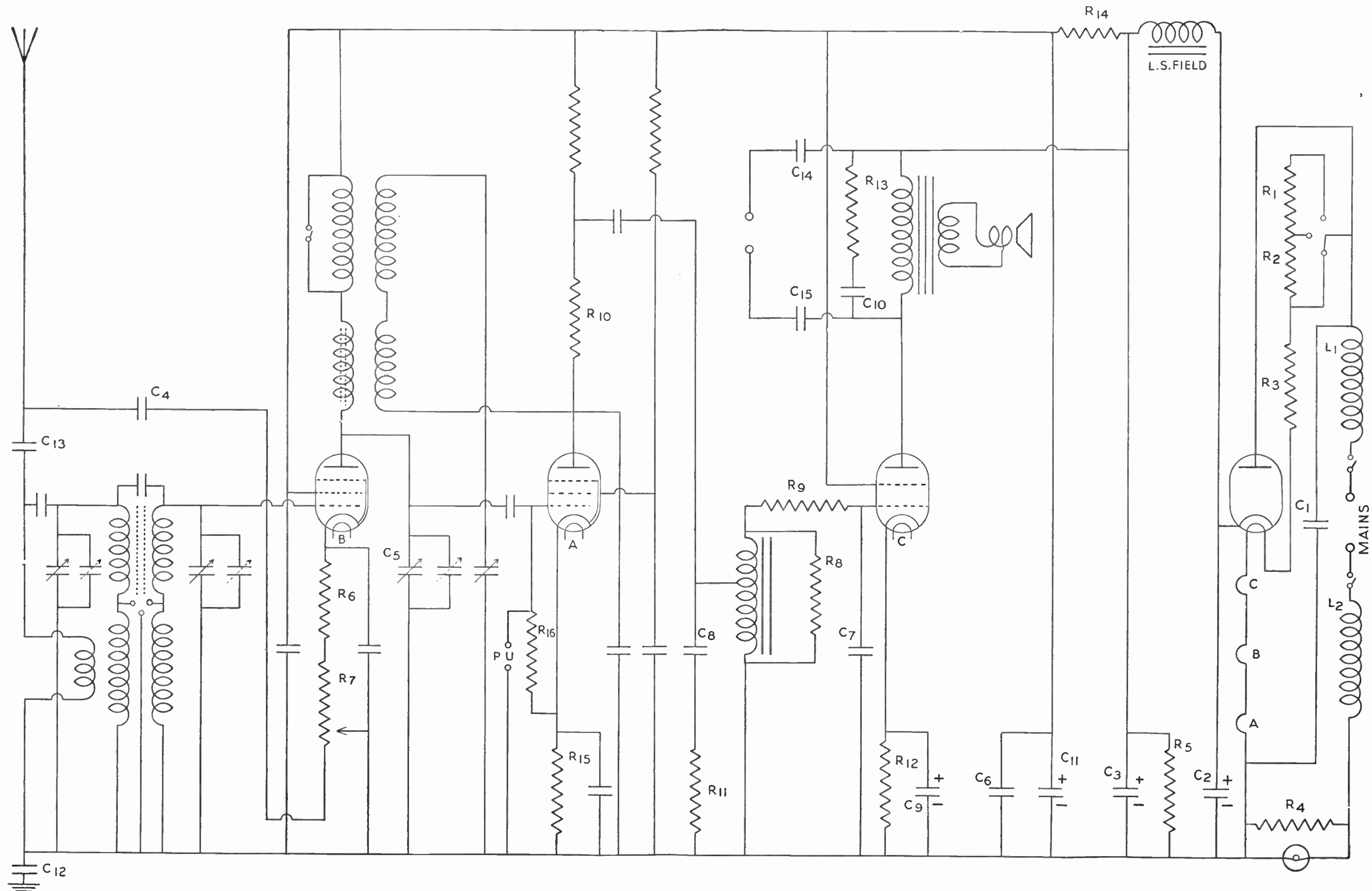
The aerial coupling is similar to that shown in the circuit facing page 40, with one exception: it will be observed that the cathode has a series resistance R_6 to provide a small fixed bias, and a variable resistance R_7 to provide variable bias to give control of gain in conjunction with the variable-mu characteristics of the first valve. It will be remembered that the grid bias on a mains valve is derived from the potential drop across the resistance in the cathode, the grid being returned to high-tension negative. A certain amount of difficulty is experienced with a variable-mu valve, since increase of negative grid potential brings about a decrease of anode current, consequently a very large resistance is required to bring about large negative bias, since this is obtained when the anode current is very small. It is difficult to obtain a bias resistance of high value and small size capable of standing a large current and able to withstand constant usage. To overcome this difficulty the lower end of the bias resistance is connected to the condenser C_4, so that movement of the volume control away from the cathode increases the negative voltage on the valve and decreases the portion of the resistance that is, in effect, connected between aerial and earth; in this manner adequate control of volume is obtained without reducing the gain of the valve to an extent which introduces the difficulties outlined above.

The First Stage.—Once again the first valve is a variable-mu high-frequency pentode, the screen being fed from the high-tension positive rail. The anode coupling is a simple tuned anode arrangement—which is chosen in preference to the high-frequency transformer, since this form of coupling is capable of very high gain—which is particularly necessary in a universal receiver, as the valves are working at an efficiency level that is lower than that of similar valves working in an A.C. mains receiver, owing to the limited high-tension voltage available. It will be observed that the tuning condenser C_5 is not connected across the coil but between anode and earth, the tuned circuit being completed by the fixed condenser C_6. This arrangement is adopted in order that one side of the tuning condenser can be at earth potential, obviating the necessity for completely insulating one section of the ganged condenser. The coupling between first and second valves is accomplished by the grid condenser and leak, which also perform a normal function as essential components of a leaky grid detector.

The Detector Stage.—Another screened pentode is used in the detector stage, with capacity-controlled reaction coupled back to the tuned anode coil. The detector anode coupling takes the form of a resistance-fed transformer, the inclusion of the latter component being desirable as a further means of increasing the gain of the receiver. It will be noted that a resistance R_8 is connected across the transformer primary ; this resistance will introduce a certain amount of damping and tend to flatten the response-curve of the transformer. Attention is drawn to the resistance R_9 and the condenser C_7, which form a high-frequency filter circuit to prevent radio frequencies appearing across the grid/cathode circuit of the output valve at sufficient amplitude to give trouble. The duty of the resistance R_{10} is usually undertaken by a high-frequency choke which is entirely satisfactory, but in the circuit under review the resistance has been included purely for economic reasons, as it is very much cheaper than a choke and is entirely adequate.

The resistance R_{11} and the condenser C_8 are included to attenuate the higher audio frequencies, but will also act as an additional means of attenuating any radio frequencies which may be present in this part of the circuit. The top cut brought about by this resistance and condenser might appear somewhat severe, unless it is remembered that the tuned anode coupling will have a peak response-curve rendered inevitable by the need for using coils with a high magnification factor to obtain maximum gain. The output valve is a tetrode, but could equally well be a pentode. Grid bias is obtained in the usual way by a cathode resistance R_{12}, with the usual bypass condenser C_9, which on this occasion is of the electrolytic type.

The anode load of the output valve is the primary of the output transformer, which is shunted by a condenser C_{10} and resistance R_{13} in series



Circuit diagram of a three-valve (plus rectifier) A.C./D.C. receiver.

to limit the impedance at the higher audio frequencies. As already mentioned, the field-energising coil of the loudspeaker is used as the smoothing choke, and in the normal course of laying out the circuit the field coil appears remote from the loudspeaker but, nevertheless, is one and the same assembly.

Decoupling.—The decoupling in this receiver must represent the basic minimum, since only one decoupling resistance is included, without which this principle would be entirely absent. The resistance R_{14} decouples the first and second stage from the output stage, but will also contribute considerably to the smoothing circuit, as it has a large capacity on the anode side, namely, C_{11}. This condenser is of the electrolytic type and might be considered unsuitable for anode decoupling, but it is not required to perform this function; it is there for the purpose of increasing the smoothing, since the condenser C_6 is in parallel.

Gramophone Pick-up.—A glance at the detector grid circuit will show that means are provided for the convenient connection of a gramophone pick-up between the grid and cathode of the detector valve, bias being obtained from the bias resistance R_{15} in the detector cathode lead. It will be noted that when the pick-up is in circuit the grid is returned through a relatively low resistance path to the negative side of the bias resistance, with the result that the potential drop across it appears as negative grid bias. When the pick-up is removed no connection exists between the grid and the negative end of the bias resistance, the grid leak R_{16} being returned direct to the cathode. It should be understood that in the absence of any switching arrangement for the pick-up it will have to be disconnected when the receiver is used on radio, usually by means of a plug and socket permitting disconnection by merely withdrawing the plug.

General Remarks.—High-tension negative is not joined directly to earth, since a condenser C_{12} is interposed to isolate the entire receiver from earth from the D.C. point of view. This precaution is, of course, unnecessary when a negative electric-light main is earthed, but is usually included as a standard precaution so that the receiver can work on any main. It is unwise to rely on a negative main being earthed, as it is not unknown for a power-supply company to change the polarity of the mains without warning when rearranging the mains on connecting new subscribers. Another precaution to prevent the possibility of shock takes the form of a double-pole mains switch, so that both mains are broken. A similar precaution appears in the aerial lead in the form of a condenser C_{13} to prevent short circuit in the event of the aerial collapsing, and danger from electric shock. The extension loudspeaker terminals are also isolated by condensers C_{14} and C_{15}, so that all external wires and terminals are isolated in the sense that they have no metallic connection with the mains. It is, of course, necessary to see that no other exposed metalwork appears in the form of grub-screws or controls. It will be observed that one pick-up terminal is connected to chassis and apparently no precautions are taken to guard against the possibility of electric shock when touching the pick-up. The actual chassis from which the circuit was taken was a small radio-gramophone in which the difficulty was overcome by the use of a suitable type of pick-up; if the pick-up connections were presented as a socket for use with an external pick-up, each lead would need to be broken with a condenser and the grid circuit completed by a resistance.

A Five-valve A.C. Mains Receiver.—The receiver shown in the inset facing page 52 is both an excellent and typical example of commercial practice; as an indication of typical resistance and condenser values, a table is given showing the values of those used in this circuit. It will be convenient to commence with the aerial circuit and work progressively through the five stages. It will be noted that a fixed condenser C_1 is connected in series with the aerial to limit the aerial capacity that may appear across the tuned circuits. The aerial and the grid of V_1 are each led to one pole of the three-pole three-way wafer switch S_1, so that each pair of coils may be selected according to the waveband required. It will be observed that the switch S_1 is of the three-pole type, but reference to the illustration will show that the switch S_3 is of the four-pole type; it is, nevertheless, of the three-way type, making it possible to gang together these apparently dissimilar switches. The reason for the additional contact on S_3 will be seen in due course.

The three sets of aerial coils are each provided with the usual trimmer across the secondary, an additional fixed condenser C_5 being placed across the long-wave trimmer to reduce its capacity and make it less prone to drift. It will be noted that the trimmers are not connected directly across the secondaries but between the high-potential end of the secondary and the earth line, a practice that is common in modern commercially built receivers, merely for the convenience of having one side of the trimming condenser in metallic connection with earth to obviate the necessity for insulating it.

It will be observed that the low-potential ends of all three secondaries are linked together and taken to the automatic volume control line, the high-frequency path being completed by the condenser C_8. It will be noticed that the cathode of V_1 is connected direct to high-tension negative without the usual bias resistor, which is rendered unnecessary by the voltage produced by the potential drop across R_{16}.

The arrangement of V_1 is quite conventional, except for the fact that the screen of this valve has a feed common with V_2 and V_3, the voltage being broken down by the resistance R_1 and the grid tied down, from the high-frequency point of view, by the condenser C_6. The anode of V_1 is taken direct to the switch S_2, and consequently the anod voltage will appear on the switch contacts. It can be seen by tracing the connections of the coils that the switch will select any one pair according to its position. The secondaries are tuned by the condenser C_{14}. which is connected direct to the grid of the frequency changer, and will appear, therefore, across whichever secondary is selected by the switch. Once again the secondaries are provided with trimmers, one side of each being taken direct to chassis, the same precautions being taken to prevent drift by the use of a fixed condenser C_{12} in parallel with the long-wave trimmer.

The Frequency Changer.—V_2 takes the form of a triode hexode, the circuit of which is conventional. It is worth noting, however, that the grid of the hexode section is biased by the voltage drop across the cathode resistor R_4, but that the triode grid is unaffected by this drop, as it is returned to the cathode end of R_4, and instead is biased by grid current flowing through R_3 and producing a voltage drop across it. This arrangement ensures that the valve is working with approximately correct bias, as it will automatically set itself so that the extreme ends of the positive half-cycle of the oscillatory waveform will just cause the valve to run into grid current. The grid of the oscillator is connected through the D.C. stopper condenser C_{16} to the switch S_3, and thence to the secondary winding appropriate for the waveband in use. It is interesting to note that, unlike the previous two switches, the high-tension voltage is excluded from its contact by the condenser C_{15}; this is in order that certain of the contacts may be earthed for reasons which are dealt with below. It will be observed that each secondary winding has its independent trimmer, and once again a fixed condenser C_{23} is used in parallel with the long-wave trimmer.

Reference to the illustration will show that the short-wave winding is connected directly to high-tension negative, and it can be assumed therefore that the vanes are shaped in such a manner that correct tracking is obtained on this waveband. The low-potential end of the medium-wave secondary includes the usual padding condenser C_{21}, which in this particular instance takes the form of a fixed condenser, which must necessarily be made with very considerable accuracy and with the precise value necessary to introduce the requisite correction. The low-potential end of the long-wave secondary is connected to high-tension negative by way of the usual variable padder C_{24}, and attention is drawn to the fact that here again the fixed condenser C_{25} is used in parallel to reduce the possibility of drift.

Reference to the illustration will show that the switch S_3 has an additional component in the form of a quarter-segment, which is so arranged that it connects together three adjacent points. The contacts are so arranged that in any one of the three possible positions of the switch, this segment (which moves as an integral part of the switch) will short one winding completely and connect it or its companion winding to earth to prevent the unused windings from influencing the coils in actual use. Admittedly, the segment will in some cases short a secondary and in others a primary, but this is unimportant, as the coupling between oscillator coils is so tight that the effect of shorting one coil will be transferred to the companion coil to a sufficiently large extent.

The hexode section of V_2 is coupled to V_3 by means of a permeability-tuned intermediate-frequency transformer, each coil having fixed condensers in parallel (C_{27} and C_{28} in the diagram). The low-potential end of the secondary is connected to the centre tap of a small coil, which is coupled to the primary. When the switch S_4 is in one position the winding of the small coil L_{21} will be in the same sense as the primary to which it is coupled and increase the coupling between L_{19} and L_{20}, but when this switch is in the other position the small coil L_{21} will be in the opposite sense to L_{20} and will weaken the coupling. When the first-mentioned condition appertains, the frequency response characteristics of the coupling will be broadened, and when in the alternative position the response characteristics will be narrowed.

The Intermediate-frequency Stage.—The pentode V_3 is a perfectly straightforward amplifier, with the possible exception of the minor point that its initial negative grid voltage is obtained by the drop across R_{16} and not by the conventional cathode resistance. The second intermediate-frequency transformer is permeability tuned and in other ways similar to the first intermediate-frequency transformer, but it is not provided with the additional coil to alter the band-width. It is, however, well worth noting that both coils are centre-tapped. The primary coil L_{22} is connected by way of the D.C. stopper condenser C_{30} to the automatic volume control diode, and by virtue of the fact that the response-curve of the primary is wider than the secondary some relief will be obtained

Component Values

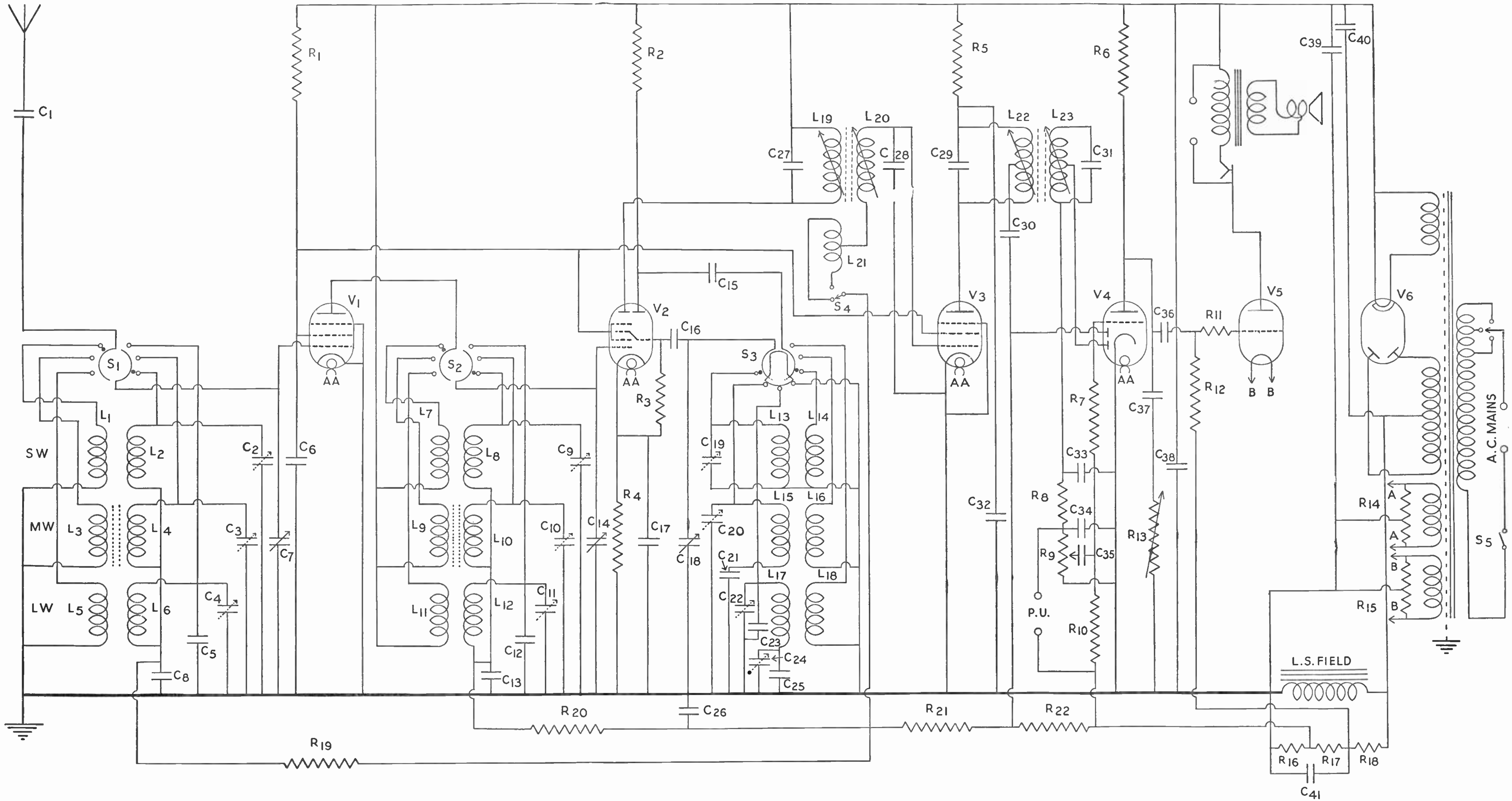
The values given below refer to the circuit shown opposite, and are included as an example of general commercial practice. These values hold good if the following valves are used: V1–MVS/Pen., V2–41STH., V3–MVS/Pen., V4–DDT., V5–2P., V6–43IU. (All Cossor.)

Resistances:

- R_1—15,000 Ω
- R_2—30,000 Ω
- R_3—25,000 Ω
- R_4—300 Ω
- R_5—5,000 Ω
- R_6—50,000 Ω
- R_7—·1 MΩ
- R_8—50,000 Ω
- R_9—·5 MΩ
- R_{10}—2 MΩ
- R_{11}—·1 MΩ
- R_{12}—·5 MΩ
- R_{13}—100,000 Ω
- R_{14}—25 Ω
- R_{15}—25 Ω
- Loudspeaker field coil—1,250 Ω
- R_{16}—20,000 Ω
- R_{17}—300,000 Ω
- R_{18}—·75 MΩ
- R_{19}—·5 MΩ
- R_{20}—·5 MΩ
- R_{21}—2 MΩ
- R_{22}—1 MΩ

Condensers:

- C_1—·0005 μF
- C_2—S.W. trimmer
- C_3—M.W. trimmer
- C_4—L.W. trimmer
- C_5—15 $\mu\mu$F
- C_6—·1 μF
- C_7—·00054 μF
- C_8—·05 μF
- C_9—S.W. trimmer
- C_{10}—M.W. trimmer
- C_{11}—L.W. trimmer
- C_{12}—15 $\mu\mu$F
- C_{13}—·05 μF
- C_{14}—·00054 μF
- C_{15}—·0002 μF
- C_{16}—·0001 μF
- C_{17}—·1 μF
- C_{18}—·00051 μF
- C_{19}—S.W trimmer
- C_{20}—M.W. trimmer
- C_{21}—570 $\mu\mu$F
- C_{22}—L.W. trimmer
- C_{23}—40 $\mu\mu$F
- C_{24}—L.W. padder
- C_{25}—120 $\mu\mu$F
- C_{26}—·05 μF
- C_{27}—225 $\mu\mu$F
- C_{28}—225 $\mu\mu$F
- C_{29}—60 $\mu\mu$F
- C_{30}—50 $\mu\mu$F
- C_{31}—75 $\mu\mu$F
- C_{32}—·1 μF
- C_{33}—50 $\mu\mu$F
- C_{34}—50 $\mu\mu$F
- C_{35}—·01 μF
- C_{36}—·01 μF
- C_{37}—·03 μF
- C_{38}—·1 μF
- C_{39}—8 μF
- C_{40}—8 μF
- C_{41}—10 μF



Circuit diagram of a five-valve (plus rectifier) A.C. superheterodyne receiver.

from sideband shriek. The secondary of this transformer is centre-tapped and feeds the detector diode ; in both cases the coils are centre-tapped to reduce the load imposed on each coil by the respective diodes. This modification will have the effect of narrowing the response-curve of the second intermediate-frequency amplifier as a whole in such a way that the sides are made steeper. The diode load consists of two portions, R_8 and R_9, thus the manual control will not reach absolute maximum, but, since the value of R_9 is some ten times the value of R_8, this effect will scarcely be apparent. The condenser C_{33} is the diode load bypass condenser, and C_{34} may be similarly regarded, as it is in parallel with the greater portion of the diode load. R_9 takes the form of a potentiometer, giving manual control, and is connected through the usual D.C. stopper condenser C_{35} and through the usual grid stopper resistance R_7 to the grid of V_4. The grid is returned to its source of negative bias through R_{10}, and it is obvious that R_{10} must be very much greater than R_7 in order that the input voltage is not seriously attenuated.

The triode portion of V_4 is coupled by the anode resistance R_6 and condenser C_{36} to the grid of the output valve, R_{11} forming the conventional grid stopper. It will be noticed that variable tone control is provided by the condenser C_{37} and variable resistance R_{13}, which are virtually in parallel with the anode load, although one end of R_{13} is connected to high-tension negative for convenience; this will allow one side of the variable resistance to be in metallic connection with the chassis or, in other words, the usual type of variable resistance can be bolted direct to the chassis without the need for insulation. The output valve is a directly heated triode, and is fed from a separate heater winding, not in this case to prevent shorting out the bias arrangements but because its filament is rated at 2 volts 2 ampères to reduce the hum-level. It will be appreciated that half the potential difference across the filament of a directly heated valve will appear on the grid and produce a proportionate hum-level ; by reducing the total potential across the filament by half, the A.C. potential appearing on the grid will similarly be reduced by half.

The Smoothing System.—The loudspeaker field winding serves also as a smoothing choke and is placed in the high-tension negative line, instead of, what is perhaps more usual, the high-tension positive line. From the point of view of efficient smoothing there is little to choose between the alternative positions. In the circuit under discussion it is placed in the negative lead so that the potential drop across it can be used for negative grid bias on the several valves, thus avoiding further voltage drop, which would otherwise reach a fairly high figure as the bias required by a triode capable of substantial output is necessarily considerable, being of the order of 30 volts. It will be observed that the resistances R_{16}, R_{17}, and R_{18} form a potentiometer across the loudspeaker field, the bypass condenser C_{41} is only connected across R_{16} and R_{17} as the potential drop across R_{18} is not used for bias purposes, the component merely being in the position shown to reduce the drop across the outer ends of R_{16} and R_{17}, since the total drop across the field winding is greater than that required for grid bias. As no grid current will flow in V_1, V_3, V_4, V_5, or the hexode section of V_2, the value of the resistance network can be relatively high, and in the receiver in question the actual values are R_{16}, 20,000 ohms; R_{17}, 300,000 ohms; R_{18}, 750,000 ohms. It is absolutely essential that the resistances together form a high figure, as they would otherwise form an appreciable bypass across the loud-speaker field and reduce its efficiency as part of the smoothing system to a greater or lesser extent. The smoothing arrangements are completed by the reservoir condenser C_{40} and the smoothing condenser C_{39}. Strictly speaking, the decoupling of a receiver is an aid to general smoothing, but in the circuit under discussion the only relevant decoupling consists of that used in the anode circuit of V_3, which consists of a 5,000-ohm resistance R_5 and a ·1 μF condenser C_{32}, the influence of which is negligible from the point of view of reducing the hum-level.

With the exception of the slightly unconventional position of the smoothing choke, the power pack is perfectly conventional and is provided with a metallic shield between the secondary of the mains transformer and the core and primary to prevent radio frequencies being transferred to the receiver by pick-up on the house-wiring system.

A Ten-valve Superheterodyne Receiver with Automatic-frequency Control and Paraphase Push-pull Output.—The inset facing page 60 shows the circuit of a relatively ambitious receiver, with some of the more important, although optional, refinements. The average British receiver employs not more than six valves, and it might therefore be considered somewhat unnecessary to qualify the description by saying that it is *relatively* ambitious. The term is quite justified in view of the fact that some slight mention has been made of American practice; judged by British standards the receiver under discussion is elaborate, but judged by American standards it might almost be considered simple, since in that country twenty-valve sets are not exceptional, and the average high-class domestic receiver often uses between fifteen and twenty valves. One may wonder how so many valves could be applied, but the fundamental answer is that the Americans prefer to use a lot of relatively low-efficiency valves, with the result that they use about twelve valves to do the work of eight, and then add a few more valves for purposes that may almost be considered as falling into the class of gadgets, such as tone-control valves, tone-expansion valves, interference-suppressor valves, and so on.

Returning to the circuit at present under discussion, the power pack needs no particular introduction, which permits the circuit to be reviewed from the aerial onwards. It will be observed that the circuit falls conveniently into two sections, the valve chain V_1 to V_7 forming the signal path, and the other section formed by valves V_8, V_9, and V_{10}, which are solely concerned with automatic-frequency control and automatic volume control.

The Aerial Coupling.—The aerial is taken direct to a wafer-type switch, which permits selection from three pairs of coils, each of which constitutes a single tuned circuit. It will be noted that the short-wave coils and long-wave coils are air cored and that the medium-wave coil is iron cored. The main tuning is done by the variable condenser C_1, which is permanently connected between the grid and chassis ; each secondary coil being provided with its own trimming condenser. The fourth position of the switch connects the grid of V_1 to earth for the purpose of positively eliminating radio noise when the receiver is being used for gramophone reproduction. It will be observed that the medium- and long-wave secondaries are taken to the usual automatic volume control line, whereas the short-wave secondary is taken to a separate automatic volume control line, which is so arranged that it provides only a proportion of the available control voltage, so that V_1 always works under conditions of appreciable stage gain, which will increase the sensitivity of the receiver on weak stations and improve the signal to noise ratio.

The second aerial A_2 is taken to the low-potential end of the short-wave primary and shows the possibility of using a di-pole or doublet aerial. When this type of aerial is not used the terminals marked AT are linked together, so that the low-potential end of the primary is connected to the chassis.

The Radio-frequency Amplifier.—V_1 is a perfectly conventional radio-frequency amplifier. Both anode and screen are decoupled, the anode by means of the resistance R_1 and condenser C_2, and the screen resistance R_2 and condenser C_3. The anode is taken direct to one side of a wafer-type switch, the other half of which is connected directly to the frequency changer V_2. Once again the switch permits one of three pairs of coils to be selected ; these take the form of high-frequency transformers, the short-wave coil and long-wave coil being air cored and the medium-wave coil iron cored.

It should be noted that the low-potential ends of the medium- and long-wave secondaries are taken to the normal automatic volume control line, whereas the short-wave secondary is taken to the reduced automatic volume control line, so that the frequency changer always works under conditions of relatively high gain, thus improving the signal to noise ratio.

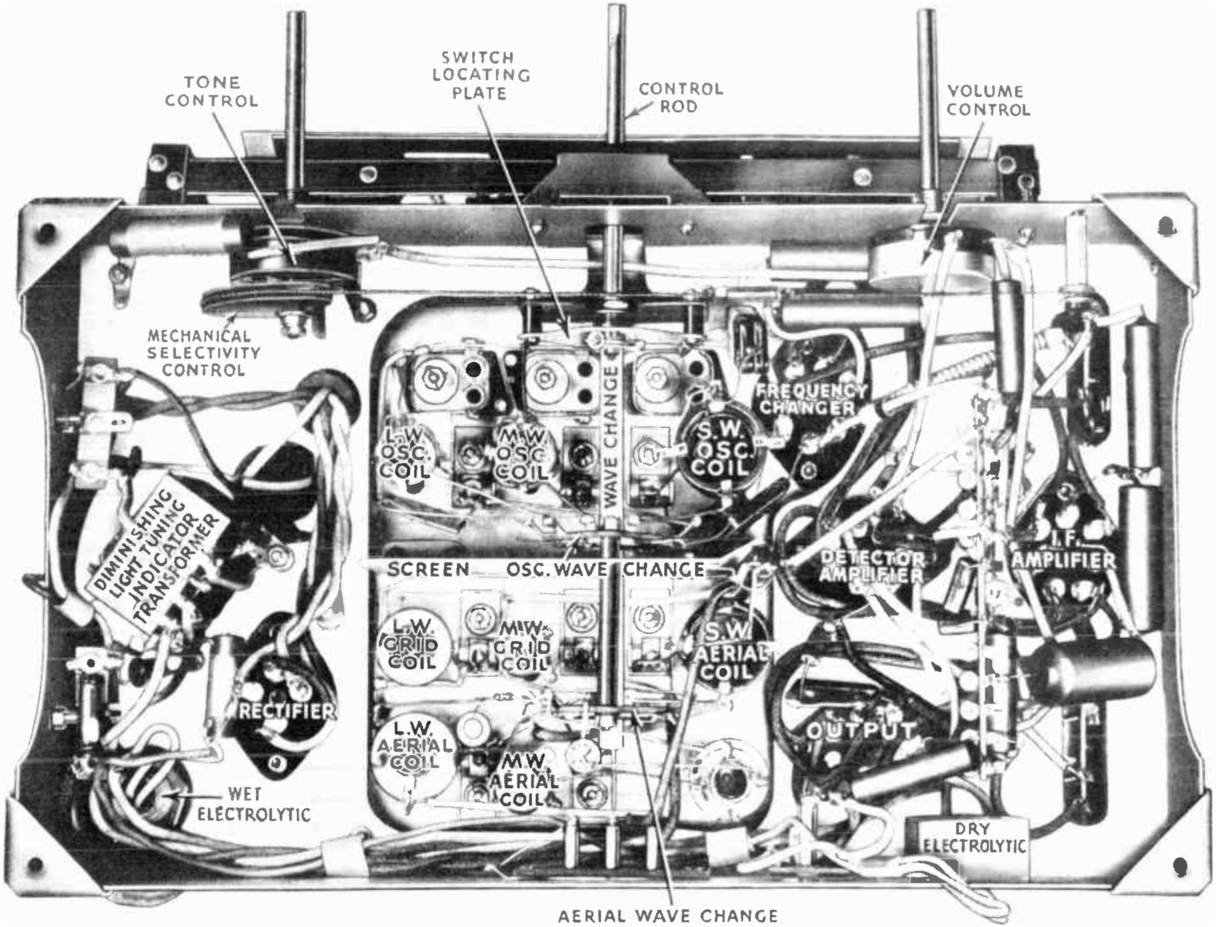
The wafer switch has only three positions, since the fourth, the gramophone position, is not required. It should be understood, however, that the switch should be so arranged that it has four positions, even although one position is without contact, so that it may be ganged with the aerial switch. Tuning of the radio-frequency amplifier anode circuit is accomplished by the variable condenser C_4, each secondary winding being provided with its own trimmer.

The Frequency Changer.—The frequency changer valve V_2 is a normal triode hexode. The hexode anode circuit and screen circuit are decoupled by the resistances R_3, R_4, and condensers C_5, C_6 respectively. The oscillator section of the valve is biased by grid current through the grid leak R_5, the grid being isolated by the condenser C_7; the hexode section uses cathode resistor bias in the normal manner.

The oscillator anode is not connected directly to the appropriate coil from the D.C. point of view, but is provided with the anode resistance R_6 and coupling condenser C_8, which is connected directly to one half of the wafer switch, the other half being connected to the grid. Once again the wafer switch is so arranged that one of three coils may be selected; all coils are air cored, the grid coil of the short-wave section is provided with a trimming condenser and padding condenser, since the oscillator section of the main ganged condenser has not specially shaped plates to give the necessary tracking. The medium-wave secondary is provided with a trimming condenser and padding condenser. The long-wave coil is provided with a variable trimmer and with a fixed trimmer C_9, so that the capacity of the former can be relatively small to minimise frequency drift. A padding condenser is also provided. Variable tuning is accomplished by the variable condenser C_{10}. The low-potential ends of the secondaries are all connected to chassis, since variable bias is not required on the oscillator, which should deliver an output that is fairly critical, since insufficient heterodyne voltage will reduce the conversion gain of the stage as a whole, while too much voltage will increase the tendency towards oscillator harmonics. The wafer switch is provided with a contact to earth, the grid of the oscillator (and, incidentally, the injection grid of the hexode), to prevent the valve from self-oscillation in the gramophone position, since without this connection the grid would be on open circuit.

The hexode anode circuit is coupled to the grid circuit of these three by means of a special type of intermediate-frequency transformer, giving a choice of two band-widths, the switch S_1 is ganged to the switch S_2, so that a top-cut circuit is automatically introduced when the switch S_1 is in the more selective position. As may be seen from the circuit, the intermediate-frequency transformer consists of two iron-cored coils and associated with a fixed capacity provided by condensers C_{11} and C_{12}, trimming being accomplished by manipulation of the respective iron cores. The secondary winding is taken to a tap on a small coil which is tightly coupled to the primary. The coil is so arranged that either half may be thrown into circuit by switch S_1, which, in effect, reverses the sense of the winding and either increases or decreases the coupling between the two coils. When the coupling is increased the band-width is also increased, and *vice versa*. The arm of the switch is taken to the normal automatic volume control line; as will be seen later, the automatic volume control is amplified by a separate valve, and it might appear that the application of the full automatic volume control voltage would cause distortion due to over-biasing. This danger could be overcome by connecting the grid to the reduced automatic volume control line, but this might militate

R.T. II—56



RADIO RECEIVER DESIGN

This illustration shows the underside of the same Cossor superheterodyne receiver as that shown in Volume I. Note the grouping of the tuned circuit components which are assembled on a rubber mounted sub-chassis.

against efficient control, and it is considered preferable to use one of the pentode valves that have a very long grid base and are capable of relatively large output; this type of valve has the advantage of a normally shaped grid characteristic at the zero end, but a long trailing characteristic at the negative end, so that it can handle a large signal when heavily biased. Such valves have high anode current, and, since maximum anode voltage is required, decoupling has been omitted.

The Intermediate-frequency Stage.—V_3 is coupled by means of a permeability-tuned iron-core transformer, which is provided with fixed capacity C_{13}, C_{14}, and is trimmed in the same manner as the first intermediate-frequency transformer. The low-potential end of the secondary is taken to the diode load, which consists of a centre-tapped potentiometer R_7. It will be noted that only the upper half of this potentiometer forms the diode load, since the centre tap is connected to the cathode, and consequently the associated condenser C_{15} is connected across this portion of the resistance. The other half of the potentiometer forms the volume control for gramophone reproduction and may be conveniently ignored for the moment, since it is associated with a fairly elaborate tone-corrector circuit. The automatic volume control diode D_1 is provided with a diode load resistance R_8, the top end giving full automatic volume control and the tap giving reduced automatic control voltage for purposes already explained. The reduced automatic control voltage is decoupled by the resistance R_9 and condenser C_{16}, which also form the necessary time-constant circuit to prevent the voltage being affected by modulation. This line is further decoupled from the grid of V_1 by the resistance R_{10} and associated capacity C_{17}. The full voltage line is decoupled by the resistance R_{11} and capacity C_{18} and decoupled from the first stage by the resistance R_{12} and capacity C_{19}.

It should be particularly noted that the automatic volume control diode D_1 does not derive its signal voltage from the anode circuit of the intermediate-frequency amplifier V_3 but from the anode circuit of an auxiliary intermediate-frequency amplifier V_8. This valve amplifies a portion of the output that appears across the primary of the second intermediate-frequency transformer, and serves the purpose of supplying both the automatic volume control diode and automatic-frequency control diodes, thus relieving the intermediate-frequency amplifier V_3 of damping. In view of the fact that the signal voltage on the diode D_1 will be many times the voltage appearing on the diode D_2, it is essential that adequate internal screening be present between the two diodes, otherwise the feed-back from D_1 to D_2 would have serious consequences. Many double diode triode valves are not sufficiently screened, and if the use of such a valve is desirable for some special reason, then it would be necessary to use a separate diode valve for automatic volume control.

The grid of the triode V_4 is connected to the moving arm of the potentiometer R_7 which provides manual volume control, but is isolated from the D.C. point of view by the condenser C_{20}. The resistance R_{13}

acts as a grid stopper, and the resistance R_{14} forms the usual resistance in the grid return to prevent the signal voltage from being shorted out. The triode section is very much over-biased by means of a relatively high resistance R_{15} in the cathode circuit, so that the valve is muted. The valve is unmuted by virtue of the fact that the grid is driven positive by the action of the automatic tuning-control diode, the action of which is explained below. It should be understood that the grid is driven in the positive direction, but not to such an extent that it becomes positive in respect to the cathode. It is apparent that unless the automatic volume control is perfect, which it certainly is not, the voltage supplied for the purpose of unmuting the valve will be subject to some variation, which means, in fact, that the grid bias under working conditions is not constant.

The variation of bias under working conditions, referred to above, is immaterial, as it will not vary on a strong signal to an extent that will permit grid current; while on a weak signal the bias will not be so great that the valve is rectifying, always providing the signal is strong enough to unmute the valve in a proper manner. Fortunately, it is unnecessary for the triode to accept a signal greater than 50 per cent. of its capacity, since adequate low-frequency gain is available, even though the anode load is relatively low. Obviously, if the valve is only required to accept half the permissible grid swing, then the bias may vary 25 per cent. above and below this point without introducing distortion.

Tone Compensation and Manual Control.—The anode load comprises the resistance R_{16} in series with a tuned circuit resonating at 6,500 cycles, which is switched into circuit by S_2 when the switch S_1 is in the position of maximum band-width. When the switch S_1 is switched to narrow band-width, the top-lift circuit is shorted out. The third position switches the top-lift circuit so that it resonates at 3,000 cycles, due to the extra capacity connected across it C_{22}, at the same time throwing a condenser C_{23} across the anode load for the purpose of cutting the top. This arrangement provides a deliberate peak at about 3,000 cycles, which gives the apparent effect of improving the top response, which is considerably attenuated by the condenser C_{23}.

Tone control is effected by the usual variable resistance R_{17} and condenser C_{24}. It functions equally on gramophone and radio, the same remark applying to the tone-selector switch S_2, although this will normally be placed in either the high-fidelity position or the middle position, as required, since it is obviously undesirable to introduce a deliberate peak, bearing in mind that the mere attenuation of the higher frequencies can be accomplished by the variable tone-control.

It will be noted that the anode circuit of V_4 is decoupled, and that it is coupled to the grid of V_5 by the usual condenser C_{25}.

The Low-frequency Amplifier.—The output valves are triodes working in push-pull, and consequently a comparatively large input voltage is required, which is developed by the low-frequency amplifier V_5, which is a small power valve, the ordinary so-called low-frequency valve being unable to produce the large output voltage required without introducing a certain amount of distortion. The output valves could be fed by means of a low-frequency transformer having a centre-tapped secondary, but for various reasons the transformer has been omitted in order to achieve the very best quality of reproduction. It is necessary to feed the two grids in opposite phase, consequently ordinary resistance-capacity coupling would be unsuitable and recourse is made to the paraphase system, which entails the dividing of the anode load and placing one portion in the cathode. These resistances are marked R_{19} and R_{20} respectively. This arrangement allows the output to be taken from the anode and cathode, which points are 180° out of phase. The actual coupling is by means of the usual coupling condensers C_{26} and C_{27} respectively, associated with the grid leaks R_{21} and R_{22}, which are connected to chassis.

The Output Valves.—Arrangements have been made so that each output valve has independent bias. As the valves are of the directly heated type, it has been necessary to supply each filament from a separate secondary winding. This additional winding is amply justified, since with common grid bias the failure of one valve will often destroy the other valves. Each filament has a small centre-tapped resistance across it which may have a value of 25 ohms; the centre tap being taken to chassis through the appropriate bias resistances marked R_{23} and R_{24} respectively, each being shunted by the usual bypass condensers C_{28} and C_{29}. It will be observed that there is no D.C. connection between the filament secondaries and the chassis, except through the bias resistance. It may be relevant to mention that the centre tap is necessary to minimise the change of grid potential due to the application of A.C. through the filaments, and, in addition, imposes half the A.C. voltage on the grid, although the latter consideration is relatively unimportant because the A.C. voltage arising from the filament circuit can be made to appear at each anode in the same phase if the filaments are connected to their respective secondaries in the correct sense. The hum voltage appearing in phase at both anodes will not appear in the loudspeaker, since the potential will be equal to each anode in respect of the centre tap of the output primary, and consequently will not produce any field, as the currents will be flowing in opposite directions.

The output circuit is made up by the usual loudspeaker output transformer and will be of reasonably massive construction, since the output valves may be expected to deliver, say, 7 watts.

The Power Pack.—It will be convenient to deal with the power pack before going on to the circuits associated with the valves V_8 and V_9, since the former is to some extent inseparable from the output stage. It will be observed that two smoothing chokes are shown. The loudspeaker field forms the choke marked L.S. field, and provides adequate smoothing for the output valves, but cannot be considered sufficient to smooth the earlier stages. The inductance of the field winding will not be very great, as it will have a relatively small number of turns and will pass a fairly heavy current; that is, of course, assuming that the normal type of heavy-duty loudspeaker is employed.

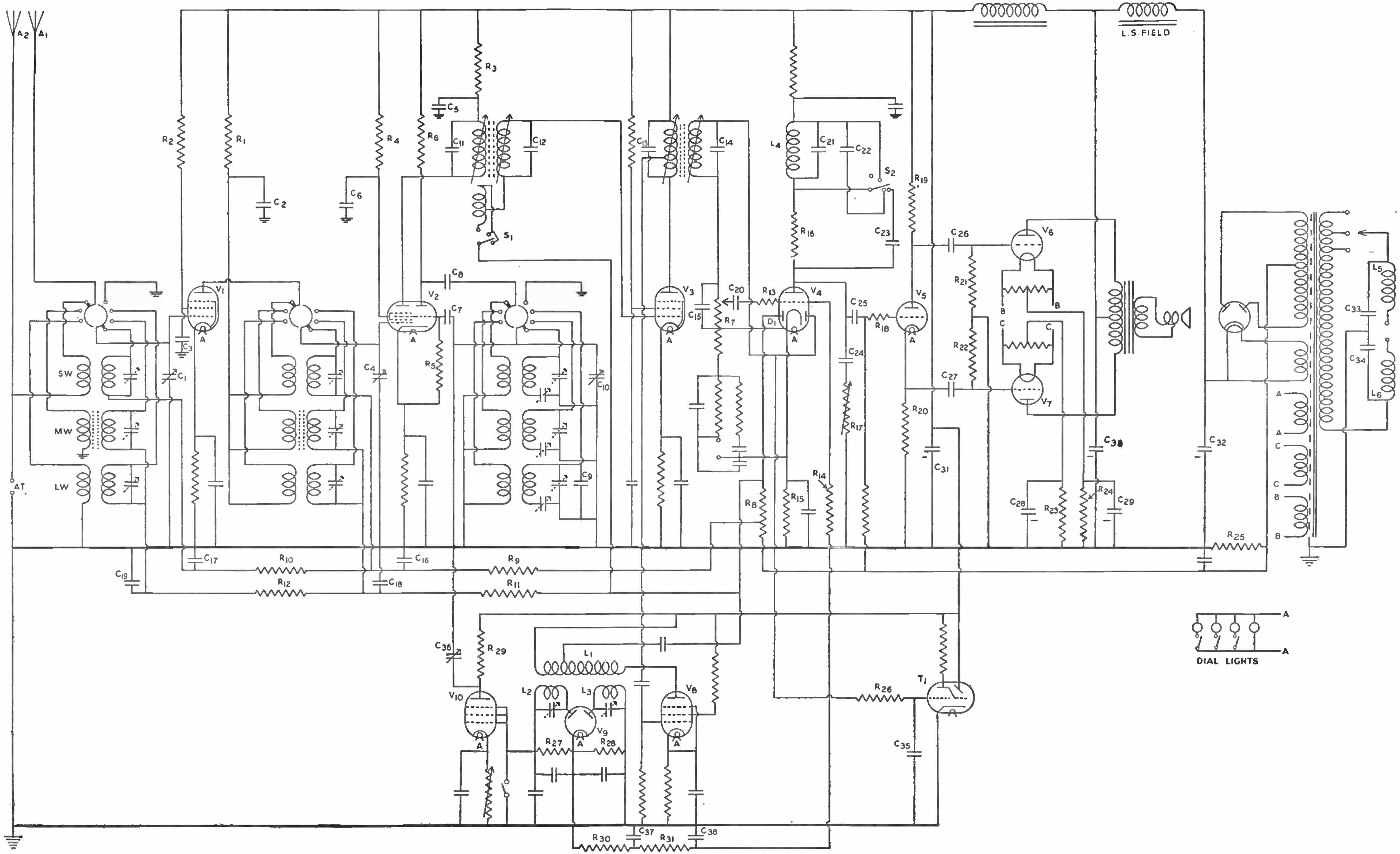
Three electrolytic smoothing condensers are used in conjunction with the choke and loudspeaker field coil. The values of these three condensers are to some extent arbitrary, but since the condenser C_{32} is the reservoir condenser, its capacity will not be unduly high, to avoid placing an unnecessary load on the rectifier, which will obviously be required to produce a large output. The rectifier circuit is quite conventional and uses an indirectly heated rectifier, although a directly heated type should be satisfactory, since the output valves are also directly heated.

It will be observed that the mains transformer is provided with three low-tension secondaries in addition to the winding supplying the rectifier heater. It is necessary to supply directly heated output valves by a separate winding to reduce hum and provide convenient means of obtaining bias. On the other hand, it is desirable to provide each of the output valves with a separate winding, so that each may work with independent bias, for reasons that have already been explained; the output valves have their filaments marked *bb* and *cc* respectively, and are connected to the transformer windings so marked.

The winding *aa* is intended to supply valves V_1 to V_{10} inclusive and also the dial lights. In the diagram four dial lights are shown, which are intended to illuminate the tuning scale, but obviously any elaborate arrangement of switching could be employed to light separate scales for each waveband or to illuminate waveband indicators. It is usual to use miniature bulbs rated at 6·5 volts, since 4-volt bulbs will not stand up to continuous running on alternating current and, in any case, the illumination is too dazzling for dial lighting.

It will be observed that a dotted line is shown between the primary and the core of the mains transformer, indicating the presence of a metal screen, which is duly earthed and is intended to reduce the transference of electrical interference from the primary and secondary. This arrangement is very satisfactory for receivers of moderate gain, but is somewhat inadequate for receivers which develop really high gain; consequently it it was thought desirable to include a mains filter in the mains lead, consisting of the chokes L_5 and L_6 and the associated condensers C_{33} and C_{34}. Attention may now be directed to the tuning indicator T_1 and the section employing V_8, V_9, and V_{10}.

Automatic-frequency Control.—The tuning indicator and the automatic-frequency control section has been relegated to the end, not because it is unimportant, but because the receiver will function perfectly well without it. They are simply and solely refinements, unless, of course, it is intended that the receiver be fitted with some form of motor-driven automatic tuning, when automatic-frequency control becomes a virtual necessity.



A ten-valve (plus rectifier and magic eye) A.C. superheterodyne receiver with automatic frequency control and other refinements which are described in the text.

The tuning indicator can be disposed of in a few lines, as it forms a perfectly conventional arrangement of the magic-eye, the grid being controlled by connection to the signal diode through the usual time-constant circuit R_{26} and C_{35}. The functioning of this device is fully explained in the chapter devoted to tuning indicators.

The automatic-frequency control circuit consists essentially of an auxiliary intermediate amplifier V_8, the discriminating valve V_9, and the frequency-control valve V_{10}. It will be observed that the grid of the auxiliary amplifier V_8 is connected to a tapping near the high-potential end of the second intermediate-frequency transformer in the anode circuit of V_3; the purpose of this auxiliary amplifier is to perform the obvious function of supplying an amplified signal to the discriminator and to relieve the normal intermediate-frequency transformer of the load and other undesirable qualities which would be imposed by the discriminator circuit. Use is also made of the auxiliary amplifier to feed the automatic volume control diode. It will be noted that the automatic volume control is tapped into the anode circuit in order that the auxiliary transformer shall not be unduly damped.

The discriminating circuit employs a double diode valve, each anode being provided with a tuned circuit L_2 and L_3, which is coupled fairly tightly to the primary L_1. It will be seen that the coils L_2, L_3 employ capacity tuning for the purpose of pre-setting their resonant frequencies. The primary L_1 is adjusted to resonate at the intermediate frequency, 465 kcs. per second, while the secondaries are tuned above and below this frequency by an equal amount, usually 2 or 3 kcs. per second. Each anode circuit is completed to cathode through the resistances R_{27} and R_{28}, the junction of L_2 and R_{27} being taken directly to the grid of V_{10}.

If the oscillator tuning condenser C_{10} is correctly adjusted, the beat note will be the true intermediate frequency, and the voltage induced across the discriminator coils L_2 and L_3 will be equal, so that equal current will flow through the resistances R_{27} and R_{28}, and consequently the grid potential of V_{10} will be unchanged. If the oscillator tuning condenser C_{10} is carelessly adjusted (or inaccurately adjusted in the case of motor tuning), the intermediate frequency will be other than 465 kcs. per second, with the result that one discriminator coil will develop a larger voltage than usual and the other a lower voltage, which will cause current to flow, since the voltages are unequal although still in opposite phase. This flow of current will cause the junction between L_2 and R_{27} to be driven progressively positive or negative according to whether the frequency appearing in the primary L_1 is greater or less than the true intermediate frequency.

To summarise, the discriminator circuit is an arrangement which will cause a potential to be developed across two appropriate points, the sign of which is dependent on whether the intermediate frequency is above or below the correct frequency, and the amplitude of which is dependent upon the amount by which the intermediate frequency differs from the correct frequency. It now remains to be seen how this change of potential can be used to correct the frequency of the oscillator circuit and so correct the intermediate frequency. It should be understood that the arrangement only corrects the oscillator frequency, which will leave the aerial and radio-frequency circuits slightly mistuned, but such mistuning is not as serious, if the tuned circuits are suitably designed, as an equivalent mistuning of the oscillator frequency. It will be remembered that the selectivity of the intermediate-frequency transformers is very much higher than the tuned circuits in front of the frequency changer.

V_{10} consists of a triode valve, the anode of which is connected through a small condenser C_{36} to the high-potential side of the oscillator secondary circuit. It is obvious that a small condenser connected between this point and chassis could be used as a manual means of correcting the oscillator frequency. The problem is to vary the capacity automatically. If this condenser is connected in series with a resistance of, say, 10 megohms, the effect of the capacity will be negligible, which suggests that the condenser could be made fixed and its influence on the tuned circuit controlled by the resistance, which would have to be variable. This arrangement is adopted in the circuit under discussion, the condenser is marked C_{36}, and " the resistance " takes the form of the valve V_{10} or, being more precise, V_{10} acts as a variable resistance in series with the capacity C_{36}, the former being varied by the potential applied to the grid; it will be remembered that the impedance of a valve is influenced by grid potential. The valve V_{10} is biased so that its impedance is normally about the middle of its useful variable range, and the discriminator circuit will, when necessary, decrease or increase the bias, which will in turn decrease or increase the impedance, which, being in series with the capacity C_{36}, will increase or decrease the frequency of the oscillator until it is sufficiently near to the correct frequency to give normal quality of reproduction.

It will be noted that the bias resistance of V_{10} is variable, to allow the valve to be biased to the middle of its useful range. The resistance R_{29} merely provides an impedance to prevent the high-tension supply from, in effect, shorting out the valve impedance.

Efficiency.—The circuit arrangement of V_8 and V_9 is quite satisfactory, but it is necessary to stress in the most definite terms that the oscillator control circuit cannot be recommended as the most satisfactory system. It will be realised that the circuit under discussion was designed purely for the purpose of co-ordinating the information contained in numerous preceding chapters, and consequently the author selected the system which could be most readily understood. Several systems are available, one of the most desirable being an arrangement using a screened-grid or screened-pentode valve, which is so arranged that the inductive reactance of the grid-circuit appears amplified in the anode circuit which is directly connected to the oscillator secondary. This arrangement feeds back energy into the oscillator circuit, which, in effect, decreases or increases the inductance.

Noise Suppression.—It has been stated that V_4 is biased to cut off, and that the grid is returned to the centre of the resistances R_{27} and R_{28} in the discriminator circuit. When a signal of sufficient amplitude is received and the oscillator frequency duly corrected, the junction between R_{27} and R_{28} will become positive and unlock V_4 by driving the grid in a positive direction. The arrangement is reasonably satisfactory, and it may be noted that this can be considerably improved by using a pentode in place of the triode V_4; the junction between R_{27} and R_{28} being taken to the suppressor grid, the control grid being returned to chassis in the ordinary way. Unfortunately, however, objection may be raised to the use of a pentode on entirely different grounds. It will be observed that the lead between the cathode of V_9 and the grid of V_4 has a double high-frequency stopper made up of the resistances R_{30}, R_{31}, and the condensers C_{37} and C_{38}; this rather unusual precaution is necessary, since the presence of high frequencies on the grid of V_4 might be expected to cause considerable trouble.

Three-valve Superheterodyne Receivers.—Fig. 29 shows the skeleton circuit of a three-valve superheterodyne, and is included in conjunction with Fig. 30 to indicate the two popular methods of designing receivers which enjoy some of the advantages of the superheterodyne receivers although limited to only three valves. In both these circuits waveband switching has been ignored, since the intention is to illustrate the sequence of the various stages.

Fig. 29 shows an arrangement where the first valve is the frequency changer, the second valve is the intermediate-frequency amplifier, and the third valve fulfils the function of signal detector, rectifier, automatic volume control rectifier, and output. For this purpose one of the specialised output valves must be used: either a double diode pentode or a double diode tetrode. It is apparent that the same arrangement could be achieved by using a separate double diode valve and a separate output valve. Obviously, therefore, the use of the combined output valve is purely an economic consideration.

Fig. 30 shows an alternative arrangement, where the first valve is the frequency changer, the second valve a high-gain detector with reaction, and the third valve the output valve. The circuit shown at Fig. 29 has the advantage of rather high gain, makes automatic volume control possible, but selectivity is limited. The circuit shown at Fig. 30 has the advantage that reaction allows gain and selectivity to be simultaneously increased, but has the disadvantage that automatic volume control is impracticable.

Fig. 31 shows a modified intermediate-frequency coupling provided with switching to vary the frequency when the receiver as a whole is switched to short waves; this coupling could be used in any of the superheterodyne circuits in this chapter. The switching is so arranged that the intermediate frequency is considerably higher when working on the short waveband, the oscillator circuit being, of course, also suitably

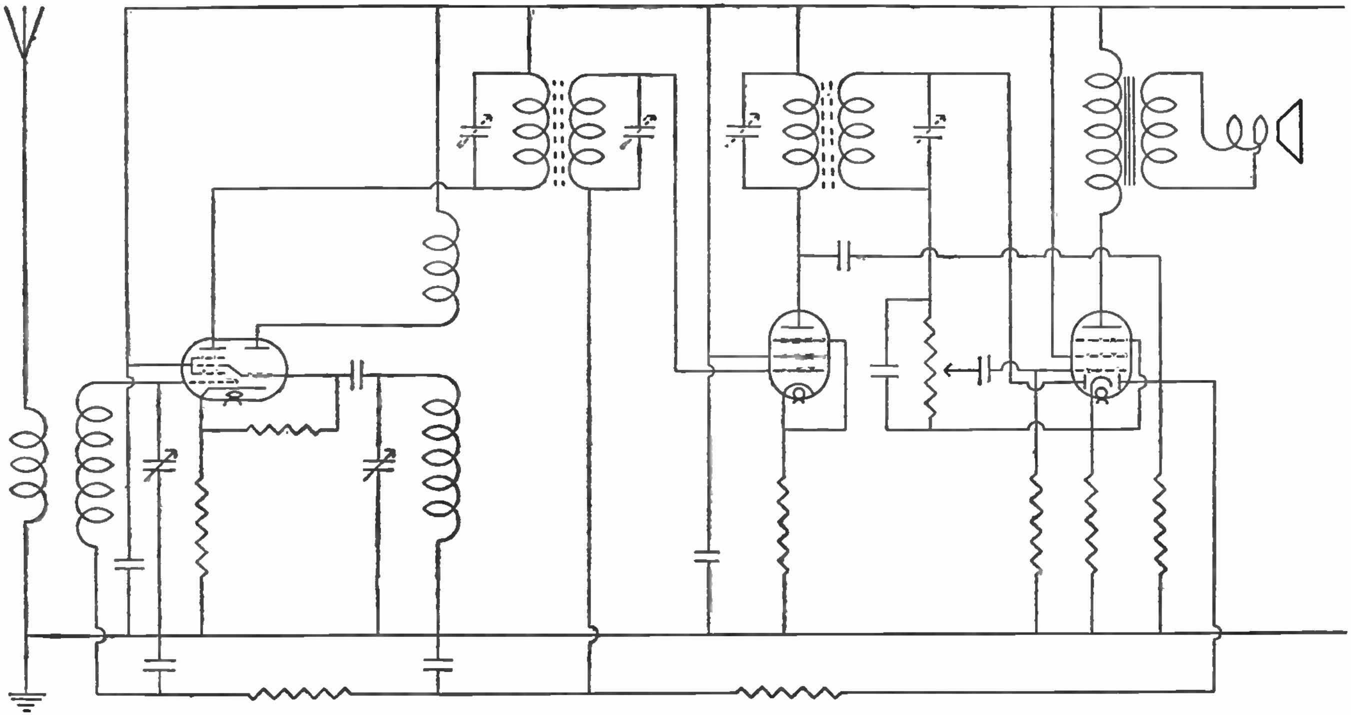


Fig. 29.—Skeleton circuit showing a possible arrangement of a three-valve midget superheterodyne receiver. The power pack is omitted, as it is perfectly conventional.

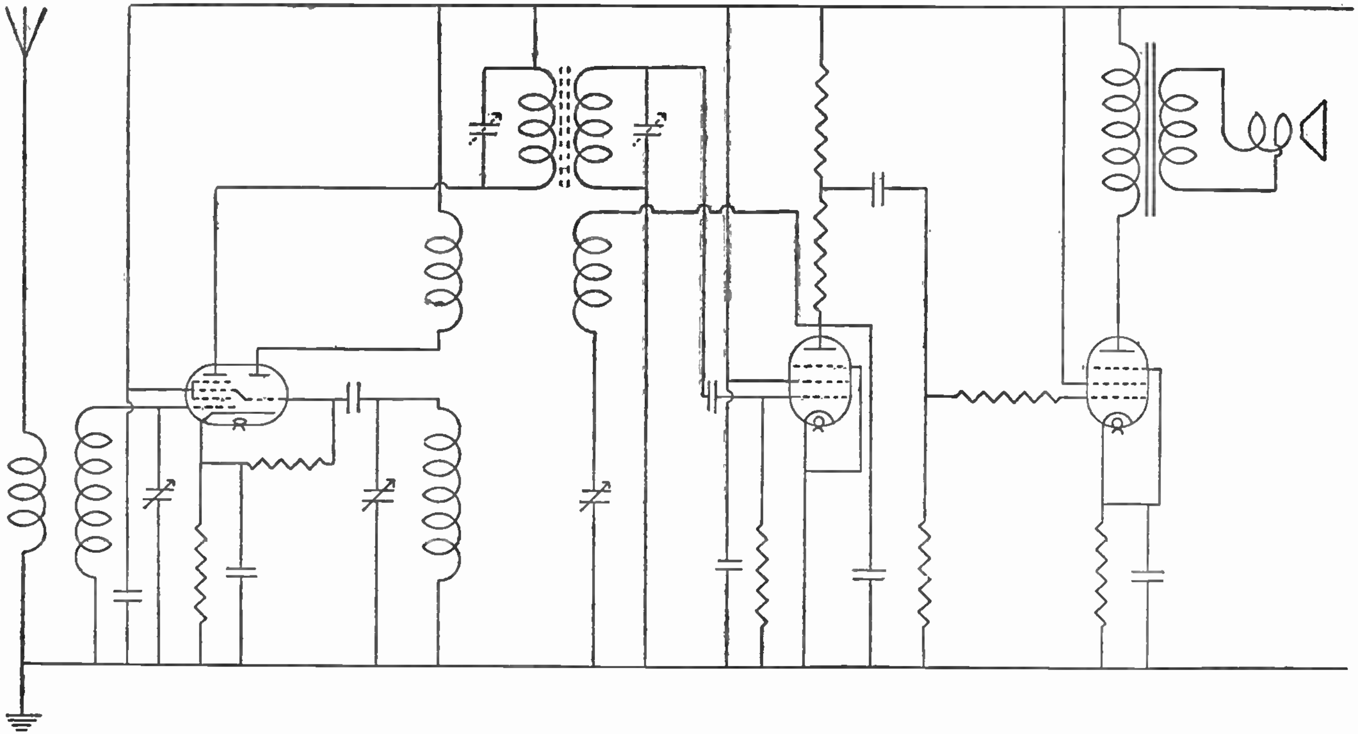


Fig. 30.—An alternative way of arranging a three-valve superheterodyne receiver. Note that no intermediate-frequency stage is used. Circuits of this type are used in midget receivers.

arranged ; the use of a high intermediate frequency on the short waveband separates the fundamental frequency from the image frequency to such an extent that the two do not fall within the compass of the sam

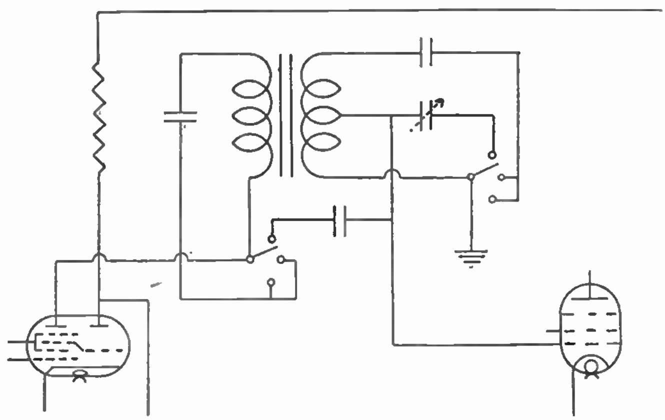


Fig. 31.—A special type of intermediate-frequency coupling, giving alternative intermediate frequencies.

waveband, thus avoiding the annoyance of powerful stations being received at two dial settings, a condition which obtains with low intermediate frequencies.

CHAPTER 6

AERIALS, EARTHS, AND NOISE SUPPRESSION

During the last 20 years the aerial and earth system has been relegated to a position of minor importance, although there is now a tendency to pay more attention to this part of the receiver equipment. It is probably not an exaggeration to suggest that a million listeners who are a little disappointed or a little dissatisfied with their receivers could be made happy by an intelligent aerial system.

Many thousands of people who should be better informed are under the most erroneous impression that the greater the gain of the receiver the more inappropriate may be the aerial. True, this idea holds good if results are judged by sheer noise, but if good reception is required, free from interference caused by local electrical machinery, it follows that an increase in receiver sensitivity calls for more care in aerial design in order that the signal to noise ratio may be favourable.

The numerous transmitting stations of the British Broadcasting Corporation are relatively powerful and close together, with the result that good reception can usually be obtained from the nearest of these stations when using a metal plate inside the cabinet or a few feet of wire. An entirely opposite set of circumstances is presented by the requirements of short-wave reception, where the desired station may be 5,000 miles, or more, away. FM reception requires adequate aerial arrangements on the outskirts of the service area, see Chapter 29, Vol. 1.

Before going deeply into the question of the several types of aerials and the various systems for reducing electrical interference, it is desirable to establish a clear understanding of its requirements. The *ideal* aerial system will be extremely efficient as a collector of energy radiated from transmitters, and entirely incapable of inducing any other form of radiated energy into the receiver: the first-named requirement can usually be achieved by making the aerial of adequate size and maximum height, but the second requirement presents considerable difficulty. The chief source of unwanted energy is that radiated by electrical machinery, which may be conveniently called man-made static, to distinguish it from natural static—atmospherics—which cannot be eliminated by aerial design.

Man-made static can appear in the aerial system from two prime causes: direct radiation from the source of interference, and interference conveyed to the site along electric-lighting wires, or similar means, and thence radiated to the aerial. Direct radiation is difficult to check, although there is one system at least which will combat it successfully; this system, curiously enough, is more efficient when the interference source is very close than when it is relatively distant. Interference carried by the mains, termed mains-borne interference, can be controlled by means of a suitably designed aerial system—comprising an aerial erected as clear as possible from the mains and led to the receiver by a screened downlead, as described below.

The Standard Aerial.—The standard L-type aerial is so familiar that some apology is necessary for mentioning it, but this course is rendered desirable as a preliminary step towards describing the modifications for eliminating mains-borne interference. Fig. 32 shows the conventional L-type aerial, although it shows points of refinement that are rarely seen at the average dwelling-house. It will be noted that the downlead end of the aerial is supported by the highest point of the building, which will have the combined advantage of keeping the aerial as far as possible from fields of mains-borne interference and make the downlead as long as possible. It may also be observed that the downlead, which marks the termination of the aerial, is some 10 feet or so away from the house, allowing the downlead to approach the house at some little distance, so that its whole length is not actually in the strongest areas of interference. It will be realised that the average house is wired so thoroughly, that the outer walls and the roof may be considered as radiators of mains-borne interference or, more correctly speaking, the wiring attached to them may be considered in this manner. In addition to the interference borne by the mains, a considerable amount of partially earthed metal work must be taken into account, such as water pipes, gas pipes, etc., which can reduce the efficiency of an aerial if placed too close to them.

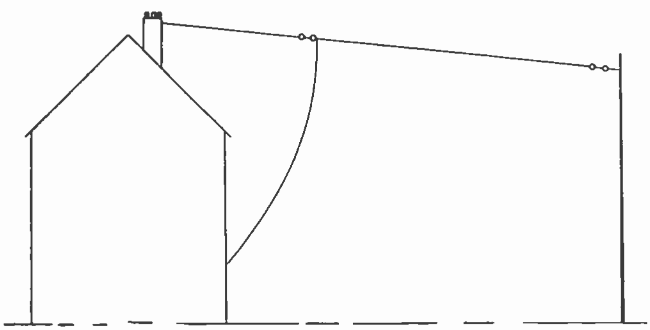


Fig. 32.—A typical L aerial.

The L aerial exhibits some directional properties, and is most efficient when the downlead is pointing towards the transmitter. In principle, therefore, the aerial downlead should point towards Central Europe, America, or wherever maximum reception is desired. In practice, however, the aerial will usually run down the length of the garden and point whichever way the house faces. Fig. 33 shows an L aerial fixed between two masts and possessing much greater effective height and, consequently, greater efficiency than the arrangement shown at Fig. 32. This arrangement is a little costly, but actually the difference in expenditure is not serious if a pole has to be purchased for the down-the-garden type. It also has the advantage of offering the choice of at least two directions, and, with a little ingenuity, the choice of several more.

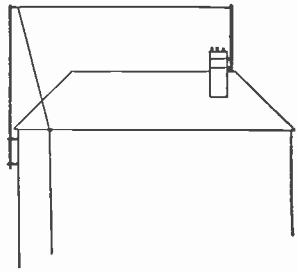


Fig. 33.—An L aerial mounted above the roof to give increased effective height.

It should be understood that the relatively large aerials referred to above are in themselves inherently fairly efficient and, furthermore, continue to fall into this category as part of the equipment of a modern superheterodyne, which is so designed that selectivity is not noticeably influenced by the amplitude of the input; it must be realised, however, that midget and *three-valve straight receivers* require rather different consideration if situated within, say, 20 miles of a powerful station, since they are insufficiently selective to cope with the large input, and give better results from the selectivity point of view with very short aerials. Such a receiver situated within, say, a mile of a powerful B.B.C. station may call for an aerial of less than a dozen feet in length if the three principle programmes are to be separated. It is desirable to mention that the expression "efficient" aerial is intended to convey the performance of the aerial quite apart from the requirements of those receivers which are incapable of dealing with reception conditions in the district in which they are used.

A glance at a few out-of-date popular textbooks will reveal a surprising number of different aerials, such as the T-type aerial with the downlead taken from the centre; the multi-wire aerial, which is intended for transmission; and various other modifications, none of which are worthy of further comment. There is one type of aerial, however, that calls for special attention, and that is the vertical aerial.

The vertical aerial has enjoyed a following for many years on account of its low capacity, and some twenty years ago specialised forms of vertical aerials made their appearance, consisting of cage-like structures, metal spheres, and even "brushes" intended to be supported on a pole fixed to the chimney-stack. These devices enjoyed a certain amount of popularity, primarily due to the ease of obtaining considerable effective height; it will be realised that such an aerial erected on a mast some fifteen feet in length strapped to the chimney-stack would naturally give better results than an L-type aerial attached directly to the chimney-stack. The same remarks apply, in substance, to a simple vertical wire fixed to the top of the mast. In the early days of broadcasting most remarkable forms of pole-top aerials were devised, without proper regard to their true efficiency.

The Sky Rod Aerial.—The strange vertical aerials referred to above have given place to a simple form of vertical aerial which makes a real contribution to aerial efficiency. It consists, in principle, of a metal rod, which may be fixed by an insulated bracket to the chimney-stack, as shown at Fig. 34, or attached to a mast as shown at Fig. 35. In either case the arrangement provides an aerial which achieves, automatically, maximum possible effective height with maximum freedom from mains-borne interference and, incidentally, possesses the attribute of neatness. The advantage of such an aerial being placed outside the field of mains-borne interference is lost if the downlead passes through it, but this difficulty can be overcome, as described below.

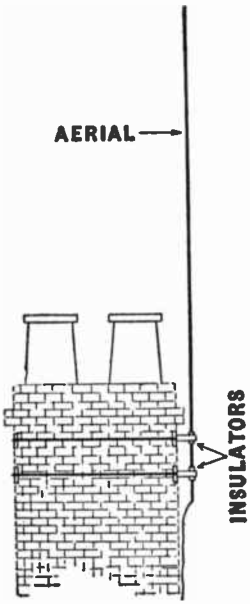


Fig. 34.—A vertical aerial.

Special aerials for short-wave reception, such as the dipole aerial, receive attention in a later chapter, but the various freak aerials which are offered to the general public can best be ignored.

Screened Downleads.—A glance at Figs. 33, 34, and 35 will show that the actual aerial is sufficiently remote from the building to be either outside the field of mains-borne interference or at least in the area where such interference is very greatly attenuated and, in order to preserve this advantage, it is necessary to lead the aerial to the set in such a manner that mains-borne interference will not be picked up by the downlead. This could be accomplished by using a screened downlead, *i.e.* a suitable conductor running through a densely woven metal-braided tube, which could be so designed that the inner conductor is separated from the outer screen by an air space with only an occasional insulated ring or loose cotton packing to hold the two or more components in position. Unfortunately, the capacity of such an arrangement would introduce very serious losses to which some dielectric losses would be added. Furthermore, the impedance of such a conductor would be very low, perhaps only 100 ohms, resulting in most unfortunate mis-matching; the load imposed by such an input arrangement would have such an adverse effect on the tuned circuit that any good qualities it might possess would be rendered completely valueless.

The low impedance of the screened downlead can be dealt with by the use of matching transformers, which will normally be placed between the aerial and the screened downlead and also between the screened downlead and the receiver. These transformers are so designed that the


Fig. 35.—A vertical aerial mounted on a mast to increase the height.

impedance of the screened aerial downlead is raised to the impedance of the aerial at one end, and the approximate impedance of the receiver input at the other end. Such transformers call for careful design in order that they shall be free from frequency discrimination. It is sometimes considered necessary to provide the lower transformer with a waveband switch, so that appropriate coils are brought into circuit; the aerial transformer may be double wound or of the auto-transformer type, but in either case it is provided with an earth connection, the most usual arrangement entailing the use of a conductor with two inner wires within the metal braiding; thus the aerial and braiding are connected to either side of the primary and the two inner wires to the secondary (see Fig. 36).

Fig. 36.—A section of twin screened feeder with each layer cut back to show the construction.

The aerial transformer is usually provided with means to attach it to the aerial, or it may be so constructed that it forms one of the aerial insulators, a purely mechanical refinement. For use with sky rod aerials, special types are available which fit to the lower end, making a very neat assembly.

Downlead Impedance.—Considerable confusion appears to exist regarding the whole question of twin or concentric downlead impedance. Many appear puzzled by the reference to a stated impedance irrespective of the total length of the cable. It should be understood that, within limits, the impedance of a feeder is independent of total length. The impedance is controlled by the ratio of capacitive reactance to inductive reactance and may be most easily determined by dividing the mean distance between the conductors by the radius of one of the conductors, the actual impedance of a twin downlead being obtained from the following formula:

$$\frac{276 \log_{10} \frac{2D}{d}}{\sqrt{K}}$$

when d is the diameter of the wire, D the mean distance between the two conductors, and K the effective dielectric constant of the material surrounding the conductors.

The above formula is for twin conductors placed parallel in space, *i.e.* without metal braiding, and is approximately correct for frequencies between 40 mcs. and 300 kcs. The calculation of the impedance of a braided conductor becomes somewhat complicated, as it entails consideration of not only the size of the braid but the disposition of the conductors within it. It is usually more convenient to arrive at the impedance of such a cable by measurement, but the method of calculating the impedance may be found in the several books which are almost entirely devoted to this subject. The impedance of a concentric downlead may be determined from the following formula:

$$\frac{138 \log_{10} \frac{D}{d}}{\sqrt{K}}$$

when D equals the internal diameter of the outer conductor and d is the diameter of the inner conductor.

The formulæ mentioned above ignore resistance, since this factor is unimportant in lengths of cable likely to be used as aerial downleads at frequencies between 40 mcs. and 300 kcs., bearing in mind that the diameter of the conductors will be fairly large for mechanical as well as electrical reasons. With suitable transformers, a non-screened twin cable may be used, providing it is terminated by a coupling coil which is earthed at the electrical centre and separated from the grid coil by an earthed capacity-shield. This arrangement is necessary so that the interference picked up by the two leads may appear in phase opposition across the coil.

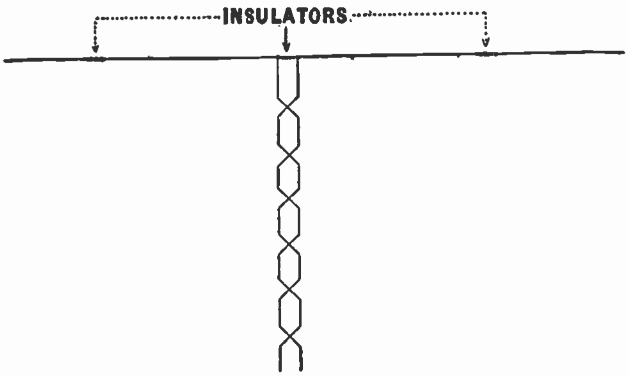


Fig. 37.—A doublet aerial.

The Doublet Aerial.—Fig. 37 shows a doublet aerial which consists of two arms which are led separately to the receiver by separate conductors, the twin downlead being called a feeder. This type of aerial is extremely useful when reception is required from a single high-frequency or narrow band of frequencies, but is inefficient at frequencies removed from that to which it is tuned. The natural wavelength of such an aerial may be determined by the following formula:

$$\lambda = \frac{L}{\cdot 48}$$

when λ is the wavelength in metres and L the total length of the two arms in metres, assuming a small gap between wires. For reception of the B.B.C. V.H.F. stations, each arm can be 32 inches long. The doublet aerial is highly directional, although it is obviously capable of receiving at maximum efficiency from two opposed directions, since it is a symmetrical structure. Its efficiency is maximum when at right angles to the transmitter. Consideration of the above formula will show that the doublet aerial is normally limited to use on the short waveband, as its size becomes somewhat impracticable for the lower frequencies. It is intended that the two inner ends be connected to the opposite ends of a coil, the centre of which is preferably earthed. It is a matter of simple switching to arrange for the two ends to be connected together, and to one end of a coil, when working on medium or long waves, so that the aerial acts as a normal T-type aerial when working on these wavebands; and, although not very efficient, on account of the small dimensions, it is nevertheless far more satisfactory than using the aerial as a doublet.

Transposed Feeder Wires.—It is intended that a doublet aerial should be led to the receiver by means of conductors which are incapable of picking up energy, and a low-loss 70-ohm twin feeder is satisfactory up to 100 mcs. or, alternatively, transposed feeder wires may be used and may also act as a normal aerial on other bands. This arrangement consists of a pair of ordinary conductors laid parallel, some 2 inches apart, for a short distance, crossed over and led for a similar distance, and crossed over again *ad infinitum.* Fig. 38 shows the arrangement of a transposed feeder and typical insulators designed to facilitate this arrangement. It is equally possible to lay the feeders side by side and separate them by insulating struts, but, owing to their displacement in space, they may not pick up the same amount of energy, with the result that unwanted interference will appear across the aerial coil in phase but not necessarily at the same amplitude; consequently the energy picked up by the feeder lines will not be entirely balanced out. The formula given on page 71 may be used to determine very approximately the impedance of a transposed feeder. It is obviously not quite accurate, owing to the effect of the numerous transpositions, but is nevertheless sufficiently accurate to give a rough idea.

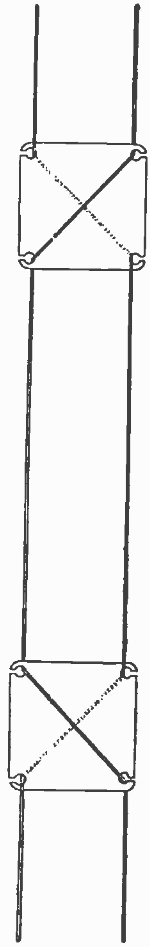


Fig. 38.—Enlarged view showing a section of a transposed feeder. Note the special insulators employed.

It should be clearly understood that the impedance of the feeder from a doublet aerial should match the impedance of the aerial at the point of connection. The impedance at the centre of a half-wave doublet is approximately 70 ohms, whereas the impedance of a normal transposed feeder will be several times this figure. It is apparent, therefore, that connection should not be made to the extreme inner ends of the aerial. When the loss associated with twin and concentric cable is not considered a serious obstacle, this cable can be used (having a characteristic impedance of 75 ohms), connection being made direct to the inner ends of the aerial.

Interference Suppression.—The screened downlead aerials described above may be considered as systems for the elimination of interference, but are ineffective when the field of interference is so great that it is impossible or impracticable to erect an aerial that is clear of it. Such a difficulty can arise when the aerial is situated close to a building using a number of electric motors. Several means have been put forward for suppressing such interference, the most interesting of which is an arrangement using the inherent phase-changing properties of a valve. Fig. 39 shows the arrangement of a suppressor valve and twin downlead which consists of two wires laid parallel and about ½ inch apart, one of which is attached to the aerial in the ordinary way and is referred to as a downlead, while the other one is left open circuit at the top and is referred to as the extra downlead. It will be observed that the aerial is connected to the grid of the valve, and the extra downlead to the cathode. The aerial circuit is completed by means of a variable resistance R_1, while the extra downlead is provided with a load R_2, which also acts as the bias resistor. Note particularly that the usual bypass condenser is absent.

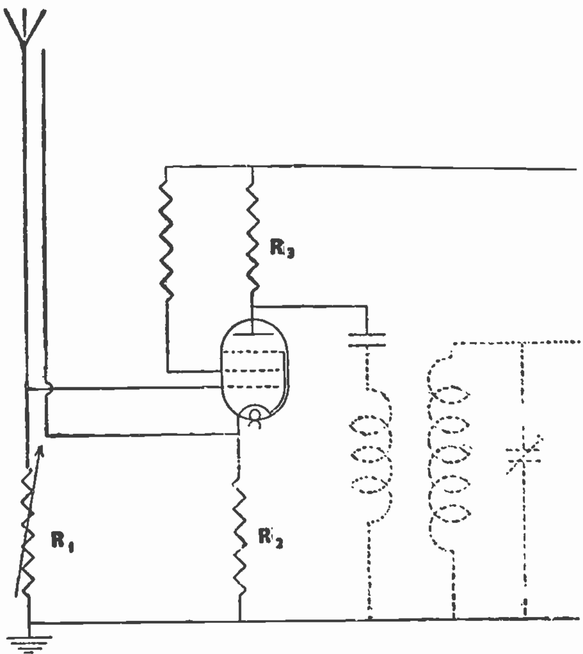


Fig. 39.—The circuit arrangement of a local interference suppressor, which utilises the phase-reversing properties of a valve.

The effect of the grid and cathode upon anode current is directly opposed. For example, if the grid is driven *negative*, the anode current is reduced; and if the cathode is driven *positive*, the anode current is also reduced. It is apparent, therefore, that similar inputs to grid and cathode will result in the anode current remaining unchanged; consequently, if R_1 is so adjusted that it is equal to R_2, then energy picked up by the two downleads will have no effect whatever on the anode current and no signal or other alternating voltage will appear across R_3.

It is apparent from the above remarks that when R_1 is equal to R_2 the downlead behaves as though it were a screened downlead. The arrangement shown at Fig. 39 goes a step farther—it relies upon the realisation of the fact that the field of *very-local* interference is so distributed that it induces more current per foot at the bottom end of the downlead than at the horizontal portion of the aerial. By suitably adjusting R_1 in relation to the voltage due to interference it is possible to cancel out the interference and leave the signal energy to appear equally across R_1 and R_2, and zero across R_3.

It is apparent that R_1 could be so adjusted as to allow just the right amount of interference to appear across R_3 to cancel out, ultimately, direct mains-borne interference *from the same source.* It has been stated above that the grid and cathode are exactly out of phase in respect to the anode current, and some qualification is necessary, since it is only true to refer to the phase as being exactly opposite when the frequency is so low that the valve capacities may be considered to have infinite reactance. In practice the phase relationship is sufficiently close to 180 degrees when using a triode valve for the device to work up to about 1,500 kcs. per second (200 metres), but by the use of a pentode valve the range may be extended to about 2,000 kcs. per second (150 metres). This improvement is brought about by a certain amount of incidental negative reaction consequent upon the load R_2 appearing in the cathode circuit without the usual bypass capacity. It is apparent that a valve must be chosen which will work with the bias resistor having a value that is not unsuitable to act as an aerial load, since for normal conditions R_1 will be so adjusted that it is of the same order as R_2.

The Frame Aerial.—The frame aerial is familiar as part of a portable receiver. It consists of a number of turns of wire on a frame which is usually square or rectangular. The frame aerial is highly directional, and is used in certain direction-finding systems where it is usual so to orientate the aerial that the station to be located is heard at minimum strength, since this position is more easily determined than the point of maximum strength. This type of aerial possesses advantages for use where an outdoor aerial is impossible, as its signal to noise ratio is more favourable than the more usual form of indoor aerial ; owing to its high inductance it cannot be connected to the average receiver, as it would be necessary to attach the ends to the aerial and earth terminals respectively, which would form two inductances in parallel and hopelessly misgang the aerial circuit.

Mains Aerials.—The average mains will act as a reasonably good collector of energy. Unfortunately they are equally efficient as collectors of interference from electrical machinery ; nevertheless, such an aerial may give satisfaction in districts that are electrically " quiet " or in districts that are so close to a powerful broadcasting station that a suitable signal to noise ratio is obtained.

A mains aerial may consist of a very small condenser, usually about ·0005 μF, connected between the aerial terminal and one of the mains leads. With this arrangement results are sometimes more satisfactory when the mains plug is inserted a certain way round in its socket. An alternative, which is perhaps a more popular arrangement, consists of a length of insulated wire, about 3 feet long, connected to the aerial terminal and intertwined with, but not connected to, the mains lead.

Makeshift Aerials.—Occasions may arise calling for use of a very temporary aerial, and there is no limit to the items which may be pressed into service to act in this manner. Popular ideas include spring mattresses, curtain wires, lead roofs (when they are reasonably well insulated from earth). There is, however, one possibility that deserves to be better known, which consists of making connection to a suitable metal plate and simply standing the telephone on it, sufficient capacity existing to make use of the energy picked up by the telephone wires. It will be understood that any direct connection would be illegal.

The Earth.—The earth connection is intended to provide a point of zero potential for the purpose of "tying down" the aerial system so that the maximum potential difference is obtained across the aerial coupling and to "tie down" certain other parts of the receiver to achieve stability. The author has had too much practical experience to offer any of the advice often given regarding the burying of a metal sheet about a yard square, not less than 3 feet deep. Such a procedure necessitates the lifting of nearly half a ton of earth. For those concerned with the practical aspects of making an earth, a decent connection to a *main* water pipe or connection to a copper earth-tube must suffice. It is, however, desirable that the earth lead should be as short as possible, and be of reasonably heavy gauge wire. For short-wave reception the earth connection is more important; with centre-tapped aerial coupling coils a good earth is necessary to balance the various twin downlead systems.

The earth connection often makes little or no difference with a mains receiver, due to the very great chassis-to-earth capacity which exists via the mains.

The Counterpoise Aerial.—The counterpoise aerial may be defined as an aerial laid near to the ground and preferably similar to and underneath the normal aerial. This arrangement is sometimes beneficial when the earth lead allows the entry of electrical interference. It also has special uses, such as in deserts, where an earth connection is impossible owing to the ground being non-conductive.

Mains-borne Interference.—Several systems have been described in this chapter for eliminating mains-borne interference radiated from the mains to the aerial. It is apparent that such precautions are useless if mains-borne interference is allowed to reach the receiver directly through its mains connection. Details of shielded transformers and mains filters are given in Chapter 1 of this volume; either or both of these devices can be used to prevent direct mains-borne interference.

Atmospheric Suppression.—Many attempts have been made to devise circuits capable of eliminating atmospherics, but little success has attended the efforts; there are, however, a number of means of making the effects of atmospherics less unpleasant by limiting audio output for the duration of bad static.

Fig. 40 shows a typical static-suppression circuit. It is particularly useful for illustrating the principle, since most systems employing valves are arranged on similar lines, but differ inasmuch as they employ noise amplifiers and other devices to increase efficiency, although such elaborate systems are not incorporated in ordinary broadcast radio. It will be noted that the diode valve has two separate cathodes, which is an essential part of the system. The diode D_1 is the normal detector diode, and is connected to the input circuit and the diode load resistance R_1. Under normal conditions the anode and cathode of the diode D_2 are at the same potential, and the diode is non-conductive. A sudden change of voltage, such as that occasioned by static, will drive the cathode of D_2 negative, although the anode will not change its potential owing to the time-constant of R_2 and C, which may have values of 1 MΩ and 1 μF respectively. When the cathode is driven negative in respect of the

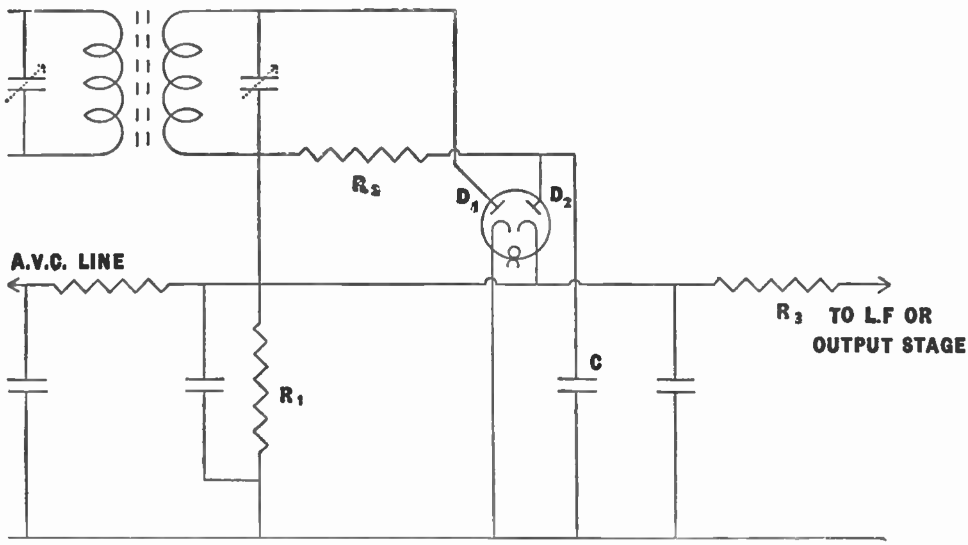


Fig. 40.—Typical static-suppression circuit.

anode, the diode becomes conductive and may have an impedance of the order of 1,000 ohms; thus the diode load is in effect shunted by the low impedance of the diode, in series with the low reactance of C, with the result that the audio output is greatly attenuated. The inclusion of a resistance R_3 will cause the audio output to be attenuated to a negligible value when D_2 is conductive, but has little effect when D_2 is non-conductive. With the circuit shown at Fig. 40 there is some danger of distortion on deeply modulated signals. This may be overcome by taking the lead at present joined to the top of R_1 to a suitable tapping, say, half-way down R_1. It will be observed that provision is made for automatic volume control in the circuit shown, this has been introduced by connecting the automatic volume control line to the top of R_1, the usual time-constant circuit being, of course, introduced.

The circuit shown above is one of many possible arrangements ; such circuits are not used to any great extent in British receivers, but are widely used in America, a large area of which is prone to atmospheric disturbances of an amplitude and duration rarely experienced in this country.

In certain localities, particularly near the Equator, some arrangement is practically essential, as without some limiting device, atmospherics would be reproduced at a volume capable of damaging a loudspeaker; when headphones are used in such areas it is absolutely imperative to employ a limiting arrangement to protect the operator from injury to the ear.

CHAPTER 7

CAR RADIO

DURING the last few years remarkable strides have been made in the development of car radio, and to-day it is possible to really enjoy reception while travelling at speed. It is undoubtedly true to consider car radio as new, from the point of view of efficient and practical apparatus; the idea, however, is far from new. The author was associated with car-radio experiments as long ago as 1925, and personally equipped a car which travelled to Edinburgh and back, and succeeded in obtaining loudspeaker reception from at least one broadcasting station over 90 per cent. of the mileage covered.

A car-radio receiver is fundamentally similar to the ordinary domestic type, but differs in certain details, and incorporates a specialised form of power supply. The experimental car radio referred to above derived its low-tension supply from the car lighting battery but employed an ordinary high-tension battery in addition. This arrangement has been used in at least one of the car-radio receivers offered for sale during the last few years, but it constitutes an exception, since the standard modern car radio employs means of obtaining a suitable high-tension voltage from the low-tension accumulator; thus the equipment is entirely independent of batteries, with the exception of the car battery, which must obviously be carried for reasons quite apart from radio.

The Power Unit.—It is apparent from the foregoing remarks that the power unit forms an essential and important section of car-radio equipment, and calls for detailed consideration. The fundamental principle employed is to convert the car accumulator current into alternating current by means of an interruptor which will make and break the circuit or, in more advanced types, make, break, and reverse the circuit. It should be understood that the waveform of the current produced in this manner does not bear the least resemblance to a sine wave, but it does possess continuous change of amplitude permitting the available voltage to be stepped up by means of a transformer.

Fig. 41 shows the full circuit of a typical power unit, while Fig. 42 shows a typical vibrator which forms an essential part of it. Reference to this latter illustration will show that the vibrator consists of an electro-magnet and an armature which is attached to a flexible steel blade, arranged so that the armature may travel approximately at right angles to the pole-piece of the magnet. The illustration shows the armature at rest, and it will be noted that while at rest it is out of line with the pole-

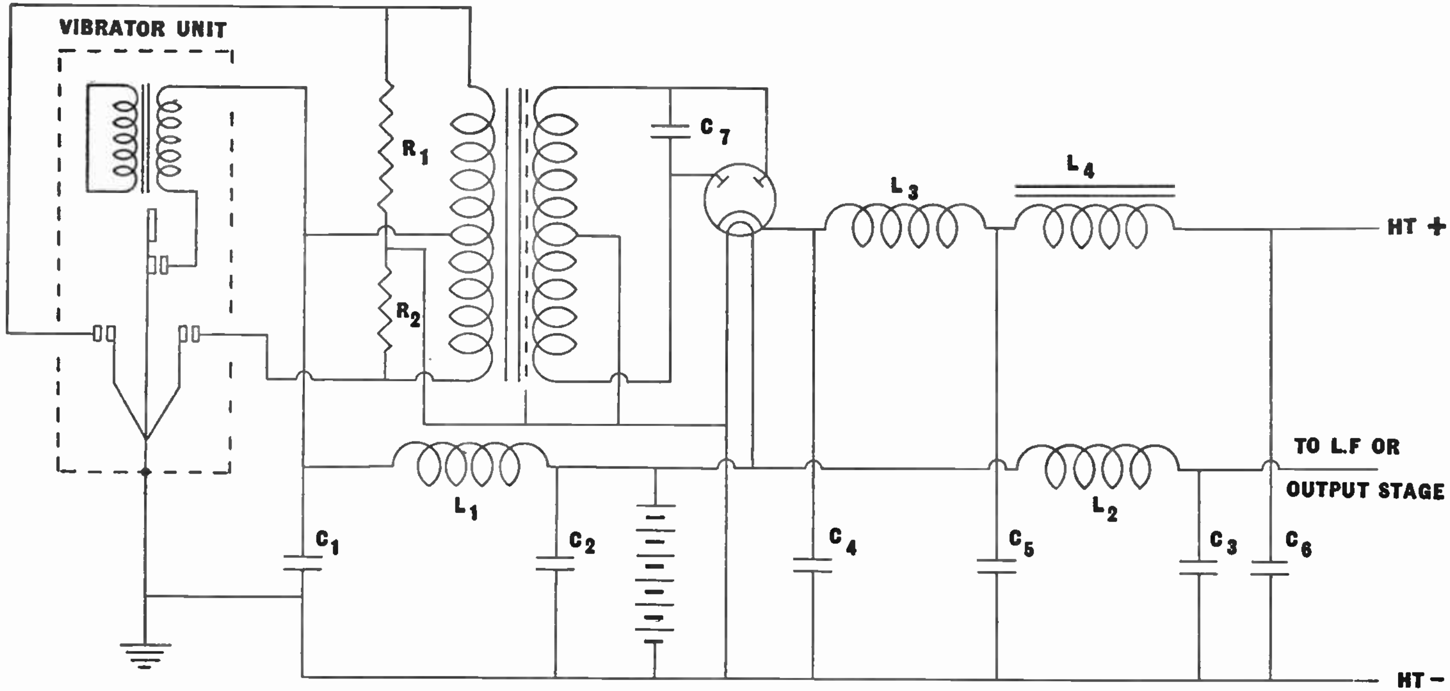


Fig. 41.—A simple car-radio power unit.

piece. The central blade is provided with a contact through which current must pass to the magnet coil. When the device is switched on the electro-magnet pulls the armature across, and in so doing breaks the circuit with the result that the spring returns the blade to its original position, while momentum makes it travel for nearly a similar distance beyond. On returning to its dead-beat position the contacts come together and the cycle is repeated.

The blade is provided with two further sets of contacts, both of which are open when the blade is in the dead-beat position, but the gap is sufficiently small to permit of each pair of contacts coming together as the blade swings in each direction. These contacts make and break the current from the accumulator, and provide the necessary alternating current.

Reference to Fig. 41 will show that the twin contacts are connected to each side of the primary, the centre of which is connected to low-tension positive; the middle blade is connected by way of the chassis to low-tension negative. It may be seen by tracing the circuit that each pair of the twin contacts will allow current to pass through the primary in a different direction. These components complete the primary circuit, with the exception of precautions to stop arcing at the contact points, which take the form of resistances R_1, R_2 over each half of the primary which have the low value of about 100 ohms each, and will therefore effectively prevent a surge voltage from being built up. To prevent arcing between the contacts which maintain the movement of the blade, recourse is made to a closed circuit winding coupled tightly to the electro-magnet winding, which very effectively damps the circuit and prevents a surge voltage appearing across these contacts. The earlier type of vibrators used the same contacts for making and breaking the primary circuit and the electro-magnet circuit, but this arrangement caused considerable trouble, as the comparatively heavy current caused the contacts to fuse together, under which condition the battery current would rise to some 35 ampères, which would ruin a battery in a few minutes unless the fuse burnt out and broke the circuit. Under normal conditions, when the vibrator is functioning correctly, the mean current is of the order of 4 ampères for a 12-volt battery. The separate contacts for

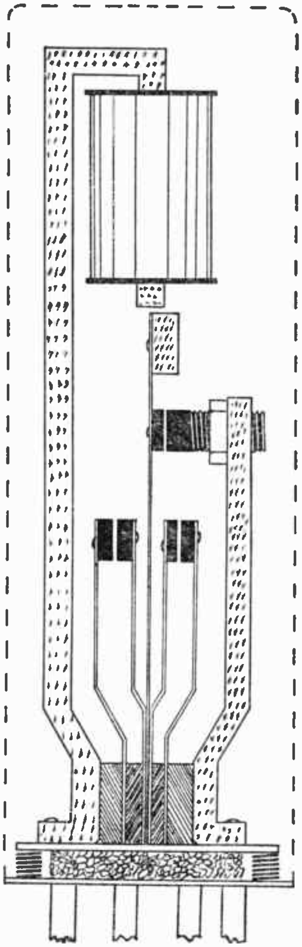


Fig. 42.—A simple vibrator. It will be noted that the whole assembly is mounted on springs which are mechanically damped by an inset of sponge rubber.

the electro-magnet circuit almost entirely overcome this danger, as they carry a current that is very small compared with the twin contacts; and there is little danger of these fusing together, as the blade is still free to move, and pulls on the shorter blade which gives sufficient leverage to break the contact apart. Consideration of the primary circuit may be completed by drawing attention to the filter circuit made up of the inductance L_1 and the condensers C_1 and C_2, which are intended to prevent radio frequencies generated as harmonics in the primary circuit from reaching the receiver. It will be noted that the shield is placed between the secondary and the rest of the transformer for the same purpose.

The secondary of the transformer will develop 300, or more, volts across the total secondary winding, which will produce a rectified voltage of 150 volts, or more. The outer ends of the secondary are connected to the anodes of an indirectly heated rectifier, the centre tap being connected to high-tension negative. It should be understood that the high-tension negative is in no way influenced by the polarity of the low-tension battery, which may be connected either way round in this circuit without making any difference to the output voltage. It is necessary to point out that the valves in the receiver are indirectly heated, consequently the polarity of the low-tension supply does not carry the effective high-tension voltage as it does in an ordinary battery receiver where the valves are directly heated.

It will be observed that a condenser C_7 is connected across the transformer secondary to limit the peak voltage, since the waveform across the secondary is such that the instantaneous peak voltage is exceedingly high when compared with the mean voltage; the value of this condenser is determined by the characteristics of the winding, but is often of the order of ·1 μF. It is interesting to note that the absence of this condenser will permit a serious modulation hum to appear in the receiver, since the filter, if of normal design, will be unable to attenuate sufficiently the peak voltage developed.

The air-cored inductance L_3 and the capacity C_4 form a radio-frequency filter, the coil, like L_1 and L_2 may consist of some 80 turns of wire wound in two or more layers, while C_4 may have a capacity of ·01 μF. L_4 is the usual iron-cored smoothing choke, and will normally have an inductance of from 5 to 10 henrys. The associated capacities C_5 and C_6 may have a capacity of 5 μF, or more, and may be of the electrolytic type.

The filter L_2 and C_3 is intended as a further precaution to keep the radio or audio frequencies from reaching the receiver; as already mentioned, I_2 may consist of some 80 turns of wire, but, in common with L_1, it must be made of heavy-gauge wire, usually 16 S.W.G., owing to the relatively heavy current that will be passing. C_3 may have a capacity of 1 μF.

The filters shown may be considered as the basic minimum likely to prove satisfactory in a modern car, and it is often necessary to add a further filter in the form of an inductance and associated capacity in the battery lead, which is not grounded to the chassis. This filter is invariably placed close up to the receiver, and its purpose is to prevent the battery lead from radiating.

The Receiver Circuit.—The receiving section of a car radio differs little from ordinary home radio, except that it must be designed to occupy minimum space and have very high overall gain, since the aerial efficiency is unavoidably low. High gain is also imperative, since the automatic volume control must be very efficient—as considerable fluctuations of input voltage must occur when the car passes between high buildings or under bridges and is shielded by other vehicles.

As already mentioned, the valves used are indirectly heated and are specially designed to occupy the minimum space and give maximum efficiency for a given heater wattage, since this last factor tends to limit the possible efficiency of the receiver. Some artificial limitations must be imposed by the current which the car accumulator can be expected to provide, bearing in mind that the accumulator will at times supply the car radio, the engine ignition system, the windscreen wiper, the side, head, and tail lamps, and such minor accessories as dashboard illumination. The average car-radio receiver is so designed that additional gain is obtained at some small expense in fidelity ; this loss is quite unimportant, bearing in mind that reproduction can never be comparable with that available from a similar home receiver, owing to the very poor acoustic properties which exist inside the body of a motor-car.

Ignition Interference.—The ignition system associated with the motor-car engine is capable of causing serious interference with reception, the extent of which may be readily appreciated when it is remembered that passing motor-cars may seriously interfere with an ordinary home-type receiver. It has been shown that under certain conditions the instantaneous peak current at the beginning of the discharge across a sparking plug may reach 100 ampères. In order to eliminate this form of interference in car radio it is usual to incorporate a suppressor system in the actual ignition circuit. In addition, some form of suppression is desirable in the receiver to deal with interference radiated from the ignition systems of nearby cars. In some receivers the latter form of suppression is relied upon almost entirely.

Suppression devices are used at various points, the first of which to be considered will be those associated with the ignition system. A special type of resistor is inserted in each sparking-plug lead close to the actual sparking plug. It may have a resistance of from 10,000 to 15,000 ohms and must be capable of standing the very considerable heat of the sparking plug and engine ; it is suggested that the ohmic values mentioned should not be exceeded, as high values are not necessary, but encourage the formation of soot on the sparking-plug contact points. If the ignition system employs a coil a suppressor must be inserted in the high-tension lead at the point where it enters the distributor ; it may have a value of from 10,000 to 15,000 ohms ; this resistance is omitted when magneto ignition is employed.

Suppression of the ignition system, whether magneto or coil, is completed by means of a condenser connected across the contact points. It may have a value of ·5 μF, and must be of special type owing to the considerable temperature of the engine, which will be in close proximity. Fig. 43 shows a typical condenser, one side of which is connected to chassis by means of its supporting clip, while the other end is provided with a pigtail for connection to the appropriate side of the contact breaker.

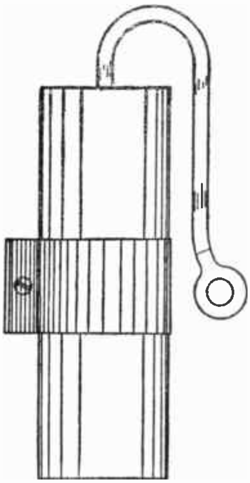


Fig. 43.—A condenser of the type specially designed for motor-car ignition interference suppression.

Interference may be caused by other electrical apparatus associated with the car, such as the charging dynamo, horn, petrol pump, windscreen wiper, self starter, and, when employed, the constant-voltage relay. Generally speaking, interference from these devices can be checked by a condenser such as that illustrated at Fig. 43, connected by means of its pigtail to the terminal that is not connected to chassis, the only exception being the constant-voltage device already referred to, which is sometimes singularly difficult to suppress and requires enclosing totally in a box made of metal perforated to give the necessary ventilation. When roof-type aerials are used, the value of the condenser indicated is seldom sufficient for the windscreen wiper, which may require a capacity of 12 μF or 25 μF. The condenser employed may be of the electrolytic type.

Static-suppression Circuits.—Innumerable possibilities exist for the suppression of certain types of static interference. Many take the form of reducing the gain of the receiver (or rendering the receiver inoperative) during the period of the actual disturbance. It will be realised, therefore, that these circuits can only be used to suppress static of short duration and relatively infrequent occurrence, such as ignition radiation from cars ; if such a circuit be used to suppress interference of a continuous nature, it would actually silence the receiver completely.

Some car receivers employ a most remarkable system, whereby advantage is taken of various peculiarities. For example, one type of car radio effectively suppresses interference by deliberately picking up interference and feeding it through a condenser to a critical point in the circuit, where it will appear out of phase with the interference voltage introduced via the aerial.

Car Aerials.—One of the greatest problems of car radio is the arranging of an aerial that is efficient and yet not unsightly. Fig. 44 shows a roof aerial which is efficient both from the point of view of energy picked up and reasonable freedom from interference radiated by the electrical equipment. The same remarks may be made about the aerial shown at Fig. 45, which differs only inasmuch as it may be considered preferable by some people purely from the appearance point of view. Connection is made to either type of aerial through one of the fixing screws by means of a screened lead to the aerial terminal of the receiver. For this purpose a special screened concentric cable is employed having a single conductor run through the middle of metal-braided tubing, spaced by some means which will reduce capacity to the lowest possible minimum.

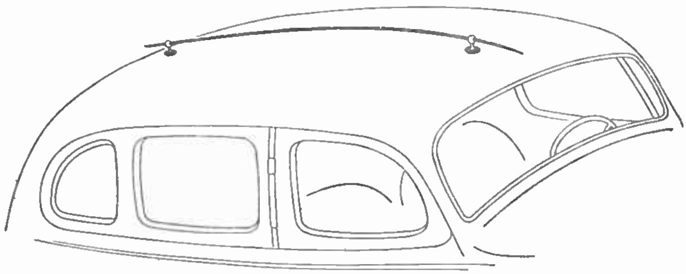


Fig. 44.—A roof aerial of the single-rod type.

Fig. 46 shows yet another type of aerial which has proved very popular, probably on account of its high efficiency. The upper half of the rod slides in the lower half, permitting the total length to be adjusted; this refinement may be looked upon as a convenient means of adjusting the aerial to a particular height determined by appearance or such exigencies as the garage roof. On the other hand, it may be looked upon as means whereby the aerial can be reduced to its minimum proportions if the car is normally used in a neighbourhood where field-strength is relatively high, but extended for exceptional occasions when the car is taken on a long journey away from the transmitter which it is desired to receive.

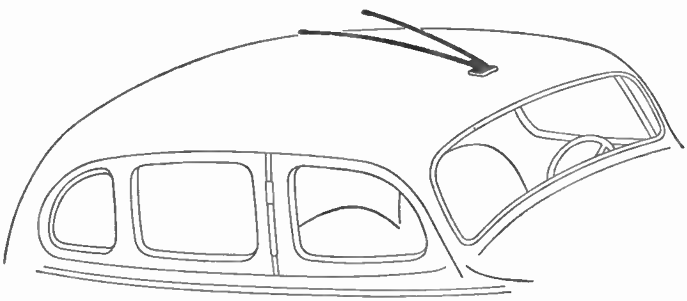


Fig. 45.—Another type of roof aerial.

When an external aerial is rejected on the grounds of appearance, it is usual to employ one of the several types of aerial intended to be fixed under the chassis. The most common example is a metal rod supported on insulators under one of the running boards; it is important that the aerial rod should be adequately spaced from the running board, which may result in the clearance between aerial and ground being reduced to dangerous limits. This difficulty has been overcome by designing the aerial in the shape of a miniature snow ski and mounting it on flexible rubber insulators so that it will yield immediately if it comes in contact with the ground while driving on a rough road. As an additional refinement this type of aerial may be obtained with dashboard control, permitting it to be raised or lowered for use on rough roads or good roads respectively.

Controls—Some form of push-button tuning obviously commends itself for car radio, as the driver will often desire to change the programme with the minimum of distraction from driving. The push-button or manual-tuning control and the volume control may be mounted on the actual receiver or extended by means of a cable to a remote-control panel which may be conveniently mounted on the steering column or elsewhere. Manual tuning and volume control are usually coupled between the remote-control panel and the receiver by means of the Bowden wire principle, but when press buttons are employed on a remote-control panel it is usually more convenient to accomplish the connection electrically.

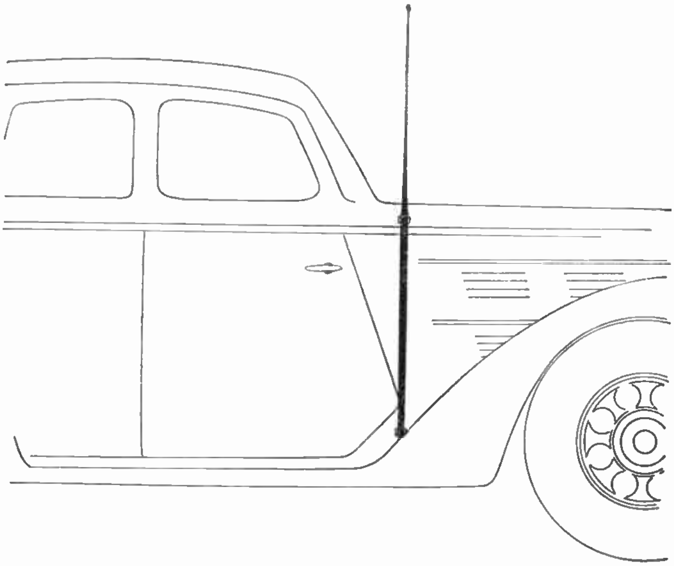


Fig. 46.—Telescopic vertical aerial.

Some receivers consist of two units, one containing the loudspeaker power pack and the bulk of the actual receiver. The other unit, which is usually very much smaller, contains the tuned circuits and the frequency-changer valve. It is connected to the larger unit by means of a multi-way cable of very special construction, various leads being independently screened as well as all the leads being run through an outer screened cable. It will be appreciated that several of the leads will be carrying radio frequency, while others will carry the high-tension supply to the frequency changer and possibly an automatic volume control line. It is also possible that the cable will carry a low-tension supply to the heater of the frequency changer, but this is often run as a separate lead, owing to the difficulty of eliminating ignition interference if one of the high-tension leads is in close proximity to a low-tension lead.

The smaller unit, which is usually referred to as the control unit or tuner unit, will almost invariably employ press-button tuning, since, in the absence of this refinement, there would be little justification for splitting the receiver into two halves, since manual tuning could easily be accomplished by means of a Bowden wire. The press-buttons may actuate a tuning condenser by direct mechanical means or may take the form of switches working in conjunction with permeability pre-set tuners. Either arrangement can be designed so that the buttons may be re-set, each by a single control from the front of the unit. It is generally considered that permeability tuning has the advantage of a degree of reliability which is not enjoyed by alternative systems, and is capable of tuning the station accurately and without readjustment throughout the course of many thousands of miles. The direct push-button operated mechanical systems have the advantage that any button may be set for any station whether on the long or medium waveband, but such examples as the author has had the opportunity of using have required some slight readjustment after a few thousand miles.

The possibility of employing pre-set trimming condensers cannot be entirely overlooked, but at the time of writing the author is unaware of any economic form of trimming condenser that will remain sufficiently constant throughout the considerable temperature-changes and continuous vibration to which any car radio must be subjected.

Car-radio receivers are available in a particular form, so that the main unit may be placed underneath the chassis. Such an arrangement commends itself for very small cars and for two-seater sports cars, where a radio unit might well prove inconvenient or even dangerous in the usual position. This type of instrument is also useful on very large cars of the limousine type, where accommodation is often restricted in the front compartment and the set is not wanted in the main compartment.

The principal unit is necessarily housed in a water-tight case of suitably robust construction and the actual receiver is usually suspended between rubber buffers as some measure of protection from such dangers as flying stones. The receiver is operated from a remote-control unit linked by either electrical or mechanical means; obviously, the loudspeaker must also be suspended and may be incorporated with remote control or comprise a separate unit.

Installation.—Some mention has already been made of the general principles of ignition-interference suppression, but these may be viewed in the light of a brief explanation. When the actual installation of a car radio is undertaken, a variety of difficulties may present themselves, including considerable ignition interference, even after the normal suppression arrangements have been fitted. Occasionally a car radio may be fitted, together with the simple suppression that has already been outlined, and the performance will be satisfactory. On the other hand, ignition interference is so bad on some motor-cars that complete elimination is seemingly impossible; before dealing with the more serious side of the installation problem it will be desirable to establish one or two points.

Earth.—The chassis may be regarded as the earth of the system as a whole and, on the average motor-car, the chassis will be in good electrical contact with all the larger masses of metal, due to deliberate contact being made for the purpose of forming an earth return for the normal electrical equipment. There are, however, a number of older cars still on the road, and one or two makes of modern cars that use two-pole systems for the headlamps and other accessories, in which case the electrical system will be insulated from the chassis. When fitting radio to such a car it will be necessary to earth one side of the system, after taking due precautions to be certain that an earth does not already exist either deliberately or accidentally. When making a test to ascertain whether or not the electrical system is in contact with the chassis it is necessary that every electrical accessory be switched on, and also the engine, to guard against the possibility that one or more accessories might be so connected or constructed that they earth the electrical system when in the " on " position only.

Large masses of metal, such as the body, are liable to cause difficulties if they are not in metallic connection with the chassis, while small pieces of metal may give rise to objectionable crackling noises if they make occasional or intermittent contact with any piece of metal which is, in turn, connected to the chassis. Such difficulties are seldom met with in the so-called " popular " make of cars, since the body is invariably riveted to the chassis and almost everything else is in turn riveted or welded to either body or chassis. The more exclusive types of cars may give rise to considerable difficulty, since the body and other metal parts may be bushed with rubber to prevent rattles and squeaks. There is at least one type of car where the four wheels fail to make any reasonably low-resistance contact with the chassis, the springs being mounted on rubber bushes and the engine being mounted on rubber; the only contacts existing, therefore, through such incidental connections as the hand brake cable and petrol pipe. In such cases it is necessary to earth the more important masses of metal. The actual engine of the small modern car is frequently mounted on rubber and may make indifferent contact with the chassis, in which case it is often essential to bond these two together.

Earth Bonding.—It should be clearly understood that earth bonding is seldom effective unless carried out in a really thorough manner. For this purpose wire may be regarded as useless, and woven copper tape having a width of at least half an inch may be considered as the only suitable conductor. If it is necessary to use a conductor of such low resistance, it is obviously necessary that it is terminated by the very best possible contact; most parts of a motor-car are extremely difficult to work on in comfort, and most parts under the bonnet are oily to a greater or lesser extent. These two factors are apt to result in an indifferent connection being made, and therefore emphasis is laid on the necessity for carrying out this part of the installation in a really thorough manner.

Preliminary Considerations.—Before taking initial steps, which may consist of fitting the aerial and receiver, it is well worth while to devote some time to considering precisely where these items can be located.

The position of a roof or side aerial is determined by obvious consideration, but the same remarks do not apply to the under-car aerial; the actual under-car aerial may be fitted with some special form of clip, enabling it to be directly fitted to the inside edge of the running-board or to some other horizontal projection (*see* Fig. 47). On the other hand, the aerial supporting pillars may be determinated by a simple lug or, alternatively, the car may not provide any suitable projection on which clips may be secured. In either case it will usually be necessary to make some form of bracket as a means of bolting lugs to the car. The nature of these will be determined by circumstances and the resources or equipment of the individual. A radio engineer may excusably be ignorant of automobile engineering, and a word of warning may not be out of place regarding the inadvisability of using existing bolts under which to clamp the aerial lugs or brackets. A body bolt can safely be used for this purpose, but it is inadvisable to use bolts associated with brakes or springing, unless the possible effects of so doing are either apparent or fully understood. The author is personally aware of a fairly serious accident which was caused by an under-car aerial being fitted under the nut on the end of a bolt holding a rear spring of the chassis.

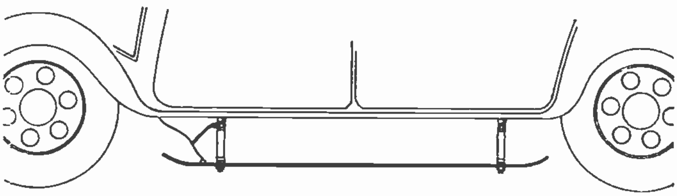


Fig. 47.—An under-car aerial.

The position of the aerial is of considerable importance, and, as already intimated, it should be fairly close to the ground. It should, for obvious reasons, be as far as possible from such fitments as the silencer or exhaust-pipe, and as far as possible from the car wiring; the latter consideration usually determines the position as being underneath the near-side running-board, since the car leads to the rear light, stop light, etc., are usually carried down on the off-side.

Although the converse might appear more logical, the aerial lead should be taken from the front end of the aerial and the aerial lead braiding should be earthed to the nearest practicable point. The importance of making good contact at this point cannot be over-emphasised, since freedom from ignition interference is literally dependent upon a low-resistance contact at this point.

The position of the receiver must be governed by considerations of comfort, but a choice of positions is usually available. Generally speaking, the best position is on the near-side of the car, attached to either the footboard or bulkhead (fire-screen). Alternatively, a suitable position may be found on the off-side of the car, although, on the average model, some inconvenience would be caused in the manipulation of the car controls. The centre of the bulkhead or underneath the centre of the dashboard may be considered as the least desirable position, as innumerable instrument leads, switch leads, and ignition leads are usually bunched together at this point and very serious difficulty may be encountered from ignition interference picked up from these leads. To summarise, therefore, it is apparent that on the average car the most practicable position for fitting the car radio is on the bulkhead, as close to the near-side as possible.

Some types of car radio are provided with a single large bolt and nut for the purpose of attaching to the bulkhead. It must not be forgotten that this nut supplies the earth return for the entire power-supply and also the earth return to the chassis from the high-frequency point of view. It is imperative, therefore, that the bulkhead should be scraped clean and bright for an area at least as large as the fixing nut or washer, if one is employed. If there is any doubt regarding the electrical connection between the bulkhead and chassis, the possibility of a bad earth should be avoided by clamping a piece of inch-wide woven copper tape under the fixing nut and connecting it in an equally efficient manner to the chassis. It is, perhaps, unnecessary to point out that the fixing nut cannot be satisfactorily screwed down on to copper braid, and that a brass or copper washer is interposed between them.

If the receiver is of the two-unit type with a tuning unit connected by electrical means, it will be necessary to determine the position with equal care. It is obviously intended that this unit should be placed in a convenient position, so that the stations may be changed while driving. On the other hand, this should not be interpreted in such a manner that the unit is placed in a field of high-interference level. It should not, therefore, be placed on the steering column or under the middle of the dashboard, for reasons that have already been mentioned. It may, however, be placed in the dashboard compartment immediately above the main unit or under the dashboard towards the middle, although not farther than necessary for the convenience of the driver. Generally speaking, it is not intended that the unit should be earthed to the metal-work of the car, but care should be taken to see that it does not make intermittent contact between the case and some metal object, which might well result in producing crackling noises.

Remote control actuated by mechanical means can be placed anywhere, so far as electrical considerations are concerned. It is important, however, that it should not be placed in such a position or at such an angle that the control cable is bent sharply, which would result in the control operating in a jerky manner and bring about a premature fracture of the inner wire.

Additional Suppression.—The standard suppression consists of a resistance in the lead between coil and distributor, a condenser between the live side of the coil and earth, and a condenser between the output terminal of the dynamo and earth. These points have already been mentioned earlier in the chapter, but some further remarks are called for, applicable to those occasions when such suppression is ineffective. It is probably true to say that any car can be satisfactorily suppressed without resistances in the sparking-plug lead. If, on the other hand, unlimited time is not available for experimenting, it will be desirable to fix such suppressors. The additional precautions are necessarily treated in a very general manner below, since the details must be dependent upon a large number of variable circumstances.

The ignition coil is usually strapped to the bulkhead, and in some types of car this results in a very long lead between coil and distributor, causing a high level of interference radiation which may be picked up by the aerial. One method of overcoming this is to move the coil nearer to the distributor; this may cause mechanical difficulties, and it is suggested that it is usually more convenient to screen this cable. While the usual type of metal screening (duly earthed) will suggest itself on the grounds of convenience, it must be pointed out that its screening properties are often inadequate, and in difficult cases it may be necessary to employ a brass or copper tube.

Motor-cars employing more than six cylinders invariably have long leads between the distributor and the outermost cylinders, which may cause serious radiation unless plug suppressors are used having a resistance greater than that recommended, and it may therefore be necessary to screen some or all of the leads in order to obviate the necessity for plug suppressors or permit the use of low-resistance types. For this purpose metal sleeving is perfectly satisfactory, providing it is reasonably densely woven. It is necessary that the sleeving should terminate an inch and a half before the plug terminal or distributor terminal, to prevent the possibility of a spark occurring between plug and sleeving which would cause the engine to misfire.

If a roof-type aerial is employed, interference may be picked up from the roof-light wire, which may carry ignition interference. The only cure for this trouble is a choke in the lead in question at a point remote from the aerial. It is assumed that the aerial circuit in the receiver will employ some form of choke capable of offering a high impedance to frequencies associated with ignition interference, but this will be insufficient to prevent ignition interference if the aerial pick-up is considerable.

When ignition interference fails to respond to the usual precautions, it is worth while reversing the low-tension leads to the coil, care being taken to transfer the suppression condenser to the other terminal, so that it is still connected to the live side. Before testing for ignition interference it is necessary to close the bonnet and secure it by the means provided. This precaution is particularly necessary if a roof aerial is employed. If interference persists, the bonnet may be opened and, if the trouble is not intensified, the fixing should be examined to ascertain if it is in electrical contact with the chassis. It is particularly important with the type of bonnet the top of which opens upwards, as in certain cases it rests on insulated material and the hinge is bolted to wood: if necessary the bonnet should be earthed by means of copper braid, which is, of course, flexible.

To ascertain whether interference is picked up through the aerial or low-tension wiring the aerial may be disconnected. If this test indicates that the interference is not due to aerial pick-up, attention may be directed to the low-tension supply-lead. It is customary to take this connection from the battery side of the ammeter or fuse-box, but when interference is known to be entering the receiver through this connection the lead should be carried straight back to the appropriate accumulator terminal. It is important that the lead should not run close to other electrical wiring, irrespective of whether connection is made to the battery or elsewhere. It may be necessary to employ a choke and condenser in this lead in addition to a similar unit which is usually fitted inside the actual receiver.

An additional cause of ignition interference arises in car-radio receivers employing a separate tuning unit, due to the multi-wave connecting cable picking up interference. It is necessary that this cable should be kept well clear of any other wiring, including the actual low-tension supply to the receiver.

Trouble may arise when a car is travelling along the road, although interference is entirely absent when the car is stationary with the engine running. This may be due to dynamo interference caused by increased engine speed, to intermittent contact between two pieces of metal agitated by road vibration, to wheel static, or, if the trouble is intermittent, it may be due to any of the electrical equipment, many items of which are suggested at Fig. 48. In every case a condenser may be connected across the component without interfering with this operation, and such precaution will usually prove adequate.

Interference from wheel static is easily distinguished by the fact that it is of a continuous nature and will appear when the car is running freely along the road with the engine switched off. The first point to receive attention should be the portions of the chassis adjacent to the brake-drums, which may be muddy and which, when dry, will set up friction between the brake-drum and the "cover plate" which is used to prevent the entry of water; this can be removed in the usual way. If this fails to effect a cure, attention may be directed to the possibility of an accumulation of powdered material rubbed off the brake linings during normal use. Removal of this dust usually requires the removal of the brake-drums, both drums and brake linings being cleaned with petrol. It should be noted that only the purest petrol should be used for this purpose, as any tendency to form a film of oil will considerably decrease braking efficiency. It is possible that wheel static may be caused by the edge of a brake lining rubbing on the drum; but this may not be seriously considered unless the brakes have been adjusted within, say, 1,000 miles before fitting the radio. Realising that brake static can be cured

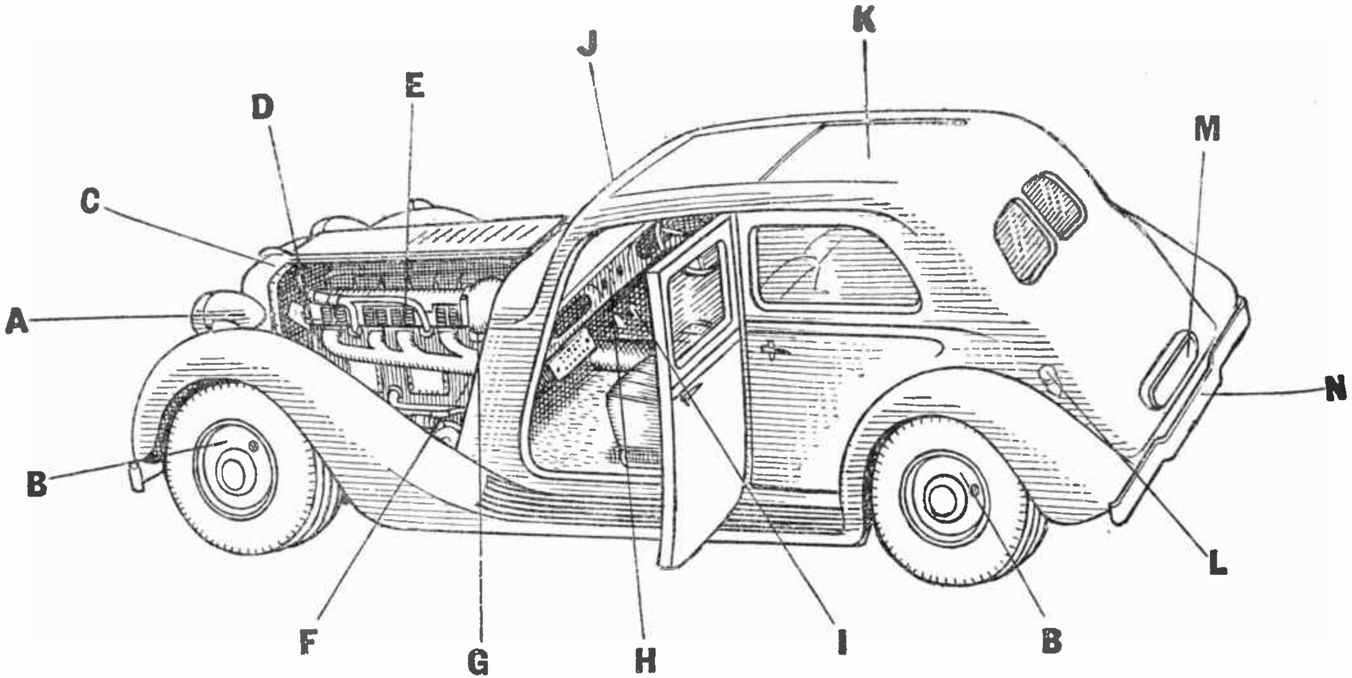


Fig. 48.—This illustration suggests some of the possible causes of car-radio interference, the actual interference being caused in most cases by bad contacts, resulting in a minute but more or less continuous arcing. (A) Headlight-dipping device. (B) Brake-drum static. (C) Radiator-temperature rheostat. (D) Fan-belt static. (E) Ignition system. (F) Dynamo. (G) Electric petrol pump. (H) Loose or dirty contacts on dashboard switches. (I) Brake-stoplight static. (J) Windscreen wiper. (K) Roof-light contacts. (This trouble is prevalent when a roof-type aerial is used.) (L) Petrol-indicator rheostat. (M) Stoplight switch (if remotely controlled). (N) Looseness of large pieces of metal, such as bumpers, mudguards, valances, etc.

by even a moderately low-resistance path between the brake-drum and chassis, engineers have suggested that the normal hub grease be replaced by a graphite compound grease. Admittedly, this will often considerably reduce the interference, *but it should never be put into practice without consulting the manufacturers of the car or a highly competent automobile engineer.* Graphite in certain forms has a pronounced tendency to creep, and may in the fullness of time work its way on to one or more of the brake linings, resulting in a very serious skid. It is, in short, a very dangerous practice.

General Remarks.—Before any elaborate precautions are taken it is usually worth while consulting the manufacturers of a car radio, the makers of the car, or both, as there are isolated cases of particular car models that cause interference in some quite unexpected manner or which call for some precaution of an unconventional nature which is not likely to be discovered until a considerable amount of time has been expended.

Occasion may arise when it is desired to fit a 6-volt car radio on to a car using a 12-volt battery. The practice is obviously wasteful, as half the wattage used will be dissipated in the resistance, but it is appreciated that many will be disinclined to purchase a new car radio when changing a car employing 6-volt equipment for one employing 12-volt equipment. It will be necessary to measure the exact current taken by the set and to place a suitable resistance in series. This will have to be capable of passing a high current and able to dissipate some 30 watts over long periods without over-heating. It is often difficult to avoid placing this resistance somewhere under the bonnet, and it should therefore be totally enclosed in copper gauze as a precaution against fire if the petrol pipe should become fractured. When practicable the resistance should be placed as far as possible from the receiver, and if modulation hum is apparent it should be shunted by an electrolytic condenser having a capacity of not less than 25 μF. It may be desirable to connect the condenser immediately across the resistance or from a point on the low-tension lead close to the receiver itself; the other end must, of course, be connected to earth and the correct polarity observed.

The average type of car radio works equally well irrespective of whether the car battery is earthed on the positive or negative side. If electrolytic condensers are used for any form of suppression, it is, of course, necessary to ascertain which side of the battery is earthed, in order that the polarity of the condensers can be correctly observed. Car radios employing self-synchronising vibrators in place of the more usual vibrator and rectifying valve call for some adjustment to be made, according to whether the positive or negative terminal is earthed.

CHAPTER 8

PRINCIPLES OF LOW-POWER TRANSMISSION

The technique of transmission is a very wide and complicated subject Reference has been made to the actual fundamental principles of both telephony and television transmission in the appropriate chapters. To deal with the subject of transmission in all its branches is quite impracticable and even undesirable, since the technique of high-power transmission can only interest the very small number of engineers who have access to such equipment. It is felt, however, that the very brief reference to transmission that appears in other chapters scarcely covers the subject in an adequate manner; for various reasons an increasing number of people are being brought into contact with small transmitters and communication equipment. Quite apart from the experienced amateur transmitters in this country, there are many who have occasion to use such apparatus in the services and elsewhere. It is thought, therefore, that the following brief outline of low-power transmission technique will not only serve as a means of illustrating the principles involved, but will also prove of genuine interest to a large number of readers.

The Oscillator.—There are many possible starting-points for a survey of transmission technique, but the oscillator seems a logical starting-point because it is the only part of a transmitter that is completely indispensable. It is the duty of the oscillator to produce the fundamental frequency, and with the aid of a morse key it is in itself a complete transmitter. The telephony transmitter must include as a basic minimum an oscillator and some means of modulating it. It will be realised that the oscillator will produce the carrier frequency, and it is the duty of the modulator to vary the amplitude of the carrier.

It will be convenient to divide the transmitter into several sections and, as already intimated, the oscillator will first receive consideration. The oscillator circuit is fundamentally a simple reactive circuit whereby oscillation is produced and maintained by reintroducing energy from the anode circuit to the grid circuit, a function that will normally be accomplished by suitable coils, ignoring specialised forms of very high frequency transmitters which employ wires of critical length. Fig. 49 shows the basic circuit of a simple oscillator connected to an aerial system. It will be observed that both the anode coil and grid coil are tuned, and it is important that the relationship of inductance and capacity shall be suitably chosen, to limit as far as possible the amplitude of the attendant but unwanted harmonics.

Grid Bias.—Grid bias is necessary with almost any type of oscillator valve, and it may be derived and supplied in a number of ways. The most obvious method is self-bias by means of a grid leak and condenser, as shown at Fig. 49. This method is satisfactory for valves with a reasonably high slope and for use at normal frequencies. It is not to be recommended for ultra-high frequencies, due to the fact that the capacity existing between earth and the actual grid leak and condenser is an addition to the input capacity of the valve and is, therefore, in parallel with the grid circuit. This difficulty can be overcome by placing the grid leak and condenser at the low-potential end of the grid winding, but this makes it impossible to earth the grid circuit directly, or if the grid circuit is earthed, it is then impossible to directly earth the main high-tension negative line. There is yet another means of introducing the grid leak, as shown in the modified circuit at Fig. 50, the high-frequency choke being introduced to prevent the grid circuit being shunted by the relatively low resistance. This circuit is usually used when grid bias is obtained from a source of fixed potential, the bottom end of the resistance being taken to that point. With the self-biasing grid arrangement it is usual to connect a suitable current-measuring meter in series with the grid circuit, as shown at Fig. 51, in order that the grid current can be measured and, since the value of the grid resistance is known, the grid potential can be determined by the simple application of Ohm's law.

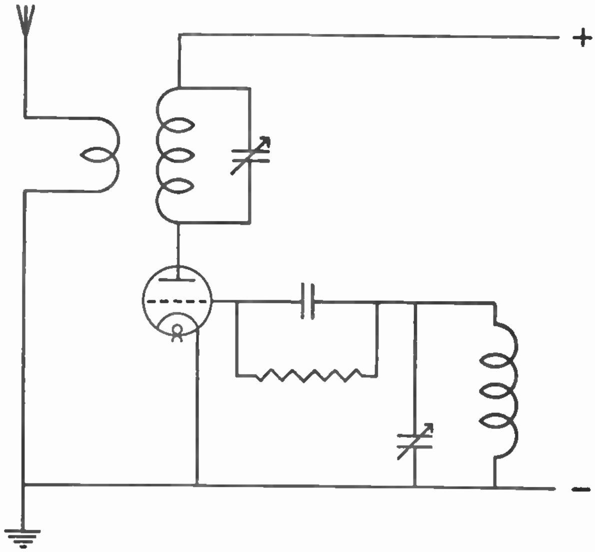


Fig. 49.—A simple oscillator loosely coupled to a single wire aerial.

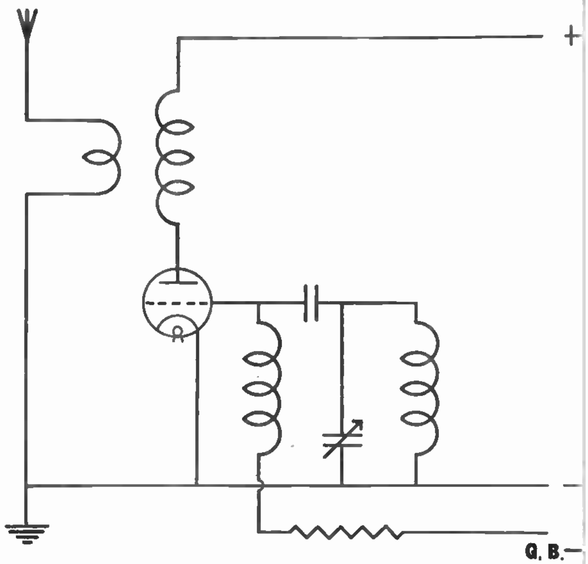


Fig. 50.—A modified oscillator circuit allowing grid bias to be obtained from a D.C. source.

Transmitters using quite low power can conveniently include a resistance in the main high-tension negative lead to provide a potential drop for the purpose of obtaining grid bias, but such a procedure is uneconomic in larger transmitters, since the grid bias obtained is a reduction in the total high-tension voltage, the further increase of which may often present problems and greatly increase the cost of power-pack

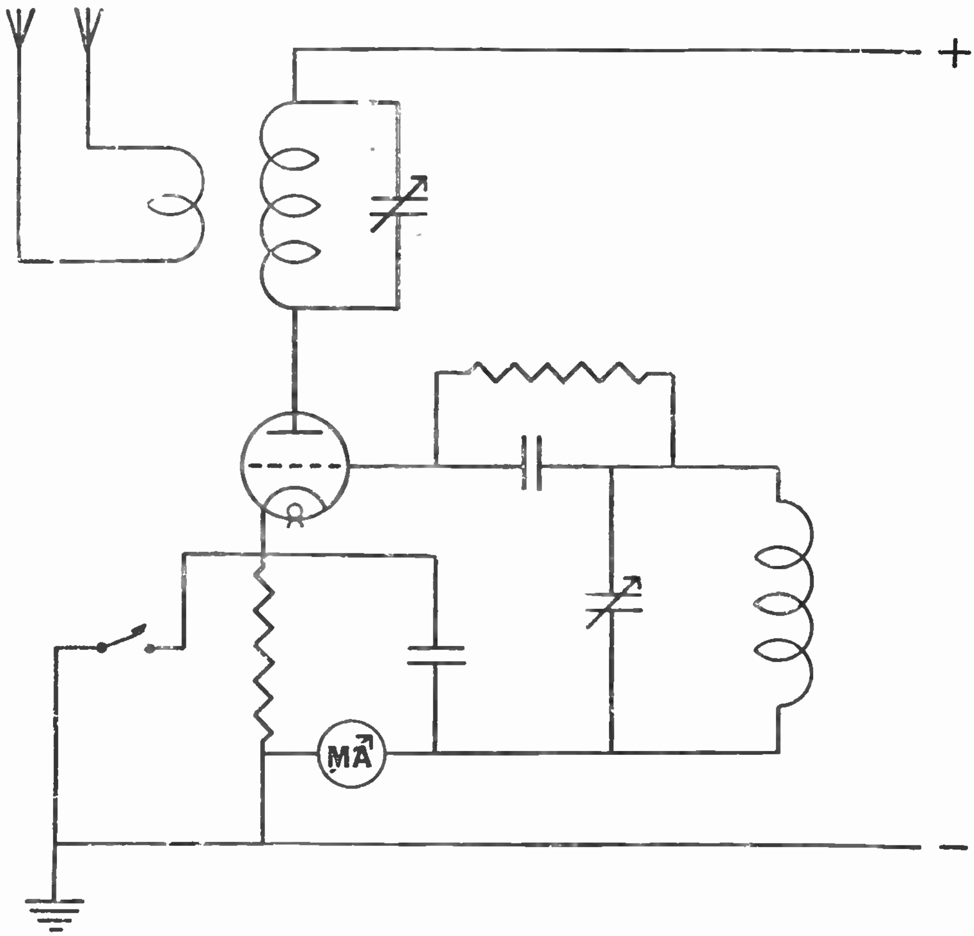


Fig. 51.—A very simple, but nevertheless complete, transmitter. The method of keying is not recommended for practical purposes.

components. In these circumstances it is both convenient and economic to provide a separate rectifier for the purpose of supplying grid bias.

Increasing Power.—The majority of transmitters will employ a high-frequency amplifier between the oscillator and the aerial, but, nevertheless, occasion may arise when it is necessary to increase the output to the oscillator to increase the output of the transmitter, if the oscillator is coupled directly to the aerial, or to provide adequate driving voltage for a larger high-frequency amplifying valve. At first sight it might appear that this could be very easily accomplished by connecting two similar oscillating valves in parallel. Such a procedure is perfectly sound at normal frequencies, but at very high frequencies it has the disadvantage of doubling the input capacity and it is more convenient to use a push-pull oscillator when the input capacity of the two valves is virtually in series. Normally, however, power output will be increased by a high-frequency amplifier, which is dealt with in detail later in the chapter.

A Practical Oscillator.—The oscillator circuits already shown are purely diagrammatic, and attention may be directed to the circuit shown at Fig. 51, which may be regarded as an elementary, but nevertheless complete, transmitter, with the exception of the power pack, which has been omitted, since it will not differ materially from the normal type of power pack associated with receivers. The illustration shows an extremely simple arrangement, with a separate aerial coupling coil which may lead to a tuned aerial by way of a low-impedance feeder line. It should be understood that the grid and anode inductances are not intended to be deliberately coupled, energy from the anode circuit being fed to the grid circuit by means of the capacity existing between the grid and anode or, in other words, the inter-electrode capacity of the valve. It should also be noted that the oscillator frequency is mainly controlled by the inductance capacity constants of the anode circuit, although the grid circuit will have some influence. Normally the circuits will not be tuned to resonance, the grid circuit being tuned to a *slightly* lower frequency.

Simple Keying.—As the illustration is intended to represent a simple, but complete, transmitter, it will be necessary to include some provision for keying the circuit, in order that the carrier wave may be broken up into the dots and dashes of morse code by the manual operation of a morse key. Many possibilities present themselves, some of which are referred to later, but for the present purpose a key is inserted in an auxiliary grid-bias circuit, so that when the key is idle the grid is so negative with respect to the filament that the valve does not oscillate. On depressing the key the *auxiliary* voltage is removed, and the valve will oscillate: it will be noted that normal operating bias is obtained by a grid leak.

The Hartley Circuit.—Fig. 52 shows a circuit arrangement known as the Hartley oscillator. It has enjoyed considerable popularity and, incidentally, also enjoyed great popularity some years ago modified for reception. It will be observed that the anode and grid coils are, in fact, a single inductance, the high-tension supply to the anode being parallel-fed through a choke or other high impedance. Since the anode current of an oscillator must be fairly considerable, it would be extremely wasteful to procure the necessary impedance by means of a pure resistance. On the other hand, a choke may introduce undesirable characteristics unless very carefully designed. A common compromise is to use a high-inductance choke in series with a small resistance, the latter being on the anode side.

It will be observed that the ends of the coil are connected from the high-frequency point of view to the anode and grid respectively, blocking condensers being provided to prevent a short circuit between the high-tension supply and earth and to allow the grid to be biased by means of a grid leak. The main earth line is connected to a tap on the inductance, the position of which will determine the amplitude of the oscillatory anode current. Under normal conditions this tap will be between a quarter and a half of the total inductance, reckoning from the earth end. Once again keying is accomplished by auxiliary negative bias, which in this case is provided by a cathode resistance which is shorted out when the key is depressed. This variation is included merely as an interesting alternative, and the previous arrangement could be equally well employed.

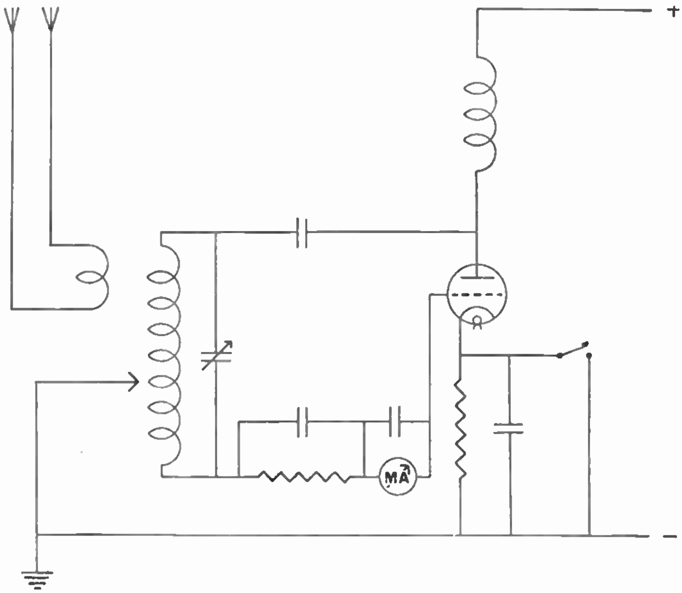


Fig. 52.—A modified oscillator using the Hartley principle.

Electron-coupled Oscillators.—The more interesting type of circuit is shown at Fig. 53, in which the triode valve is replaced by a tetrode and anode to grid coupling and is achieved by so-called electron coupling, making use of the fundamental principle that the cathode circuit possesses characteristics in common with the anode circuit. Reference to the illustration will show that the circuit used is a modified Hartley oscillator, the total inductance being connected between grid and high-tension negative and that the cathode is connected to a suitable tap. The position of this tap will control the amplitude of oscillation, and it must be most carefully adjusted to obtain the best results and to maintain adequate stability of the output frequency when the transmitter is keyed.

It is imperative that this type of oscillator is very carefully arranged and provided with adequate screening. As a further adjunct to proper stability it is customary to so arrange and manipulate the tuned anode circuit that it resonates at a frequency equal to the second harmonic of the fundamental grid-circuit frequency. Other points that need care are the correct choice of operating potentials, which in the case of the grid potential implies suitable choice of the grid leak.

Frequency Drift.—The circuits so far described can be classed as self-controlled oscillators and are extremely liable to frequency drift. This tendency to drift may be classed under two headings: the effect on frequency during that period after switching on when the valve has reached working temperature, and when it is thoroughly warmed up.

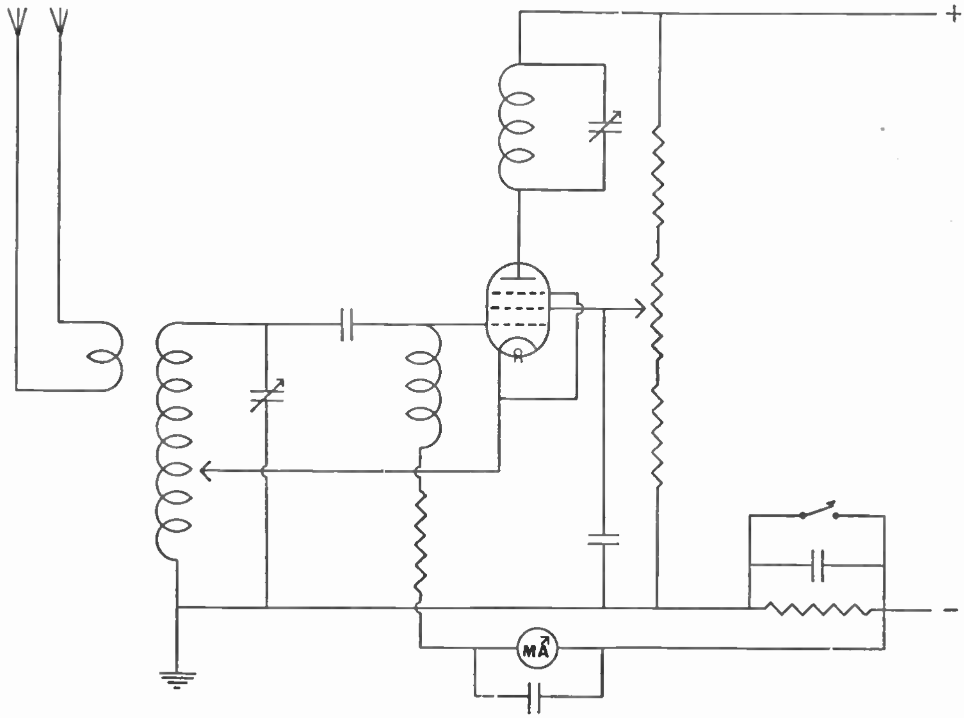


Fig. 53.—An example of the so-called electron-coupled oscillator; note that keying is accomplished by means of a biasing resistance in the high-tension negative lead.

The drifting during this period will be relatively considerable and is normally overcome by switching on the transmitter some time before it is actually intended to radiate; a procedure which is obviously inconvenient. The tendency to drift, which may be classed under the second heading, is slight but continuous, and is caused by the capacity change of condensers due to temperature-rise in addition to changes of valve characteristics. These remarks apply to all the circuits so far mentioned, and although this difficulty can be overcome to some extent by under-running the oscillator and providing it with adequate ventilation, it is obvious that some method must be introduced to bring about real frequency stability, particularly if the transmitter is allocated a definite frequency to which it must adhere with very small tolerance.

Large transmitters employ the most elaborate systems for frequency stability, but for low-power work it is convenient to make use of the properties of quartz crystal.

Crystal Control.—It does not seem desirable to break the present sequence of presentation in order to digress on an elaborate explanation of the numerous variations to be obtained by cutting quartz crystals in various ways. It is sufficient, therefore, to mention that a piece may be cut from a quartz crystal in the direction known as the X axis. If an X-cut crystal is clamped between two metal plates which are connected to the grid and cathode of a triode valve in the manner shown at Fig. 54, the circuit can be made to oscillate at a frequency determined by the thickness of the crystal. It is, however, necessary to produce the requisite feed-back from the anode circuit to the grid circuit, which can be conveniently achieved by a tuned circuit to act as an anode load, adjusted to a frequency a little in excess of the natural, or fundamental, frequency of the crystal. It is apparent, therefore, that the frequency of the oscillator is directly determined by the thickness of the crystal, and that it is only possible to produce one particular frequency or its harmonics with any particular specimen. Crystals may be purchased accurately ground to oscillate at stipulated frequencies; on the other hand, many amateur transmitters undertake the grinding of crystals, which is not actually difficult, but is tedious and calls for considerable care, as a crystal must necessarily have truly flat surfaces, otherwise numerous undesirable characteristics are introduced.

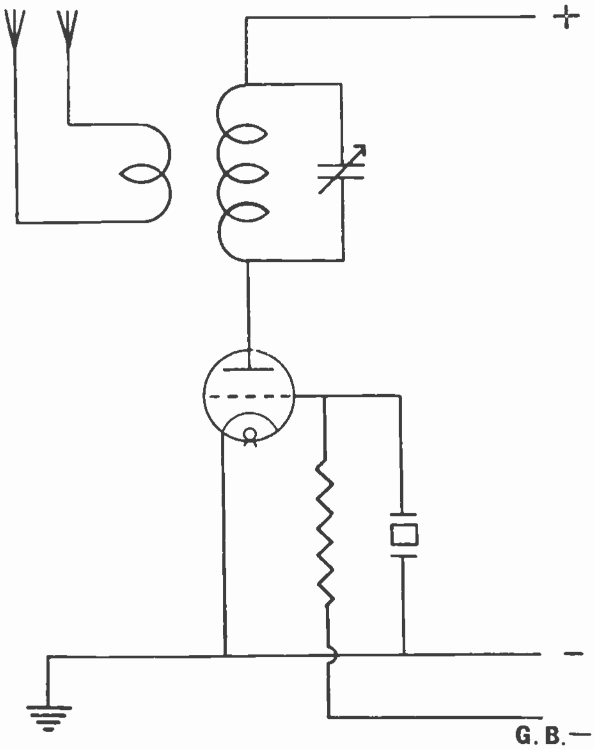


Fig. 54.—The basic arrangement of a crystal-controlled oscillator.

While a crystal-controlled oscillator is a perfectly practicable arrangement, its use is limited to relatively small output, since the energy in the grid circuit must be limited in order that the crystal is not damaged and, furthermore, it is desirable that the energy of the grid circuit be further limited to prevent heating up of the crystal unit, which would bring about a different pressure between plates and crystal, which would, in turn, cause a very small, but nevertheless undesirable, frequency drift. To summarise, it is apparent that the energy in the grid circuit of a crystal-controlled oscillator should be small, and since it is desired that the output should be as large as possible, the valve used should possess high sensitivity or, in brief, a crystal-controlled oscillator will normally employ a screened tetrode or screened pentode valve.

The circuit is not illustrated, since it is precisely the same as the circuit shown at Fig. 54, except that the valve is a tetrode, necessitating a suitable high-tension supply to the screening grid, which will be tied to earth from the high-frequency point of view by the usual condenser connected between screen and cathode. If a pentode valve is used, the suppressor grid is, of course, tied to the cathode in the usual manner. There is, however, one additional modification which may be necessary with valves having an exceptionally low control grid/anode capacity resulting in inability of the valve to *commence* oscillation. This rather paradoxical drawback can be overcome by introducing a minute capacity between the anode and control grid, which will usually be of the order of 1 to 3 $\mu\mu$F. The introduction of this small capacity presents some practical difficulties, owing to the distance between the anode and grid terminals of the valve, which means that the lead must be long and liable to introduce unwanted coupling with other parts of the circuit, while, if the wires are screened to overcome this difficulty, the input and/or the output capacity is increased. Nevertheless, it is customary to introduce this capacity when necessary, but the author has had some success with this class of oscillator feed-back being increased by introducing a few ohms in series with the condenser connected between screen and cathode, so that the control grid/anode capacity is thereby raised. Before leaving the subject of artificially raising anode/grid feed-back, it will be desirable to draw attention to the fact that the very minimum should be employed consistent with obtaining reliable excitation, since too much feed-back may well destroy the crystal.

A glance at Fig. 54 will show that the operating negative grid bias is parallel-fed, an arrangement for which there is no alternative, since the crystal forms an effective stopper. It is, however, quite feasible to use grid-leak bias connecting the resistance in question in series with a high-frequency choke between grid and cathode. The choke is necessary, since the value of resistance required to obtain the requisite bias will be low enough to introduce a severe load on the grid circuit. Yet another arrangement is to return the grid to cathode through a choke and resistance and to provide additional bias by means of the conventional cathode-bias resistance. This latter arrangement or, alternatively, the first-mentioned arrangement, will be employed with valves having relatively low mutual conductance, whereas the first two methods may be considered suitable for normal use with valves having a high mutual conductance.

Reference to Fig. 54 will show that the circuit employs a single tuned coil, which will be tuned to the frequency of the crystal. It should be understood that this adjustment has a negligible effect on the frequency of oscillation, but is necessary to provide the highest possible anode load in order to obtain optimum power output.

When the anode coil is connected to the high-frequency amplifier a load will be introduced into the anode circuit, and once again it will be desirable to tune the anode coil to a frequency slightly higher than the natural frequency of the crystal. The reason for this can be readily seen by reference to Fig. 55, which shows anode current plotted against frequency. It will be observed that the circuit is liable to be unstable when tuned to resonance, as a very small change in the direction of a lower frequency will bring about a considerable rise in plate current and the valve will cease oscillating. If, on the other hand, the anode circuit is tuned to the frequency denoted by the dotted line, a change in this frequency will bring about a relatively small change in the anode current and stability of oscillation will be maintained. In order to emphasise this point the curve shown at Fig. 55 is typical of the type of oscillator under discussion when not working into an external load; a load introduced by a coupling in the anode coil will cause a dip to be much less pronounced, but the sharp rise in anode current just below the fundamental frequency remains, and it is therefore equally important that the anode circuit should be tuned just above the fundamental frequency.

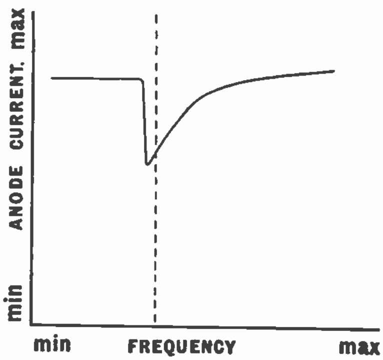


Fig. 55.—The relationship between frequency and anode current of a normal oscillator.

Crystals.—The very briefest mention has been made of the actual crystal and some further details are desirable. The quartz crystal has numerous uses in the world of mechanical, electrical, and optical engineering. The properties of the crystal are determined by the angle at which it is cut out of the natural raw crystal. The original crystal has a number of axes, the principal three being known as the X, Y, and Z axes, which are classed as electrical, mechanical, and optical axes respectively. This arbitrary division is an unhappy one, since a crystal in one class may have useful properties in another class; this is particularly true of the mechanical and electrical. Fig. 56 shows diagrammatically the orientation of X and Y crystals, it being understood that the hexagon represents the perfect crystal when viewed from above. The Z axis is at right angles, but is of no interest when considering the design of a transmitter.

The most commonly used crystals are those having an X cut, Y cut, and A.T. cut, while a V-cut crystal is occasionally employed. The A.T.

cut may be described as a Y-cut crystal, which is cut at an angle to the perpendicular, while retaining its horizontal axis. It will be desirable to describe the three major cuts in some detail.

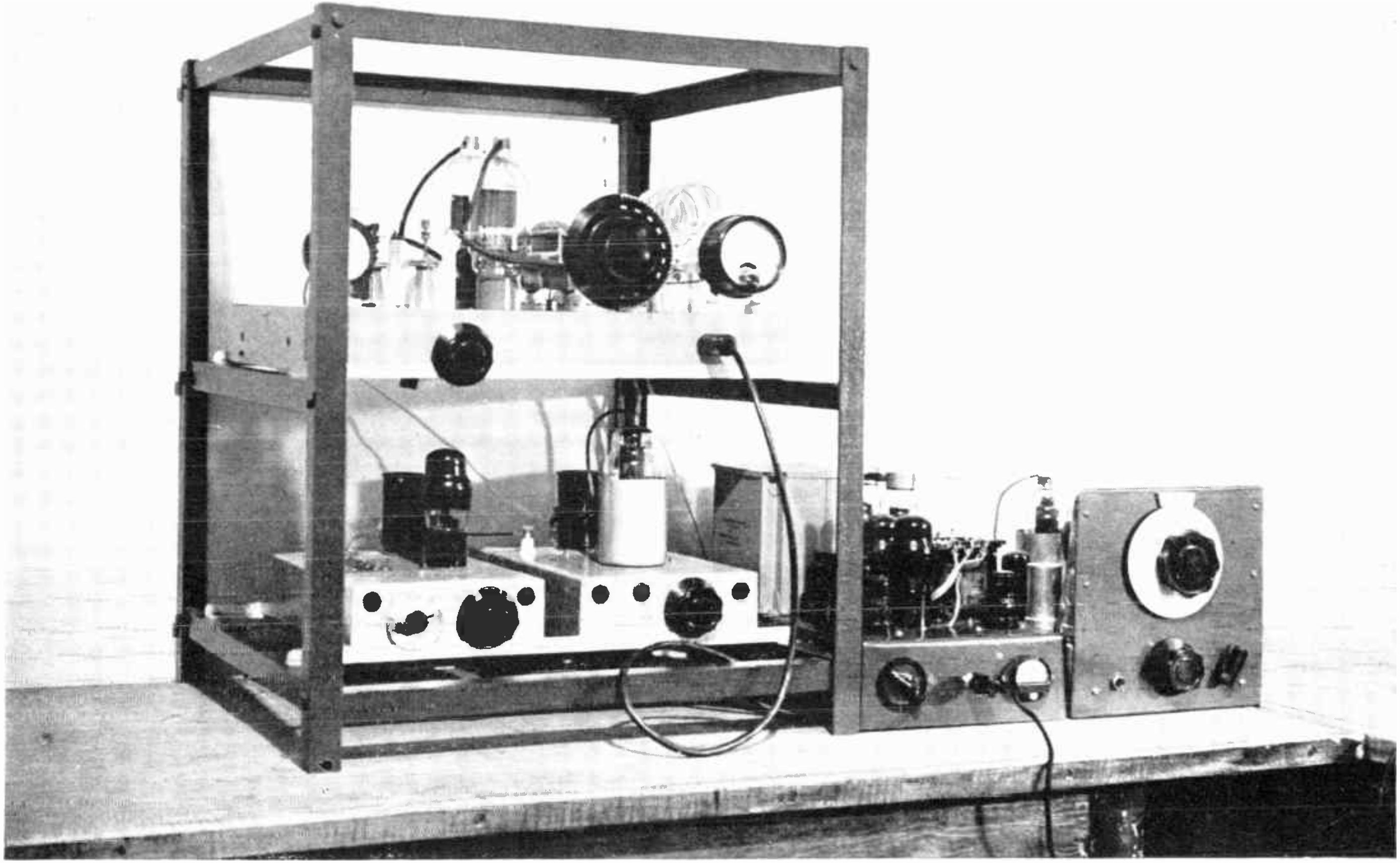
The X Cut.—The X-cut crystal has a negative temperature characteristic; that is to say, the natural oscillatory frequency of the crystal decreases when the temperature of the crystal increases—the actual frequency drift for each degree of temperature-change being of the order of 25 in 1,000,000 cycles. It will be selected in preference to a Y-cut crystal when it is to be used near the upper edge of the restricted band, so that the frequency cannot drift outside the prescribed limits.

A Y-cut Crystal.—The Y-cut crystal nominally has an opposite characteristic to the X-cut crystal, inasmuch as it has a positive temperature coefficient, so that frequency increases with temperature-rise. It must be pointed out, however, that specimens are sometimes obtained having a reverse temperature-characteristic, *i.e.* negative. The extent of frequency drift is of a somewhat higher order, being 50 in 1,000,000 cycles per second. Bad specimens, however, often reach three times this figure. Some indication of frequency drift is readily apparent from the following example: A crystal that has a fundamental frequency of 10 megacycles per second at 50° Centigrade may drift 25 kilocycles if the temperature is raised to 100° Centigrade; if the receiver is reasonably selective, the transmitter frequency would drift into inaudibility. Methods of combating temperature-rise are dealt with later, but in the meantime attention may be directed to the A.T.-cut crystal.

Fig. 56.—The axes of a quartz crystal: (*Left*) the X cut; and (*Right*) the Y cut.

The A.T. Cut.—An A.T.-cut crystal has the advantage of a sensibly zero temperature coefficient and it might appear at first sight that a crystal so cut should always be selected. There are, however, other considerations, the most important of which is the permissible power that may be handled in the grid circuit which is excited by the crystal, and in this respect the A.T.-cut crystal is at a disadvantage, since the permissible power is rather less than half that obtaining with X- and Y-cut crystals.

The Crystal Holder.—There are two types of crystal holder or crystal clamp in general use and they differ fundamentally from each other. One type is arranged so that the crystal is actually clamped between two metal surfaces, while the other type has the crystal in contact at one plate only and an air-gap between the other face of the crystal and the opposite plate. This air-gap may vary between $\frac{1}{500}$ and $\frac{1}{2000}$ of an inch, and has the advantage that adjustment of the gap effects a change of the natural frequency of the crystal, although, unfortunately, it only amounts to a few kilocycles per second.



AN AMATEUR TRANSMITTER

This photograph shows the 150 watt transmitter (telephony and c.w.) G2UK, built and operated by Dr. A. C. Gee, of Boston, Lincs. The units of the transmitter are: Top, push-pull power amplifier using HY25 valves. Bottom row, *left to right*, crystal oscillator, frequency doubler and quadrupler, modulator and variable frequency oscillator. Amateur radio G2UK is one of over five thousand in the United Kingdom; amateur radio is equally popular in almost every country in the world.

The gap type of crystal holder is usually used only with an A.T.-cut crystal, since crystals cut on other axes are apt to introduce frequency instability. If for any reason this type of holder is used for a crystal having an unfavourable temperature coefficient, it is necessary to provide means for limiting temperature-rise.

The crystal holder intended to be used with an X- or Y-cut crystal is usually provided with some cooling fins and, as an additional means of controlling temperature, one plate, which may conveniently form the base, possesses considerable mass. This feature is restricted to one plate, owing to the inconvenience of having both sides of large dimensions, which would result in undesirable stray capacities. While this chapter does not cover purely practical considerations, it is perhaps not out of place to mention that a crystal may fail to oscillate if there is the least trace of oil on its surface, even the minute trace resulting from picking it up in the fingers.

When *absolute* frequency stability is necessary, it may be desirable to directly control the temperature of the crystal. It is obviously inconvenient to limit temperature-rise, since any such arrangement as water cooling would introduce innumerable difficulties and it would be extremely difficult to obtain automatic control. It is convenient, therefore, to enclose the crystal and holder in a small "oven," which is heated to a temperature above that which the crystal could reach under normal operating conditions. To obtain stability it is simply necessary to arrange a thermostat to control the source of heat so that it cannot rise above the predetermined limit. Obviously, the thickness of the crystal must be such that the desired frequency is obtained at the selected temperature.

The High-frequency Amplifier.—It will be apparent from the foregoing remarks that it is impracticable to obtain any considerable power from the oscillator and quite impossible if it is crystal-controlled. Therefore, in order that the oscillator output can be raised to the ultimate output power, it is necessary to employ one or more stages of high-frequency amplification; this stage may employ almost any class of valve possessing a control grid, the actual choice being determined by a number of considerations. The amplifier may be divided into two distinct classes, that using some form of screened-grid valve, so that the energy fed from the anode circuit to the grid circuit to the capacity within the valve will not be sufficient to cause self-oscillation or, alternatively, a triode valve may be used, in which case it will be necessary to introduce some means to prevent self-oscillation, which may take the form of neutralisation, the principle of which is discussed later.

Before going deeply into the merits of a screened grid as opposed to neutralised circuits, attention may be directed to one or two fundamental facts which are common to all types of amplifiers, excepting those intended for use on comparatively long wavelengths, which are outside the scope of this chapter, as low-power transmitters invariably employ a fairly high frequency.

The conditions under which a transmitting amplifier functions are fundamentally different from those obtaining in a receiver. If it is intended to realise an output approaching that of which the valve is capable, it will be necessary to allow some portion of the input cycle to encroach on the positive region of the grid characteristic, with the result that heavy grid current will flow. It might appear at first sight that this excursion into grid current would introduce distortion, but this is not actually the case, since the anode load will only reach a high dynamic resistance at the resonant frequency. Admittedly, some distortion of waveform will result, but, being at radio frequency, it will not directly introduce distortion which will be apparent after detection at the receiving end, and, furthermore, the modulation may be unaffected if reasonable care is used.

Harmonics.—Waveform distortion introduces undesirable effects in a sphere quite removed from the considerations of audio-frequency quality and takes the form of generating unwanted harmonics. If a single valve is used, the harmonic generated will be the complete range, second, third, fourth, etc., but fortunately the higher harmonics are greatly attenuated unless the design of the anode load is very bad. It is apparent, therefore, that the second and third harmonics and, to a lesser extent, the fourth harmonic, may be radiated at considerable amplitude and steps must be taken to prevent this occurring by suitably designing the tuned circuit coupling and even the aerial itself. Quite apart from the natural desire of all good operators to avoid unnecessary interference, the radiation of the harmonics may well place an operator in a serious position, since the transmitter will be radiating outside of the frequency band officially allocated. The necessity for suppressing harmonics suggests the use of a push-pull output amplifier, since this class of working automatically cancels out all even harmonics ; thus the principal harmonic remaining to cause trouble will be the third, which is well removed from the fundamental frequency. The cancellation of even harmonics is, of course, only complete providing the two halves of the circuit are adequately matched. Valves in push-pull will radiate approximately the same power as two similar valves in parallel and require the same order of input from the oscillator. They have the additional advantage that the grid to earth capacities of the two valves are effectively in series and also the anode to ground capacities of the two anodes are in series, resulting in a lower capacity across the coils, which is advantageous at the higher frequencies, since it permits a more favourable inductance/capacity ratio.

Coupling.—The coupling between the oscillator and amplifier is not as straightforward as it might appear, particularly when working at frequencies above, say, 10 megacycles per second. The simplest form of coupling is shown at Fig. 57, and is similar to the tuned anode coupling used in a receiver. For the latter purpose tuned couplings resonating at the frequency of the received signal are not usually employed at very high frequency, the superheterodyne principle being usually used. Difficulties arise in the transmitter, although from somewhat different directions. Reference to the illustration will show that the inter-electrode capacity of both valves will appear across the tuned circuit, which will place limitations on the inductance/capacity ratio and effect a reduction in the anode load of the oscillator. Furthermore, any losses arising from dielectric material in both valves will also appear across the tuned circuit. Fig. 58 shows an alternative method of capacity coupling which overcomes the paralleling of the two valve capacities, but calls for some care in selecting circuit constants, since the effect that it is desired to avoid is only obviated if the tap is near the centre of the coil, and in this and the previous circuit it is intended that the tap should be so adjusted that the output load of the oscillator is matched to the input impedance of the amplifier, which, it will be remembered, will consume power if it runs into grid current during some portion of the cycle.

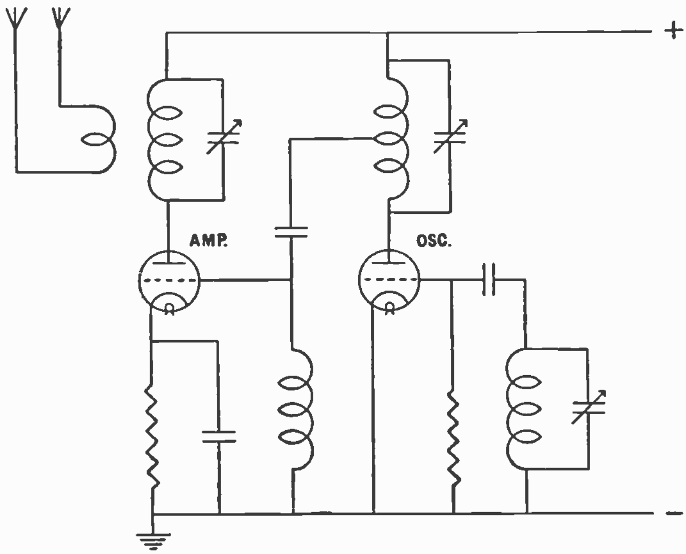


Fig. 57.—A straightforward high-frequency amplifying stage.

Inductive Coupling.—The obvious way of avoiding the difficulty of parallel valve capacity and, at the same time, the convenient adjustment of ratio, is by the use of inductive coupling, which may take the conventional form of a high-frequency transformer, both the anode circuit of the oscillator and the grid circuit of the amplifier being tuned. This arrangement, however, may advantageously be modified at higher frequencies by employing a closed circuit coupling link. Fig. 59 shows an inductively coupled circuit in which it is intended that two coupling coils should be coupled together by a low-impedance feeder line. While it is often convenient to use the low-impedance twin feeder associated with feeder aerials, it cannot be recommended except, perhaps, for coupling an oscillator to an amplifier when the former is worked under such a condition that the voltage developed across the load is relatively small. This form of coupling introduces a very convenient feature, inasmuch as the feeder may be several feet long without appreciable attenuation, thus permitting the oscillator and amplifier or when employed, a second amplifier, to be built on the unit principle and conveniently spaced from each other. There is no alternative means whereby such units could be coupled together without the introduction of loss or the danger of instability. At frequencies of the order of several megacycles and above, the coupling coils will consist of a few turns of wire, but in order to facilitate the impedance matching of the oscillator output and amplifier input, some arrangement must be made for varying the coupling. Loose coupling in the sense of varying the distance between the coupling coil

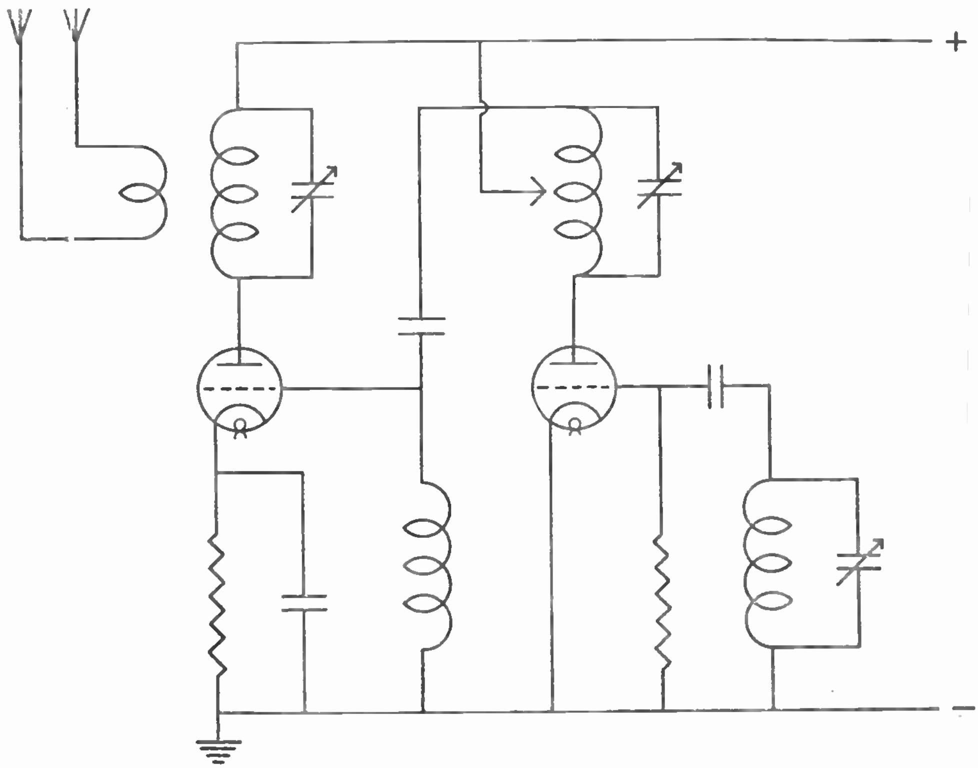


Fig. 58.—A high-frequency amplifying stage with an improved type of coupling which is explained in the text.

and tuned coil is very unsatisfactory, as a large movement is necessary and, quite apart from the necessary mechanical arrangements, the moving coil is inclined to come into some external field. When the purpose to which the transmitter is put permits of such manipulation, it is convenient to expand the coupling coil spring fashion and thus vary its inductance and consequently the mutual inductance between the coils. This method is admittedly clumsy, and for service or commercial receivers recourse is usually made to a coupling coil that is arranged to rotate in relation to the tuned circuit. It should be noted that in the illustration the coupling coils are shown at the low-potential end of the tuned circuits, and this relationship is normally preserved in practice. In the case of a push-pull amplifier coupled to a push-pull oscillator, the coupling coils will normally be wound over the centre of the tuned coils, which is, of course, a point of low radio-frequency potential. If it is desired to couple a single oscillator to a push-pull amplifier, then one coupling coil will be placed at the low-potential end of the anode coil and the other at the

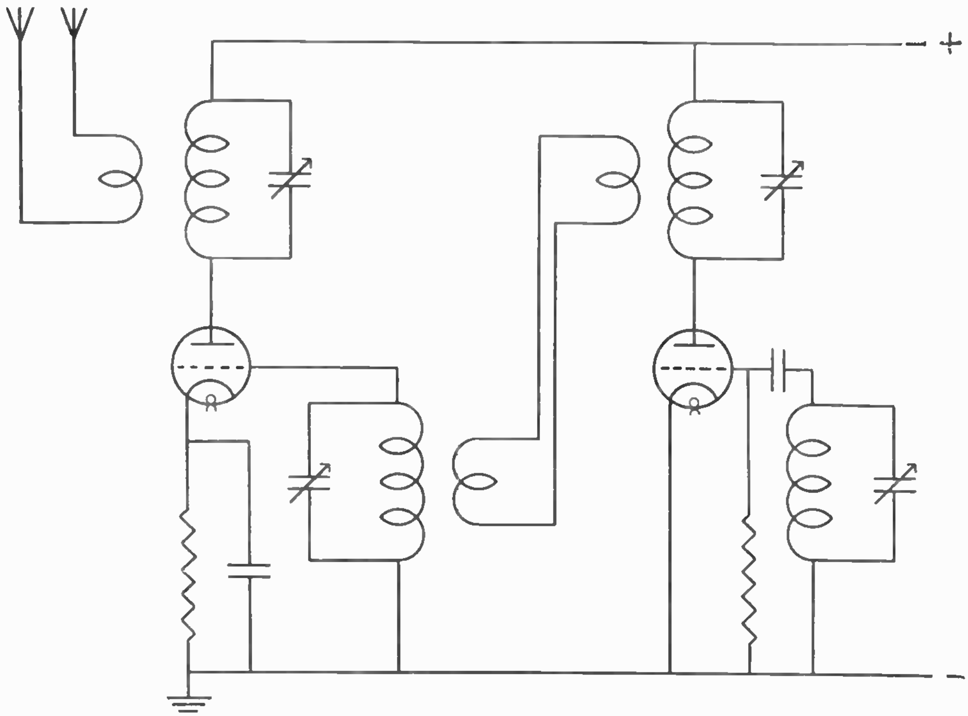


Fig. 59.—This illustration shows the use of link coupling between the oscillator and high-frequency amplifier.

centre of the grid coil ; the converse applies if a push-pull oscillator is used to drive a single amplifier.

The Choice of Amplifier Circuit.—As already intimated, the amplifier may employ a triode or some form of screened valve. Considerations of the latter are straightforward and may be conveniently dealt with before the principle of neutralisation. The circuit arrangements of an amplifier using a screened valve is so straightforward that it is almost superfluous to illustrate it, nevertheless a typical arrangement is shown at Fig. 60. Attention is drawn to the necessity for tying down the heater circuit from the radio-frequency point of view unless, of course, the amplifier is not to be worked on the higher frequencies. The circuit is arranged to be coupled to the oscillator by an inductive link, but if capacity coupling is used the grid circuit is removed and the grid of the amplifier fed through a condenser to a suitable tap on the oscillator anode coil.

Since it is necessary to apply a negative bias to the amplifier, it will be essential to provide a D.C. return between the grid and the source of bias. Note particularly that a resistance must not be used for this purpose, as it is intended that the valves shall run into grid current, and therefore a choke must be employed having a low D.C. resistance but adequate impedance.

If two stages of amplification are used, the anode load of the first will

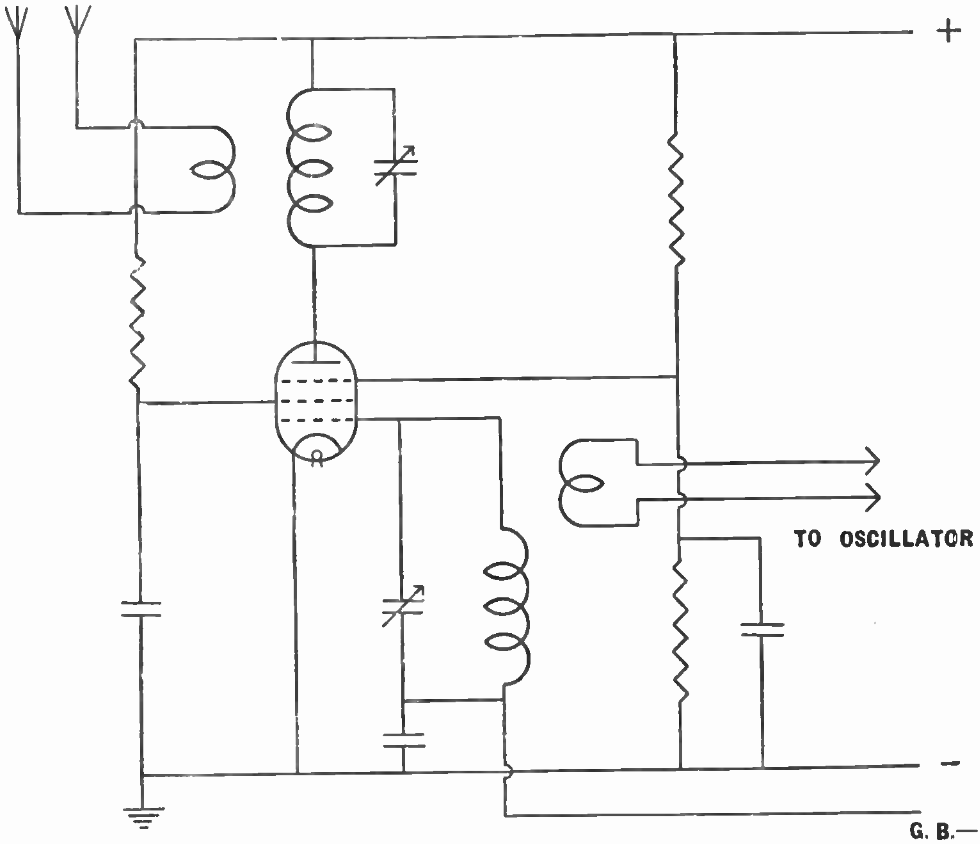


Fig. 60.—A high-frequency pentode as amplifier. It is desirable but not essential to apply a small positive bias to the suppressor grid.

be coupled to the grid of the second, and while the same coupling will normally be used as that employed between the oscillator and first amplifier, there is no fundamental reason why this should be so, but the consideration that caused the particular coupling to be suggested for the one purpose will usually suggest that the same method be employed throughout.

When working at very high frequencies it may be difficult to obtain adequate stability, even when employing screened valves of good design. This condition is somewhat aggravated by the difficulty of adequately screening the grid and anode circuit, while providing adequate ventilation. Stability can be maintained by the introduction of a little out-of-phase feed-back from anode to grid, a subject which will be further discussed after the principle of neutralisation has been explained in some detail.

Neutralising.—The tendency of a triode to oscillate when its grid and anode circuits are tuned to the same frequency is fully discussed in the appropriate section of Volume I; it will be remembered that the cause of this tendency to oscillate is due to the capacity existing between the anode and grid, permitting the feeding back of energy in the anode circuit to the grid circuit. This inherent tendency can be offset by applying the principle of neutralisation, which can be briefly described as the introduction of energy into the grid circuit which is out of phase with that fed back to the valve capacity. This principle was popular in the receiving set some years ago, and receivers so arranged were often called neutrodynes. While perfectly satisfactory from the stability point of view, it fell into disuse owing to the inherent stability of the screened-grid valve, which had the additional advantage of higher stage-gain. The requirements of a transmitter are somewhat different, with the result that triode amplifiers stabilised by the neutrodyne principle have not fallen into disuse. Admittedly, this arrangement is more popular for C.W. working, but nevertheless it is often met with in telephony transm ters, where its use is sometimes objected to, owing to the slight difficulty of maintaining proper neutralisation when the audio frequency is modulated on the carrier. Although the practice of neutralising really belongs to the triode amplifier, it is often used to balance out the effect of the minute grid/anode capacity of a screened tetrode or pentode, either to preserve stability at very high frequencies or to increase efficiency when conditions are such that feed-back is detrimental to performance.

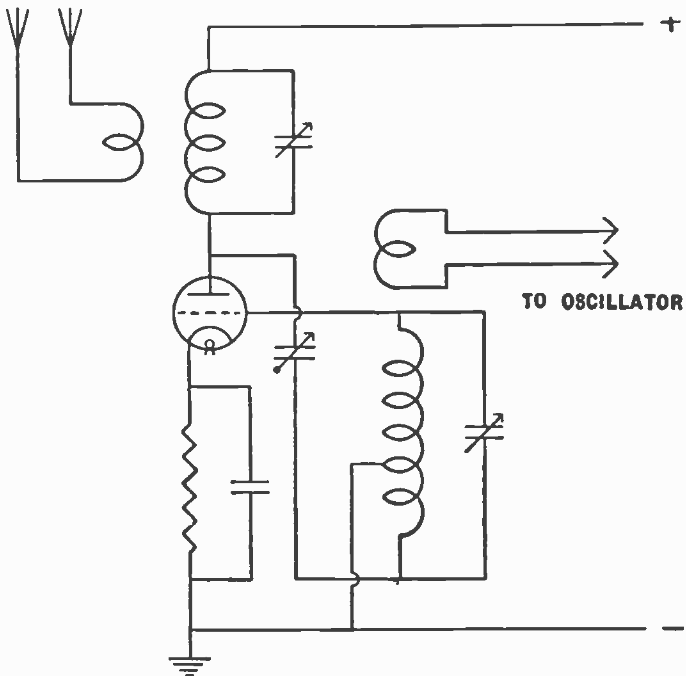


Fig. 61.—A typical high-frequency amplifier employing grid neutralisation.

The possible detailed arrangements for neutralising the amplifier are extremely numerous and three circuits must suffice to illustrate the principle. The first two represent fundamental groups which can be classed as grid-neutralising circuits and anode-neutralising circuits. The third circuit is merely a rearrangement which has certain advantages of pure convenience. Fig. 61 shows a typical circuit employing grid neutralising, which takes the form of a feed-back circuit from anode to a tap on the preceding tuned circuit. It will be noted that the small variable condenser in this lead acts as a means of controlling the amount of feed-back and, incidentally, acts as a D.C. stopper. It should be understood that the connections to the preceding tuned circuit must be so arranged that the energy fed back through this condenser produces a voltage across the grid/cathode of the amplifier that is out of phase with the voltage produced by the energy fed back through the valve. In the circuit used as an example this condition is obtained by introducing the tap at a point on the opposite side of the earth tap, so that the current fed back through the neutralising condenser flows through the coil in the opposite direction to that fed back through the valve capacity.

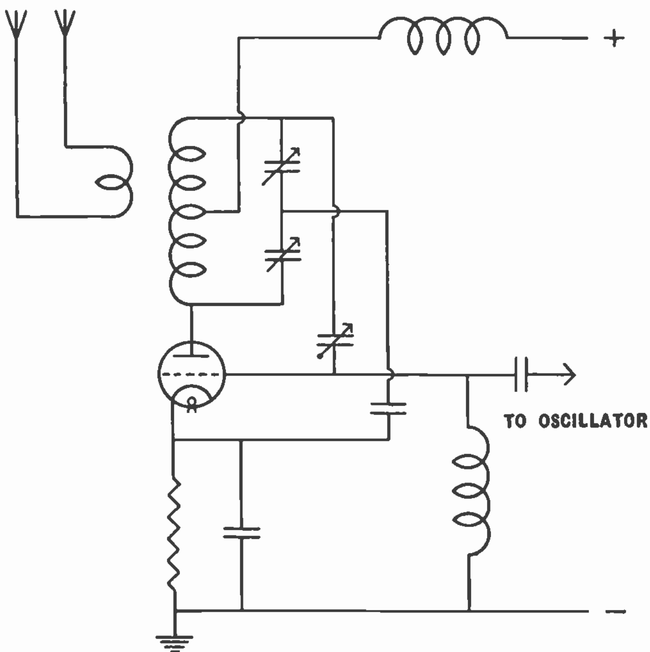


Fig. 62.—An improved arrangement for anode-circuit neutralisation.

An example of anode neutralising is shown at Fig. 62, which makes use of a twin variable condenser for tuning the anode coil. This refinement is not fundamentally necessary, but is desirable, since the anode to cathode capacity can be almost double the capacity across the coil as a whole, resulting harmonics being somewhat attenuated. The neutralising principle is exactly the same, inasmuch as energy is fed back out of phase into the grid circuit, the out-of-phase component being obtained by connecting a neutralising condenser to the opposite end of the anode coil, which is earthed at the centre from the radio-frequency point of view, with the result that the opposite ends of the coil are in opposite phase.

The third example is included to illustrate the considerable variation of detail that exists. The connections are exactly the same as that of a reactive circuit, as may be seen by reference to Fig. 63. The difference lies in the fact that the coil shown in series with the neutralising condenser bears the reverse relationship to the grid coil, so that the energy fed back by the magnetic coupling is out of phase with that fed back through the valve capacity. By suitably proportioning the turn ratio between the coils and their physical separation, it is possible to cover a reasonable waveband range without the necessity for serious readjustment of the neutralising condenser.

When the principle of neutralisation is applied to screened-grid valves, precisely similar circuit arrangements can be used, but difficulty sometimes arises in providing a sufficiently small neutralising capacity. With particularly good screened valves it may be impossible to provide a capacity of sufficiently small value, and it may be necessary to slightly increase the inter-electrode capacity of the valve in order that it may be large enough to neutralise. This is extremely easily accomplished by allowing a short length of wire connected to either anode or grid to be unscreened.

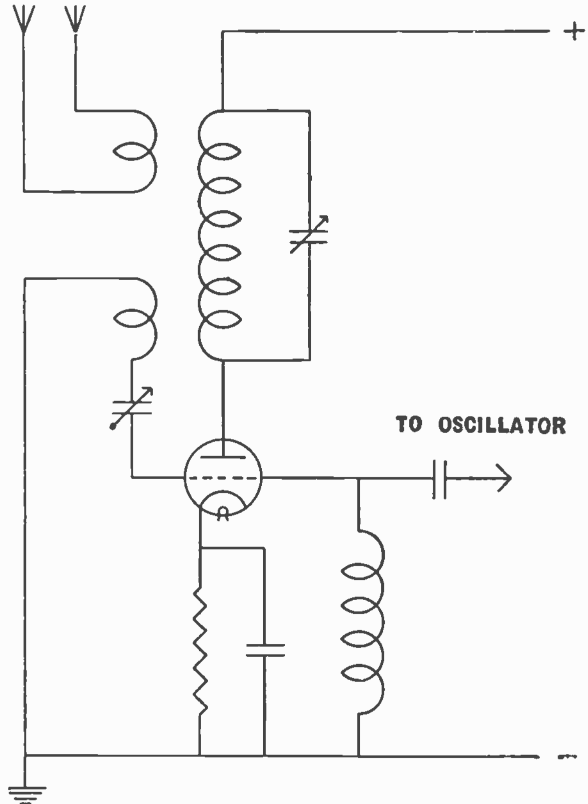


Fig. 63.—Another arrangement for neutralising a high-frequency amplifier; the grid coil is so connected that the energy fed back is out of phase with the energy fed through the inter-electrode capacity of the valve.

Frequency-multiplying Circuits.—It is common practice to transmit on a frequency that is a harmonic of the oscillator frequency, and circuits for achieving this condition are known variously as frequency multipliers, harmonic generators, or frequency doublers; the use of the latter term being restricted when the radiated frequency is the second harmonic of the oscillator frequency. The reasons for employing this principle are somewhat varied; the most obvious reason being that of economy, quite apart from the fact that the monetary value of a crystal increases rapidly with frequency, it is possible to use a single crystal to work on several wavebands by frequency multiplying, always providing, of course, that the bands to be worked have a suitable relationship to each other. Another reason for using frequency multiplication is to avoid the difficulties of obtaining completely stable operation of the oscillator stage at very high frequencies. In the case of portable transmitters or those that may be subjected to rough usage, the value of frequency multiplication is obvious, as it avoids the necessity for using a very thin crystal, which would be easily broken.

Frequency-multiplying circuits are subject to considerable variation, but they may be grouped under two fundamental headings, the adaptation of a high-frequency amplifier for frequency multiplying, or a special circuit arrangement where a single valve performs the dual function of oscillator and frequency multiplier. An example of the first-named group is a simple high-frequency amplifier in which the anode circuit is tuned to a harmonic of the input frequency. It is, however, necessary to vary the operating conditions in order to produce the greatest possible waveform distortion. It is usual to bias the valve well beyond anode current cut-off, and to drive it by a large input voltage, so that the maximum waveform distortion is obtained. Such an arrangement will provide a range of harmonics of useful amplitude. If, for some reason, only odd harmonics are required, the circuit can be arranged with two valves to function as a push-pull arrangement, which will result in the automatic cancellation of all even harmonics.

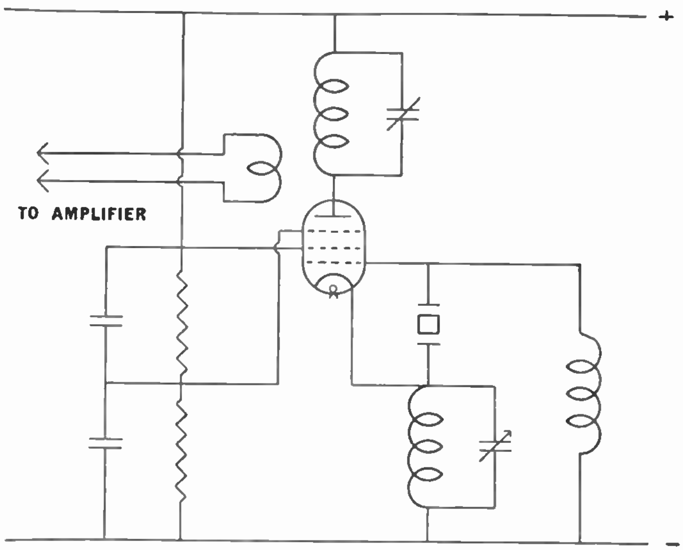


Fig. 64.—A pentode valve arranged as a combined oscillator and harmonic generator.

The other type of harmonic generator, the existence of which has already been mentioned, is shown at Fig. 64, which shows a pentode arranged to perform the dual functions of oscillator and frequency multiplier. It will be noted that the cathode is taken to a point above earth, although both the screen and suppressor grids are at earth potential from the radio-frequency point of view. It is intended that the tuned circuit in the cathode lead be adjusted to a frequency very much higher than the fundamental frequency of the crystal, while the tuned anode circuit is adjusted to resonate at the crystal frequency or at a harmonic thereof. Circuits of this type are satisfactory for C.W. transmitters, but they suffer from frequency instability when used for telephony unless elaborate precautions are taken, so elaborate, in fact, that it is advantageous to use a separate frequency multiplier.

Keying.—Surprising difficulties arise when it is desired to control a transmitter by means of a key for the purpose of splitting the carrier wave into the dots and dashes of the morse code. A simple arrangement is referred to earlier in the chapter for the purpose of illustrating a principle, but attention can now be directed to more detailed considerations. The fundamental requirements of good keying are *absolute* cessation of the carrier until the key is depressed, and complete absence of frequency drift at the instant of depressing the key or relaxing it. Failure to maintain the carrier frequency at all times results in what is colloquially called chirpy keying. This condition is extremely difficult to avoid if keying is accomplished in the oscillator stage. The desirability of the complete cessation of the carrier is obvious, since any radiation of power when the key is inoperative means that the dots and dashes will be received as a rise and fall in volume instead of an audible note " cut up " by complete silence.

If chirpy keying is to be avoided, it is apparent that keying must be accomplished in the amplifier, and if a silent background is to be obtained the amplifier must cease to function absolutely. If a single amplifier is used, this can be realised by the application of sufficient negative voltage to the grid, but if it is preceded or followed by a further stage there is danger of some energy being radiated by the aerial. It is apparent that the negative bias system of keying is fundamentally satisfactory, but not altogether easy to accomplish in practice.

The most certain method of keying is to block the high-tension supply to the amplifier or amplifiers, the oscillator being adequately screened and its power-supply leads adequately filtered. The most obvious way of arranging cessation of high-tension supply is to include a relay in the high-tension negative lead, which can be operated by the key. Objection to this method is the severe strain placed on the rectifier. The difficulty can, however, be overcome by using a special type of rectifier valve known as the grid-control rectifier.

The Grid-control Rectifier.—The circuit arrangement of a high-tension supply using grid-control rectifiers is shown at Fig. 65, where a key-operated relay throws the requisite negative bias on the grid until the key is depressed. The valves are of the gaseous type, and emission will cease completely if adequate negative voltage is applied. It should be understood that this type of rectifier cannot be used to control a rectified current, since it is necessary for the anode voltage to fall to zero for the grid to regain control once ionisation has taken place. This condition is fulfilled when the valves are used as rectifiers, since the anode potential will swing maximum negative once during each cycle. A modified form of valve is available in which ionisation is controlled by an external magnetic field, making it possible to dispense with the relay, since the key may be connected directly in series with the coils without the risk of shock which would obtain if the key were connected directly into the grid circuit of the grid-controlled type.

Telephony Transmission.—This work is mainly concerned with the science and art of broadcasting. The above remarks on the subject of keying are perhaps incidental, and attention may be turned to the more important subject of modulating a carrier wave at speech frequency. Before describing suitable arrangements for modulating it is desirable to

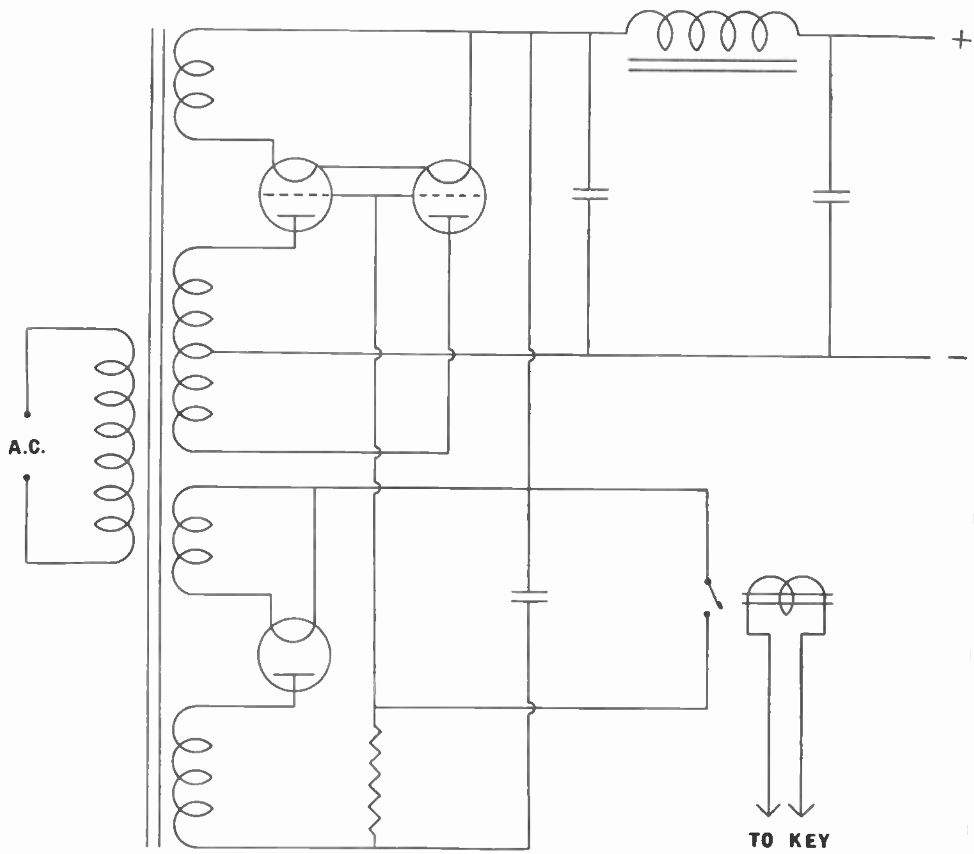


Fig. 65.—The use of grid-controlled rectifiers for keying a transmitter.

mention that the oscillator, the amplifier, and the buffer stage, if used, shall form a team capable of producing a carrier wave of constant amplitude and frequency unaffected by the modulator except when the amplitude is deliberately varied in the process of modulation.

It will be remembered that a modulated carrier is made up of a fundamental frequency, the amplitude being varied at audio-frequency or, in other words, modulated. The actual modulator valve will be comparable with the ultimate amplifier, it may even dissipate more energy than the amplifier, and it is obvious that the modulator will require its own audio-frequency amplifier in order that the output from a microphone may appear at sufficient amplitude to drive the modulator valve. A portion of this amplifier is sometimes called the microphone amplifier when low-output microphones are employed which require

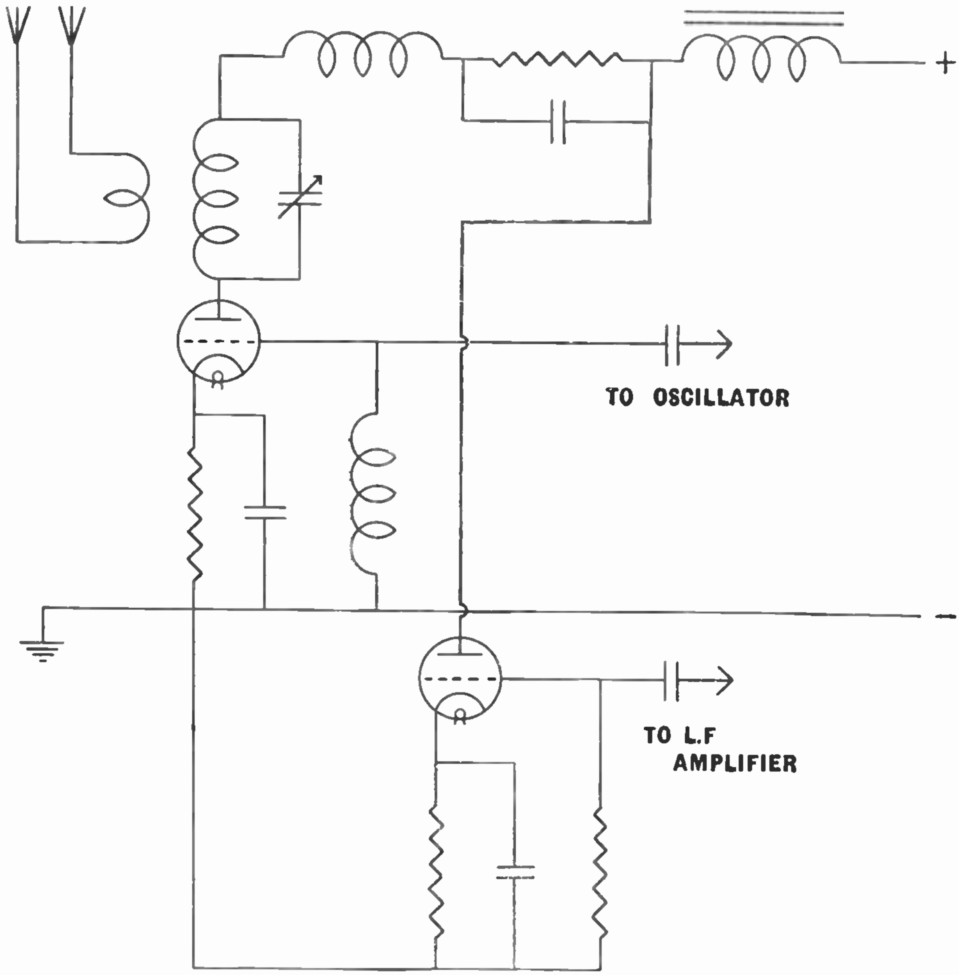


Fig. 66.—The basic circuit of the Heising modulating system ; neutralising is omitted for clarity.

one or more stages of amplification closely associated or even actually built into the head or base of the microphone itself.

Modulation.—Various circuits are available for modulating, some of which are extremely complicated. For the present purpose three basic types may be considered, the Heising, or choke modulator, the auxiliary-grid modulator, and the grid modulator. These three all bring about amplitude modulation, but differ in the manner of its achievement. Frequency modulation is also used in low-power transmission and a general explanation may be found in Vol. 1, Chapter 29, which also outlines the basic principle of transmission.

The Heising Modulator.—The Heising modulating system may be classed as anode modulation and the basic circuit is shown at Fig. 66. It will be observed that the ultimate amplifier is driven either directly from the oscillator or by a chain of valves commencing with the oscillator, and is loosely coupled to the aerial system. The modulator is driven from its speech amplifier and both valves derive their high-tension supply through an audio-frequency choke. The output of the modulator is developed across the choke and is superimposed on the high-tension current of the amplifier, thus varying the amplitude developed across the anode coil of the radio-frequency amplifier. It will be noted that a high-frequency choke is interposed between the anodes of the modulator and the anode of the amplifier in order to prevent the high frequencies appearing in the anode circuit of the latter from appearing in the modulator circuit. If it is desired to modulate at a depth anywhere approaching 100 per cent. it will be necessary that the voltage appearing in the anode of the modulator must be greater than that appearing on the anode of the amplifier. A convenient way of securing this condition is to return the high-tension feed of the amplifier to the positive side of a suitable resistance in the high-tension positive line, the high-tension feed of the modulator being returned to the other or less-positive side of the resistance.

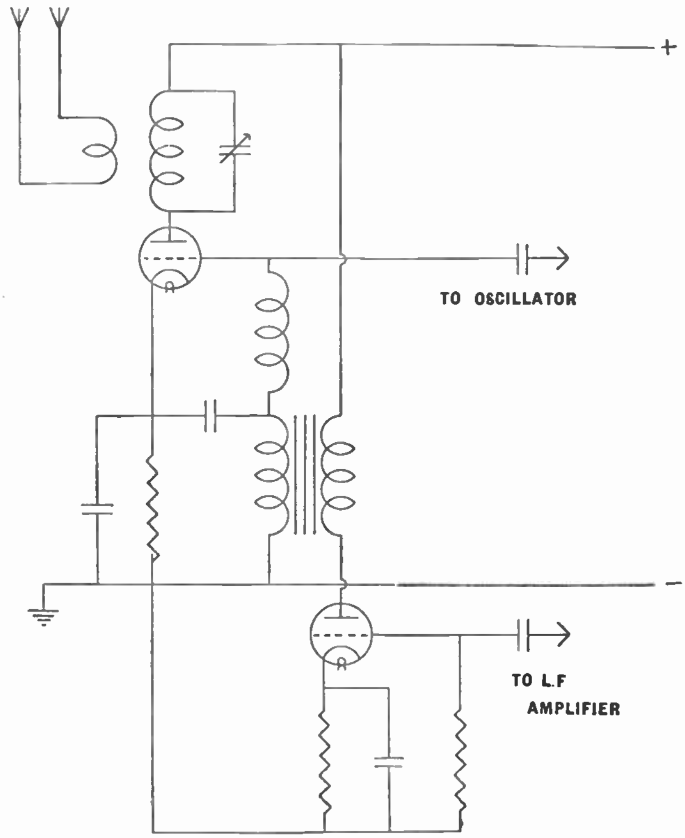


Fig. 67.—The basic circuit for grid-bias modulation: neutralizing is omitted for clarity.

Auxiliary-grid Modulation.—Providing the amplifier is of the tetrode or pentode type it is possible to modulate by varying the potential of one of the electrodes at audio frequency. Modulation of the screening grid produces such serious difficulties that it is rarely, if ever, used, but suppressor-grid modulation of a pentode amplifier is quite practical and straightforward and, providing the valve is expressly designed for this purpose or happens to have suitable characteristics, it is possible to modulate to a depth approaching 100 per cent., while distortion is kept to negligible limits. It is convenient to hold the grid at a suitable negative potential in respect to the cathode, and it is desirable to interpose a simple radio-frequency filter consisting of a choke and condenser between the suppressor grid and the audio-frequency coupling. In the illustration, coupling is effected by means of an audio-frequency transformer, but this is not a fundamental necessity, and it requires little imagination to visualise that the resistance which appears across the secondary could be the anode resistance of a low-frequency amplifier always providing that the amplifier derived its high-tension supply in such a manner that its anode will be negative in respect to the cathode of the high-frequency amplifier by an amount equal to the negative bias required from the suppressor grid. Admittedly, resistance coupling could be more simply arranged by feeding the resistance through the D.C. stopping condenser, but the possibility of direct coupling is interesting.

Grid-bias Modulation.—As its name implies, grid-bias modulation is a system whereby the grid voltage of the high-frequency amplifier is varied at audio frequency, in order that it may so control the amplitude of anode current. A typical circuit is shown at Fig. 67, where the audio-frequency output of the modulator appears directly across the grid/cathode of the high-frequency amplifier. Note that the small standing negative voltage is provided by resistance in the filament to high-tension negative connection of the valve. Once again it will be possible to apply direct coupling, as suggested above. This system is relatively efficient, but requires very careful design, particularly if the high-frequency amplifier works under conditions which allow grid current to flow during a portion of the operating cycle, a condition which usually obtains in transmitters where it is desired to maintain a favourable ratio between input power from the source of supply and energy delivered to the aerial.

Fidelity and Bandwidth.—It is unnecessary to generalise on the fact that the design of the transmitter as a whole will limit the maximum possible quality of reproduction at the receiving end ; there are, however, one or two points that can be emphasised. Both amplitude and frequency distortion can be introduced at the receiving end ; in fact, both these undesirable characteristics can be introduced in a single stage of the low-frequency amplifier. This is, however, an aspect that is properly dealt with in an earlier chapter which is devoted to low-frequency amplification.

Perhaps the first consideration when reviewing fidelity is the microphone itself, since its characteristics are, broadly speaking, the optimum characteristics of the transmitter as a whole—although it is possible to correct certain inherent shortcomings by means of corrector circuits or by suitable amplifier design. There are various types of microphone in general use, including the carbon, moving coil, ribbon, and crystal; all have their particular advantages, but for broadcasting purposes their directional properties cannot be overlooked. Some types of programme require a microphone that is, as far as possible, equally sensitive in all directions; other types of entertainment demand a highly directional microphone in place of, or in conjunction with, a non-directional pattern. Whatever type of microphone is used, it is imperative that its output is handled in such a manner that its good qualities are not impaired.

The question of over-all response is not entirely controlled by the wishes of the designer; the first consideration is the available bandwidth on the frequency at which the transmitter is to be worked. On the official broadcasting bands the separation between stations is only 9 kilocycles per second, which imposes a seemingly serious restriction; on the other hand, it is possible to find room for much wider bandwidths on the short and ultra-short wavebands. The other limitation on bandwidths is one of economics, since a wide-band amplifier is necessarily more expensive and more bulky than one of less-ambitious design.

CHAPTER 9

THE HIGH-VACUUM CATHODE-RAY TUBE AND ITS APPLICATION TO TELEVISION

THE following chapters in this volume are devoted to the principles of television and an example of modern vision receiver design. No detailed reference is made to optical-mechanical systems as they have disappeared at least for domestic purposes. The modern television receiver is based on the cathode-ray tube which is viewed directly except in the case of projection type receivers when the image on a small very high voltage tube is magnified by optical means and thrown on to a screen, usually from the back. In order that the principles and details may be readily understood, it is imperative that the functioning of the high-vacuum cathode-ray tube should be made quite clear at the outset.

The basic function of a cathode-ray tube is to produce a beam of electrons that can be focused to cover a very small area and be so controlled that it can be made to terminate at any point on a fluorescent screen. Fig. 68 shows a skeleton diagram of a cathode-ray tube, while the plate in Chapter 12 shows the external appearance of a typical 17-inch rectangular tube. Reference to the diagram will show that the electrode assembly is denoted as the gun, although it is actually made up of a number of electrodes, described below. In the meantime it will be convenient to look upon the electrodes as a single entity capable of projecting a beam of electrons so that they impinge on the screen at the end of the tube. It should be clearly understood that this beam is in no sense light, but simply an electric current projected into space; the speed of these electrons is considerable and in high-voltage television tubes it often exceeds one-tenth of the speed of light, that is to say, the electrons often travel at speeds of

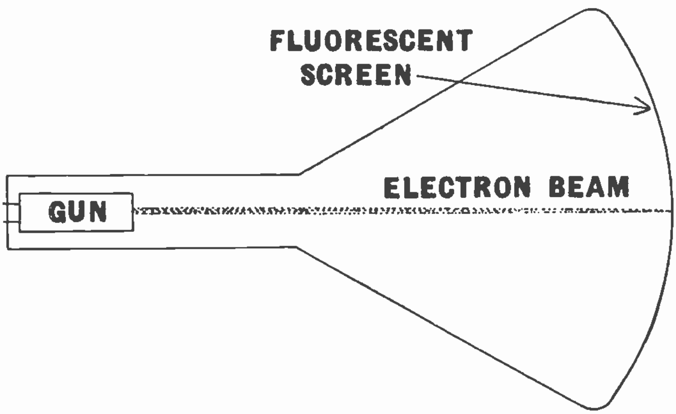


Fig. 68.—A sketch illustrating the fundamental principles of a cathode-ray tube.

the order of 20,000 miles a second. Electrons travelling at considerable velocity will cause certain materials to become fluorescent, and this phenomenon is taken advantage of by utilising materials which exhibit this property to a marked degree. Various materials produce different colours of fluorescent light, the best known of which is zinc silicate, which gives a greenish-blue. Such a colour is unsuited for the needs of picture reproduction, and complex formulæ are used to produce a material giving a black and white picture. The screen may be backed by a "film" of aluminium little more than a few atoms thick which reflects in the forward direction light that would otherwise be wasted. A tube so treated is called an aluminised tube.

Fluorescent materials exhibit the property of persistence in varying degrees. Persistence may be described as the property of the material to remain fluorescent after electrons have ceased to impinge upon it; persistence is often called after-glow, which aptly describes it.

Providing that the gun is so designed that the beam will remain sharply in focus, it is possible by means of additional electrodes or coils so to control the beam that it may be deflected to any point on the screen. When stationary it produces a spot of fluorescent light, and if made to move sufficiently rapidly and repeatedly over some particular path, the route taken by the spot will appear to form a solid trace. Examples of this phenomenon appear in various chapters in the form of oscillograms, but the most noteworthy examples are perhaps Figs. 3–8 in Vol. I. As will be seen in a subsequent chapter the beam is so controlled in a television receiver that it systematically traverses the entire visible portion of the screen. In the meantime attention is directed to the methods of focusing the beam, varying its intensity, and controlling its movement. There are two main types of high-vacuum tube which are magnetically or electrostatically focused. Various modifications are employed in commercial practice, but these do not fundamentally affect the principle, and therefore one of each type will serve as examples.

The Electrostatically Focused Tube.—Fig. 69 shows the complete focusing and modulating electrode system, from which it will be seen that the gun consists of a heater, cathode, modulating grid, and three anodes. The heater is similar to that used in a mains valve, but is not enclosed by the cathode, as this latter electrode is very small, in order that electrons are not emitted remote from the influence of the other electrodes. The total emission is of the order of 50–250 microampères.

The cathode is partially surrounded by the modulating grid, which has a small hole in the centre, usually less than 1 millimetre in diameter. This electrode is held at a suitable negative potential with respect to the cathode and controls the intensity of the electron stream which passes through it. It also has the effect of narrowing the beam as it passes through the hole, owing to the mutual repulsion between the electrons and the negatively charged electrode.

The electrons are pulled through the modulation grid by the positive charge of the several anodes and do not divert from their path and flow to the positive electrodes, partly due to the symmetrical assembly which results in the pull being substantially equal in each direction, and partly due to the very considerable velocity at which the electrons are travelling. It should be understood that the term gun usually implies the electrode system as a whole but references may be found elsewhere in which the term gun is used in the sense of an anode.

The electron beam tends to diverge owing to the mutual repulsion between the electrons, and some means must be found of marshalling them so that they cover a very small area when they impinge upon the screen. In the tube under discussion this is accomplished by the action of the three anodes, which together form what is often termed an electronic lens. The first anode is purely an accelerator and may require a potential of anywhere between 100 and 5,000 volts, according to the spacing of the electrode system as a whole. Anode 2, on the other hand, will be held at a relatively low potential, of the order of 350 volts, while the third anode will be held at a relatively high potential, usually between 3,000 and 15,000 volts, according to the brightness and area of the spot. The higher the potential of anode 3, the smaller and brighter can be the spot.

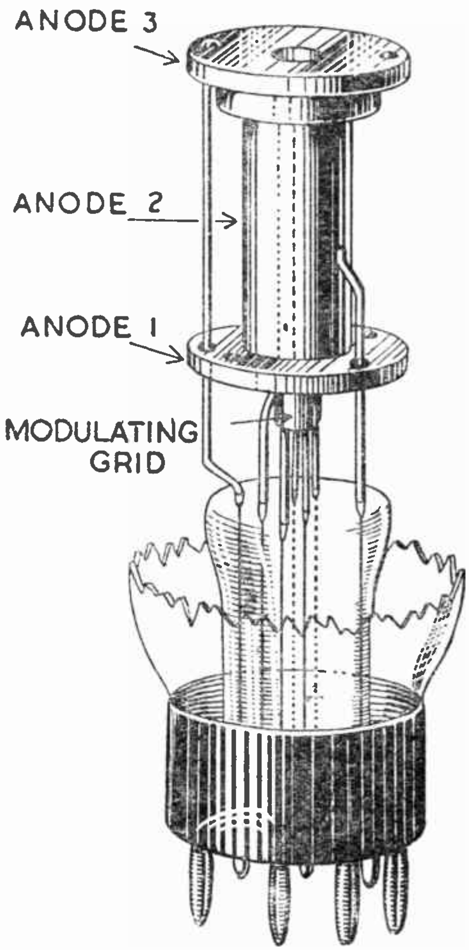


Fig. 69.—Electrode assembly of a typical magnetically focused and deflected cathode-ray tube. The heater and cathode are placed vertically in the centre of the modulating grid.

Anode 2 and 3 will have a very small gap between them, with the result that the field round them will join together and, owing to the dissimilar number of lines caused by the varying potential on the two electrodes, the electron stream will be bent something in the manner of that indicated at Fig. 70. This has the effect of bending the electrons so that they may be made to form a very elongated cone, the base of which is situated in the neighbourhood of anode 3, and the apex on the screen. In order that this condition may obtain it is obvious that bending must take place to a very precise extent, and, to facilitate this, the potential of anode 2 is varied by means of a potentiometer or other device so that it may be adjusted manually to give the smallest possible spot. This control is appropriately termed the focus control.

Mention has already been made of the influence of the modulator grid on beam intensity. As will be seen in a subsequent chapter the modulator grid-volts/beam-current curve of a high-vacuum cathode-ray tube is similar to the grid-volts/anode-current curve of a triode. It will also be seen that for the best operating conditions the tube is biased so that beam current is almost negligible. To facilitate this adjustment the potential applied to this electrode is made variable by means of a potentiometer or other device, which is known as the brightness control, since it does, in fact, control the general brightness of the television picture.

As already explained, the beam is, in fact, a flow of electrons from cathode to screen, and if some form of return path is not provided it is

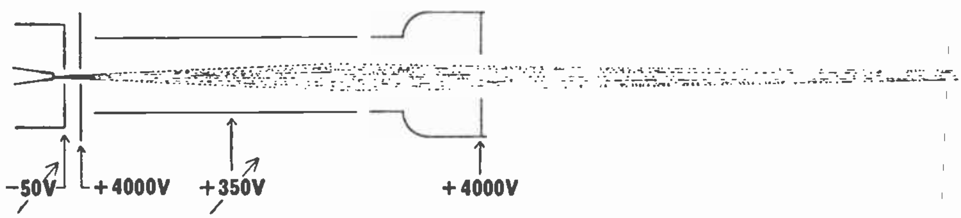


Fig. 70.—An impression of the focusing of an electron beam due to the varying fields of the anodes.

apparent that the screen will quickly acquire such a large negative charge that further electrons would be repelled from it ; this state of affairs does not arise, owing to the presence of secondary emission from the screen. The velocity of the electrons of the beam is such that their impact with the screen material knocks out secondary electrons—which are comparatively slow-moving and are pulled by the most positive object in their vicinity, which will be anode 3—completing what would be a normal electrical circuit, if it were not for the fact that the electrons leaving the cathode are replaced by others given off by the screen as secondaries. Secondary electrons do not travel directly to the anodes but sideways to the inner side of the tube, which is almost invariably lined with some conducting material, usually zinc sulphide or graphite. This lining is in metallic connection with anode 3, in addition to acting as a collector of secondary electrons it serves to prevent the accumulation of charges on the glass which would shift or distort the picture. It should be understood that the beam is deflected *after* passing through the aperture in anode 3, and for the purpose of *deflection* the voltage of this electrode may be regarded as zero.

Electrostatic focusing is by no means obsolete for television tubes.

Deflection.—Deflection may be accomplished by magnetic or electrostatic means, but is almost invariably the latter when electrostatic means are employed for focusing. Reference to Fig. 71 will show that four plates are mounted above the gun which are arranged as two parallel pairs mutually at right angles to each other and so arranged that the beam will pass through their exact geometrical centre, providing, of course, that it is not deflected. These electrodes are known as the deflector plates, and by suitable application of potential they will bend the beam in any required direction. If, for example, a certain plate is made positive with respect to anode 3, then the beam will bend towards it to an extent proportional to the potential difference. If, on the other hand, a certain plate is made negative with respect to anode 3, it will repel the beam and by the application of a suitable potential to one plate in each pair the beam can be bent so that it impinges on any point on the screen. When only two plates are so used, the other plates are shorted to anode 3, but for the purposes of television it is convenient to use push-pull deflection, the input to each pair of plates being so arranged that one plate is driven positive while its opposite plate is driven negative, and *vice versa*. An exception is, however, sometimes made when the screen area is very small.

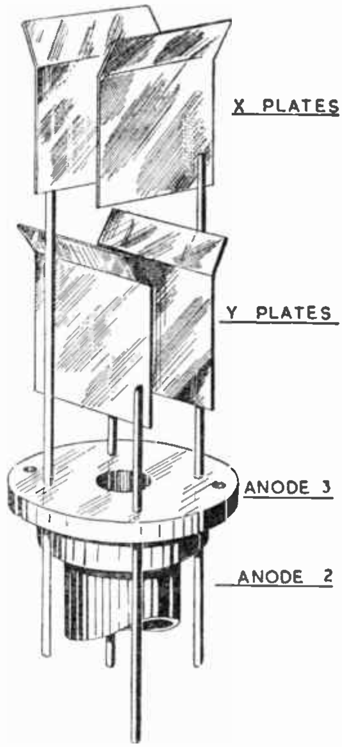


Fig. 71.—The arrangement of deflector plates in a typical electrostatic cathode-ray tube.

Reference to Fig. 72 will show the manner in which the deflector plates are expressed diagrammatically, and this illustration includes all the normal electrodes to be found in the electrostatically focused and deflected high-vacuum cathode-ray tube. It will be appreciated that minor modifications appear in varying makes of tube, as, for example, a screen between each pair of deflector plates. It is perhaps not out of place to mention that these tubes must be pumped to an exceptionally high vacuum, otherwise ionised gas is inclined to collect in the centre of the tube and with the assistance of unfocused electrons will

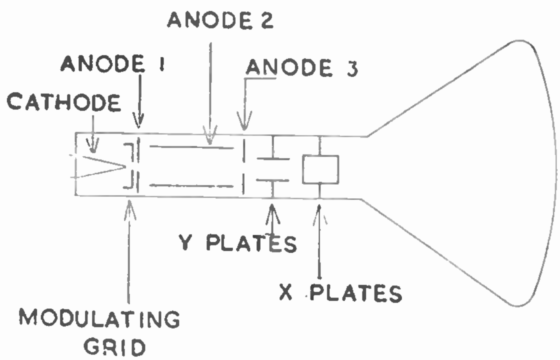


Fig. 72.—Symbolic representation of an electrostatically focused and deflected cathode-ray tube.

produce an unpleasant phenomenon which will take the form of a disc or ring of indistinct light. The assembly of the various electrodes calls for great accuracy, since the several electrodes are provided with diaphragms for the purpose of trapping any electrons which are not properly marshalled into the beam, and it is necessary that the various apertures be so aligned that the cathode may be seen by looking straight through the assembly from the far end. Reference to the plate in Chapter 12 will show that there is a projection from the side of the tube, this terminates in a metal thimble and is, in fact, the connection to the gun. It is usual, for convenience, when referring to the tube to divide it into three pieces, the neck, the bulb, and the shoulder; the first two expressions being self-explanatory, while the latter is the general area of the junction between the first two mentioned.

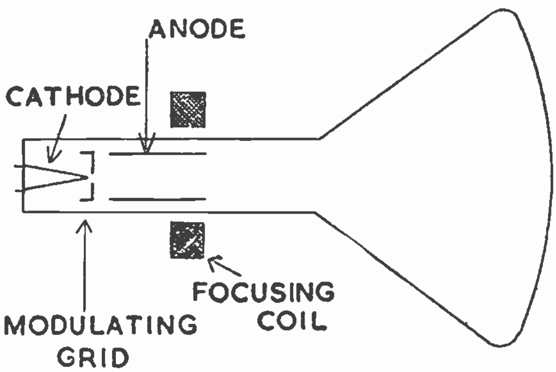


Fig. 73.—Symbolic representation of a magnetically focused and deflected cathode-ray tube. The shaded area can represent either coil or magnet.

The Magnetic Tube.—Remarks that have already been made relative to the electrostatically focused tube are applicable to the magnetically focused type, excepting the means of focusing and deflection, which are by means of a magnet and coils. Such a tube is shown diagrammatically at Fig. 73, from which it will be seen that only three electrodes are used—cathode, grid, and anode. Some tubes are described as tetrodes and have an additional electrode. The cathode and grid perform their normal functions, the anode which may easily be at a potential of 15,000 volts, acts as an accelerator to pull the electrons through the aperture in the modulating grid and give them the necessary velocity; unless some external means is provided to control the electrons they could continue on their way in a divergent beam and impinge upon the screen in a cloud some inches in diameter.

Focusing is accomplished by means of a magnetic field supplied from an external source. It may take the form of a coil energised by direct current or a ring magnet which is slipped over the neck of the tube in the approximate position shown in Fig. 73, where the coil is shown in section. The precise effect of the magnet is somewhat difficult to describe in words, and even more difficult to illustrate; the electrons when passing through the magnetic field are deflected by the latter in a somewhat corkscrew fashion, but owing to their very great velocity they will not complete even one turn, but in the average type of tube about a quarter of a turn. This change of direction controls the ultimate direction of the individual electrons so that they converge and form a small spot on the screen. Focusing in the active sense of the word is accomplished by changing the strength of the magnetic field and consequently the extent by which the electrons will converge. Bearing in mind that the magnetic field will have a limited influence on account of electron velocity, it is apparent that anode voltage may also influence focusing, and this fact is used to advantage in some receivers in which a potentiometer is used to vary the anode voltage to a small extent, say, plus or minus 100 volts, to provide a vernier control.

As already mentioned, the electro-magnet can be replaced by a permanent ring magnet which is magnetised in such a manner that one *face* is north and the other south. Obviously some alternative means is required to give the actual manual control of focus, and in the modern television receiver this is accomplished by means of a split magnet or a magnet with a damping sleeve; the strength of the magnetic field is varied by moving either one half of the magnet with respect to the other half or by varying the relationship between magnet and damping sleeve. This movement is controlled by a lever in some receivers and in others by a knob which actuates a screw mechanism. Disadvantages of the system include a tendency for focus to shift slightly when the hand is removed from the lever, due to a form of mechanical backlash, while the screw method is too slow to permit the optimum position to be found readily. A further difficulty arises with large screen receivers due to cabinet size making it difficult to operate the lever or knob at the back and view the screen at the same time.

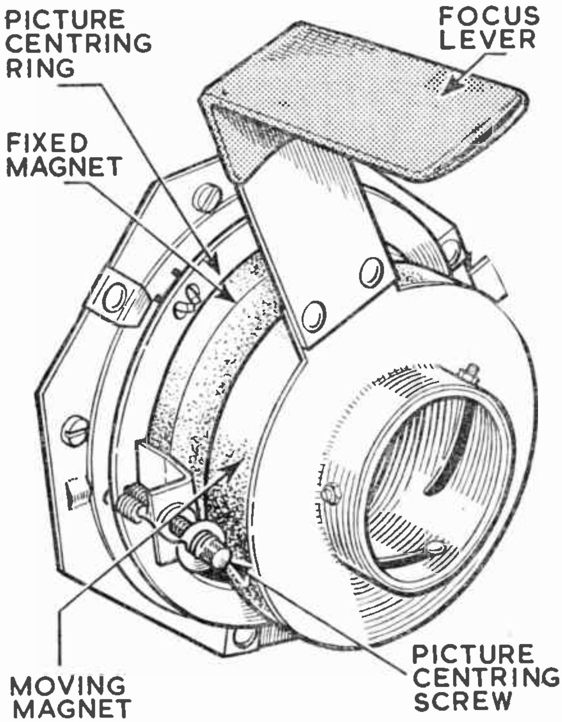


Fig. 74.—A ring magnet focusing assembly with picture shift plate and "screw" type focus lever.

The magnet assembly Fig. 74 includes a round iron plate behind the magnet known as the picture centring ring; this control is referred to later in this chapter. It would not surprise the author if electrostatic focusing for television again became popular.

Magnetic Deflection.—If a coil is placed in such a position that its field cuts the beam, it can be made to deflect the beam so that the effect is the same as that of the deflector plates in the electrostatically deflected tube. If a coil is placed above the neck of the tube so that its axis is vertical, it will deflect the beam upwards or downwards according to the direction of the current passing through the winding, and if a further coil is placed so that its axis is horizontal and at right angles to the beam, it will have the effect of deflecting the beam sideways. In practice, two pairs of coils are used in order to achieve what may be termed magnetic push-pull deflection. A typical scanning coil assembly is shown at Fig. 75 and consists of four coils wrapped in insulating tape and bent to conform with the tube neck. The technique of winding and shaping such coils is very exacting as small irregularities will cause uneven focus and various forms of non-linearity distortion; critical also is the question of insulation since high peak voltages develop across each coil and proportionately between turns. Note that the sleeve on which the assembly is built is encircled with a clip which grips the neck of the tube. Note also the small components which are mounted on the assembly. It is of vital importance that each pair of coils be critically adjusted so that coupling is entirely absent, in order that the current controlling the vertical section does not cause horizontal deflection, and *vice versa*. For reasons that will be apparent in the next chapter, horizontal deflection is referred to as line deflection and vertical deflection is known as frame deflection.

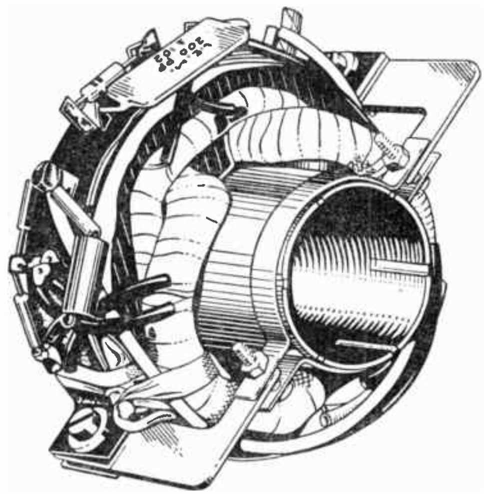


Fig. 75.—A typical deflector coil assembly, note that it carries small components.

Picture Shift Control.—When a cathode-ray tube is used for such purposes as investigating a waveform, it is perhaps unimportant if the horizontal deflection is not quite horizontal and the vertical deflection is not quite vertical, but this condition cannot be permitted in a television receiver, and means must be provided to correct any such deviation. In the case of the electrostatically deflected tube, the only available means is the rotation of the tube itself to such a position that the pairs of deflector plates are precisely vertical and horizontal respectively. The magnetically deflected tube offers a more convenient method of adjustment, since the coil assembly (Fig. 75) can be rotated on the tube until the desired result is obtained.

In addition to squaring up the area of deflection it is necessary to have some means of shifting it up and down or to left or right in order that the area of deflection may be in the centre of the tube. This is easily effected in electrostatically deflected tubes by means of a variable voltage applied to one plate of each pair. The circuit is so arranged that the D.C.

potential of the plate can be made 50 volts or so positive or negative with respect to anode 3; when the plate is negative in respect to the anode the beam will be moved away from it, the opposite effect obtaining when the plate is positive in respect to the anode. The actual resistances or potentiometers used to perform this function are known as shift controls.

The magnetically focused tube does not offer such ready means of providing shift control and, broadly speaking, two possibilities present themselves. Shifting of the beam by means of the ring magnet, which must, in effect, be provided with a mounting permitting it to be moved in any direction that is at right angles to the beam or, alternatively, by varying the spacing between the deflector coils and the tube. As the requirements of these two systems are different, it will be convenient to deal with them separately.

Shift control by means of the ring magnet would be too critical if the actual magnet were moved, and one means of overcoming this is the use of a large soft-iron washer, the outside diameter of which may be equal to that of the magnet, the inside diameter perhaps a quarter of an inch larger than the neck of the tube. This ring is placed flat against one face of the magnet and will give an adequate control by moving it in the required direction. This arrangement, however, has one slight drawback, and that is that movement of the ring and resulting movement of the beam will not coincide. It will be recollected that the ring magnet imparts to the beam a corkscrew movement equal to about 90 degrees, with the result that a movement of the washer in, say, the vertical direction will deflect the spot (and consequently the whole of the deflection area) in the horizontal direction either to right or left, according to whether the magnet is mounted with its south or north face towards the front of the tube.

Shift control by means of deflector coils would be extremely awkward from the mechanical point of view if it were actually necessary to move the coil, but in practice the same result is achieved by providing the coil with an iron core, which can be moved towards or away from the tube, as may be necessary.

There is yet another method of shift control, but one that is rarely used in practice. It consists of either two or four magnets, which may be of the permanent or electromagnetic type; these are arranged about the neck of the tube quite independently of the focusing or deflection arrangements. If permanent magnets are used, the actual shifting is accomplished by movement of the magnet and, in the case of electromagnets, the same effect can be obtained either by moving the coils or varying their magnetic effect.

The several controls referred to in this chapter are given special names when incorporated in a television receiver. These names have been standardised by a responsible Association, and are listed in Chapter 12 of this volume, which contains other details enabling these terms to be completely identified.

Ion Traps.—The introduction of the tetrode cathode tube, which came into more or less general use at the end of the last decade, produced a problem in the form of ions liberated by electrons hitting odd gas molecules at great speed; unlike the electron the ion is relatively heavy and if permitted to impinge on the screen after being accelerated by the anode it can easily cause damage of a type known as ion burn. To prevent such damage the ions are prevented from reaching the screen by deflecting them to parts of the tube where they can do no harm. There are two basic methods used to overcome this difficulty, both of which take advantage of the fact that the relatively heavy ion is slower to change direction than the very much lighter electron. One is a method of gun construction and the other makes use of a small magnet mounted on a ring which is slipped over the end of the tube; the ring may be rotated and moved backwards and forwards to obtain optimum setting. The aluminising technique referred to earlier in this chapter is also a protection against ion burn.

CHAPTER 10

THE TIME BASE

In presenting the theory of what is generally known as the time base the difficulty presents itself that this device also belongs to the cathode-ray oscillograph and it is realised that those who are interested in this subject may or may not be interested in television, and *vice versa*. Bearing in mind that the requirements of television time bases are somewhat peculiar, the subject is treated separately in this chapter, even although a certain amount of overlap is inevitable.

Many years ago various ideas were put forward for the transmission of a picture, and experiments were being conducted well back in the last century which were necessarily confined to the transmission of visual intelligence over land-line, since radio communication was, at that time, unknown. It is no part of this book to give a detailed history of television, since those who are interested will find ample works available dealing largely with historical development. It may, however, be worth while to touch on one aspect, in order to set aside the popular belief that cathode-ray television is a really recent idea or, indeed, that the cathode-ray tube is in itself new. Cathode-ray tubes were manufactured in this country at the end of the last century, and as far back as 1902 Professor McGregor Morris read a paper before the Institution of Electrical Engineers on the application of this device. The first entirely satisfactory reference to the cathode-ray tube for television can be found in 1911, in the form of a remarkable prophecy by the eminent physicist, Campbell Swinton,who in his presidential address to the Röntgen Society indicated that in the near future a considerable amount of attention would doubtless be devoted to the problem of television, and went on to say that he believed that the idea of television reception with the aid of a slotted disc would prove too crude and that the cathode-ray tube would prove the ultimate solution. How true was this prophecy (or perhaps foresight would be a better word)! His whole address is well worth reading and is printed in the proceedings of the Röntgen Society, and elsewhere. His suggested method of scanning the field of vision was a remarkable effort to overcome a problem which to-day is solved by the time base.

Before dealing with the question of the time base and scanning, it is desirable to touch on the subject of nomenclature, since certain standardisation of terms has made the words " time base " into something which is abstract instead of the physical entity housed in a square box; in other words, it is recommended that the term time base be reserved for the regular movement of the cathode-ray beam in any direction that may be required. In earlier chapters various oscillograms have been shown, notably in Chapter 1, Vol. I, where sound waveforms are shown which are, in fact, graphs plotted between amplitude in a vertical direction and time in the horizontal direction. Such graphs were actually produced by an electrostatically deflected tube. The fluctuating "speech" voltage was connected across the vertical deflecting plates and the time-base generator across the horizontal deflection plates; the latter device can for the moment be described as an arrangement which causes the spot to travel from side to side in a linear manner at a predetermined speed and, after reaching the end of its excursion, to fly back to the commencing point as quickly as possible, thus providing the time dimension which can be used as a time reference if the speed of the spot is known—and is therefore called a time base. It is recommended that the device which produces this deflection is known as a time-base generator. In a television receiver two such devices are employed, one for vertical deflection and the other for horizontal deflection, and a committee of engineers has come to the conclusion that when this device is used in the television receiver the term time-base generator is unsuitable, as it does not, in fact, have any significance in terms of time; nevertheless the terms "time base" and "time-base generator" continue to be used.

The term blocking oscillator is sometimes used to mean a time-base generator but is not so used in these volumes, since the term in itself suggests a particular type of circuit which is used in some television receivers but not in others, and is also confusing when qualified by the words "line" and "frame."

Scanning.—Sound is essentially one-dimensional, inasmuch as the cone in the loudspeaker is only required to be in one place at any one time. In the same way the diaphragm of the ear may change its direction 10,000 times, or more, in a single second, but nevertheless it is only required to record one value at any particular instant. When the eye rests on, say, a photograph, it will convey to the brain a wealth of tone values simultaneously; in fact, the human eye can register upwards of 200,000 tone values (picture points) simultaneously. It is apparent, therefore, that whereas sound requires a single channel for effective reproduction, television would require some thousands of channels if some means were not found to circumvent the difficulty. Such means are available in the form of scanning, which is, in fact, the transmission of a picture point by point, arrangements being made to synchronise the receiver and the transmitter so that the tone value of each point is reproduced in the same position at the receiving end as it occurs at the transmitting end. To accomplish this some method must be adopted to explore the picture to be transmitted. This could doubtless be done in many ways, even to the fantastic extent of exploring the image catherine-wheel fashion, starting from the centre and working outwards. In actual practice it has been found convenient to explore or, to use the right term, scan the picture in a series of horizontal lines, starting from the top left-hand corner and finishing up at the bottom right-hand corner, such a sequence being shown at Fig. 76, where the scan-lines are shown solid and the fly-back lines are shown broken. In this illustration only a relatively small number of lines are shown for the sake of clarity, but actually some 200 will be necessary, which must be scanned some 50 times per second in

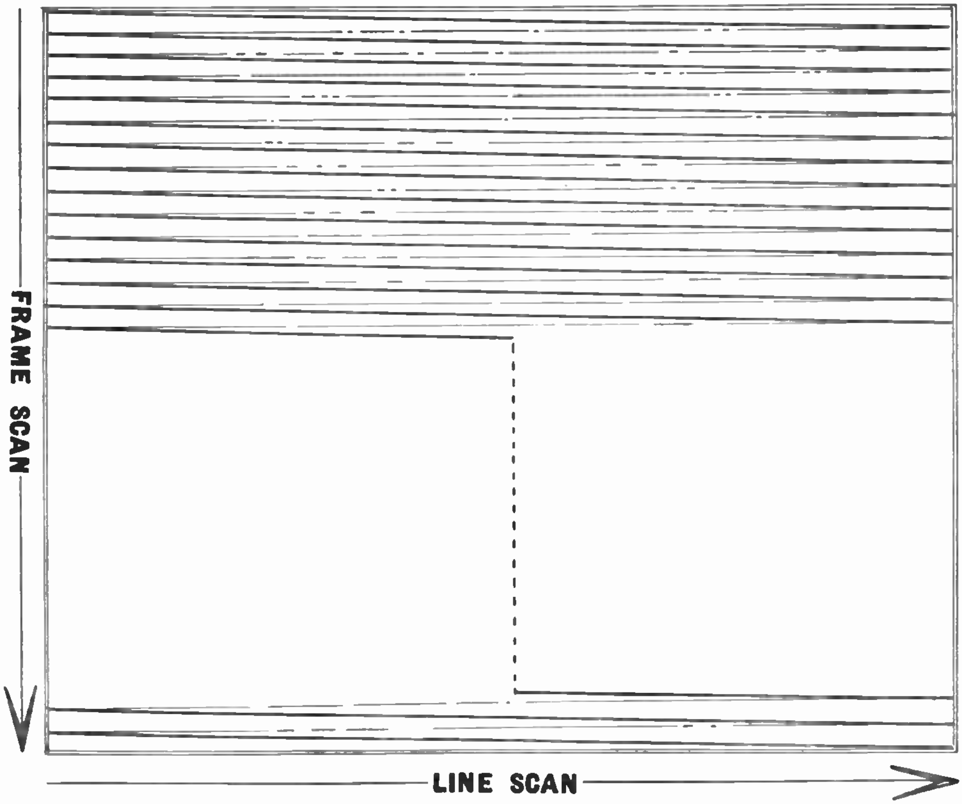


Fig. 76.—A sequential, or continuous raster; the thick lines represent the line scan, and the thin lines the fly-back.

order to achieve that wealth of detail which is referred to as high-definition television.

Reference to Fig. 76 will show that each line occurs immediately after the one above it and is known, therefore, as sequential or continuous scanning; the actual pattern or route followed by the spot is known as the raster. The present system of television does not use sequential scanning but interlaced scanning, a refinement which is dealt with later. Attention can now be directed to the circuits which cause the cathode-ray beam to scan the picture area of the receiver.

Time Base.—As already intimated, the purpose of the time base is to cause the spot to travel across the screen, while another one causes the spot to move from the top to the bottom. As the former will accomplish one line in each cycle of its operation, it is known as the line time base, while the latter will have completed one cycle of its operation when the entire field of view has been covered, and is known as the frame time base. The only convenient method that suggests itself for causing the spot to travel across the screen is a device which will build up a voltage or current at a linear rate of increase, and to provide it with means for rapidly breaking down to the amplitude at which it commenced. Reference to Fig. 77 shows the resistance R in series with the condenser C, the junction of the two being connected to a deflector plate. High-tension negative is connected to the anode of the cathode-ray tube, and the opposite deflector plate similarly connected. When the switch is closed the condenser C will charge through the resistance R and the point X will become progressively positive and so will the plate to which it is connected, with the result that the beam will be pulled in the direction of the plate in question and a single-line sweep will have been accomplished. Means must be found for quickly discharging the condenser so that the spot can return to its original position and recommence the line scan when the condenser C recommences to charge. A skeleton circuit for this purpose is shown at Fig. 78, where it will be seen that a triode valve is connected across the condenser C. Suppose that the applied high-tension voltage is of 500 volts. Circuits of this description have a cumulative action, and it is therefore easier to

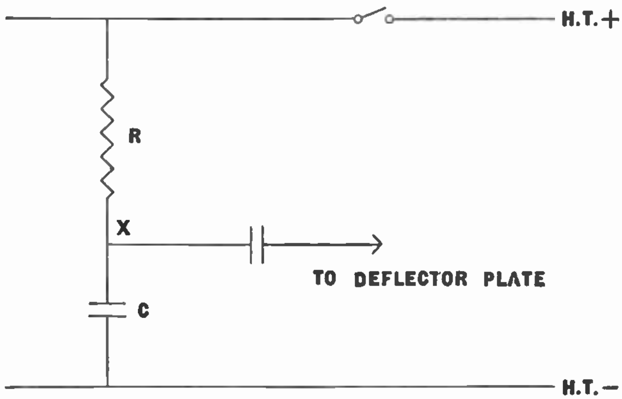


Fig. 77.—Diagram illustrating the principle of a time base.

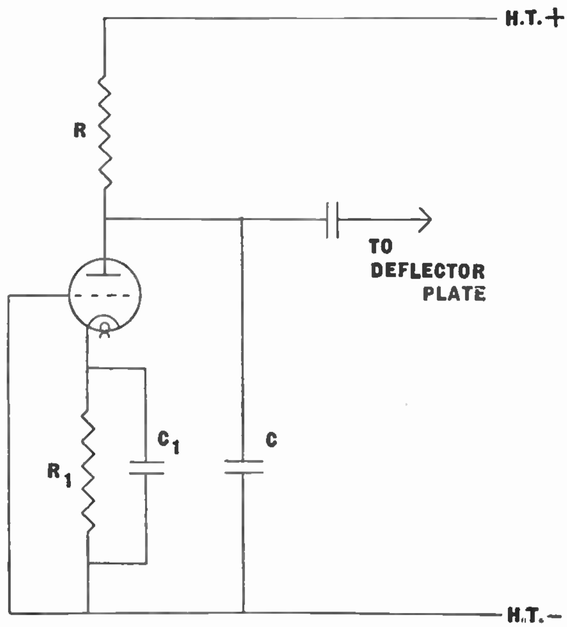


Fig. 78.—Diagram of an elementary time base, to illustrate the text.

investigate the performance of the circuit on the assumption that it has been working for some time. The purpose of the triode is to discharge the condenser C, and when it does so the discharge current will form the anode current of the valve and must pass through the bias resistance R_1, which may be assumed to have such a value that the maximum potential developed across it is 100 volts, which will charge the bias condenser to approximately this value. It is now convenient to take up the action of the circuit from the point where anode current has ceased to flow, simply because the condenser has discharged to a low value and the grid of the valve is held at a high negative value, sufficient, in fact, to prevent the flow of anode current. The condenser C will now charge, while the negative voltage applied to the grid will decrease, due to the charge in C_1 leaking away through R_1, and the potential across C will continue to increase and, incidentally, deflect the cathode spot, until the anode potential has reached such a value that, associated with the decreased negative grid voltage, will allow anode current to pass and discharge the condenser C. The circuit shown at Fig. 78 has served to illustrate the principle of a time-base generator, but is fit for little else, since the discharge time may well be of the same order as the charging time, and the difference between the charge and discharge potential across the condenser C will be small. Attention may now be directed to Fig. 79, which shows an elaboration of Fig. 78 and may be considered as a workable time base. Once again it will be convenient to commence at the point where the condenser C is in a discharged condition, anode current has ceased to flow, and C_1 is charged to a potential of 100 volts. Assuming that the characteristics of the valve are such that anode current will not flow under the conditions indicated until the anode potential is 350 volts, then a change of nearly 350 volts is available for deflecting the spot, since the action of the circuit will almost completely discharge the condenser C. When the potential across C has reached the requisite value, anode current will commence to flow and must pass through the primary winding of the transformer, which will induce a voltage across the secondary which can be so connected that it drives the grid in the positive direction. This will have the effect of increasing anode current, which will, in turn, develop a

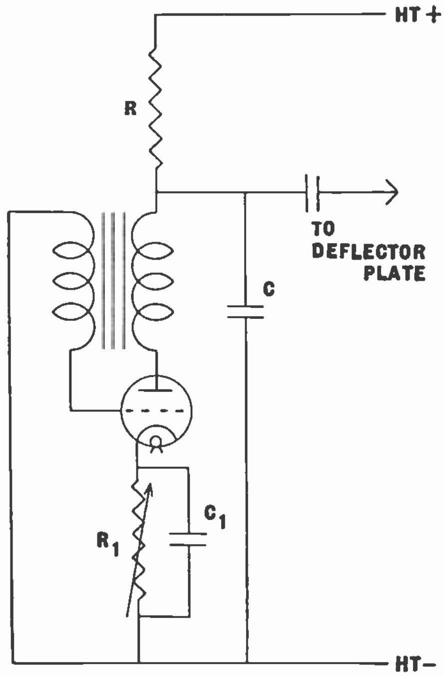


Fig. 79.—The circuit shown at Fig. 78, modified to speed up the discharge.

larger potential across the secondary, driving the grid still more positive, and so on until the condenser C is almost completely discharged. The whole action of the discharge valve is to decrease rapidly the discharge time, and in practice the voltage built up across the secondary will drive the grid so positive that the effective impedance of the valve is only a few ohms and the instantaneous anode current is of a very high order. If it were not for the fact that the capacity of C is necessarily small, the duration of the discharge would be such that the valve would only last for a few operation cycles and then completely collapse ; assuming that the value of C is small, the resulting waveform will be such that the mean anode voltage is perhaps 20 volts, although the peak anode potential may be 500 volts or more.

No mention has yet been made of means for controlling the frequency of the time base so that the same number of lines per second is completed at both receiving and transmitting ends. Bearing in mind that one of the controlling factors is the negative bias on the valve, it is apparent that the frequency of operation can be controlled by making R_1 variable, which will determine the initial charge of the condenser C_1 and the rate at which this charge will leak away ; thus, the lower the value of R_1 the greater will be the frequency. Providing R_1 in physical reality is an exceedingly well-made variable resistance, it will be possible to hand-synchronise the line time base of the receiver with the transmitter. Infinite patience is required, but it is nevertheless possible. Fortunately such dexterity is not required, as the transmitter radiates a series of synchronising impulses which can be made to control receiver time bases.

Although Fig. 79 is a workable time base, it has one great objection, and that is that the potential across C will not build up in a linear manner, since the charging of a condenser through a resistance follows an exponential law, with the result that the spot will travel much faster at the commencement of the line than at the end, causing a type of distortion which results in, say, a man of normal proportions in the middle of the screen being exceedingly stout if he walks to one edge of the picture, and equally thin if he walks to the other edge. This non-linearity can be overcome by the use of another valve, which can be described conveniently, if a little incorrectly, as a push-pull amplifier (see Fig. 80). It should be understood that the push-pull action is not between the two valves but between the charging resistance and condenser and the valve V_2: the valve V_1 performs an entirely separate function—that of discharging.

The arrangement is shown at Fig. 80, from which it will be seen that the charging condenser takes the form of two condensers in series marked C and C′ to form a capacity potentiometer. If the capacity ratio between C and C′ is equal to the amplification of V_2, it is apparent that the waveform across R_3 will be of equal amplitude, but in opposite phase to the potential across C and C′, and consequently the non-linearity of the increase of positive potential on the one plate is offset by corresponding non-linearity in the decrease of potential on the other plate. The deflection of the spot will be equal to the *mean* potential change, which is linear. This explanation would be entirely accurate if the characteristic of V_2 was in itself linear. Unfortunately this is not the case, and the value of R_3 has to be carefully adjusted and the ratio between C and C′ also carefully calculated to produce as nearly as possible the required linearity. It will be noted that V_2 is biased by grid current, which is a convenient arrangement. It will also be noted that R is variable; since R_1 will determine the frequency of discharge, it follows that R will determine the voltage across C and C′ when discharge occurs, or, in other words, the total deflection of the spot or length of the line and therefore the width of the picture. It should be observed that only a portion of the charging resistance is made variable, which is highly desirable, since if the whole were variable it might be turned to the minimum position in the process of adjustment, which would place the whole applied high-tension voltage across the valve and cause it to collapse. This is particularly important, as the applied voltage will often be 1,500 volts, or more, in order that the action of the time base be confined to a relatively small portion of the charging curve of C, C′ and thus achieve an improvement in linearity at the onset and make the correcting action of V_2 considerably less critical.

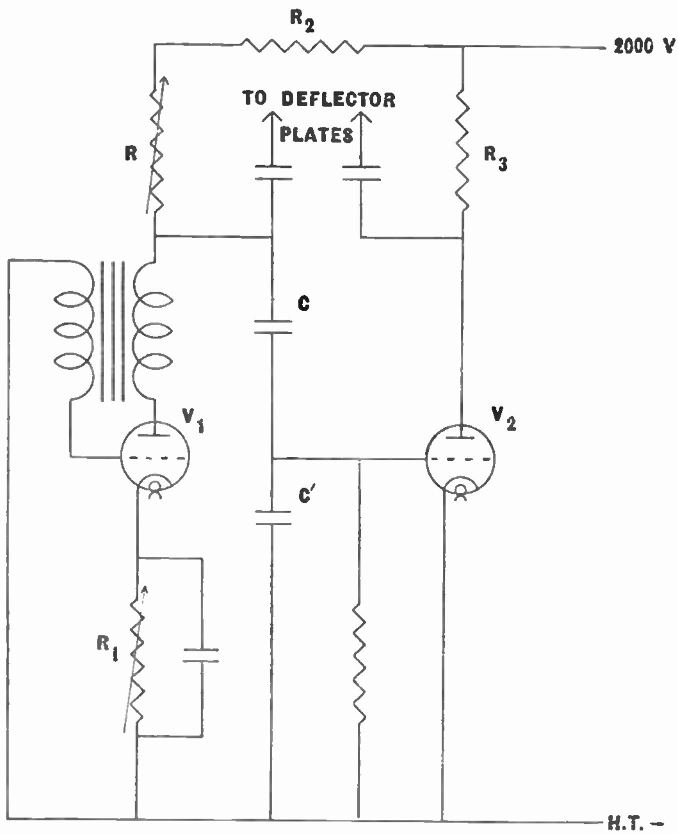


Fig. 80.—Circuit shown at Fig. 79, with an additional valve to obtain linearity. It should be noted that R and R_2 together form the charging resistance.

The Frame Time Base.—The action of the frame time base (*i.e.* the vertical deflection) is very much slower than the line time base—the actual frequencies for the system radiated by the British Broadcasting Corporation and also by the Independent Television Authority being respectively 10,125 lines per second and 50 frames per second, each frame consisting of 202½ lines. The circuit shown at Fig. 80 would work equally well as a frame time base, although the values of C, C′ would be several times greater and the values of R, R_2 somewhat larger. The line and frame time bases can be considered as independent units and each may employ an entirely different principle or, alternatively, may employ the same principle. For the purpose of describing the method by which the transmitter controls the receiver time bases it will be convenient to consider the circuit shown at Fig. 80 for both the line and frame time base.

Synchronism.—The television transmitter is modulated to a depth of almost 100 per cent. From zero to 30 per cent. is used for transmitting synchronising intelligence and from 30 per cent. to 100 per cent. for picture intelligence ; the end of each line is terminated by a short synchronising impulse, which consists of a fall to almost zero for about $\frac{1}{100,000}$ of a second, while at the end of a frame a long impulse is transmitted which is equal to the duration of several lines. This aspect of television technique is dealt with later in the chapter, and it is sufficient for the moment to bear in mind that impulses are transmitted at the end of each line and each frame and it will be necessary to arrange receiver time bases so that the action of the line time base is controlled by the line-synchronising impulse and the frame time base by the frame-synchronising impulse. This obviously needs some discriminating arrangement so that the one does not affect the other.

Fig. 81 shows a complete time base using the principle shown at Fig. 80. It may be regarded as a line time-base circuit unless a time-constant condenser is included (shown dotted), when it will function as a frame time base. The separator valve, V_3, is in all ways a conventional pentode, with the exception of the anode, which is split into two sections insulated from each other, and led out to separate connections. In order that the separator valve shall give the maximum response to a given impact the screen may be run at a relatively low potential and the control-grid biased to approximately cut-off, which in the circuit under review is accomplished by a cathode bias-resistor. The total incoming signal is applied across the grid/cathode circuit of the separator valve, some form of filter usually being provided to prevent the higher frequencies associated with the picture from appearing across the grid/cathode circuit of the valve at sufficient amplitude to affect it materially. The input signal which will have passed through a detector and output stage will be so phased that it drives the grid in the positive direction and brings about a large change of anode current in both anode circuits. On the occasions of a line impulse the effect on the frame time base will not be appreciable, owing to the action of the time-constant condenser (shown dotted) across the inductance in the anode circuit of the valve preventing any great change taking place due to the long time-constant of the circuit and the short duration of the line-synchronising impulse. The effect on the line time base will be considerable, as one of the anode circuits of V_3 includes the tertiary winding of the discharge transformer, which will be so connected that the change in anode current of V_3 will drive the grid of V_1 in the positive direction and will cause V_1 to commence discharging C, C′, providing the valve is nearly ready to discharge on its own. In practice R_1 is adjusted so that the valve is *nearly* ready to pass current at the termination of a line, and the synchronising impulse (which terminates the line) from the transmitter starts the discharge action, thus holding the line scan of the receiver in synchronism with the line scan of the transmitter. The control R_1 is known as the line hold or line-synchronising control, although the actual synchronising is controlled by the transmitter. The same action occurs in the frame

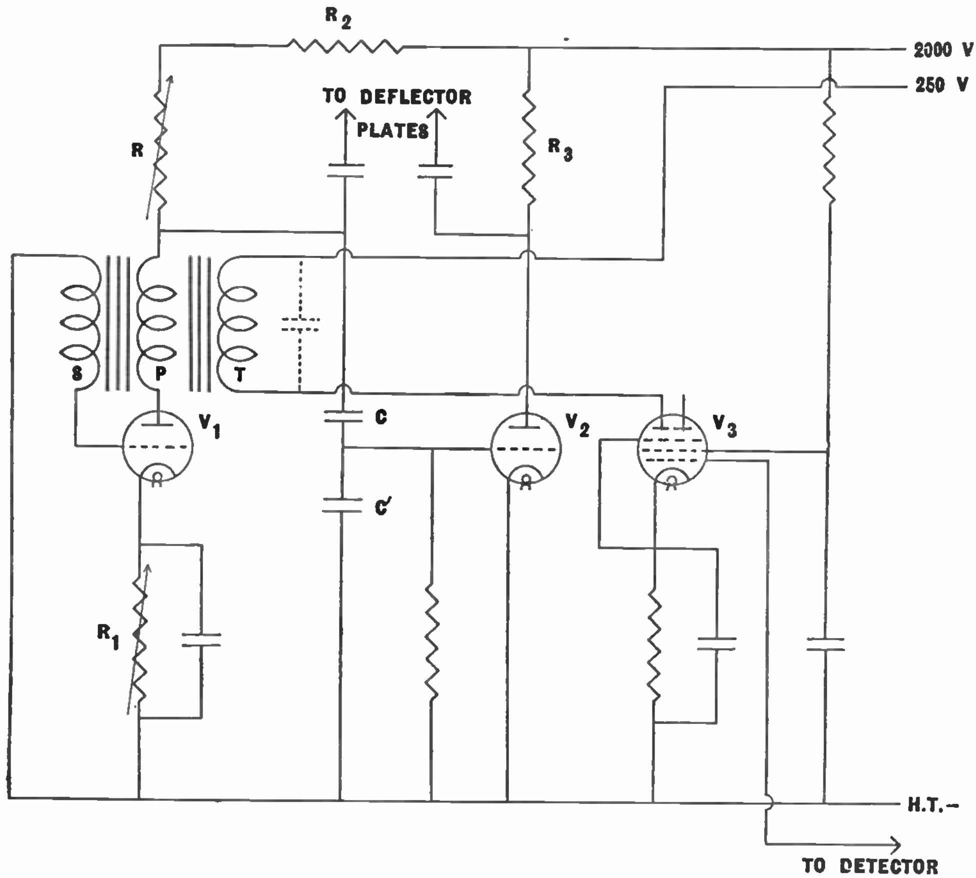


Fig. 81.—A complete time base for either line or frame, with synchronising separator valve.

time base, the cathode resistance of the discharge valve being known as the frame hold or frame-synchronising control, which again is adjusted so that the frame-discharge valve is nearly ready to pass current at the end of the frame, but the action is actually started by the frame-synchronising impulse, which will develop the necessary voltages across the secondary of the frame transformer, due to its long duration.

It will be noticed that the leads to the deflector plates are provided with D.C. stopping condensers to prevent the high-tension voltage from appearing on the deflector plates. It should not be assumed, however, that the plates can be left floating from the D.C. point of view, but must be connected to the C.R.T. anode. This may consist of a direct connection through a very high resistance ; sufficiently high, in fact, to avoid appreciably loading the time-base circuit or, alternatively, may be taken through a high resistance to a potentiometer suitably connected so that its mid-point is approximately at anode potential, permitting deflector-plate potential to be varied a few volts in the positive or negative direction in order to shift the mean position of the spot; or, in other words, shift the picture from side to side or up and down, as the case may be, for the purpose of centring.

The arrangement shown at Figs. 80 and 81 are essentially suitable for operating an electrostatically deflected tube and are not convenient for producing the power output that is required for the magnetically deflected type. Suitable circuits for this purpose are dealt with at the end of this chapter, and attention may now be directed to the nature of the transmitted waveform and the principle of interlaced scanning.

The Television Signal.—The modulation of a television signal is often referred to as D.C. modulation, since it is from maximum to minimum and not a symmetrical modulation as used for sound transmission. The term is, however, somewhat confusing and should not lead the reader into regarding the resultant changes of amplitude in the light of direct current. So rapid are the changes that some components of the signal may change at the rate of 2 megacycles per second and will behave like any other current or potential of this frequency. Many readers will be familiar with the type of diagram shown at Fig. 82, and it is emphasised that this drawing is, in fact, the *modulation performance* of the transmitter and is not the actual *radiated waveform* which is symmetrical and requires the action of a detector before it can be utilised and, incidentally, appear in the manner indicated in Fig. 82.

Reference to Fig. 82 will show diagrammatically the manner in which the available power is divided between the synchronising intelligence and picture intelligence. It will be observed that the maximum output from the transmitter corresponds to maximum white and that a 30 per cent. output corresponds to black. The amplitude below black may be regarded as infra-black or, to use the colloquial phrase in common use, " blacker than black." This latter term is particularly apt, because if the tube is working below the black level it may be driven the corresponding amount in the direction of white and still fail to show any illumination.

As already intimated, Fig. 82 shows the modulation of a typical television signal expressed diagrammatically. The illustration shows three complete lines, and it will be interesting to study the diagram in detail. It will be observed that the portion marked A is all above the black level and constitutes, therefore, picture intelligence. Commencing from the extreme left-hand end, it will be observed that the modulation rises rapidly to halfway between black and white, and a correctly adjusted receiver would be modulated so that the cathode-ray tube would produce a brilliancy that may be termed middle-grey. Further progress in the right-hand direction shows a succession of increases and decreases of modulation, and one point actually touches maximum white. It will be appreciated that the portion marked A represents a complete visible line, and as the cathode-ray beam at the receiving ends travels along the line its brilliancy will vary in accordance with the amplitude of the modulation. Although the *visible* line is the portion marked A, the complete line may be regarded as the portion marked B, which has a duration of precisely $\frac{1}{10125}$ second. At the end of the portion marked A there is a very slight rest and then a sudden decrease of modulation from 30 per cent. to zero. This change is intended to actuate the synchronism-separator valve of the receiver and cause the receiver time base to trip and the cathode-ray beam to return to the beginning of the next line. To allow time for this to be accomplished there is an appreciable rest pause, which is of the order $\frac{1}{100000}$ of a second. Note particularly that the modulation is at zero and therefore well below the black level, consequently there will be no visible sign of the return trace, or fly-back as it is generally termed.

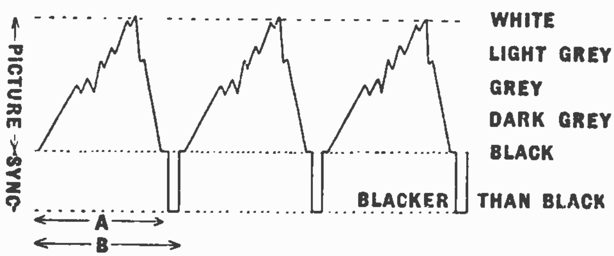


Fig. 82.—Modulation waveform of the television signal.

There is a tendency to regard the cathode-ray beam as a tangible entity passing from left to right and quickly from right to left *ad infinitum*, but looking into the matter a little more deeply it is apparent that the beam will not exist during the fly-back, as the fall in modulation will have so biased the modulating grid that no gun current will flow. It is therefore correct to regard the beam as a tangible entity when travelling from left to right, at which point it ceases to exist and again becomes a tangible entity at the beginning of the next line. It might be argued that when reproducing a picture containing the black section the beam would cease to exist when scanning that particular section, but this is not, in fact, the case, as normal picture modulation falls only to the black level, at which a very small gun current will continue to flow, although it will be insufficient to cause any visible illumination. The fly-back, it will be observed, occurs at the "blacker than black" level, which will completely stop the beam current which is necessary, as the returning trace would otherwise make itself apparent where it crossed such portions of the screen that were still fluorescent due to after-glow from the previous trace.

After the short rest at the "blacker than black" level the modulation returns to the black level, and there is a very short rest of the order of $\frac{1}{500000}$ second to enable both the transmitter and receiver to recover from the rapid change of modulation before commencing the picture-intelligence portion of the next line.

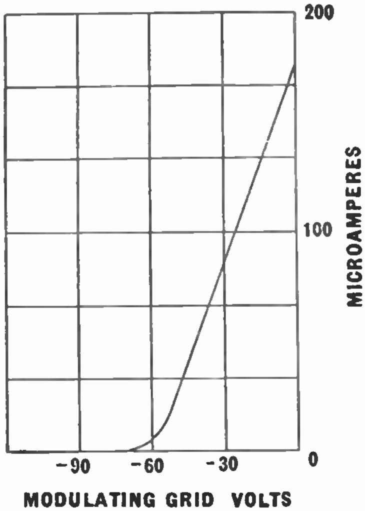


Fig. 83.—Modulating-grid-volts/beam-current curve of a typical cathode-ray tube.

Cathode-ray Tube Modulation.—Before going on to the relatively complex frame-synchronising impulse, it is convenient to consider exactly how the modulation is applied to the tube. Fig. 83 shows a conventional modulator-grid-voltage/beam-current curve of a cathode-ray tube. It will be observed that the tube possesses characteristics similar to those of a triode valve and that in the example chosen cut-off is achieved when the modulating grid is held at a negative potential of 70 volts in respect to the cathode. For the convenient consideration of modulation it is desirable to represent the curve in a more direct form by plotting modulator grid voltage against illumination, see Fig. 84.

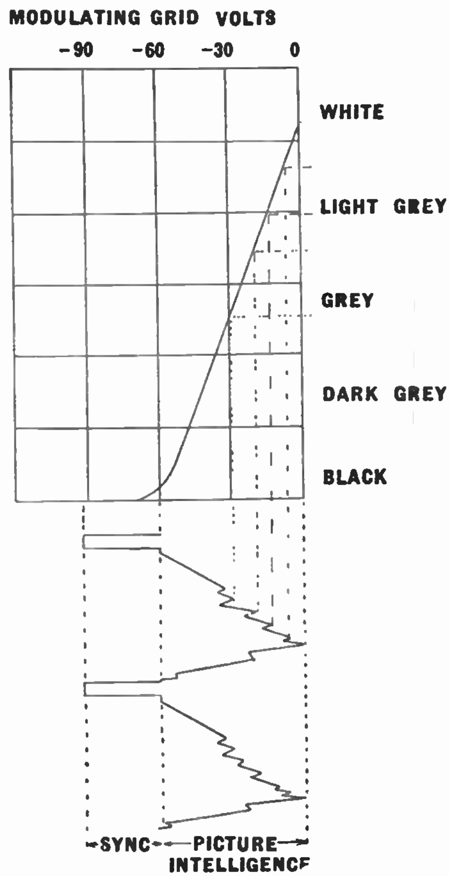


Fig. 84.—The television signal applied to the modulating grid of a typical cathode-ray tube.

It will be observed that the modulation is applied in such a manner that the black level coincides virtually with cut-off, adjustment being provided to facilitate this in the form of variable D.C. bias on the tube. If this is so adjusted that the bias applied is rather less than that required to achieve the cut-off, the general illumination of the screen will be increased, and *vice versa*. This control is labelled " brightness " for the convenience of the user, who will normally be quite unacquainted with the manner in which the control functions.

The modulation must be applied to the tube in the correct sense, that is to say the change from black to white must be a change in the positive direction. When the detector is followed by a single vision frequency amplifier, usually called the video amplifier, the detector must be so arranged that its output is in the opposite sense, since the video amplifier will reverse the sense and black and white would become interchanged. If, for any reason, two stages of video amplification are used then the detector should be arranged in the same manner as when no video amplification is used; in other words, each video amplifier reverses the sense of the output, consequently in this respect two amplifiers cancel out. It is important to note that these remarks apply only to amplifiers following the detector, the number of stages preceding the detector is immaterial insofar as the correct sense of output is concerned.

Although the video amplifier corresponds to the output stage of a sound receiver, it should be clearly understood that the waveform of a vision signal cannot be regarded as a low-frequency waveform, as it will be made up of frequencies up to about 2 megacycles : although the signal has passed the detector stage it is necessary to treat it as a very high-frequency current and to take most elaborate precautions to prevent loss of the highest components. Returning to the diagram, Fig. 84, it will be noted that modulation from black to white increases the gun current and consequently the illumination produced by the cathode-ray beam; modulation from "blacker than black" has no appreciable effect. This diagram readily illustrates the point already raised that during modulation below the black level the movement of the beam will not produce any visible phenomena.

The Interlaced Raster.—The principle of scanning has been touched upon earlier in the chapter, and it has been stated that sequential scanning is not used in present-day television. The objection to this system is the production of a " flicker," caused by the fact that the general area of maximum illumination tends to move progressively from the top to the bottom of the screen. To overcome this difficulty the obvious method would be to speed up the velocity of the beam, so that a sufficient number of complete scans be produced each second to deceive the eye. This is impracticable, as the velocity of the trace is inherently tied up to the bandwidth of the transmitted waveform and the required velocity would require such an immense band-width that amplification at the receiving end would present an almost insurmountable problem. An alternative method of overcoming this difficulty was devised in the form of the interlaced raster, which is a system whereby the cathode-ray beam scans each *alternate* line and then returns and scans those which were missed out on the previous occasion. This has the effect of shifting the general area of maximum brilliancy at twice the speed and also pairs up each point of maximum brilliancy with the corresponding point of the next line which is rapidly dying away.

The design of a circuit to produce an interlaced raster would appear somewhat complex, but most of the difficulties are swept away if each frame (*i.e.* the complete interlaced raster has two frames) is made up of an odd number of lines. This will be more readily apparent after studying the diagram at Fig. 85. Only a few lines are shown for the sake of simplicity. Starting from the top left-hand corner line 1 is scanned, then the fly-back occurs, then line 3 is scanned, and so on. The last line is interrupted half-way and scanning recommences at the top centre and continues to the end, the fly-back occurs and line 2 is scanned, and subsequently 4, 6, 8, and 10, and so on until the end, at which juncture an odd number of complete lines are achieved and the spot returns to the top left-hand corner and repeats the entire sequence. No mention has yet been made of the actual manner of the return of the spot from the end of one field to the beginning of the next. Certain popular publications indicate that the trace returns in a straight line; actually, the time taken is relatively considerable. In the standard British system there are 405 lines per raster and 25 rasters, or 50 fields, per second. It is apparent, therefore, that the line time base must function 10,125 times per second and the

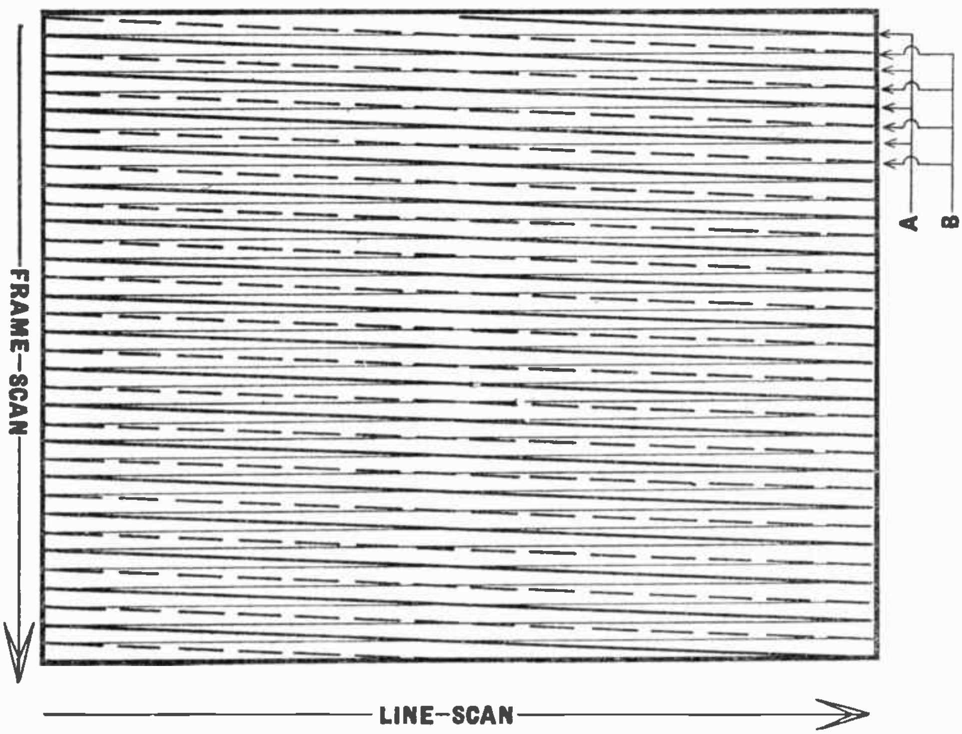


Fig. 85.—Two scanning fields, comprising lines marked A and B, which together form a complete interlaced raster.

frame time base 50 times per second. The time constants associated with the relatively slow frame time base make it extremely difficult to achieve rapid discharge, and in the present system some six lines are " wasted " at the end of each scan to allow time for the collapse of the frame time base. During this interval, line time-base impulses continue to be transmitted, in order that line synchronism is not lost ; thus, the return trace takes a zigzag path in the manner indicated at Fig. 86, which shows the return after the end of the scan that terminates in a full line. The decreasing spacing is due to the non-linearity of the time-base discharge.

Considerable stress is laid on the fact that Fig. 86 is purely imaginary, as there is no actual trace, for reasons that have already been explained, but the diagram can be considered as a curve showing the voltage relationship between line synchronism and the collapse of the frame time base or, alternatively, the trace which would appear if the bias were taken off the modulating grid of the cathode-ray tube.

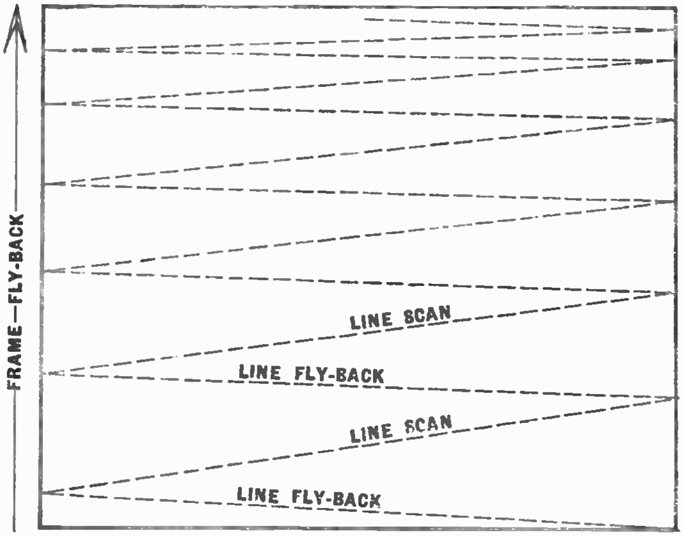


Fig. 86.—The frame fly-back following a scanning field which terminates in a complete line.

The Frame-synchronising Impulse.—The frame-synchronising impulse is, as already mentioned, of relatively long duration, partly to allow the necessary time interval and partly to differentiate it from the line impulse, although the latter requirements could probably be achieved in some other way. Fig. 87 shows the frame impulse at the end of a scan which terminates in a complete line. It will be observed that after the last line modulation drops to the "blacker than black" level forming the line impulse. It is then held at this level for nearly half a line, and then returns to the black level, where it remains for about $\frac{1}{100000}$ second, forming what is a line impulse, which occurs at an interval of half a line to the previous one, and so continues until the end of the complete frame impulse, when it recommences the picture intelligence of the first line of the next scan. The reason for the half-line interruption is not immediately apparent, but is actually used to simplify the achievement of the half-line break at the end of the alternate fields which finish at the termination of a half-line. The occurrence of these half-line impulses has no effect on the

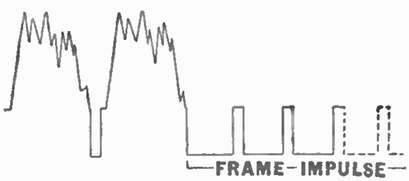


Fig. 87.—Frame impulse terminating a scanning field which ends with a complete line.

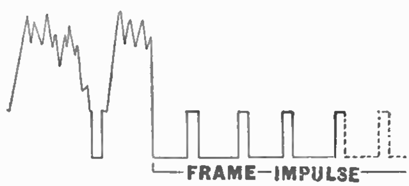


Fig. 88.—Frame impulse terminating a scanning field which ends with a half-line.

receiver whatsoever, since they occur at an instant when the line time base is so far from being in a condition to discharge that the change of anode current in the synchronism-separator valve fails to trip it.

Fig. 88 shows the termination of the last line of the alternate fields which finish on a half-line. It will be observed that picture intelligence is maintained for half a line, when it drops to the " blacker than black " level and causes the frame time base to function at the appropriate instant and continues with the usual half-line impulses, at the termination of which it reverts to picture intelligence.

It should be clearly understood that the illustrations Figs. 82, 84, 87, and 88 show the waveforms purely diagrammatically. There are no purely vertical lines in any waveform, since they would represent a change of amplitude in zero time. They are actually all sloping to a greater or lesser degree. It should also be noted that the abrupt changes of amplitude as represented by right angles are equally impossible and, in actual fact, time-base impulses have more the appearance of the response-curve of a sharply tuned circuit. The author has produced a number of oscillograms of waveforms, but these do not lend themselves to reproduction, as the changes of amplitude which occur are so rapid that it is difficult to produce more than a barely discernible trace on the photograph, which trace would be completely lost in the course of printing.

Synchronism Separation.—Fig. 81 has already been described, and shows a type of time base which can be used for either line or frame deflection. The differentiation between the line and frame impulse is easily obtained, since it is merely necessary to connect a condenser of suitable capacity across the tertiary winding of the frame transformer, which will so adjust the time constant of the circuit that the short duration of the line impulse is insufficient to bring about a change large enough to trip the frame time base when the latter is properly adjusted.

The type of synchronism separator already discussed is an example of one particular line of thought and is subject to numerous minor modifications. There are, however, synchronism separator arrangements that may be considered as being in a separate category. In this purely preliminary survey of television principles, it is not possible to go into the subject very deeply, as when taken in detail it is so interdependent on the time-base circuit as a whole that the subject becomes complicated and could probably occupy this entire volume without including any really superfluous information ; before leaving this subject, however, there is one other arrangement which deserves specific mention and employs a double diode in place of the split anode pentode already discussed.

The Double Diode as Synchronism Separator.—Fig. 89 shows the relevant portion of a television receiver and comprises the vision detector V_1, the video amplifier V_2, the synchronism separator diode V_3. It will be observed that the synchronism separator diode differs from the vision detector, inasmuch as the former has separate cathodes.

The functioning of the arrangement is comparatively simple. It will be remembered that the synchronising impulse so modulates the transmitter that the carrier amplitude falls virtually to zero for the duration of the impulse. This change will bring about a fall of potential across the diode load R, L, or, in other words, the grid of the video amplifier is driven in the positive direction, with the obvious result that the potential across the cathode resistance R_1 R_2 is duly increased to an extent more or less corresponding to the 30 per cent. change in the transmitter modulation. This increase of voltage drives the anode of the synchron-

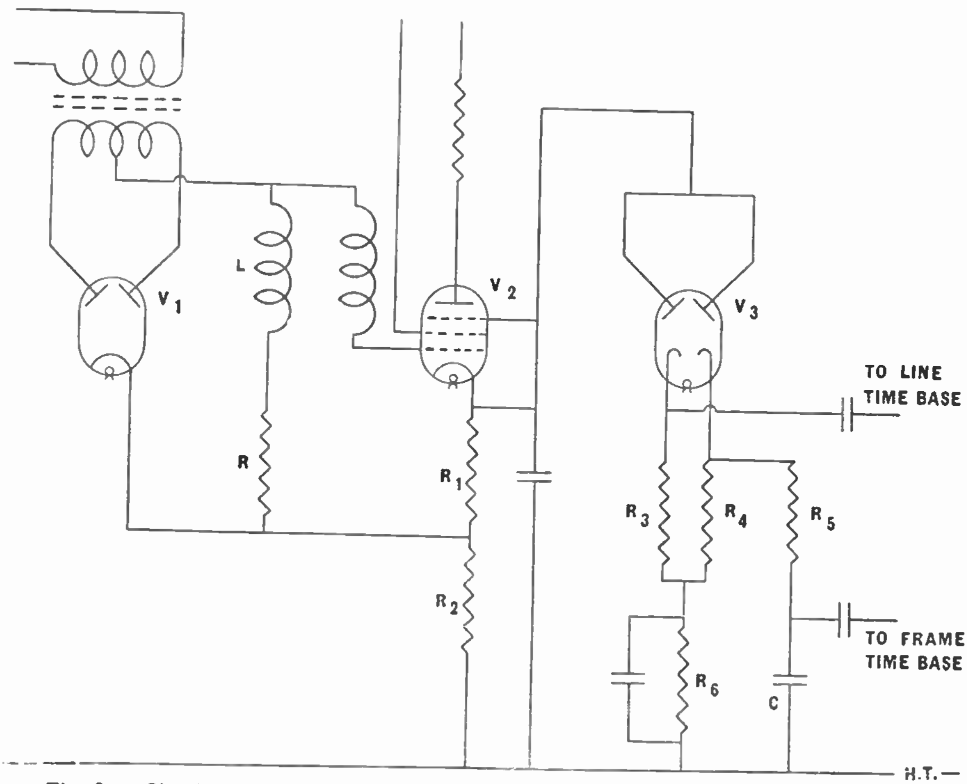


Fig. 89.—Circuit arrangement for using a double diode valve for synchronism separation.

ism separator diode in the positive direction, bringing about a rise of potential across the cathode resistances R_3 and R_4 respectively. This increase drives the cathodes in the positive direction, which change appears directly across the grid/cathode of the line discharge valve, causing discharge to commence, always providing that the valve is in a suitable condition, which is allowed for by the adjustment of the line synchronising control in the usual manner. Some discrimination must be introduced to prevent the frame time base discharging on the occurrence of the line impulse, and in the circuit in question this is accomplished by the simple time-constant arrangement introduced by R_5 and C, which prevents any effective rise of potential during the short duration of the line impulse, but naturally allows an adequate potential to build up during the long frame impulse. The action is such that the frame-discharge valve will discharge at the instant of the first half-line interruption.

The actual anode current passed by the diode will flow through the extra bias resistance R_6, which is shunted by a relatively large condenser; suitable values could be ·5 megohm and ·3 μF. This will produce a standing bias on the valve, so this anode current does not flow between maximum signal amplitude and 30 per cent. amplitude, therefore the diode is inoperative during picture intelligence and passes current only when signal amplitude falls below 30 per cent., which, it will be remembered, is reserved for synchronising intelligence.

There are one or two minor points to which attention may be drawn; it will be noted that the two leads from the cathode circuits of the synchronism separator diode are provided with stopping condensers in order that the relatively small grid return resistances of the time-base valves do not, in effect, short the standing bias resistance R_6. Should necessity arise to provide the synchronism separator circuit with pre-set control in order that it may function at optimum, it is merely necessary to make R_6 variable, although such control is somewhat superfluous. Reference to the illustration will show that the lead to the diode anodes is apparently returned to the suppressor grid as well as to cathode of the video amplifier. This is merely incidental, and it should not be allowed to confuse the interpretation of the circuit, since the connection is, in fact, solely due to the necessity for returning the suppressor grid to the cathode; if the suppressor grid were returned to the H.T. negative line, its potential would be considerably different from that of the cathode, owing to the voltage drop across R_2 as well as across the usual bias resistance R_1. In selecting a valve or, alternatively, a pair of single diode valves to perform the function of synchronism separation, it must be borne in mind that the cathode will run between 20 and 50 volts above the H.T. negative line and, consequently, the insulation between cathode and heater must be able to stand this potential difference. The average type of diode valve is not designed to work under such conditions.

The time-base circuits which have been described in this chapter employ hard valves and are arranged for electrostatic deflection. Fig. 90 shows a hard valve time base arranged for magnetic deflection. The circuit shown is stripped of almost all refinements and is included solely to illustrate the principle involved. As will be seen later, such refinements as negative feed-back can be introduced for the purpose of correcting linearity or, alternatively, modifications can be introduced to give pre-set control of linearity as an alternative when it is inconvenient to introduce negative feed-back.

Reverting to the circuit under discussion, it will be observed that V_1 is a discharge valve which functions in very much the same way as that already described in conjunction with the charging resistance R and the charging condenser C. In this case the anode is not taken to the deflecting arrangements but through a condenser to the grid of a pentode valve. As the condenser C charges, it will drive the grid of the pentode positive and increase the anode current, the variable component of which will

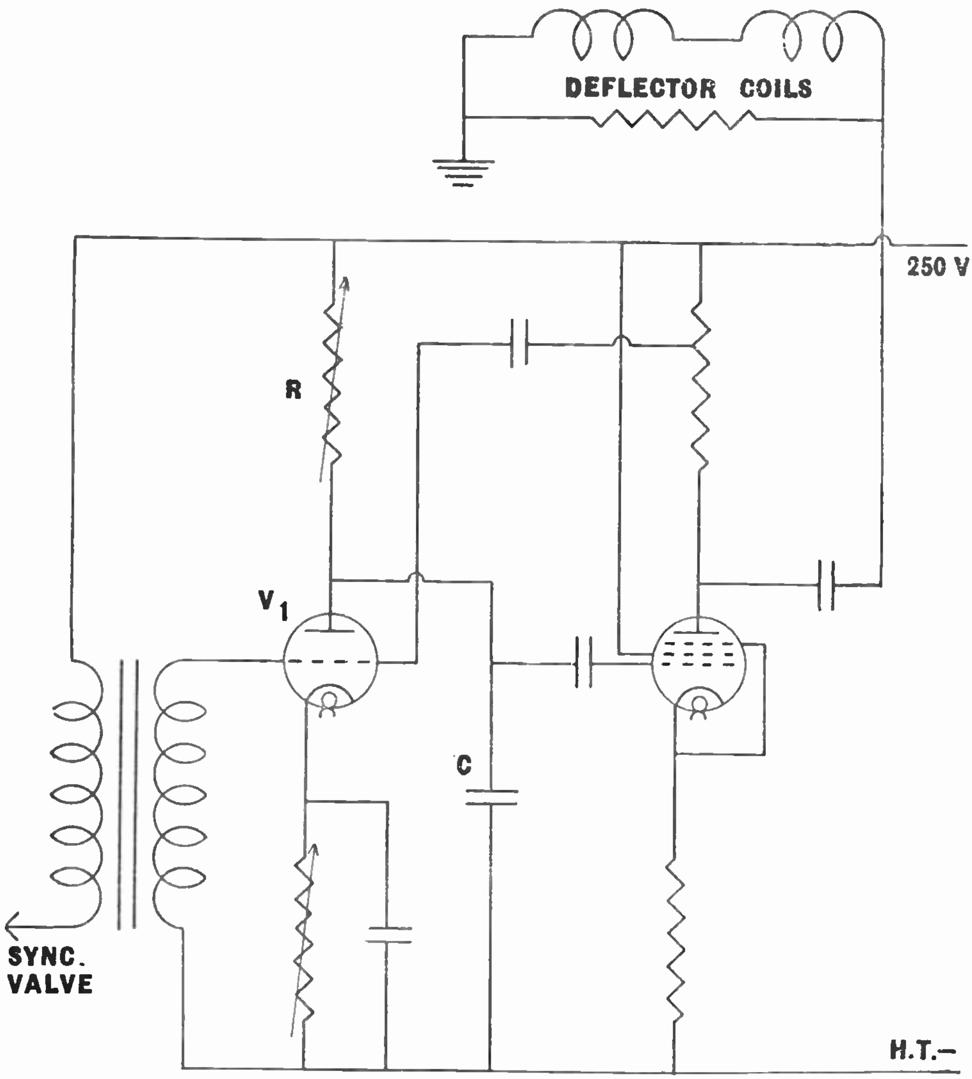


Fig. 90.—A skeleton circuit of a time base suitable for magnetic deflection.

flow through the deflector coils. It should be noted that the condenser which acts as a D.C. stopper between the pentode anode and the deflector coils must necessarily have relatively large capacity, and when the arrangement is employed as a frame time base it may be as large as 10 μF. It will be noticed that the deflector coils are shunted with a resistance, which is very necessary to prevent excessive peak voltages from developing across the coils. This type of circuit is dealt with in greater detail in Chapter 12, which deals with a complete television receiver circuit.

Time Bases using Gas-discharge Triodes.—The principle of the gas-discharge triode is touched upon in the next volume, where its use is referred to in connection with the cathode-ray oscillograph. Unavoidably, therefore, the following brief description of this device appears in two chapters. The gas-discharge triode functions differently from an ordinary hard valve. When the anode voltage is raised to the requisite potential commensurate with the grid potential, current begins to flow which ionises the low-pressure gas content of the envelope, forcing down the internal impedance and increasing the anode current; as anode current increases ionisation also increases and impedance falls still lower. Within a very short space of time, of the order of $\frac{1}{50000}$ second, or less in special types, the valve will pass an anode current large enough to destroy itself unless an adequate limiting resistance is included in the circuit. Once ionisation has started the grid loses control and no amount of negative grid voltage will stop the flow of anode current, which can only be stopped by interruption of, or a drastic reduction of, the anode potential. The rapid discharge of the gas-filled triode is used to discharge a condenser in the same way as a neon tube is used in the most rudimentary form of time base.

At one time objections were raised against the use of the gas-discharge triode on the grounds of uncertain and inconstant action; there can be no doubt, however, that even a moderately well designed valve is perfectly satisfactory for use in the frame time base where the frequency to be dealt with is relatively low. The gas-filled valve, providing it is well designed, is also satisfactory for use as line frequency, providing the circuit is so designed that the operating potentials are kept constant; which means, among other requirements, that the grid-bias potential must be obtained from an independent source and not be solely dependent on the discharge current. The gas-discharge triode permits the associated time-base circuit to be comparatively simple and also effects certain direct and indirect economies. Nevertheless, many engineers exercise a preference for time bases employing hard valves.

The Basic Circuit.—Fig. 91 shows the basic circuit of a gas-discharge triode and its attendant amplifier, the whole circuit being arranged for magnetic deflection. The discharge valve V_1 is a gas-discharge triode, and is provided with a variable anode load R_1 and variable grid bias derived from varying the cathode potential by means of the resistance R_2. By appropriate adjustment of R_2 ionisation can be prevented until the anode has reached the appropriate potential, when discharge begins. Consequently, the setting of R_2 will determine the frequency of discharge, and is therefore the synchronising control. The anode resistance R_1 and the fixed resistance R_2 together form the charging resistance, while the condensers C_1 and C_2 together form the charging condenser. The capacity ratio existing between C_1 and C_2 provides potentiometer feed for the amplifier V_2. It will be noted that the amplifier is biased by grid current through the resistance R_3, and that its gain is controlled by the variable trailer resistance R_4.

It is apparent that the setting of R_1 will determine the potential that can be built up across C_1 and C_2 in the time permitted for the setting of R_2, and it therefore exercises some control over the ultimate scanning

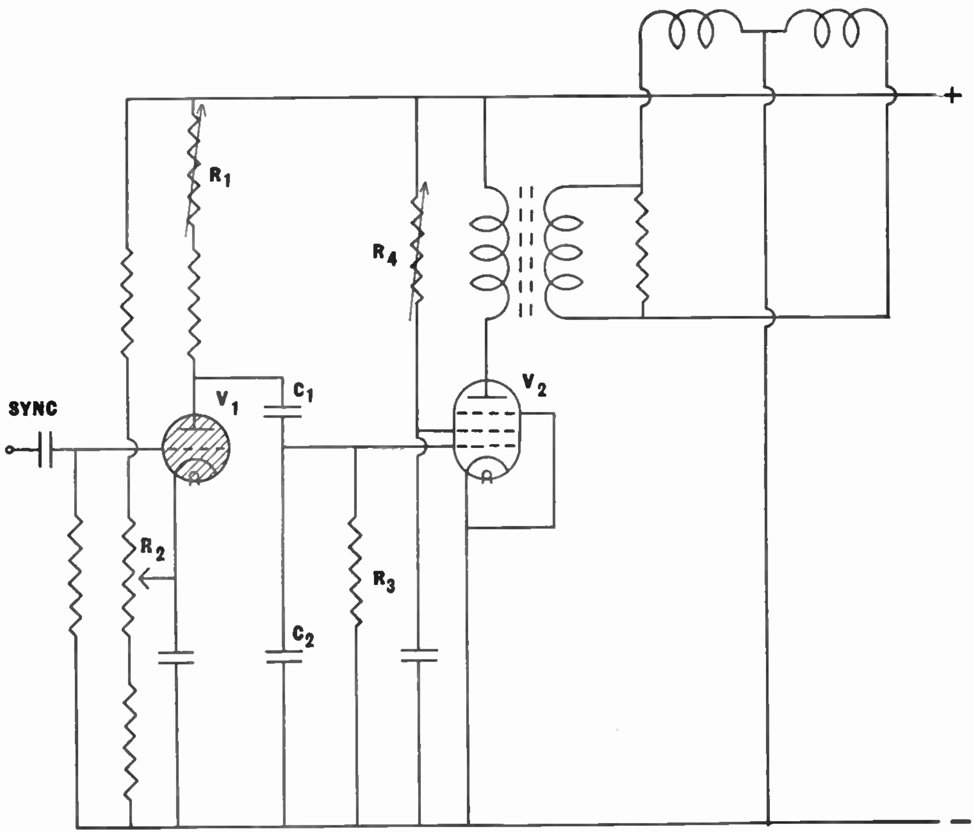


Fig. 91.—A simple circuit using a gas discharge valve and arranged for use with a magnetically deflected cathode-ray tube.

amplitude. Actually, however, it only effectively varies the amplitude at one end of the scan, since its greater effect is to determine what portion of the charging curve is used to drive the valve V_2. It is convenient, therefore, to use this resistance as linearity control, and to use R_4 as the gain, or scanning amplitude control, which function it performs by varying the gain of the amplifier valve V_2. The output arrangements do not call for any comment, as they are precisely similar to those used in the previous illustration.

The circuit under discussion is held in synchronism by a perfectly standard arrangement, such as the split anode separator circuit or double diode separator circuit, the synchronising impulse being fed to the grid of the gas-discharge triode, which will be so biased by the appropriate setting R_2 that it is more or less on the threshold of ionisation at the appropriate instant, and the commencement of ionisation is brought about by the grid being driven in the positive direction by the impulse from the synchronism separator. The circuit arrangement, while

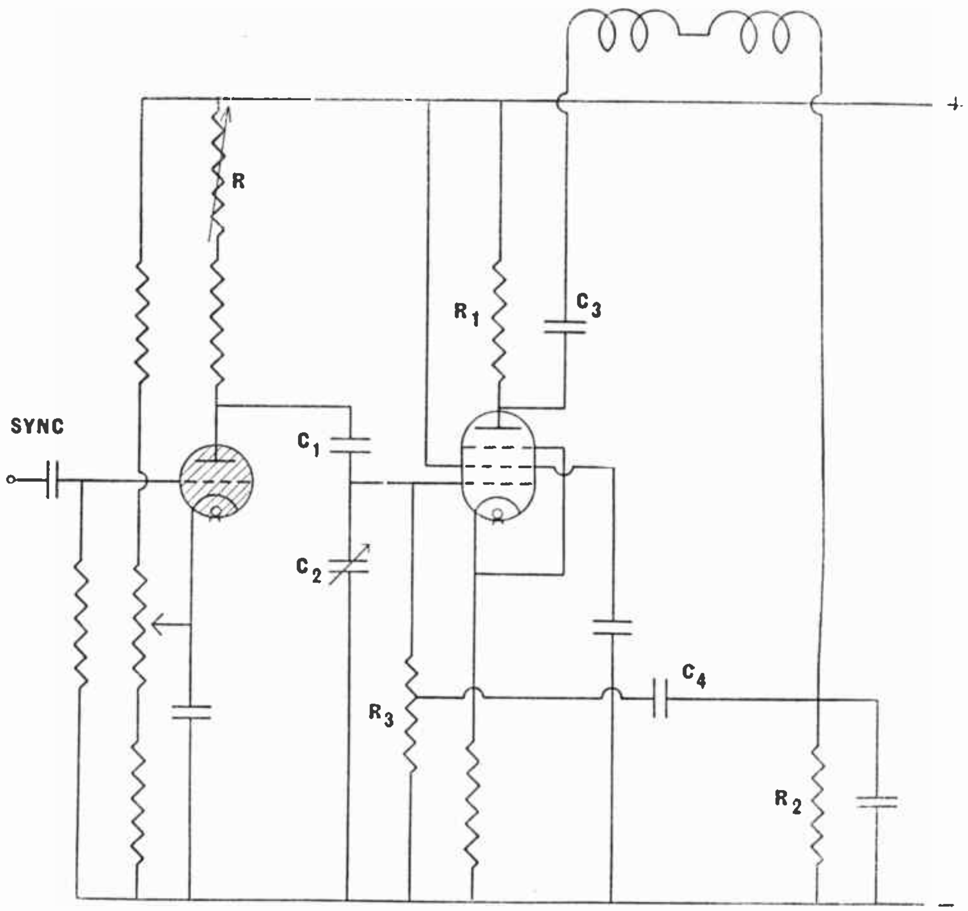


Fig. 92.—An improved arrangement of Fig. 91, employing a form of negative feed-back to correct linearity.

suitable for explanatory purposes, cannot be considered as adequate for modern television; the chief objection being that R_1 will not exercise sufficient control of linearity when used with valves selected at random without forcing the length of scan to ridiculous dimensions. The second major objection is that variation of R_4 will not bring about the necessary change of gain with many types of valves. Other disadvantages include the absence of any means of overcoming non-linearity introduced by the amplifier valve itself. It will be interesting to see what modifications can be introduced, using this circuit as a basis.

Linearity Control.—The circuit diagram shown at Fig. 92 shows a possible variation in which the discharge circuit is unaffected, with the exception of the potential splitting arrangements, which act as a feed to the amplifier valve. In the modified arrangement this takes the form of a potential splitting arrangement formed by C_1, C_2. Consideration of the circuit will show that these two condensers are virtually in series with each other and are so arranged that variation of C_2 will determine the percentage of the total voltage which will appear across the grid/cathode of the amplifier valve and consequently determine the length of the ultimate scanning. It is possible, therefore, to so adjust the resistance R and the condenser C_2 that the voltage appearing across C_2 is constant, and in this way the resistance R may be adjusted to any extent as a means of correcting linearity without upsetting the size of the picture. Normally the condenser C_1 will be adjusted by the manufacturer and will not appear as a pre-set control; but, on the other hand, it is possible to visualise the advantage of ganging R and C_2, each working on a definite law of value against rotation, so that linearity could be controlled without affecting picture-width, making the condenser C_1 variable to perform this latter function. The advantage of this seemingly complicated refinement is that each control performs a single function, which renders adjustment very much easier than is the case when controls are interdependent.

Simple Negative Feed-back.—As a further means of correcting the linearity of the time base as a whole use is made of negative feed-back. It will be observed that the deflecting coil is parallel-fed by the anode resistance R_1 and the feed condenser C_3. It will also be noted that the low-potential end of the deflecting coil is connected to the high-tension negative line through the resistance R_2. A portion of the scanning voltage will appear across R_2, this is fed back to the grid of the amplifier valve by means of the condenser C_4, which is connected to a convenient tap on the grid return resistance, an arrangement which prevents the considerable artificial increase of input capacity which would obtain if C_4 were connected directly to the grid.

It will be noticed that the amplifier valve is biased by means of a resistance in the cathode circuit, an arrangement which permits the grid return resistance R_3 to be of relatively low value, which is a great advantage if the high tension has appreciable mains ripple imposed upon it; even if R_3 is of the order of a megohm, the maximum unsmoothed ripple which could be tolerated across the high-tension rails would be of the order of ·01 per cent.

The Fuller Use of Negative Feed-back.—Negative feed-back is employed as a means of correcting non-linearity, but at the same time a loss of gain is inevitable, since negative feed-back brings about a portion of the voltage appearing across the anode load reintroduced into the grid circuit out of phase. It is seldom possible to apply sufficient feed-back to virtually remove non-linearity, owing to the enormous sacrifice of gain involved. It is apparent, therefore, that the normal amount of feed-back can be increased with advantage. By extending this line of argument a little farther it may be seen that negative feed-back can be used as a means of controlling the scanning amplitude, and if the output valve is otherwise worked under conditions of maximum gain the variable negative feed-back may be used to reduce the size of the picture to the

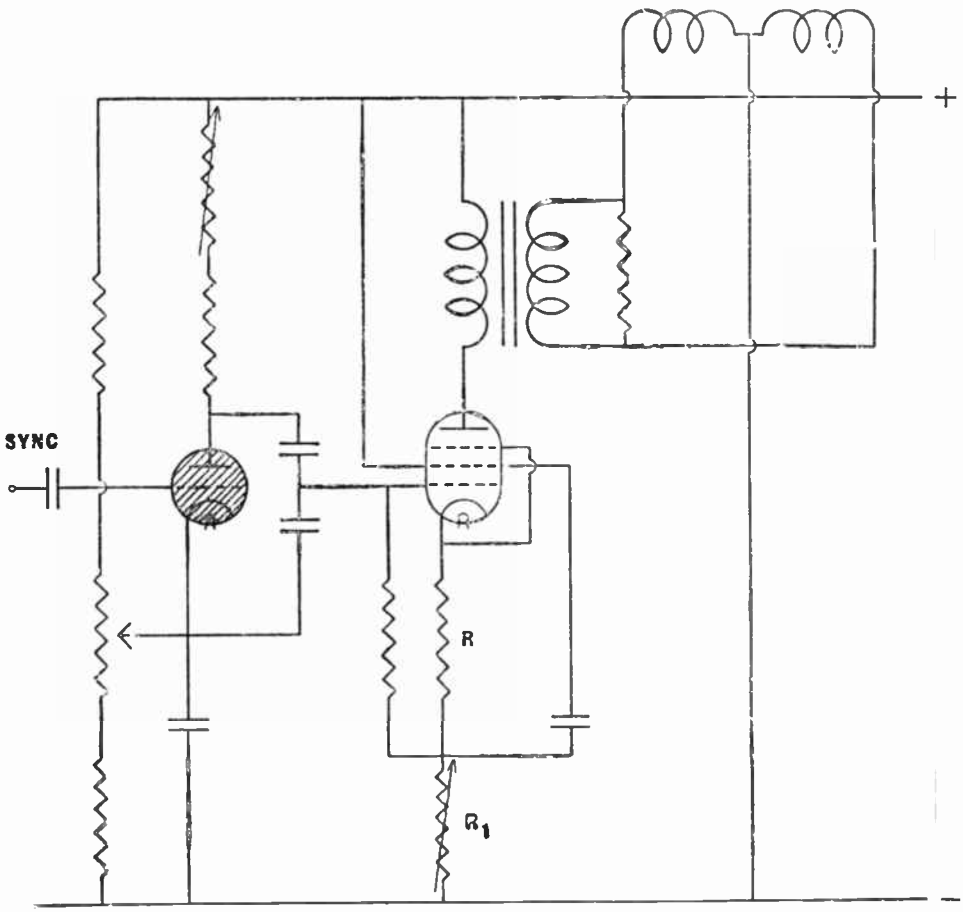


Fig. 93.—Another arrangement somewhat similar to Fig. 91, but employing the principle of cathode feed-back which is described in the text.

required dimensions, automatically ensuring that the maximum possible feed-back is introduced and that the linearity is as good as may be obtained with the valve employed, the capacity dissipation of which is, of course, limited by considerations of practicability and economics.

There are various ways in which negative feed-back can be introduced to simultaneously provide amplitude control and improve linearity. It should be clearly understood that the principle can be equally well introduced to the hard-valve time base or the time base employing the gas-discharge triode. One fairly obvious way of introducing it into the circuit shown at Fig. 92 is by making R_3 a potentiometer or, alternatively, making R_2 a potentiometer and connecting C_4 to the sliding member in either case. The latter alternative is suggested as being more desirable. It should be understood that it will be necessary to retain at least the resistance R as a variable, in order to provide some measure of linearity control in the earlier portion of the circuit. It should, however, be possible to dispense altogether with a variable condenser and to make both C_1 and C_2 of fixed capacity. There is one possible objection to this arrangement, and that is that the correct adjustment of R might so decrease the size of the picture that the amount of negative feed-back would have to be reduced in order to maintain the picture at the requisite dimensions. This disadvantage can only be overcome with this arrangement by making C_2 variable, which introduces a further complication, unless use is made of the suggestion of ganging R and C_2.

An alternative method of employing negative feed-back as amplitude control is shown in Fig 93, which is the skeleton circuit of a system that has been used successfully in domestic television. It will be observed that the grid of the amplifier is returned to the junction between the resistances R, R_1. A portion of the available output voltage is developed across R_1, the extent of which is determined by the value of the resistance, which is of the variable type; by increasing the value of this resistance the available portion of the output is decreased and the picture dimension is reduced accordingly. It will be observed that the grid is returned to the low-potential end of R_1 from the A.C. point of view, consequently the voltage developed across R_1 appears as a load on the grid circuit, with the result that a form of negative feed-back is achieved.

The Squegger Time Base.—An entirely different type of time-base circuit is shown in skeleton form at Fig. 94. The principle can be applied in a variety of modified forms. Reference to the illustration will show that it consists of a valve arranged as an oscillator, the grid return being by way of the condenser C and the resistance R. The grid and anode coils are coupled together sufficiently tightly to maintain oscillation, even when the grid is driven considerably in the negative direction; the frequency of the oscillation being determined by the inductance of one or both the coils. At the commencement of the operating cycle the valve oscillates and charges the condenser C until such time as the grid becomes so negative that oscillation ceases. The charge held by the condenser C leaks away through R until the grid has become less negative by that amount which will allow oscillation to recommence, and the cycle of operation is repeated. In the form shown in the illustration the waveform differs from that obtained by other time bases, inasmuch as the charging is linear but the rate of discharge follows an exponential law. This difficulty is overcome in a practical squegger circuit by replacing the resistance with a suitable constant-current device, such as a pentode valve, which has the additional advantage that the rate of discharge is easily controlled by varying the auxiliary grid potential. In this way it is possible to obtain a saw-tooth waveform which, when duly amplified, forms a satisfactory time base. Objection is often raised that time bases employing the squegger principle are inclined to be affected unduly by working conditions, which are often influenced by such external sources as fluctuating mains voltage. The author has done very little work with this type of circuit and is not prepared to express his opinion, but as the criticism has been made, it is only fair to say that the principle has been successfully applied in domestic television.

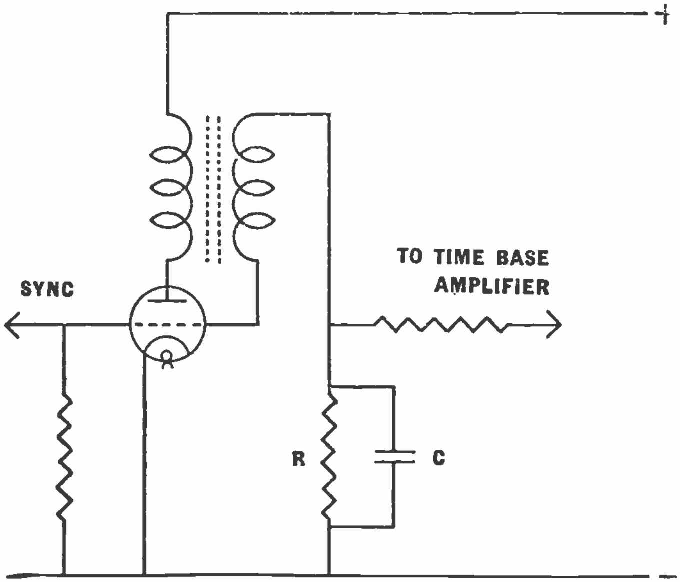


Fig. 94.—The basic circuit of the squegger time base.

The several basic time-base principles outlined in this chapter may be considered as typical examples.

There are, however, others in use in this country and abroad, and doubtless others will be evolved from time to time to meet changing conditions.

A Variation for Electrostatic Deflection.—Several circuits shown in this chapter employing the gas-discharge triode are arranged for use with magnetically deflected tubes. For the sake of completeness Fig. 95 is included, showing a gas-discharge triode time base arranged for use with electrostatic deflection; in this circuit the first valve acts as a pure discharge valve, the second valve acts as a line amplifier, and the third as a push-pull amplifier. The use of the third valve makes it possible to obtain a high degree of linearity, as the voltage output from the discharge circuit will be small.

Band-width.—Some mention has already been made of the relationship between velocity and band-width, to which may be added picture detail. This relationship is extremely complicated and requires a very advanced mathematical analysis to do justice to the subject. Nevertheless, it is hoped that the following explanation will serve to illustrate the principle involved, even although it is open to question from the purely mathematical standpoint. Assume that the width of the picture is 10 inches and that a portion of a line 1 inch long scans an iron railing at such a distance that 40 uprights are reproduced within the space of 1 inch. It is apparent that if the railings are black against the white background, a change from black to white and white to black will occur 40 times, which will appear, if the waveform is drawn, as 40 cycles (it is not suggested that the waveform will even remotely resemble a sine wave). One inch of a picture 10 inches wide represents a time period of $\frac{1}{100000}$ second. The periodicity, therefore, of the change of amplitude

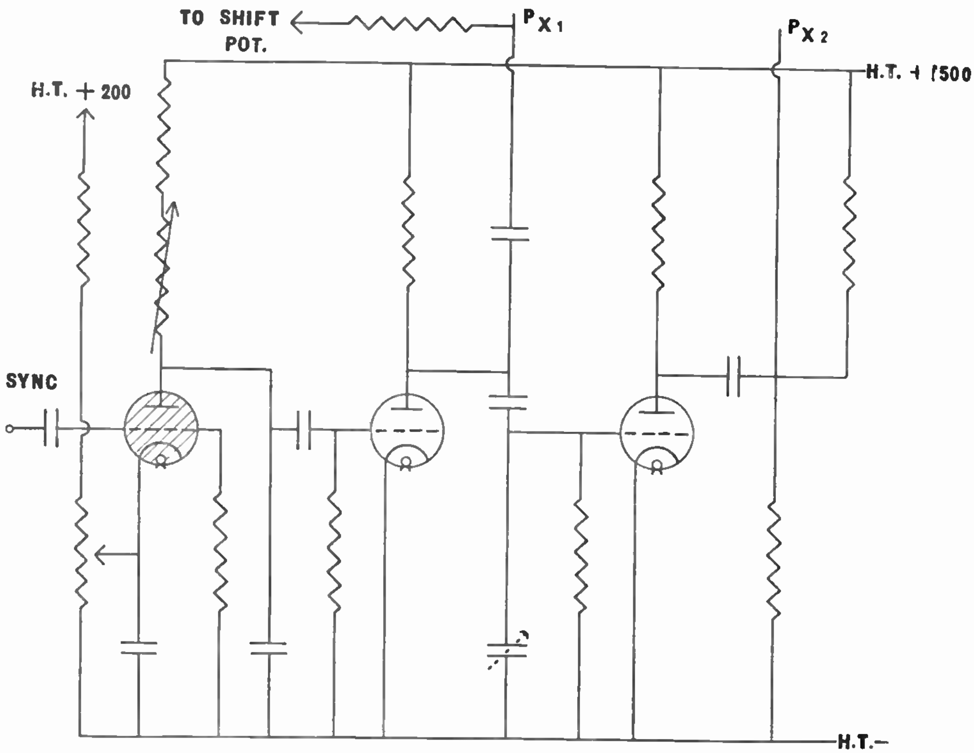


Fig. 95.—A relatively elaborate gas-discharge valve time base arranged for use with an electrostatically deflected cathode-ray tube. By using a separate push-pull amplifier, the initial sweep can be very small, thus allowing a high degree of linearity to be obtained.

in the particular section in question will be at the rate of 4,000,000 times per second (4 megacycles), and may, therefore, be expected to produce a sideband of this width. As already mentioned, this explanation is not entirely accurate, as such details as fly-back time and certain secondary effects have been ignored, while the fact that the modulation is of a D.C. character has not been taken into account.

The wide band-width associated with television transmission introduces numerous difficulties in receiver design, the most important of which is the necessity for designing both radio-frequency and intermediate-frequency tuned circuits so that the higher frequencies are not appreciably cut. Similar difficulties occur after detection, and, as will be seen in a later chapter, various means are used to boost the higher frequencies and precautions have to be taken to avoid their attenuation, which include an extremely low diode load, usually only 1,000 ohms or so, this being the only means of reducing the shunting effect of the cathode/anode capacity of the diode valve itself.

Fly-wheel Sync.—Special time-base circuits have been developed to minimise " tearing " of vertical lines in the picture caused by interference making the start of the lines a little late or a little early. These special time-base circuits do much towards making each line start at exactly the right place so that each line is exactly below the one above it. There are several ways of arranging these time bases each having certain advantages and disadvantages; the term fly-wheel sync. is more correctly applied to a particular circuit but tends to be used as a general term. Since interference appears as an adverse signal-to-noise ratio it is obvious that fly-wheel sync. time bases become more and more important as the distance from the transmitter increases.

CHAPTER 11

AN OUTLINE OF TELEVISION TECHNIQUE

THE two previous chapters have outlined the cathode-ray tube and the time bases, and before going on to the question of television-receiver design it is desirable to outline the general layout of both transmitter and receiver, and the broad principles involved. The nature of the transmitted signal was outlined in the previous chapter; it remains, therefore, to outline the manner in which such a signal may be produced.

The transmitter might be conveniently divided into three sections. The actual transmitter which will supply and modulate the aerial current, and two distinct sources of modulation—picture intelligence and line and frame impulses. It is apparent that these two sources of modulation cannot be regarded as entirely separate, as a link must exist in order that the picture intelligence may be collected in step with the electron beam of the receiver in order that the intelligence may be presented in the same form as it appears in the studio (or elsewhere). As a case in point, it is apparent that if the apparatus for collecting the picture intelligence could be, say, two hundredths of a second ahead of the receiver, then the picture would be cut in half horizontally and the halves transposed. Such an effect can, in fact, be obtained by allowing the receiver to slip out of synchronism.

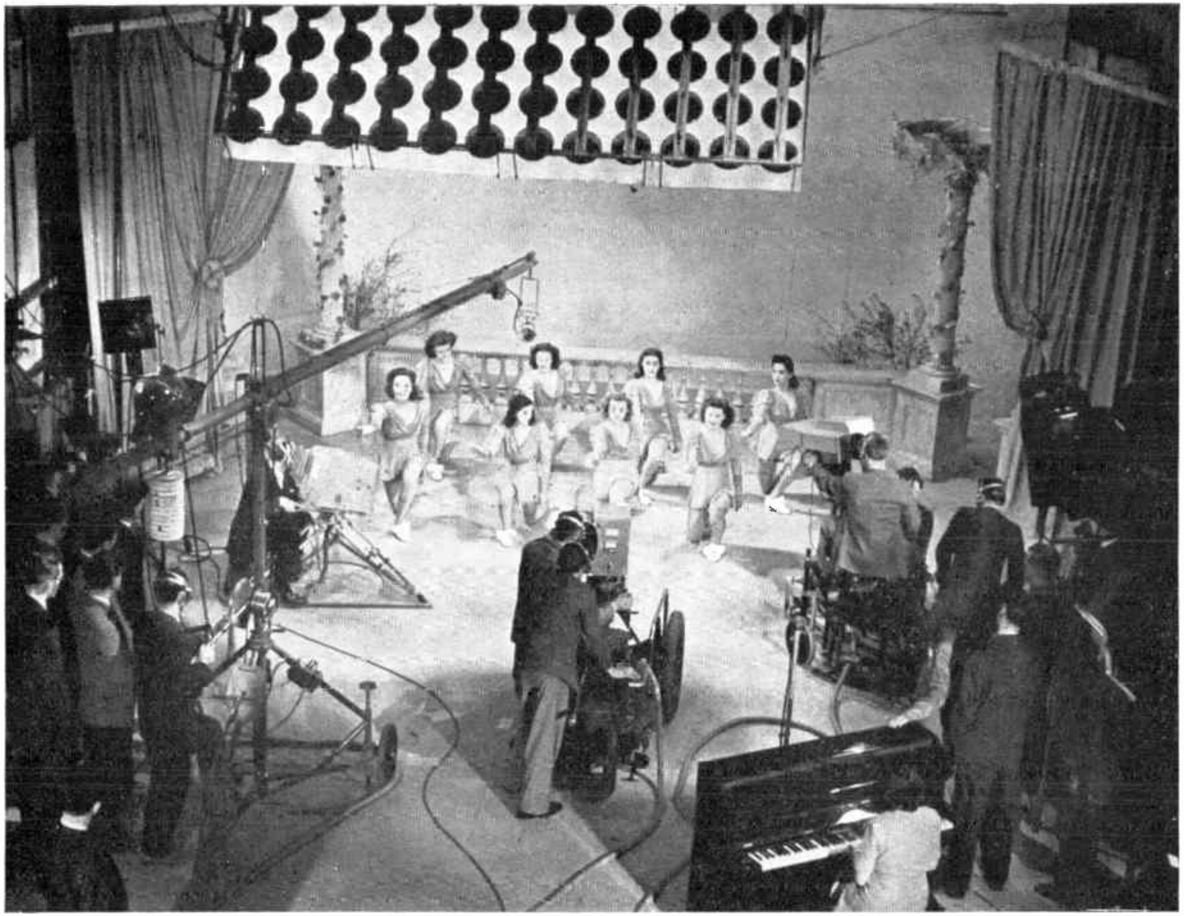
The Transmitter Time Bases.—In order to achieve synchronism the picture-collecting apparatus and the receiver must be in step. It follows, therefore, that the transmitter time bases are the key or master-control of the system as a whole. The problem is to produce two devices which will keep step with each other and modulate the transmitter to a predetermined depth, namely, about 30 per cent. The actual duration of the impulses must be rigidly controlled in addition to their spacing. One method of achieving this is to use a mechanically driven synchronous disc; such a disc could have 405 holes punched at precisely equal distances apart around the outer disc and two slits placed nearer the centre and opposite to each other. Two lamps with carefully focused beams are placed on the circular track followed by the outer holes and the two inner holes, and photo-electric cells are placed on the other side of the disc. This arrangement will provide 405 impulses from one photo-cell circuit and two impulses from the other photo-cell circuit. This will give the required relationship between line and frame impulses; the requisite number of frame impulses (and, incidentally, line impulses) will be produced if the disc is revolved 50 times per second at a constant speed—a function that can be easily performed by a synchronous motor driven by frequency-controlled mains.

A description of the synchronising disc above is intended to serve as a general guide to the arrangement, and certain complications have been omitted in the interests of clarity, including, for example, the necessity for putting additional holes in the outer ring at appropriate points to provide the half-line interruptions during the frame impulse. It is interesting to note that the most exceptional accuracy is necessary in setting out the holes, as an error of one ten-thousandth of an inch might well be perceptible to a casual observer situated a dozen feet from the receiver screen.

An Alternative Method.—As an alternative to the semi-mechanical system outlined above, the possibility of using a valve time base presents itself. In order to prevent drift at the receiver end, it is desirable that the synchronising impulses should have a " square " waveform, or at least something closely approaching it. Such a waveform can be generated by a series of oscillators producing the fundamental frequency and a number of harmonics of precisely determined amplitude—all frequencies being held in a definite relationship to each other by means of a master circuit. Such an arrangement is actually used at the present time for television transmission. A time base functioning on this principle, and including appropriate amplifiers, may well incorporate more than 70 valves, and in this connection it may not be out of place to mention that radiation of a normal programme from a B.B.C. station will entail the simultaneous use of more than 1,000 valves, all performing various functions.

The Electron Camera.—The manner of producing the master synchronising impulses has been very briefly outlined, and attention may be directed to means of gathering the actual picture intelligence. By some means the picture must be scanned in step with the cathode-ray beam of the receiver and, as already explained, this is achieved by allowing the transmitter synchronising impulses to control the movement of the cathode-ray beam at the receiver end and the picture scanning at the transmitter. It is now apparent that some device is required capable of exploring the picture to be transmitted and controlling the current or voltage, in more or less strict proportion to the illumination obtaining at each particular point. Several such devices are available, but only one, which is actually used in this country, need be considered here, namely, the Iconoscope or, to give it its popular name, the Electron Camera. It is convenient to regard the Iconoscope as the tube which forms the basis of the system, and the expression Electron Camera as meaning an Iconoscope complete with lens and other accessories in a suitable box, for practical utility. The Iconoscope consist of a high-vacuum tube, somewhat resembling a cathode-ray tube, and containing an electrode system capable of producing an electron beam and deflecting it in much the same manner as a magnetically deflected cathode-ray tube. It differs from a cathode-ray tube in one fundamental manner—it does not employ a fluorescent screen, but a mosaic of photo-cells constructed in a particular manner.

R.T. II - 160



A B.B.C. TELEVISION STUDIO

This photograph gives a general idea of the technique of television production. Three television cameras can be seen and also the microphone on the end of the universally movable and extendable boom. Note the battery of lights at the top of the picture and that many of the operators wear headphones through which they receive instructions from the producer who overlooks the scene from a gallery.

The invention of the Iconoscope is attributed to Dr. Zworykin, and it is, perhaps, one of the most brilliant examples of clear thinking applied to the harnessing of electrons. The remarkable feature of this device is its energy-storing properties. It does not rely like the photo-cell on producing energy for a brief instant during which a rapidly moving beam will fall upon it, but collects energy practically continuously and gives it up point by point as the beam travels across its photo-cell mosaic.

Fig. 96 shows the Iconoscope as applied to television transmission. It will be seen that the picture, object, or scene (X) to be transmitted is focused on to the photo-cell mosaic by means of a suitable lens. This mosaic is scanned by the cathode-ray beam, the movements of which are determined by scanning coils which derive their energy from the transmitter's master frame and line time bases respectively. This mosaic consists of a thin sheet of mica, the face of which is covered with a light-sensitive mosaic made of some hundreds of thousands of minute globules of cæsium oxide deposited on silver (it should be understood that each

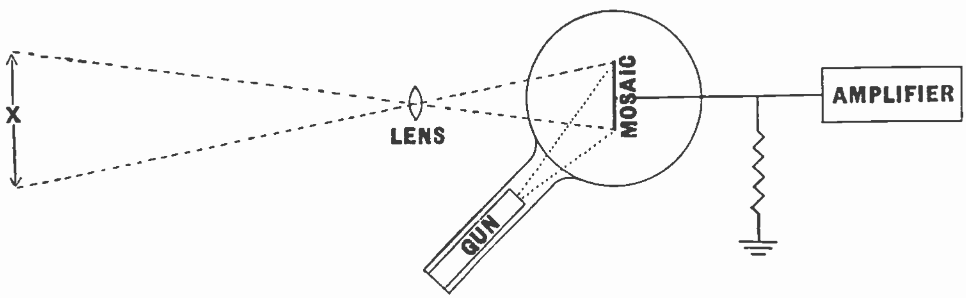


Fig. 96.—A diagrammatic illustration of the Iconoscope applied to television transmission.

globule of cæsium oxide is deposited on its own minute silver backing, there is no electrical contact between these minute units).

Each minute globule forms a cathode of a minute photo-cell (and there are hundreds of thousands of them). On the other side of the mica sheet there is a metal coating which acts as an anode common to all the hundreds of thousands of minute photo-cells. As may be seen from the illustration, the mosaic is set at an angle permitting the beam to scan the surface and the picture to be projected upon it. The lens is carefully adjusted so that a sharply defined image falls on the mosaic. In the bright parts of the picture a relatively large amount of light will fall upon the appropriate photo-cells, causing them to become positive to a proportional extent, and where the lesser amount of light falls they will become proportionately less positive. *Note particularly that this process is continuous.* As the cathode-ray beam scans the mosaic, electrons will be restored to each cell, the quantity of which will be proportionate to the amount lost, which, it will be remembered, is in turn proportional to the brilliance of the light which has fallen upon it. As each individual photo-cell is restored by the beam, a like charge is repelled from the anode which, passing through a resistance, will set up a potential across it. This potential is proportional to the light value of the group of cells from which it has been derived, and may therefore be fed to a suitable amplifier, which will raise the amplitude as necessary to modulate the transmitter.

It will be appreciated that very special design is called for in the Iconoscope amplifier, as the Iconoscope current will be subject to considerable variation and, in the interests of maintaining a reasonable band-width, it will be necessary to impose a limit for the purposes of modulating the transmitter ; the amplifier, therefore, is designed to be sensibly linear to changes up to about 2,000,000 cycles per second. It is probably apparent from the above remarks that the cathode-ray beam will impinge upon each photo-cell considerably less than one-millionth of a second, but that each mosaic will accumulate its appropriate positive charge for almost one twenty-fifth of a second between each visitation of the beam.

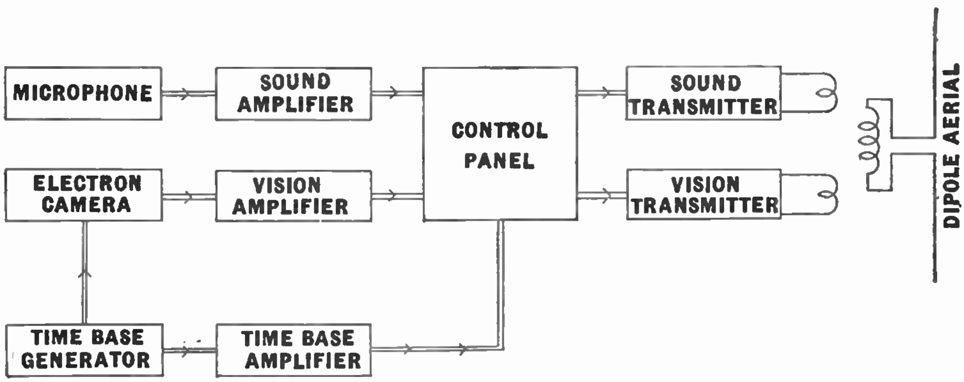


Fig. 97.—Diagram showing the various sections of a television transmitter. Only the essential units are included in this diagram.

This gives a relatively high output and a very favourable signal to noise ratio. It is perhaps desirable to mention that the word "relatively" is used in its narrowest sense, since the anode current of an Iconoscope is a fractional part of a micro-ampère. The word " noise " is something of a misnomer when applied to a picture, but it is colloquially used as indicating unwanted energy intermixed with wanted energy. Unfortunately there is no alternative word in general use.

Fig. 97 is a block diagram showing the principal units of the transmitter. It will be noted that various sub-units are fed into the control panel, which in its simplest form would comprise a cathode-ray tube on which the picture is reproduced, and at least one additional cathode-ray tube switched so that it may be used to show the waveform of the time bases and the relative amplitude of time-base impulses and picture intelligence. The output of the time-base generator is led to a time-base amplifier and then to the control panel, and from the studio or other source of intelligence there are two channels, one from the electron camera through its attendant amplifier to the control panel, and another from the microphone through the microphone amplifier to the control panel.

Two channels lead from the control panel—one to the sound transmitter and the other to the vision transmitter. The output from these transmitters are both fed into the same aerial circuit. This is a purely optional arrangement, and separate aerials can be used for each transmitter.

The arrangement at Fig. 97 does not include all the units that comprise a first-class transmitter, such as that operated by the B.B.C. and I.T.A.; more obvious omissions include a producer's control panel (as distinct from the engineer's control panel) permitting the switching in and out of two or more electron cameras offering different viewpoints, and the mixing of effects on the sound side. It will be understood that the control panel is in itself a remarkable piece of apparatus and includes a multitude of correcting circuits, some of which are variable, permitting picture brightness to be increased in the middle and decreased at the sides, or *vice versa*, and other similar adjuncts to television-picture production.

The Receiver.—Fig. 98 shows a block diagram of a simple receiver. The receiving aerial normally consists of a dipole, and is coupled to both the vision receiver and sound receiver. The output from the vision amplifier is led to the modulating grid of the cathode-ray tube, while the frame and line time bases feed the line-deflection and frame-deflection arrangements respectively. It will be noted that there is a link between

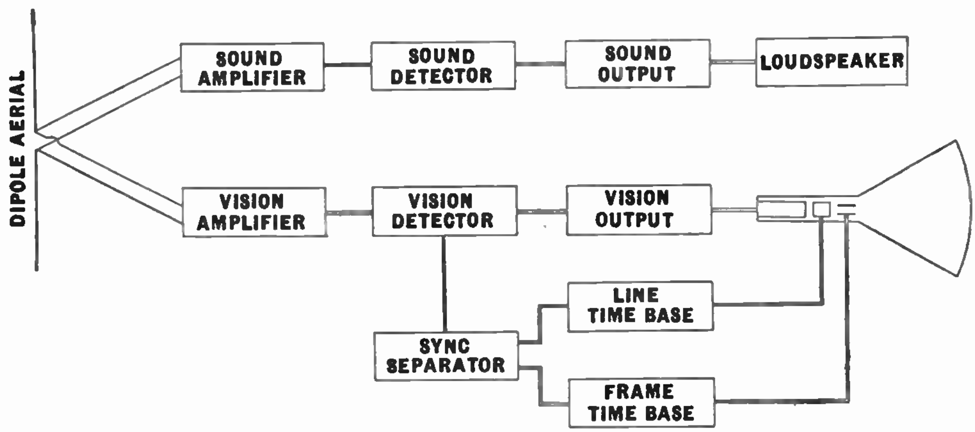


Fig. 98.—Diagram showing the various sections of a simple television receiver.

the vision receiver and the time bases which is intended to signify the passing of synchronising intelligence from the latter to the former. The sound receiver may be a perfectly normal arrangement, the output being taken to a loudspeaker in the appropriate manner. The sound and vision receivers may or may not be entirely separate, since it is possible to combine the two so that the first two or three valves amplify both vision and sound; such an arrangement is referred to in the next chapter.

Transmitter-scanning Correction.—A careful study of Fig. 96 will reveal the fact that as the mosaic is placed at an angle, the picture will appear upon it slightly wedge-shaped and, furthermore, as the mosaic is also at an angle to the scanning beam, the latter will normally scan a slightly wedge-shaped area. It is necessary that irrespective of any other consideration the cathode beam must scan the precise area of the picture, consequently the deflecting currents fed to the deflecting coils of the gun must be corrected so that the scanning pattern of the beam coincides with the shape of the picture. Obviously this trapezium-shaped picture cannot be transmitted in such a form, and it would appear at first sight that serious difficulties present themselves. Actually, the difficulties can be very easily overcome by supplying the deflector coils with a normal deflecting current and having a separate piece of apparatus to supply an additional source of deflection current to bring about the necessary peculiar shape of the scanning. The first-mentioned currents are derived from the master time bases, but the last-mentioned currents are isolated and *are not linked with the transmitter*; consequently, although the scan is of peculiar shape, a rectangular picture appears at the receiver.

The Transmission of a Film.—The reader will doubtless be aware that the cinema presents a series of stationary pictures, the projector light being actually interrupted for the instant during which one stationary film is moved on and the next takes its place. By careful design of the interruptor and by suitably speeding up the time taken to effect each change the eye is deceived and fails to convey the impression of the interruption. It is perhaps something of a paradox that the cinema picture flickered unbearably until the interruptor was invented.

However quickly a film is moved from one picture to the next, a proportionate amount of time is lost, and if the same arrangement were adopted in a television transmitter the best available picture definition would not be transmitted. It will be remembered that the band-width of the transmission is limited; if the picture intelligence is to be crowded into less than the normal time for the frame in order to give time for the film to change, it is apparent that the frequency will increase and that a certain amount of detail will be lost. An additional complication would arise, as the rest at the end of each frame would have to be longer, which would produce a black band at the bottom of the picture and, incidentally, one at the side.

All these difficulties have been overcome by adopting a method of transmission whereby the film is continuously moving. The scanning beam is controlled by normal master line and frame impulses, and an additional voltage is applied to the vertical deflector plates, which is such that the beam is deflected at the rate of movement of the film. In this way the whole field of scan follows the moving film, and at the completion of the scan the frame fly-back functions in the normal manner, its return being due to the collapse of both the normal frame time base and the additional voltage device, the latter being especially designed to accomplish collapse in the very shortest space of time. The additional voltage device is not linked with the actual transmitter, consequently only the normal rectangular scan is transmitted, and the picture appears as a normal rectangle at the receiving end.

The appropriate sound accompaniment to a film takes the form of a sound track along its edge. This is reconverted into sound by means of a light and photo-cell or, in other words, the normal sound head of the cinema projector. The cinema pictures are intended to be projected at the rate of 24 per second, but the present system of television uses 25 complete rasters per second, and the only solution to this discrepancy is to run the film at the same rate, namely, 25 per second. This means that the sound track will also be running some 4 per cent. fast, with the result that the pitch of music or speech will be proportionately increased. In this connection it is interesting to note that the author has demonstrated television to some hundreds of people, and up to the time of writing nobody has noticed this spurious increase of pitch, possibly due to the fact that speech and music rendered from films are often of such indifferent quality that lesser imperfections are not readily apparent.

Mechanical Systems.—Although apparently obsolete, at least for domestic use, it is interesting to touch briefly upon mechanical systems of picture reproduction. Briefly, the light from a lamp or other convenient source is passed through a Kerr-cell and is then deflected by a mirror drum so that it scans a screen in the normal manner, *i.e.* 25 complete rasters of 405 lines each. The mirror drum can be defined as a drum rotating at a most carefully controlled speed, on the edge of which are fixed the requisite number of mirrors, each one being tilted more than its predecessor by such an amount that it will cause the beam of light to scan the screen one line lower. The Kerr-cell can be defined as a device which will permit the intensity of a beam of polarised light to be varied by an electric field.

Many readers will remember that the original experimental transmissions in this country were by mechanical means, scanning at both the transmitter and receiver being accomplished by means of a rotating disc with holes punched around its edge. The author is of the opinion that the cathode-ray system holds the greater possibilities, but realises that some bias may exist, owing to a connection with work on this system extending over a period of nearly ten years.

It is perhaps relevant to conclude this chapter by a brief note on the subject of picture size. There is a tendency on the part of the general public to look to the future for much larger screens than those generally existing. The optimum viewing distance for a screen measuring some 14 × 11 inches is about 8 feet, at which distance the lines just cease to be apparent. If the screen is increased to double this size, then the optimum viewing distance must be also doubled in order that the lines are not apparent. This in turn means that the picture appears to be of similar size. In other words, the only advantage of the larger screen is that it may be viewed by more people with the same degree of comfort and convenience. Twelve people can very comfortably view a picture measuring about 14 × 11 inches without anybody being nearer than the optimum distance of 10 feet. It is therefore suggested that a picture of this size is adequate for domestic requirements. Quite apart from the fact that a larger picture has no advantages except for larger audiences, it may well prove a disadvantage, as in a normal household some difficulty may arise in comfortably seating a group at a distance of 15 feet, or more, from the receiver.

CHAPTER 12

TELEVISION-RECEIVER DESIGN

The possible variations in the design of a television receiver are so vast that it is difficult to generalise, and the bulk of this chapter is, therefore, devoted to a comprehensive survey of a typical circuit which will serve as an example; but, as an introduction to the survey, some mention must be made of the broad possibilities which appear as alternatives.

Television receivers can be conveniently split into two groups: those which employ separate sound and vision chassis and the more usual type which combine the two functions when the first three or four valves act as combined sound and vision amplifiers, arrangements being made to separate the two types of signal and feed them to their separate detectors and output stages. Generally speaking, separate chassis are used when the receiver combines broadcast wavebands or radiogram facilities, but there is at least one exception, which takes the form of a receiver incorporating a combined sound and vision chassis and a separate chassis for the broadcast wavebands.

Whether or not the vision chassis is a separate entity or combined with sound reproduction, it must fall into one of two well-defined groups —magnetic focusing or electrostatic focusing; these alternative possibilities have been dealt with in Chapter 9, and attention can be directed solely to the question of the actual " vision " amplifier and the possibility of incorporating this function with that of sound reproduction.

The Vision Amplifier.—A vision amplifier consists fundamentally of :

The radio-frequency amplifier.
The frequency changer.
The intermediate-frequency amplifier.
The detector.
The video amplifier.

The above sequence is typical, although there is a school of thought which prefers a receiver that does not employ the superheterodyne principle, but uses radio-frequency amplification throughout. At least one stage of radio-frequency amplification is generally considered essential to relieve the frequency changer of a certain amount of damping, to increase the input to the frequency changer, and thus to improve the signal to noise ratio and to prevent re-radiation from the frequency changer. This latter function is but poorly performed in many television receivers, with the result that one type may re-radiate and adversely affect another one in its immediate neighbourhood. The frequency changer can be perfectly conventional, using such a valve as the triode hexode, although it is highly desirable that it shall be so designed that the triode section may function in a stable manner especially when working on the higher frequencies of Band III, which, of course, is allocated to the Television Independent Authority.

The aerial circuit and the coupling between the radio-frequency amplifier and the frequency changer usually employ a single tuned circuit giving a peak response, although sometimes flattened by deliberately introduced damping. The intermediate-frequency amplifier, on the other hand, will require coils having a very wide frequency response capable of passing a band-width of the order of 2-3 megacycles. As explained in an earlier chapter, this wide band-width is necessary in order to carry the requisite picture detail, and this requirement introduces considerable difficulty in amplifier design, since the dynamic resistance of wide band coils is necessarily low and stage gain can only be made to reach double figures by the use of infinite care. Two stages of intermediate-frequency amplification may be regarded as the minimum, and the coupling may take the form of over-coupled intermediate-frequency transformers or single-tuned circuits adequately staggered. The former arrangement provides the greater opportunity for a flat-topped response-curve, while the latter arrangement can be identified with slightly higher stage gain and will give a satisfactory response-curve with the assistance of the peaked radio-frequency coils.

Special Valves.—The ultimate intermediate-frequency amplifier and sometimes the penultimate amplifier will require a high-frequency pentode of a special design, capable of handling a large output when working into the very low load incidental to the type of tuned circuit into which it works. Such valves have a slope in the neighbourhood of 8 mA/V and pass a combined anode and screen current of about 10-15 milliampères, sometimes higher. Metallised valves have fallen into almost complete disuse partly because the metal coating has little screening effect at very high frequencies, but materially increases the anode to earth capacity of the valve, which slightly militates against stage gain, since the inductance of the coils would need to be proportionately lower. Trimming of the various circuits may be performed by a small trimming condenser, but is more often accomplished by variable inductance in the form of permeability tuning or a tapped coil. This makes it possible to dispense altogether with condensers, since the input and output capacity of the valve is sufficient in itself and allows the coils to have maximum inductance.

The Vision Detector.—Detection is sometimes accomplished by means of a double diode working as a full-wave detector (see Fig. 99). Considerable difficulties present themselves in the detector stage owing to the very high frequencies which will appear across the diode load, of the order of 2 megacycles per second. Diode loads of the order of half a megohm are absolutely impossible, owing to the attenuation which would result, due to the shunting effect of the cathode/anode capacity of the valve itself. The only means of off-setting the effects of valve capacity is by using a very low load, which is often as low as 1,000 ohms and rarely more than 2,500 ohms. In order to off-set the lack of efficiency which would result from the use of such a load with a normal diode valve, special types have been introduced having very low internal impedance, in the neighbourhood of 100 ohms. Full-wave detection will not give quite the same output as half-wave detection, but is employed as a means of balancing out the intermediate frequency, which is extremely important, as it would seriously upset the picture if it were allowed to appear at the modulating grid of the cathode-ray tube at any appreciable amplitude.

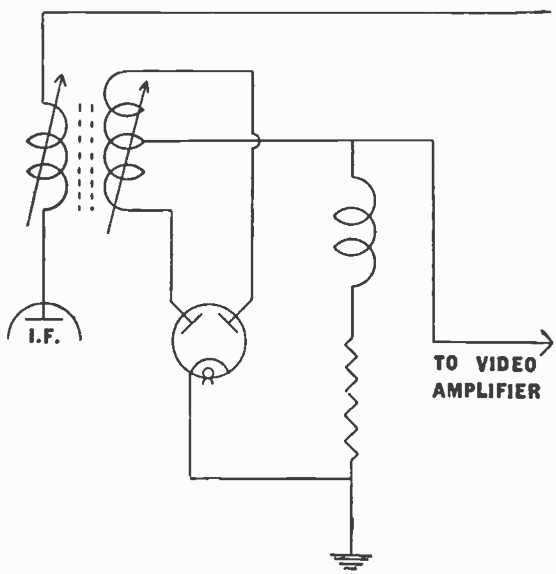


Fig. 99.—A typical vision detector.

High-frequency Accentuation.—Whatever means are employed to produce the necessarily wide response characteristics of the receiver, some attenuation of the higher frequency will occur if an attempt is to be made to obtain reasonable stage gain, and it is usual to introduce some high-frequency correction or, to use the colloquial phrase, "top lift." "Top lift" can be introduced into the detector circuit by the use of a small choke in series with the diode load so that the impedance of the load is greater at the higher frequencies than at the lower frequencies. Such compensation cannot be carried to excess, since over-compensation produces a peculiar effect on the picture and is likely to accentuate any deliberate or accidental over-compensation that may be present in the actual transmission.

The Video Amplifier.—A moment's thought will reveal that the voltage appearing across the diode load is in the wrong sense, inasmuch as maximum modulation, *i.e.* maximum white, will drive the diode anode negative, which will modulate the cathode-ray tube in the direction of black, if directly connected. It is apparent, therefore, that a phase reversal is necessary, which is accomplished by means of a video amplifier, which further amplifies the vision signal after detection, and performs the quite indispensable function of phase reversal. The video amplifier also gives further opportunity for adding a little "top lift," by making the anode load a resistance and inductance in series. Here again the anode load must be small to off-set the effect of the anode to earth capacity of the valve.

The D.C. Component.—The actual link between the anode of the video amplifier and the modulating grid of the cathode-ray tube is not quite so simple as it might appear. The anode will be held at a potential of some 200 volts positive in respect to the chassis, and it might seem desirable to isolate this voltage from the cathode-ray tube by means of a D.C. stopping condenser, but, unfortunately, such a procedure will have serious repercussions. The absence of direct metallic connection will result in the A.C. component only appearing between the modulating grid and cathode of the cathode-ray tube, and the D.C. component will be lost; the A.C. component produces the picture detail, and this will not suffer directly. The D.C. component, on the other hand, controls the general brilliance or average tone value of the picture, and if this is lost the picture will become muddy if the signal is weak or, if the signal is sufficiently strong, the picture will become strangely unreal; the effect is, in fact, difficult to describe in words, but is very apparent to the eye. Some circuits are so arranged that the D.C. stopping condenser must be included, and the D.C. component is restored by the use of a diode or metal-oxide rectifier, which biases the cathode-ray tube in proportion to the amplitude of the A.C. component. An alternative arrangement is to make metallic connection between the anode of the video amplifier and the modulating grid of the cathode-ray tube and connect the cathode to a point that is adequately positive in respect to the modulating grid. Such an arrangement is very simple to achieve. If, for example, the anode of the video amplifier is 150 volts positive with respect to chassis, it will be necessary to connect the cathode to a point that is 200 volts positive in respect to the chassis, assuming that the tube is intended to work with a negative grid bias of 50 volts. Actually, the cathode will be made variable within certain limits, to act as a brightness control.

Combined Sound and Vision Amplifier.—As already intimated, certain stages may amplify both vision and sound frequencies. The arrangement is not particularly complicated, and the radio-frequency amplifier and its tuned circuits will only be affected to the extent that their response-curve must cover both the vision and sound frequencies. Vision frequency is 45 megacycles and sound 41·5 megacycles and, bearing in mind the required band-width of the vision signal, it will be necessary for the coils to respond approximately from 47 to 41·5 megacycles. The frequency changer is perfectly normal, and when the two fundamental frequencies (sound and vision) are introduced two separate beat-notes will appear in the anode circuit and the intermediate-frequency coupling will take the form of two tuned circuits in series, one tuned to the vision intermediate frequency and one to the sound intermediate frequency. If transformers are used for coupling at the vision intermediate frequency, it is, nevertheless, possible, and even convenient, to employ a tuned anode in series with the primary to provide the necessary load for the sound frequency. If this arrangement is adopted, however, it will be necessary to use mixed capacity and magnetic coupling, so that both frequencies appear across the grid/cathode of the next valve. This procedure can be repeated until it is desired to split the frequencies, which can be done very simply, a typical arrangement being shown at Fig. 100. When the intermediate-frequency amplifier is used to perform the dual function, it may be necessary to align the vision frequency coils somewhat off the vision intermediate frequency, in order that the response of the tuned circuits is negligible at the frequency corresponding to the second harmonic of the sound intermediate frequency. A modern receiver will almost certainly have a multiband tuner to cover all B.B.C. channels on Band I and I.T.A. channels on Band III, but this complication is ignored for the moment and referred to in detail later.

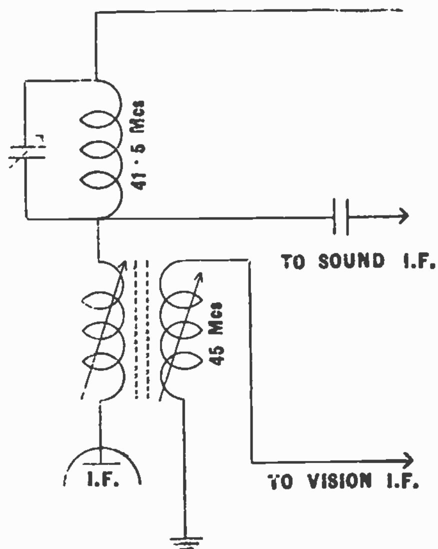


Fig. 100.—The separating stage of a combined vision and sound receiver.

A Complete Circuit.—The inset facing page 172 shows the circuit of a television receiver for use with a magnetically deflected cathode-ray tube, it is deliberately simplified and does not perform the dual function of handling sound and vision, as such an arrangement considerably complicates a point-to-point description without materially contributing to its value. The actual aerial and the means of separating sound and vision frequency in the aerial circuit are dealt with later, and it is convenient to assume that the vision signal appears as a current flowing through the primary of the input circuit.

The Radio-frequency Amplifier.—The first stage employs a high-frequency pentode and is generally a normal arrangement, although the values associated with it are somewhat unusual when judged by radio standards. The cathode bypass condenser C_2 and the screen decoupling condenser C_1 can each have a capacity of ·001 μF. No useful purpose would be served by using a larger capacity, while such capacities as those usually associated with this function, *i.e.* ·1 μF, would be definitely detrimental, as their impedance would be relatively large at 45 megacycles. The anode resistance R_3 may have a value of some 10,000 ohms, since it is desired that the radio-frequency coupling coil shall have a relatively sharp response-curve. The coupling condenser C_3 may be relatively small, and no useful purpose would be served by exceeding 100 μμF. It will be noted that the coupling coil is shown transfixed by an arrow, indicating that its inductance is variable, and attention is also drawn to the fact that there is no capacity deliberately introduced across the coupling coil, the output capacity V_1 and the input capacity V_2 being adequate.

The Frequency Changer.—The frequency changer V_2 employs a triode hexode, the circuit being quite conventional, although the associated capacities are relatively small. The cathode bypass condenser C_5 may have a value of the order of ·01 μF. The grid condenser of the triode section, on the other hand, may be about 100 μμF associated with a grid leak of normal value, R_5.

The intermediate-frequency coupling takes the form of an over-coupled transformer, both primary and secondary being damped with resistances of relatively low value, R_7 and R_8; these may have a value of 5,000 ohms each.

The Intermediate-frequency Amplifier.—It will be observed that two stages of intermediate-frequency amplification are used, coupling being effected by over-coupled transformers damped by the resistances R_{12}, R_{14}, and R_{15} respectively. It will be noted that these transformers are aligned by permeability tuning, and that no actual condensers are associated with either winding; the output capacity and input capacity appear across primaries and secondaries respectively, and are adequate. The first valve is a high-frequency pentode specially designed to work into

---

COMPONENT VALUES

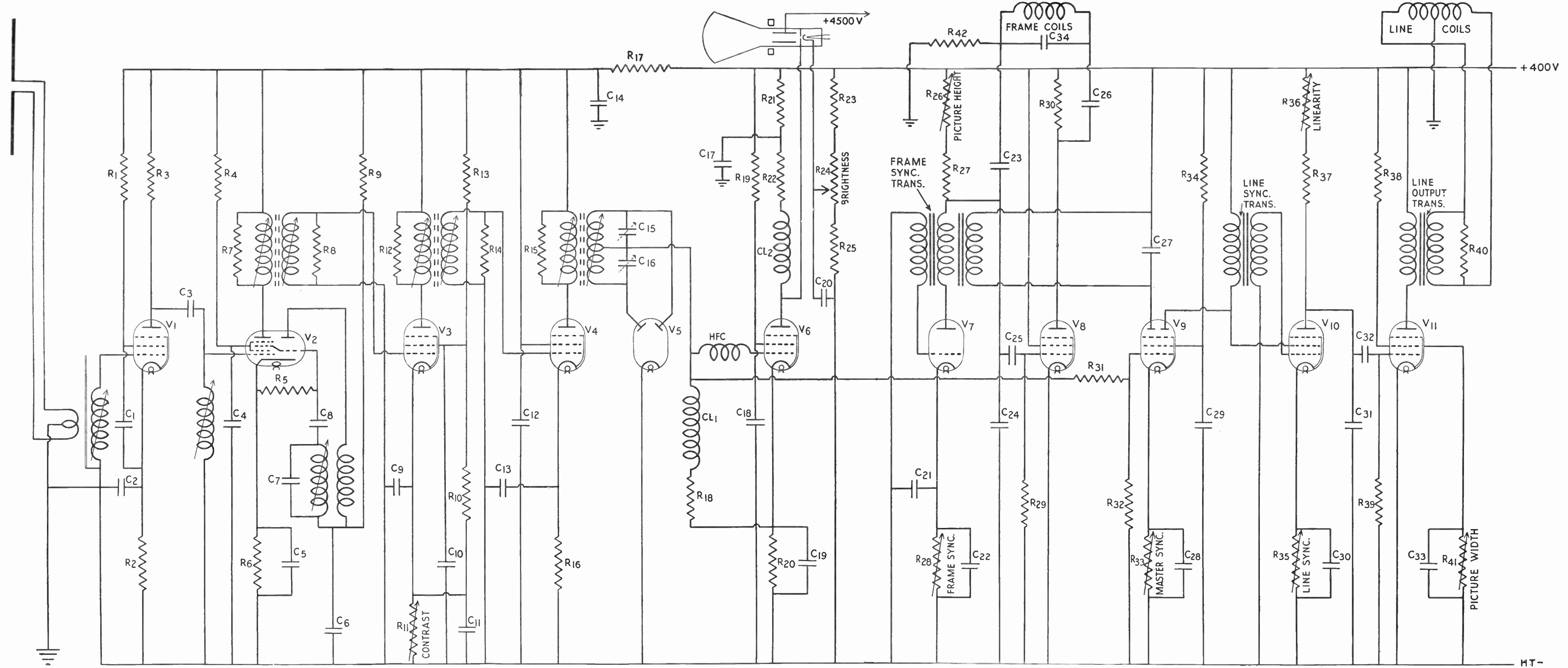
Resistances :

R_1—50,000 Ω	R_{15}—4,000 Ω	R_{29}—5 MΩ
R_2—250 Ω	R_{16}—200 Ω	R_{30}—10,000 Ω
R_3—10,000 Ω	R_{17}—1,000 Ω	R_{31}—25,000 Ω
R_4—50,000 Ω	R_{18}—2,000 Ω	R_{32}—20,000 Ω
R_5—30,000 Ω	R_{19}—10,000 Ω	R_{33}—75,000 Ω
R_6—400 Ω	R_{20}—200 Ω	R_{34}—10 MΩ
R_7—5,000 Ω	R_{21}—1,000 Ω	R_{35}—100,000 Ω
R_8—5,000 Ω	R_{22}—2,500 Ω	R_{36}—2 MΩ
R_9—25,000 Ω	R_{23}—2,000 Ω	R_{37}—1 MΩ
R_{10}—100,000 Ω	R_{24}—20,000 Ω	R_{38}—20,000 Ω
R_{11}—5,000 Ω	R_{25}—50,000 Ω	R_{39}—2 MΩ
R_{12}—4,000 Ω	R_{26}—2 MΩ	R_{40}—1,000 Ω
R_{13}—12,000 Ω	R_{27}—3 MΩ	R_{41}—100,000 Ω
R_{14}—4,000 Ω	R_{28}—200,000 Ω	R_{42}—1,000 Ω

Condensers :

C_1—·001 μF	C_{13}—·05 μF	C_{24}—·0002 μF
C_2—·001 μF	C_{14}—1 μF	C_{25}—·1 μF
C_3—100 μμF	C_{15}—15 μμF	C_{26}—8 μF
C_4—·01 μF	C_{16}—15 μμF	C_{27}—·0025 μF
C_5—·01 μF	C_{17}—·05 μF	C_{28}—2 μF
C_6—·001 μF	C_{18}—·005 μF	C_{29}—1 μF
C_7—50 μμF	C_{19}—100 μμF	C_{30}—·0003 μF
C_8—100 μμF	C_{20}—·1 μF	C_{31}—·0001 μF
C_9—·001 μF	C_{21}—·001 μF	C_{32}—·01 μF
C_{10}—·05 μF	C_{22}—·1 μF	C_{33}—2 μF
C_{11}—·05 μF	C_{23}—·02 μF	C_{34}—·05 μF
C_{12}—·1 μF		

Note.—V_1, V_3, V_8, and V_{10} are normal high-frequency pentodes, whereas V_4, V_6, and V_{11} are of the larger 12-watt type. The cathode-ray tube uses permanent ring-magnet focusing and picture centring is by mechanical means.



Circuit diagram of a deliberately simplified television receiver intended to illustrate the text rather than to portray exemplary design.

a low load and capable of passing some 20 milliampères when the grid is held at a potential of 1 volt negative. It will be observed that the screen of this valve is potentiometer-fed to maintain the screen potential sensibly constant when grid voltage is varied. It will also be observed that the control grid of this valve is variably biased by means of the resistance R_{11}, which acts as a gain control and provides a manual means of adjusting the contrast of the ultimate picture. In practice, it is so adjusted that maximum modulation increases the electron beam in the cathode-ray tube to the extent which gives the impression of maximum white.

The second intermediate-frequency amplifying valve is capable of a relatively large output and has a very high slope, and under normal working conditions will pass an anode current in the neighbourhood of 40 milliampères and a screen current of about one-fifth of this figure. The coupling between this valve and the detector has a particular point of interest, inasmuch as the primary is tuned by means of an iron core, whereas the secondary is tuned by means of an iron core and trimming condenser over each half. This arrangement allows the output across each half of the secondary to be balanced, always providing that the centre tap is accurately placed, the major adjustment being performed by moving the iron core. Providing these trimmers have sufficiently large capacity, it will be possible to introduce a little "faking" to off-set any minor peaks produced in the earlier tuned circuit. It is perhaps not irrelevant to mention at this point that a perfectly symmetrical and relatively flat response-curve does not give the best picture in all cases, and in the receiver under review the best picture is obtained when the over-all response-curve resembles that shown at Fig. 101.

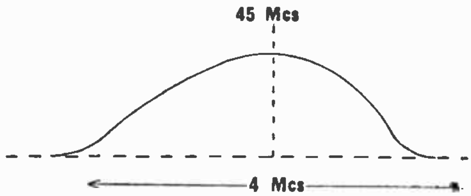


Fig. 101.—The type of response-curve to be expected from a vision receiver.

The Detector.—The detector valve is the conventional low-impedance double diode and works into a very low load for reasons that have been mentioned earlier in the chapter In the present instance the diode load resistance R_{18} is actually 2,000 ohms, while the correcting inductance CL_1 consists of 35 turns of 30 S.W.G. double-silk-covered wire wound on a former with a diameter of half an inch. It will be observed that a choke HFC is placed in the grid circuit of the video amplifier to discourage parasitic oscillation and to attenuate any spurious frequencies that are well above 2 megacycles, since frequencies of this order must not be appreciably attenuated if the picture detail is to be preserved. In the actual receiver in question the correcting inductance consists of 20 turns of 28 S.W.G. on a former having a diameter of a quarter of an inch.

The Video Amplifier.—The video amplifier employs a high-frequency pentode, which is the inevitable choice considering that relatively high frequencies must be handled and that the valve is required to develop a relatively large voltage across a low anode load. The anode is connected directly to the modulating grid of the cathode-ray tube, and therefore it would be unnecessary to employ a D.C. restoring circuit. It will be observed that the cathode of the tube is taken to a potentiometer R_{24}, which " floats " between two resistances R_{23}, R_{25}, allowing the cathode to be varied between 35 and 65 volts positive with respect to the modulating grid. Generally speaking, some form of inverter or black-spotter circuit could be introduced to off-set the effects of motor-car ignition interference. Such an arrangement is, in fact, fitted to the receiver under discussion, but for the sake of clarity it has been omitted from this circuit and is described separately later in the chapter. It will be noted that the high-potential end of the diode load is also taken to the grid of the double anode pentode V_9, which is a synchronising separator valve and must be linked to some convenient point so that the incoming signal appears across its grid/cathode, in order that it may perform its function of tripping the time bases at the incident of each appropriate synchronising impulse.

The Frame Time Base.—The frame time base is somewhat similar to that described in Chapter 10, but is modified for magnetic deflection. The discharge valve V_7 discharges the condenser C_{24}, which is charged through the resistances R_{26} and R_{27}. It will be observed that the portion of the charging resistance (R_{26}) is variable to control frame velocity or, in other words, the height of the picture.

The anode is coupled to the grid by means of the primary and secondary of the frame discharge transformer, in order to speed up the discharging of the condenser by driving the grid in the positive direction consequent upon the flow of current through the primary. The frequency of discharge can be determined by the setting of the frame synchronising resistance R_{28}, although, as previously explained, this resistance will be set at a value appropriate to the frequency, slightly lower than the frame frequency of 50 cycles per second, in order that commencement of discharge will be actually caused by a change of anode current in the synchronism separator valve, which is, in turn, caused by the appropriate impulse received from the transmitter. Attention is drawn to the time-constant condenser C_{27}, which has a value of ·0025 μF and introduces such a time constant that the short line-impulse will not materially affect the grid potential of the discharge valve to the extent of causing discharge so occur. The high-potential end of the charging condenser is coupled by means of the grid condenser C_{25} to the grid of a low-impedance pentode, which acts as an amplifier and provides the necessary current output to the frame deflector coil. It will be observed that the frame coil is not transformer coupled, being of high-impedance type. It will also be noted that the frame coil is shunted by a condenser C_{34} and is in series with the resistance R_{42}, both these components being introduced to improve the discharge waveform. The feed condenser C_{26} must necessarily have a high value, since the frequency to be handled is 50 cycles per second. Condensers of the order of 10 μF are commonly used for this purpose and may be of the electrolytic type. Particular attention is drawn to the condenser C_{23}, which performs the function of a negative feed-back coupling; that portion of the output of V_8 that is developed across the resistance R_{42} is applied to the grid/cathode of V_8 by virtue of this coupling. This feed-back is introduced to combat the non-linearity arising from the charging of C_{24} through R_{26} and R_{27}, which follows an exponential law.

The Synchronism-separator Valve.—The function of the synchronism-separator valve has been previously discussed and again mentioned in the course of reviewing the frame time base. The valve is biased sensibly to cut-off, and the input capacity of the valve in conjunction with the grip stopper R_{31} serves to attenuate to some extent the higher frequencies associated with picture intelligence which might otherwise trip the time bases. The grid, however, is biased nearly to cut-off by the cathode resistance R_{33}, which will have a relatively high value—in the present instance 75,000 ohms. The screen resistance is also of a high order, 10 megohms, so that the valve is in such a condition that a small input will bring about a large change of anode current; but the change in anode current caused by half the input to be expected will not be very great, and it remains, therefore, for the greater change to be caused by the synchronising impulse and not to any appreciable extent by the picture intelligence, which will never be greater than 70 per cent. of the total voltage change of the synchronising impulse. The cathode resistance R_3 is variable, allowing bias to be adjusted for the most definite synchronism This refinement, however, is purely optional and is not fitted to all receivers.

The Line Time Base.—The line time base could perfectly well employ the same circuit as the frame time base, with the sole exception of the time-constant condenser, which would be omitted to allow the circuit to respond to the short line-impulse; in addition, certain values would require modification, particularly the charging resistance and condenser. Actually an entirely different type of circuit is used for the line time base which is convenient, as it will enable a different arrangement to be considered.

A pentode, V_{10}, is used as a discharge valve, R_{36} and R_{37} forming the charging resistance and C_{31} the charging condenser. As the condenser charges, it drives the grid of the amplifier in the positive direction and increases anode current; coupling to the line coils being through the line output-transformer, which has a step-down ratio, since the line coils are of the low-impedance type. It will be noticed that the line coils are earthed at the centre and that they are shunted by a resistance R_{40} to prevent an excessive peak voltage being developed across them. The valve used for the line amplifier must necessarily be capable of standing a considerable potential difference between the electrodes, as the A.C. potential between the valve anode and cathode will be between 2,000 and

3,000 volts peak, although the applied D.C. voltage is rather less than 400 volts. It will be noticed that the line amplifier is biased by grid current.

The discharge valve V_{10} has its screened circuit coupled to its grid circuit by means of a suitable transformer, and the appropriate anode of the synchronising separator valve draws its current through the primary winding of this transformer. Assuming that the line-synchronising control R_{35} is correctly adjusted so that the discharge valve is nearly ready to pass current at the end of the line, the following sequence will occur. The line-synchronising impulse radiated from the transmitter will appear across the grid/cathode of the synchronism-separator valve, causing a sharp increase in anode current through the primary winding of the line-synchronising transformer, the secondary of which is so connected that it drives the control grid in the positive direction, anode current commences to flow, and the charging condenser begins to discharge. Coincident with the commencement of anode current screen current will flow, which must pass through the primary of the line-synchronising transformer and will drive the grid in the positive direction, which will increase both screen and anode currents; and the former will drive the control grid still more positive, which will, in turn, increase the anode and screen currents, and so on, until the sequence is stopped when the charging condenser is virtually discharged.

A perfectly normal high-frequency pentode valve may be used for the discharge valve in the type of circuit described, but to achieve rapid discharge it should be of a type which, worked under appropriate conditions, will pass a fairly heavy screen current. It is essential that the valve passes screen current in the normal direction and is not one of the freak types with reverse screen current. It is interesting to comment upon the fact that the discharge could be still further speeded up by joining the appropriate end of the line output-transformer secondary to the grid of the discharge valve, when the following additional sequence would occur.

When discharge begins the grid of the amplifier valve will go in the negative direction and the anode will, therefore, be driven in the positive direction, which change could be made to appear across the grid/cathode of the discharge valve and increase the rate of discharge. In the circuit under review such additional refinement is quite unnecessary, and this possibility is only commented upon as a matter of interest.

It should be noted that a portion of the charging resistance (R_{36}) is made variable as a means of correcting the linearity of the line sweep. Line amplitude (picture width) is controlled by R_{41}, which varies the gain of V_{11}, which is the line amplifier.

The Power Pack.—It will be observed that two high-tension supplies will be required and preferably, though not essentially, two heater supplies. The requirements of the two high-tension supplies are directly opposed. The supply to the valve anode circuits will need to be some 200 milliampères at about 400 volts, while the high-tension supply to the gun of the cathode-ray tube may be only about 50–250 micro-ampères at about 4,000 volts. It is apparent that two separate rectifiers will be required, a typical circuit being shown at Fig. 102. Two separate transformers are used, which permits better heat distribution and gives more convenient opportunity for the heavy insulation necessary for the high-voltage winding. As a means of discriminating between the output of these two rectifiers it has become customary to refer to the relatively

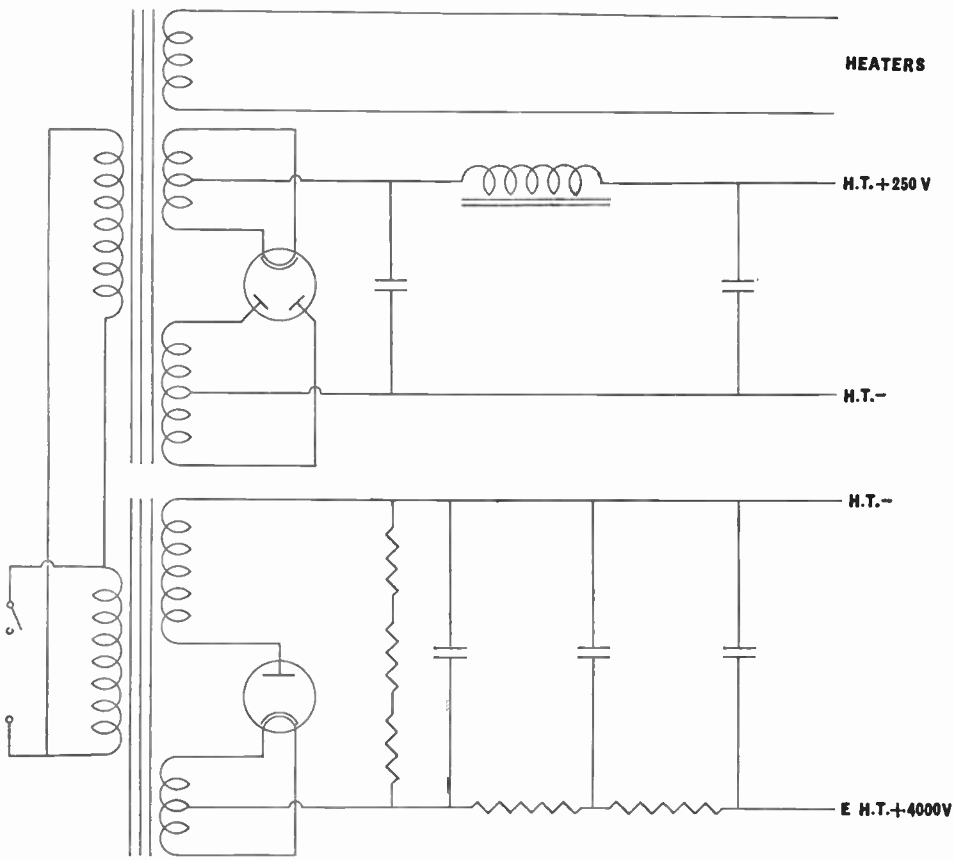


Fig. 102.—Circuit of a power pack for supplying a vision receiver.

low voltage as the high-tension voltage (abbreviation H.T.) and the other supply as the extra-high-tension voltage (abbreviation E.H.T.).

The H.T. supply does not require any detailed explanation, since it differs little from the corresponding section of an ordinary broadcast receiver. There are, however, one or two points of note on the E.H.T. supply circuit. The E.H.T. rectifier is usually of the half-wave type with a large clearance between cathode and anode. A sketch of a typical example may be seen at Fig. 103. The smoothing arrangements are somewhat unusual when judged by ordinary standards, as the smoothing choke is replaced by a resistance, which is possible owing to the very small gun current of the receiver, which will permit two ·5-megohm resistances to be used with a potential drop across them of the order of 100 volts. It will be observed that three resistances are connected in series between the anode and cathode of the valve, forming a permanent load, to prevent undue voltage variation when the cathode-ray tube is modulated. This load would be of the order of 25 megohms, and it is convenient to use three resistances of about 8 megohms each in series owing to the danger of surface discharge if the whole E.H.T. voltage appeared across one resistor. When subjected to voltages of this order certain resistances of the composition type allow a peculiar phenomenon to take place, which can best be described as a series of minute arcs between particles on the surface. It has the appearance of a brush discharge.

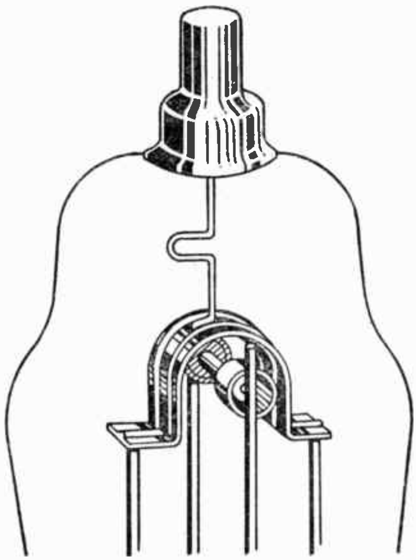


Fig. 103.—A typical high-voltage rectifier.

The E.H.T. rectifying valve should preferably have an indirectly heated cathode to obviate the possibility of a stationary spot on the screen if the beam current commences to flow before the time bases function. It will be appreciated that a stationary spot of any appreciable brilliance will burn the screen and leave a brown mark which will thereafter appear as a dark patch on the picture.

A study of the circuit shown at Fig. 102 will reveal that the heater winding of the E.H.T. rectifier is maximum positive in respect to earth (*i.e.* between 3,000 and 5,000 volts), and consequently this winding must be heavily insulated from other windings and the transformer core.

The diagram at Fig. 102 cannot be regarded as complete unless the sound receiver is to derive its high-tension supply from the same source as that used to feed the vision amplifier. Such an arrangement is not usually employed, owing to the danger of feed-back from sound to vision, or *vice versa*, and consequently a separate circuit is usually employed. It has, however, been omitted from this diagram for the sake of simplicity.

The Aerial.—The ordinary aerial is not employed for television reception because of its poor efficiency and signal to noise ratio at very high frequencies. In practice a dipole aerial is used, consisting of two rods, the length depending on the local B.B.C. frequency, see Fig. 104. The transmitting aerial is vertical, and consequently the radiated energy is vertically polarised and the receiving aerial must, therefore, be similarly placed. It is intended that the aerial shall be so placed that its signal pick up will be reasonably high, and that it will be remote from motor-car interference to an extent commensurate with the amplitude of the receiving signal.

The height of a television aerial will obviously vary in different neighbourhoods, and must depend on the number of elements of which it is composed; other factors are the intensity of motor-car ignition interference, the height above sea level, and the sensitivity of the receiver to be used. A good picture may be obtained at a location at, say, 50 miles from the transmitter with an aerial about 75 feet high, whereas an equally good picture can be obtained at another location at, say, 70 miles with an aerial only about 45 feet high. On the other hand, certain areas can be pockets of low signal strength even when completely surrounded by a general area of high signal strength. Variation is even more apparent on Band III, but it is easier to provide multi-element aerials.

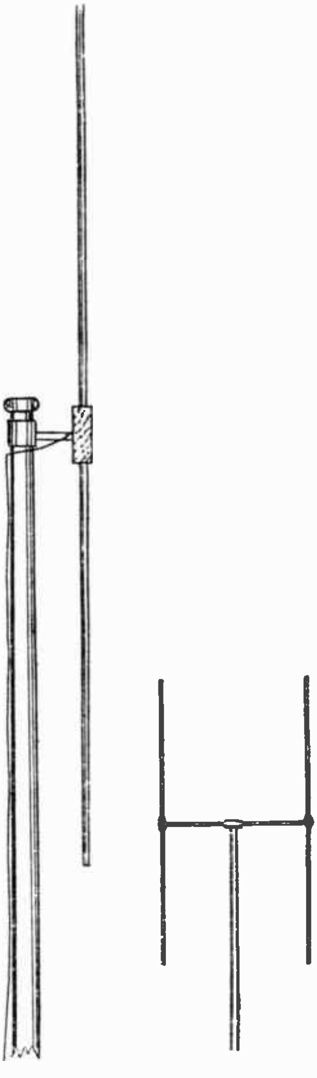


Fig. 104. — (*Left*) A typical dipole. The feeder should be led away at right angles for a distance of at least 12 inches; dipole aerial must be horizontal for receiving certain B.B.C. transmitters. (*Right*) Dipole aerial with reflector.

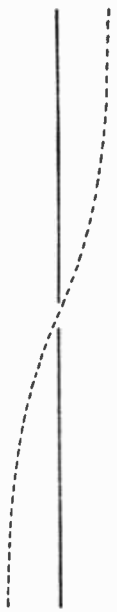


Fig. 105.—Voltage distribution on a dipole aerial of the "split centre" type.

Fig. 105 shows the general distribution of voltage on a dipole aerial, from which it will be seen that the voltage is at a maximum at the ends (in opposite phase) and zero at the centre, while current is at a maximum at the centre and minimum at the outer ends. The problem is to connect the dipole to the input coil of the receiver without picking up any unwanted interference, bearing in mind that the downlead will normally pass through fields of interference reaching a high level. This difficulty is overcome by using either a screened feeder of a particular type or a twin feeder and a balanced aerial circuit. The special screened feeder is known as concentric cable and is so designed that it has a surge impedance of 60–80 ohms, in order that it may match the aerial, which has a similar impedance at its centre. The surge impedance of a concentric feeder is given by the formula:

$$Z = 176 \log_{10} \frac{D}{d}$$

when Z equals the surge impedance, d equals the diameter of the inner conductor, and D equals the internal diameter of the outer conductor. The formula assumes that the dielectric between the inner and outer conductors is air. If an appreciable amount of insulating material is used the entire formula must be divided by the square root of the effective dielectric constant. The type of concentric cable used for television consists of a relatively thin inner conductor and a densely woven outer conductor having a diameter of about half an inch; the inner is spaced from the outer by skeleton insulators placed about an inch apart.

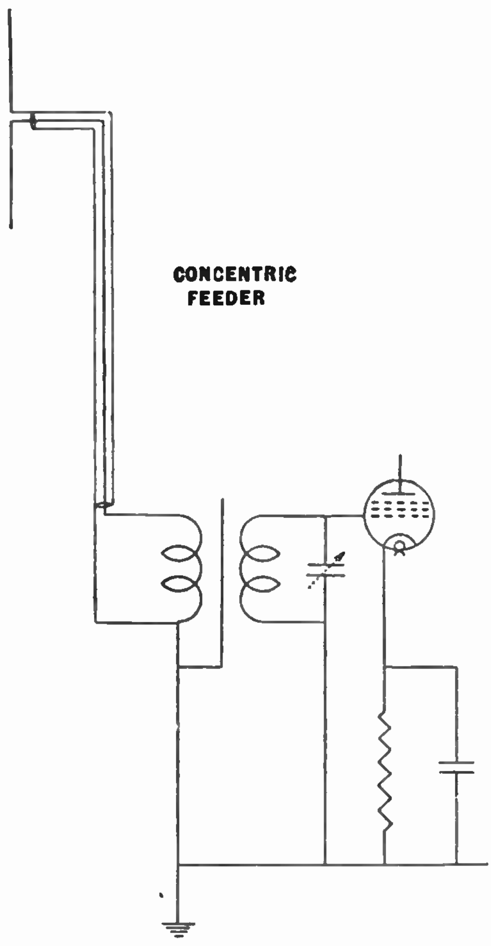


Fig. 106.—The aerial circuit arranged for use with concentric feeder.

The inner and outer conductors are joined to the bottom and top halves of the dipole respectively (the reverse is possible, but unusual). The other end of the concentric feeder is similarly joined to the two ends of the aerial coil, and the outer conductor earthed so that it acts as a screen to the inner conductor, see Fig. 106. A screen is usually placed between the primary and secondary windings to prevent a capacity coupling between the two coils, so that the voltage appearing across the secondary is due only to current flowing through the primary.

Twin Feeder.—If concentric cable has any disadvantage other than of a mechanical nature it is that its efficiency as a means of excluding interference is somewhat dependent upon the efficiency of the earth connection. When the alternative arrangement of twin feeder and a balanced input circuit is employed, the efficiency of the earth is unimportant in so far as the signal to noise ratio is concerned. Twin feeder for this purpose is available with an impedance of 60–80 ohms, the wires being embedded in what is apparently a flexible plastic. Due to the excellence of the insulating material the loss is low, being about 3 decibels per 100 feet, and in this respect is equal to good concentric feeder.

The arrangement of a twin feeder is shown at Fig. 107. The outer ends of the dipole aerial are placed approximately half a wavelength apart, and the potential difference between them is relatively great and sufficient to cause current to flow in each direction alternately. The two feeder wires are placed very close together, being only about one-tenth of an inch apart, with the result that they pick up energy in the same phase. The flow of current originating in the dipole will pass through both halves of the primary in one direction and effect magnetic coupling with the secondary, but energy picked up by the feeder will flow through each half of the primary in opposite directions, and, providing the tap is at the electrical centre, two equal fields will be produced in opposite phase, so that no voltage is set up across the secondary. Note particularly that an earth screen is placed between the two coils to prevent capacity coupling.

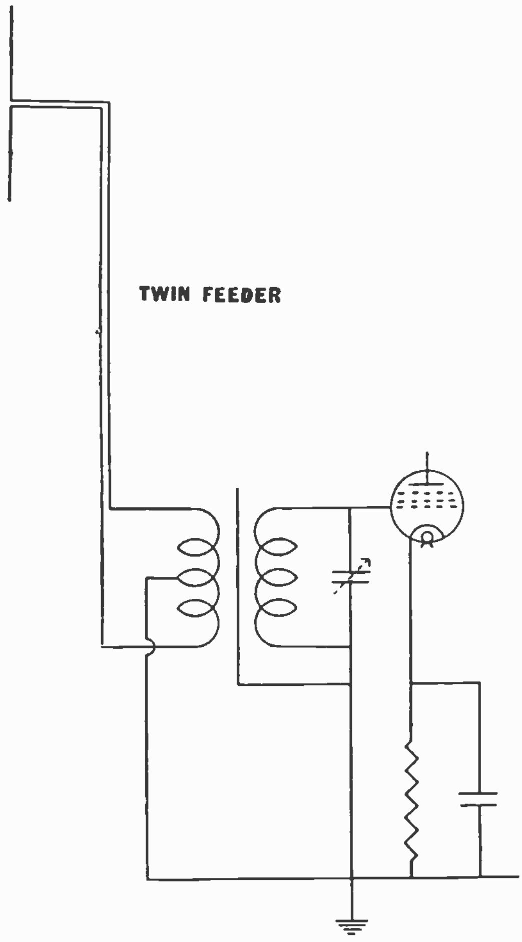


Fig. 107.—The aerial circuit arranged for use with twin feeder.

In practice, the centre tap shown at Fig. 107 can be dispensed with, since current picked up by the feeder will not flow through the circuit, as no difference of potential exists, the only movement being current to charge the coil screen capacity and self-capacity, but here again current will flow equally in each direction and no voltage will be induced across the secondary.

The split centre dipole shown at Fig. 104 is often known by the rather unfortuate name of current-fed dipole, and has the practical disadvantage that the feeder *should* run at right angles for about a quarter of a wave before it is dropped to the receiver, in order to prevent coupling between the feeder and the lower half of the dipole. This requirement presents no difficulty if the dipole is fixed to a chimney, but is very ugly if fixed to a mast, with the result that this distance is usually reduced to some 12 inches. To overcome this difficulty another form of dipole has been evolved which has become known by the equally unfortunate name of the voltage-fed dipole. It is illustrated diagrammatically at Fig. 108, and consists of one wire 14 feet 9 inches long and the other 4 feet 11 inches long, the wire being of 14 S.W.G. and spaced precisely 3 inches apart. The portion of the long wire, marked 9 feet 10 inches long in the illustration, is the actual aerial, the lower portion and the short length parallel to it may be considered as a piece of feeder, and is known as a matching stub. Its purpose is to allow the ordinary low-impedance feeder to be used, which cannot be connected directly to the outer end of the dipole, as it has a terminal impedance of about 3,000 ohms. The matching stub must be so designed that its surge impedance is equal to the square root of the product of the feeder impedance and terminal impedance of the dipole, or, expressed as a formula:

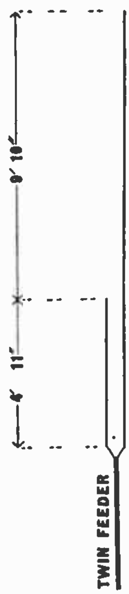


Fig. 108.—A dipole aerial with matching stub.

$$Z_1 = \sqrt{\frac{Z_3}{Z_2}}$$

when Z_1 equals the surge impedance of the matching stub, Z_2 equals the surge impedance of the feeder, and Z_3 equals the terminal impedance of the dipole.

The Reflector.—The efficiency of a dipole may be increased by the use of a reflector, which is placed immediately behind the dipole at a suitable distance, see Fig. 104. If the aerial is of half-wave type, *i.e.* each arm is a quarter wavelength, the reflector may be of similar length or a little longer if it is desired to increase the efficiency of the aerial array at the sound frequency at the expense of a corresponding loss at the vision frequency. The nominal distance between a half-wave reflector and dipole is a quarter wavelength, but measurements have shown that this may be advantageously decreased by about an inch, although it is not apparent why this should be so. Assuming the dipole and reflector are of the same length and made of the same material, the efficiency is increased to such an extent that the current flowing in the aerial circuit is nearly doubled.

A reflector array exhibits marked directional properties, and its optimum direction is when the reflector is behind the dipole and in direct line with the transmitter, always assuming that direct radiation is being picked up and not a reflection. The directional properties of the reflector can be used to improve the signal to noise ratio under certain conditions, such as when the major interference comes from the opposite direction to that of the transmitter. Under such circumstances the reflector will double the signal and also reduce the interference by feeding such energy to the aerial out of phase with the energy directly picked up.

Numerous forms of dipole aerial are available, such as the folded dipole, which is usually accompanied by one or more pairs of rods called directors, in front of the actual dipole aerial as well as a reflector behind it. Quite different forms of aerial exist, such as the tilt-wire aerial which has great directional properties but takes up a lot of room both vertically and horizontally.

Frequency Separation.—It is usual to use a single aerial for both sound and vision signals, and when separate chassis are used for these functions some means must be provided for preventing the sound frequency from appearing in the vision amplifier, and *vice versa*. Generally speaking, the selectivity of the vision amplifier will not in itself be adequate. Various arrangements are possible in the form of rejector circuits, but there is one arrangement which is sufficiently interesting to deserve special mention. Fig. 98 (in the previous chapter) shows the sound and vision chassis connected to the main feeder by two small lengths of feeder which terminate in parallel. Both these short lengths of feeder are cut to a critical length, so that the piece feeding the vision chassis is equal to one-quarter of the sound wavelength, and the piece feeding the sound chassis is equal to one-quarter of the vision wavelength. As these critical lengths are terminated by a closed circuit they will offer something approaching infinite impedance to frequencies to which they bear the relationship of one quarter of a wave. In this way the vision frequency is excluded from the sound amplifier, and *vice versa*.

The White-spot Limiter.—Invertor.—Television receivers always have some arrangement to decrease the effects of bad interference of the type radiated by motor-cars. The ignition systems of motor-cars radiate considerable interference unless suppressed, unfortunately there are many motorists who have not yet taken the trouble to respect the enjoyment of other people. The most satisfactory way of combating this form of interference is to improve the signal to noise ratio by increasing the height of the aerial. There are, however, limits in this direction and, furthermore, circumstances may arise whereby bad interference is experienced only occasionally and some less-costly means is desirable for lessening interference.

Motor-car interference will tend to drive the beam in the direction of white, and if it is only sufficiently strong to drive the beam to maximum white it will appear as a small spot of normal size travelling across the screen and, incidentally, the principle of inversion cannot be applied. If the motor-car interference is received at an amplitude of about double that of the received signal its effect is very distressing, as it modulates the tube beyond white, which has the effect of defocusing the spot so that large white spots travel across the screen, which may well be sufficiently large to cover five or more lines, and it is in this condition that the white-spot limiter may be employed. Another device is the black spotter or invertor.

The black spotter functions by modulating the cathode-ray tube in the direction of black when the input is greater than maximum white.

This has the effect of turning the spot dark grey or black, which is less obvious than white, and reducing its size. The relationship between modulator grid voltage and gun current is generally similar to that of a triode, but the introduction of an additional diode can bring about a decrease of gun current when the modulator grid is driven beyond zero into the positive region, and, if driven sufficiently far, the flow of gun current is virtually stopped.

Band III Reception.—Preceding chapters on television have ignored almost completely operation on Band III, which covers from 174–216 megacycles. This band is reserved for television and is divided into eight channels. Only three channels in Britain are allocated and these are at the disposal of the Independent Television Authority, they are channels 8, 9 and 10, and the appropriate carrier frequencies are as follows:

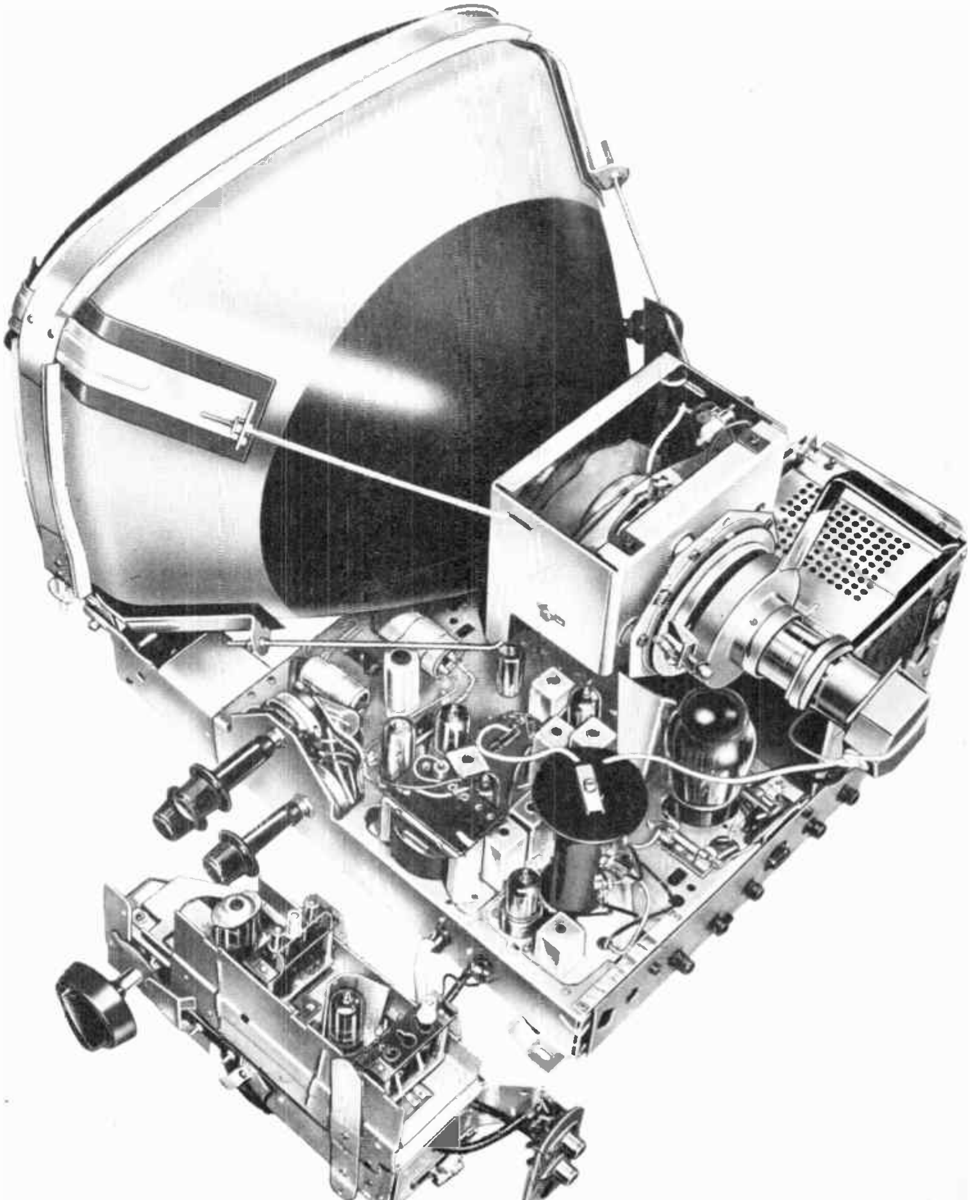
Channel	Sound	Vision
8	186·25	189·75
9	191·25	194·75
10	196·25	199·75

Many receivers originally designed for Band I, the B.B.C. band, have been converted for Band III operation by means of an " add-on " unit, and there probably remains some three million receivers that are incapable of conversion or which have not been converted for some reason or other. This chapter is devoted to television-receiver design and attention must therefore be directed to receivers actually designed and manufactured for combined Band I and Band III working.

Broadly speaking, Band III is about four times the frequency of Band I, and while this increase is significant, it does not call for fundamentally new techniques but rather for a tightening up of component tolerance and special care to prevent frequency drift. Coils and condensers must have very stable frequency temperature characteristics.

Multiple-band Receivers.—Receivers for Band I and Band III reception, known as multiple-band receivers, vary from one manufacturer to another in the manner of switching channels. Most, if not all, channel-selector switches present a somewhat similar outward appearance and consist of a fairly large knob with twelve or thirteen numbered " click " positions with a small knob concentric with the large one for the purpose of fine tuning. The basic arrangements employed divide conveniently into groups and are best dealt with separately.

The Turret Tuner.—Probably of American origin, the turret tuner consists of twelve or thirteen sets of coils—aerial, H.F. amplifier coupling and oscillator—arranged in a form of drum which is rotated by the programme-selector switch so that the desired set of three coils line up with a single set of three stationary contacts. In any one position of the turret a single set of three coils is connected in circuit while all others are completely disconnected. Fine tuning is usually provided in the form of a variable condenser across the oscillator coil. Each separate coil in the



A MODERN TELEVISION CHASSIS

This chassis, manufactured by Ultra, shows very clearly the focusing magnet assembly and the deflector coils in their screening box. The E.H.T. unit is in the metal box with perforated lid. The small chassis is a programme selector of the "sliding turret" type.

drum can be independently trimmed by means of screwed iron cores.

The reason why twelve sets of coils is possible for a thirteen-channel tuner is that the fine tuner which has a greater effect at the high-frequency end of the band is able to make one coil cover two channels. The fine tuning condenser usually takes the form of two fixed plates while the moving vane is of dielectric material and by rotating it between the fixed plates the capacity between them is varied.

The Permeability Tuner.—Another popular arrangement consists of only two sets of three coils, one for Band I and the other for Band III, tuning being controlled by sliding iron cores, the position of which is determined by cams actuated by the programme-selector knob. This system requires coils manufactured to close tolerances. Fine tuning is not normally confined to the oscillator but operates on all three circuits by means of a mechanism which allows the entire coil assembly to move a small distance, to reiterate, the programme-selector switch causes a relatively large movement of the cores in relation to the coils whereas the fine tuner moves the coils by a small amount in relation to the cores.

Incremental Inductance Tuning.—This system uses a triple-gauged wafer switch each capable of selecting the required tap on three multi-tapped coils for aerial, H.F. amplifier coupling and oscillator respectively. Although each coil is normally a single winding, the actual tapping points fall into two groups for Bands I and III respectively and a trimmer is usually provided to trim each complete group. The user is normally provided with a fine tuner which takes the form of a small variable condenser across the oscillator coil.

The Three-channel Tuner.—Some manufacturers took the view, noteably around 1953–54, that no viewer wherever situated would be likely to have available a choice of more than three programmes during the life of the television receiver and simplified the tuning system by providing only three positions. One for Band I and two for Band III, the actual channel being determined by the use of appropriate clip-in coils. These coils are readily changed if the set is moved to another neighbourhood where different channels are in use. One form of three-programme tuner took the form of a sliding turret which was moved backwards or forwards by the switch across a single set of three contacts in exactly the same way as a rotating-turret tuner except that the movement was backwards and forwards. In this arrangement fine tuning was accomplished by a small variable condenser across the oscillator coil.

Nomenclature.—(Controls).—Alternative terms have crept into use for describing the controls of television receivers. The following list is therefore included: the first-named term in each group is that recommended by a responsible Committee that has drawn up a list of standardised terms, while the alternatives are others in more or less general use:

Time Base. (Time-base generator.) The circuits responsible for producing vertical and horizontal deflection.

Brightness. (Brilliance, brilliancy.) The control which adjusts the negative bias on the modulating grid of the cathode-ray tube and determines the over-all brightness of the picture.

Contrast. (Gain). The amplifier gain control which determines the general contrast of the picture.

Vertical hold. (Frame-synchronising control, frame synchronism.) The variable adjustment for obtaining optimum performance of the circuit responsible for the vertical deflection.

Horizontal hold. (Line-synchronising control, line synchronism.) The variable adjustment for obtaining optimum performance of the circuit responsible for horizontal deflection.

White-spot limiter. (Black spotter, interference limiter.) A device for reducing the effect of certain types of interference.

Picture width. (Line amplitude, line velocity, line length.) The control for adjusting the total width of the picture.

Horizontal form. (Horizontal linearity.) The control for adjusting the line scan so that it occurs at uniform velocity.

Picture height. (Picture amplitude, frame amplitude, frame velocity.) The control for adjusting the total height of the picture.

Vertical form. (Vertical linearity.) The control for adjusting the frame scan so that it occurs at uniform velocity.

Horizontal shift. (Line shift.) The control for moving the picture in the horizontal direction for the purpose of adjusting its position.

Vertical shift. (Frame shift.) The control for moving the picture in the vertical direction for the purpose of adjusting its position.

Focus. The control for reducing the size of the spot to such proportion that the picture is sharp.

Tuner. (Programme selector.) The control for selecting the desired channel; it usually has a fine tuner control incorporated with it.

CHAPTER 13

ADJUSTMENTS AND FAULTS OF A TELEVISION RECEIVER

THE operation of a television receiver may entail the intelligent manipulation of perhaps only two knobs, but in addition there may be between five and ten pre-set controls, which in some receivers will be placed out of the way while in other receivers some, at least, of the pre-set controls will be placed in an accessible position permitting the viewer to adjust them from time to time. Television in its practical form is a relatively new art and a few remarks on operation may not be out of place in addition to notes on the pre-set controls.

High Voltage.—Voltages of the order of 15,000 volts above earth are common in television receivers, and appear as both alternating- and direct-current potentials at appropriate points. It will be unnecessary to draw the reader's attention to the necessity for taking adequate care when handling a television receiver when the back is removed. Presumably no one would deliberately touch a conductor or terminal which is known to be at a high potential, but attention is drawn to the fact that high potential may appear at most unexpected points. For example, a valve which is known to be designed for working at an anode potential of, say, 250 volts D.C. might appear perfectly safe, but if such a valve happens to be working as a time-base amplifier it may generate peak potentials of several thousand volts. While the reader is warned against touching points of high potential, it is perhaps desirable to make some attempt to place the whole question of danger into some reasonable sense of proportion. Some contemporaries suggest that accidental contact with such voltage is fatal, but in the course of experiments the author has several times accidentally touched the E.H.T. rails whilst standing on an ordinary wooden floor and has received no worse effect than a shaking and a determination to be more careful in future.

The Controls.—The precise method of handling a television receiver is dependent upon the type of circuit used, consequently the following must be considered as being of a general nature. The text is conveniently split up under the heading of the control to which it refers, and it will be understood that all normal controls are included.

Brightness.—This control is invariably situated on the front of the receiver and is intended for more or less continuous use. It may have combined with it the on/off switch, which is a very good feature as it compels the viewer to adjust the brightness on each occasion. The brightness control is actually a variable negative bias applied to the modulating grid of the cathode-ray tube and controls the general brightness-level of the picture. Its use is somewhat interdependent on the setting of the contrast control, and innumerable combinations between these two controls will give a picture varying from the "soot-and-whitewash" type, where only dead black and dead white are present and the half-tones are lost, to the muddy effect when black and white are absent and the picture is composed of a limited variation of grey. It is apparent that between these two extremes there is a combination which will give the best possible tone values. The adjustment is soon acquired with practice, but the following procedure is a useful method when adjusting certain types of television receiver for the first time.

Withdraw the aerial feeder plug so that no signal is received. In a completely dark room turn up brightness until the raster is just apparent and then slightly decrease the control until the raster is just lost. The tube is then biased to its effective cut-off point, and when the aerial plug is replaced a good picture should be obtained by advancing the contrast control until the high lights are just apparent in the darkest places.

Contrast Control.—The contrast control is a means of varying the gain of the vision amplifier and will determine the instantaneous modulating voltage applied to the tube, and is set so that the tube is modulated to maximum white when the transmitter modulates at maximum. In practice it is adjusted so that portions of the picture intended to be white are brilliant without defocusing the spot or turning black portions to grey. If the receiver is fitted with automatic gain control (A.G.C.) the contrast control will set the black level.

Tuning.—A tuning control is fitted to combined B.B.C. and I.T.A. receivers and is more critical on Band III (I.T.A.) than on Band I (B.B.C.); optimum adjustment is not easy but generally speaking it should be adjusted for maximum sound performance and the picture ignored. Modern television receivers work on one vision sideband and in these circumstances correct sound will not appear at the same setting as the *brightest* picture, but if the control is correctly set for sound the picture will have *maximum detail* (as distinct from brightness) and this is the correct adjustment. It may so happen that a receiver of this type will fail to give an acceptable picture when the tuning is precisely set for the best sound reproduction, due either to pattern interference, excessive grain or disturbance of line on frame hold on loud music or effects. In such cases a slight re-adjustment is the only remedy. Owing to the relatively high frequency at which the amplifiers are required to work, some trouble may be experienced due to oscillator drift, necessitating readjustment of the tuning when the receiver gets thoroughly warm. The only means of off-setting this trouble is the obvious one of switching on in advance to give the receiver time to become well warmed up, unless sufficient apparatus is available to re-trim the sound circuit to give a wider response-curve, so that a certain amount of drift can take place without any audible manifestation.

Focus.—Focus is normally adjusted by means of a lever or knob, which should be set so that the spot is as small as possible or, in other words, so that the black spaces between the lines are as wide as possible. These lines will not be apparent when the picture is viewed from the correct distance and the actual image will be sharply defined. The optimum viewing distance is that position when the lines just cease to appear as such and is normally a distance equal to about eight times the width of the picture.

On older sets the focus control will usually appear on the front or side of the receiver, but it may be that it is in the form of a vernier and that another focusing control is available and is intended to be regarded as a pre-set adjustment. Television receivers made prior to 1939 often used a ring magnet for focusing which was pre-adjusted by an iron sleeve capable of sliding up and down the neck of the tube. It is intended that this sleeve shall be correctly set when the focusing potentiometer is in the central position, so that the latter acts as a vernier control for the convenience of the viewer to correct slight variations from time to time. It is interesting to mention that there is yet a third adjustment in this arrangement, which is the movement of the ring magnet itself, this may be moved forward or backward; the effect of the iron sleeve varies widely but very roughly the full swing of the potentiometer is equal to moving the sleeve about half an inch, and the total available movement of the sleeve is equal to moving the ring magnet about one-eighth of an inch.

Picture Alignment.—Picture alignment may be defined as the rotation of the picture on its axis so that it is square with the mask. This is accomplished by rotating the tube bodily in the case of the electrostatic type or by rotating the deflector coil assembly in the case of the magnetically deflected tube.

Picture Centring.—Picture centring should not be confused with picture alignment and is intended to mean the movement of the picture bodily in the vertical or horizontal direction so that it is central within the confines of the mask. A variety of means is available for this adjustment which was easy in the days of electrostatic deflection by using potentiometers to vary the D.C. potential on the deflector plates; as the control is rotated the picture moves in either direction as may be required and a precise adjustment is effected. In the modern permanent magnet assembly, picture centring is accomplished by means of an iron disc on the rear face of the magnet which may be moved in any direction, the adjustment is somewhat complicated by the fact that the picture does not move in the same direction as the disc, but approximately at right angles to it, it is easy, however, after a little practice. The effect is a little difficult to master and particularly baffling if the operator is unaware of it. It is due to the twisting effect imparted to the beam by the magnet. In the older sets using permanent magnet focusing adjustment is provided by means of moving the focusing coil in any direction, the operation being simplified by cams or other devices, so that a small movement is obtained.

Vertical Hold.—This control is the frequency adjustment of the frame time base and when incorrectly set the picture may revolve in the vertical direction giving the appearance of a rotating drum. When the frame hold is correctly set the picture will be rigidly locked. In some receivers the latitude of the control may be such that the frequency of the frame time base may be set to half the correct frequency, which will cause two long narrow pictures to appear on the screen one above the other and separated by a black line. This control is sometimes called frame hold.

With the majority of receivers the picture is held rigid when the frame-hold control is anywhere within a certain segment of its possible rotation. Generally speaking, the adjustment should be left in the centre of the segment over which frame hold is achieved. Certain receivers provide an exception, as this tolerance is used to adjust interlacing, as described in the next paragraph.

Interlacing.—A few receivers are provided with a pre-set interlacing control and those which are so equipped may be divided into two groups. (1) Interlacing control by critical adjustment of the frame hold, and (2) by some adjustment to the frame deflecting coil or coils. The method of interlacing control is self-explanatory in the first group. In the case of the second group adjustment may be effected in some cases by shifting the coil slightly on its mounting, while in others it is achieved by the movement of a small piece of iron which forms an extension of the core. Interlacing in the last group is invariably critical, inasmuch as 90 per cent. of the total movement has no effect at all, while movement through 10 per cent. will take the interlacing through the correct point and out again. Incorrect interlacing causes the odd and even scan to be superimposed on each other, giving some 200 thick lines interspaced with thick and very apparent black spaces, instead of some 400 lines separated by very narrow black spaces.

Horizontal Hold.—This control adjusts line time base frequency and when incorrectly set it produces an effect quite different from that of the frame-hold control, inasmuch as the picture becomes a meaningless jumble. When correctly set the picture appears as a picture and the position is quite unmistakable. It should invariably be set at the central point of the movement through which the picture can be held. This is important, as careless adjustment may produce ragged edges. This control is sometimes called line hold.

Vertical Form.—Also called frame linearity, this controls the scanning speed at the top of the picture as compared with the bottom. When incorrectly set a figure appearing full length will be long from the waist to the head and short from the waist to the feet, giving a most grotesque effect. Adjustment is effected until the spacing between lines is uniform at the top and bottom of the picture.

Horizontal Form.—Also called line linearity, this controls scanning speed at the beginning of the line as compared with the end. When incorrectly set, objects will appear much wider on the right-hand side than at the left-hand side. Adjustment is effected until this distortion is not apparent, and can only be accurately accomplished when a picture is available, having a regular pattern in the horizontal direction, *e.g.* a railing.

Picture Height.—Also known as frame amplitude, this control may be a variable resistance or inductance permitting the height of the picture to be adjusted. It is essential that the frame linearity-control should first be adjusted (if one is fitted) before attempting to adjust the height of the picture, which should be just greater than the vertical dimension of the mask, so that one line is hidden at the top and one at the bottom.

Picture Width.—Sometimes called line amplitude, adjusts the length of the line scan and should be set so that the " border " is just covered by the mask. If a line linearity-control is fitted this must be adjusted before the line amplitude-control can be operated intelligently. It is important that the small margin of the picture that is hidden by the mask shall be equal in the horizontal and vertical dimension, otherwise the true proportions of the picture will be lost.

Synchronism-separator Control.—A few old sets were fitted with means of adjusting the amplitude of the synchronising impulse delivered to the frame and/or line time bases. It may take the form of a single control influencing both time bases, in which case it is usually a means of varying the grid bias on the synchronism-separator valve. The control should be adjusted so that the tolerance on the line hold and/or frame hold is as great as possible. When separate controls are provided these are both adjusted in the same way. There is, however, at least one exception to this rule, where the frame synchronising separator control is used to force the frame-hold control to function at a point where correct interlacing is brought about.

White-spot Limiter (Black Spotter, Invertor).—The control provides means of minimising the effect of motor-car interference. When such interference is not present, the control should be turned so that the device is completely out of action. When interference is present, it should be adjusted in the following manner: carefully set brightness and contrast control on a normal picture and then turn the invertor control until the point is reached where the white portions of the picture just begin to suffer (*i.e.* become grey and lose the finer points of definition). Next turn the invertor control slightly in the opposite direction, so that the picture is just, but only just, returned to normal and the device is set for optimum results. It should be noted that in its common form the invertor will not function on slight interference, its advantage being most apparent when the interference level is 60 per cent. or more higher than picture level.

Astigmatic Control.—A control fitted to old sets to provide means of preventing the spot from deforming as it travels from one end of the line scan to the other. When astigmatism is present to a marked degree, the spot becomes elongated in the horizontal direction at one end and a parted jagged appearance is given to any vertical lines which may form part of a normal picture. At the other end it may be elongated in the vertical direction, giving a curious effect, somewhat similar to incorrect focus, accompanied by loss of brilliance. The method of adjusting the receiver to avoid this fault is different in almost every receiver, and the maker's instructions should be rigidly adhered to, particularly if the method recommended entails putting both time bases out of action so that a stationary spot is obtained. It will be appreciated that a stationary spot will burn the fluorescent screen unless the brightness control is turned to a very low level.

Common Faults.—If the law of averages applies to television receivers, it can be assumed that faults will occur much more frequently than in the case of sound receivers on account of the number of valves used, even if the associated components are neglected. In practice, however, the average television receiver seems to enjoy reliability approaching that of an ordinary sound receiver of equivalent quality. It might appear at first sight that the complexity of a television receiver would make fault finding exceedingly difficult. The reverse, however, is the case, since each small section performs a separate and definite function and a mere glance at the screen will usually determine the section in which a particular fault may be found. A few of the more general faults are mentioned below.

No Illumination of the Screen.—This condition must mean that the electron beam is absent, which can only be due to one of four causes: (1) a broken heater in the tube itself, (2) E.H.T. supply not functioning, or (3) excessive negative bias on the modulating grid, (4) a blown fuse. Inspection will usually clear up the first possibility, as the characteristic red glow is quite apparent in the neck of the tube, while the lack of E.H.T. can be determined with the use of an electrostatic voltmeter. The gun voltage can only be measured directly by an electrostatic meter, but if a little calculation is not objected to it can be determined by the use of a very high resistance, say, 50 megohms, and a 0-1 milliampère meter. Obviously the value of the smoothing resistance must be known.

Picture Absent but Raster Normal.—If the picture is entirely absent but a normal raster appears when the brightness control is turned up, it is apparent that the cathode-ray tube is not being modulated and systematic testing is necessary, starting from the modulating grid of the tube and working progressively through the various stages to the input aerial circuit.

Line Scan Absent.—If the line time base fails to function, a vertical line will appear near the middle of the screen. It will be intensely bright, but if reduced by means of the brightness control, some sign of modulation

Fig. 109.—A drawing to illustrate the effect of bad line linearity. It will be observed that while the right-hand side of the picture is fairly normal, the left-hand side is progressively cramped.

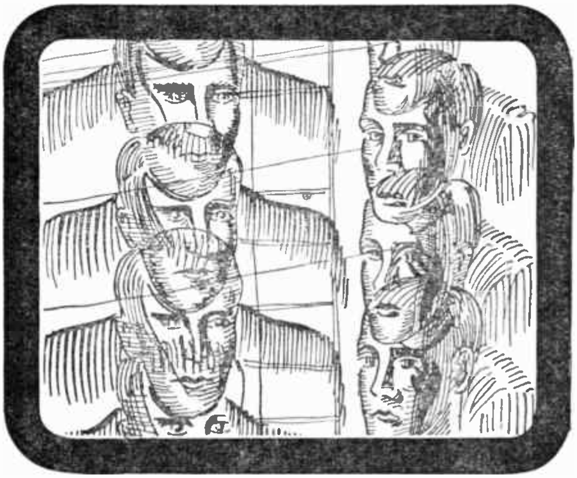


Fig. 110.—A sketch giving an impression of the effect obtained when the frame time base is slightly out of adjustment. This effect is impossible to photograph and difficult to draw accurately.

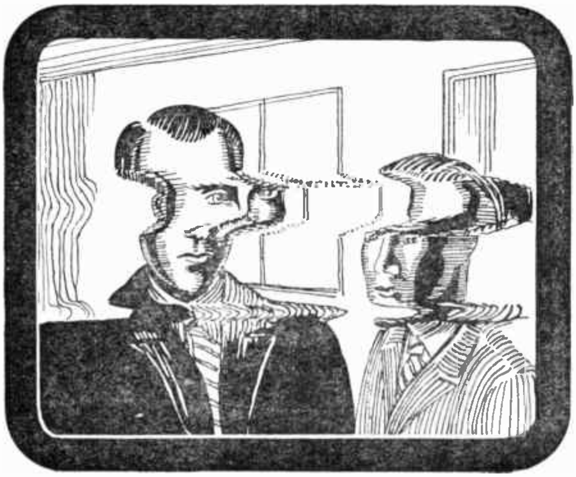


Fig. 111.—Another drawing which gives an idea of the effect resulting from an unstable line time base. Single lines or isolated groups of lines slip out of synchronism, with the result that a portion of the picture moves to the right, as shown.

may be apparent. The line time-base circuit including line-deflection coils should be systematically checked. It should be noted that the performance of valves in a time base cannot be checked satisfactorily except by substitution, as they usually work under abnormal conditions in these circuits.

Frame Scan Absent.—If the frame time base fails to work, a horizontal line of intense brightness appears across the screen. The appropriate action is that outlined above for the line time base, except that it is, of course, applied to the frame time-base circuit and coils.

Picture Failing to Fill Mask.—If the picture appears about half its normal height or width the trouble may be due to a number of causes; the most probable, however, are as follows: In the case of an electrostatically deflected tube, the trouble is probably failure of the amplifier valve in the appropriate time base. In the case of magnetically deflected tubes, the appropriate time-base amplifier should be suspected. Note that in the former case the reduction in size will be about half, whereas in the latter case the reduction may be almost any percentage.

Picture Too Small.—If the picture appears too small but correctly proportioned, the trouble is almost certain to be an unduly large high-tension voltage supply to the time-base valves. This fault may reduce the picture to any extent and the picture that is normally, say, 14 × 11 inches may be reduced to, say, the size of this page.

Tube will not Focus.—If a condition occurs whereby manipulation of the focus control will allow adjustment of focus through the best point, but yet fail to give satisfactory sharpness of definition, low E.H.T. voltage or a soft tube may be suspected. The former will be accompanied by lack of brightness at a definite setting of the brightness control.

Frame or Line Hold Unstable.—If either of the "hold" controls are critical and require frequent readjustment, a number of possibilities present themselves, the most probable of which are a leaky charging condenser, a leaky grid-bias condenser, or a soft discharge valve in the appropriate time base. (See also next paragraph.)

Frame and Line Hold Unstable.—In the average circuit there are only two items common to both time bases, the high-tension supply and the synchronism separator circuit; systematic attention to these should reveal the trouble.

Excessive Interference.—Excessive interference from motor-cars may be attributed to an inefficient aerial system or, if a marked increase occurs suddenly, suggesting a fault, a break may be suspected in the feeder wire if of the twin type or, in the case of the concentric type, the outer casing may have become disconnected.

Patterns on Screen.—A more or less symmetrical pattern superimposed on the screen, and suggestive of a watered-silk or Scotch-plaid effect, may be attributed to an alien frequency in the vision amplifier. Whether or not this arises from the sound receiver can be determined by putting the latter out of action. If the trouble persists, external interference may be suspected in the form of re-radiation. A stationary and solid pattern in the form of horizontal, straight, or zigzag bars can be attributed to the type of radiation experienced from diathermy or other medical apparatus, or apparatus functioning in a similar manner.

Two or More Images.—Two or more images may appear on the screen; the spurious images being displaced to the right-hand side of the primary image. The normal cause of the phenomenon may be attributed to reflections from metal objects in the neighbourhood. Such reflections are often caused by such a structure as a gasometer; the effect is caused by the reflected radiation arriving slightly behind the signal received direct from the transmitter, due to the slightly longer route, and if the difference in time is sufficient for the spot to have moved appreciably in the line direction, the image will be repeated. The trouble can almost always be cured by the use of a reflector aerial, which is orientated until the unwanted effect disappears.

Stationary Spot.—If a stationary spot should appear on the screen and remain there, the receiver should be immediately switched off, as the tube will undoubtedly be damaged. Such a condition is caused by failure of both time bases, due to some common fault such as failure of the high-tension supply to this section of the receiver.

Scanning Lines unduly Apparent.—A condition may occur when the scanning lines become very obvious when observed from the optimum viewing distance. This is caused by partial or complete failure of the two scanning fields to interlace. Some receivers are provided with an interlacing control which may, for example, take the form of slight movement of one of the deflector coils or, alternatively, the trouble may be due to some fault in the frame time base. Many receivers will not interlace properly unless the contrast control is set to a position approaching the optimum for the purpose it was designed to serve.

Uneven Focus.—Uneven focus may be due to a number of causes. In the case of the electrostatic tube the probable cause is limited to displaced electrodes, for which there is obviously no cure other than replacement of the tube. Some care is necessary, however, to distinguish between uneven focus and astigmatism, as the superficial effect is somewhat similar. Astigmatism may be controlled on old receivers by an appropriate control or controls. Uneven focus of magnetic tubes is usually due to the focusing coil or ring magnet being out of alignment with the neck of the tube. The method of correcting this error is obvious, but it is by no means easy to accomplish with some focusing assemblies. It should be noted that the very smallest adjustment is normally required to correct such an error, misadjustment of the order of $\frac{1}{50}$ inch is often sufficient to produce noticeable lack of focus at one part of the picture.

Luminous Halo.—Certain types of cathode-ray tube when in a slightly soft condition produce a ring or halo of soft faint light more or less central on the screen. This phenomenon is caused by electrons colliding with the rarefied gas within the tube causing them to stray outside the beam; due to the twisting motion imparted by the magnet these unfocused electrons form a ring-shaped patch.

Corner Shadow.—When a cathode-ray tube is first installed a sharply defined shadow may appear at the edge of the picture, usually in the corner. This is due to a shadow cast by the end of the neck of the tube due, perhaps, to a slight irregularity in the contour of the glass. The difficulty can be usually overcome in the case of the magnetic tube by correcting the position of the deflector coil assembly on the neck of the tube. If the tube is of the type provided with an ion trap very particular attention should be paid to its correct setting; it should be moved in a circular direction and also slid backwards and forwards until the brightest picture is obtained; in some receivers, however, it must be set a little farther away from the screen than optimum to present the left-hand side of the picture from spreading in the vertical direction.

MODERN PRACTICAL RADIO AND TELEVISION

A PRACTICAL AND COMPREHENSIVE TREATISE DEALING WITH EVERY PHASE OF RADIO ENGINEERING, INCLUDING DESIGN, CONSTRUCTION AND MAINTENANCE, WITH SPECIAL CHAPTERS ON TELEVISION, ETC.

BY

C. A. QUARRINGTON, A.M.Brit.I.R.E.

AND EDITED BY

W. H. DATE, B.Sc., A.M.I.E.E.

VOLUME III

THE CAXTON PUBLISHING COMPANY LIMITED
LONDON · NEW YORK · MELBOURNE
TORONTO · WELLINGTON

First published	.	*January*	1946
Second Edition	.	*June*	1948
Reprinted	.	*May*	1949
Reprinted	.	*April*	1950
Reprinted	.	*November*	1950
Reprinted	.	*March*	1951
Reprinted	.	*June*	1951
Reprinted	.	*November*	1951
Reprinted	.	*May*	1952
Reprinted	.	*September*	1952
Reprinted	.	*December*	1955
Reprinted	.	*May*	1957

CAXTON'S
LIST OF ENGINEERING BOOKS

PRINTED AND BOUND IN ENGLAND BY
HAZELL WATSON AND VINEY LTD
AYLESBURY AND LONDON

CONTENTS OF VOL. III

CHAPTER 5

INSTABILITY AND MOTOR-BOATING

CHAPTER 6

TRACING DISTORTION

CHAPTER 7

TRACING MAINS HUM

CHAPTER 8

TRACING BACKGROUND NOISE

CHAPTER 9

VALVE TESTING

CHAPTER 10

RECEIVER ALIGNMENT (GANGING)

CHAPTER 11

WHISTLES AND BREAK-THROUGH

CHAPTER 12

LOUDSPEAKER FAULTS

CHAPTER 13

TESTING COMPONENTS

CHAPTER 14

FAULT-FINDING PROCEDURE (A SUMMARY)

CHAPTER 15

LOCAL INTERFERENCE

CHAPTER 16

MISCELLANEOUS WORKSHOP HINTS

CHAPTER 17

ACCUMULATOR CHARGING AND MAINTENANCE

APPENDIX I

RADIO MATHEMATICS

APPENDIX II

FULL-PAGE PLATES

and

FOLDING DIAGRAMS

VOL. III

FULL-PAGE PLATES

FOLDING DIAGRAM

Various circuits, devices and principles described in this volume form the subject matter of letters-patent or provisional protection.

MODERN PRACTICAL RADIO AND TELEVISION

VOL. III

CHAPTER 1

MEASURING INSTRUMENTS

THERE are probably quite a number of ways in which a fault may be traced, but they can all be grouped under two headings: logical fault finding and hit-and-miss fault finding.

In the early days of broadcasting hit-and-miss methods were possibly as good as any other, as the average receiver contained so few components that the location of a faulty one did not require any pronounced degree of skill, and in any case certain components were so prone to failure that they could be suspected with reasonable certainty. One very old but very popular receiver consisted of three valves, a coil, and tuning condenser and a number of resistances and condensers, both couplings being accomplished by the resistance-capacity system. When a receiver of this type ceased to function, a quick and ready test could be made by bridging each resistance in turn with the fingers, when a broken resistance would be at once apparent because the receiver would function after a fashion, the fingers acting as the resistance, and representing perhaps 50,000 ohms.

Fault Finding.—Fault tracing in a modern superheterodyne becomes almost impossible if prejudice, suspicion, and guesswork are the only means of finding the trouble, particularly if there happens to be two faults present at the same time—a very likely possibility, because failure of a component will often damage one or more other components.

The condemnation of the hit-and-miss method contained in the opening paragraphs of this introduction should not give the impression that fault finding can only be properly accomplished by the use of elaborate test equipment. Admittedly a reasonable amount of equipment is essential for rapid diagnosis, but even in the complete absence of any test equipment there is no reason why some logical sequence should not be adopted, as it is only by this means that a fault in a complicated circuit can be detected, unless, of course, an element of luck is present.

It is probably true to say that a bandpass superheterodyne cannot be properly aligned without the use of a ganging oscillator and oscillograph, but if certain well-ordered rules are followed, alignment may be achieved in a manner that will give quite satisfactory reception, although not perfection. As will be seen in the appropriate chapter, it is possible to adjust the padding and trimming condensers and align the intermediate-frequency transformers with tolerable accuracy, providing that the receiver has a dial which is accurately calibrated in either wavelengths or frequencies; in fact, the accuracy of trimming and alignment will be as accurate as the dial calibration, providing the correct trimming and padding frequencies are known—information that may be obtained from the manufacturer of the receiver.

Many of those who read the following chapters will not possess any but the simplest equipment, and every endeavour has been made to provide the most practical information for their guidance. On the other hand, there will be those who are equipped with the normal test gear used by the practical service engineer; here, again, the need is covered. Finally, there will be those who are fortunate enough to possess a satisfactory oscillograph, and consequently several chapters and sections will be found dealing with certain aspects of this apparatus. It should be noted, however, that reference to the oscillograph has been isolated as far as possible, in order that those who are not interested may easily ignore the various references.

Service engineering does not necessarily cease when a receiver is working in a normal manner; the accessories may provide unforeseen difficulties; for example, connection of a gramophone pick-up may result in an unacceptable hum-level; alternatively, connection of an extension speaker may cause instability on the long waveband, even though provision is made for such a connection by the manufacturers and the loudspeaker is of suitable design.

A receiver may function in a perfectly normal manner, but reception may be impaired or totally spoilt by local interference arising from trams, trolley-buses, electrical machinery of a domestic or industrial nature, and, on the short waveband, from the ignition system of motor cars. A chapter is devoted to this whole question, and covers means of suppressing the source of interference and means of minimising interference at the receiving end.

The professional service engineer is expected to be able to renovate a damaged cabinet or, at least, to be able to touch up and fill up scratches or chips in such a manner that the general appearance is satisfactory. The repolishing of a cabinet will normally be left to those who specialise in this class of work, but some notes on touching up and renovation are included in Chapter 16.

The location of a fault is not always the end of difficulty, as some receivers almost convey the impression that they have been designed for the sole purpose of making repairs as difficult as possible, and in this direction the chapter devoted to workshop hints is offered to suggest ways and means of overcoming certain obvious difficulties. The question of removing the chassis from its cabinet has not been overlooked, as this apparently simple procedure may often present difficulties—although these remarks are not intended for the professional service engineer, who will be only too conversant with such operations.

Considerable space has been devoted to valve testing, as this is a subject of great importance, and it is perhaps remarkable that so few retail establishments are equipped to test a simple type of valve with sufficient thoroughness to be able to pronounce definitely that it will or will not work. Many still rely on the emission tester, and it may be a revelation to many to read of the many faults which may exist although emission is normal.

Measuring Instruments.—The most important item of the service engineer's kit is undoubtedly a good serviceable multi-range test set; such a piece of apparatus is simply a moving-coil milliammeter with a convenient switching arrangement to bring various resistances, a rectifier battery or, possibly, a condenser into circuit. A typical test set is described later in this chapter, and in the meantime attention is directed to the principle in construction of the several types of meter.

There is no fundamental constructional difference between the voltmeter, the ammeter, and the ohmmeter, but any of these may be designed to work on one of several principles and may be classed under four headings: (*a*) moving iron; (*b*) moving coil; (*c*) thermal; and (*d*) electrostatic.

The Moving-iron Meter.—The moving-iron meter in its simplest form consists of a pointer to which a small iron armature is attached, deflection being obtained by a suitably placed coil, which may be wound as a solenoid with the armature travelling along its axis. The pointer must be suitably pivoted and provided with some controlling force to return the pointer to zero and provide the necessary work for the field to accomplish; this is usually arranged by a small spiral hairspring similar to that which controls the balance-wheel of a watch. An instrument designed on the somewhat crude lines indicated above would be both unreliable and insensitive, that is to say, its deflection would be inconstant and would be small for a given current. The modern instrument is designed on more advanced lines.

The accompanying plate shows the construction of a moving-iron instrument. Reference to the illustration will show that the needle is mounted on needle-point pivot; the front bearing may be clearly seen, but the rear bearing is not apparent, as it lies more than an inch deep in the segment-shaped tunnel. The spiral hairspring can also be seen in the illustration; it is adjusted externally by a link action which is operated by the cam action of a small screw. It is intended that the cam be so adjusted that the pointer comes to rest precisely on zero. The long needle-point pivot forms the edge of an iron vane, which appears in the illustration as a long narrow wedge which is, in fact, the edge turned over to give a measure of rigidity.

The plate also shows the rear half of the instrument, the principal feature of which is the coil so shaped that its hollow centre fits over the segment-shaped tunnel which houses the pivot and the iron deflecting vane. When current flows through the coil the field produces a twisting force on the iron vane which causes it to move away from the zero position. The extent of the movement does not bear a linear relationship to the current flowing, with the result that the scale is unequally divided. Fig. 1 shows the scale of a typical moving-iron instrument; it will be noted that the deflection from 0 to ·5 ampère is only about $\frac{1}{16}$ in., whereas the deflection between 4·5 and 5 ampères (again a difference of ·5 ampère) is about twelve times as great. The non-linear scale is one of the greatest drawbacks to the use of the moving-iron principle: the instrument scale shown at Fig. 1 is obviously useless for taking readings between 0 and ·5 ampère, and of doubtful value between ·5 and 1 ampère; the rest of the scale may be considered satisfactory. The moving-iron instrument still retains certain popularity for alternating-current instruments, as it obviates the necessity for using a rectifier, an aspect of meter design which is dealt with later in the chapter.

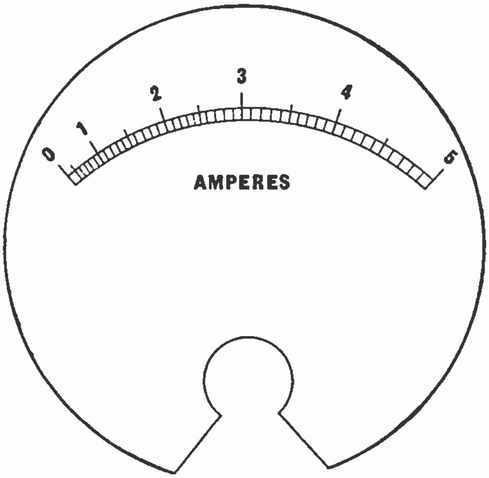


Fig. 1.—Scale of a typical moving-iron meter. Note particularly the non-linear division of the scale.

The Moving-coil Meter.—The most generally used type of meter is that employing a moving coil. The mechanism of a typical instrument of this type is also shown in the accompanying plate; this photograph shows the complete instrument with the exception of the scale and case, which have been removed for obvious reasons. It may be seen that the actual coil assembly is located between the poles of a permanent magnet and is so aligned that the pointer travels within the area occupied by the magnet. A more detailed idea of the moving unit may be obtained from the enlarged view of the mechanism which has been removed from the magnet. The mechanism consists of a moving coil which is wound in the form of a square with a very fine gauge of wire, often as thin as 60 S.W.G., on a former made of aluminium foil. The pointer is of non-magnetic material, usually aluminium foil, and is attached to the coil, the whole being mounted on a very slender steel spindle, needle-pointed at each end. The whole assembly is extremely light, and those used for really first-class instruments weigh about $\frac{1}{15}$ oz.

The actual moving assembly is mounted between two bearings which have slight hollows in which the needle-points rest. For normal instruments these bearings may be of white metal, but first-class instruments often employ sapphires in much the same manner as these jewels are used in watches. Other refinements are possible, and many laboratory instruments employ a bi-metal structure automatically to overcome the effects of temperature variation. It will be observed that the controlling force is provided by means of a spiral hairspring at each end of the spindle. This is to prevent wear, which can occur at the bearing remote from the spiral spring when only one is used. The movement illustrated has three short arms, which form with the pointer a cross, the end of each arm being provided with a small circular weight. These arms are provided to offset the weight of the spindle, so that the entire moving assembly is perfectly balanced. Although it is not apparent in the photograph, two delicate springs are provided to check the movement of the needle when and if it overruns the ends of the scale.

One of the greatest advantages of a moving-coil instrument is that the deflection is linear with respect to the current flowing through the coil. The actual deflection is caused by the field of the moving coil (which is, of course, dependent upon the current flowing through it) and the field of the permanent magnet. The coil is placed so that its field is approximately at right angles to the field of the permanent magnet when in the mid-way position, and the force exerted by the two fields is such that the coil tends to move to a position where the fields are in the same sense. The behaviour of a moving coil in the field of a magnet is dealt with in some detail in Volume I, Chapter 5.

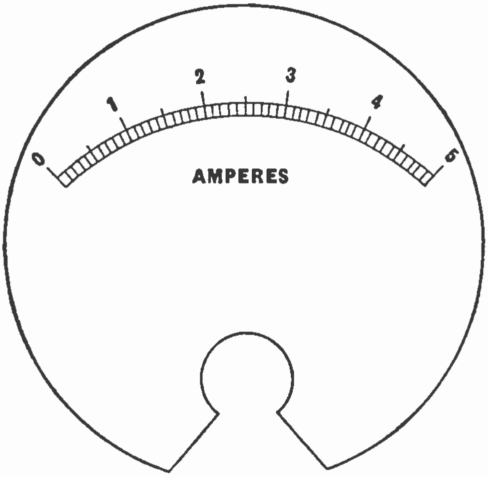


Fig. 2.—Scale of a moving-coil instrument. Note the linear division of the scale.

Fig. 2 shows the scale of a moving-coil instrument designed to cover the same range as the moving-iron meter, the scale of which is shown at Fig. 1. It will be seen that the divisions are equal, and that accurate reading may be accomplished at any portion of the scale. The other great advantage of the moving-coil instrument is its high sensitivity.

The Thermal Meter.—Instruments that function directly or indirectly through heat are normally employed for measuring high-frequency current and are particularly valuable for this class of work, as they are reasonably independent of frequency. They may be divided into two sections, the hot-wire ammeter and the thermo-couple ammeter. The hot-wire type is extremely simple, and consists of a needle which is held at the zero position by a wire usually made of iron and, unlike other meters, a spring is used to pull the pointer towards the maximum position. The current to be measured is passed through the wire, which heats up and expands, permitting the pointer to travel across the scale. Since the expansion of the wire is small, an arrangement of levers is usually employed to allow a large movement of the needle for a small expansion of the wire.

The thermo-couple ammeter takes advantage of the fact that a current is generated if heat is applied at the junction of two suitable dissimilar metals, thus the instrument actually measures current generated by a miniature thermo-couple which is heated by the current to be measured. The current generated by the thermo-couple is measured on a moving-coil instrument.

The Electrostatic Voltmeter.—For measuring high voltages in circuits that possess very high resistance, difficulties arise when attempting to use any of the meters already described, since the small current taken by the meter will completely alter the value of the voltage that is to be measured. The electrostatic voltmeter has no coil or other device forming a D.C. path, but is, in principle, a meter in which deflection is accomplished by the electrostatic pull between two plates. The actual movement is necessarily very small, but an arrangement of levers is used to magnify the movement ; such meters have a non-linear scale and, generally speaking, it is not possible to measure voltages below 100 volts, although an indication may be obtained for perhaps half of this value. From the point of view of the circuit to which it is connected the electrostatic meter appears as a capacity, and in high-frequency circuits it is often just as objectionable on this account as other forms of meters having relatively low resistance.

The various types of movement have been briefly introduced, and attention may now be directed to the purposes that may be fulfilled. Unless otherwise stated, the following remarks are made on the assumption that the type of movement employed is the moving coil, since this type is recommended for normal purposes.

The Voltmeter.—The voltmeter, as its name implies, is intended for the measurement of potential difference in terms of the volt. A moving-coil voltmeter is, in fact, a very high-resistance milliammeter and actually deflects in proportion to the current which flows through it. Since the current flowing through the coil will be precisely proportional to the voltage across the coil and its resistance, it follows that the deflection of the pointer will be proportional to the voltage across the coil and it is apparent that by suitably calibrating the scale the instrument will give a direct voltage reading. In order that the voltage to be measured will be substantially unaffected by the current passing through the meter the latter should be as small as possible, which means that the resistance should be as high as possible. Good-quality instruments usually have a resistance of 1,000 ohms (or more) per volt, that is to say, a meter reading 0–5 volts will have a resistance of 5,000 ohms, a meter reading from 0–200 volts will have a resistance of 200,000 ohms, and so on. It is somewhat difficult to accomplish such high internal resistance in multiple test sets, consequently the resistance of this type of instrument is often lower.

The Ammeter.—The ammeter, milliammeter, and microammeter are all in general use in radio engineering, and all are intended to measure current in terms of ampères, milliampères, and microampères respectively. The requirements of an ammeter are the converse of the voltmeter. It will be required to measure current flowing in a circuit, and it will necessarily be connected in series—consequently its resistance should be as low as possible, so that it does not materially add to the total resistance of the circuit. The internal resistance of a good ammeter is very low, usually a fraction of an ohm. The internal resistance of a milliammeter is unavoidably a little higher, owing to the necessary greater sensitivity, but a good instrument reading, say, 0–10 milliampères will often have an internal resistance of only 5 ohms. On the other hand, first-class instruments have an internal resistance in the neighbourhood of 50 ohms, and are entirely satisfactory for measurements likely to be made in radio engineering.

The microammeter, will usually have a fairly considerable internal resistance, but this is unimportant in radio engineering, as such measurements will invariably be made in circuits having resistance of a very high order. The microammeter is extremely sensitive, and consequently the moving mechanism is very delicate and easily damaged.

The Ohmmeter.—For measuring resistance an ohmmeter is sometimes employed which is actually a normal milliammeter calibrated in ohms. It requires the use of a battery and, in effect, measures the current which a known voltage will drive through an unknown resistance. It is usually provided with two variable resistances, which, in effect, obviate the use of a voltmeter for checking the battery voltage, since the two variable resistances are so adjusted that the needle rests precisely on zero when the terminals are shorted. If it is impossible to achieve this setting it is necessary to replace the battery. Resistance may be measured by other means, the best known of which is the Wheatstone bridge, or its more practical modification, the Post Office box. The ohmmeter is, however, the most convenient and practical device for fault finding and is in general use.

Measurement of Inductance and Capacity.—The measurement of inductance belongs to the laboratory rather than to the service bench. It calls for fairly elaborate preparation and considerable experience of high-frequency measurement. It is, in fact, a subject which monopolises more than half of a large book which is devoted solely to the measurement of inductance and capacity. Generally speaking, the measurement of capacity is simple, providing the value is relatively large. Two methods are in general use, the most convenient of which is to apply an alternating voltage of some definite frequency and measure the current flowing through the condenser ; such an arrangement is incorporated in most multi-range test sets. The alternative method is to use a neon lamp in conjunction with a time-constant circuit which is made up of a known resistance and the unknown capacity; the basic circuit is shown at Fig. 3. By using a suitable value of resistance the neon lamp can be made to flash sufficiently slowly to permit the flashes being counted; the capacity may be determined from the following formula:

$$\text{Flashes per second} = CR\,\frac{V_s - V_b}{V - V_m}$$

when C equals capacity in farads, R equals resistance in ohms, V equals the applied voltage, V_s equals the striking voltage of the tube, V_b equals the breaking voltage, and V_m the mean voltage on lamp. The objection to this arrangement is the large number of constants, all of which are liable to more or less continuous variation, with the single exception of the resistance. Nevertheless, it enjoyed some popularity until test sets were designed to include capacity measurement.

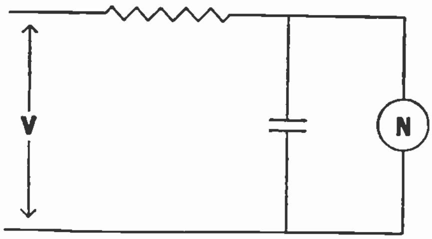
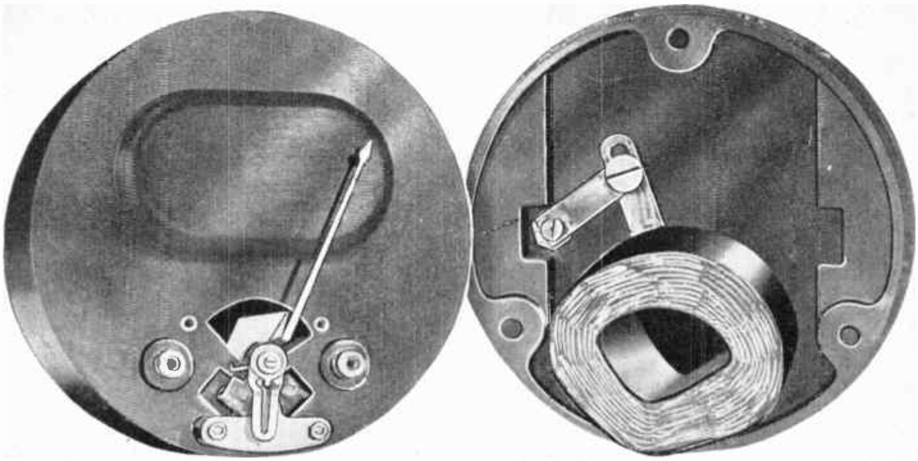


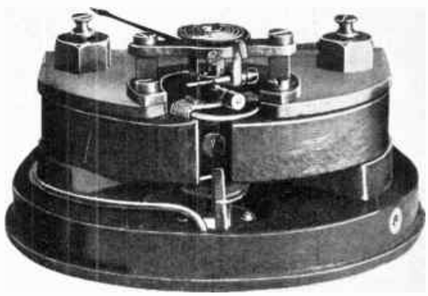
Fig. 3.—Basic circuit for measuring capacity with the aid of a neon lamp.

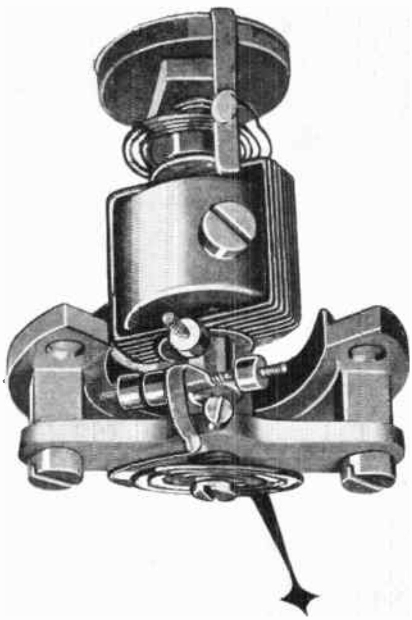
The Measurement of Alternating Current and Voltage.—Meters for measuring alternating current and voltage may be of the moving-iron type, although they are not entirely satisfactory for reasons that have already been made clear, and once again the moving coil is in general use. It should be understood, however, that the moving-coil meter is unsuitable for measuring alternating current and voltage unless provided with a rectifier, which is almost invariably housed within the instrument. The scale is calibrated with regard to the characteristics of the rectifier. The actual rectifier is of the metal-oxide type and is very small, except when used in ammeters capable of measuring fairly high values. Rectifier instruments are entirely satisfactory for the general-purpose measurement of voltage and for the measurement of relatively small values of current. Some objection may be levelled against this type of instrument for measuring heavy current, owing to the high resistance of the rectifier; the difficulty is to some extent overcome by using meters employing fairly large shunts, but some limitation is imposed on the relationship between shunt resistance and internal resistance owing to some tendency towards inconstancy of the rectifier element.

The Parallax Effect.—Considerable error may be introduced by the parallax effect, which is the name given to the inaccurate reading resulting from looking at the pointer from a position other than directly above it. This effect is most marked on clocks situated high above the ground; if the hand is, say, at fifteen minutes past the hour, and the hand is well raised from the face, it will appear to register fourteen or even thirteen minutes past when viewed from below. This effect may be minimised



A typical moving-iron meter. (*Left*) Front of instrument, showing mechanism. (*Right*) Front view of rear portion, showing deflecting coil.





(*Above*) A typical moving-coil meter, showing the location of the moving coil between the poles of the circular permanent magnet.

(*Left*) An enlarged view of the moving mechanism shown right. This photograph shows clearly the moving coil, the two hair-springs and balance-weights. It should be understood that the heavy top assembly, the structure inside the coil and the base are stationary. This photograph is about twice natural size.

MOVEMENTS OF MEASURING INSTRUMENTS.

by reducing the distance between the pointer and the scale, a procedure which is not always desirable, owing to the danger of a light pointer bending and touching. It is more convenient to space the pointer adequately and place a narrow strip of mirror along the edge of the dial. When taking a reading it is necessary to note that the reflection of the pointer cannot be seen because it is hidden by the pointer itself, a condition that only obtains when the eye is exactly over the pointer.

The Multi-range Test Set.—There are numerous types of multi-range test sets available, and it would be unreasonable, or even misleading, to direct attention to a particular example. Nevertheless, it was felt that this chapter would be incomplete without some indication of the scope of such an instrument. The illustration, Fig. 4, shows

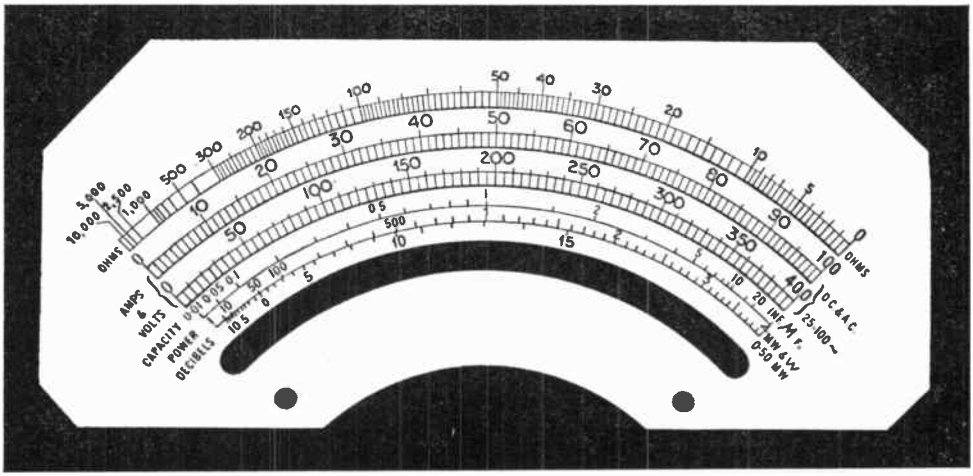


Fig. 4.—Scale of a typical multi-purpose moving-coil instrument.

the scale of a typical test set, and, although the scale in itself gives some indication of its many uses, some further remarks are necessary.

The test set in question is provided with two rotary switches, which permit of the required range being instantly selected. It is provided, incidentally, with a cut-out to protect the meter, and three adjustments for zero and maximum setting on different resistance ranges. Ten ranges are available for measuring direct current from 0–1 milliampère, when each division is equal to 10 microampères, to 0–10 ampères, when each division is 100 milliampères. The direct-current voltage ranges number twelve, varying from 0–50 millivolts to 0–1,000 volts.

Eight ranges are provided for measuring alternating current, the lowest being 0–5 milliampères, when each division is equal to 50 microampères, to 0–10 ampères. Similarly, there are eight ranges for measuring alternating voltage, the lowest being 0–5 volts and the highest 0–1,000 volts.

R.T. III—2

For measuring resistance there are five ranges, two of which are available when using the small internal cell giving actual calibrated reading of resistance from ·5 ohm to 100,000 ohms. By using the internal 9-volt battery, the range is extended to 1 megohm, and by employing an external voltage the range may be still further increased to 40 megohms when using the lighting mains or other source of high potential.

Provision is made for measuring capacity with the aid of an external alternating-current supply; the instrument is set on the supply by means of one of the variable resistances already referred to, after which capacities may be directly read from ·01 μF to 20 μF. The instrument may also be used to measure power and will give calibrated readings from 1 milliwatt to 4 watts. Quite apart from its obvious application of measuring audio output, the instrument may be used in conjunction with a calibrated oscillator for the alignment of superheterodyne receivers. The same function can also be interpreted directly in decibels, as a scale is provided from − 10 decibels to + 15 decibels, the reference-level being 50 milliwatts, in accordance with standard practice.

These few indications do not do justice to the possibilities of multi-range test sets or to the particular instrument to which the remarks actually refer; nevertheless, they provide an indication of their versatility. The particular model in question passes 2 milliampères for maximum deflection on the 1,000-volt scale and 1 milliampère on the 500-volt scale. The total length of the scale is 5 inches, which is equal to doubling the internal resistance when it is compared with a meter with a 2½-inch scale, since a higher range may be used for a given deflection per volt.

Calibration.—The question of accuracy is difficult to discuss in general terms. It is a relative one, and dependent upon the purpose for which the meter is to be used. The average meter is accurate to within about 2 per cent., which is perfectly adequate for fault finding where a general indication is desired to show whether a particular part of the circuit is functioning in the normal manner. For general service work, robustness and versatility are of prime importance. It is infinitely preferable to use a meter which will *remain* reasonably accurate when subjected to rough usage and sudden temperature change, than a meter that is accurate within close limits under ideal conditions and fails completely when subjected to vibration or an occasional bump. It is necessary to check calibration from time to time, preferably against standard or sub-standard instruments, but in the absence of such equipment a check may be carried out if a resistance of known value is available, simply by applying a known voltage and measuring the current and applying Ohm's law. If the figures obtained fail to agree with Ohm's law, then either the resistance or the meter is at fault.

Shunts and Switching.—It is quite possible to make any measurement with the use of a suitable milliammeter and an adequate number of accurate resistances. In principle, the range of the milliammeter is increased by the use of shunt resistances, while it may function as a voltmeter if used with series resistances. The choice of the meter will be determined by the lowest reading that is likely to be required. It is usually convenient to use a moving-coil milliammeter reading from 0 to 1 milliampère. The following values are based on the assumption that the milliammeter has an internal resistance of 45 ohms.

Fig. 5 shows the milliammeter in question and its attendant shunt resistance. If the value of the resistance is 5 ohms, it may be seen by applying Ohm's law that one-tenth of the current will flow through the meter and nine-tenths of the current will flow through the shunt and it will be necessary to multiply the milliammeter reading by ten, that is to say, when the meter shows ·5 milliampère the current flowing will be 5 milliampères, and when the meter records 1 milliampère the current flowing will be 10 milliampères, and so on. By the use of a variety of shunts any reading can be taken, but there are certain precautions and limitations, as will be seen later.

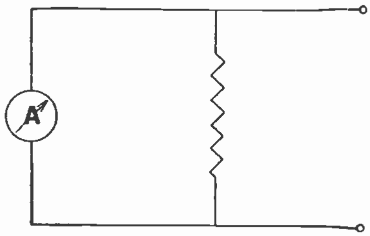


Fig. 5.—A simple shunt to increase the range of an ammeter or milliammeter.

To use the 0–1 milliammeter as a voltmeter it will be necessary to use a series resistance, as shown at Fig. 6. Suppose that the value of this resistance is 955 ohms, making a total with the internal resistance of the meter of 1,000 ohms, then full-scale deflection will register when 1 volt is applied. If the resistance is 9,955 ohms, making 10,000 ohms with the internal resistance, then full-scale deflection will occur if 10 volts

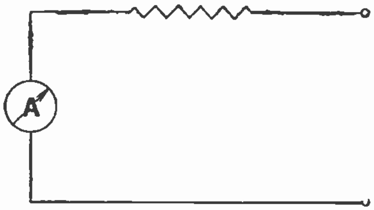


Fig. 6.—A series resistance to increase the range of a voltmeter or to enable voltage to be read with a milliammeter.

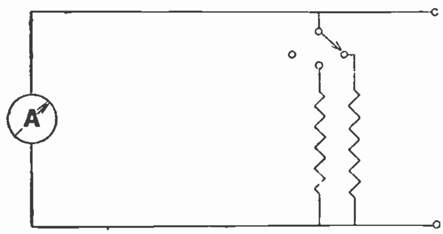


Fig. 7.—The *incorrect* method of switching shunts; the resistance of the switch is in the actual shunt circuit and may introduce considerable error.

is applied. If the value of the resistance is 199,955 ohms, making 200,000 ohms with the internal resistance of the meter, then the full-scale deflection will be 200 volts, and so on. The value suggested, namely 199,955 ohms, is quoted for the purpose of explaining a principle, it is unnecessarily pedantic for practical purposes, when 200,000 ohms could very well be used, as it would only introduce an error of ·02 per cent.

It is apparent from the foregoing remarks that a milliammeter could be made up into a unit with suitable switches enabling various resistances to be connected in series or parallel at will for the purpose of making a multi-range test set. There are several pitfalls in the use of switching which must be avoided. Fig. 7 shows a milliammeter and switch allowing a choice of two shunt resistances. These might well be 5 ohms, giving a reading of 0–10 milliampères, and ·45 ohm, giving a reading of 0–100 milliampères. A very good switch after a period of use could easily have a resistance between its contacts of ·1 ohm, which would introduce an error of nearly 25 per cent. in the latter case. It is apparent, therefore, that some other arrangement will be necessary. Fig. 8 shows the correct method of switching. A careful study of this circuit will reveal the fact that the contact resistance of the switch marked "A" is in series with the circuit as a whole; that is to say, the resistance of the switch does not form part of the shunt. The contact resistance of switch "B" does not form part of the shunt, but is in

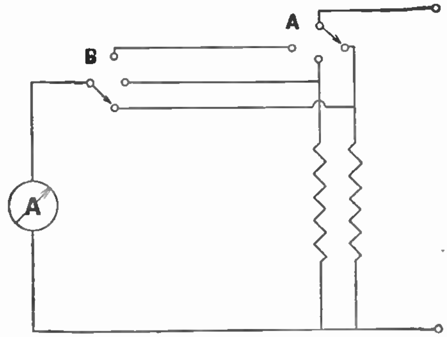


Fig. 8.—The *correct* method of switching shunts; the switch A is not included in the actual shunt circuit, being outside the point of connection between meter and shunt. The switch B is in series with the meter, which has relatively high resistance, and not in series with the shunts, which have relatively low resistance. The switches must be ganged.

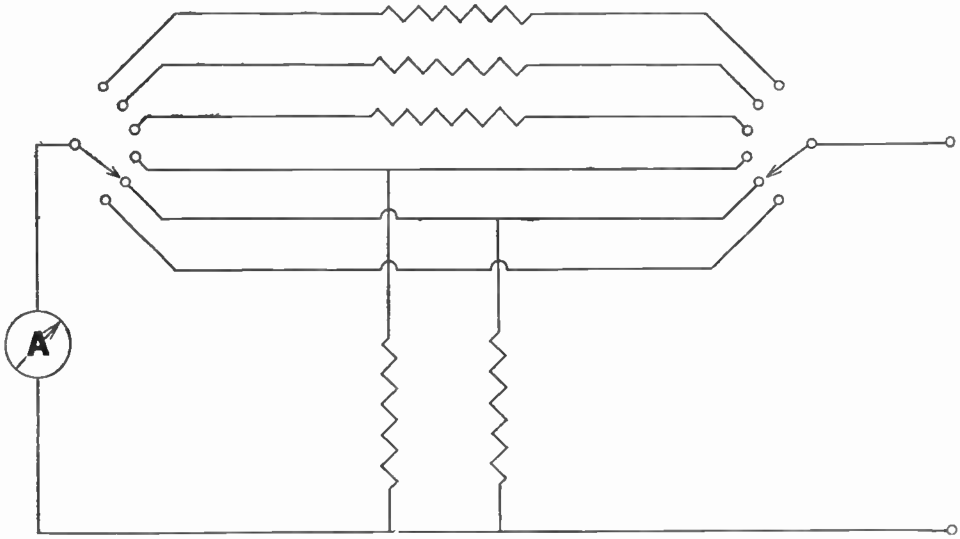


Fig. 9.—An arrangement by which a single meter measuring from 0–1 milliampère and having an internal resistance of 45 ohms may be used for three current ranges and three voltage ranges. It is essential for the switches to be ganged.

series with the meter which, for the example chosen, has a resistance of 45 ohms. The addition of ·1 ohm to 45 ohms is not serious, and as the current passing through the meter will not at any time exceed 1 milliampère, there is no reason why the switch contact should become burned or pitted. It will be appreciated on the other hand that the switch "A" may be required to carry 100 milliampères or more.

The two contacts joined directly together allow the meter to work on its natural range, *i.e.* 0–1 milliampère. It is questionable whether the circuit as shown at Fig. 8 could be used for values much above 100 milliampères, owing to the extremely low value of shunt resistance and the effect of inevitable variations due to temperature change and other factors.

Fig. 9 shows the switching arrangement for a combined volt and milliammeter. With the values shown and using a 0–1 milliammeter with an internal resistance of 45 ohms, the following ranges will be available :

(1) 0–500 volts.	Series resistance 499,955 ohms.[1]
(2) 0–100 volts.	Series resistance 99,955 ohms.
(3) 0–10 volts.	Series resistance 9,955 ohms.
(4) 0–100 milliampères.	Shunt resistance ·45 ohms.
(5) 0–10 milliampères.	Shunt resistance 5 ohms.
(6) 0–1 milliampère.	(Natural range of meter.)

When constructing a multiple-range instrument it is advisable to put a small loading resistance in series with the meter, perhaps about 5 ohms, altering the value of the multiplier resistances accordingly. In the event of the meter being damaged, it is possible that its internal resistance would be varied in the course of repair; such a contingency can be countered by increasing or decreasing the small loading resistance, so that the combined resistance remains unchanged. Without this small resistance it will be necessary to alter the value of the majority of the shunt and series resistances, which would be a relatively formidable undertaking.

Shunt and Series Resistance Formulæ.—It is quite simple to calculate the value of shunt resistance for any given requirement ; the following formula is applicable :

$$R = \frac{R_m}{(n - 1)}$$

when R_s equals the resistance of the required shunt in ohms, R_m equals the resistance of the meter (including the loading resistance, if used), and n equals the ratio by which the range is to be extended.

It is equally simple to find the value of a series resistance for any given voltage range as follows :

$$R_s = \frac{V}{I_m} - R_m$$

[1] For all practical purposes 500,000 ohms would be satisfactory.

when R_s is the required series resistance, V equals the full-scale voltage reading required, I_m equals the full-scale reading of the meter in *ampères*, and R_m equals the resistance of the meter (including the loading resistance if used).

CHAPTER 2

THE GANGING OSCILLATOR

For the accurate alignment of the superheterodyne a signal generator and an output meter or cathode-ray oscillograph are indispensable, and this chapter is devoted to the signal generator, but it is desirable to outline the function of the entire equipment. It will be remembered that the trimming and padding of a superheterodyne must be carried out at certain precise frequencies, in order that the tracking error of the oscillator circuit is reduced to a minimum over the whole of each waveband. The normal type of signal generator may be called upon to supply any frequency covered by broadcast receivers, and, in addition, any of the several intermediate frequencies. For trimming and padding the output from the oscillator is usually injected into the aerial circuit, and the appropriate trimmer or padding condenser adjusted for maximum output, determined by an output meter or a cathode-ray oscillograph, the latter having the advantage, among others, of showing the *shape* of the response-curve. The procedure to be adopted is very fully covered in the appropriate chapter. In the meantime, attention is directed to the actual signal generator.

As already intimated, the signal generator will be required to cover a wide frequency band, and as intermediate frequencies in general use fall between the highest and lowest broadcast frequencies, it is convenient for the oscillator to cover the necessary frequencies by a number of overlapping bands. The actual maximum and minimum frequency varies, but it will usually be from about 90 kilocycles to 20 megacycles.

Accuracy is the prime consideration of a ganging oscillator. It is difficult of achievement, particularly as for normal purposes the instrument must be moderately priced. The standard degree of accuracy is plus or minus 1 per cent., but even this narrow tolerance can introduce an error of about 4½ kilocycles per second when working on the normal intermediate frequency of 465 kilocycles per second.

Some means must be provided for varying the output of the oscillator within wide limits, partly because amplitude will vary with frequency, which is practically unavoidable in a moderately simple instrument covering a wide wave-range, but largely because control is necessary during the operation of ganging. If the ganging of a superheterodyne is hopelessly incorrect, a large output is required in order to facilitate the finding of some deflection on the output meter or oscillograph, after which the output is attenuated as the deflection becomes large when correct alignment is approached. It is imperative that final adjustment should be carried out with a minimum output from the oscillator, so that the operation is not upset by the action of automatic volume control.

The simplest form of ganging oscillator will be provided with the two adjustments outlined above, namely frequency control and amplitude control, but more versatile instruments will be provided with two further refinements, modulated output and frequency modulation. The modulated output consists of a carrier, the frequency of which is variable, as described above, but modulated with an audio-frequency which is usually 400 cycles per second, but sometimes 1,000 cycles per second ; this modulation may be cut out at will. The modulated output is useful for general testing and also assists in preliminary alignment used in conjunction with a cathode-ray oscillograph.

Frequency Modulation.—When using an output meter little can be done towards correcting the shape of the response-curve, but when a cathode-ray oscillograph is used the shape of the response-curve can be accurately determined. Examples of curves appear in Chapter 10, taken with an ordinary cathode-ray oscillograph used for ganging. These curves actually show the relationship between amplitude in the vertical dimension and frequency in the horizontal dimension ; the actual curves referred to show the variation of amplitude compared with a frequency change of some 10 kilocycles per second each side of the fundamental intermediate frequency. To obtain such a curve it is necessary to inject into the intermediate-frequency amplifier an unmodulated waveform the frequency of which varies over an adequate width, usually plus *and* minus 15 kilocycles per second. An oscillator capable of producing this variable-frequency output is known as a modulated frequency or wobbulated oscillator.

Various methods of frequency modulation are possible, some mechanical and some electrical. The mechanical arrangement consists of a specially shaped condenser rotated by means of a small motor ; this practice, however, is virtually obsolete for the purpose at present under discussion, and it is only necessary to consider the electrical system. It is neither practicable nor necessary to describe all the variations, as one will serve as an example. The following description explains the method of frequency modulation employed by the oscillator used in recording all the oscillograms shown throughout this work. The basic circuit of the arrangement is shown at Fig. 10, all modifications and refinements having been removed for the sake of clarity.

The problem is to produce an H.F. output at any frequency within the range of the instrument, but which varies 15 kilocycles per second either side of the required frequency. One of the major difficulties is the evolution of a circuit which will preserve the variation of plus or minus 15 kilocycles per second, irrespective of the fundamental frequency and, furthermore, it must be so arranged that the frequency variation may be immovably locked with other apparatus.

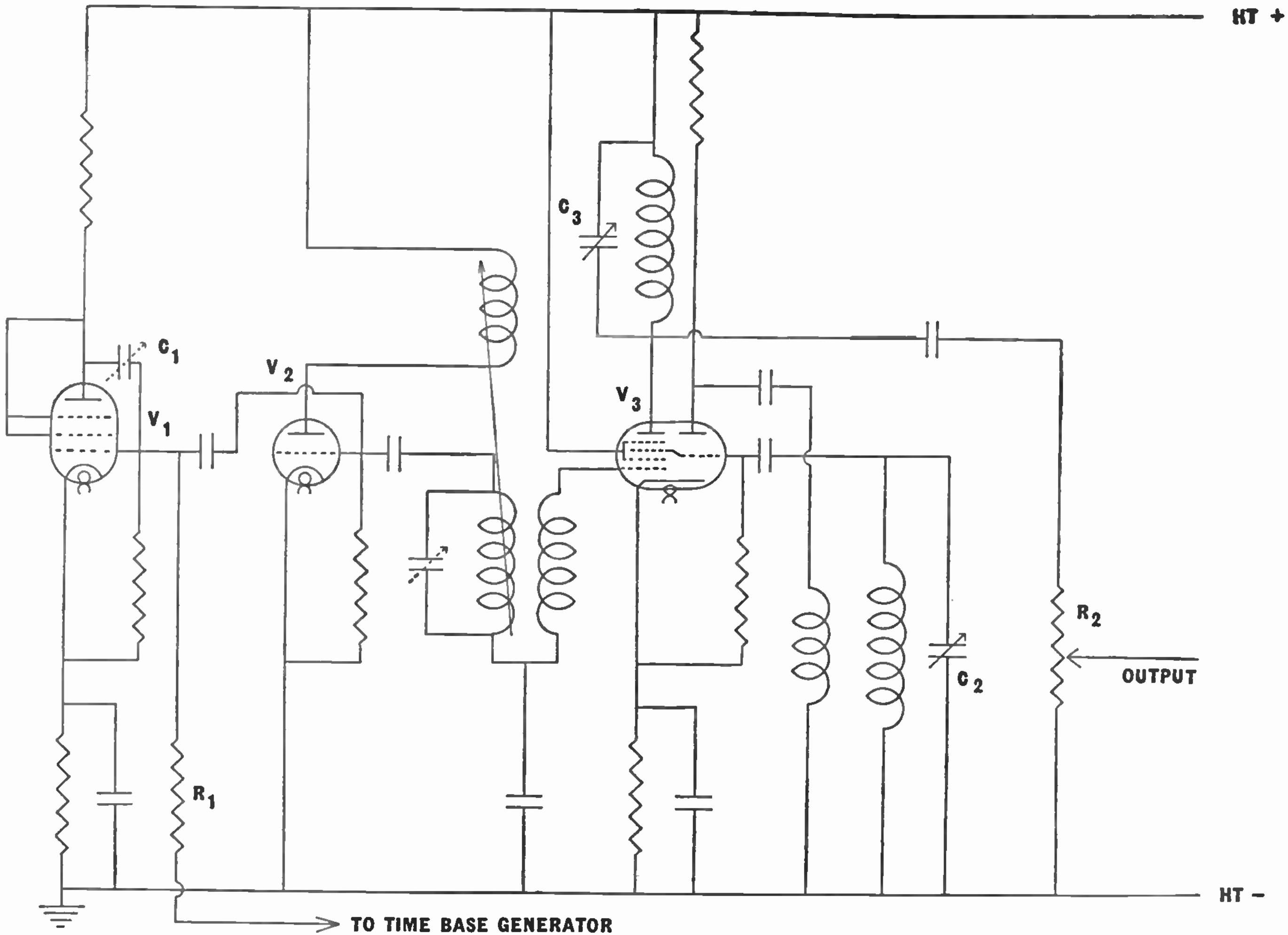


Fig. 10.— Basic circuit of a frequency-modulated oscillator suitable for nse with an oscillograph for receiver alignment

V_1 is a variable-mu pentode, with screen and suppressor grids strapped to anode so that it functions as a triode. This arrangement is necessary, as variable-mu triode valves are not generally available. The anode circuit is resistive, and consequently the input capacity of the valve will vary in proportion to gain. The grid of the valve is connected through resistance R_1 to the time-base generator in the oscilloscope. As will be seen in the next chapter, the time-base generator will provide a continuously variable voltage which starts from zero, rises to a maximum, and returns very rapidly to zero: this is shown diagrammatically at Fig. 11. In this way the time-base generator will control the input capacity of V_1, the maximum capacity being adjusted by the pre-set condenser C_1; thus the Miller effect provides a variable capacity, the variation of which is controlled by the time-base generator. The grid of V_1 is connected through a condenser to the grid of V_2, consequently the change of capacity due to the Miller effect appears across the grid circuit of the fixed oscillator.

The fixed oscillator is an ordinary regenerative triode with tuned grid inductance, the condenser taking the form of a pre-set type for adjusting

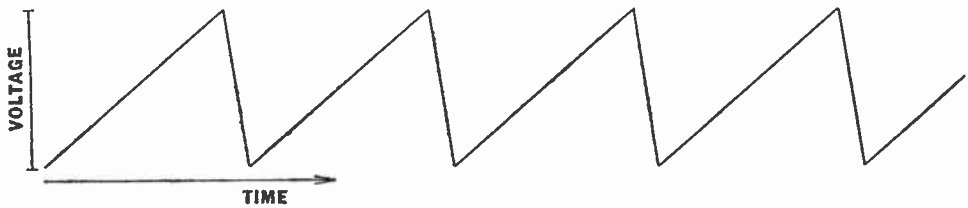


Fig. 11.—Waveform of a perfect time-base generator. This relationship between time and voltage is known as a saw-toothed waveform; the voltage rises from zero to maximum following a truly linear law and then returns to zero very rapidly.

to the desired fixed frequency. The purpose of the fixed oscillator is to ensure that both amplitude and frequency variation are constant, which would not be the case if the Miller valve controlled the oscillator V_3. The output from the fixed oscillator, which will appear as a waveform of constant amplitude but frequency varying plus and minus 15 kilocycles per second, is coupled to the grid of the mixer section of V_3. It will be observed that the coupling is of the mixed capacity-coupled bandpass type in order to suppress harmonics, which would otherwise appear in the output circuit and cause serious confusion when using the instrument.

The oscillator section of V_3 is quite conventional and resembles the oscillator circuit of a superheterodyne receiver. The grid inductance is tuned by means of the condenser, C_2, which is of the variable type and ganged to C_3. For the sake of clarity a single grid inductance is shown, but in practice there will be a separate inductance for each frequency range, which may be selected at will by means of a switch ganged to the switch selecting the appropriate anode coil for the hexode section. The grid of the triode section is connected internally to the mixer grid of the hexode, and thus the valve behaves exactly the same as in a superheterodyne receiver, with the exception that the normal radio signal is replaced by the output of V_2. There is, however, one essential difference, and that is that the anode circuit of the hexode section is variably tuned, and it must keep in step with the grid circuit of the variable oscillator, since it is essential that any output frequency is obtainable. As already intimated, the anode coil will consist of the same number of separate coils as used in the grid circuit, the selector switches being ganged so that the appropriate coil in each circuit is simultaneously selected. The purpose of the tuned anode coupling is the further suppression of harmonics and other unwanted frequencies, but it must invariably have a flat response, since the required output will vary plus and minus the 15 kilocycles per second. The presence of some harmonics is therefore unavoidable. For aligning frequency modulated receivers the frequency swing is usually plus and minus 150 kilocycles per second.

The potentiometer R_2 is, in effect, across the anode coil, a condenser being used at the high-potential end as a D.C. stopper. This potentiometer gives control of the output amplitude, while its total resistance controls the damping of the anode circuit.

To summarise, the output waveform may have a fundamental frequency selected at will within the range of the instrument by the manual setting of the ganged condenser C_2/C_3, which will employ an accurately calibrated dial. The output voltage, however, will vary plus and minus 15 kilocycles per second irrespective of the fundamental frequency, such variation taking place at a rate strictly determined by the time-base generator which controls the gain of the valve V_1.

To simplify the circuit the anode coil is shown with the condenser C_3 connected directly across it. This would make ganging inconvenient, consequently the condenser would be connected between the anode and H.T.—, with a suitable condenser between H.T.+ and H.T.— to ensure that the former is at earth potential from the H.F. point of view.

General Precautions.—Oscillators are prone to pick up stray fields from the mains and other sources, consequently the output lead should be screened. Failure to protect the output circuit from pick-up can introduce various secondary effects, which prove very confusing. At the higher frequencies an oscillator is naturally prone to a capacity effect, which is avoided by housing the complete instrument in a metal case which is earthed in the normal manner.

Very High Frequencies.—Occasion may arise when it is necessary to inject a very high frequency, say, of the order of 45 megacycles per second ; it would, in fact, be necessary to inject precisely this frequency when realigning a television receiver. Very few moderately priced oscillators are capable of working at frequencies of this order with anything like the requisite degree of accuracy. For realignment at very high frequencies, manufacturers invariably use crystal-controlled oscillators, but unfortunately such equipment is not usually available to the service engineer.

If a cathode-ray oscillograph is available, it is a relatively simple matter to adjust the oscillator with precise accuracy by using the Alexandra Palace transmission, preferably choosing a period when it is not being modulated by picture intelligence. Even if 45 megacycles is not the required frequency, it will be possible to get a very good idea of the calibration error obtaining on the highest frequency range. Work should be commenced immediately after checking calibration, unless the oscillator is known to be free from frequency drift due to temperature-change; for the same reason the oscillator should be switched on at least 15 minutes before calibration is attempted, in order that it may reach its normal working temperature.

CHAPTER 3

THE CATHODE-RAY OSCILLOGRAPH

OSCILLOGRAMS taken by means of the cathode-ray oscillograph have appeared in various chapters. For such purposes the instrument is of great value, but it also has other uses in the field of practical fault-finding and receiver alignment.

The Cathode-ray Tube.—The external appearance of a typical cathode-ray tube may be seen from the accompanying plate, while a section of the electrode assembly is shown at Fig. 12. They may be divided, broadly, into two classes, known respectively as gas-focused tubes and high-vacuum tubes ; the former are so called because a trace of gas, usually argon, is introduced into the tube after it has been exhausted to a high degree of vacuum. Gas-focused tubes have fallen into disuse, but the following brief explanation is included for the convenience of those possessing a tube of this type, or an oscilloscope incorporating a gas filled tube. No reference is made in this chapter to the functioning of the hard tube as it is adequately described in chapter 9, volume II.

In modern terminology, the grid shield and anode together form the gun; when gas focused tubes were in common use the anode was called the gun and the base so marked. To avoid confusion, the word gun is used in this chapter as referring to the anode only.

The several components of the electroed assembly of a typical gas-focused cathode-ray tube are indicated at Fig. 12, and are shown diagrammatically at Fig. 13. It may be seen that the lowest point of the electrode system is a filament, although in certain types this element is replaced by a heater and indirectly heated cathode. The filament in the tube under discussion differs from the ordinary conception of a filament, inasmuch as it is not coated with

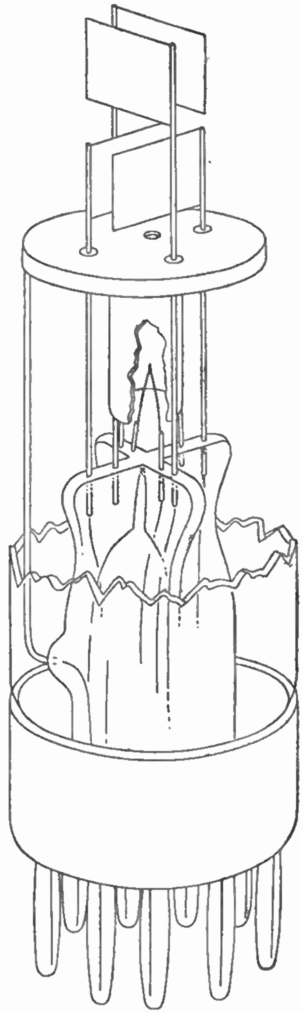


Fig. 12.—The electrode assembly of a typical gas-focused cathode-ray tube. The focusing shield is cut away to show the cathode, the circular aperture can be clearly seen in the disc-shaped gun. Note also the two pairs of deflector plates.

electron-emitting material throughout its whole length, but only at the tip; this is to ensure that electrons are emitted from a small area.

The filament is surrounded by an electrode called the focusing shield, and above this is a disc electrode known as the gun. These electrodes are known by various other names, which are mentioned in the notes at the end of this chapter. Above the gun are the deflection plates, which consist of two pairs placed mutually at right angles. The pair of plates nearer to the gun are known as the y plates and are usually referred to as Py_1 and Py_2 respectively, the other pair of plates are known as Px_1 and Px_2 respectively. This nomenclature has been more or less standardised and is open to criticism, since from the earliest days of scientific records it has been customary to refer to the vertical direction of a graph as the y direction and the horizontal as the x direction, a custom that has hitherto been observed in referring to the dimensions of an oscillogram. Often the plates nearer to the gun may be used for vertical deflection and the other pair of plates for horizontal deflection, when the standardised classification is perfectly in order, but it often happens that the plates nearer the gun have to be used for horizontal deflection owing to their greater sensitivity, as, for example, in television. Under this condition the confusing position arises that the y plates are being used for deflection in the x direction and *vice versa*.

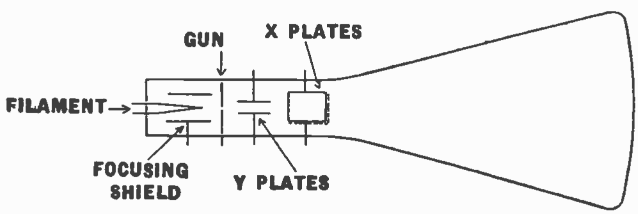


Fig. 13.—Symbolic representation of a gas-focused cathode-ray tube. Unfortunately there is no precise standardisation, but that shown above is typical.

The functioning of the tube may be easily followed by reference to Figs. 12 and 13. The filament is heated to an appropriate temperature at which it emits electrons ; these electrons are simultaneously influenced by the pull of the gun, which is held at a relatively high positive potential, and the repelling force of the shield, which is held negative in respect to the filament. When suitably adjusted, the repelling force of the shield marshals the electrons into a comparatively narrow beam, in which condition they are accelerated by the positive potential on the gun and pass more or less straight through the latter. The electrons do not flow to the gun as might be expected, partly owing to the symmetrical assembly whereby the sideways pull of the gun is approximately equal in each direction, but principally because of the great velocity at which the electrons are travelling, which will be of the order of thousands of miles per second under normal conditions.

On its way to the screen the beam must pass between the y and x deflector plates, which will deflect its direction if suitable potentials are applied. If, for example, Px_1 plate is shorted to the gun and Px_2 plate is made positive in respect to the gun, then the beam will bend in the direction of the last-mentioned plate. A little thought will show that by applying suitable potentials to the deflecting plates the beam may be deflected to any point on the screen.

The Screen.—The screen consists of a light deposit of a fluorescent material, usually zinc silicate or a mixture including this substance ; the material exhibits the peculiar phenomenon that it glows when bombarded by electrons, the actual glow exhibited on the screen being colloquially known as the spot. The electron beam may be considered for the present application as being free from momentum and inertia and is capable of tracing any "pattern" on the screen, giving a faithful visible tracing in fluorescent light of the voltage applied to one or more of the deflector plates. Various screen materials are available which produce several different colours. Green is usually employed for visual work, blue for photographic work, owing to its high actinic value (such a tube was used for the various oscillograms appearing in earlier chapters, with the exception of the waveforms of the vowel sounds), and red for observing slow phenomena, as it possesses considerable after-glow ; blue-green tubes are now available, however, giving an even greater after-glow.

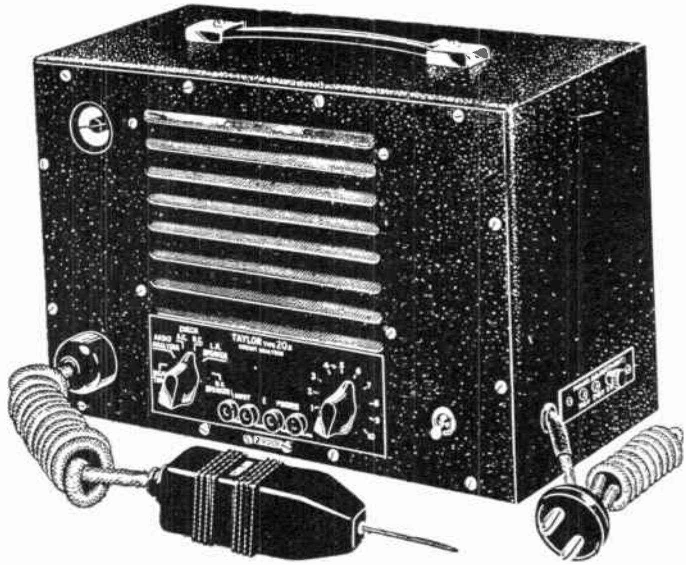
After-glow (Persistence).—After-glow, or persistence, is the quality of the screen material to continue glowing at any given point after the electron beam has moved away from it. Tubes are now available having an after-glow extending to several seconds, which makes possible the observation of a relatively slow-moving spot so that it appears to trace a line rather than show as a moving spot. If the phenomenon under observation is such that it is periodically recurrent, then the tracing on the screen of the cathode-ray tube appears as a continuous line and looks, in fact, exactly like the various oscillograms in the earlier chapters. If the phenomenon recurs relatively slowly, say, five times a second, it can be made to appear as a continuous trace by using the tube having a screen with a long after-glow ; but if the recurring period is comparatively rapid, say, fifty per second, the trace will appear continuous without the assistance of after-glow, due to the phenomenon of persistence of vision. Persistence of vision is that quality of the human eye which makes an object appear stationary and always present if it is seen sufficiently frequently in exactly the same place. For example, the eye gives to the brain the impression that a cinematograph picture is continuous, although the screen is actually black for an appreciable period between each successive frame.

In order that the shape of an elaborate trace can be accurately interpreted, it is desirable that the trace be as narrow as possible ; in other words, the electron beam must be sharply focused so that the spot is as small as practicable. In the gas-focused tube the manual operation of focusing is carried out by suitably adjusting filament temperature and focusing shield potential in relation to the gun voltage. Usually the filament temperature is fixed reasonably critically and the shield potential is variable. In the high-vacuum type of tube the elaborate gun assembly is capable of focusing the spot without assistance or, in simpler assemblies, with the aid of an external magnetic field. The gas-focused tube is assisted by the rarefied gas within its bulb, which functions in the following manner. The beam of electrons travels through the rarefied gas and collision occurs between electrons and gas molecules, with the result that the latter are ionised; the ions are relatively slow moving, and consequently remain within the electron beam and form a positive charge along it which draws the outermost electrons in towards the centre, thus cleaning up the edge of the spot, making it small and of reasonably uniform brilliance.

Origin Distortion.—The presence of gas, although valuable for the purpose of focusing, introduces an undesirable secondary effect known as origin distortion, which is caused by a slowing up of the beam at the electrical centre of the plates, which results in slight non-linearity plus a brightening at this point. When the pattern traced by the spot is so elaborate as to more or less fill the screen, origin distortion will appear as a faint white line down the centre and across the middle of the screen. Origin distortion can be minimised by a special type of tube where one x plate and one y plate is split horizontally into two. It is not, however, considered necessary to go into this refinement here.

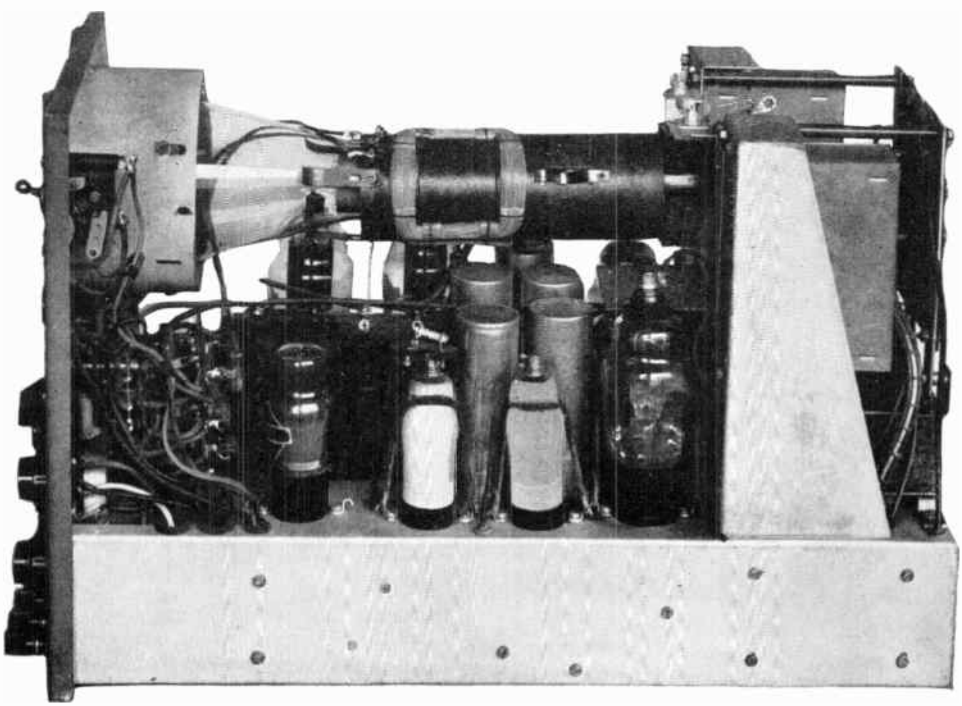
To summarise, the cathode-ray tube may be looked upon as a superbly delicate instrument (although robust in use) capable of showing visibly electrical phenomena, which may be introduced as voltage on the deflector plates or current passing through deflector coils situated close to but outside the bulb. Most phenomena to be observed will be change of voltage or current in relation to time or frequency. The oscillograms illustrating the chapter on sound show change of voltage in the vertical direction plotted against time in the horizontal direction, while the various oscillograms showing frequency characteristics of coils are voltage in the vertical direction plotted against frequency in the horizontal direction. To set up an oscillograph for the latter condition Py_1 would be shorted to the gun and the voltage to be observed connected between the gun and Py_2, while the ganging oscillator supplying the input voltage would also supply the horizontal traverse by linking together the frequency modulation arrangements with a voltage change between the x plates. It will be remembered that the control of frequency modulation in the ganging oscillator was supplied by the oscillograph time base. It is therefore convenient to direct attention to the time base which performs this function and also provides the horizontal deflection when some phenomena are being plotted against time.

The Time Base.—The oscillograph time base may be defined as a device for producing a change of voltage which preferably occurs in a linear manner and which collapses after reaching a predetermined value in a predetermined time. In other words, a piece of apparatus is required which will build up progressively a voltage which collapses to zero in the shortest possible time and then repeats. The comparatively slow excursion is sometimes called the scan voltage, while the collapse of voltage



A CIRCUIT ANALYSER

The cathode-ray oscilloscope has a competitor for general fault finding in the "signal chaser" or "circuit analyser." The Taylor circuit analyser shown above can perform, among other functions, the checking of the oscillator stage and A.V.C. and can trace the signal right through the receiver.



A DOUBLE-BEAM OSCILLOSCOPE

A modern double-beam cathode-ray oscillograph, using the modern high-vacuum tube ; this type of oscillograph was used by the Author for the various oscillograms used to illustrate this work.

is known as the fly-back. When this piece of apparatus is connected between the plates of the cathode-ray oscilloscope, the effect is to cause the spot to travel at a predetermined speed across the tube and at the end of the excursion to allow the spot to fly back very rapidly for the beginning of the next excursion.

A Simple Time Base.—The simplest form of time base employs a neon tube, which may be of the type used for domestic lighting. The neon tube has the peculiar property that its striking and extinguishing voltages are separated by a wide margin. The average tube will not light until a voltage of about 190 volts is applied, but once alight the voltage may be reduced to perhaps 130 volts before illumination ceases; the former condition is known as the striking voltage, and the latter as the breaking voltage. In describing the simple circuit shown at Fig. 14, the tube is assumed to have the above characteristics. It would perhaps be desirable to mention at this juncture that the gun, although held at a positive potential, is treated as zero in respect to the deflecting plates, and that it is usually convenient to earth the gun; the fact that the gun is held at positive potential presents no obstacle to a direct earth connection, since every other point of the equipment will be insulated from earth. It is general practice to connect to the gun any plate that is not otherwise connected; if the plate was left at open circuit it would collect a static charge capable of deflecting the beam. Fig. 14 shows the basic circuit of a neon-tube time base which works in the following manner: It should be understood that the applied voltage V can be derived from the same source as that used to supply the gun. Reference to the circuit will show that the condenser C will charge through the resistance R until the potential across C is equal to the striking voltage of the tube, in the present case 190 volts. The tube will then become conductive (and incidentally illuminated) and will continue to discharge condenser C until the potential across it falls to the breaking voltage, which in the present instance is 130 volts. In this condition the neon tube is non-conductive, permitting the condenser C to charge, which it will continue to do until the potential across it reaches the striking voltage of the tube, which will again become conductive and discharge the condenser, a process which will be repeated as long as the applied voltage V is available.

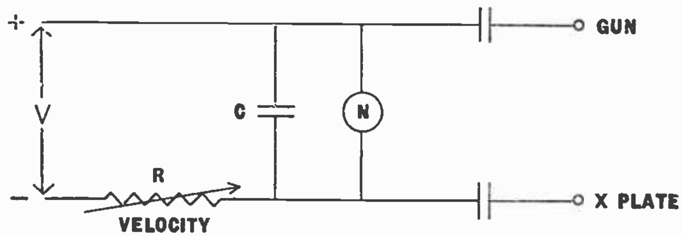


Fig. 14.—A neon-lamp time base. The illustration above shows the circuit of the simplest possible form of time base.

The action of the neon tube is to produce a recurrent voltage change of 60 volts across the condenser C, which is made up of the striking voltage minus the breaking voltage. The plates of the condenser are connected to the gun and Px_2 respectively, which will cause the spot to travel across the screen in one direction as the condenser charges, and in the other direction when the condenser discharges. By choosing the values for R and C suitably, charge and discharge can be made to occur at any desired frequency within wide limits, and, furthermore, by making the value of C small, proportionately increasing the value of R to retain the required frequency, the discharge will be more rapid than the charge. By making C sufficiently small the discharge can be accomplished so quickly that the fly-back of the spot is almost imperceptible to the eye, so that the trace will plot a curve showing the relationship between the voltage to be observed (vertical displacement) and time (horizontal displacement) without the fly-back confusing the image. Condensers are included in each output lead as a D.C. stopper. R is shown variable, permitting the frequency of the time base to be controlled.

The time base shown at Fig. 14 is open to criticism, inasmuch as the time-base sweep is non-linear, that is to say, the spot will travel much faster at the beginning of the sweep than at the end. This is due to the fact that in the charging of a condenser through a resistance the flow of current through it will decrease as the potential across it falls consequent upon the potential across C increasing. This difficulty may be partially overcome by replacing the resistance R with a constant-current device, such as a saturated diode. Such an arrangement is shown at Fig. 15, where a diode is formed by strapping the anode and grid of a triode, a procedure made necessary by the difficulty of procuring a diode of the bright-emitter type, whereas bright-emitter triodes are obtainable. If the filament potential of the constant-current valve is so adjusted that it is saturated below the breaking voltage of the neon, then it will pass the same current irrespective of the potential applied, which will always be between the striking and breaking voltage of the neon tube, with the result that the condenser charges in a linear manner and the time-base sweep thus produced is also linear. The main objection to the arrangement is the difficulty of controlling the frequency, which can only be varied by altering the value of C or the filament temperature of the diode, which is somewhat inconvenient.

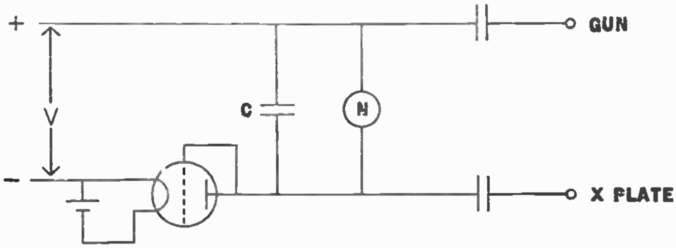


Fig. 15.—An improved form of time base in which a saturated diode is used to improve linearity.

The frequency of the time base shown at Fig. 14 may be determined by the following relationship:

$$\text{Frequency in cycles per second} = CR\,\frac{V_s - V_B}{V - V_m}$$

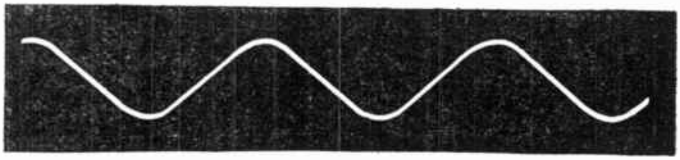
when C equals the capacity of C_1 in farads, R equals the value of the resistance R, V_s is the striking voltage of the neon tube, V_B is the breaking voltage of the tube, V is the applied voltage, and V_m is the mean voltage of the neon tube.

The frequency of the improved time base shown at Fig. 15 may be determined by the following relationship :

$$C\frac{V_s - V_B}{I_s}$$

when I_s is the saturated current of the constant-current valve, and the other constants are as above. The value I_s may be obtained by means of a milliammeter with the condenser C short circuited.

The Gas-discharge Triode.—With the exception of time bases intended for use at low frequencies, objection can always be raised against the use of any form of gas-filled discharge tube, but, nevertheless, the time base using the gas-discharge triode is satisfactory for operating at frequencies up to 100,000 cycles per second at least. Quite apart from any other consideration, it readily permits the application of synchronism. Synchronism is a term applied to the practice of locking the time-base sweep to the phenomenon under observation. In order that a recurrent phenomenon appears as a single trace, it is necessary that the commencement of each recurrent trace occurs at the same point of the vertical displacement. Figs. 16 and 17 are excellent examples of a recurrent phenomenon recorded with and without synchronism ; the illustration actually shows thirteen time-base sweeps, the frequency of which differs slightly from a multiple of the frequency being observed, with the result that each sweep occurred at a different point. The necessity for some form of synchronism is greatly increased by the impossibility of limiting the action of the time base to a single sweep unless elaborate apparatus is available. The oscillograms of the vowel sounds in the early pages of Volume I are, in fact, single sweeps taken by means of a rotating-drum camera, which actually controls the beam of the oscillograph to the extent that it only permits the beam to function during the period of one drum revolution, the photographic film being fixed round the perimeter of the drum.



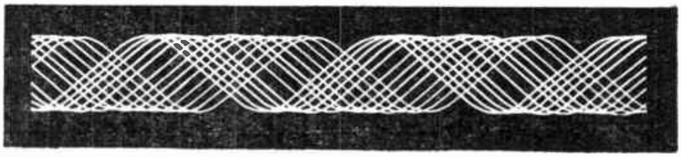


Fig. 16 (*top*).—A simple waveform, and Fig. 17 (*below*) an attempt to show the effect produced when the waveform being examined is not a multiple or sub-multiple of the time-base frequency. The effect thus produced will appear in a photograph like the complicated trace shown above, but with many types of tubes it will appear to the eye as though a single or perhaps a double trace is moving across the screen.

The principle of synchronism is simple. The time base is adjusted manually so that its natural frequency is a little less than a sub-multiple of the frequency being observed, the latter being fed into the time base so that it assists the discharge of the condenser by raising it to the necessary voltage to strike the discharge valve. Such an arrangement may be accomplished with a neon-tube time base, but it is neither efficient nor convenient; however, it may readily be incorporated in a time base using a gas-discharge triode. A gas-discharge triode is a triode valve which is filled with gas at low pressure after pumping. Various gases are used, a mixture with neon gas predominating is perhaps the most popular. In order to bring about consistency of working, the gas pressure is determined by the manufacturer within narrow limits, and in order to shorten the minute period between the beginning of discharge and maximum discharge the anode is usually designed with a large surface area on the honeycomb principle.

Fig. 18 shows the circuit of a time-base generator using a gas-discharge triode. This type of valve functions differently from an ordinary high-vacuum triode. When the anode voltage is raised to the requisite potential, current begins to flow which ionises the gas, forcing down the internal impedance and increasing the anode current; as anode current increases, ionisation also increases, and impedance falls still further. Within a very short space of time, possibly of the order of $\frac{1}{50000}$ second, the valve will pass an anode current big enough to destroy itself, unless there is sufficient resistance to limit the current to a reasonable figure. Once ionisation has started the grid loses control, and no amount of negative grid voltage will stop the flow of anode current, which can only be stopped by interrupting the anode voltage. The rapid discharge of the gas-filled triode is used to discharge a condenser in the same way as a neon tube is used in the time base previously described. Reference to Fig. 18 will show that the charging condenser C is charged from the high-tension line through the resistance R_2. A lead is taken from the high-potential end of condenser C and led to one of the deflector plates of the cathode-ray tube, the

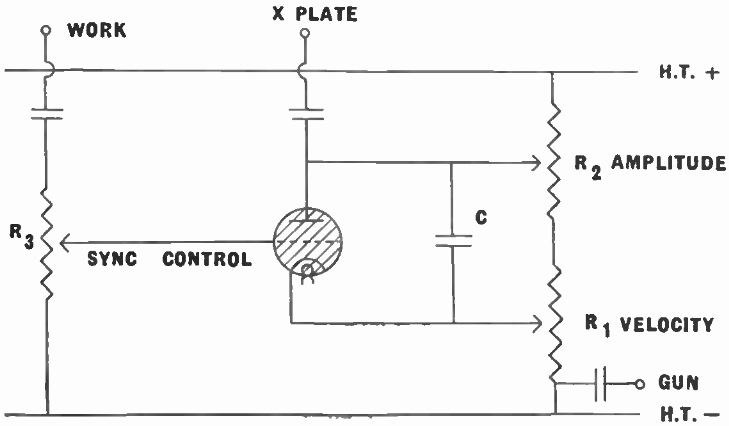


Fig. 18.—A simple time base using a gas-discharge triode. Although non-linear, it is nevertheless useful for certain types of work, and has the advantage of synchronising control. The valve symbol is shaded to indicate that a gas-filled valve is represented.

opposite plate being connected to the gun. It will be observed that the condensers are placed in the output leads to act as D.C. stoppers.

The grid is returned to the high-tension negative line, the cathode being returned to a point which is positive in respect to the grid to an extent dependent on the setting of the potentiometer R_1; thus the grid potential may be varied. When the valve is functioning, C will charge up until the anode potential is sufficient to overcome the bias, when the valve will become conductive and discharge C until ionisation decreases owing to fall of anode potential, and the grid will again assume control, the process being repeated as long as high tension is available. It will be noted that the high-tension voltage is variable by means of the potentiometer R_2, which allows control of the maximum voltage to which the condenser C may be charged, thus controlling the difference of potential across C in the charge and discharge condition; thus the output from the time-base generator may be adjusted to any predetermined amplitude within the limitations of the circuit.

The charging rate of the condenser C is unaffected by the valve, which will stop this process when the voltage on its anode is sufficient to overcome the grid bias; thus the latter will control the frequency with which the valve will discharge and consequently control the frequency of the output waveform. By adjusting R_1 and R_2 both the frequency and amplitude of the output may be controlled. The change of voltage when applied to the cathode-ray tube will determine the journey of the spot across the screen; it follows that the spot must travel faster as frequency increases, thus the control R_1 is often referred to as velocity.

Synchronising.—The potentiometer R_3 is connected between the negative rail and the waveform which is to be observed. In other words, the top end of the potentiometer will usually be connected to one of the *y* plates; by suitable adjusting R_3 any desired portion of the "work" voltage can be made to appear across the grid/cathode circuit. In order to follow the function of the synchronising control it will be necessary to choose some arbitrary values. Assume that the negative grid bias is 15 volts, and that the applied high tension is 250 volts; assume also that at this voltage the valve cannot discharge if the grid bias is more than 14 volts. If the waveform to be observed is connected across R_3 and the potentiometer adjusted so that 1 volt peak appears across the grid/cathode circuit, it follows that the effective bias on the valve will be reduced to the required 14 volts at peak of the positive half-cycle and the triode will discharge. When the discharge has completed and the charge across C is building up, the alternating potential across R_3 will not have any effect until the anode potential is high enough to cause the valve to discharge when the grid is 14 volts negative. Thus the condenser C will become fully charged, but the triode will not discharge until the peak of the positive half-cycle applied to the synchronising circuit trips the grid circuit.

To summarise, the triode will only discharge at the precise moment when the work voltage reaches maximum positive, and, providing the behaviour of the valve is constant, the time-base sweep will always occur at the same instant in relation to the work voltage, and consequently each trace on the cathode-ray tube will be in synchronism with the previous one, giving the appearance of a single stationary waveform. Obviously these remarks only apply when the work voltage is of a recurrent nature, or at least sufficiently so to make synchronism possible.

Hard-valve Time Bases.—The gas-discharge triode is unsuitable for very high frequencies owing to the uncertain performance of the ionisation

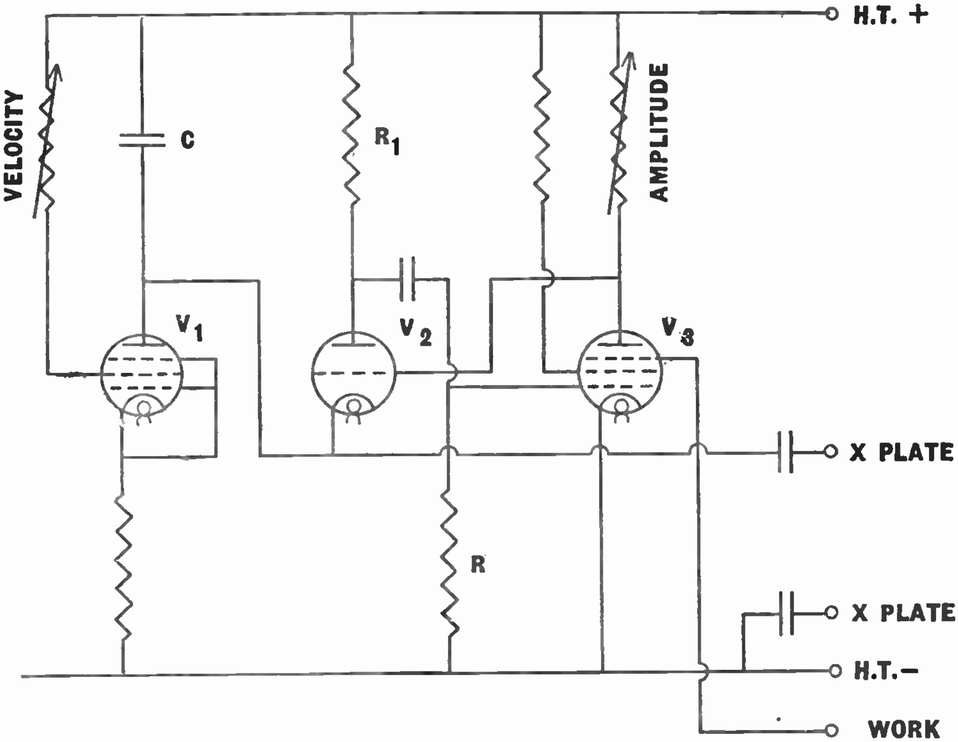


Fig. 19.—Basic circuit of a time base using high-vacuum valves. In acknowledgmeut of the engineer who introduced it, the circuit is often referred to as the Puckle time base.

time, and recourse is made to a time base using hard valves. Such a time base is shown at Fig. 19, which also employs a constant-current device to improve linearity. The sweep voltage is obtained by charging the condenser C through the constant-current valve V_1, which may be either a saturated diode or a pentode operated on the flat part of its anode-voltage/anode-current characteristics. The pentode is to be preferred, as it gives reasonable immunity from the effects of mains-voltage fluctuation (it is presumed that the apparatus will be mains driven). It will be observed that the screen voltage is variable, which determines the anode current, which is, in fact, the charging current or the condenser C, and thus the screen potentiometer becomes the frequency control.

The triode V_2 is biased well beyond the cut-off by the drop across the resistance R. It will be understood that the cathode of V_2 is held at positive potential due to the very considerable voltage drop across V_1. The condenser C continues to charge, driving the cathode of V_2 in the negative direction until a point is reached when anode current begins to flow which will cause a drop across the resistance R_1, thus driving the grid of V_3 in the negative direction ; this, in turn, drives the grid of V_2 in the positive direction, which will increase the anode current to the resistance R_1, driving the grid of the valve V_3 yet more negative. which will decrease still further the drop across the resistance R, thi, will drive the grid of the valve V_2 still further in the positive directions In short, a kind of " vicious circle " is commenced by the mutual influence of the valves V_2 and V_3 upon each other, the action gaining tremendous speed once it has commenced, which has the result of discharging the condenser C in a very short space of time. At the end of the discharge the current flowing through R_1 is decreased and the " vicious circle " reverses and the circuit resets itself for the next sweep.

It will be observed that one of the output terminals is taken from the cathode of V_2. The other terminal could be taken from the high-tension negative rail, but some non-linearity would result, although not as great as that experienced with the time-base generator shown at Fig. 18. It is, however, often desirable to use balanced output (Fig. 20), which is brought about by means of the valve V_4. It will be noted that two resistances are connected across the constant-current valve, forming a potentiometer allowing a portion of the voltage generated to appear across the grid/cathode circuit of the valve V_4. The ratio between the resistances R and R_1 is equal to the magnification of the valve V_4, thus the alternating potential produced across R_2 is equal in amplitude to the potential between the cathode of V_2 and the negative rail, but is 180° out of phase, thus producing a symmetrical output giving push-pull deflection when applied to opposite plates in the cathode-ray tube.

It would be equally possible to use a hard valve to correct the non-linearity of the gas-discharge triode time base shown at Fig. 18, applying the same principle as that used in Fig. 20, the grid voltage for the phase-changing valve being derived from a condenser potentiometer formed by placing a condenser in series with the charging condenser C. The three time-base circuits shown may be considered to represent the simplest possible arrangement (Fig. 14), a simple but practical circuit (Fig. 18), and a more advanced type capable of really serious work (Fig. 20). The circuit shown at Fig. 18 illustrates the principle usually employed in time bases intended for general service work. The possible variations of hard-valve time bases are exceedingly numerous, but the principle of any time base is an arrangement whereby a saw-toothed waveform is derived similar to that shown at Fig. 11 in the previous chapter, which shows absolute linearity. The output waveform of a non-linear time base would be similar, except that the sweep would appear as a curve. For all

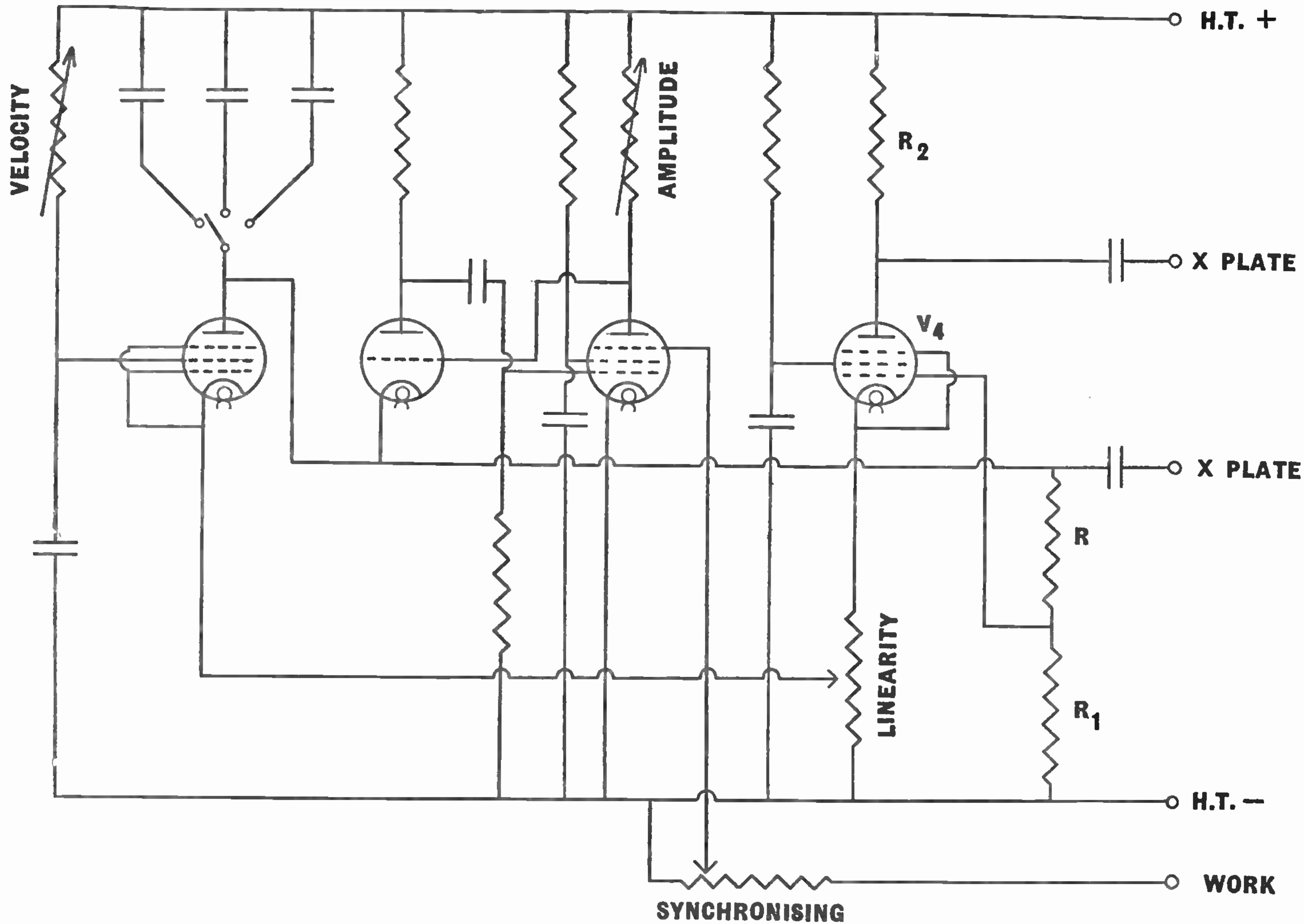


Fig. 20.—Complete circuit of a time base using high-vacuum valves, with an additional valve to give a balanced output and correct linearity.

normal purposes it is immaterial whether the discharge is linear or otherwise, with the proviso that non-linearity must not reach proportions which will result in the fly-back time being unduly increased or make synchronisation difficult. The normal method of achieving linearity of the sweep voltage is the use of a phase-changing valve, giving push-pull output, as described above, but sometimes a form of negative feed-back is used as a means of improving linearity.

A Simple Oscillograph.—The principles of the cathode-ray tube and the time base have been outlined, and attention may now be directed to the circuit of a complete oscillograph with its own independent power pack. Fig. 21 shows the complete circuit of a simple oscillograph. It will be observed that the X plates are led out to terminals permitting the use of a balanced time base, a link being provided to short one plate to gun when desired. If some form of electrical phenomenon is to be observed, it must be made to deflect the spot at right angles to the time base, when it will be possible to observe it in relation to time. Suppose, for example, the phenomenon to be observed is the waveform of ordinary electric light mains, then one lead can be taken to one *y* plate and the other lead taken to the gun, when the waveform will appear on the screen the horizontal direction representing time and the vertical direction representing amplitude. Oscillograms shown in this manner appear in Chapter 6 of Volume I. It should be noted that a D.C. path must be provided between all plates and the gun, either directly when a plate is not in use, or through a high resistance when work is applied. It is often more convenient to connect one plate of each pair directly to the gun, connecting the work circuit and time base to the two remaining plates. Any voltage waveform can be observed in this way, although if its amplitude is inadequate to provide reasonable deflection, it will be necessary to use an amplifier ; if it is desired to observe a current waveform, then deflection must be magnetic, the current to be observed being fed through a pair of coils situated one on each side of the tube.

For the observation of waveforms which will include alignment of receivers, the time base will be used to provide a horizontal deflection. It should be particularly noted, however, that when aligning receivers the horizontal dimension does not represent time, since the time-base voltage is used to vary the frequency of the ganging oscillator so that the actual excursion of the spot will represent a change of frequency which, as mentioned in the previous chapter, will usually be plus and minus 15 kcs. per second. An oscillogram produced in this manner shows amplitude against kilocycles off-tune or, in other words, the frequency response of the tuned circuit or circuits under observation.

General Application.—The principal use of the oscillograph as a service instrument is the aligning of receivers, particularly those of the superheterodyne type which, by this means, may be undertaken by relatively inexperienced operators. The oscillograph in the hands of a competent individual can be used for a variety of purposes, but the

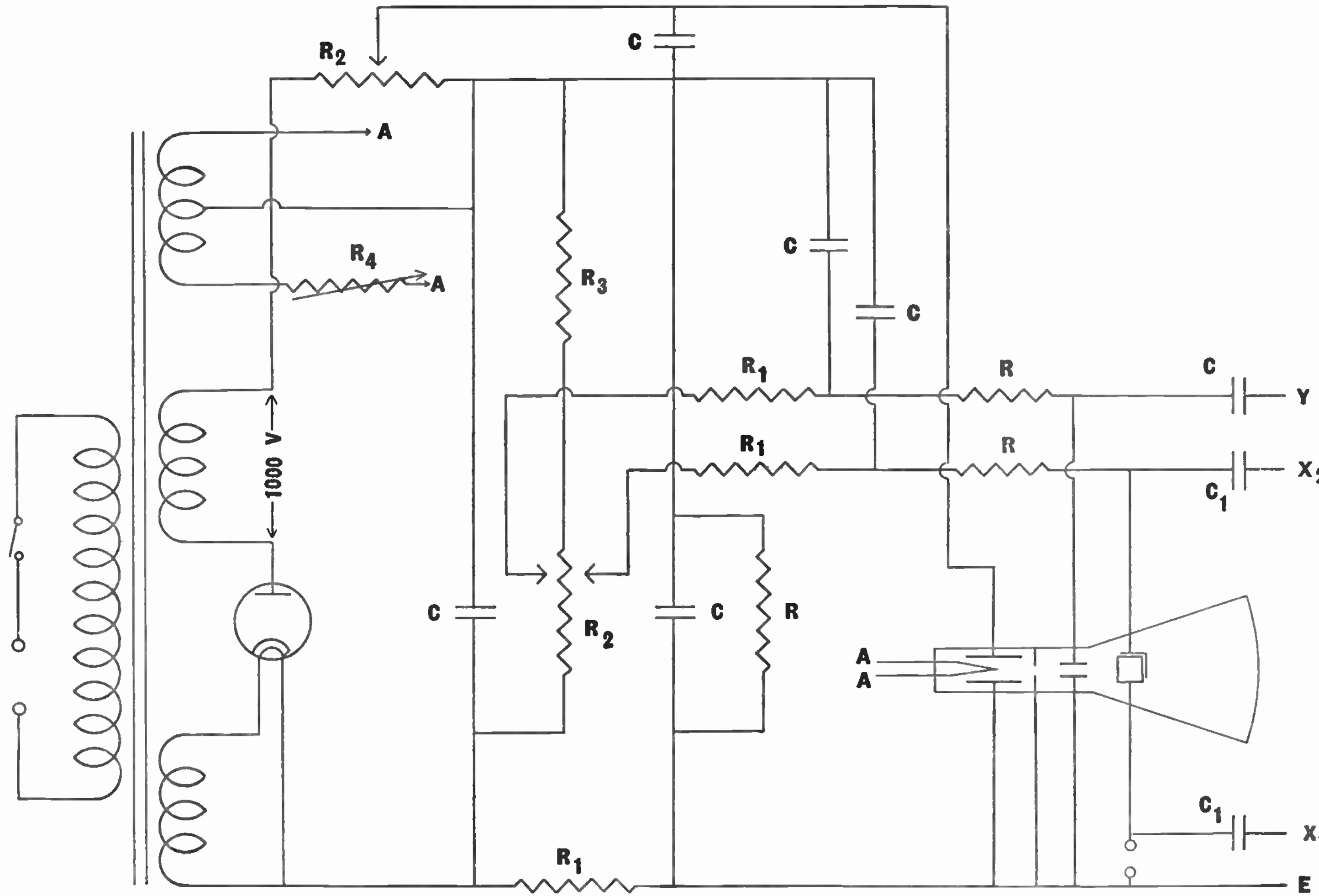


Fig. 21.—Circuit of a simple but useful oscillograph built by the author, using a gas-focused cathode-ray tube. The values are subject to some variation to suit different makes of tube.

instrument is worse than useless without the necessary knowledge to interpret the information obtained. Its possible uses include : detection of motor-boating and other feed-back trouble, the detection of distortion and conditions of over-load, hysteresis of iron-core components, the measurement of leakage reactance in transformers, and an almost unlimited number of applications. Many of these applications call for a highly specialised knowledge, but some of the more simple applications must suffice for the present purpose.

Tracking Mains Hum.—The oscillograph is quite useful as a means of tracking mains hum, but unless the hum is very severe an amplifier will be necessary ; this is, however, included as part of some commercially built oscillographs. A time base is employed to provide a horizontal deflection, and the Y plates are connected to two test prods which can be tried across each grid and cathode circuit or elsewhere. The aerial is disconnected, allowing the presence of mains hum to be revealed by its appearance as a waveform on the screen of the tube.

Distortion.—The oscillograph may be used for tracking distortion in amplifiers by connecting the Y plates across each grid or anode circuit, carefully watching the waveform for divergence from the input waveform, which will previously have been carefully observed by the same means. When the amplifier forms part of a radio receiver a ganging oscillator can be used, if it is provided with *low*-frequency modulation, which will give a waveform of regular shape ; this facilitates the recognition of distortion. If the amplifier is purely for use with a low-frequency input, suitably attenuated A.C. mains may be used for the input and the test carried out in the same way.

High-frequency Feed-back.—Instability in a low-frequency amplifier may be due to the presence of high frequencies fed from the pre-detector section of the receiver. The oscilloscope may be used to locate the leads through which the feed-back occurs. A convenient method is to feed a low-frequency modulated input to the aerial and earth terminals from a ganging oscillator, and to connect the Y plates across each grid circuit and anode circuit working backwards from the loudspeaker primary. The presence of high frequencies will be detected by a thickening of the trace on the end of the cathode-ray tube. This test, however, requires a high-gain amplifier capable of working at the highest radio-frequency that is liable to be met with. Conversely, the same method can be used for detecting hum in the high-frequency circuits using an unmodulated input, when the presence of hum will be detected by a thickening of the trace.

Summary.—To summarise the application of the cathode-ray oscillograph, it is apparent that its principal use is for aligning receivers, and it is probably true to say that the correct alignment of a superheterodyne using bandpass coils cannot be carried out by any other means with the same accuracy.

It is apparent that there are many useful applications of the oscillograph other than for alignment, but with certain exceptions a considerable amount of skill is required, and sufficient experience to interpret the information that may be deduced from the trace on the end of the tube. Such experience can only be acquired by continual use of the instrument.

Nomenclature.—There are a number of alternative terms in common use which are given below; in addition, the meaning of certain terms is defined more fully than in the text above.

Filament.—The filament of a cathode-ray tube is often called the cathode, whether or not it is indirectly heated.

Focusing Shield.—Variously known as shield, focusing shield, grid, and Wehnett cylinder.

Screen.—Often referred to as the fluorescent screen.

Y Plates.—The plates nearest to the gun are almost invariably termed the *y* plates, and it is conventional so to orientate the tube that these plates perform the vertical deflection.

X Plates.—The plates farthest from the gun which are usually used for horizontal deflection.

Time Base.—Sometimes called time-base generator or saw-toothed generator.

Sweep Voltage.—A term given to signify the length of the traverse on the screen of the cathode-ray tube: if the trace appearing on the screen may be regarded as a "picture," then sweep may be defined as picture width.

Trace.—The line of fluorescent light produced on the screen by the electron beam. However complicated the waveform, it is nevertheless made up of a single line.

Work Voltage.—A term given to the potential or current which is to be observed. The term is useful to differentiate between the work voltage or current and the time-base voltage.

Linearity.—When applied to a time base, linearity is used as a reference to the traverse per second at the beginning of the time-base sweep, as compared with the traverse per second at the end of the sweep.

Synchronism.—The locking of a time base by means of the work voltage to ensure that successive traces are imposed one upon another so that a single stationary waveform appears.

CHAPTER 4

VOLTAGE AND CURRENT TESTING

THE basis of any systematic fault-finding is almost invariably voltage and current measuring. As will be seen later, incorrect voltage or current will usually localise the fault, so that it can be easily and quickly discovered. When the normal voltage and current readings for the receiver are available the whole operation is simplified, but when such data are not available a certain amount of experience is helpful to assist in determining whether the figures obtained are reasonable and therefore unlikely to be abnormal to the extent of drawing attention to a fault.

Before outlining the procedure of systematic testing it is necessary to deal with certain pitfalls which may lead the unwary to draw incorrect conclusions. The measurement of current is usually quite straightforward, as the meter will be in series with the various components in the circuit, but a voltage measurement is taken with the meter in parallel with some components and the shunting effect of the meter can, under certain circumstances, have a profound effect upon the reading obtained. Fig. 22 shows a high-frequency pentode used as a leaky grid detector; if it is desired to measure the voltage drop across, say, a bias resistance, the voltmeter is connected across it and an accurate reading is obtained owing to the relatively high ratio between the resistance of the meter and the resistance of the bias resistor; the former may well be 10,000 ohms, while the latter will be of the order of 500 ohms.

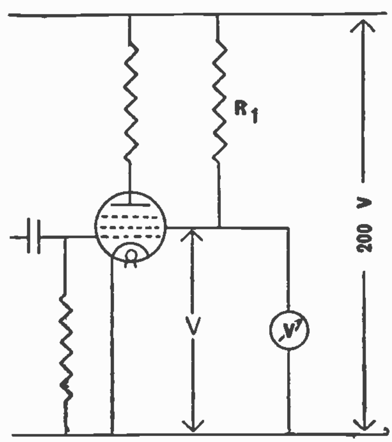


Fig. 22.—The error introduced by connecting a voltmeter in this circuit is described in the text.

If it is desired to measure the voltage on the screen of the valve, the operation is far from simple. It is probable that a meter having a 0–100 volts scale would be employed which would have a resistance probably not greater than 1,000 ohms per volt, making a total of 100,000 ohms. The resistance of R_1, on the other hand, may well be 500,000 ohms. To investigate this circuit farther it will be necessary to fix some arbitrary values. Let the potential difference across the positive and negative rails be 200 volts, the resistance of R_1 500,000 ohms, and the screen current of the valve under these conditions ·2 milliampère. Application of Ohm's law will show that a current of ·2 milliampère flowing through 500,000 ohms will drop 100 volts, so that the screen voltage V will be 100 volts. It should be understood that all these values are obtained without the meter connected. When the meter is connected from the screening grid to the high-tension negative rail, a totally different set of conditions is obtained, and it will be interesting to see the voltage that will be registered by the meter, bearing in mind that it has an internal resistance of 100,000 ohms.

To simplify this analysis it will be convenient, although highly improper, to look upon the screen to cathode path of the valve as though it were a pure resistance, and to ignore for the time being the influence of screen voltage upon screen current. The screen current is ·2 milliampère, and we know that the potential difference is 100 volts; we may, therefore, for the time being, regard the screen to cathode path as a pure resistance equal to 500,000 ohms, *always remembering that the assumption is for convenience only.* It is now possible to redraw the circuit in the manner shown at Fig. 23, when R_1 is the resistance similarly indicated in Fig. 22, R_m is the internal resistance of the meter, and R_v the *assumed* D.C. resistance of the valve. R_v has a value of 500,000 ohms, which is in parallel with R_m, which has a value of 100,000 ohms, making a total resistance of approximately 83,000 ohms. The equivalent resistance of 83,000 ohms is in series with R_1, which is 500,000 ohms, and the application of Ohm's law will show that the potential difference across R_m in parallel with R_v is approximately 30 volts, or less than one-third of the potential difference when the meter is not connected.

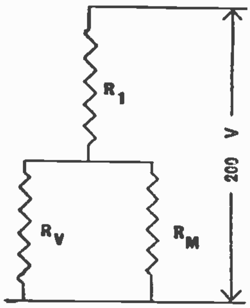


Fig. 23.—Symbolic rearrangement of Fig. 22, when R_v represents the resistance through the valve and R_m the resistance of the meter.

The above analysis indicates the astonishing error that can be introduced by the meter with which it is desired to obtain a reading. Considerable emphasis is laid on the fact that the above set of conditions is fictitious, since the assumption that the screening-grid cathode path of the valve is a D.C. resistance is a misstatement of fact for a number of reasons, the most serious of which is that the screen will not continue to take ·2 milliampère if the potential difference is reduced to 30 volts. In actual fact, when the meter is connected as described the screen voltage is reduced, owing to the current flowing through the meter, which must also flow through R_1; the reduced screen voltage will usually reduce the screen current, which tends to raise the screen voltage, but not to the same extent that the resistance of the meter reduces it.

To summarise, it is apparent that the connection of a meter will so affect the potential to be measured that a totally incorrect reading is obtained. This condition is met with when the meter is connected across any two points in the circuit where a high resistance is in series with the meter. It is important that the expression " high resistance " should be interpreted as meaning high in comparison with the internal resistance of the meter. In the example cited above the meter was assumed to have a resistance of 1,000 ohms per volt ; instruments in general use for service work will often have a resistance of half this value, which will accordingly increase the error ; cheap instruments often have still lower resistance, and examples may be found which when connected, as shown at Fig. 22, will not show any readable deflection.

A possible solution is to correct the reading obtained by making due allowance for the resistance of the meter in relation to the relevant resistances in the circuit, but at best this is an approximation, owing to the actual change of screen current which takes place. The alternative method which should be used when an accurate reading is desired entails the use of an indirect method. The following procedure is typical of such indirect reading, but is subject to various modifications which may be convenient from time to time.

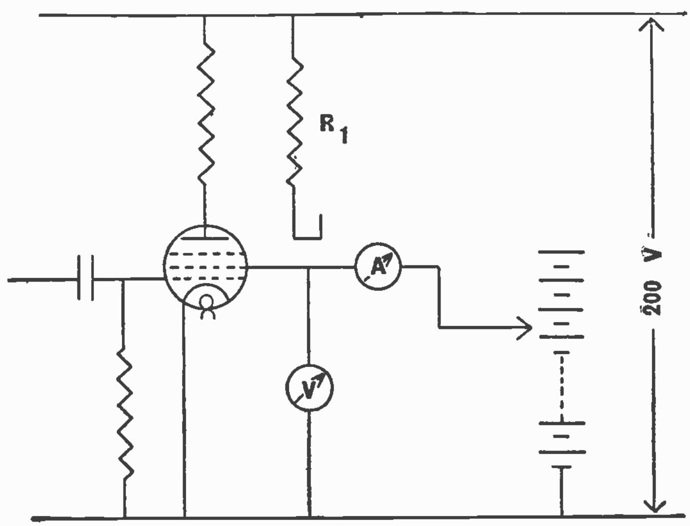


Fig. 24.—Circuit illustrating a suggested method of measuring the screen voltage in the circuit at Fig. 22.

Connect a suitable milliammeter in series with R_1 and *most carefully* note the current. Next, disconnect R_1 from the screen and connect a high-tension battery between the screen and high-tension negative with the milliammeter in series and a voltmeter in parallel, as shown at Fig. 24. The high-tension battery voltage is adjusted by means of the tappings until the milliammeter denotes the screen current which was previously registered and duly noted. The voltmeter will then read the screen voltage which obtained when the screen was connected to high-tension positive through R_1. When great accuracy is required, it may be necessary to use a potentiometer in order to obtain intermediate voltages between the tappings of the high-tension battery.

The fundamental idea underlying this procedure may not be readily apparent ; the screen current of the valve under test will be proportional to the screen voltage, providing that all other potentials are kept constant. If, for example, the screen current is ·2 milliampère when the screen voltage is 100 volts, then the potential temporarily applied by means of the battery must be equal to the potential applied through R_1 from the normal high-tension positive rail. It will be understood that whereas the internal resistance of the meter greatly influenced the screen voltage when the screen current necessarily passed through the resistance R_1, the internal resistance of the meter has no effect when it is shunted across the temporary high-tension battery, the internal resistance of which will be relatively small. In fault-finding it is seldom necessary to employ indirect methods for voltage readings, but occasions may arise when the procedure will be found useful.

Voltage and Current Readings.—Current readings are usually far more informative than voltage readings, but there is a great tendency to employ the latter in preference to the former, presumably owing to the fact that voltage readings may be obtained with a minimum of trouble, whereas current readings usually necessitate the unsoldering of one joint for each reading to be taken, although in battery receivers the majority of readings may be taken by connecting the milliammeter in the high-tension negative lead and withdrawing all valves except the one being tested. This procedure, however, only measures total space current and will not separate anode and screen current.

The author ventures to suggest that current measurements ultimately take less time, owing to the directness with which they indicate the fault if it is of such a nature that it may be detected by either voltage or current readings. The following tabulated procedure is offered *as an indication* of fault-tracing purely on the evidence obtained by *current* measurements; obviously the items under "possible cause" and "procedure" will require addition or deletion when applied to various types of receivers :

(1) *No anode current throughout set.*

Possible Cause.	*Procedure.*
Broken connection in battery leads or automatic bias resistance if used.	Repair break or substitute resistance.
High-tension battery "dead" or low-tension supply run down.	Test high-tension battery and accumulator.
Valves "dead."	Substitute or test valves, particularly for open-circuit filaments or heaters.
Fuse blown.	Replace fuse or test for open circuit.
High-tension reservoir condenser shorting.	Temporarily disconnect and re-test for anode current
Faulty switch.	Examine on/off switch or test each pair of contacts for continuity.
* Mains lead open circuit.	Repair break.

* **Faults so marked are peculiar to mains receivers.**

Possible Cause.	*Procedure.*
* Mains transformer with broken winding.	Test windings for continuity; measure resistance of windings if correct values are known, or test voltage across each winding.
* Faulty rectifier valve.	Substitute or test if means are available.
* Open circuit smoothing choke or loudspeaker field if in series with high-tension supply to all valves.	Substitute choke or test for voltage across it. A broken winding will cause a relatively high reading to be obtained, whereas a zero reading will be obtained if the winding is intact and no current is flowing.
* Short circuit in reservoir or smoothing condenser.	Replace or temporarily disconnect.
* Dial lights, open circuit.	Applicable only when dial lights are in series with high-tension circuit and are not shunted. Replace.
* Mains resistance open circuit. Applicable to universal receivers only.	Test as for smoothing choke above.
* Mains filter chokes, open circuit.	Temporarily short circuit.
Break in circuit	Inspect wiring for dry joints or broken joints and connection to chassis.

(2) *Low anode current throughout set.*

Possible Cause.	*Procedure.*
Valves losing emission.	Substitute or test.
High-tension battery run down.	Test under load or temporarily replace.
Low-tension accumulator run down or shorted internally.	Test under load or temporarily replace.
* Short-circuited turns in transformer heater winding.	Measure voltage across winding. This fault is highly improbable.
Bad joint in heater or filament leads.	Inspect or preferably compare voltage across heaters with voltage across heater winding.
* Shorted turns in mains transformer high-voltage secondary.	Test with A.C. voltmeter.
* Short circuit or serious leak in smoothing condenser.	Replace or temporarily disconnect.

* Faults so marked are peculiar to mains receivers.

(3) *No anode current to one valve only.*

Possible Cause.	*Procedure.*
Valve faulty.	Substitute or test with particular reference to continuity of filament or heater.
Filament or heater circuit broken.	Measure voltage across filament or heater.
Break in anode circuit.	Connect anode through milliammeter (and, if necessary, a suitable resistance) to high-tension positive rail. Normal current will prove break between high-tension rail and anode or short circuit decoupling condenser.
Screen circuit broken (applicable to multi-grid valves only).	Connect screen through suitable resistance direct to high-tension positive rail.
Bad contact of valve-pins in valve-holder.	Open and clean valve-pins.
* Broken bias resistor.	Temporarily short circuit. This is unsafe with output valves capable of passing heavy current, in which case connect a suitable resistor in parallel.

(4) *Anode current low to one valve only.*

Possible Cause.	*Procedure.*
Valve losing emission.	Substitute valve or test.
Grid bias too high.	Check bias and total anode current if bias resistor in high-tension negative lead is used.
Grid open circuit.	Connect grid direct to bias.
Screen volts too low (applicable to multi-grid valves only).	Check screen volts; if low, test screen decoupling condenser.
Valve oscillating.	Touch anode terminal with finger and note if anode current changes. (Not recommended if high-tension voltage is too high.)
Short circuit decoupling condenser in anode circuit.	Substitute or temporarily disconnect.

* Faults so marked are peculiar to mains receivers.

(5) *Anode current high to one valve only.*

Possible Cause.	*Procedure.*
Leaky coupling condenser.	Temporarily disconnect high-tension supply from preceding valve.
Leak between windings of low-frequency transformer.	Temporarily disconnect high-tension supply from preceding valve.
Grid open circuit.	Connect grid direct to bias.
Bias too low.	Check bias, suspect short circuit bypass condenser.
Valve oscillating.	Touch anode terminal with finger and note if anode current changes.
Screen volts too high (applicable to multi-grid valves only).	Check screen volts, if potentiometer-fed test between screening grid and chassis for continuity.
Grid leak open circuit. Applicable to frequency changer only.	Substitute or test.

(6) *Anode current normal to all valves but signal completely or partially absent.*

Possible Cause.	*Procedure.*
Loudspeaker failure. (Appropriate only when signal completely absent.)	Connect permanent-magnet speaker to extension speaker terminals. Substitute or test primary and secondary circuits for continuity.
Anode circuit component short circuited.	Test with ohmmeter. Test trimmers for short circuit.
Grid circuit components shorted.	Test with ohmmeter. Test trimmers for short circuit.
Open grid circuit.	Change grid bias value and note if anode current responds.
Oscillator valve not oscillating—or not oscillating on certain frequencies.	Short circuit oscillator tuning condenser and note if anode current increases. Check voltage to all electrodes. Substitute valve. *Note.*—A frequency-changer valve is difficult to test.

(7) *Fluctuating anode current to all valves when signal is not being received.*

Possible Cause.	*Procedure.*
Loose contact or dry joint in filament, high-tension bias connection, anode circuit, or grid circuit.	Connect anode to a suitable resistance to high tension and grid direct to bias.
Intermittent on/off switch.	Short circuit switch with wire.
* Intermittent connection in mains lead, fuse, or mains filter choke.	Test connections, short circuit filter chokes, replace fuse.
* Intermittent shorting turns in transformer windings.	Connect voltmeter and look for variations.
Intermittent short in valve.	Substitute or test.
Intermittent short in automatic volume control diode.	Disconnect automatic volume control line and connect to temporary bias.
* Shorting dial lights.	Disconnect dial lights, remove from direct contact with chassis as may be required by the design of their holders.
* Shorted turns in loudspeaker field, applicable only if in series with high-tension supply to all valves.	Temporarily short circuit, or if potential drop across it is large, remove and replace.
Intermittent short circuit in smoothing, by-pass, or reservoir condenser.	Temporarily disconnect former, substitute latter.
Faulty contact in high-tension battery.	Substitute.
Intermittent short circuit between high-tension rail and chassis.	Test with ohmmeter.
Faulty contact in rectifier or other valve-holder.	Open and clean valve-pins.

(8) *Fluctuation to one valve only when signal is not being received.*

Possible Cause.	*Procedure.*
Loose contact or dry joint in filament, high-tension bias connection, anode circuit, or grid circuit.	Connect anode to a suitable resistance to high tension and grid direct to bias.
Bad contact in valve-holder.	Open and clean valve-pins.
Intermittent short in automatic volume control diode, if applied to one valve only.	Disconnect from automatic volume control line and connect to chassis.

* Faults so marked are peculiar to mains receivers.

Possible Cause.	*Procedure.*
Bad joint in heater or filament wiring.	Inspect connections.
Intermittent short circuit in anode, screen, decoupling condenser, or intermittent short in cathode bias resistor bypass condenser.	Substitute or temporarily disconnect.
Leak in coupling condenser.	Disconnect *preceding* valve from high-tension positive rail.
Intermittent contact in screen supply.	Connect voltmeter to measure screen voltage and watch for fluctuation.
Loose electrodes or intermittent contact in valve.	Temporarily replace or test.
Leak across wave-change switch.	If possible, disconnect switch or clean.

(9) ***Fluctuating anode current to one or more valves only when signal is being received, due to causes other than fading or depth of modulation.***

Possible Cause.	*Procedure.*
Intermittent short in aerial and earth system.	Disconnect aerial and earth and substitute a temporary aerial.
Intermittent short circuit in tuned circuits.	Suspect tuning condenser, wave-change switch, and particularly trimming condensers.
Intermittent contact in high-frequency coupling condensers, resulting in change of capacity.	Substitute suspected condensers.
Erratic performance of automatic volume control circuit.	Short circuit automatic volume control diode load resistance.
Erratic behaviour of tuning indicator, applicable only when current passing through indicator is reasonably high.	Remove or disconnect or short indicator, whichever is most convenient.
Note.—Care must be taken to differentiate between random fluctuations of anode current and normal fluctuation due to the action of a leaky grid detector or to slight over-loading in the post-detector stages.	Test on unmodulated carrier wave and note if fluctuation continues.

The above tables do not pretend to be complete, as certain specialised circuits will have their own peculiar faults, nevertheless they serve to indicate the general procedure that may be adopted and also the type of interpretation that may be applied to abnormal anode-current readings.

It will be observed that the table is divided into nine sections, each of which is applicable to a particular irregularity in anode current, although further subdivision calls for voltage reading in certain cases. Considerable emphasis is laid on the fact that many of the above faults would not be revealed by a *voltage* reading.

In further explanation of the above table the left-hand column shows possible causes for the abnormal anode-current reading, while the right-hand column shows the further test that may be applied to ascertain whether or not each of the possible causes is, in fact, responsible ; where several different tests are shown in the procedure column it should be understood that the first-named is the most reliable, but when inconvenient for any particular reason the further suggestions may be adopted. Certain types of faults have little influence upon anode current or, alternatively, may affect anode current only in certain circumstances. Such faults may be roughly grouped under the headings : instability, distortion, mains hum, background noise, whistles, and fading. These various aspects of fault-tracing are dealt with in subsequent chapters, where suggestions are given for applying suitable tests, although in many circumstances the procedure outlined above will enable the trouble to be found, as such faults usually directly or indirectly influence anode current, and when correcting the fault responsible for abnormal anode current it will often be found that some less tangible fault is automatically eradicated.

CHAPTER 5

INSTABILITY AND MOTOR-BOATING

THE term instability is somewhat ambiguous, as it may manifest itself in a variety of ways, which may be dependent upon fairly exact circumstances. In order to deal with this subject in a logical manner it will be necessary to make some arbitrary distinctions between the various types of instability, although such a procedure is not entirely satisfactory, since the various groups cannot be well defined.

High-frequency Instability.—High-frequency instability may be defined as a tendency for the receiver to whistle or howl at any point of the wave range covered, while, on the other hand, it may be limited to one waveband or even to a small section of one waveband. The following suggestions for tracing the cause of instability assume that the receiver has previously performed in a stable condition, and the trouble is therefore not due to faulty design.

The most prolific cause of instability is condenser failure, since a large number of the condensers used in receivers are included for the sole purpose of preserving stability. The inset facing page 48 shows the complete circuit diagram of an A.C. mains receiver. This circuit is the same as that used for another purpose in Chapter 5 of Volume II, but is reproduced here for convenience. It will be interesting to trace the components which, by failing, could introduce instability. Attention is first directed to the condenser, C_{26}, which forms the high-frequency bypass for the automatic volume control line. If this condenser leaks, the bias on all the valves might be reduced to a point where instability occurs, due to a condition of abnormally high gain. If, on the other hand, the short circuit were complete, the valves would be entirely without bias, when any tendency towards instability would be stopped by grid current. The screen condenser, C_6, is intended to hold the screening grids of V_1, V_2, V_3 sensibly at cathode potential (from the high-frequency point of view), and if this condenser becomes open-circuited the screening grid will be unable to perform its proper function, and the valve will behave like a triode, when the most violent instability can confidently be expected.

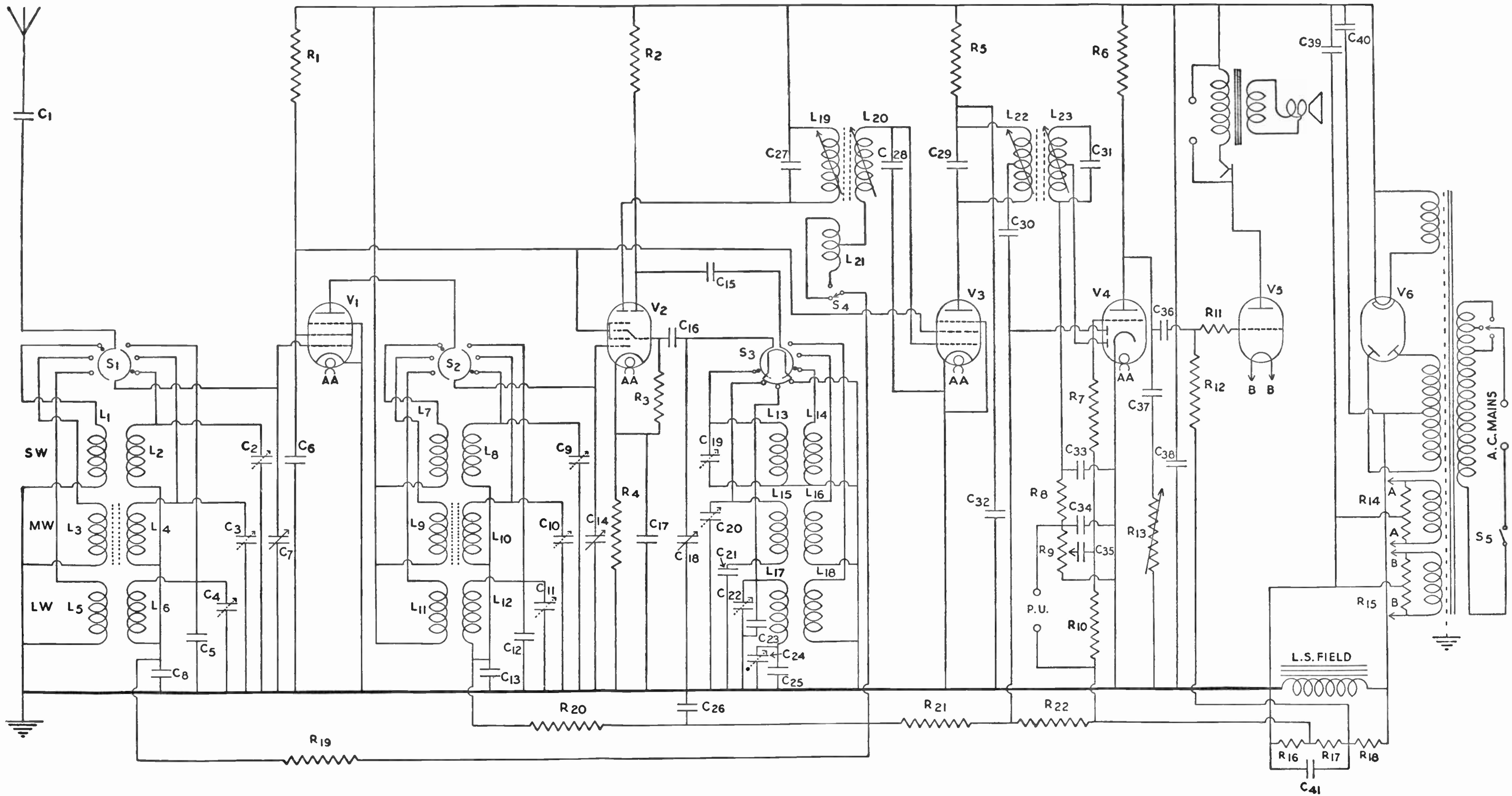
Continuing with the review of condensers, attention is next directed to C_{17} which, partially short circuited, will reduce the bias on the frequency changer. It is unlikely, however, that this will cause instability, although it is within the bounds of possibility if the receiver is on the verge of instability. The A.V.C. decoupling condenser, C_{26}, is likely to cause serious instability if it is open-circuited, as it will permit energy to be transferred between the grid circuit of V_3 to V_1 and V_2. Proceeding more or less logically through the circuit, the next condenser liable to cause instability is the anode decoupling condenser of V_3 (C_{32}) which, if open-circuited, will allow the relatively large high-frequency voltage developed across V_3 to feed back into the other valve circuits by way of the common impedance existing between the high-tension positive and negative rails.

The automatic volume control feed-condenser, C_{30}, will prevent the system from working if it is open-circuited, which may result in instability, but will undoubtedly result in hopeless overloading on any but the weakest signal.

Generally speaking, broken resistances will not introduce instability; the exceptions are resistances in the automatic volume control line and resistances forming the lower half of a potentiometer system feeding the screen, if such an arrangement is used. Open-circuit resistances in the automatic volume control line prevent bias being applied to one or more of the pre-detector valves, resulting in instability and, at least, some overloading when a signal is tuned in. If the lower half of a potentiometer system feeding the screen of one or more valves becomes open-circuited, the screen potential will rise very considerably, gain will be increased, which may or may not result in instability, purely depending upon the design of the receiver. Obviously some receivers will remain stable when gain is increased, whereas others are unable to tolerate even a small increase in gain.

It is obviously impossible to detail a list including all the possible causes of instability, owing to the great variation in receiver design. The circuit illustrated is typical, but, nevertheless, it is only possible to treat the subject in a general manner. Instability due to a faulty condenser has been touched upon, and attention may be directed to less-obvious causes. A break in the grid circuit of V_1 would undoubtedly cause motor-boating on strong signals, owing to the choking effect of the grid, which would be without any D.C. connections to its cathode. If such disconnection is caused by a broken winding, obviously the trouble will be peculiar to the appropriate waveband. The same remarks apply to the grid circuit of the frequency changer V_2, although the possibilities are somewhat narrowed, since a break in a grid circuit on the high-potential side of the coils would result in the complete absence of signal. The same remarks do not apply to the grid circuit of V_1, as the gain of the receiver is high enough to pick up some signals on the actual grid lead.

There are several possible causes of instability in the grid circuit of V_3. First of all there is the possibility of a break in the secondary winding, which will cause very violent motor-boating, owing to the relatively great amplitude of the signal at this point. An equally likely source of trouble is failure of the selectivity switch, resulting in the coupling coil not being



Circuit diagram of a five-valve A.C. superheterodyne receiver.

returned to the A.V.C. line in either position. In certain circumstances a break in the coupling coil could have a similar effect, but it would require a simultaneous break in both halves.

There are a number of other probable sources of instability which are of a semi-mechanical nature. For example, the coil-cans may not make proper contact with the chassis due to looseness in the fixing arrangements; similarly, the tuning condenser may not make proper contact with the chassis. Similar possibilities may be found in the condenser itself, due to bad connection between the moving vanes and the framework, possibly through a broken pig-tail, or a retaining spring having fallen out of position. The various condensers referred to as capable of causing instability are quite unable to perform their function if their appropriate leads are not making proper contact. Dry joints are a frequent source of instability when they form part of a decoupling condenser circuit.

A Quick Test.—It is possible very quickly to test both decoupling condensers and their appropriate leads in the following manner: Equip a ·1 μF tubular-type condenser with suitable leads terminated by "crocodile" clips permitting this condenser to be connected across each condenser in turn. It will be appreciated that if a condenser in the receiver is open-circuited, the temporary condenser will restore the receiver to normal.

Certain types of receivers employ deliberate damping in one or more tuned circuits which usually takes the form of a resistance in parallel with one or more inductances. Should these resistances become broken or in other ways open-circuited, instability may result, due to the increased magnification of the tuned circuit. This type of fault is particularly liable to be met with when tuned anode coupling is used, when instability is liable to occur at the high-frequency end of each waveband. This tendency is checked by a parallel resistance, as referred to above.

Another prolific cause of instability arises in the screened leads which are often used between coils and the top terminal of high-frequency amplifying valves. The spiral or braided outer covering performs the normal function of screening the lead within it and is usually bonded to earth inside the coil-can. Should it become unbonded it is highly probable that instability will result, and is often difficult to locate, as the bonding cannot be readily inspected and may make reasonably good D.C. contact, giving rise to a misleading conclusion when making a rough continuity test. Fortunately, however, this trouble can usually be detected by placing the hand near the lead, resulting in a violent change of instability when the hand is placed close to the faulty lead. This test is even more effective if the aerial terminal is held with the other hand. It is common practice to rely on the metal coating of metallised valves to screen the electrodes. This metallised coating is connected to a filament pin in the case of battery valves and to the cathode of mains valves—unless a seven-pin base is used, when the metal coating may be connected to a separate pin. In any case there is a possibility of the wire becoming detached from the metallised coating, which will often cause instability, but it may be readily found in the same manner as suggested for tracing an unbonded lead by placing the hand close to each valve in turn.

Instability in the Low-frequency Section.—A study of the low-frequency section will reveal several possible causes of instability. Attention may first be directed to the tone control comprising C_{37} and R_{13}. If the resistance is of the type which has no "off" position, it is possible that loss of high-frequency bypass may be sufficient to cause instability if open-circuited. A break in the grid circuit of V_5, due to a break in the resistance R_{12} or the tapping being disconnected in the resistances R_{17}–R_{18}, will result in motor-boating and very bad distortion. The anode current, however, will fluctuate wildly, and a fault of this nature will be revealed if a preliminary anode-current check is carried out.

The condenser C_{41} is primarily intended to prevent random fluctuations in anode current (due to overload) from unduly influencing the several bias voltages. Nevertheless, it is possible for a condenser in this position to cause instability if open-circuited. It is equally possible that a short circuit of certain sections of the bias resistance could result in instability due to an increase in gain of the pre-detector valves.

The loudspeaker field coil offers most subtle possibilities. It will be observed that the resistances R_{16}, R_{17}, and R_{18} form a potential splitting arrangement to take advantage of the potential drop across the loudspeaker field coil. It is not uncommon for a short circuit to occur between adjacent turns, which will result in a slight drop of the potential across the coil as a whole; this will, in turn, result in a decrease in bias to the pre-detector valves. On occasions the number of shorted turns will be such that a critical value of bias is applied. Admittedly, shorted turns will reduce the sensitivity of the loudspeaker, but it is surprising that no *readily apparent* loss of sensitivity occurs when quite a large percentage of the turns are shorted and, furthermore, a small drop in loudspeaker sensitivity is not likely to be easily noticed when the receiver is in an unstable condition.

The condenser C_{39} could undoubtedly produce instability if open-circuited, but must also introduce very serious mains hum, which will draw attention to it. The condenser C_{38}, however, will cause very violent instability if open-circuited, as it forms the high-frequency bypass of the power pack. The triode section of V_4 must not be overlooked, it is a low-frequency amplifier and naturally must be included in this section. In the circuit under discussion the only likely cause of instability is an open grid circuit due, perhaps, to failure of the resistance R_7 and R_{10}. The grid lead of this stage is often shielded, in which case steps should be taken to see that the shielding is properly bonded to the chassis.

In some receivers the loudspeaker chassis is earthed, and this connection should be inspected or tested for continuity. Generally, instability caused in this manner will be confined to the long waveband or, alternatively, will be more serious on this waveband than on the medium or short bands.

Instability due to Misalignment.—Instability may be due to misalignment of the receiver, the radio-frequency tuned circuits probably being responsible if instability is not apparent on all wavebands, while the intermediate-frequency alignment should be suspected if instability is apparent on all wavebands and there is reason to believe that misalignment is responsible. Do not, however, attempt to realign the receiver unless an accurately calibrated oscillator is available, together with an output meter or, preferably, a cathode-ray oscillograph.

As already intimated, the subject of instability can only be dealt with in the most general terms, but it is hoped that the above suggestions for tracing instability in the particular circuit shown will act as a guide to the general procedure to be adopted. When testing for instability or, incidentally, for any fault, it is desirable to narrow the field where possible by taking such steps as disconnecting the extension speaker or gramophone pick-up, if used, throwing the tuning indicator out of action by removing it, or by other means, and removing the noise-suppression valve, tone-control valve, or, in fact, *anything* that may be removed without preventing the receiver from functioning. Should these steps chance to cure the trouble, the various items may be replaced until instability is reintroduced, thus indicating where the trouble lies.

Eliminators.—A battery receiver may behave in a perfectly normal manner when used with the usual high-tension batteries but may motor-boat violently if used with an eliminator. This difficulty may sometimes be overcome by connecting a relatively large condenser across the output terminals; otherwise it will be necessary to introduce additional decoupling into the receiver. Twenty years ago battery receivers were designed to work equally well with eliminators, but this manufacturing tendency is fast becoming obsolete, as the low price of the mains receiver has made the battery set with eliminator redundant.

Instability at Very High Frequencies.—Receivers which cover the B.B.C., V.H.F. or any ultra-short wavebands are liable to a number of additional and often obscure causes of instability. Instability at these frequencies can be caused by any of the faults outlined in the foregoing portion of this chapter, but, in addition, there are other likely causes.

The most usual cause of instability is an increase of impedance in one or more of the earth-return circuits; as a routine precaution the fixing of all coil cans should be inspected for oxidisation and tightened up as much as is practicable. Careful inspection should also be made of the appropriate soldered joints, since resistance caused by even slight corrosion may be sufficient to cause violent instability on the ultra-short frequencies. Other points that should receive attention are the valve-pins and switch contacts; another frequent cause of instability is a decoupling condenser that has developed increased impedance owing to oxidisation or corrosion of internal connections.

Frequency Modulation.—Reference has been made to additional causes of instability on the B.B.C., V.H.F. band and it is desirable to mention that this possibility is due to the very high frequency and not because the particular transmission happens to be frequency modulated. Although not relevant to this chapter, it may be interesting to note that while frequency modulation will not normally be the cause of instability in the H.F. and I.F. circuits, it can cause instability in the L.F. part of the receiver if the frequency-amplitude convertor is not correctly balanced.

CHAPTER 6

TRACING DISTORTION

BEFORE actually discussing methods for tracing distortion it is desirable to outline broadly the various causes. There are two distinct types of distortion, frequency distortion and amplitude distortion. Amplitude distortion may be defined as the inevitable consequence of overloading, and may therefore be regarded as harmonic distortion in certain circumstances. Frequency distortion may be defined as the attenuation or accentuation of a particular frequency, a number of particular frequencies, or a band of frequencies.

Amplitude Distortion.—When the input to a valve is too great for the conditions under which it is working, some form of distortion must result. Whether or not it proves objectionable to the listener is dependent on the percentage overload, the stage in which it occurs, and the conditions under which the valve is working ; for example, suppose that the input to an intermediate amplifier is too large, the valve will rectify, either due to the flow of grid current or to the signal encroaching on the curvature near the point when anode current ceases to flow. It is even possible that both conditions exist at the same time. The inevitable result is that the signal is partially detected and passed on to the detector stage in this condition, with the result that the low-frequency waveform appearing in the anode circuit of the detector is not a true replica of the modulation imposed on the incoming carrier-wave. It will, in fact, possess an artificial harmonic content, which is usually almost entirely the second and/or third harmonic.

Extreme amplitude distortion may render speech unintelligible and turn music into a farce. Such conditions, however, are not produced by overloading in the generally accepted sense of the term, but are caused by some fault resulting in a valve working under conditions whereby it can only accommodate a fraction of its normal input, due, perhaps, to a broken resistance interrupting the D.C. path between grid and cathode of a low-frequency amplifier. Later in the chapter further reference is made to amplitude distortion.

Frequency Distortion.—Frequency distortion may occur in any stage of a receiver that is actually handling the received signal, as distinct from an oscillator or some other valve which cannot influence the frequency range. Frequency distortion in radio and intermediate-frequency stages is normally due to loss of sidebands due to sharply tuned circuits, and in the case of bandpass coupled stages to misalignment, resulting in the normal flat-top response-curve taking the form of a peak. Frequency distortion may appear in the detector stage, due to the use of unsuitable values of grid resistance and condenser, or to an improper relationship between the external anode impedance and the anode bypass capacity or, in the case of a diode detector, to the use of an incorrect anode-load bypass condenser. It is desirable to mention that frequency distortion in the detector stage may take the form of either high-note or low-note loss.

The opportunities for introducing frequency distortion in the low-frequency section are very numerous, and it is here that the full meaning of this term is realised; frequency distortion in the detector and pre-detector stages will usually take the form of a more or less gentle attenuation of either or both ends of the audio-frequency range and,

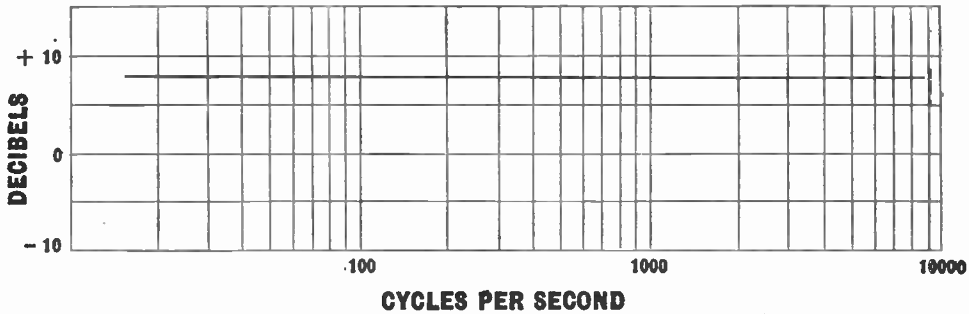


Fig. 25.—A theoretically perfect response-curve; frequency distortion is entirely absent.

although this undoubtedly is frequency distortion, the term is usually used to nepress peaks or troughs in the audio response-curve. Fig. 25 shows an arbitrary response-curve of a radio receiver and represents theoretical perfection. Fig. 26 shows the type of frequency distortion due to attenuation of the high and low audio frequencies. Fig. 27 illustrates the full meaning of the term frequency distortion. An examination of this curve will show that there are a number of peaks and troughs, notably a peak at about 300 cycles, which will result in reception sounding woolly, while there is a very serious trough at about 450 cycles which would rob speech of much of the speaker's individual characteristics. It will also be noted that there is a peak at 100 cycles which will give the receiver a tendency to "boom," and, incidentally, considerably increase the level of mains hum if the receiver is used on 50-cycle mains and employs a full-wave mains rectifier.

Generally speaking, the type of frequency distortion shown at Fig. 26 is associated with some form of inductive coupling, such as a low-frequency transformer or output transformer. It will be appreciated that other forms of coupling cannot readily produce more than two deviations from the average response-curve, but, on the other hand, several sharp deviations at varying frequencies, each occurring in a different coupling, may combine to give a response-curve of the type suggested by Fig. 27.

When considering frequency distortion the loudspeaker calls for special attention, as it is a most prolific cause of this trouble, either due to bad design or subsequently due to a fault, such as a dent in the cone or departure from proper alignment. The response-curve of even a really good moving-coil loudspeaker is suggestive of a range of mountains. At the

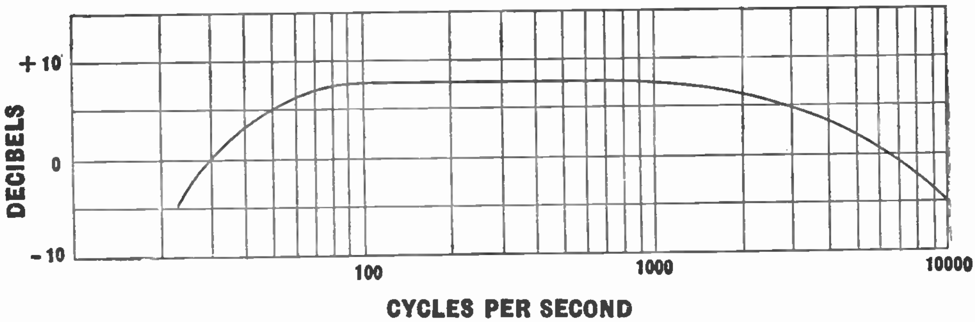


Fig. 26.—A response-curve where frequency distortion takes the form of attenuation at both ends of the audio scale.

present time it would appear that a straight response-curve is virtually impossible, but efforts are directed to keeping the deviation from the mean response-curve to the narrowest possible limits. Good examples of a moving-coil loudspeaker are described as having sensibly linear response between 50 and 6,000 cycles, which may be interpreted as meaning that the response-curve does not deviate at any point within

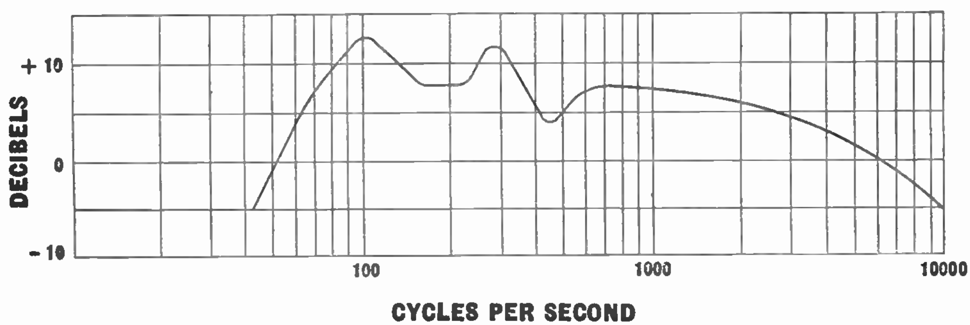


Fig. 27.—A purely imaginary response-curve, showing frequency distortion in the form of peaks and troughs as well as attenuation at both ends of the audio scale.

these limits to an extent greater than, say, 2 decibels either side of the mean response-curve.

The possible faults in a radio receiver which may directly or indirectly cause distortion are very numerous; so numerous, in fact, that the subject is somewhat difficult of approach. Some attempt has been made to classify the possible causes under the headings of the stages in which they occur. In interpreting the foregoing remarks it must be understood that the causes suggested are in the nature of faults arising through breakdown of a component or connection, and it is assumed that the receiver is capable of giving satisfactory reproduction when working in a normal manner.

Radio-frequency Distortion.—Distortion in a radio-frequency stage can occur through two causes, spurious detection and sideband cutting. The unwanted rectification may occur through overload, a condition that can only obtain when the receiver is used very close to a powerful station, or through the grid being open-circuited or held at insufficient negative potential. Sideband cutting may be due to misalignment if the receiver is ganged or, alternatively, if the anode coupling is of the bandpass type sideband cutting may occur through shorted turns in the primary winding or through a broken damping resistance, if one is employed.

Distortion in the Frequency-changing Stage.—Probably the most prolific cause of distortion in the frequency-changing stage is misalignment of the intermediate-frequency transformer, particularly if it is so designed that its response-curve is fairly sharp. Other causes are shorted turns in the winding, and if an iron core is used, the possibility of a fracture here must not be overlooked. The frequency changer can also introduce distortion if its grid is open-circuited or without adequate negative bias. Certain types of frequency changers are prone to introduce distortion of an inherent nature; this does not therefore come within the scope of this chapter, which is devoted to faults appearing subsequent to manufacture.

Distortion in the Intermediate-frequency Amplifier.—This stage is equally susceptible to sideband cutting in the tuned circuit, the causes being exactly the same as those described for the frequency changer, above. The remarks relating to the possibility of the grid being open-circuited are also applicable. There are, however, one or two other possibilities. Distortion may occur in this stage due to overload, a condition which may be caused by the actual amplitude of the input or to the grid being held at a negative potential which is either too high or too low, resulting in spurious anode bend or grid detection; unless the low-frequency gain is considerable, the intermediate-frequency amplifier will be required to handle a fairly large input, and, when tuned to the local station, the bias applied to the valve may be very considerable, owing to the action of automatic volume control. It may well be that distortion from this cause is not apparent under normal conditions, but may prove very noticeable if the valve loses emission through age or shortens its grid base for any other reason, such as reduced anode voltage arising from a fault in the power pack or reduced screen voltage caused by an increase in the value of the screen-feed resistance. Some types of resistances are inclined to increase their value to a surprising extent after a period of some years.

Distortion in the Detector.—It will be convenient to further sub-divide this section to cover the leaky grid detector, the diode detector, and the anode-bend detector. Distortion in the diode detector may be due to the diode load resistance being open-circuited, or a leak between cathode and anode permitting current to pass in both directions. Although the whole question of valve faults is dealt with in a separate chapter, it may be mentioned here that the leak may take the form of hot leak, that is to say, the insulation may be irreproachable if the valve is measured when cold, but may show relatively low resistance when the cathode is raised to working temperature. There is also a remote possibility that distortion may be due to the diode being soft ; such a condition, however, is extremely unlikely, as the valve will not readily ionise, owing to the absence of sufficient potential difference between the electrodes.

Distortion in the leaky grid detector may be caused by any of the faults in the valve mentioned in the above paragraph dealing with the diode, or to the grid being open-circuited. Faults peculiar to the leaky grid detector include lost emission, softness of the valve, or grid emission, all of which can be easily checked by substituting the valve. Distortion in the anode circuit is only likely to arise from two causes, shorted turns in the primary of the low-frequency transformer, if this type of coupling is used, or to the anode bypass condenser being open-circuited. There is, however, an indirect cause of distortion, and that is the use of excessive reaction made necessary by loss of gain in the stage itself, due to lost emission of the cathode, grid emission, or other causes.

Distortion in the anode-bend detector is considerable when the valve is functioning normally, but additional distortion may be caused by either the application of incorrect bias or a change in the valve characteristics through age requiring bias to be deliberately varied. If transformer coupling is used, distortion may be introduced by shorted turns. The remarks relating to the anode bypass condenser and the excessive use of reaction outlined in the previous paragraph are equally applicable to this type of detector.

The Low-frequency Amplifier.—Distortion in the low-frequency amplifier may be caused by a fault in the valve itself, an open-grid circuit, the application of incorrect grid bias due to, say, a short circuit in the bias bypass condenser, or to a leak in the coupling condenser, if resistance-capacity coupling precedes the stage in question. A leak in the coupling condenser may be difficult to trace. For example, if the grid leak has a value of 1 megohm, and the high-tension voltage applied to the previous valve is 200 volts, it follows that the leak in the condenser equal to 100 megohms will drive the amplifier grid about 2 volts in the positive direction, which may well cause the valve to run into serious grid current when handling relatively large input. It should be noted that condensers may register infinity when tested with a relatively low potential across the plates, but may show a leak when the working voltage is applied.

Distortion in the Output Stage.—Distortion in the output stage may arise from any of the causes mentioned in the previous section, but in nine cases out of ten it is attributable to softness or low emission of the output valve. The output valve usually passes a high anode current, and in the case of a pentode the working temperature of the electrode may be high. These two causes are liable to cause softness and low emission respectively. The possibility of shorted turns in the primary of the output transformer must not be overlooked, while due attention must be paid to the possibility of low anode current in the case of a pentode due to low screen voltage.

Distortion in the Loudspeaker.—There are a number of faults which may cause distortion in the loudspeaker, many of which are of a mechanical nature; various forms of buzzing and rattling may be caused by the speech-coil being out of centre or becoming distorted in shape due to the warping effect of excessive heat. It is comparatively common for this type of distortion to appear when the receiver has been working for an hour or more, which is the time necessary for the internal temperature of the set to rise to that point where the speech-coil becomes warped.

In the case of the mains-energised speaker, the possibility of shorted turns in the field coil is often overlooked but, nevertheless, is a likely source of trouble. The energising current should always be checked; if this falls below the minimum value required to energise the speaker, distortion will be caused to a greater or lesser degree.

Quite apart from the speech-coil being out of centre, it may be out of position in the direction in which it moves, that is to say, it may be too far within the pole pieces or too far out, due to the spider not being flat when at rest, the surround having become distorted in shape. A word of warning may not be out of place at this juncture regarding the re-alignment of loudspeaker cones and spiders, which require a certain amount of experience in order to find the position which will allow the greatest movement of the coil without fouling the pole pieces.

Automatic Volume Control Distortion.—Distortion, arising through a fault in the automatic volume control line, may be due to the development of an inadequate or excessive negative voltage. Excessive voltage may be due to a short between the electrodes, as already intimated under another heading, or to a leak between the diode anode and the high-tension circuit of the preceding valve. Failure of the system to produce an adequate bias voltage may be due to a short between cathode and anode in the valve, or a short in one of the decoupling condensers. In certain circumstances this may result in seriously reducing the bias voltage applied to all valves, even though the faulty condenser is primarily associated with a single stage. Low negative voltage may possibly be due to low emission, but this is rare in a diode valve.

Distortion in Inter-station Noise-suppression Circuit.—The wide variety of circuits and principles used for quiet automatic volume control are so numerous that it is impossible to deal with the subject in detail. All faults in this section, however, are due to some failure which results in the circuit requiring an abnormally large signal voltage to unlock it; in other words, the suppressor arrangements are functioning to a certain extent when a signal of normal amplitude is being reproduced by the loud-speaker.

Distortion caused by Station Indicators.—The various forms of station indicators are very numerous, and the majority of them cannot conceivably introduce distortion. There are, however, one or two types which may be responsible for trouble of this nature. The neon tuning indicator may under certain conditions of gas pressure introduce a type of high-frequency motor-boating which gives the impression of distortion. It is, however, a very simple matter to check this possibility, as the device is removable with the same ease as a valve. The magic-eye type of tuning indicator may on rare occasions become soft, when it will introduce distortion if it is connected to the detector diode. It may also cause distortion if connected to the automatic volume control diode by upsetting the function of this circuit, but, generally speaking, the value of the decoupling resistance is high enough to preclude this possibility. The diminishing light indicator and the mechanical types are not likely to introduce distortion unless they do so by virtue of a short circuit which reduces the potential applied to one of the valves.

General Notes.—When tracing distortion it is advisable to eliminate as many possibilities as convenience will allow; for example, it is a simple matter, if the necessary material is available, to temporarily replace all valves, and in the case of battery receivers the several batteries. Most receivers are provided with extension-speaker terminals, and in this manner a spare loudspeaker may be connected, to eliminate the possibility of a loudspeaker fault. Such accessories as tuning indicators can be easily removed if of the plug-in type. The more complicated type of receiver using such devices as inter-station noise suppression and automatic-frequency control require special attention in this direction, as these particular sections may well be responsible for distortion. Generally speaking, they may be put out of action by removing the appropriate valve. For example, the valves in the auxiliary intermediate amplifier, discriminator, and oscillator control circuits can be removed from most receivers that are so equipped without affecting the normal functioning of the main circuit. It is obvious that if substitution of a component brings about a cure, then the cause must be the component in question, or that part of the circuit that is closely associated with it.

Short-wave Receivers.—Reception on the short wavebands is subject to certain forms of distortion due to natural causes, but which give the audible impression of a fault in the receiver. The phenomenon of high-speed fading causes reception to sound as though a low-frequency valve has an open grid circuit or, alternatively, is over-biased; due to the action of the automatic volume control, high-speed fading brings about a corresponding rise and fall of background noise, which tends to make the actual fading less obvious.

Relatively rapid selective fading often occurs on the short wavebands and can also be mistaken for distortion. It is simple to distinguish between distortion and the effects of fading, since distortion must occur on all wavebands unless the fault is in a radio-frequency circuit, where it is highly improbable that distortion could be produced on any but a very powerful signal.

Frequency-modulated Receivers.—There is a form of distortion peculiar to frequency modulation which directs suspicion to the receiver but which in fact is due to an external cause called multipath distortion. A transmission at very high frequency is easily reflected by large objects such as gasometers and large buildings, with the result that the signal is received from reflected as well as direct sources each taking a path of different length so that minute time differences exist. The same thing can happen with an amplitude modulated signal, but little distortion is caused; with frequency modulation, however, distortion can be very serious.

Distortion within the receiver can be due to many causes, but the most common is frequency drift and the presence of a form of amplitude modulation detection due to unbalance in the frequency-amplitude convertor, see note on page 96 of Volume III.

CHAPTER 7

TRACING MAINS HUM

THERE are numerous possible causes of mains hum arising through a break-down in one of the very numerous components in a modern receiver. Generally speaking, location of the faulty component is comparatively simple if an adequate supply of valves, condensers, and other items is to hand. The converse applies if the trouble has to be located without these aids. Probably the most common cause of hum is faulty insulation between the cathode and heater of a valve. Such a fault is obviously detected with a minimum of trouble if the valves are replaced and the hum-level is then found to be normal. When a suitable set of valves is not available, it is extremely difficult to determine that a valve is at fault or to test the valve which is suspected, unless suitable test instruments are available.

Before undertaking to find the cause of abnormal hum-level it is desirable to ascertain that such a fault really exists, as the apparent hum-level may well be increased by moving the receiver to a different posit on in the room. For example, the receiver might stand in a position where it is backed by sound-absorbing material, such as tapestry or curtains, and under these conditions have a given and acceptable hum-level, but when moved to another position in the room, where it is backed by, say, glass windows, then the apparent hum-level may increase to a marked degree. It should also be noted that the low-note distribution from the average loudspeaker is very uneven, and it will be found that certain points at varying angles from the cone will produce widely varying sound-levels. A receiver may come under suspicion, not because it has developed a fault, but because the listener, who is accustomed to sitting at a particular place in relation to the receiver, has chosen to sit elsewhere.

A fault resulting in an increase in the mains hum-level may occur in one of several clearly defined sections of the receiver, and it will be convenient, therefore, to deal with the subject under these headings, which will present the various tests in a practical manner and at the same time draw attention to the manner in which the trouble can be isolated.

A Fault in the Power Pack.—This particular section will include the mains transformer, rectifier valve, smoothing condensers (which will include that condenser which is usually called the reservoir condenser), and the smoothing choke or chokes (which may take the form of the loudspeaker field coil). Dealing with these items in order, attention is naturally directed to the mains transformer. This component is capable of introducing a particular fault known as mechanical, or lamination hum. As its name suggests, the trouble is caused by one or more of the laminations becoming capable of movement due, possibly, to the dislocation of a fragment of pitch or movement of the winding bobbin releasing or varying the pressure exerted on the laminations. When a lamination is free to move it will vibrate in sympathy with the mains frequency, making a direct mechanical hum and usually introducing an electrical hum. The correct method of securing the loose lamination is by tightening the clamping bolts or, if this proves ineffective, by dismantling and re-assembling. There is, however, a quicker and usually quite effective method, and that is by denting the end of the lamination with a sharp instrument and a hammer so that the dents wedge it firmly between its neighbours.

Faults of a purely electrical nature include a short between turns and a short between a winding and core; the latter can be readily determined by connecting a suitable measuring instrument in the earth lead and noting the result. It can also be determined in most cases by measuring the resistance between each winding and the core. Shorted turns are also fairly easy to detect, as mains hum is only likely to be introduced when a sufficiently large section is shorted to throw the centre tap out of the electrical centre, and a simple A.C. voltage measurement between the centre tap and each outer end will show whether approximately equal voltage is being developed.

The Rectifier Valve.—A single-wave rectifier valve is unlikely to introduce mains hum, but several possibilities occur in the case of the full-wave rectifier, the most common of which is failure of the half-filament associated with one of the two anodes. Failure of the filament will reduce the smoothed voltage by a surprisingly small extent, but will result in the mains hum having a frequency similar to the mains periodicity; that is to say, on a 50-cycle mains the hum will be of the same frequency instead of double; this change may well increase the mains hum very considerably, as the reactance of the smoothing condensers will be exactly doubled. In addition, this fault may cause hum through other circumstances, but the apparent result is the same.

Smoothing Condensers.—Smoothing condensers are at least as prone to break-down as any other component in the power pack. The paper dielectric condenser can become short-circuited or open-circuited. In the former condition the smoothed high-tension voltage becomes so reduced that the fault is noticeable in other ways, but in the case of open-circuit the resulting trouble is usually mains hum alone; it can be easily detected by temporarily connecting another condenser of suitable capacity in parallel.

The electrolytic condenser has faults peculiar to its type, and often loses its effective capacity until, after a suitable lapse of time, it becomes useless as a condenser. This type of fault can often be checked by connecting a condenser of suitable capacity in parallel. This temporary condenser may be of either the paper dielectric or electrolytic type. Some care is required, however, as the electrolytic condenser may develop a leak that is serious enough to cause mains hum indirectly due to the reduction in its effective capacity, but at the same time the leak may not be sufficiently serious to affect the receiver in other ways. It is therefore desirable to make a practice of substituting electrolytic condensers instead of connecting a temporary condenser in parallel. It is, of course, essential when using a temporary condenser to make sure that it is capable of withstanding the voltage to which it will be subjected.

A Peculiar A.C./D.C. Fault.—A most peculiar condenser fault is prone to occur in universal receivers which have been used on direct current for a considerable period and then used on alternating current. For some reason that has never been satisfactorily explained, so far as the author is aware, an electrolytic condenser that has worked satisfactorily during the service of the receiver on direct current will break down at the moment of switching on when the receiver is used on alternating current. An extraordinary aspect of this fault is that the same receiver will give general satisfaction if it is always used on alternating-current mains.

The particular condenser affected in this way is invariably the reservoir condenser, and most experienced service engineers immediately test this component when a receiver is brought for service that has worked satisfactorily on direct current but failed on alternating current. An explanation that is occasionally put forward is that the condenser has been faulty for some time, but the owner has not been aware of it as it is practically a " passenger " when the receiver is used on direct current. This explanation is not a true one, as the condenser is invariably found to be leaking so badly that the high-tension voltage is seriously reduced; which cannot fail to pass unnoticed on a universal receiver where the high-tension voltage is necessarily of a low order even when conditions are normal.

Testing Condensers.—The paper type of condenser may be tested by disconnecting it and charging it from a convenient direct-current source such as a high-tension battery; if the condenser is normal it will hold the charge for some considerable time and a spark will be noted if the terminals are shorted by a piece of wire or a screw-driver. It is difficult to suggest any definite time-limit, but a condenser having a capacity of 1 μF or more and charged at a potential of some 100/200 volts should show a very noticeable spark when discharged after a waiting period of about five minutes. Some of the special high-voltage paper condensers used in television receivers and elsewhere will retain a charge for a very long period. The author has received a very unpleasant shock from such a condenser more than forty-eight hours after disconnection from the mains.

Electrolytic condensers cannot be tested in the same manner as paper condensers, as they have a small permanent leakage which can, however, be measured by means of a milliammeter connected in series with the condenser across a suitable *direct-current* supply. Here, again, it is impossible to suggest any hard-and-fast rules, but the average type of condenser rated at 250 volts working has a leakage of about ·07 milliampère per microfarad when new, a figure which may be exceeded by about three times before serious thought need be given to the necessity for replacement.

Smoothing Chokes.—A short circuit between turns in a smoothing choke is not as uncommon as might be supposed. A short circuit affecting a comparatively small portion of the choke may in certain circumstances bring about a disproportionately large decrease in inductance. Such faults are very easy to locate by means of an ohmmeter, providing the normal ohmic value is known, otherwise the fault is difficult to determine, unless it becomes apparent due to the component smoking or discolouring or becoming sufficiently hot to make the temperature-rise apparent and quite distinct from the normal working temperature. The field coil of a mains-energised loudspeaker often serves as the main smoothing choke and is more prone to shorting turns than the normal iron-cored choke. This tendency is due to the wire being somewhat enclosed by the magnet, resulting in the normal working temperature being higher than that experienced with the iron-cored choke. If the number of shorted turns is sufficiently large the sensitivity of the speaker will fall off very considerably and attention will thus be drawn to the loudspeaker ; otherwise attention may well be focused on this component due to abnormal working temperature, which is liable to be very apparent owing to the enclosed nature of the structure.

Hum in the Loudspeaker.—The main cause of hum arising in the loudspeaker has necessarily been dealt with in the previous paragraph, but attention is drawn to the fact that shorted turns may, in certain circumstances, cause hum, even though the field winding does not form part of the smoothing system.

There is one other possibility in the loudspeaker, and that is a short circuit in the humbucking coil, which will obviously raise the hum-level to that which would obtain if such a device were not used or to such an amount as may result from only a portion of the coil being shorted. When the field coil is used as a smoothing choke, the possibility of a leakage between the field coil and humbucking coil must not be entirely overlooked, although it is highly improbable with modern types of loudspeaker.

Hum due to Valves.—Reference has already been made to the possibility of hum being caused by defective valves, due to faulty insulation between cathode and heater. Often such a fault may be detected with the use of an ohmmeter used to measure the resistance between heater and cathode. When a low reading is obtained, say, below 10,000 ohms, the valve may be confidently suspected, but if a high reading is obtained the test is not conclusive, because a different resistance may obtain under working conditions due to the expansion of the heater when warm. Another possibility is an internal leakage between heater and grid, but here again the fault may not be present when the valve is cold. The method of testing valves under conditions approximating to those obtained in a receiver are dealt with in the chapter devoted to valve testing.

Modulation Hum.—Modulation hum has been defined elsewhere in this work, but is repeated for convenience. It is a type of hum which *only* becomes noticeable when the receiver is tuned to a station. It may arise through alternating current appearing between the grid/cathode circuit of any pre-detector valve due to one or more of the following causes: (1) Faulty insulation between cathode and heater of the detector valve or one of the pre-detector valves. (2) A reduction in the effective smoothing of the high-tension supply to the pre-detector valves. This may take the form of a fault in the power pack or, alternatively, to a decoupling condenser becoming open-circuited. It will be understood that decoupling forms an important addition to the smoothing of the high-tension supply of the valve so equipped. (3) High frequencies finding their way into the power pack due to a condenser being open-circuited, that is, associated with some high-frequency stopping device or, alternatively, mains pick-up from the local station feeding through the mains transformer into thepower pack. This may be due to the screen between the mains transformer core and primary becoming disconnected from earth or a filter condenser becoming open-circuited. (4) Accidental rectification of any pre-detector valve, resulting in cross modulation between the signal or other high frequency and the mains frequency. Such rectification may be due to a valve working without bias, brought about by a short circuit of the bias resistance or condenser; alternatively, rectification may be due to a fault in the automatic volume control circuit resulting in one or more of the pre-detector valves being either under-biased or over-biased.

Mains Hum (Gramophone Reproduction only).—Hum arising when reproducing gramophone records, but not when using the instrument for radio reproduction, may be due to a number of causes, three of which may be treated in a general manner. The most common cause is a disconnection between the screening of one of the pick-up leads and earth. The same remarks apply equally to a disconnection between the metal casing of the pick-up and earth.

The other two possibilities are: (1) a break in the pick-up windings; in this case the mains hum will almost certainly be supplemented by a whistle and distortion arising from the grid of the first amplifier being open-circuited and (2) disconnection between the gramophone-motor frame and earth. This possibility is a rather comprehensive one, as with some types of motor various portions of the framework may cease to be in electrical contact with the mains framework (and consequently in contact with earth) due to the percolation of oil under the heads of fixing bolts and similar places.

Reducing Permanent Hum.—Occasions may arise when it is desired to reduce the *normal* hum-level of the receiver ; where possible, steps should be taken to ascertain if the general hum-level is made up largely from a particular source, but, in general, the use of additional smoothing condensers in parallel with the existing ones will bring about some reduction. If the loudspeaker is of the mains-energised type and does not employ a humbucking coil, temporary use should be made of a permanent-magnet type to ascertain the amount of hum that may be attributed to the loudspeaker ; if this test warrants such a course, the loudspeaker may be replaced with a more efficient type.

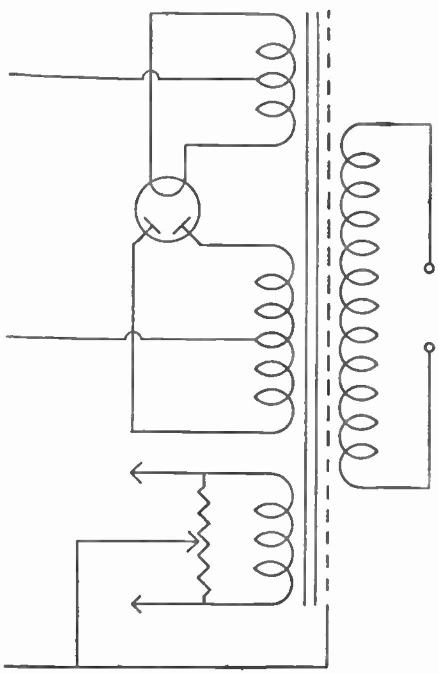


Fig. 28.—Showing the connection of a potentiometer across the heater winding to form a hum-dinger.

A hum-dinger may be tried experimentally, as it is quite problematic whether it will be of real assistance. Fig. 28 shows the usual hum-dinger arrangement, which consists of removing the centre tap of the heater transformer and connecting it to the centre of a potentiometer which is connected across the outer ends of the winding ; the potentiometer will normally have a resistance of about 25 ohms, and it is adjusted for minimum hum. When two or more heater windings are used, each may be treated separately with its independent hum-dinger.

The possibilities of reducing the hum-level are exceedingly numerous, the majority being applicable to some particular circuit arrangement. There is, however, one other suggestion of a general nature which applies only to receivers using a directly heated output valve. Directly heated valves of the 4-volt type unavoidably introduce a certain amount of hum, due to half the potential across the filament appearing as a potential difference between the grid and filament. If the valve is of the popular triode type dissipating between 10 and 12 watts, it may be thought worth while to substitute a new filament transformer designed to give an output of 2 volts at 2 ampères for each valve used and replace the 4-volt valves by 2-volt valves, which will automatically halve the A.C. potential between grid and filament, since the potential difference across the filament itself is also halved. In the unlikely event of a directly heated output valve being supplied by the same heater-winding as that used for the indirectly heated valves, it will almost certainly be possible to reduce the hum-level by arranging a separate filament transformer for the output stage.

CHAPTER 8

TRACING BACKGROUND NOISE

BACKGROUND noise may be roughly defined as sounds emanating from the loudspeaker from causes other than a transmitted radio signal. Background noise can arise from three main causes : firstly, interference from electrical machinery in the neighbourhood, which falls outside the scope of this chapter ; secondly, interference arising within the receiver due to a broken or intermittent connection ; and thirdly, a condition whereby a fault in the receiver increases the pick-up of electrical interference in the neighbourhood. It will be convenient to deal with the second category first.

The possible faults that may cause interference within the receiver are very numerous. An experienced radio engineer can sometimes reduce the possibilities by listening to the particular type of background noise ; that is to say, intermittent crackling, continuous crackling, occasional " bangs," and so on. Unfortunately it is quite impossible to convey in print the various distinctive sounds, therefore attention must be directed to the causes, many of which suggest in themselves the type of background noise that may be expected.

Noisy Valves.—Suspicion usually falls on the valves in the first instance, and this course is probably justified, particularly if they have seen a reasonable period of service; the modern valve of the indirectly heated type ends its useful life through becoming noisy more frequently than through any other single cause. When possible, the complete team of valves should be substituted for others that are known to be satisfactory ; alternatively, the valves in the suspected team can be tried in another receiver. These methods, while entirely satisfactory, call for a set of duplicate valves or a similar receiver, either of which will not always be avafilable, and recourse must be made to other methods. A noisy valve will oten betray itself if continuously struck with reasonable force when actualy working, by causing a pronounced uproar in the loudspeaker due to the impact. Some care is, needed, however, as the impact imparted to the valve may shake or move some other component or connection and result in a mistaken conclusion. If the receiver is of the universal type or of the direct-current type, the valve must not be struck with the fingers if it is of the metallised type, owing to the danger of electric shock.

When a valve tester is available the valve may be plugged in in the usual way and subjected to a certain amount of rough treatment to ascertain whether a sharp tap will bring about a change of anode current. This test is, however, not always conclusive, as it will seldom reveal a leak along the pinch due to a deposit of the electron-emitting material or particles of magnesium from the "getter."

A very frequent cause of background noise is loose and dirty connections between the valve-pins and sockets. The former are comparatively easy to clean by means of a fine emery cloth or by use of a suitable cleaning solution which does not leave a film of grease, *i.e.* carbon tetrachloride, or one of the proprietary solutions sold expressly for the purpose of cleaning electrical contacts ; the sockets are not so readily acctessible, but they may be cleaned by means of a piece of fine emery clonh wrapped round a piece of stiff wire or by the use of one of the above-mentioned solutions applied with a match-stick. Modern valves are fitted with the so-called banana pins, which may be slightly opened by the careful application of a pen-knife, to ensure good contact. The alternative type of split pin may be opened by simply passing the blade of a knife between the prongs.

Noise may sometimes arise through the metal coating of a metallised valve making bad contact with the wire connecting it to the appropriate pin. This may be checked by wrapping several turns of wire tightly round the metallised coating and connecting it direct to the appropriate pin ; connection cannot be made to the chassis if the valve uses a bias resistor, as this would be shorted out. When binding the wire tightly round the bulb, care should be taken not to break the glass, which is often much weaker than might be supposed. For this reason it is desirable to bind the wire close to the base.

Bad Contacts.—Another very prevalent source of background noise is a bad connection in the actual wiring of the receiver or in one of the components. If the bad contact is due to looseness, it can be detected by testing the joints with the fingers, and presents no difficulty for those joints which are accessible. It is equally possible that a bad connection may exist inside one of the components, and it is obviously impossible to dismantle every component and examine it ; fortunately this is unnecessary, as those components which carry current can be tested for bad internal connections by means of a voltmeter connected between suitable points if there is enough resistance present to produce an adequate reading or otherwise by the use of an ohmmeter. This remark will not apply to such items as tuning coils which are not carrying D.C., but these can be tested by temporarily short circuiting them, commencing from the aerial coil and working progressively through to the detector. Naturally, this procedure will stop the signal, but this is not usually important, as the crackling may be expected to continue unabated or in certain cases show a marked increase due to the action of the automatic volume control.

In the more elaborate type of receiver it may be desirable to take steps to isolate the fault, in order that attention can be concentrated on the smallest number of components or connections. The exact procedure must vary with different circuits, but the following suggested sequence of operations will serve as an example based on a 6-valve superheterodyne receiver for alternating-current mains having the following stages: (1) radio-frequency amplifier, (2) frequency changer, (3) intermediate-frequency amplifier, (4) double diode triode, (5) directly heated triode output, and (6) mains rectifier. First of all remove aerial and earth and note that the crackling continues without the signal; it is then possible to isolate the radio-frequency amplifier by breaking the connection between the anode circuit of the first valve and the grid circuit of the second valve, care being taken that in so doing the grid circuit of the second valve is not left open. The next stage, the frequency changer, can be isolated in the same manner, preferably by positively short circuiting the secondary of the intermediate transformer connected in its anode circuit; this will effectively prevent any input from this stage to the intermediate-frequency amplifier and will not leave the grid circuit of the latter open, which would result from any form of disconnection. The possibility of noise arising in the intermediate-frequency amplifier can now be checked by putting the detector out of action, which may be conveniently accomplished by short circuiting the diode load. The whole automatic volume control circuit can then be tested by short circuiting the load resistance of the appropriate diode. If the background noise still persists, it is apparently in the low-frequency section of the receiver, and several alternative procedures are possible. When headphones are available these may be connected across the anode resistance of the double diode triode, and if the offending noise is not heard it must be in the output stage or power pack. If headphones are not available, the grid of the triode section may be shorted to the chassis, and if the noise still persists the output stage and the power pack alone remain under suspicion.

No practical means presents itself for separating the output stage from the power pack, but the remaining components are comparatively few, and by narrowing the fault down to this comparatively small section a great deal of unnecessary work will be avoided, and it is doubtful whether any advantage would be gained by isolating any small sections, with the possible exception of the loudspeaker. This may be checked by connecting a permanent-magnet type in series with the built-in speaker, and shorting the primary of the built-in speaker (see Fig. 29). If the field coil is intermittent, this possibility will have been suspected when the double diode triode was put out of action due to a marked decrease in the volume of the background noise. As an additional check a voltmeter may be connected across the field coil, when any intermittent connection will produce a fluctuating voltage. It might be thought that an intermittent short circuit between a comparatively small number of turns would introduce noise into every stage of the receiver, but this is not so, since the last magnetically coupled H.F. stage will act as a barrier unless the noise is being passed from stage to stage in the form of cross modulation, but here again this is impossible with the aerial disconnected, owing to the absence of a suitable-carrier frequency.

Cross Modulation.—It may so happen that the crackling or other noise ceases to appear when the aerial is disconnected. This is often suggested as proof that the cause is external interference, but with the right set of circumstances this may be a wrong conclusion. It is quite possible for noise to appear due to, say, a leaky condenser in an early stage, and be passed on to subsequent stages through magnetic couplings by cross modulation; in other words, the crackling is modulated on the incoming carrier-frequency, and consequently disappears when the carrier-frequency is removed on the aerial being disconnected. Cross modulation will occur when a radio-frequency or intermediate-frequency valve is overloaded, consequently the test should be carried out when the receiver is tuned to a station that is known to be received in the district at low strength. This will prevent cross modulation due to signal overload, and cross modulation due to excessive bias supplied by the automatic volume control circuit when influenced by a powerful signal. The possibility of cross modulation due to under-biasing is virtually ruled out, because such a condition would introduce very noticeable distortion. It is, however, a simple matter to test the bias by means of a voltmeter applied between grid and cathode in the case of a mains valve, and grid and L.T. negative or chassis in the case of a battery valve.

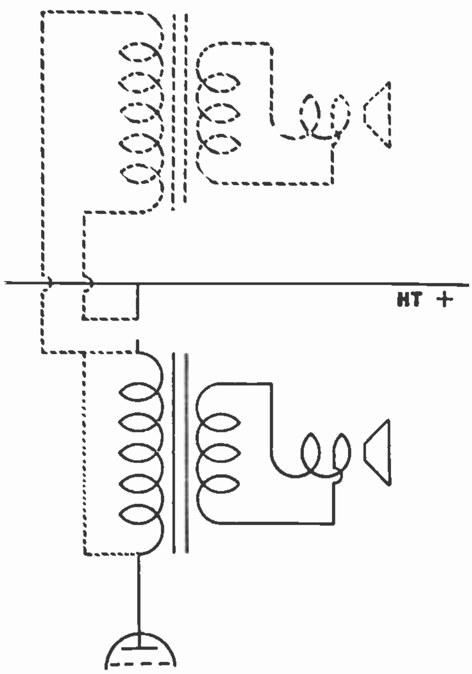


Fig. 29.—This diagram shows (dotted) the temporary connection of a loudspeaker as a means of checking the original speaker.

The foregoing remarks outline a suggested procedure for isolating that section of the receiver in which the background noise arises, and the next step will be to test the several components which are included in the section. A general indication for testing some types of components has already been touched upon; the subject of component testing is dealt with in Chapter 13 of this volume. It will be recollected that noise was placed in three groups in the opening paragraph of this chapter, and attention can now be directed to the third group, namely, the condition whereby a fault in the receiver increases the pick-up of electrical interference in the neighbourhood.

Such a fault must necessarily be of such a nature that the gain of broadcast signals is reduced, while at the same time the gain of other types of received energy is more or less unaffected. It is perhaps necessary to mention that the usual type of interference radiated by electrical machinery does not possess a fundamental frequency, and is therefore sometimes referred to as untuned interference, a colloquialism that is as technically incorrect as it is expressive. Such a fault can only exist in one or more of the tuned circuits, and may be due to the disconnection of capacity from one of the tuned circuits or misalignment. If the variable condenser becomes disconnected from its associated coil, then the latter will function as a high-frequency choke and the magnification previously given by the circuit will be lost; thus the following valve will amplify both the wanted signal and stray background noise equally, whereas under normal conditions the magnification of the tuned circuit would be added to the gain of the valve on the wanted frequency, but the background noise would be amplified by the valve only.

An increase in background noise by misalignment is due to the fact that the mistuned circuit or circuits will attenuate the required signal but make little or no difference to the background noise; thus the signal to noise ratio will be reduced, and, since the manual volume control will be turned up so that the signal is at the required volume level, the actual background noise will be proportionately increased (see Fig. 30). Misalignment in the radio-frequency stages will have to be fairly serious if the background noise is to be noticeably increased, but the converse applies if the intermediate-frequency transformers are out of alignment or, alternatively, if the oscillator circuit is out of alignment, resulting in the intermediate frequency being different from the frequency to which the couplings are tuned.

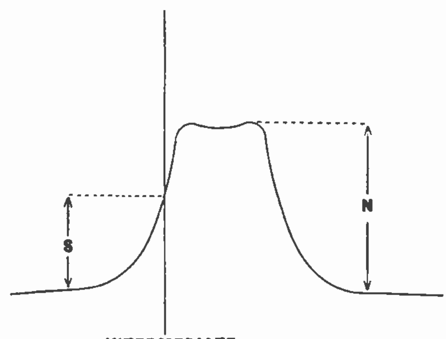


Fig. 30.—An exaggerated drawing, showing the decrease of signal to noise ratio resulting from misalignment. N represents the response to noise and S the response to the signal.

It is obvious that misalignment in the intermediate-frequency amplifier will increase background noise more or less proportionately over all wavebands. On the other hand, misalignment in the radio-frequency or oscillator stage will normally be restricted to a single waveband unless the receiver has been tampered with, since it is unreasonable to assume that the several wavebands should become misadjusted at the same time. It may be noted that the incorrect setting of a trimmer associated with the radio-frequency circuits will result in the background noise at the high-frequency end of the waveband being much more pronounced than at the other end, since a small change of capacity will have considerable influence at the bottom of the scale and practically negligible influence at the top of the scale. The same remarks apply to the trimming condenser associated with the oscillator, but if the misalignment is in the oscillator padding condenser, then interference will be normal at both ends of the waveband and approximately at the centre, but background noise will increase very considerably between these points.

Iron Cores.—In exceptional circumstances a mechanical fracture in an iron core can cause a type of noise that may be described as being similar to valve hiss. Presumably this phenomenon is due to small random changes of inductance causing corresponding changes of sensitivity by varying the resonant frequency of the associated tuned circuit.

Causes Peculiar to Frequency Modulation.—Background noise arising in the receiver is amplitude modulated and is, therefore, rejected by the frequency-amplitude convertor and the basic feature of the system is freedom from external "man-made static", but this freedom will not be realised if the input signal is not big enough : one of the first signs of inadequate signal input is interference from motor-car ignition systems ; the cure is a better aerial, comments on which may be found in Volume I, page 250.

CHAPTER 9

VALVE TESTING

VALVE testing forms a most important part of service engineering, since when tracing faults in a receiver it is almost essential that the valves should be above suspicion before serious work is commenced. Admittedly, the most satisfactory procedure is to substitute the valves in the set being tested for another team that are known to be satisfactory, but this procedure will not usually be possible, particularly as there are upwards of 2,000 different valves on the British market, and the use of a valve of similar type, but different manufacture, is not always satisfactory. It is apparent that for general purposes some means must be available for testing practically any type of valve if serious service work is undertaken. Valve testing appears to be screened by a veil of mystery, but there is no reason why this should be, as it is a comparatively simple procedure, although it is made somewhat elaborate by the large number of valve types available and by the diversity of pin-connection combinations used on valves which are in other ways similar. There are a number of different characteristic measurements and tests, and it will be convenient to deal with each separately. The measurement of certain of the characteristics is touched upon in the chapter dealing with the principles of the thermionic valve, but they are repeated below, as practice requires a slightly different viewpoint from principles.

Mutual Conductance (Slope).—The measurement of slope is the logical beginning when testing a valve, because if the figure obtained is inadequate, then further tests are unnecessary, as the valve is obviously incapable of giving a satisfactory performance. It might be thought that the logical commencement is to note that the filament or heater is not open-circuited and that anode current is flowing; this is, however, unnecessary, as the slope test automatically takes these factors into account indirectly, unless it is desired to find the reason for failure as distinct from the more direct question of whether or not the valve is fit for use.

It will be remembered that slope is measured by changing the grid potential and noting the anode-current change. In order to obtain a direct reading it is convenient to change the grid potential by 1 volt, which will give a direct reading in milliampères per volt; thus, if the grid potential is raised from 0 to 1 volt negative and the anode current is decreased by 3 milliampères, then the slope is 3mA/V. The conventional arrangement for measuring simple characteristics is shown at Fig. 31, the valve chosen for this example being a pentode. It will be noted that both anode and auxiliary grid voltage can be read directly from the voltmeters provided, the potential being varied by manipulation of the appropriate potentiometer. The grid potential is obtained by the drop across a potentiometer in the high-tension negative lead, and once again a voltmeter is provided to give direct reading. When using the arrange-

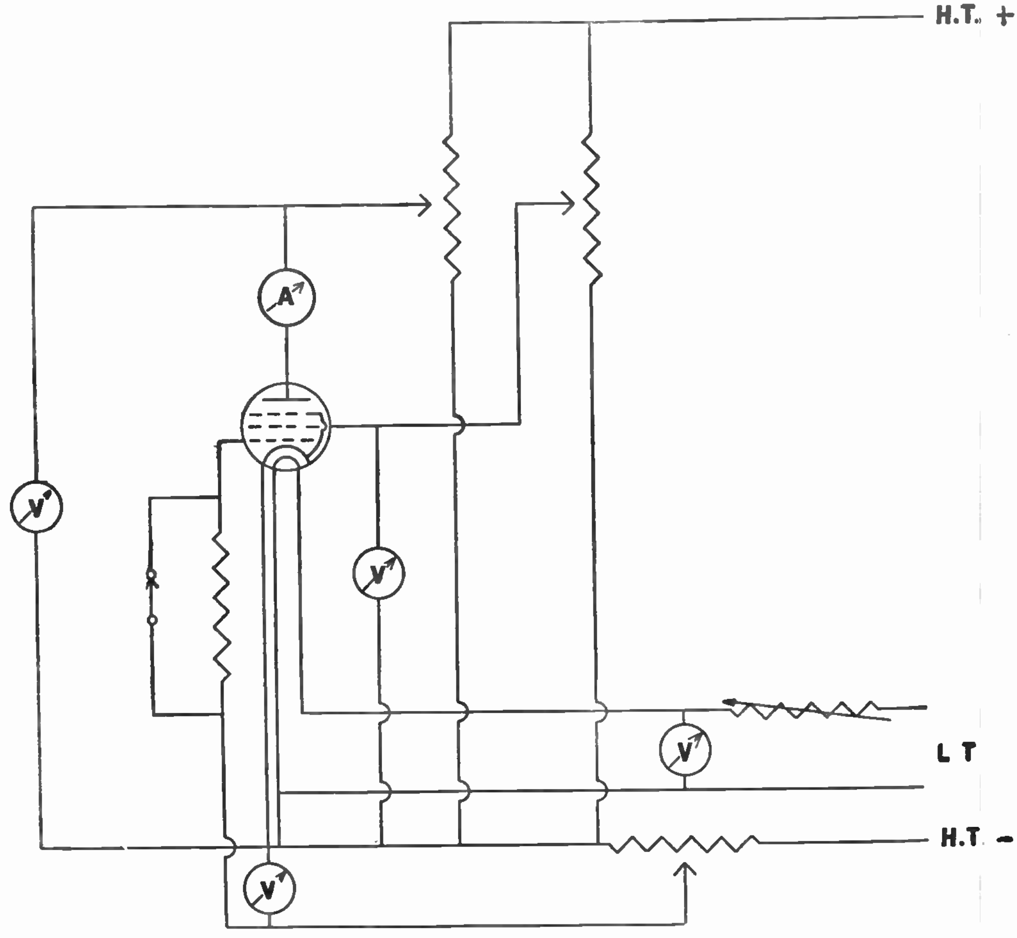


Fig. 31.—A circuit permitting the characteristics of any valve to be measured, providing the meters used have adequate ranges. In addition, a number of faults can be detected, as described in the text. This may be taken as the basic circuit of a valve test-board, but the complete circuit is greatly complicated by the diversity of valve types and the non-standardisation of their pin connections.

ment shown at Fig. 31 for measuring slope, the anode potentiometer is adjusted for the required anode voltage, the screen potentiometer is adjusted for the required screen voltage, the grid potentiometer set to zero, and the anode current duly noted. The bias voltage potentiometer is then adjusted to give 1 volt, and the resulting anode-current reading noted and subtracted from that previously obtained. *It should be* *particularly noted that the anode and/or the screen potentiometers may require readjustments, unless their total resistance is very low, to correct the change of anode and screen potential caused by the reduction of anode and screen current when the negative bias is applied.*

It is probably unnecessary to mention that the anode and screen potentials should be those specified by the valve manufacturers concerned, when quoting the nominal slope. The majority of valves are specified under conditions of $Va = 100$ $Vg = 0$. There is little standardisation in the more complicated valves, and there is an increasing tendency to quote the slope for a condition including negative grid voltage, usually 1·5 negative; in the case of a screened tetrode inaccuracy will be introduced by applying a further volt in the negative direction, as the anode current will be abnormally reduced. It is preferable to take the initial anode-current reading with a grid potential of 1 volt negative, and the second reading with a grid potential of 2 volts negative, thus the slope is taken at a mean grid potential of 1·5 volts negative, which is the required condition. For practical purposes this care is unnecessary when dealing with valves such as output pentodes, where the initial bias is fairly high, but in any case the characteristics of this class of valve are usually quoted under conditions of zero grid voltage. On the other hand, the older type of screened tetrode having extremely high impedance will not tolerate a grid-potential change of 1 volt, and measurement must necessarily be conducted by applying a smaller change and multiplying the current change accordingly. For example, the grid potential might be varied between 1·25 volts and 1·75 volts, a change of ·5 volts, the change in anode current being multiplied by two in order that the slope is obtained in terms of milliampères per volt.

The circuit shown in Fig. 31 is liable to very considerable modification, and if desired the anode and screen potentiometers could be dispensed with and the voltage obtained direct from suitable tappings on a high-tension battery, the grid potential being supplied from the potentiometer across a battery having an E.M.F. of, perhaps, 3 volts. By the use of plugs and jacks, or suitable switching, a *single* multi-range meter may be used for measuring all potentials and currents.

Anode Current.—When testing slope it is convenient to test the anode current and, if desired, the screen or auxiliary grid current. The measurement will usually be made with working potentials applied, that is to say, the anode, grid, and any other voltages being similar to those obtained in the receiver or, alternatively, voltages selected from known working conditions appropriate to the valve. Generally speaking, it is only necessary to note that the current is not excessively abnormal, as it is not an important factor, except in the case of battery valves, when economy of high-tension current is important.

Impedance.—Impedance may be measured with the circuit shown at Fig. 31, and is accomplished by keeping the grid voltage constant and noting the change in anode current for a definite change in anode voltage.

The grid voltage will normally be 0 or 1:5 as declared by the manufacturer when specifying this characteristic and, similarly, a definite anode voltage will be quoted. In the case of triodes this is usually 100 volts, and it will be convenient to vary the voltage between 95 and 105 volts and note the change in anode current, the formula being as follows:

$$\text{Impedance in thousands of ohms} = \frac{\text{change of anode potential (volts).}}{\text{change of anode current (mA)}}$$

If, for example, the change in anode voltage is 10 volts and the change in anode current is 2 milliampères; 10 divided by 2 is 5, and, as the answer is in thousands of ohms, the impedance is 5,000 ohms. Generally speaking, the change of anode voltage should be as small as practicable, consistent with obtaining a sufficiently large change of anode current to permit the readings being taken with the necessary degree of accuracy. The measurement of high-impedance valves is somewhat more difficult, as the change in anode current is extremely small, and for accurate work a really large-scale instrument is necessary; a meter of suitable range and with a scale of not less than 5 inches is satisfactory when a general indication is required to ascertain if the valve is likely to be capable of performing in a normal manner.

Amplification Factor.—When service testing it is not usual to measure the amplification factor, as this is directly dependent on slope and impedance, but if this measurement is required, the method to be adopted is outlined in Chapter 10 of Volume I.

Microphony.—The most satisfactory test for microphony is to place the valve in its normal position in the receiver and tap it with the knuckles, having previously turned up the gain control to maximum. Means are available for testing microphony with the aid of a pair of headphones, but it is somewhat unsatisfactory, as a mild tendency to develop this fault would probably only appear when the valve is working under adverse conditions.

Loose electrodes may be readily detected with the aid of the circuit shown at Fig. 31, the potentiometers being adjusted so that the maximum permissible voltages are applied on all electrodes. The valve is then subjected to a certain amount of rough treatment, the meters being kept under strict observation; looseness in electrodes or intermittent short circuit between electrodes will show up as a change in one of the meter readings. In addition to the rough treatment already referred to an additional test may be applied by striking the valve in several directions with a sponge-rubber hammer, made by fixing a piece of sponge rubber about 2 inches cube on the end of a light wooden handle about 6 inches long and $\frac{1}{4}$ inch in diameter. It may appear that such a test is ridiculous if the value has withstood being generally knocked about with the hand, but actually the test is a useful one, as valve electrodes are usually made of very soft metal and will often show signs of displacement when treated in the manner described, although sharp taps fail to reveal the fault, owing to the natural power of soft metal to absorb an impact of short duration.

It is *imperative* that before testing for loose electrodes the multi-range meters be set to such a range that the reading is as near as possible to the zero end of the scale, to minimise the danger of damage if the electrodes should develop a short circuit.

Emission (Rectifiers).—The emission test is practically useless for valves other than mains rectifiers and diodes, although emission testers are quite frequently met with on the counters of retail establishments, where valves are tested with the aid of this device and pronounced as satisfactory or otherwise. They exist in various modified forms, but in principle the various electrodes are strapped together, a few volts applied to them, and the anode current measured. They are quite unsatisfactory, however, as they give no indication whatever of impedance or slope and will show a satisfactory reading when two or more faults are present which cancel the effects of each other when the valve is tested in this manner. A valve that has been accidentally flashed and lost most of its sensitive filament coating will often give normal anode-current reading if it is also soft owing to the great reduction of internal impedance due to the ionisation of the unwanted gas. The more elaborate types of valves, such as those used for frequency changing, might have several faults and still pass the so-called emission test as 100 per cent. efficient.

The mains rectifier or diode has only two electrodes, and therefore can be tested by emission in a satisfactory manner. Once again the circuit shown at Fig. 31 is satisfactory, although *great care* must be exercised not to apply an excessive anode voltage. The procedure is to move the anode potentiometer to the minimum position and insert the valve and, in the case of indirectly heated types, allow sufficient time for the cathode to reach normal working temperature. The anode voltage can then be slowly increased until the valve is passing its maximum rated current, when the anode voltage is noted and compared with the emission curve which is supplied by certain manufacturers. Some manufacturers do not supply emission curves, but load curves, which means that the valve must be tested under working conditions and supplied with the full rated A.C. anode voltage and the D.C. output voltage, measured when the valve is delivering the maximum permissible rectified current. It is essential that a reservoir condenser be included, as this will have a profound influence on the D.C. output. It is not always convenient or desirable to make special arrangements for testing a mains rectifier, in which case emission tests may be considered satisfactory, and in the absence of an emission curve the performance of the valve may be compared with that of a similar valve which is known to be satisfactory.

There are two other possible faults in a mains rectifier, softness and internal arcing, and a rough-and-ready test for both of these faults may be applied by means of a simple circuit shown at Fig. 32 or, alternatively.

by the general circuit shown at Fig. 31, provided provision is made to include a current-limiting resistance in the anode circuit. To test for electrode shorts a fairly large external high-tension voltage may be applied and the low-tension supply switched off, when any tendency to arc may be detected either by observation or by fluctuation of the milliammeter in the anode circuit. Here, again, it is essential that the meter be used on a scale which will obviate damage if the rectifier develops an internal short. It is desirable when making this test that the valve be subjected to a certain amount of rough treatment to detect the presence of loose electrodes.

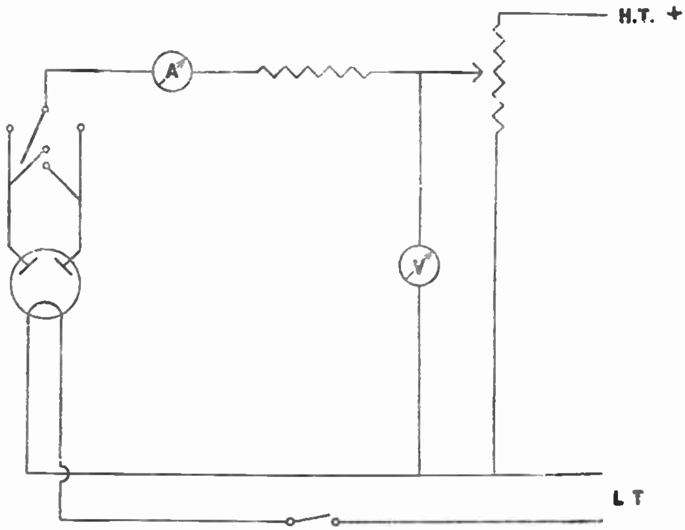


Fig. 32.—Circuit arrangement for measuring emission of a rectifier or diode valve. The switch permits emission to be measured for either or both sections. By opening the single-pole switch relatively high potential may be connected between anodes and filament to test for leak. This circuit could be incorporated with that shown at Fig. 31 or Fig. 33, but is shown separately for clearness.

To measure for softness the same test may be applied, when the presence of gas may be detected by means of the characteristic blue glow inside the valve. Indirectly heated rectifiers intended for use in alternating-current receivers are not liable to develop low insulation between cathode and heater, and in any case such a condition is not particularly detrimental. The converse applies to rectifier valves intended for use in universal receivers, but this subject is dealt with separately below under the sub-heading of Heater Insulation.

Softness.—Any type of valve may suffer from softness, and it is important to remember that this condition may take some considerable time to develop. It is necessary that the valve be allowed to run under working conditions for at least three-quarters of an hour, since the valve may show conditions of softness after this period but may be perfectly normal after a shorter run.

There are two methods of measuring softness, one which is very simple but not altogether satisfactory, and the alternative, which entails the use of a microammeter. It is usual to measure softness under conditions approximating to those which are likely to obtain when the valve is used in the receiver, and it is necessary that care should be exercised to differentiate between softness and grid emission, the procedure being dealt with later. It should, however, be understood that for the purpose of merely ascertaining whether a valve is fit for service, it is unimportant whether the valve is suffering from softness or grid emission, as the effect is very much the same and it is only the extent of the trouble that becomes important.

The simplest method of measuring for softness is to connect a high resistance between grid and cathode and arrange for a switch to short circuit this resistance (Fig. 31). It is convenient for this resistance to have a value of 1 megohm, which allows a straightforward reading to be obtained, the procedure being as follows: With the switch in its normal position, *i.e.* shorting the resistance, note the anode current. Open the switch and again note the anode current; if there is a difference between the readings the valve is soft, the extent being determined by dividing the difference in milliampères by the slope of the valve, when the answer is softness in microampères, that is to say:

$$\text{Softness (in } \mu\text{A)} = \frac{A_{max} - A_{min}}{g_m}$$

when A_{max} is the anode current in milliampères when the grid resistance is short circuited, A_{min} is the anode current in milliampères when the grid resistance is in circuit, and g_m is the slope of the valve in milliampères per volt (this formula only holds good if the grid resistance has a value of 1 megohm).

Consideration of the circuit at Fig. 31 will reveal the working of the vacuum test described above. The grid current due to ionisation must flow through the grid resistance when the switch is in the open position, each microampère flowing through the resistance (which has a value of 1 megohm) will produce a voltage drop of 1 volt. Consequently the anode current will be reduced in proportion to the grid bias derived in this manner, and the slope of the valve. If 3 microampères are flowing, it will produce a bias of 3 volts; assuming that the valve has a slope of 2mA/V per volt, then the application of this negative grid voltage will reduce the anode current by approximately 6 milliampères. It will be remembered that the formula requires the changing anode current to be divided by the slope; 6 divided by 2 equals 3, which will give the softness in microampères, which was the assumed grid current mentioned at the beginning of this example.

The Grid-current Meter.—The measurement of vacuum by means of a microammeter is the only direct method, and is advisable when provision of the necessary instrument is not in itself a drawback. It is convenient to use a meter having a central zero position, so that it shows the deflection in opposite directions, according to the direction of the current. This refinement is not necessary for actually measuring vacuum, but is useful for other tests which are described below; whether of the centre-zero type or otherwise, the microammeter can conveniently have a range of 0 to 5 microampères. Fig. 33 shows the simple connections of the microammeter, the circuit being that used for general tests, as shown at Fig. 31. In use the meter shows the grid current directly in microampères.

When using the microammeter it is comparatively simple to differen-

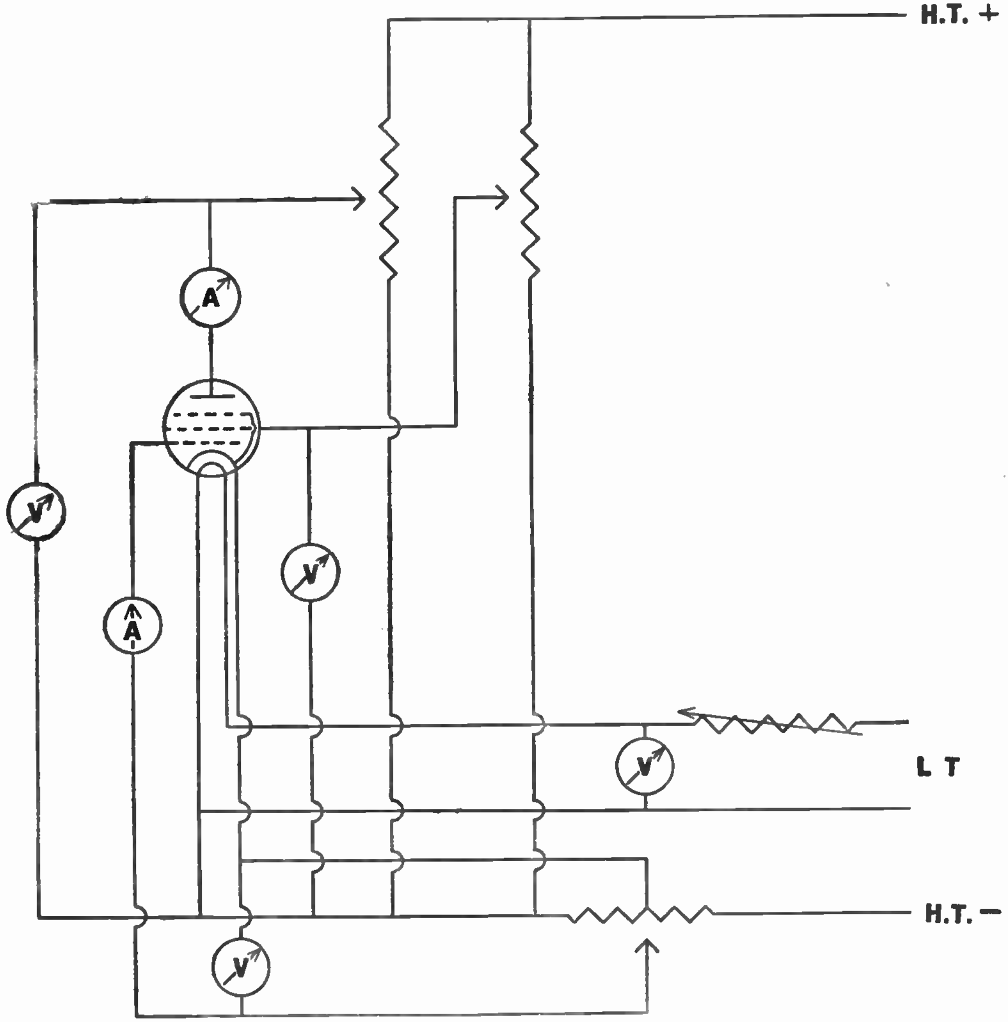
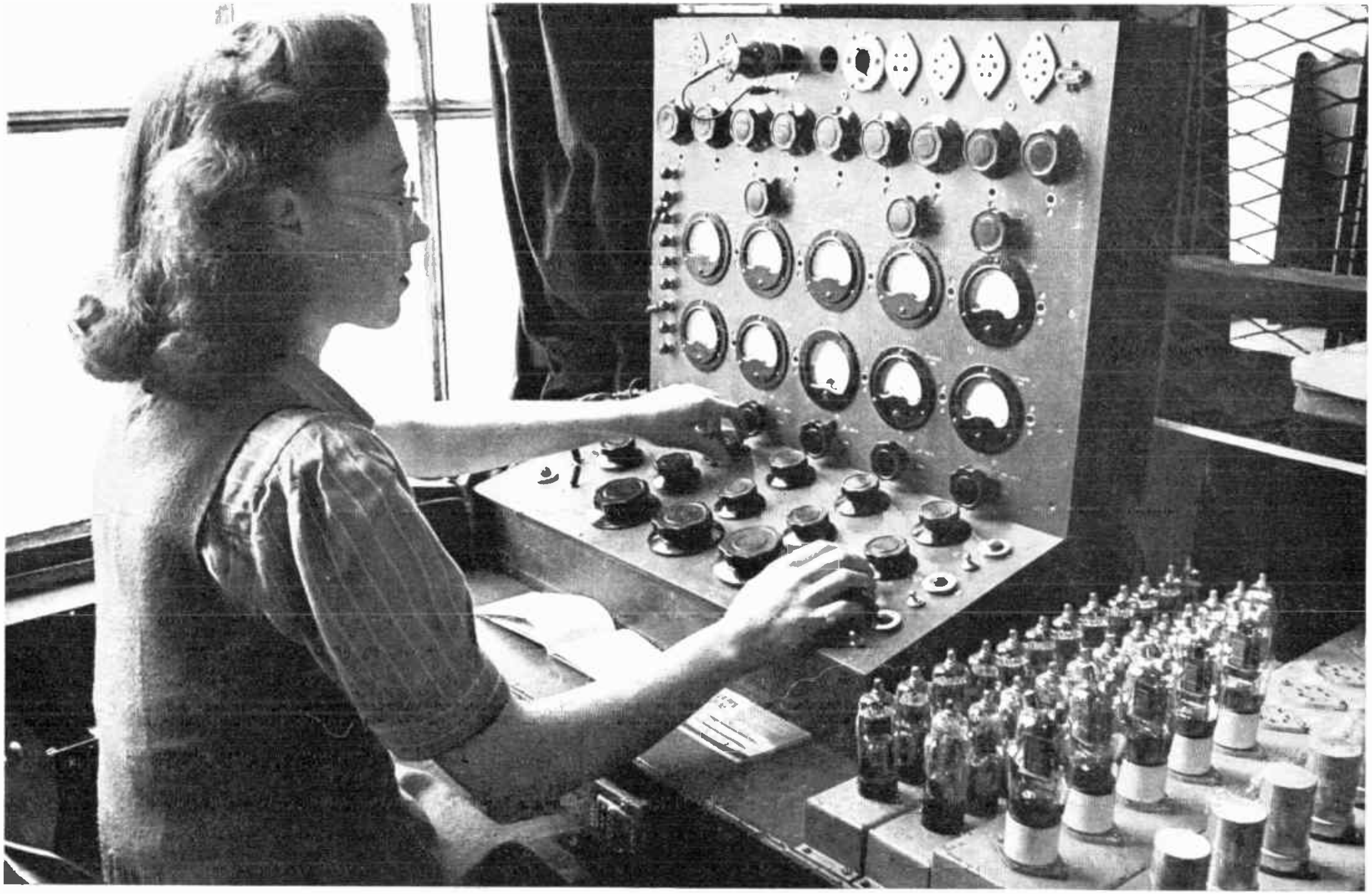


Fig. 33.—A modification of Fig. 31 to include a microammeter for measuring grid current. It is intended that the centre-zero type should be used. Note that the grid return is so arranged that either positive or negative bias may be applied to the control grid.

tiate between grid emission and softness by increasing the negative bias on the valve by means of the biasing potentiometer until the cut-off point is reached and anode current ceases to flow. In this condition ionisation cannot exist, as there will be no electrons to collide with the gas atoms and ionise them. If, therefore, the grid-current meter returns to zero, it is apparent that the grid current is due to ionisation; if the reading remains unchanged, then the grid current is obviously due to grid emission



MANUFACTURER'S VALVE TESTER

One of the Universal valve testers used in the factories of the M.O. Valve Company. Any characteristic of any valve can be measured in a matter of seconds. Valves on right are pre-heating to save warming up time when plugged into the tester.

or leakage ; it is possible for softness and grid emission to be present at the same time, in which case the microammeter will show a reduced reading when the valve is biased to cut-off.

Grid Emission.—Grid emission is a phenomenon peculiar to mains valves, as it is caused by the grid reaching a temperature at which it will emit electrons under certain conditions, and it is unlikely that such a temperature would be reached with a battery valve. Obviously, mains valves are designed so that their grids do not reach that temperature which will cause electrons to be emitted from the metal of which they are made, but now and again active material from the cathode or from the "getter" will become deposited on the grid ; such material is capable of emitting electrons at a low temperature, and consequently grid emission results.

It might appear at first sight as though grid current due to softness and grid emission would flow in opposite directions, but actually this is not the case ; when grid emission occurs electrons leave the grid, which tends to drive the grid positive, with the result that electrons flow through the external circuit to the grid. When ionisation is present the grid will collect positive ions, and once again the movement of negative electrons will be towards the grid. It will be remembered that the flow of electrons is in the opposite direction to conventional current.

As intimated in the section dealing with softness, grid emission and leakage are difficult to differentiate ; if leakage is present in its normal form it is readily detected by noting the flow of current between two or any more electrodes when the heater or filament is cold, but some leaks do not appear unless the electrodes have reached a considerable temperature. Alternatively, a leak may only appear between two electrodes when the potential difference between them has reached a sufficiently high value, the insulation being infinity when lower potentials are applied.

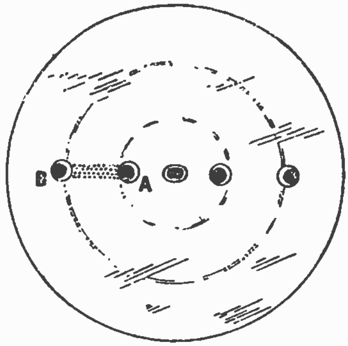


Fig. 34.—Top view of a mains triode, showing the ends of the electrode supports located in holes of a mica locking disc. This sketch illustrates a cause of hot leak, as described in the text.

Hot Leaks.—The term hot leaks embodies leakage arising through any cause whereby insulation approaches infinity when the valve is cold, but shows a relatively low resistance when the valve electrodes become warm. It may be due to various causes, one of which will serve as an example. Fig. 34 shows a typical mica disc used for locking valve electrodes ; the holes punched in it are slightly larger than the electrode supports, A, B, to allow for expansion when the latter warm up. It will be noticed that the electrode support B occupies a position away from the electrode A, it being assumed that the illustration shows the position of the electrode supports when the valve is cold. The dotted line represents the leak along the mica which will, however, have no effect, as the electrode supports do not come in contact with it, but when the valve warms up the electrode supports will expand or alter their position slightly and may then touch the end of the leak path, causing a leak between the electrodes A and B.

It is extremely difficult to differentiate between grid emission and hot leaks, since the current is in the same direction, is of the same order of magnitude, will often be unaffected by grid potential, and will commence after the valve has been working for a similar period. It is sometimes possible to distinguish between grid emission and a hot leak by connecting a high resistance in the grid circuit, when grid emission will cause the anode current to continue to increase, often until the valve collapses, whereas the usual type of hot leak will result in the anode current reaching a certain value fairly quickly after current starts to flow in the grid circuit and there remain.

Heater Insulation.—Heater insulation is extremely important, since inadequate resistance between heater and cathode may introduce such troubles as modulation hum, background noise, and, in extreme cases, may affect the slope of the valve. Fig. 35 shows a voltmeter connected between heater and cathode which can be held at a potential difference determined by the setting of the potentiometer. The milliameter will be of the multi-range type and will be switched into circuit with the meter switch in the high-range position. Lower ranges will then be introduced, until the lowest is in circuit. It should be noted that the insulation should be measured with the heater at normal temperature, since it will expand considerably and may well show a low resistance when hot and infinity when cold, or *vice versa*; the valve should be tapped briskly with the fingers to see if an intermittent short circuit or partial short circuit is present.

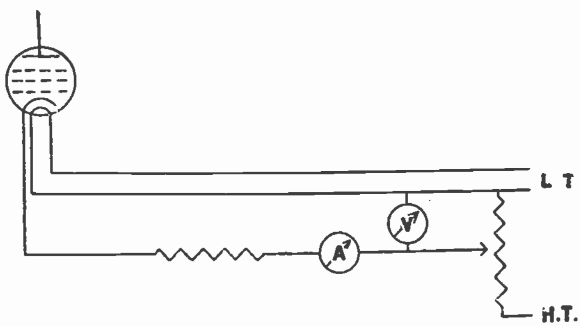


Fig. 35.—An arrangement for testing insulation between heater and cathode of a mains valve. When testing A.C. types the potential difference between the two electrodes should not normally exceed about 10 volts, but when testing universal types the potential difference may be relatively high. (See text.) This circuit could be incorporated with that shown at Fig. 31 or Fig. 33, but is shown separately for clearness.

It is important that a suitable potential difference be applied between heater and cathode, since an inadequate potential difference may not show the fault, whereas an excessive value will often break down a valve that was previously satisfactory. As a general rule, the voltage applied may be equal to the sum of the bias volts normally applied to the valve plus the peak volts which normally appear across the heater (that is to say, the normal heater voltage rating multiplied by 1·4); thus a 4-volt indirectly heated valve which normally has a grid bias of 7 volts could be tested with a potential difference between heater and cathode of about 13 volts, which is made up roughly by the bias voltage plus the peak voltage applied to the heater.

The insulation between the heater and cathode of universal valves is particularly important and must be tested with a considerable potential difference between them. When working in a receiver, the potential between cathode and heater will be equal to the sum of the smoothed high-tension voltage plus the peak A.C. voltage, which, assuming a mains voltage of 250 volts, may be approximately 600 volts. The method of testing is exactly the same as that already described, except that a resistance should be kept in series with the meter, which will limit the flow of current so that the meter is not damaged by a short circuit developing between cathode and heater. Admittedly, most meters are provided with fuses or cut-outs, but neither of these devices are likely to act quickly enough to save a low-reading milliammeter when a potential of 600 volts is suddenly applied across it.

Tolerances.—No mention has yet been made of the departure from nominal characteristics that can be tolerated or the conditions under which various types of valves should be tested, but some attempt has been made below to deal with each type of valve separately and give some broad indication, to draw distinction between valves that are serviceable and those that are not serviceable. It must be understood, however, that a tremendous amount of discretion must be used. For example, a screened pentode may have a nominal slope of 3 mA/V and may prove noticeably inefficient when used in a superheterodyne for long-distance reception when its slope has fallen to 2 mA/V. On the other hand, the valve may give results which are satisfactory to the user in a three-valve straight receiver used for reception of local stations and perhaps half a dozen other stations of relatively high power. To take another example, a frequency changer may have a slope of 3 milliampères per volt (it is impracticable to measure conversion conductance with a test-board), and be perfectly satisfactory in nine out of ten superheterodyne receivers when the slope has fallen to, say, 2·5 mA/V, but in the case of the tenth superheterodyne, it may refuse to oscillate on the long waveband, resulting in complete silence.

Triodes.—Valve manufacturers usually quote characteristics of triodes under conditions of $Va = 100$, $Vg = 0$, and consequently impedance or slope should be taken at these conditions. Generally speaking, a rise or fall of $33\frac{1}{3}$ per cent. will not materially affect the results. When measuring vacuum the maximum rated anode voltage and appropriate grid bias should be applied. If the valve is working with an appreciable resistance in the grid circuit, a limit of 1 microampère softness can be imposed; but, on the other hand, if the resistance to the grid circuit is low, as in the case of an output valve preceded by transformer coupling, then 3 to 5 microampères can be tolerated. It is important to note that the average modern valve which is only a microampère or so soft will usually harden up after a reasonable period of working, due to the very considerable absorbing power of the "getter" material. The figures quoted for softness apply to grid emission, although valves suffering from this trouble should preferably be scrapped, as this phenomenon tends to increase with life.

Screened Tetrodes and Pentodes.—The nominal characteristics of screened tetrodes and pentodes vary considerably with different manufacturers. Impedance and slope should be measured at the nominal values, while tests for softness and grid emission should be made at maximum operating conditions. These valves usually work with a very low resistance in the grid circuit, often only an ohm or so, and consequently softness or grid emission will not greatly affect reception, unless it is bad enough to pass a relatively high grid current. In the case of mains valves cathode to heater insulation is important, as a low resistance between these electrodes will usually introduce hum. If the screen is fed by a trailer resistance, the screen current should be measured, as this type of valve sometimes develops a condition of zero screen current when comparatively old, resulting in the maximum high-tension voltage being applied to the screen ; occasionally specimens will be found with reversed screen current.

When a screened tetrode or pentode is used in a detector stage it should be very thoroughly tested for loose electrodes and defective heater insulation, as quite small shorts or leaks will result in the valve being very noisy. Test for vacuum and grid emission very carefully, as even ·5 microampère of grid current will result in a very serious loss of gain, owing to the high value of grid leak which will probably be used. Wide tolerance may be given for impedance, since a decrease or increase of 50 per cent. may well be undetectable by ear.

Output Tetrodes and Pentodes.—Fairly generous tolerance may be allowed for impedance, although variation in this direction will be more objectionable than in the case of the triode. A drop in slope may, or may not, be important, depending upon the ability of the preceding valve to fully load the output valve when its sensitivity has fallen, consequent upon the fall in slope. Permissible softness may range between 1 and 5 microampères, according to the resistance in the grid circuit. Valves in this class are inclined to run at a high temperature, and are therefore prone to grid emission.

Frequency Changers.—Unless a very elaborate test-board is used it will be necessary to test frequency-changer valves of the double assembly type, *e.g.* triode hexode, as two separate valves. The remarks given above for triodes apply to the triode section, while the other section will be tested under conditions stated by the manufacturers for the nominal characteristic rating. Unfortunately, some manufacturers do not quote any characteristics for the mixer section, in which case it may be tested as a screened tetrode in the case of the hexode and a screened pentode in the case of a heptode by connecting the oscillator grid to about 3 volts positive ; in this way slope may be measured, the figure obtained being judged in relation to the heater rating of the valve and other relevant details.

Special Tests.—It is sometimes necessary to test to ascertain the condition at which normal grid current commences to flow. This characteristic is unimportant if the valve works under conditions of negative grid voltage, but in certain old-type portable receivers triodes are used as high-frequency amplifiers at zero grid potential, and results are considerably impaired if appreciable grid current flows under this condition. To find the commencing point of grid current decrease bias or, if necessary, apply positive bias until a deflection is shown on the microammeter in the grid circuit. It is for this test that it is convenient to use a microammeter with a central zero position, as the deflection will be in the opposite direction to that showing grid current due to softness or grid emission ; in the absence of a central zero type of meter it will be necessary to reverse the connections.

Meters.—The several meters necessary for valve testing should be of robust type and provided with either fuses or cut-outs to protect them in the event of short circuits. Even if fitted with protective devices they will be subjected to fairly rough treatment, owing to the inevitable time-delay of protective devices. Even the most robust types of meters are liable to develop inaccuracy when used for valve testing, and consequently they should be checked at frequent intervals.

Fig. 36.—Sketch showing the appearance of a broken filament or heater (much enlarged).

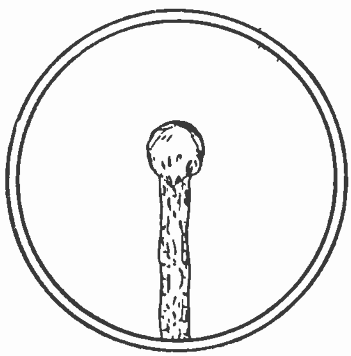


Fig. 37.—Sketch showing the appearance of a filament or heater that has been fused due to the application of excessive voltage. (Much enlarged.)

Special Note.—When leaving a valve test-board for any length of time it is desirable to shift *all* potentiometers to the minimum position before switching off. This is particularly important in the case of a filament or heater supply, as if this is left in a position appropriate for, say, a mains valve, it may burn the filament of a battery valve if the latter is accidentally plugged in before appropriate adjustment is made.

Filament or Heater Failure.—Occasion may arise when it is desired to know whether heater or filament failure is due to a break or to the application of excessive voltage. Examination under a low-power microscope will usually reveal the cause of failure ; Fig. 36 shows the appearance of a broken filament, and Fig. 37 shows the characteristic appearance of a fused filament.

CHAPTER 10

RECEIVER ALIGNMENT (GANGING)

Receiver alignment is one of the most important aspects of service engineering; the increasing tendency towards receivers with high over-all selectivity makes accurate alignment increasingly necessary. It is realised that some readers will possess very complete equipment, including, possibly, a modulated-frequency ganging oscillator and an oscilloscope. On the other hand, others will be without aligning equipment or, alternatively, may be called upon to make some adjustment when the appropriate equipment is not available. The procedure to be adopted necessarily varies with the equipment available, and consequently this chapter is split up into suitable sections, so that those who are without the equipment mentioned at the beginning of each section can conveniently omit it if they so desire. These remarks apply rather directly to aligning the superheterodyne, since the alignment of the straight receiver presents little difficulty and can, therefore, be conveniently dealt with first and will permit of one or two facts being established.

Realigning the Straight Receiver.—It must be understood that when two or more tuned circuits are ganged together it is essential that the inductances are accurately matched (with the exception, of course, of the oscillator circuit in a superheterodyne), since it will be impossible to keep the circuits in step by any normal means. The function of the trimming condenser is not to compensate for inductance mismatching, which is quite obvious when it is remembered that the change in frequency of a tuned circuit is inversely proportional to the square root of both inductance and capacity; it is, therefore, necessary that the capacity in each tuned circuit must be equal and the inductance in each tuned circuit must be equal; if additional capacity is added at some particular frequency so that all circuits resonate, then it is apparent that they will no longer resonate at the same frequency at another point of the scale and the discrepancy in inductance will introduce a proportionate variation.

The function of the trimming condenser is to balance the stray capacities in order to prevent misalignment at the high-frequency end of the scale where the capacity of the tuning condenser will be relatively small, permitting the stray capacities to be an important part of the total capacity. The stray capacities will be made up by the self-capacity of the coils, the capacity incidental to the wiring, valve-holder, valve, and other small residual capacities. Bearing in mind that stray capacities will exert the greatest influence at the lower end of the waveband, it is apparent that adjustment should be made when the receiver is tuned to this part of the scale. In principle, the trimmers are adjusted for maximum signal strength, and it is perfectly practicable to adjust them by ear with the receiver tuned to the lowest available station, care being taken to swing the trimmers through the apparently correct point fairly rapidly so that the point of maximum signal is not confused by the rise and fall of modulation.

When a ganging oscillator is available its output terminals may be connected between aerial and earth and the instrument adjusted to oscillate on a frequency that is about 10 kilocycles per second lower than the highest frequency to which the receiver may be tuned ; the oscillator output being modulated at low frequency. The trimmers are then adjusted until maximum signal strength is recorded by means of an output meter or oscilloscope. Generally speaking, the output meter should be connected across the anode load of the output valve, but an oscilloscope can more conveniently be connected across the detector load. It is important that the following points be observed :

1. If the receiver employs automatic volume control it must either be thrown out of action or, alternatively, the output from the oscillator must be reduced to the minimum that will permit of reasonable deflection of the measuring instruments in order that the action of this circuit does not deceive the operator.

2. When the procedure is finished the capacity of the trimmers should be as low as possible.

Item number two requires a little further explanation. Correct alignment will be achieved when the stray plus the trimmer capacity of each circuit is equal, and this might occur, for example, when the trimmers are set at 25μμF, 25μμF, and 30μμF respectively. It is apparent, then, that alignment would be achieved if the third trimmer is greater than the other two trimmers by 5μμF ; consequently the trimmers could be reset to, say, 10μμF, 10μμF, and 15μμF, thus reducing the total capacity at the lower end of the dial by 15μμF, which will considerably extend the range of the band in the high-frequency direction. It will be appreciated that a trimmer can never be taken to zero capacity, as it has its own definite minimum. The point to be observed is that on the completion of alignment at least one trimmer should be near to its minimum setting consistent with the accuracy of dial calibration while the tuned circuits are, of course, in perfect alignment. When the receiver is provided with only one trimmer to each tuned circuit this must be adjusted at the bottom of the shortest waveband, but when a trimmer is provided for each waveband the procedure outlined above must be repeated for each band.

Superheterodyne Alignment with Modulated-frequency Oscillator and Cathode-ray Oscillograph.—There is little doubt that a *modulated frequency* ganging oscillator and cathode-ray oscillograph are the most practicable and efficient instruments for aligning a superheterodyne, and it is scarcely an exaggeration to say that a bandpass superheterodyne cannot be aligned to maximum efficiency by any other means, as it is the only method whereby the shape of the response-curve can be observed. The detailed procedure to be adopted will vary considerably with different receivers, and also to some extent with different types of modulated-frequency oscillators. It would appear, therefore, that the most practicable way of approaching the subject is to detail the procedure that can conveniently be adopted with a typical oscillator and oscilloscope in conjunction with a receiver, the circuit of which is facing page 48 of this volume. Assuming that the receiver is to be completely realigned, it is desirable to deal with the tuned intermediate-frequency circuits first, the procedure being as follows:

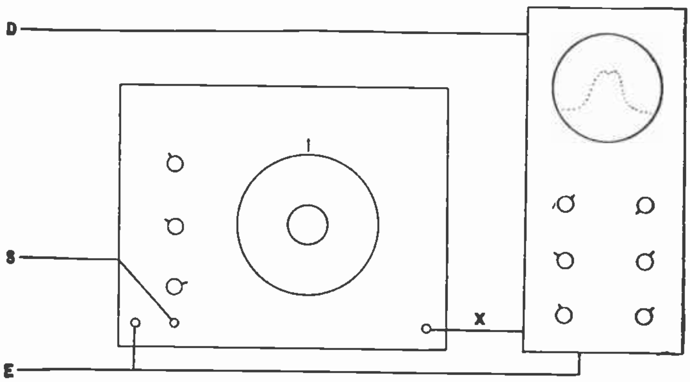


Fig. 38.—Connections for an oscillograph and ganging oscillator will vary with different types. The connection of the instruments used by the author are used above. E is connected with the earth terminal of the receiver, S to the grid of the frequency changer or the aerial terminal, depending upon whether the intermediate-frequency or the over-all response-curve is to be observed, and D is connected to a suitable output point, usually the high-potential end of the detector diode load. X is the link between the frequency modulation of the oscillator and the time base of the oscillograph.

Stop the frequency changer from oscillating by short circuiting the oscillator tuning condenser and connect the output of the ganging oscillator to chassis and the modulator grid of the frequency changer (see Fig. 38). The input terminals of the oscillograph can be most conveniently connected across the detector diode load, although some prefer to use the automatic volume control diode load; the author, however, has had little success with this arrangement. Should instability arise, a small resistance may be connected between the grid of the frequency changer and the oscilloscope, which may have a value of 1,000 ohms, and be connected as close to the valve as possible. It should be noted that the modulator grid of a frequency changer is usually the top cap of the valve, consequently a connection can be easily made; in many receivers the pick-up connections are across the detector diode load, in which case these offer a convenient way of connection to the oscillograph. When the apparatus has been set up as already described, the actual alignment may commence; it is assumed that all four of the tuned intermediate-frequency circuits are hopelessly misadjusted, when it is convenient to adopt the following sequence:

1. Carefully adjust the ganging oscillator to the correct intermediate

frequency of the receiver. If this is not known it must be ascertained from the manufacturer of the receiver, unless the tuned circuits are only very slightly out of alignment, when it will be possible to recognise the figure, if it is one of those in general use, by noting that maximum response is obtained at an input frequency close to a standard frequency.

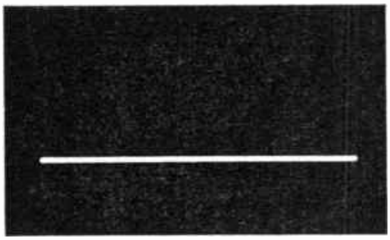


Fig. 39.—The trace on the oscillograph at the commencement of alignment when the receiver is so far out of adjustment that no deflection is obtainable. Figs. 40 to 46 show the subsequent stages of alignment.

2. Adjust the ganging oscillator attenuator to fairly high output. If the intermediate-frequency circuits are very badly out of alignment no deflection will be seen on the oscillograph (Fig. 39). Next proceed to search for some deflection, commencing with the coil nearest to the detector, until some deflection appears (see Fig. 40). If the oscillator is fitted with low-frequency modulating arrangements, it should be switched to this position, as it will show the first signs of deflection much more readily (see Fig. 41).

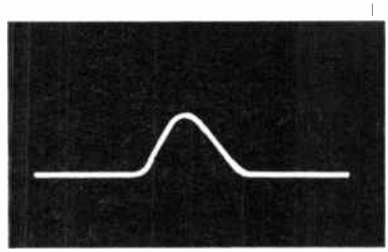


Fig. 40.—By adjustment of the intermediate frequency amplifier the first trace is obtained.

3. Carefully adjust each tuned circuit for maximum response, reducing the output from the oscillator by means of the output attenuator, if the deflection on the oscillograph gets inconveniently large (see Fig. 42). When the tuned circuits are all tuned for maximum gain the deflection on the oscillograph will be a peak (see Fig. 43). If low-frequency modulation is used to find the first signs of deflection, this should be switched out of circuit as soon as manipulation of the trimming has raised the amplitude of the deflection to about one inch.

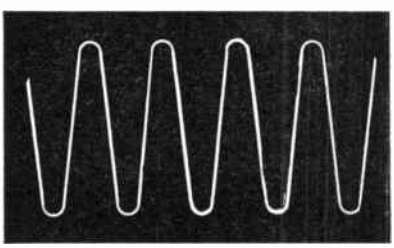


Fig. 41.—If the oscillator is fitted with low-frequency modulation, this can be used in the preliminary stage, as it makes the first sign of deflection much more apparent and appears as shown above.

4. Reduce the output of the ganging oscillator as low as possible and increase the gain of the amplifier of the oscillograph, if fitted with one, the aim being to produce a reasonable-sized deflection with the smallest output from the oscillator, so that the automatic volume control does not function and mislead the operator. Each tuned intermediate-frequency circuit should now be critically adjusted for maximum deflection (Fig. 43).

5. The response-curve shown at Fig. 43 will obviously introduce a very bad sideband cutting, and attention must now be directed to improving the shape. If the intermediate-frequency

amplifier uses over-coupled bandpass coils, each pair should be slightly turned in opposite directions. When one only has been so adjusted, the response-curve will resemble Fig. 44, but by carefully adjusting both trimmers a response-curve such as that shown at Fig. 45 can be produced.

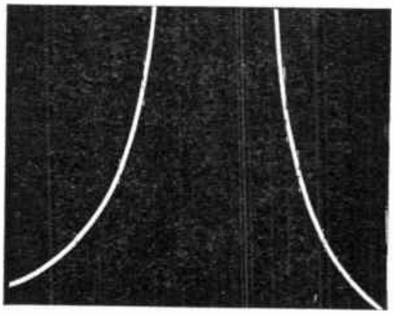


Fig. 42.—When the trimmers are brought more nearly to the correct positions deflection will usually be so large that only a portion is visible. The input is then reduced so that the complete trace is visible as shown in Fig. 43.

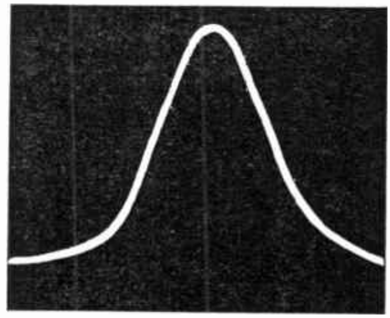


Fig. 43.—The intermediate-frequency amplifier for peak maximum response. It is important that the peak is in the centre of the screen.

It should be understood that these illustrations were prepared from an actual receiver, the circuit of which is shown facing page 48 of this volume. When using over-coupled bandpass coils the response-curve can be made reasonably flat-topped and with steep sides as shown at Fig. 45, and any other adjustment will produce either a tendency to peak or double hump (see

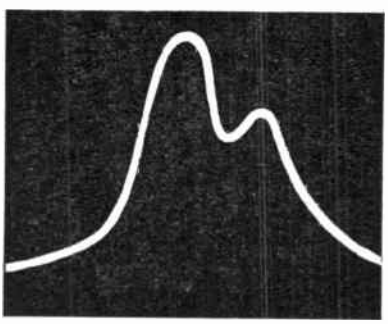


Fig. 44.—By suitable adjustment of the trimmers an effort is made to flatten the top of the response-curve. (Operation not yet complete.)

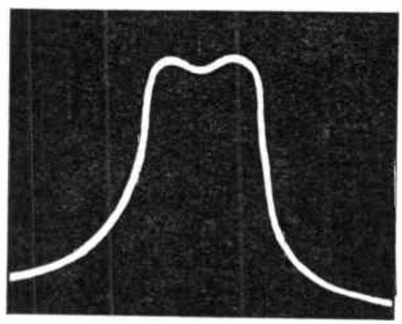


Fig. 45.—Alignment of the intermediate-frequency amplifier duly completed, the response-curve being as flat as possible and also as high as possible.

Fig. 46). Some receivers use tuned anode coils, which must be staggered to produce a more or less flat-topped response-curve. The average receiver using one intermediate-frequency amplifier will have two coils, and consequently one must be tuned slightly above the other and slightly below the true intermediate frequency; the actual departure from the fundamental frequency is usually about 2 kilocycles in either direction, but in practice the coils are tuned to these frequencies by suitably adjusting the ganging oscillator and appropriate trimmer and then returning the ganging oscillator to the fundamental intermediate frequency and slightly "faking" the adjustment to remove any lack of symmetry which may be apparent. The actual trimming may be accomplished by variable trimming condensers or, in the case of permeability-tuned coils, by screwing the iron core in or out; the latter arrangement is used in the circuit which has been cited as the example to this chapter.

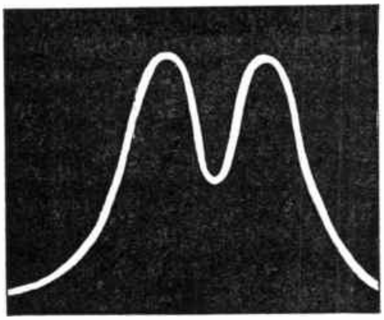


Fig. 46.—Incorrect adjustment. The response-curve is too wide, resulting in a very pronounced double hump.

7. The intermediate-frequency amplifier should now be correctly aligned, and the short circuit can be removed from the oscillator tuning condenser and attention be directed to the oscillator section. If correct tracking is accomplished by means of specially shaped vanes, or a *fixed* padding condenser, trimming can be proceeded with, otherwise it will be necessary to adjust the padding condenser. It is absolutely essential that the correct padding frequency for each waveband is known, when it is simply a matter of tuning the ganging oscillator to this frequency and adjusting the padding condenser for maximum response. This adjustment will vary the amplitude but not the shape of the response-curve. Some manufacturers mark the correct padding and trimming frequencies on the dial by means of very small and intentionally insignificant dots.

8. The remaining trimmers will be associated with radio-frequency circuits—which may be adjusted as described in the previous section, which is devoted to the realignment of straight receivers. The adjustment of these circuits will usually have some very considerable influence over the shape of the response-curve for the receiver as a whole, and if the very best possible alignment is required some *very slight* adjustment may be made to the alignment of the intermediate-frequency coils. The response-curve should be noted at two widely separated points on each waveband, and it will often be found that the response-curve develops an objectionable peak on one waveband while retaining the more normal shape of curve on another waveband, in which case it is de-

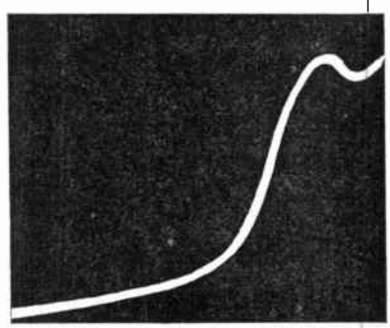


Fig. 47.—In this illustration the shape of the response-curve is probably correct but out of centre, due to the coils being adjusted to a few kilocycles off the correct frequency.

sirable to slightly readjust the intermediate-frequency coils to effect a compromise.

9. Before disconnecting the apparatus the receiver may be subjected to a certain amount of rough treatment, to see that the adjustments are reasonably rigid and will not therefore become misadjusted through ordinary usage. It is not suggested that the chassis should be so roughly handled that a fault may be actually caused, but it should be possible to hit the chassis with the hand sufficiently hard to move it along the bench for half an inch or so without altering the shape of the response-curve or causing any damage, unless to a defective component, which will then become apparent and can be dealt with suitably.

The more elaborate type of receiver using automatic frequency control calls for very careful alignment of the discriminator circuit, as if incorrectly aligned, a host of peculiar troubles will result, the chief of which is to achieve automatic *mistuning*. It is quite impossible to generalise on the alignment of discriminator circuits; the manufacturers responsible for their design issue definite instructions peculiar to their product, and these should be rigidly followed.

Superheterodyne Alignment with Ganging Oscillator and Output Meter.—Satisfactory receiver alignment can be carried out with an output meter and an accurately calibrated oscillator (with low-frequency modulation), but this equipment does not possess the possibilities of that mentioned in the previous section, simply because the shape of the response-curve cannot be observed. It can, however, be determined indirectly with a reasonable degree of accuracy.

The preliminary steps are precisely similar to those adopted for ganging with the oscillograph, inasmuch as the various tuned circuits are adjusted for maximum response, which in this case will be indicated by the pointer of the output meter. The oscillator is connected in the normal manner as described above, while the output meter is usually connected across the anode load of the output stage. It will be realised that a simple oscillator that is not modulated at audio frequency is little use for ganging a receiver, but if such an instrument is in the reader's possession and known to be sufficiently accurate, it may be thought worth while to obtain a low-frequency modulating unit (this accessory should not be confused with the more common frequency modulating unit).

When the intermediate-frequency tuned circuits have been adjusted to maximum response, it is desirable to give some attention to their shape; by swinging the oscillator for a distance of, say, 4 kcs. per second either side of the fundamental intermediate frequency, it is possible to obtain a very rough idea of the frequency characteristics of the amplifier. If the output meter falls off rapidly when the fundamental intermediate frequency is departed from by a few kilocycles, it follows that the response-curve is in fact a peak, and by carefully manipulating the trimmers it is quite possible to arrive at an adjustment if the output meter deflection remains sensibly constant when the oscillator is swung over the required band-width. By noting that the attenuation is equal for a given swing on either side of the intermediate frequency, reasonable assurance is obtained that correct alignment has not been lost.

When checking the shape of the response-curve, *great care* must be taken to see that the input from the oscillator is well below the delay voltage of the automatic volume control system, or if this is put out of action the input should not be allowed to reach an amplitude that will cause over-loading, as this condition will bring about a spurious flat top or double hump in the response-curve.

Receiver Alignment without Instruments.—This section is included for the sake of completeness and in the hope that it may be of assistance in an *emergency* such as that arising after effecting a repair which has resulted in misalignment. It should be understood that such methods are intended as a *temporary* means of dealing with an emergency, and as the ultimate accuracy of the adjustment obtained will be dependent upon an element of luck, no surprise should be felt if the several wavebands are troubled by whistles at various points. It is virtually impossible to trim a receiver completely in this manner, but the necessity should not arise, as it is unreasonable to suppose that more than one main section on each waveband is thrown out of alignment by effecting a repair.

If it is desired to realign the intermediate-frequency amplifier, it is essential that the receiver should possess accurate dial calibration or, alternatively, that the dial setting is known with a high degree of accuracy for a station approaching either end of one waveband, preferably the medium waveband. The intermediate frequency has a profound influence upon calibration, since, when incorrectly aligned, maximum response will be obtained with an oscillator frequency that is not the normal one, and consequently calibration will be affected. The discrepancy thus obtained will be most noticeable at the high-frequency end of the scale, and consequently a suitable station should be selected. The procedure simply consists of adjusting the intermediate-frequency circuits until correct dial calibration is obtained coincident with maximum response, which must unavoidably be judged by ear ; the input should be reduced by means of the volume control to the absolute minimum, as it is far easier to note a change of volume when the volume-level is small than when it is large. Once again, it is important that the input to the receiver should be very small ; to ensure this, limit the aerial to a few feet of wire.

The task of trimming and padding an oscillator can be undertaken with reasonable hope of success if the correct trimming and padding frequencies are known, or are marked on the dial by the manufacturers, once again assuming that the dial calibration is accurate. It entails the selection of a station *as near as possible* to the correct frequencies, and adjusting for maximum response. Once again, volume must necessarily be judged by ear, and it is advisable to reduce the volume to a low level.

As an additional check a known station can be carefully tuned in at either end of the dial, when inaccurate calibration will indicate that the trimming and/or padding adjustments are inaccurate, assuming, of course, that the dial calibration is normally accurate.

The trimming of the radio-frequency circuits is relatively simple, and in order to achieve alignment and at the same time preserve accuracy of calibration, the procedure should be as follows : Tune in a station at the high-frequency end of the waveband and set the pointer accurately for the station as determined by calibration and not by the sound obtained, then trim for maximum response.

Calibration Adjustment.—The dial calibration of the modern receiver is usually reasonably accurate. Should recalibration be necessary it may be carried out with an oscillator or by the use of reliable stations, but it is desirable that response should be indicated by an oscillograph or output meter. The calibration at the top end of the dial should first of all be corrected; this may mean shifting the intermediate frequency very slightly, which is only permissible if the tuned circuits are reasonably flat-topped, providing that such variation is quite small; that is to say, not more than 1 or, as a maximum, 2 kcs. Considerable stress is laid on the necessity for most carefully checking the setting of the oscillator padding condenser before any attempt is made to recalibrate. When the calibration at the top of the dial has been corrected, the calibration at the bottom of the dial, *i.e.* the high-frequency end, can be adjusted by setting the pointer correctly to the frequency or wavelength of a known station and then trimming for maximum response.

It will be noted that an accurately calibrated oscillator and an oscillograph or output meter is essential for making preliminary tests and adjustment and for aligning the intermediate frequency, although the actual calibration can often be more easily accomplished by the use of a reliable broadcasting station, as the frequency from such a source will be determined with far greater accuracy than is available from the average ganging oscillator.

Special Precautions.—Special tools are required for receiver alignment, owing to the change of capacity that is introduced if a metal screw-driver or spanner is allowed to come in contact with any part of the tuned circuit. Special screw-drivers are available which are made of insulated material and tipped with a minute piece of metal; these are intended for adjusting trimmers which are provided with a screw-driver slot. Some trimmers are adjusted by means of a nut ; box spanners are available made of bakelite, ebonite, and other non-metallic substances. When trimming is accomplished by screwing an iron core, even greater precautions are necessary, as some mistuning may result if any metal is allowed to come in contact with the core, and it is necessary therefore that even the edge of the screw-driver be made of some non-metallic substance. Fortunately, screwed cores are comparatively free to move, making possible the use of a wooden screw-driver, which may be made by sharpening an ordinary wooden skewer to a short and fairly blunt point.

Some types of cores are attached to a slotted head made of some insulating material; and if a particular circuit fails to respond to adjustment, the core should be removed in order to ascertain that the two elements have not become detached. If adjustment of an iron core produces some response, but fails to produce a normal peak, it is very probable that a leak has developed in the fixed condenser which is connected across almost every permeability tuned coil.

Alignment of Frequency-modulator Detectors.—When aligning a receiver incorporating a frequency-modulation detector or frequency-amplitude convertor it is necessary to give special attention to this task as this type of receiver is very dependent on the correct functioning of this stage. Quite apart from the several basic types of circuit there are numerous manufacturers' modifications most of which affect alignment procedure which makes general advice impossible; when re-alignment is being undertaken it is imperative to obtain the manufacturers' detailed instructions and follow them carefully.

CHAPTER 11

WHISTLES AND BREAK-THROUGH

THE more elaborate superheterodyne receivers employ a radio-frequency amplifier in front of the frequency changer, and are relatively free from whistles and other troubles peculiar to the superheterodyne because the selectivity of the radio-frequency stage will attenuate all unwanted frequencies to negligible proportions—with the possible exception of one or two channels on either side of the required station. The intermediate-frequency amplifier is normally designed to give the necessary adjacent channel selectivity, and consequently the two sets of tuned circuits effectively eliminate all unwanted frequencies. The same remarks do not apply to the more simple type of receiver, which is without the refinement of a radio-frequency amplifier but which enjoys a certain popularity on purely economic grounds.

The simple type of superheterodyne receiver not only lacks a radio-frequency stage, but also bandpass coupling, the input selectivity being dependent upon a single tuned circuit. It is inevitable, therefore, that certain unwanted frequencies will appear across the grid cathode of the frequency changer, some of which will beat with oscillator harmonics, while others will beat with each other, producing whistles at various points on the dial. These whistles are colloquially known as " birdies," and are discussed in some detail in Chapter 17 of Volume I, which deals with the technique of the superheterodyne, and need not therefore be repeated here. Attention may therefore be directed to the possibility of obtaining some relief.

With receivers of this type a number of whistles are unavoidable, but there is no reason why they should be allowed to interfere unduly with the enjoyment of listening, since means are available whereby their position may be controlled to some extent. Superheterodyne whistles can be split up into two groups: (1) those which are caused by two stations beating with each other; and (2) those which are caused by stations beating with the oscillator frequency or its harmonics.

The selectivity of the first tuned circuit can be assisted by the use of an intelligently designed aerial system. The aerial itself should have relatively low self-capacity or, in other words, should be well spaced from earth objects and should not be unduly long. In the average locality a length of 50 feet for the combined aerial and downlead may be regarded as the maximum, while this figure can often be halved with advantage. Reduction of aerial length will improve the inherent selectivity in tuned circuits by reducing damping, and will also assist by reducing the input to the receiver.

Whistles of the group (2) under discussion will be dependent for their amplitude and number upon aerial input, aerial circuit selectivity, and heterodyne voltage ; unless the aerial circuit is to be redesigned reduction of aerial length is the only expedient to deal with the first two items, and attention can now be directed to heterodyne voltage.

Fig. 48 shows the relationship between conversion conductance and heterodyne voltage ; it will be noted that there is no appreciable gain in conversion conductance when the heterodyne voltage exceeds 5 volts for the particular valve, but it is important to remember that an increase of heterodyne voltage will greatly increase the amplitude of oscillator harmonics. It is important, therefore, that the heterodyne voltage should not exceed the optimum value in receivers of the type under discussion. The measurement of heterodyne voltage is not easily accomplished outside the laboratory, but its approximate amplitude can be obtained indirectly with the aid of an oscillator and output meter or oscillograph. The oscillator is used to inject a signal into the aerial circuit and the oscilloscope or output meter used to show a deflection for such input, which should be carefully noted. The next step is to reduce the heterodyne volts by decreasing the oscillator anode voltage ; if the deflection commences to decrease fairly rapidly with a comparatively small reduction of anode voltage, it is apparent that the heterodyne voltage must be approximately the optimum. If, on the other hand, a considerable reduction of anode voltage can be effected without materially reducing the gain of the frequency changer (and, incidentally, the gain of the receiver as a whole), it is equally apparent that the heterodyne voltage is excessive and the oscillator anode voltage can be permanently reduced. This test should be carried out on at least two points on every waveband, as with average coils heterodyne voltage varies with frequency. The possibilities of reducing the number and amplitude of whistles has been broadly dealt with, and attention can now be directed to whistles

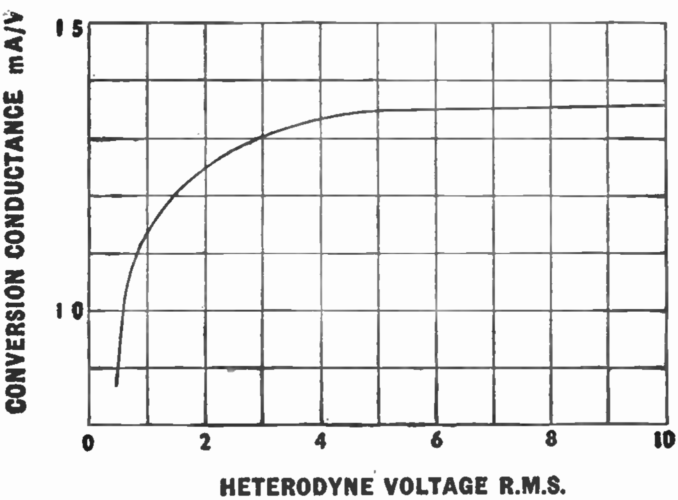


Fig. 48.—A curve showing the relationship between the heterodyne voltage and conversion conductance of a typical frequency changer.

in Group 1, namely, those produced by two stations beating with each other.

The most ready means of reducing whistles caused by two stations beating together is to reduce the signal input and increase the selectivity of the first tuned circuit; aspects of the question that have been dealt with above. As a means of shifting whistles away from particular stations recourse is sometimes made to a change in the intermediate frequency, but this method is discouraged, as it is impossible to correctly trim and pad the oscillator stage with existing coils if the intermediate frequency has been materially shifted; it is quite useless to contemplate a change of 1 or 2 kcs. Whistles can appear on the long waveband due to short-wave stations beating together. It is comparatively simple to stop such interference, as the offending stations will normally be powerful local transmitters. As the trouble is caused by two such stations beating together, it is only necessary to eliminate one of them, which can be most conveniently accomplished with the aid of a pre-tuned circuit, so placed in the circuit that it will be either shorted or put out of circuit when the receiver is switched to other wavebands. Such a circuit is called a rejector and is, in fact, similar in every way to the so-called wave trap which enjoyed a short term of popularity some ten years ago. The rejector circuit can be put in the aerial lead with a shorting switch which will be open on the long waveband and closed on the other bands. It is, however, possible to dispense with this switch by incorporating it into the actual long-wave aerial circuit, Fig. 49 being a typical example.

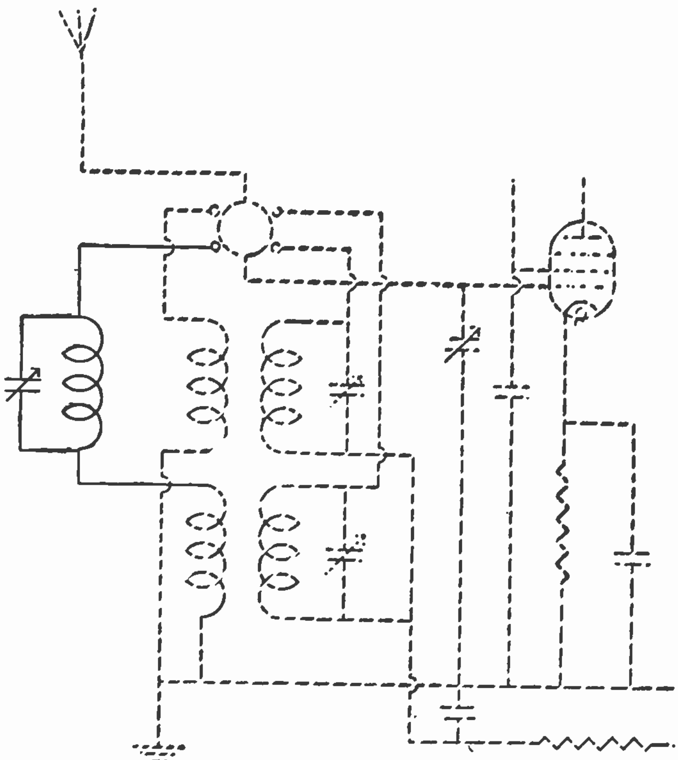


Fig. 49.—A rejector circuit placed in series with the long-wave winding so that it is automatically switched out of circuit on the medium waveband.

At the present time the allocation of frequencies to the various broadcasting stations is reasonably satisfactory from the point of view of reducing whistles, but as changes are made from time to time it is conceivable that a combination of frequencies might be used that would make it desirable to reject more than one medium waveband frequency when listening on the long waveband; the circuit at Fig. 49 shows a single rejector in series with the long-wave aerial coil, but it is perfectly feasible to use two or more rejector circuits in series.

The actual rejector circuit comprises inductance and capacity, one of which must be adjustable for the purpose of tuning it to the required frequency. In the interests of maximum rejection the tuned circuit should have the highest possible magnification (Q). Generally speaking, a Litz coil with an iron core will be employed, and it is convenient that the latter be screwed to permit permeability tuning, allowing the parallel capacity to take the form of a fixed condenser of a type which is not prone to drifting. Such coils are somewhat troublesome to make, and it is suggested, therefore, that an ordinary tuning coil be used, with all unnecessary material removed, such as untuned primaries and secondary windings associated with other wavebands.

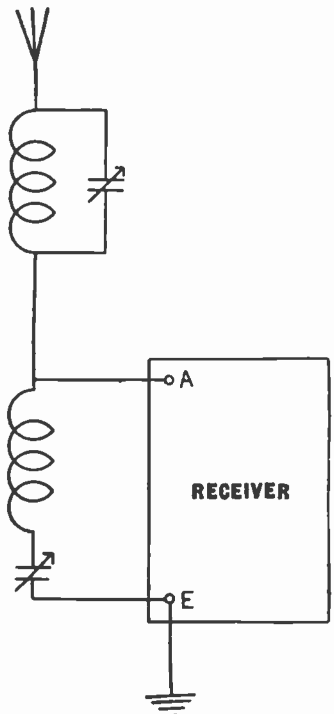


Fig. 50.—This illustration shows a rejector connected in the aerial lead aided by an acceptor circuit connected between the aerial and earth terminals of the receiver.

Many commercial receivers were at one time equipped with rejector circuits which could be retuned in the event of wavelength changes. Those receivers which employed two rejectors usually had one tuned to the medium-wave National wavelength, which was reasonable, since there were a number of stations working on this wavelength all over the country; the other rejector was usually tuned to London Regional, which was a trifle peculiar, as a rejector so tuned was not likely to be very much use in, say, the north of Scotland, and outside the radius where London Regional was received at considerable volume it might have been useful to retune the appropriate rejector to the local regional wavelength or that of some other transmitter which was received at great strength and known to cause whistles.

Intermediate-frequency Break-through.—In certain districts reception may be very seriously interfered with by untunable morse interference; that is to say, the unwanted morse signals are audible on all wavebands, irrespective of the dial setting. This trouble is due to transmissions at or close to the intermediate frequency; the most generally used intermediate frequency is 465 kilocycles per second (this is 645 metres), which is in the neighbourhood of short-range ship-to-coast transmitters. As 645 metres falls outside the normal broadcast bands, the trouble can be dealt with by the use of a rejector in the aerial lead tuned to the appropriate frequency; once again it is desirable to use a Litz-wound iron-cored coil, and, in order to avoid the time and trouble required to make such a coil, it is convenient to use an intermediate-frequency transformer with either primary or secondary removed or, if this is inconvenient, either winding may be connected in the aerial lead and both coils duly tuned to the correct frequency. In particularly severe cases, where morse signals are received at tremendous volume, it may be necessary to use both a rejector circuit and an acceptor circuit. This arrangement is shown at Fig. 50; the rejector circuit is similar to that used in Fig. 49, whereas the acceptor circuit takes the form of inductance and capacity in series. It should be noted that the capacity associated with the acceptor circuit should be relatively high, that is to say, of the order of $\cdot 001 \mu F$.

Intermediate-frequency break-through may be caused partly or entirely by energy picked up in the intermediate-frequency amplifier components and wiring, in which case relief can be obtained by additional screening. It is also possible that the intermediate-frequency amplifier may pick up energy from the aerial downlead, in which case the rejector circuit should be placed in the aerial lead at some little distance from the receiver, say, about 6 feet.

Ultra-short-wave Break-through.—Difficulty is occasionally experienced from interference on the medium or long wavebands due to a powerful ultra-short-wave transmitter situated at comparatively short range; certain receivers are prone to this type of interference, which is sometimes very difficult to cut out. The first suggestion that presents itself is a filter choke in the aerial, earth, and/or the mains leads, and it is important to note that chokes used for this purpose should be fitted as close as possible to the receiver.

If chokes of adequate inductance fail to alleviate the trouble, it is reasonable to suspect that some portion of the receiver will resonate at a frequency equal to or close to the frequency of the interference. The author investigated a complaint of this nature, which took the form of interference from the television transmission at Alexandra Palace which broke in on the medium and long wavebands of a superheterodyne situated about three-quarters of a mile from the television transmitter. In this particular instance the sub-chassis holding the tuning condenser had a natural frequency equal to one-third of the break-through; the difficulty was overcome by bridging the sub-chassis to the chassis at two additional points, copper braid being used in order to make a very low-resistance connection. Obviously, the example chosen requires a number of conditions to be satisfied, but it serves to illustrate the type of fault and the manner which may be adopted to overcome it.

Break-through from Non-radio Sources.—From time to time instances become known of interference to broadcast reception from non-radio sources such as the telephone or telegraph ; usually this is due to direct induction between the aerial and the service wires in question, the design of the receiver being such that sufficient impedance is offered to these relatively low frequencies to cause a significant potential to be built up. Transference of low frequency picked up by the aerial can also be transferred to the low-frequency end of the receiver if cross-modulation phenomenon is present in the predetector stages. The method of eliminating such interference is immediately obvious when the cause has been determined.

CHAPTER 12

LOUDSPEAKER FAULTS

LOUDSPEAKER faults are far more common than is generally supposed; they often pass unnoticed, as they are frequently of a minor nature and do not therefore make themselves sufficiently evident to demand attention. Alternatively, the more blatant type of fault may not make itself obvious unless the receiver has been used for an exceptionally long period and become somewhat over-heated.

For the purpose of dealing with loudspeaker faults this chapter is divided into two main sections, covering moving-iron and moving-coil types separately.

Moving-iron Loudspeakers.—The moving-iron loudspeaker has gradually fallen into disfavour, and for domestic purposes it may be considered obsolete from the point of view of intended purchase; but some consideration of faults common to this type of speaker is justified by the large number that are still in use either as the main speaker or relegated to the duty of extension speaker for occasional use. Furthermore, the majority of this type of speaker in use to-day will be between fifteen and twenty years old, and may be expected to give a certain amount of trouble due to weakened magnets and perished cone-suspension. When replacement of a speaker is contemplated, it is presumed that a moving-coil type will be put into service, but, nevertheless, moving-iron types are often worth repair for extension use.

Complete silence, if the fault is in the loudspeaker, can only be due to open-circuit winding or windings or, alternatively, a short circuit, unless a very obvious mechanical fault has developed, causing the armature to rest on the pole piece. This condition, however, is obvious on the most casual inspection and, furthermore, usually permits the loudspeaker to admit some trace of sound, however unpleasant the quality may be. A simple test with an ohmmeter will serve to reveal either a short circuit or open circuit, but in addition there is the possibility of shorted turns. Here, again, the ohmmeter will indicate the fault, since the bulk of the turns would be shorted if the loudspeaker is completely silenced, and consequently the ohmmeter would give an unduly low reading; various types of moving-iron speaker will have different resistances, but as a guide it may be mentioned that 600 to 1,000 ohms is the usual value. It is not impossible that the short circuit will be present only when a considerable potential difference is applied to the winding, a possibility that may be easily checked by testing the loudspeaker under working conditions, but without a signal, with the aid of a voltmeter connected across the speaker terminals to show whether an adequate voltage drop is obtainable.

Many of the better moving-iron loudspeakers incorporate a simple tone-correction circuit consisting of a condenser connected across the winding, and the possibility that this component has developed a short circuit should not be overlooked if the ohmmeter gives a short-circuit reading when connected across the loudspeaker terminals.

Low Sensitivity.—Both electrical and mechanical faults may be responsible for low sensitivity; the most probable cause is a weakened magnet or shorted turns. If the correct resistance of the coil or coils is known, a simple ohmmeter test may be applied and a direct indication obtained. In the absence of such information the ohmmeter will only indicate whether or not the resistance is reasonable. In the absence of special equipment a weakened magnet can be tested by the usual expedient of removing it from the chassis and testing its strength with a piece of iron. Here, again, it is impossible to give a direct indication, but it may be said that a magnet should be capable of supporting considerably more than its own weight.

Other probable faults resulting in low sensitivity are weakness of the armature spring and mechanical resistance caused by the cone-mounting becoming rigid. These faults, however, usually make themselves apparent by introducing other faults, namely, a tendency for the armature to become temporarily stuck on the pole face when the spring is weak, and frequency distortion when the cone-mounting becomes rigid; that is to say, the high notes are reproduced at something like normal volume, whereas the lower frequencies are seriously attenuated.

Distortion.—The most probable type of distortion met with in the moving-iron speaker is frequency distortion and rattle. The former may be due to the cone-mounting becoming rigid on account of the suspension material becoming perished. Rattle may be due to one of several causes: a piece of grit or other foreign substance between the pole piece and armature, looseness of the armature suspension either at the point where the armature is riveted to its spring or where the spring is anchored to the chassis, and play in the mechanism which couples the armature to the cone. The cure for each of the three possibilities is too obvious to require further comment, but it may be desirable to mention that looseness in the mechanism coupling the cone to the armature may appear perfectly tight when tested with the fingers, but may not be tight enough to remain perfectly rigid at the higher frequencies.

The balanced-armature type of speaker supports the actual armature on pivots, and when rattle is apparent the armature should be tested most carefully for play in the pivots, as this condition is a highly probable one, due to wear; the pivots are adjustable on most of the good balanced-armature speakers.

Moving-coil Loudspeakers.—It will be convenient to deal with the permanent-magnet type of loudspeaker, as its faults are common to both permanent-magnet and energised types. This type of speaker is not prone to loss of sensitivity, although distortion and rattle will sometimes occur. Assuming that the magnet is above suspicion, which will nearly always be the case, distortion can only be due to the spider having become bent, resulting in the speech-coil being at rest either not far enough in or too far in the gap (Fig. 51). Since the suspension material of practically every moving-coil loudspeaker lies in a flat plane, inspection should indicate whether or not the cone is in its correct place.

Rattle.—Tendency to rattle or buzz may be due to four possible causes: a piece of foreign material between the coil and the pole pieces, distortion of the voice-coil, causing it to touch the pole piece as it travels to and fro, loose turns on the voice-coil, or the spider out of adjustment allowing the speech-coil to touch the pole piece. These faults are comparatively easy to locate by inspection or by centring the cone.

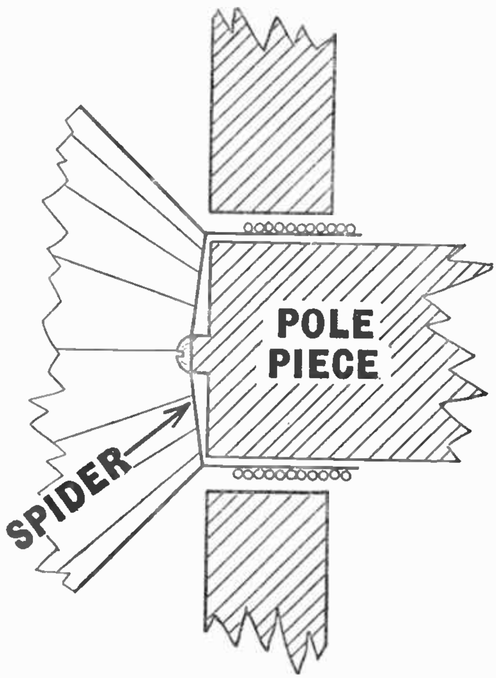


Fig. 51.—This illustration shows how a bent spider will cause the speech-coil to rest out of alignment with the magnet.

Centring the cone is a very difficult operation, and requires a surprising amount of experience to accomplish successfully, particularly if the gap is relatively small. For successful adjustment some form of audio oscillator is almost essential, as the average loudspeaker cone becomes slightly distorted at certain frequencies, with the result that correct centring at one particular frequency may cause rattle at some other frequency. When an audio oscillator is available it should be adjusted to give an output equal to the maximum handling capacity of the speaker and set for a low frequency of about 25 cycles per second; the screw holding the spider is then slightly loosened and the cone moved about until the points are found where chatter is apparent in each direction, the spider is then placed in the mid-point and temporarily secured. It is the ability to find this middle point that is only acquired through practice. An alternative method of centring the cone is by the use of special feeler gauges sold for this purpose, which may be used to test the width of the gap round the speech-coil, adjusting the spider until the gap is equal all round; this method has the advantage of simplicity, but here, again, some experience is required to accurately measure the gap by means of a feeler gauge and, furthermore, *great care is required, as the voice-coil is easily bent and the turns of wire forming the actual coil are easily displaced.*

When the coil has been adjusted, the frequency of the audio oscillator should be increased progressively up to about 7,000 cycles per second, the amplitude of the output being maintained at a wattage equal to the handling capacity of the speaker ; as the frequency is gradually increased it is necessary to listen attentively for rattle. If a rattle should appear, the spider will have to be moved first in one direction and then in another until the frequency band can be covered without chatter or any tendency to buzzing. It should be noted that it is normally impossible to cover the full frequency band at optimum volume without chatter if the speech-coil is warped or if the cone suspension is so unequal that there is a tendency for the latter to be pulled in one direction.

If chatter appears on *one particular frequency*, suspicion should fall on something other than the speech-coil. The speech-coil *may* be responsible, but it is equally probable that a loose terminal, soldering tag, rivet, or some similar item is resonating.

The Mains-energised Moving-coil Loudspeaker.—The remarks made above in reference to permanent-magnet moving-coil speakers are all applicable to the mains-energised type, which has still further possibilities for partial or complete breakdown. Possible faults which may develop in the field-coil are short circuit, open circuit, short to earth, or shorted turns ; the use of an ohmmeter will give a direct indication of a short-circuit or open-circuit condition. Shorted turns may usually be detected in the same way, as the correct resistance is usually marked on the speaker or, alternatively, will be readily available. It is highly possible that the short-circuited turns will only appear when the coil gets hot or even when it reaches maximum temperature, and once again the voltmeter may be more convenient, a reading being taken across the field-coil directly the current reaches maximum, which will normally be thirty seconds or so after switching on ; the reading can be taken again when the coil has been allowed to become heated and the readings compared. It should be noted that a *slight* increase of resistance may be expected consequent upon the wire becoming warm. Shorted turns will, however, produce a decrease of resistance.

A short circuit between field-coil and earth may appear at any temperature or, alternatively, at some particular temperature, and in exceptional cases may only appear when the current passing through the coil has an alternating-current component. If the loudspeaker chassis is not earthed the presence of a leak may be unimportant, but if the chassis is earthed a milliammeter in the earthing wire may be used to indicate the presence of current passing. It should be understood that a small alternating current may be perfectly normal, but D.C. should be entirely absent.

The Humbucking Coil.—The possibility of a fault existing in the humbucking coil will normally come under review when the hum-level of the receiver is above normal. As a preliminary test the humbucking coil may be short circuited to observe whether or not it is functioning. If this procedure does not materially increase the hum-level, a short circuit may be suspected. The average humbucking coil has a resistance considerably less than 1 ohm, and may not be measurable on some types of resistance-measuring instruments. The possibility of the coil being open-circuited does not arise, as this condition will break the speech-coil circuit and render the loudspeaker inoperative.

Deformation of Speech-coil by Heat.—If the temperature-rise of a moving-coil loudspeaker is fairly considerable, the temperature of the speech-coil may cause it to warp and chatter. In extreme cases the coil former may warp to such an extent that it presses on the pole piece hard enough to reduce volume considerably, in addition to causing very bad distortion; this condition cannot be cured by any other means than fitting a new cone and coil-assembly or by reducing the temperature-rise. The latter is obviously impracticable if the current passing through it is normal, unless it is possible to improve the ventilation of the interior of the receiver. The usual cause of this trouble is that the coil former is made of material the thickness of which is not uniform. This remark applies particularly if the former is made of metal such as aluminium. Warping in cardboard formers is usually due to insufficient or uneven varnishing or impregnation, permitting damp to enter the actual material.

The Loudspeaker Transformer.—The several tests mentioned in the foregoing part of this chapter have ignored the possibility of a fault in the loudspeaker transformer, and attention can now be directed to this component. The secondary winding comprises a few turns of comparatively thick wire and trouble is rare. The same remarks, however, do not apply to the primary, where trouble is fairly prevalent, and which usually takes the form of a break in the wire which may be easily traced by means of an ohmmeter, milliammeter, or even a voltmeter, since a simple continuity test is all that is necessary. The possibility of shorted turns must not be overlooked, but this condition is usually of short duration, as the primary current will be considerable, even in battery receivers, and the shorted turns usually develop into a broken winding within a fairly short space of time; assuming that a reasonably large number of turns are shorted. If only a few turns are shorted it is unreasonable to suppose that the ear will detect any fault, and the question does not therefore arise. Those who are fortunate enough to possess an oscillograph, and are competent to use it for the more advanced tests, can test for shorted turns by measuring the phase relationship between primary and secondary.

The loudspeaker transformer is often placed close to the accumulator in a battery receiver, and it is quite frequently suggested that fumes from the accumulator cause premature transformer breakdown. Investigations conducted on transformers with broken primaries do not suggest that this explanation is correct, since the actual break occurs in the centre of the winding as often as at any other point, and as the winding is usually impregnated with wax, pitch, or some other material, it is obvious that breaks would occur more frequently on the outer turns if fumes from the accumulator were, in fact, responsible for the damage.

Resonance.—It frequently occurs that what appears to be loudspeaker resonance is, in fact, resonance elsewhere in the receiver actuated by sound propagated from the diaphragm. Such resonance is often exceedingly difficult to locate, as it may be actually inside a component or even in a valve ; owing to the acoustic properties of the cabinet the resonance often appears to come from a totally different direction from which it does, in fact, originate. Whether or not the loudspeaker is at fault can be determined by extending the speaker on long leads and taking it sufficiently far from the receiver to determine whether or not the resonance is coming from it. Unfortunately, this procedure will usually stop the resonance if it is coming from the receiver itself, but, nevertheless, serves to prove that the loudspeaker is responsible if resonance continues.

Resonance in the receiver may often be traced by holding every individual part in turn, an operation that calls for patience rather than skill. It is perhaps not out of place to mention that care should be taken to avoid the risk of electric shock, particularly in the case of universal receivers, when the chassis and numerous unexpected components are alive at the full mains potential. Practically any component may have some loose tag or piece of metal capable of vibrating, but attention is directed to the possibility of a noisy valve, particularly if the sound suggests glass ; many valves have a piece of glass tube in the base to protect the anode lead from short circuit, and this is capable of vibrating at a very precise frequency and is therefore very elusive, as it will normally occur for very short periods at a time.

CHAPTER 13

TESTING COMPONENTS

In the several foregoing chapters dealing with fault-finding brief mention has been made from time to time of the necessity for testing various components as occasion may demand. In the appropriate chapter valve testing is fully dealt with, and this chapter is devoted to methods of testing components in so far as this may be done with a few simple instruments. Certain components cannot be completely tested by such means, in which case substitution is the usual remedy. For example, a Litz-wound coil may have normal D.C. resistance and irreproachable insulation, but may introduce almost unbelievable damping if one of its many strands are broken. It will be appreciated that even if the correct D.C. resistance is known, it will be impossible for practical purposes to detect the difference if a single one of, say, twenty-seven strands is broken. Such a break would increase the D.C. resistance by rather less than 4 per cent., but may well increase the high-frequency resistance by a hundred times or more.

The methods of testing components given below are not necessarily the only available means, but are offered as suggestions which are as free as possible from pitfalls; in the interests of quick reference the various classes of components are dealt with separately.

Resistances.—The obvious method of testing resistances is with an ohmmeter or, in the absence of such an instrument, by applying a known potential across it and measuring the resulting current. This method is perhaps entirely satisfactory in the case of wire-wound resistances, but can be most unsatisfactory for those resistances which consist of a semi-conductive deposit on an insulated former, and to some extent for the solid composition types. Resistances in these classes may give a correct reading when cold and quite another reading when raised to working temperature. The most direct method of testing the resistance is to apply a potential across it that will cause current to flow that is equal to that flowing through it when in normal use or, alternatively, a current that will cause the resistance to dissipate its maximum rated wattage. A voltmeter may be connected across the resistance, which will give the voltage drop across it, and with a knowledge of the current flowing. Ohm's law can be applied, which will show directly the resistance under working conditions.

To take an example, assume that a resistance of 100 ohms, having a rating of 1 watt, is suspected of unduly changing its resistance when warm.

Apply a potential difference of 10 volts across the resistance, when it should pass 100 milliampères; 100 milliampères passing through 100 ohms will dissipate 1 watt, and any change of resistance must change the voltage or current or both, according to the nature of the supply. When the resistance is properly warmed its value may be checked by noting both current and voltage. In practice, the resistance can be tested quite simply by allowing it to warm up in the receiver in which it is used and measuring the current flowing through it and the voltage drop across it when quite cold, and again when it has reached maximum temperature. It should be understood that some change of resistance must be expected, but this should not exceed about 10 per cent. At first sight it might appear possible to test the resistance actually in the receiver by measuring the voltage drop across it when cold, and again when hot, but this is not satisfactory, as the voltage across it may well be varied by a change elsewhere in the circuit, and consequently it is necessary that both voltage and current be measured on each occasion.

It should not be assumed from the above remarks that every resistance in the receiver should be tested in this elaborate manner, as normally an ordinary test with an ohmmeter will suffice; the more elaborate test being applied when a few resistances come under suspicion, due, perhaps, to an unaccountable change in the anode current of a valve after the receiver has been working for a few minutes and the valve itself is known to be normal.

Certain types of resistance are prone to a peculiar fault when the potential difference across them is exceptionally high, a condition that is often met with in a television receiver. A resistance of certain type may be perfectly normal when cold or when working at its maximum temperature, but will virtually flash over if a potential of, say, 5,000 volts appears across it, even though the rated wattage of the resistance has not been exceeded. This trouble can be due to one of two causes, arcing between the granules of which the resistance is composed, or arcing between points which are close together but at considerable difference of potential; the latter remark applies to that type of resistance which is formed by a semi-conductive coating on an insulating rod, but which has a spiral cut to lengthen the resistance path. Such a resistance is illustrated at Fig. 52, the dark portions representing the resistive element and the white line the comparatively small gap between adjacent "turns" where, under certain conditions, an arc may occur.

Fig. 52.—A spiral-cut resistance which is referred to in the text.

Condensers.—Condensers of all types other than electrolytics can be tested very simply. To test for leak an ohmmeter or other resistance-measuring device can be brought into service, but it should be borne in mind that a condenser may develop a puncture in the insulation and show a resistance of infinity when the potential difference across it is relatively low, but show poor insulation if the potential difference is high. Fig. 53 shows the circuit of a simple but satisfactory arrangement for testing condensers under conditions of high voltage. Adequate high-tension voltage is obtained by a simple power pack, which may well be made from components gathered from an old receiver; the condenser to be tested is placed in series with a relatively high resistance, of adequate wattage, and connected across the appropriate voltage tapping, a milliammeter being in series with the condenser. If the insulation of the condenser is adequate, current will not flow; but if, on the other hand, the condenser should develop a short circuit, the flow of current will be limited

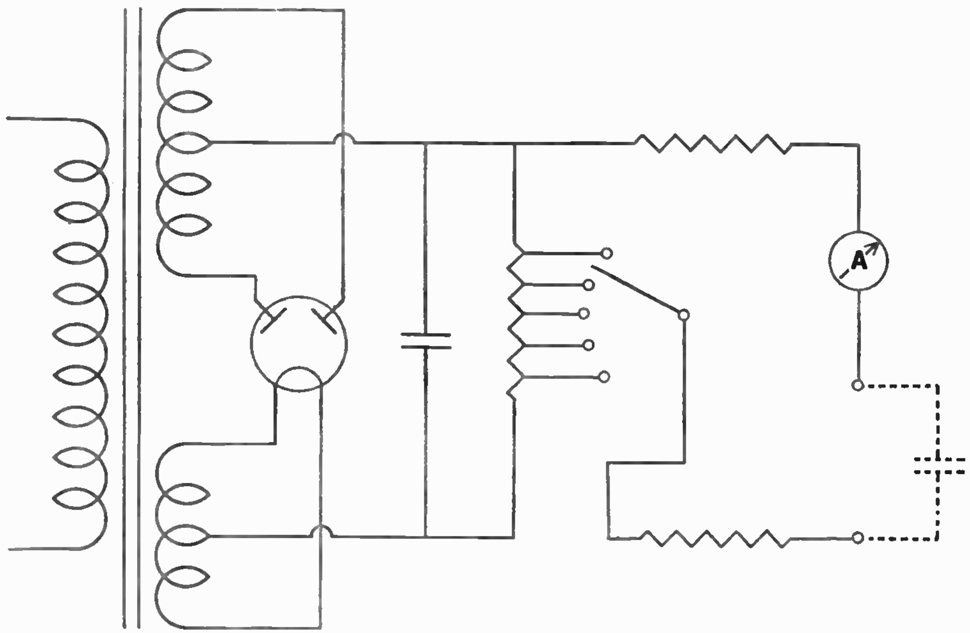


Fig. 53.—An arrangement for testing condensers for leakage which has the advantage over usual methods that the full working voltage may be applied. A tapped resistance permits the selection of a suitable voltage consistent with the type of condenser under test. A tapped resistance is used in preference to a potentiometer, to dispense with a voltmeter.

by the fixed resistance and the meter will not be damaged. Obviously the resistance must be chosen so that full-scale deflection is obtained on the meter if the condenser under test shows a complete short circuit. For example, if the power pack is capable of giving a rectified output of 1,000 volts and it is proposed to use a milliammeter with a full-scale deflection of 1 milliampère, then the resistance should be 1 megohm, or, to give a margin of safety, say 1·2 megohms. As an additional precaution this latter figure could be made up of two resistances in series of 600,000 ohms each, so that in the event of an accidental short circuit across one resistance the meter would not be too badly damaged. To make such a precaution effective the two resistances should be placed in different parts of the circuit, as shown at Fig. 53.

The capacity of a condenser can be measured most conveniently by some form of commercial capacity meter, such as that incorporated in most test-sets; otherwise it may be measured with an A.C. ammeter or milliammeter if alternating current is available. Condenser and meter are connected in series across the alternating-current mains, the mains voltage will be known, the current may be read, and the capacity determined from the following formula:

$$C = \frac{I}{\omega V}$$

when C is the capacity of the condenser in farads, ω equals $2\pi f$ (f equals the frequency of the mains in cycles per second), and V equals the voltage of the mains. Fig. 54 shows a modification whereby a resistance is included to prevent damage to the meter if the condenser develops a short circuit. The presence of this considerably complicates the calculation of capacity, and the reader must decide between this inconvenience and the possibility of damage to the meter. As a compromise, the resistance may be employed for the initial test and then short circuited.

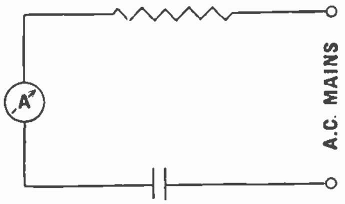


Fig. 54.—A method of determining the approximate capacity of a condenser. This arrangement must not be used for electrolytic types.

The capacity of the condenser may also be measured by means of a neon lamp used in conjunction with a known voltage and a known resistance. The circuit and other particulars of this arrangement will be found in Chapter 1 of this volume. There is another very simple method of testing a condenser which will give a very good *indication* of insulation only. It consists of charging the condenser by flashing a suitable voltage across it, and after an adequate time-interval discharging it by some convenient means, such as a screw-driver with an insulated handle, the size of the spark obtainable being an indication of the condition of the condenser. Condensers that must have really high insulation, such as those used for inter-valve coupling, should be allowed to stand after charging for a quarter of an hour or more. On the other hand, when the condenser is used in a position where really high insulation is not required, such as the smoothing condensers in the mains pack, then a period of five minutes, or even less, may be considered satisfactory. Although this test is a simple one, some experience is needed to know the intensity of spark that should be expected from condensers of various capacities charged at varying voltages. Generally speaking, a condenser should be charged with the voltage that it has to withstand in normal use. This test requires modification for capacities under about $\cdot 1\mu F$, as the spark obtained will be too small to give a proper indication. For small capacities the condenser may be charged from a $1\frac{1}{2}$-volt cell, and after an appropriate period may be discharged into a pair of headphones, which should give a loud click. In the absence of headphones the condenser may be charged from a source of higher potential, such as a high-tension battery, and discharged through a high-resistance voltmeter, which will give an appropriate kick of the needle.

The testing of an electrolytic condenser is somewhat difficult without specialised apparatus, as it is not permissible to apply alternating current to this class of component. It is generally satisfactory, however, to test for leakage only, which will also indicate loss of capacity, because the latter is almost invariably accompanied by an increase in the former. The procedure is to apply a D.C. voltage at the *correct polarity* and equal to the working voltage and measure the current that flows with a milliammeter. As a general guide, the current should not exceed about ·07 milliampère per microfarad.

The above tests cover the usual faults to which condensers are prone, but there is always the possibility that a condenser has become inductive to an objectionable extent, and this should be suspected when instability is present. The most convenient method of checking this possibility is to connect a non-inductive condenser across the suspected condenser, when disappearance of the instability will indicate that the condenser requires replacing.

Tuning Coils.—Inductance bridges can be reasonably considered as laboratory equipment, and will not therefore be available in normal circumstances. The only possible means, therefore, of testing tuning coils is by measuring their resistance. If a manufacturer's service manual appropriate for the receiver under test is to hand, these values will usually be included. In the absence of such information the values may be taken to see if they are reasonable; that is to say, short-wave coils will usually have a resistance of something less than 1 ohm, medium-wave coils a few ohms, for windings other than the aerial coil, which may be 10 ohms or more, and between 10 and 50 ohms for long-wave windings, other than the aerial coil, which may be 100 ohms or more. Windings of intermediate-frequency transformers are liable to considerable variation in sets of different manufacture, but will usually be between 2 and 30 ohms. It might appear that these figures are too wide to be of real assistance, but it should be realised that a complete break in the winding will show infinity, and anything in the nature of a dry joint will normally increase the resistance to an extent that will make the reading obtained highly suspicious. When selecting points for connecting the ohmmeter, *care should be taken that the wave-change switch is not included in the circuit.*

Generally speaking, the possibility of leakage between coils or between a coil and earth can be checked by means of an ohmmeter. There are, however, exceptional circumstances when an insulation resistance of, say, 100 megohms is inadequate between two coils used for inter-valve coupling when the low-potential end of the secondary is connected through a high resistance to earth. In such circumstances a current of 1 microampère flowing between the coils and passing through a resistance of 2 megohms would vary the grid potential of the following valve by 2 volts. The ordinary ohmmeter will not read such values, and recourse must be made to the indirect method of measuring the anode current of the following valve and then breaking the high-tension circuit to the preceding valve and noting if the anode current varies. Such an arrangement is shown at Fig. 55, the letter "X" denoting the point for breaking the high-tension circuit and "M" the lead in which the milliammeter should be inserted.

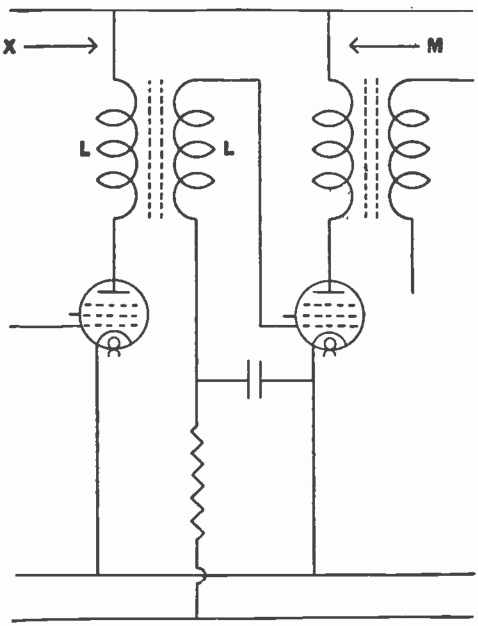


Fig. 55.—Skeleton circuit, showing an indirect method of measuring for leakage between the coils LL. A suitable milliammeter is inserted at the point marked M, and the high-tension feed is broken at the point marked X.

Switches.—Loss of stage gain or selectivity may often be traced to high-resistance contacts on a wave-change switch, which may be checked by measuring each contact in turn when in the closed position, care being taken that the contacts are not virtually short circuited externally by, say, a short-wave coil which is directly across the switch contact. It is impossible to suggest a definite resistance that may be acceptable for switch contacts, but it is apparent that on the usual type of switch all the contacts should have approximately the same value, and any contacts giving a reading considerably in excess of the others should be suspected. As a very rough guide, however, a really good switch will have a contact resistance of the order of ·1 ohm, but switches used with coils having a fair high-frequency resistance can be somewhat higher without introducing any apparent loss of efficiency.

Most of the switches in a receiver can be tested by means of an ohmmeter, but those that are not associated with tuning coils may show a resistance of ·5 ohm or so without giving grounds for suspicion. A main switch may show a fairly high resistance, often several ohms, particularly if the contacts become slightly burned through use. A mains switch which requires attention will usually show signs of excessive arcing when switched *on*.

Valve-holders, Plugs, and Sockets.—The contact between a valve-pin and its socket or between a plug and its socket may be checked by means of an ohmmeter. In the case of plugs and sockets, the ohmmeter should, when possible, be connected to the socket and the far end of the lead which is fixed to the plug, so that the contact resistance between plug and socket will be shown and also the contact resistance between the lead and the plug. This latter remark applies particularly to those plugs in which the lead is fixed by means other than soldering, as, for example, a wander plug. The average plug, which is fixed to its lead by mechanical means, will often show surprisingly high resistance between lead and plug, since the design of many of these accessories is indifferent or even thoroughly bad.

Low-frequency Transformers and Chokes.—Chokes and transformers of all descriptions can be tested for continuity with an ohmmeter or a voltmeter and battery. If the D.C. resistance of the winding is known, the ohmmeter will give a reasonably accurate indication of shorted turns. If the correct D.C. resistance is not known, or cannot be obtained, the ohmmeter will only give a vague indication, and substitution is the only practicable procedure—unless specialised equipment is available, combined with the necessary skill to carry out measurements of phase shift between the windings and to interpret the result in terms of shorted turns.

Mains Transformers.—If a multi-range A.C. voltmeter is available, it is comparatively easy to apply effective tests to a mains transformer, as it is simply a matter of measuring the voltage across each secondary winding in turn. The voltage to be expected from each low-tension secondary can be easily determined by noting the heater rating of the valve or valves that it supplies; that is to say, a winding supplying the heater of normal A.C. mains valves should measure approximately 4 volts R.M.S., or if the valves are of the octal base type the heater rating is usually 4 volts or 6·3 volts. The same principle may be applied to the low-tension winding feeding the rectifier or filament. The voltage across the high-voltage secondary can be easily checked if the correct figure is known, otherwise an indication may be taken by measuring the voltage across each half, when reasonably similar readings can be expected and any serious discrepancy can be taken to indicate the existence of shorted turns, or a rectifying valve, the two halves of which have dissimilar characteristics. The latter possibility can be excluded by substituting another valve, or if it is thought worth while, by reversing the leads to the two anodes.

Other Components.—The remaining components not mentioned above, such as loudspeakers, pick-ups, and tuning indicators, can be tested by obvious means to see whether or not they are functioning or completely inoperative. Loudspeaker faults are dealt with in a separate chapter, while pick-ups can be tested for insulation or short circuit by means of an ohmmeter, although, generally speaking, test by trial is satisfactory. The method of testing the various types of tuning indicators cannot be gone into in detail, but the mechanical types can be tested for open circuit or short circuit by means of an ohmmeter, whereas what might be termed the thermionic types will usually be tested by substitution when they are noted to be inoperative.

It cannot be too strongly emphasised that it is essential to make certain that a particular fault is not due to a defective valve. An enormous amount of time can be wasted in testing components when actually the trouble is due to a valve. As pointed out in the appropriate chapter, substitution is the most satisfactory method of checking valves, as even quite elaborate valve testers may occasionally fail to reveal certain types of faults.

CHAPTER 14

FAULT-FINDING PROCEDURE (A SUMMARY)

THE preceding chapters in this volume have all dealt with aspects of fault-finding in service engineering, and the author has endeavoured to deal with the various types of faults and to indicate suggested methods of locating them, in so far as it is possible to generalise on faults which can occur in widely different types of receivers. Such generalisation must unavoidably be a trifle vague, and to complete the section it is necessary to reverse the process and summarise the suggested procedure for fault-finding on a particular receiver. As the example it will be convenient to use the same five-valve A.C. mains receiver as that employed in Chapter 5, Volume II, since those who have read the full description will be now more or less familiar with it, and thus reduce the necessity for back reference to the illustration in question, which, unfortunately, is unavoidable.

The summary of fault-finding below is sub-divided into sections, many of which are appropriate for a particular symptom, since, generally speaking, fault-finding will not be undertaken unless some fault is apparent to the ear, and the nature of the fault should lead with some directness to the cause. As an introduction to this summary the author would like to draw attention to what appears to be an obvious fact—if all components and valves in a receiver are correct and the wiring is intact and there are no dry joints, it follows without any possible doubt that the receiver must work in a normal manner ; if the receiver does not work in a normal manner, it follows with equal certainty that some component or connection is faulty. This seemingly obvious statement is emphasised solely because of the large number of amateurs and even service engineers who have written for advice from time to time and quite unashamedly stated that a certain receiver has this or that fault but everything individually has been tested and found perfect ; this outlook is the wrong angle from which to tackle a fault. If one is present, there is a cause for it, and it has got to be found or defeat admitted.

Preliminary Steps.—Generally speaking, it is useless to attempt fault-finding with the chassis in its cabinet ; unless valves or loudspeaker are suspected—which may be tested by substitution or by the use of a valve tester in the first case or by the use of an extension speaker in the second case. If the receiver is completely " dead," check the following points :

(1) Ascertain that the mains supply point is alive, and, if the heaters of valves do not light, inspect the mains plug attached to the receiver and check that its connections are tight.

(2) That the plugs making contact between receiver, power pack, and loudspeaker are making good contact.

(3) Inspect aerial and earth, to avoid the possibility of a dead short or other circumstances that would make the receiver "dead" on even the local station.

If the receiver is merely weak or, alternatively, becomes over-heated, check the mains voltage adjustment. Most receivers have about three tappings on the mains transformer, each one covering a certain range of mains voltages; the range covered by each tapping is not always equidistant from its neighbours, and care should be taken to see that the tapping used is that intended by the manufacturer for the particular mains voltage. When possible, the mains voltage should be actually measured, as cases are not unknown of considerable discrepancy between the mains voltage as declared and as supplied.

Weak Signals.—Check coils and switch contacts for continuity. If the trouble is limited to one band, suspect the appropriate radio-frequency coils, but if on all bands, suspect intermediate-frequency coils. Test C_1, C_{15}, C_{16}, and C_{36} for open circuit or low capacity. Test for short circuit C_7, C_{14}, and C_{18} (*i.e.* the three sections of the tuning condenser); also C_{30}, C_{37}. Test C_{38}, C_{39}, and C_{40} for leakage. Ascertain that the triode section of the frequency changer is oscillating by temporarily shorting C_{18} and noting whether the anode current changes; a change denotes that the valve is oscillating. In order to avoid unsoldering, a change of current may be noted as a change of voltage across R_2 by means of a voltmeter across this resistance. The high-frequency stage may be tested by connecting the aerial to the hexode-control-grid of V_2 and then to the control grid of V_1 and then to the aerial terminal. An increase of signal strength should be apparent on making each connection in the order stated.

If all efforts to trace the cause of weak signals fail, the ganging may be suspected. No attempt should be made to check alignment of the receiver unless suitable equipment is available. The question of realigning and the procedure to be adopted is dealt with in Chapter 10, Volume III, which is devoted exclusively to this subject. It may, however, not be out of place to emphasise the desirability of obtaining the manufacturers' trimming and padding frequencies for the particular receiver before realignment is attempted.

Decrease of Selectivity.—Bearing in mind that the receiver under discussion is a superheterodyne, lack of selectivity may manifest itself in two ways: (1) lack of adjacent-channel selectivity; and (2) whistles. When the necessary equipment is available the alignment should be checked, particularly in the intermediate-frequency circuit, if lack of selectivity causes whistles. If alignment is found to be satisfactory, attention should be directed to the possibility of a bad connection in the tuned circuit introducing resistance. If lack of adjacent-channel selectivity is apparent. the intermediate-frequency coils should be suspected, otherwise the radio-frequency coils should receive attention. The unwanted resistance may take the form of a dry joint, high resistance contact in the wave-change switch, or in the case of a Litz-wound coil, to a single broken strand; this latter possibility may be checked by endeavouring to tune in a station that is normally weak; with a strand of the Litz wire broken the station will be unobtainable or very greatly attenuated. Other possible causes for loss of selectivity are softness of the valves V_1, V_2, or V_3, a leak in one of the trimming condensers, or a bad joint in the tuned circuit as a whole.

Instability.—Test C_6, C_{17}, C_{26}, C_{32}, C_{38}, and C_{41} for open circuit. This can be most conveniently carried out by paralleling each condenser with another known to be in good order. Carefully inspect all earth bonding, *i.e.* ascertain that all coil-cans are making good electrical connection with the chassis and that all leads connected to the chassis directly or indirectly are also making good electrical contact. Check all switch contacts, including S_4, and test all grid return circuits for continuity. If these tests fail to locate the cause of instability, check the alignment of both radio-frequency and intermediate-frequency circuits.

Background Noise.—A noticeable increase in the level of background noise may be due to some addition to the electrical machinery in the neighbourhood. To check this possibility remove the aerial and earth; if this results in the noise-level being much reduced, the receiver is probably not the cause of the trouble. If, on the other hand, the noise-level continues more or less unchanged, test all valves, preferably by substitution or, alternatively, by means of a valve tester or by tapping each valve in turn; the latter procedure will only show certain types of faults. Inspect all wiring and test all joints, and note particularly that a wire has not become displaced and is causing a partial short circuit. Test or inspect valve-holders, switches, mains leads, plugs, and sockets. If this simple inspection fails to reveal the cause of the trouble, follow the more detailed procedure outlined in Chapter 8, Volume III. The possibility of incorrect alignment must not be overlooked, as a sudden change of alignment due to a mechanically unstable component will bring about a proportionate change in the signal to noise ratio of the receiver.

Mains Hum.—If possible substitute the rectifier V_6. Alternatively, test the current of each anode to see that both are functioning and passing reasonably similar currents. Test R_{14} and R_{15} for continuity. Each half should be tested separately, which necessitates the use of an ohmmeter, or, alternatively, disconnection of one end, as there is an alternative shunt path which will prevent a short circuit from being apparent, even if one half of the resistance is broken. Substitute the valves if possible, or test for faulty insulation between cathode and heater, particularly if hum-level increases or only becomes apparent when a signal is tuned in. Test C_{39} and C_{40} for loss of capacity and C_{41} for short circuit; test also C_{38} if hum-level increases when signal is tuned in. Test humbucking coil for short circuit and loudspeaker field for short-circuited turns. Ascertain if mains transformer core and shield are properly earthed to chassis. If mechanical hum is apparent, see that the mains transformer is securely bolted or riveted to the chassis, and test for loose laminations in the mains transformer by inserting a sharp instrument between the laminations at various points.

Improper Action of Automatic Volume Control.—Test for normal action of automatic volume control; insert a milliammeter in the anode circuit of V_1, the hexode anode circuit of V_2, and the anode circuit of V_3, and note that the reading falls appreciably in each case when a strong signal is tuned in. To test that the delay voltage is present, tune in a very weak station and short circuit R_{22}, which should not result in any increase in volume. If for any reason a strong signal is not available to test the normal functioning of the system, test for a change of anode current in each valve by inserting a milliammeter in the anode circuit of V_1 and short circuit C_8, this should appreciably increase the anode current, particularly if a signal of even moderate strength is tuned in; next connect the milliammeter in the hexode anode circuit of V_2 and short C_{13}, then insert the milliammeter in the anode circuit of V_3 and short circuit C_{26}. If the automatic volume control circuit is found to be inoperative, test C_{30} for open circuit and the top end of C_{30} and the anode of V_3 for continuity (this test must be carried out with the mains switched off). Test for continuity between the automatic volume control diode and grid of V_1, V_2, and V_3 in turn, also test C_8, C_{13}, and C_{26} for short circuits. Substitute V_4. Inspect wiring of automatic volume control line as a whole for short circuit. If the receiver is more or less rendered " dead " due to excessive negative voltage as revealed by short circuiting R_{22} when the receiver is tuned to a fairly powerful station, test C_{30} for short circuit or leak and substitute V_4 or test for defective insulation between diode and cathode.

Miscellaneous Faults.—There are a variety of faults, such as intermittent faults, fluctuating volume, distortion, intermittent blasting, which can only be determined by a systematic test of the receiver as a whole. The systematic checking of a receiver by measurement of anode current is dealt with in Chapter 4, Volume III, but the specific procedure is given below, making direct reference to the components in the circuit under discussion.

Abnormal High-tension Voltage.—Test C_{38}, C_{39}, and C_{40} for short circuit; test C_{40} also for open circuit. Test mains transformer, preferably by taking a voltage reading across the high- and low-tension windings feeding the rectifier and test the loudspeaker field for open circuit. Examine plugs and sockets coupling power pack with the mains chassis for bad contact or open circuit. Make a rough test of current taken by each valve to ascertain if sufficiently abnormal to materially affect the total high-tension voltage.

METHOD VERSUS MUDDLE

A contrast in radio service workshops; a properly planned workshop like the example illustrated in the upper picture is not only a paying proposition but builds up goodwill by making possible quick and efficient repairs; these two illustrations were made available by Messrs. E.M.I. Service, Ltd., who specialise in planning radio service for the dealer.

Abnormal Heater Voltage.—Test heater winding of transformer, preferably by a voltage reading ; if greatly reduced, check the possibility of a short circuit on the dial light circuits or a short circuit across half of R_{14} or R_{15}, according to whether the valves V_1, V_2, V_3, and V_4 or, alternatively, V_5 have an abnormal potential across the heater circuit. Inspect the heater circuit as a whole for dry joints. The possibility of a short circuit across the heater in the actual valve itself can be checked by withdrawing V_1, V_2, V_3, and V_4 in turn ; an internal short circuit in V_5 would be at once apparent, as the filament would glow very brightly.

Operating Conditions of V_1 Abnormal.—If abnormal condition is peculiar to one waveband, check appropriate contacts of wave-change switches S_1 and S_2 and appropriate aerial and high-frequency coupling coils. Test R_1, R_{19}, R_{21}, and R_{22}. Test C_6 for short circuit or leak. If anode current is too high, test C_8 for a short circuit or leak, substitute valve by another known to be in good order or test valve. Check valve-holder connection and associated wiring. It should be noted that the screening grids of V_1, V_2, and V_3 are in parallel ; if, therefore, the screening-grid voltage of V_1 (and consequently the anode current) is too low, substitute V_2 and V_3 or measure screen current of V_2 and V_3.

Operating Conditions of V_2 Abnormal.—Test primary of intermediate-frequency transformer for open circuit. Test R_1, R_2, R_{20}, R_{21}, and R_{22} for correct values. If the abnormal condition is on one waveband only, check the appropriate switch-contacts of S_2 and the secondary of the appropriate coil. It should be noted that S_3 is isolated from the D.C. point of view and cannot, therefore, affect the static operating conditions of the valve. Test C_6, C_{17}, C_{13}, and C_{26} for a short circuit or leak. Note that the screening grids of V_1, V_2, V_3 are in parallel, therefore substitute V_1 and V_3 or test screen current of V_1 and V_3 if screen voltage and, consequently, hexode anode current are too low. Check that the triode section is oscillating by shorting C_{36} and noting that the anode current increases or, more conveniently, note that the voltage drop across R_2 increases. If the triode is not oscillating, test the oscillator coils for continuity and the wave-change switch. Test C_{15} and C_{16} for short circuit, also test for capacity by means of a suitable measuring device or by substitution. If the triode fails to oscillate on one waveband only, test C_{19}, C_{20}, C_{22}, and C_{23}, as may be appropriate, for short circuit. If all wavebands are affected, test C_{18} for short circuit.

Operating Conditions of V_3 Abnormal.—Test primary of second intermediate-frequency transformer for open circuit. Test R_5, R_1, R_{21}, R_{22}, and R_{16} for continuity and correct value. Test C_6, C_{30}, and C_{32} for short or leak, substitute or test V_3, and check connections to valve-holder. Note that the screening grids of V_1, V_2, and V_3 are in parallel. If, therefore, screen voltage is low (and consequently anode current is low) substitute V_1 and V_2 or measure the screen current of these valves.

Operating Conditions of V_4 Abnormal.—Test R_6, R_7, and R_{10} for continuity and C_{36} and C_{37} for short circuits. If grid bias is low or absent, check that R_{16} is not short circuited and test C_{35} and C_{41} for short circuit. If an appreciable potential difference appears between the detector diode and cathode, test for leak between primary and secondary of the intermediate-frequency transformers. Substitute V_4 or test, also check valve-holder for good contact with valve-pins.

Operating Conditions of V_5 Abnormal.—Test primary of loudspeaker transformer for open circuit. Check connections to loudspeaker. Test R_{16}, R_{17}, and R_{18} for correct value, and R_{11}, R_{12}, and R_{15} for continuity; also check that one half of R_{15} is not shorting. Measure voltage across filament as a check on the appropriate low-tension heater winding. Substitute V_5, or test. Note that a very slight leak across C_{38} will produce a serious change of grid voltage of V_5, owing to the relatively high resistance of R_{12}.

Operating Conditions of V_6 Abnormal.—Incorrect voltage at both anodes of the rectifier valve will influence high-tension voltages throughout the receiver. Furthermore, a discrepancy of serious proportions between the anodes will result in mains hum, unless the smoothing is exceptional; if, however, operating conditions of V_6 are incorrect, test heater winding by a voltage measurement across it. Test each half of the high-tension secondary by means of a voltage reading and check for leak between either winding and core. If over-heating of mains transformer is apparent and secondary voltages are normal, and total anode current to all valves is also normal, then the primary may be suspected. If the correct wattage of the receiver is known and a wattmeter is available, a direct measurement can be made, otherwise the approximate wattage can be obtained by measuring the primary current and multiplying by the supply voltage. Note particularly that the product of the voltage and current is known as volt-ampères and will not agree with the figure quoted by the manufacturers for the consumption of the set, since voltage and current will not be in phase. The actual phase displacement varies with the design of the transformer, but for ordinary moderately priced receivers the power factor will be in the neighbourhood of ·8, that is to say, the product of volt-ampères must be multiplied by ·8 to arrive at the nominal wattage consumption. If the secondary windings are behaving normally and the primary wattage is excessive, check for leak between primary and core, and if this is found to be satisfactory it is reasonable to conclude that an appropriate portion of the primary winding is shorted internally.

General Note.—Before attempting to trace any but a " normal " fault it is desirable to ensure that the trouble is in the receiver and is not due to some external cause; as an illustration of the type of possibility that the author has in mind, details are given below of a personal experience.

A number of two-valve mains receivers were installed in the several buildings which form an isolation hospital on the northern outskirts of London. It was only intended that the National and Regional programmes should be received, and for various reasons, which need not be entered into here, it was necessary to use indoor aerials; and not withstanding the fact that the buildings were of corrugated iron, trouble was not anticipated, as the Brookman's Park transmitter could be clearly seen from the hospital grounds.

Five of the six receivers functioned in a perfectly normal manner, but the other one had the peculiar habit of suddenly falling to a volume-level that was barely audible. Unlike fading, the change from normal to diminished volume occurred apparently instantaneously. The whole affair appeared to be rather a mystery, and the usual steps were taken, and eventually a new receiver was installed with a new aerial and earth connection and a recording voltmeter was placed across the mains; but the trouble persisted, though the voltmeter registered perfectly steady mains voltage.

At this stage the author was asked to investigate the matter, and at first there did not appear to be any solution. In an endeavour to find some possible cause the duration of maximum volume and minimum volume was recorded, when it became apparent that the periods of low volume were always of about the same length, approximately a quarter to a third of a minute, but the duration of the periods of normal volume varied between half a minute and five minutes.

The metal building was comparatively well insulated from earth, since it simply rested on the brick foundation, water pipes and electric-light conduit being run through the wooden uprights. In view of the resistance between the building and earth, the former became a vast aerial, and normal volume was obtained with reaction in a certain position, but when a bucket of water was thrown down the sink the insulation between the building and earth fell to a very low figure, and consequently the volume of reception was reduced accordingly. Once the trouble was found the remedy was simple, as it merely entailed earthing the building so that the volume was permanently reduced to the low level which, in turn, could be overcome by advancing reaction to an appropriate degree.

When dealing with official buildings peculiar regulations are sometimes enforced, so on this occasion it was considered discreet to earth the building "accidentally" by using a bare earth wire and twisting it round one of the framework bolts ostensibly to hold it in position. This experience is included as an example of reception being affected by certain circumstances outside the control of transmitter and receiver. It is surprising how often even really experienced service engineers will overlook the possibility of reception being affected by some such external cause as that outlined above.

As a further example of faults that appear to arise in a receiver, but which are actually attributable to external causes, mention may be made of bad house-wiring installation. A bad contact in a house-wiring circuit may result in a significant fall of mains voltage across the receiver input when a relatively heavy load is switched on elsewhere in the circuit. This fall of voltage may cause a number of faults, including, for example, complete silence on the long waveband of a superheterodyne due to the high-tension voltage being insufficient to allow the frequency changer to oscillate.

Signals Absent on Certain Frequencies.—If signals are absent at the low frequency end of the scale, check oscillator anode voltage and if normal suspect low efficiency of the oscillator valve or a leak across the appropriate oscillator circuit tuning condenser, also inspect and, if necessary, clean relevant switch contacts. If signals are absent on one complete waveband, but normal on the other waveband or wavebands, suspect any of the faults outlined above but also check for a break in the appropriate oscillator coil and short or open-circuited trimming, and where appropriate, padding condenser.

CHAPTER 15

LOCAL INTERFERENCE

THE term "local interference," in so far as it is used as a heading to this chapter, is intended to mean interference with radio reception caused by electrical machinery and other electrical equipment in the neighbourhood of the receiver; in other words, "man-made static." Those who are fortunate enough to live in an electrically quiet neighbourhood may not realise that the level of man-made static in some districts makes reception from all but the local stations literally impossible, while even on the latter reception can be so cut up that it is scarcely worth while listening to for pleasure. The question of improving the signal to noise ratio has been dealt with in its several aspects in various chapters, and particularly in Chapter 18, Vol. I, and it is clear that relief from widespread man-made static is impossible at the present stage of science, but attention can be usefully directed to the question of suppressing such interference at its source, which will usually mean electrical apparatus in the listener's own house or in the houses of immediate neighbours who are friendlily disposed or, alternatively, have some sense of the unquestioned moral obligation to refrain from permitting domestic or industrial apparatus from radiating beyond their own premises to an extent which will spoil the entertainment of listener neighbours.

Before actually attempting to classify sources of interference that may be considered as being within the control of the listener, it may be useful to emphasise the necessity for taking the obvious precautions of employing some form of anti-interference aerial and a mains filter. If the interfering apparatus is in the listener's own house, and the neighbourhood is otherwise quiet, it may be expedient to ignore the question of an anti-static aerial and deal directly with the offending apparatus. If, on the other hand, interference is produced by machinery on other premises but in the immediate neighbourhood, it may be convenient to endeavour to clear the trouble by means of an anti-interference aerial and/or mains filter. The question of anti-interference aerials is dealt with in Chapter 6 of Vol. II, but there is one possible arrangement which is included here, since its prime purpose is to deal with interference actually arising on the listener's own premises or within a few yards of it. The scheme entails the use of the usual anti-interference aerial equipment, but arranged in the manner shown at Fig. 56, which shows an aerial placed at some considerable distance from the house so that it is quite outside the field of any interference that is likely to be radiated from electrical machinery.

Reference to Fig. 56 will show that the major portion of the shielded cable is buried underground ; specially constructed shielded cable being available for this express purpose. The placing of the cable below ground ensures that the section so placed cannot pick up any interference, but it is realised that such a procedure may be considered undesirable from the point of view of disturbance to the garden, in which case it is often possible to run the cable along the fence high enough from the ground to avoid risk of damage. The arrangement shown at Fig. 56 may also be used with advantage when trams or trolley-buses pass the front of the house, the aerial being placed at the end of the garden with the sole idea of increasing the distance between the aerial and the tramway as much as possible.

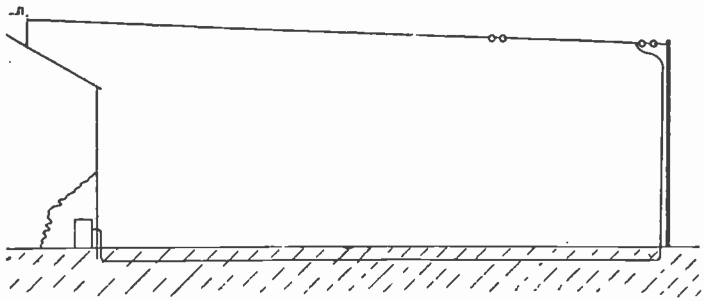


Fig. 56.—An anti-static aerial erected remote from the house.

Causes of Interference.—Apparatus causing electrical interference can be broadly divided into two classes, periodic or regular interference and spasmodic interference. Under the heading of periodic interference may be included most electrical machinery, such as refrigerators (electric), vacuum cleaners, washing machines, electric fans, sewing machines (electric), and certain medical apparatus, such as diathermy machines, violet-ray and X-ray equipment. Under the heading of spasmodic interference a wide range of electrical devices may be classed, such as door bells, interference from motor-car ignition systems, and the operation of electric-light switches, which may extend to those used in neighbouring houses or even beyond.

The various possible sources of interference will always have one thing in common, and that is that the waveform radiated is such that it will influence any type of receiver yet devised, providing it reaches the grid of an amplifier or detector stage. On the other hand, the waveform is such that a tuned circuit will not attenuate it to negligible proportions. It is apparent, therefore, that receiver design cannot eliminate such troubles in the strict sense of the term " receiver design." Admittedly, the circuit shown at Fig. 39 of Vol. II shows a method of balancing out interference, but, as explained, this arrangement is only applicable when the interference per foot at the lower end of the aerial is greater than the interference per foot of the aerial itself, a condition that will not always apply. Again, arrangements exist for silencing the receiver for the duration of an interference impulse, such as the diode arrangement shown at Fig. 40 of Vol. II, but again the arrangement is limited, as it can only be applied when interference impulses are relatively few and far between, and then only when their amplitude is much greater than the received signal.

From the above remarks it may be concluded that noise-suppression arrangements can only be applied in certain circumstances. It is also apparent that a mains filter can be used to advantage if the interference is mains-borne and, similarly, anti-interference aerial equipment will give relief if the interference arises in the listener's house or is conveyed to it by the mains. In a large number of cases electrical interference can only be suppressed by dealing with it at the source, and such possibilities have been isolated within the confines of this chapter, as it is assumed that only a percentage of readers will consider undertaking such work personally, the remainder preferring to leave it to engineers conversant with the particular class of apparatus which is causing interference or, alternatively, placing the matter in the very capable hands of the Post Office engineers. The possible course of leaving the question of suppression of certain types of apparatus to those who are conversant with it is suggested, as considerable damage might be done in inexperienced hands; for example, the suppression of interference from neon signs cannot be advisedly undertaken by anyone who is not experienced in the precautions necessary when modifying high-voltage equipment, and in the event of a breakdown resulting in fire, it might well involve those concerned in legal difficulties. For reasons which have already been expressed the reader may not desire personally to undertake the fitting of suppression devices, but brief details are given below as a matter of general interest and for the information of those who may be qualified to use some or all of them.

Total Suppression of Re-radiated Interference. Elsewhere in this work it has been explained that the ordinary domestic house-lighting system will convey to the user's premises electrical interference over a wide area and re-radiate it so that it is picked up by the aerial downlead, the receiver, or both, and there may be occasions when it is thought desirable to suppress the entire house system. Before considering the best way in which this could be done, some remarks are called for to suggest circumstances in which such a procedure would be worth while. For example, it is doubtful whether any useful purpose would be served by suppressing the mains system in a semi-detached house if the aerial system is anywhere adjacent to a neighbouring structure; if by mutual arrangement mains suppression is fitted in both houses, then something useful would have been achieved, otherwise some alternative arrangement is suggested for achieving the same result by means of a remote aerial system which is illustrated at Fig. 56.

When complete suppression of the house-lighting system is desired, it may be accomplished in the following manner. In order that the suppression will be as complete as possible, the suppressor should be fitted to the mains at the point where they enter the house. Unfortunately, however, the mains are led directly to the electric-light meter, and it is extremely doubtful if any electrical undertaking would allow suppressors to be connected on their side of the meter. Therefore, connection will usually be made to the consumer's side of the meter, and it will probably be convenient to make connection to the main switch or fuse-box. A simple suppressor consists essentially of a pair of condensers, but it is strongly advocated that a fuse should be in series with each condenser and suitable ready-made units can be obtained which comprise two condensers and two cartridge-type fuses. Fig. 57 shows the suggested connection of a suppressor for D.C. mains which, it will be seen, consists of two condensers in series connected across the mains with their centre-point earthed. Fig. 58 shows the arrangement of the condensers for A.C. mains, the arrangement being one condenser connected across the mains and a further condenser between the neutral main and earth. In both illustrations fuses are shown in the appropriate lead.

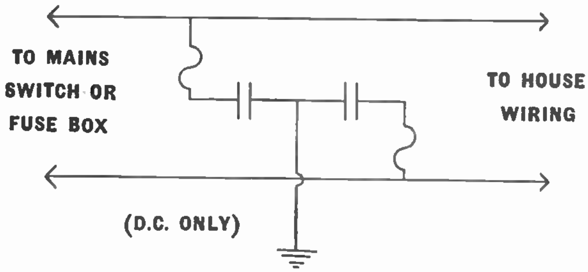


Fig. 57.—A simple suppressor circuit for use on D.C. mains; the fuses shown in this and other diagrams in this chapter are optional.

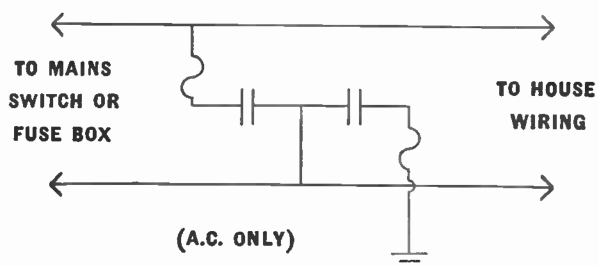


Fig. 58.—A simple suppressor circuit for use on A.C. mains.

In industrial neighbourhoods, where interference is very bad indeed, condensers may be insufficient, and chokes can be used as an additional aid. Fig. 59 shows chokes and condensers connected for D.C. mains while Fig. 60 shows the same components arranged for suppressing A.C. mains. It will be realised that the total current used to supply

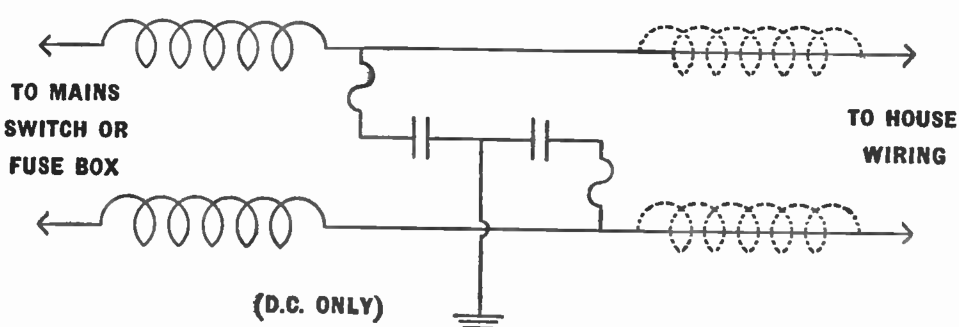


Fig. 59 —A more elaborate suppressor circuit for use on D.C. mains employing either two or four high-frequency chokes.

the various lights or other domestic apparatus will have to pass through the chokes, which must therefore be capable of passing the required current for long periods. Chokes capable of carrying heavy

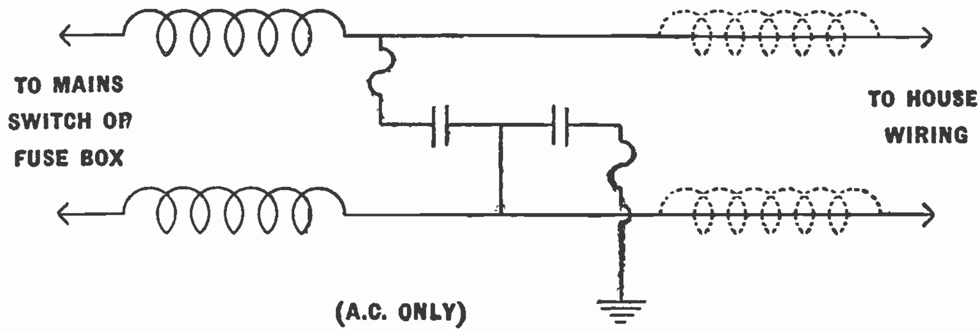


Fig. 60.—A more elaborate suppressor circuit for use on A.C. mains employing either two or four high-frequency chokes.

current are necessarily somewhat costly, and it will often be worth while to consider the possibility of dealing with domestic power circuits and domestic lighting circuits separately, when the house is so wired that power and lighting constitute separate circuits. In the average modern house the total length of the lighting cables may well be ten times the length of the power cable, and a compromise may be effected by suppressing the lighting circuit with chokes and condensers and the power circuit with condensers only.

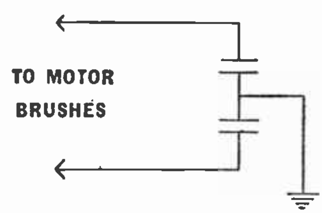


Fig. 61.—A simple suppressor circuit suitable for a small D.C. motor.

Domestic Electric Motors.—It is obviously quite useless to suppress a complete house-wiring system at the mains if apparatus capable of causing interference is used in the house, unless this also is adequately dealt with. Such apparatus may well comprise such items as a refrigerator incorporating an electric motor, sewing-machine motor, or vacuum cleaner, although the latter item is perhaps less important, as it will be used only for short periods. A motor working on direct current can usually be successfully suppressed by connecting a condenser between each brush and the frame, preferably with a fuse in series with each condenser. It is important that the leads between the condensers and the brushes be as short as possible. Fig. 61 shows this arrangement diagrammatically, while Fig. 62 shows a modified arrangement which may give better results in certain circumstances.

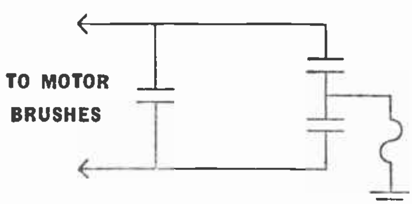


Fig. 62.—A slightly improved suppressor circuit for use with a small D.C. motor.

A.C. Motors.—Induction and synchronous motors do not give rise to interference, excepting those types of induction motors which incorporate an automatic switch for starting purposes, which will cause interference when the motor is actually started. A.C. motors of the repulsion type use a commutator and brushes, the latter being short-circuited, making it useless to connect the suppressor condensers in the manner described for D.C. motors. For the repulsion-type motor a condenser should be connected from each lead to the body of the motor, which should preferably be earthed or, when more effective suppression is required, the arrangement shown at Fig. 63 can be adopted.

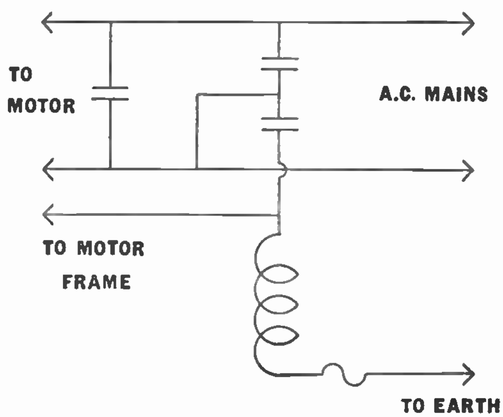


Fig. 63.—A suppressor circuit suitable for use with a repulsion-type motor. It is also useful for use on D.C. motors, in which case connection is made to the brushes.

Electric Bells and Switches.—Electric bells usually cause the most unpleasant interference with the radio receiver, while the click resulting caused by switching on or off an electric light can prove irritating. Generally speaking, interference from an electric bell can be prevented by connecting a condenser straight across the bell terminals, although in obstinate cases two condensers may be connected in series across the bell, and the centre tap earthed. It is scarcely practicable or even desirable to connect a condenser across every switch in the house, and it is convenient to eliminate disturbance of this type by a simple mains filter in the actual mains lead to the receiver. It will be understood that a complete suppression of the whole house-wiring system is advocated to prevent radiation of interference external to the house, but the radiation caused by the make or break of a switch will be very small, and it is only direct interference along the wire which has to be prevented.

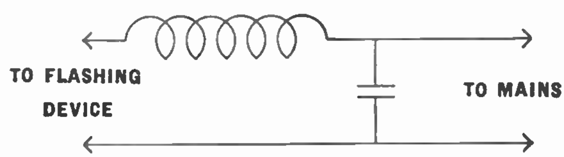


Fig. 64.—A simple circuit for suppressing a make-and-break device. Also suitable for suppressing an electric bell.

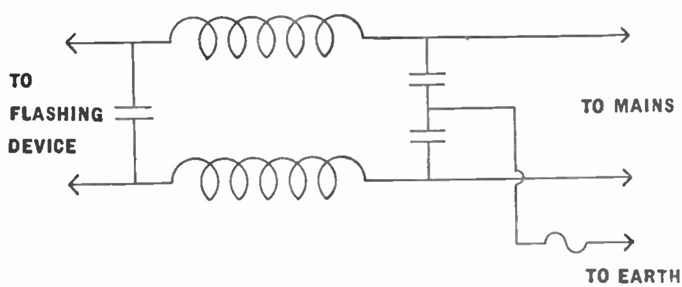


Fig. 65.—A filter circuit for use with a heavy-duty make-and-break device.

Mechanical or Thermal-sign Flashers.—Devices are available that are intended to make and break a circuit continuously, and are used for various purposes, examples of which are thermal-flashing bulbs of the type used for Christmas trees to the elaborate apparatus used for controlling the group flashing of large advertising signs. Flashers that carry a relatively small current can be effectively suppressed by the arrangement shown at Fig. 64. On the more elaborate types the arrangement shown at Fig. 65 should prove more effective. It will be understood that when the flasher is motor-driven, the actual motor will need suppressing in addition to the actual flasher contacts.

Neon Signs.—Suppression of neon signs presents certain difficulties, as intimated in the earlier part of this chapter, and is a job that should be undertaken by an electrical engineer accustomed to high-voltage work. The bulk of the interference from a neon sign comes from the high-tension side of the installation, where voltages of a high order are used which make use of condensers impracticable or impossible. Generally speaking, suppression of a neon sign will take the form of a low-frequency choke in serieswith the neon sign, and, if possible, at its electrical centre. When the sign consists of a single tube the choke must necessarily be connected at one end, but where several tubes are used the connection between two tubes can be broken and a choke inserted. The choke may have a value of 50 to 100 henrys, and must be of special design with very high insulation between winding and core, and must be contained in a metal box from which it is adequately insulated, in order to obviate the possibility of a short circuit between the neon tube and earth through the choke and its mounting. Large neon installations may have two or more high-tension circuits, in which case each must be suppressed with a separate choke.

Generally speaking, suppression on the high-tension side of a neon sign is adequate, but if necessary it may be supplemented by suppressor condensers across the low-tension terminals of the neon transformer, in the manner shown in Fig. 66. Some attention should be given to the high-tension transformer of the neon sign to see that all insulators are clean.

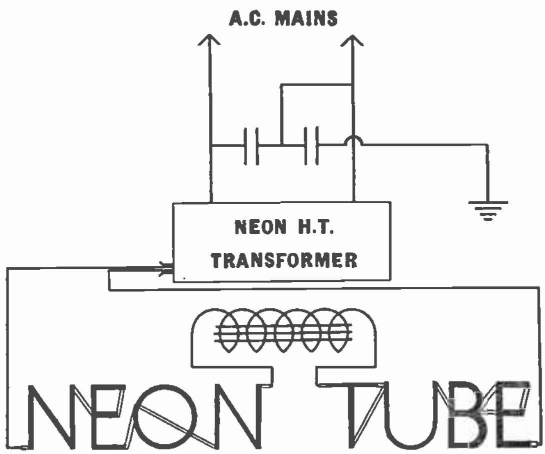


Fig. 66.—Suppressors fitted to the high- and low-tension circuits of a neon sign.

Other precautions include the use of screened cable, but here, again, it must be a special type specifically designed to withstand the very high voltage to which it will be subjected. It is also necessary that the metal covering should be stripped back for several inches at the end of each lead.

Bad Contacts.—Normally, non-"mechanical" electrical apparatus does not cause interference, but when faulty or in bad condition the converse applies. Electric irons and electric fires will cause a continuous but intermittent crackle if a bad contact is present, resulting in an arc; such an arc may be minute and imperceptible except under very careful examination, but nevertheless capable of causing serious interference to a radio receiver. The proper and only course to adopt is to trace bad contacts and repair.

Motor-car Interference.—Short-wave receivers may be troubled by interference from the ignition system of motor-cars. Such interference reaches maximum intensity between 9 and 15 metres, and little can be done to reduce the trouble if the receiver is used on these wavelengths, except by placing the aerial higher and farther away from the source of interference and employing a screened downlead. Many receivers, however, do not tune below about 16 metres, in which case some relief may be obtained by connecting a suitable choke in the aerial lead. In order that reception is not impaired the choke should be so designed that its impedance is very low at the lowest wavelength to be received, but as high as possible on lower wavelengths. A suitable choke may be wound by winding some 10 feet of wire round a pencil and connecting it in the aerial lead. A short-wave station should be tuned in, and the choke shorted to see if the sacrifice of sensitivity is too great, in which case turns may be removed until shorting the choke indicates that no great sacrifice is being made.

Electro-medical apparatus used for diathermy, X-ray, etc., can cause very severe interference indeed on the short wavebands, and diathermy apparatus may interfere with television apparatus to a very serious extent. Such interference can only be cured at the source, and usually means encasing the whole apparatus in a screened room. Diathermy interference may be experienced over several miles. Motor-car interference of a frequency-modulated transmission is almost certain to be due to inadequate signal input and the cure is a better aerial, suggestion for which may be found on page 250 of Volume I.

General Remarks.—No mention has yet been made of suitable values for the condensers shown in the various circuits included in this chapter. Generally speaking, condensers of the order of 1 μF are suitable. The tendency is to use condensers larger than this value on direct current and smaller on alternating current, often as low as ·1 μF. When a condenser is connected between the live wire of A.C. mains and earth a current will flow through it which will be a wattless current, that is to say, voltage and current will be 90° out of phase. It should be borne in mind that an electric shock can be obtained from the terminal of a condenser when the other terminal is connected to a live A.C. supply. It is essential, therefore, that the earth lead of a suppression arrangement should be properly insulated. With an applied voltage of 200/250 volts a severe shock can be obtained from the remote side of a 1 μF condenser, but ·1 μF may be considered as safe.

CHAPTER 16

MISCELLANEOUS WORKSHOP HINTS

WORKSHOP procedure is something that can only be gained by experience and really consists of an accumulation of various ways and means of overcoming the innumerable mechanical difficulties which are just another side of service engineering. Obviously problems will present themselves from time to time which must be dealt with as they arise in a manner suited to convenience. On the other hand, there are a number of minor difficulties that will frequently arise, and some effort has been made to classify these below. No attempt is made to touch upon the subject of the actual workshop equipment, as this will vary widely to suit the needs of readers and will be determined by a number of factors depending upon the frequency with which service-work is undertaken and, no doubt, upon economic considerations.

Removing the Chassis.—When serious fault-finding is contemplated it is usually necessary to remove the chassis, which is not always as simple as might reasonably be expected, because some manufacturers pay inadequate attention to accessibility. Nowadays really serious problems are not presented, but a few years ago it was not unknown for a receiver to be so designed that pieces of wood were glued into position after insertion of the chassis, which had to be removed before the latter could be withdrawn. To still further complicate service-work, at least one such receiver was so arranged that when the wooden blocks were chiselled out there was considerable danger of splitting the cabinet.

The modern chassis is usually held in place by four fairly obvious fixing bolts or, alternatively, is of the so-called floating type, which often means that the chassis is jammed in position between four or more rubber bushes. A brief examination of the fixing will undoubtedly determine the method of release. The next step is to remove the control-knobs, which are usually secured by grub-screws, one for the light controls and two for the heavy controls, such as tuning. Another popular method of fixing knobs, particularly on receivers of American origin, is by means of a key-way and spring, requiring merely a determined effort to pull the knobs off the spindles. There is, however, a variation of this arrangement, whereby a retaining collar must be sprung off the spindle before the knob can be withdrawn. A special tool is available, and although it is not impossible to remove the collars without its use, it is virtually impossible to replace them without it. It is obvious that considerable care must be taken not to attempt to pull these knobs off their spindles without removing the collar, as such an attempt is likely to result in damage.

Whatever the type of knob, there is a high probability of scratching the cabinet unless precautions are taken. A simple method of obviating this possibility is to cut a hole in the middle of a suitable-sized piece of cardboard, and slit the cardboard from the hole to one edge, thus permitting it to be slipped over the spindle and protecting the cabinet from accidental damage.

Some receivers have one or more controls at the side, and mere removal of the control-knob will not permit the chassis to be withdrawn, as the spindle will still project. Almost invariably the projecting spindle takes the form of a small extension of the main spindle, which must be released on the *inside* of the cabinet; it is usually held to the main spindle by at least two grub-screws. The general arrangement is shown at Fig. 67. Some controls, such as, for example, the on/off switch, may be mounted on an individual escutcheon, probably by means of a large nut. Unless a special spanner is available it is extremely difficult to loosen such a nut, but if the escutcheon is any shape other than a pure circle it should be possible to release the escutcheon and pass it through the hole in the cabinet which it covers.

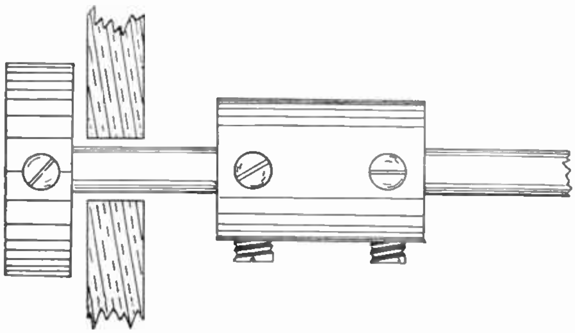


Fig. 67.—A spindle coupling; this device has special significance when the control is on the side of the cabinet.

The loudspeaker will usually be a separate fixture. It will, therefore, be necessary to either disconnect the loudspeaker from the chassis, or release the loudspeaker so that it may be withdrawn side by side with the chassis. If connection is made by means of a multi-way plug, the loudspeaker can be quickly released, but if it is necessary to remove individual wires, it is highly desirable that a note should be made of their colour-coding in relation to the speaker-terminals or tags, as it may be extremely difficult to trace the connections behind the loud-speaker transformer. If it is decided to remove the speaker, it is usually desirable to remove the loudspeaker from its baffle rather than to adopt the alternative of removing the baffle from the cabinet, as this may damage the silk or other material used as backing for the speaker fret; it is extremely tedious to stretch new silk across the baffle-opening, unless a proper frame is available, owing to the difficulty of getting the grain or pattern perfectly straight.

It will often be found that when all fixing devices and controls have been removed the chassis can only be withdrawn for a fraction of an inch. Many manufacturers place a wooden batten immediately inside the chassis and secure it to the bottom of the cabinet; this will foul and even damage the components or wiring unless the chassis is lifted before it is withdrawn. When the chassis is replaced it will almost invariably be found that some tolerance is available, probably due to the hole in the cabinet being larger than the fixing bolts which pass through them; this is to allow the controls to be properly centred and just clear of the cabinet. If knobs, other than the grub-screw fixing type, are employed, it will be expedient to push the chassis in as far as it will go, replace the control-knobs, and withdraw and centre the chassis so that the knobs are just clear of the cabinet; the chassis can then be secured by its fixings.

Care of the Chassis.—It will be unnecessary to dwell upon the necessity for preventing damage to the chassis through such causes as the structure falling over through being unsuitably propped up to secure the necessary accessibility. There is, however, a possibility of damage in certain types of receivers through a cause that may be entirely unsuspected; there are a number of receivers in which a very simple form of trimmer is used, consisting only of one plate, the dielectric and tension arrangements, the actual chassis itself forming the other plate; such an arrangement is shown at Fig. 68. The modern chassis is made of fairly heavy material, but, owing to the weighty components affixed to it, it is comparatively easy to bend or warp it slightly, with the result that one or more of the trimmers varies its capacity, making realignment of some of the tuned circuits necessary, an operation which may be simple enough if reliable instruments are available, but otherwise may present almost unsurmountable difficulties. It is, perhaps, relevant to point out that misalignment can occur in receivers using this type of trimmer, due to the base of the cabinet warping and bending the chassis. If misalignment is suspected, and one corner of the chassis springs up when released, it may be safely concluded that this has, in fact, occurred and, after realignment, those corners which do not rest on the baseboard should be packed, so that the shape of the chassis is not changed when the securing devices are tightened up.

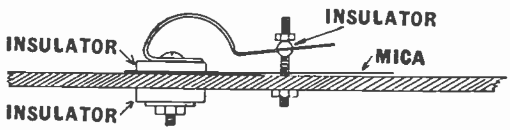


Fig. 68.—A trimming condenser of the type which utilises the chassis as one of its plates.

Removing Rivets.—The practice of riveting components to the chassis may be economical from the manufacturers' point of view, but it cannot be said that it affects the service engineer in the same way. Three types of rivets are used: the bifurcated rivet shown at Fig. 69, the solid rivet shown at Fig. 70, and the eyelet shown at Fig. 71, which is used for light fixing. It is assumed that a nut and bolt will be used for refixing and, therefore, the necessity for preserving the rivets intact does not arise, and it is usually quickest in the long run to file both the bifurcated and solid rivets until they can be withdrawn. If the bifurcated type of rivet is loose, it may be possible to withdraw it if the tags are bent upwards in line with the shank, but, more often than not, the bend forms a kink, making withdrawal difficult, even after the tags have been filed off. The eyelet can be very easily removed by inserting a file tag through the hollow centre from the under side and simultaneously pushing and twisting.

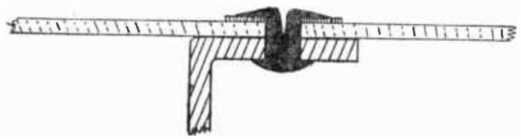


Fig. 69.—A bifurcated rivet.

Some manufacturers paint the thread of a bolt which protrudes from the nut to prevent the nut from becoming loose, and the author strongly advocates the practice of putting a spot of oil on the nut before any attempt is made to unscrew it, as otherwise the nut may become jammed, which may, in turn, result in damage to some component if the nut is in an inaccessible position and considerable force has to be applied.

Sometimes electrical connection is necessary between a coil-can or fixing-lug and the chassis itself, and care should be taken when replacing the components to see that adequate connection is made. Some chassis are sprayed with aluminium or copper paint, which substances can be more correctly described as insulators than conductors, and it is therefore necessary that the paint be scraped off if a nut and bolt fixing is used. This may not have been done by the manufacturer, because either the eyelet or solid rivet will expand and make contact with the inner wall of the hole. As scraping paint from a chassis is somewhat tedious and, unless carefully done, is inclined to make the chassis look shabby, it is suggested that a stock of lock-tight washers be kept, and placed under the nut when electrical contact is desired. This type of washer will completely obviate the possibility of a nut coming loose and, for the information of those who are unacquainted with this device, it is a steel washer with teeth on both faces which are capable of cutting through any type of paint into the actual iron chassis.

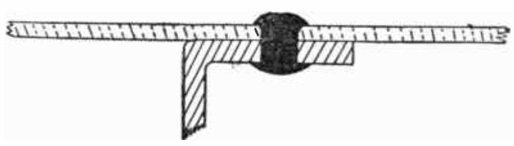


Fig. 70.—A solid rivet.

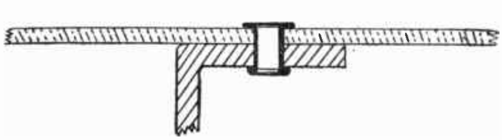


Fig. 71.—A hollow rivet or eyelet.

Replacements.—Generally speaking, the golden rule for replacing components is to use exactly the same type of manufacture unless, of course, the new component is being fitted rather more in the nature of a modification than a repair. The use of a non-standard replacement is liable to introduce difficulties, even assuming that its electrical specification is precisely correct. Firstly, the fixing holes will usually be differently spaced and, although drilling the chassis does not present any difficulty when the chassis is bare, considerable care must be exercised when all the components and wiring are in their normal position, partly to ensure that fragments of metal from the drilling do not find their way into places where they can do harm, and also on account of the difficulty of starting a hole in a hard metal chassis without the usual centre-punch dent, which cannot be made owing to the probable damage which would result from the jar caused by the hammer-blow. It may be noted that a sharp diamond-shaped drill is much easier to start without a punch dent than the twist drill, and it is worth while keeping a few of these drills to start the hole, after which a twist drill can be employed in the interests of speed. Should occasion arise to make a large hole, and a bench drill is not available, the usual practice can be adopted of making a ring of small holes, but it is essential that these should be very close together in order that rough handling is not necessary to knock the centre out.

If the component to be replaced has a number of terminals which, in all probability, will not be marked, it is essential to make a detailed plan before the old component is removed. It is also advisable to compare the connections of the new component carefully, even though it is reputed to be a replica of the old component ; quite apart from the possibility of the supplier making an error, manufacturers occasionally modify components in order that one type may serve for two or more receivers. They sometimes fail to take adequate steps to draw attention to such changes, and, no doubt, occasions might arise when the incorrect wiring (which results from the change if it passes unnoticed) could result in damage to the component itself, or some other associated with it.

Wiring.—When replacing wiring it is necessary, in certain circumstances, to pay adequate attention to gauge and insulation. Gauge is only important for heater circuits, which may call for heavy wire, in the case of receivers using a large number of valves. Insulation is particularly important with connections between a high-voltage secondary of the transformer, as the voltage across the outer terminals will be in the neighbourhood of double the D.C. smoothed voltage, and may be 600 volts or more in quite unambitious receivers. There is quite a lot of insulated sleeving on the market that will break down on voltages considerably lower than 600 volts, possibly resulting in damage to the transformer winding, or even causing the receiver to catch fire.

Switches.—Repairs carried out on switches are usually more or less unsatisfactory, whether the switch is of the on/off or wave-change type. It is not possible to generalise on the subject of switch repairs, but it is probably true to say that 90 per cent. of switch faults are due to blades or contacts losing their original springiness. This loss of springiness in on/off switches is very often due to the affected part having warmed up by an arc occurring between dirty contacts. When examining the switch in this condition it may well appear that the trouble is dirty contacts, and that the fault will be obviated by suitably cleaning them; if the contacts have lost their springiness, arcing will very soon recommence.

Wave-change switches do not normally carry sufficient current to become over-heated, but the blades may well become tired with use, and replacement of the complete switch is the only reasonable procedure to adopt. When replacing wafer-type switches the greatest care should be taken to ensure that the new component is really identical with the old. Wafer switches are available with innumerable major and minor modifications, such as the linking together of selected contacts, which are often carried out in such a manner that they will not readily be noticed; one manufacturer of wafer switches has issued for the convenience of receiver manufacturers and others no less than thirty-one different two-pole three-way types, and it is little exaggeration to say that, superficially, they are of identical appearance.

Soldering.—The soldering iron must necessarily play an important part in service work, and some remarks on the subject may prove useful. Generally speaking, the servicing of a receiver calls for a number of joints to be unsoldered and re-soldered at fairly frequent intervals, as, for example, when breaking a series of connections for the purpose of taking current readings. For such a purpose the electric soldering iron is entirely suitable, and by keeping constantly hot will obviate unnecessary delay. If it is well designed, it will not readily over-heat, and, therefore, frequent re-tinning will be unnecessary.

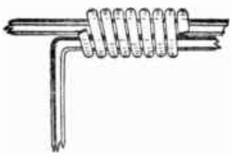


Fig. 72.—A connector used to facilitate soldering a joint between two wires.

In some receivers direct-soldered connections are made to the chassis. For re-soldering such a connection the average electric soldering iron will be found unsuitable, owing to the conduction of heat by the chassis itself resulting in the iron being incapable of raising the solder adhering to the chassis to melting-point; for such purposes the ordinary tinsmith's iron is much to be preferred.

When planning the production of modern receivers, care is taken to avoid as far as possible the joining of wires to each other, connection being effected at the soldering tag or other convenient point. When connection between wires is unavoidable, the modern engineer is rarely content with a plain soldered joint, as it is well known that in mass production such connections are prone to result in dry joints. For making such connections various methods are adopted, the most common of which employs a miniature tinned copper "spring" (Fig. 72). It is intended that these should be slipped over the two wires to be joined, the junction then being soldered; in order that the solder will run inside the "spring," it will have to be decidedly hot; so hot, in fact, that a dry joint is improbable. These "springs" are easily obtainable and their cost is negligible.

Very considerable care should be exercised in choosing a soldering flux, on account of the very real danger of corrosion. There are a number of fluxes on the market which are stated to be free from this danger, and, for normal purposes, this is unquestionably correct. Some of these, however, will behave differently when influenced by an electric current, which will promote electrolysis and make a non-corrosive flux into the exact opposite. It is suggested, therefore, that care be taken to procure a flux which is specially made for soldering electric joints. At one time this question was so serious that a famous wire manufacturer produced a suitable flux, in order to refute the suggestion that transformer breakdowns could be attributed to the wire, whereas the real trouble was the use of unsuitable flux.

Many engineers prefer to use a resin-cored solder, which takes the form of a metallic tube filled with resin, and this substance is admirable for use in receiver manufacture, when all joints are chemically clean; but it is not altogether satisfactory for service-work, where the surfaces to be soldered may be greasy or dirty and, furthermore, resin is more liable to produce dry joints than any other flux and is, therefore, unsuitable for use under unfavourable conditions.

Emergency Soldering.—Occasion may arise when a joint has to be soldered and the necessary equipment is not available. With a little ingenuity it will be found possible to improvise the necessary materials from the normal equipment of almost any household. Any piece of brass or copper, of suitable shape, can be made to serve for a soldering-iron, and tinfoil, such as that used in cigarette packets, can be made to serve the purpose of soldering, although an unexpectedly large quantity will be required to form a fair-sized "blob." Several substances can be used for flux, the most obvious of which is resin, which will be available if any member of the household plays the violin or other stringed instrument ; tennis players also use resin. The next suggestion is pure tallow, which may be available in the form of a tallow candle or, failing this, recourse must be made to killed spirits of salt. This solution is prepared by taking a small quantity of domestic spirits of salt and dropping therein a few scraps of zinc, which can usually be found projecting from the roof of an outbuilding or elsewhere. This flux should not, however, be used if any other substance is available, as it is likely to cause corrosion. To minimise this danger, care should be taken completely to kill the spirit by dissolving in it as much zinc as it will consume and, after the joint has been made, a small quantity of some alkali, such as ammonia, can be applied and the joint then wiped with a clean wet rag.

Soldering Inaccessible Connections.—The assembly of a radio chassis is planned in such a manner that all joints and components are readily accessible, providing that the assembly order is adhered to, but when a repair makes necessary the soldering of a connection that is surrounded or covered by components and wiring, it may be impossible to bring the iron in contact with the joint without risk of damage to some component by over-heating or other cause. It may be necessary to remove one or more components, but very often the following can be tried with success. Take a piece of copper wire of about fourteen gauge and wrap it round the bit of an ordinary (non-electric) type of iron, some half a dozen turns will be necessary, which should then be hammered to bring the wire into firm contact with the iron; if necessary the end of the wire may be flattened to form a soldering bit. One or two inches of wire will be left projecting from the iron, which can be bent to such shape as will permit the end of the wire to be brought in contact with the joint. It will be found that if the iron is heated considerably above the normal soldering temperature the extension wire can be made hot enough to solder a small joint, providing that the operation is carried out quickly.

Soldering Litz Wire.—If it becomes necessary to re-solder a piece of Litz wire, considerable care is needed if the operation is to be successfully accomplished. It must be borne in mind that serious loss of efficiency will result if a single one of the many strands is broken, either literally, or in the sense that it is not properly soldered and, consequently, not making proper contact. A Litz coil using, say, 27/40 wire could have a high-frequency resistance of 2·5 ohms, but if a single strand is broken, the high-frequency resistance might well rise to some hundred ohms.

Each individual strand of Litz wire is separately insulated, usually by spun silk, and the whole is encased in a further layer of spun silk. It is obviously necessary to remove the insulation from each individual wire without breaking it, which requires considerable care, after which the strands should be counted to see that one has not broken off, and the whole lightly twisted together. The end is then tinned, preferably by applying a little flux and then dipping it in molten solder. It is imperative that a non-corrosive flux be used, owing to the thin gauge of wire and the impossibility of removing surplus flux from between the individual strands. It is, perhaps, of sufficient interest to mention that manufacturers strip Litz wire either by a special machine or by dipping it in a chemical which will speedily eat away the silk covering but will not in any way dissolve or corrode the copper; some types of Litz wire use enamel insulation, which is available in a specialised form, so that the enamel can be readily dissolved in alcohol.

Sealed Trimmers.—Trimming condensers and permeability iron-core trimmers are usually sealed after adjustment, either with paraffin wax, beeswax, sealing wax, or paint. This presents little difficulty in the case of trimming condensers, as a small spanner will allow the application of sufficient force to break the sealing material. True, a certain amount may have worked its way into the thread, but this may be of assistance, as it will make the adjustment comparatively stiff—which is perhaps desirable, as only a very small movement should be necessary when realigning. The unsealing of iron cores may present some difficulty, since the core will often be sunk some distance within the moulding, forming a cup which may hold a considerable quantity of sealing material, which must be removed with care, as iron cores are easily broken. Quite apart from the inconvenience involved, considerable expense may be entailed, as it is usually necessary to purchase the complete component, as many manufacturers use iron cores under licence and are not permitted to sell them separately. When cores are sealed with sealing-wax it can be softened with a few drops of methylated spirit and, when sealed with paraffin or beeswax, gentle heat must be applied by means of an old screw-driver or file suitably warmed. It is necessary to remove practically every trace of sealing material before attempting to unscrew the core, otherwise the sealing material may enter the thread and fix the core immovably.

Finding Polarity.—If the workshop is supplied with D.C. mains, it may sometimes be desired to find the correct polarity, which can be done by various means, the following being two examples. It can, of course, be ascertained by a moving-coil voltmeter, providing that its terminals are marked.

In the absence of a polarised meter polarity can be found by dipping the conductors in weak acid (vinegar will serve), when one lead will quickly become surrounded by bubbles, indicating that it is the negative lead. Special impregnated paper can be obtained in small books, known as pole-finding paper. A small piece is slightly damped and the two leads drawn across it: the *negative* lead will trace a coloured line just as if it were a coloured pencil.

Renovating Damaged Cabinets.—A badly damaged cabinet is a job for an experienced french polisher, but minor renovation can be successfully undertaken after very little practice. The average radio cabinet is made of veneered plywood and finished with either french polish or cellulose lacquer. There are, however, examples of cabinets which are not veneered, but are made of bare plywood on which is printed the grain and colouring of rare wood in a very realistic manner. After printing, these cabinets are either french polished or sprayed with cellulose lacquer. Such cabinets are extremely difficult to renovate, and are best left alone as, unless the work is done by an expert, the probability is that a portion of the "grain" will be rubbed off. Even the too-vigorous application of furniture polish may so rub the edges of this type of cabinet that white wood appears.

Minor imperfections, in the form of dents or bruises, can be quite easily removed with a piece of damp rag and a soldering iron. The damp rag is folded over to make a wad of several layers and laid on the damaged part. Next, touch the cloth at a point immediately over the dent or bruise with the hot iron; only light pressure is necessary, for a few seconds at a time. The idea is to drive steam into the bruise or dent, causing the wood to swell and thus regain its original level. It may be necessary to prick the wood slightly, particularly in the case of walnut veneer and, in the interests of the ultimate appearance, a *very fine* needle should be used. When steaming-out bruises and dents it should always be borne in mind that plywood is actually a series of thin wooden sheets glued together, and that if heat is applied indiscriminately the glue will become soft and the wood will blister, a condition that is very difficult to remedy. After the bruise or dent has been removed the surface should be rubbed very gently with a piece of old sandpaper of fine grain, of the variety known as "wet or dry." For this purpose the sandpaper should be dipped in water before use.

After smoothing down the bruise with sandpaper, a little clear cellulose lacquer or french polish should be applied with a soft brush and the cabinet put aside for several hours. The next step is to rub down the lacquer carefully, until the dividing line between the old lacquer and the new is imperceptible. For this operation sandpaper is quite unsuitable and special rubbing-down compound should be used. It is obtainable from any source that supplies french-polishing sundries, and consists largely of very finely ground pumice stone or commercial rouge, after which the affected portion can be given a thin coat of cellulose lacquer or french polished. Lacquering or polishing a small part of the cabinet necessitates some experience, and those who feel unable to undertake the task can produce a very similar effect with piano cream; several applications will be necessary, and the secret of success is to use the smallest quantity of polish and the largest amount of energy.

It is important to note that a lacquer finish can be repaired with french polish but that it is absolutely fatal to attempt to touch up french polish with lacquer, as the solvent will strip off or blister the surrounding french polish.

When the bruise or dent is steamed out and rubbed down with sandpaper the surface may be damaged and white wood appear, in which case it should be coloured with a little suitable spirit stain, applied with a soft camel-hair brush or a feather. The former is preferable when the grain of the wood is not very contrasting, otherwise the feather will be found more convenient. It is extremely difficult to obtain a perfect match, and it should be remembered that, all things being equal, the touch-up area will be less conspicuous if it is darker, rather than lighter, than the cabinet as a whole. After applying the stain time should be allowed for it to become thoroughly dry, so that the colour can be carefully compared.

Some cabinets have a dull finish or even an egg-shell finish, in which case it will be necessary to treat the repaired area to match by rubbing it *very gently* with very fine pumice powder in the case of egg-shell finish, or commercial rouge in the case of dull finish.

Scratches may be dealt with in exactly the same way as dents and bruises, providing they are not deep, always assuming, of course, that the wood is actually scratched and not only the polish. For deep scratches it will be necessary to employ a suitable stopping material of the type specially made for this purpose. White stopping may be used and subsequently stained with spirit stain, but it is generally more satisfactory to use a coloured stopping, even if it has to be slightly darkened with stain afterwards. It is advisable to use rather more stopping than necessary, so that it dries above the level of the cabinet and may be rubbed down and treated as described above.

As a final suggestion on this subject attention is drawn to the desirability of making the fullest possible use of the grain of the wood to assist in hiding a repair. If the damaged section cuts across any pronounced graining the latter should be carefully copied and even exaggerated, as a little boldness will do much to hide any suggestion that a repair has been effected. Those with artistic ability can completely disguise a repair by carefully staining it to represent a burr in the grain, always assuming, of course, the wood is normally liable to contain such figures.

Slow-motion Drives.—The majority of modern receivers employ some form of slow-motion drive, of which there are various types, some being more prone to mechanical defect than others. The most popular type of slow-motion drive is a small wheel driving a large disc by friction, and when trouble arises it can be found by inspection, and the necessary repair effected. The planetary gear gives very little trouble, but when it becomes defective through age it is normally impracticable to repair it, and replacement of the entire unit is the only satisfactory procedure to adopt. Another popular form of slow-motion drive consists of a cord wound round a driving pulley and several small jockey pulleys, the ends being terminated by small springs fixed to the centre-boss of a drum. When replacement of the cord becomes necessary its length should be such that the springs are under considerable tension, to prevent slipping and to take up any slight stretch. It is imperative that some form of cord be used which has the smallest possible tendency to stretch and which is unaffected by humidity and temperature. Few types of cord will comply with these conditions, but a densely woven damp-resisting fishing-line is satisfactory.

Cleaning Metallised Valves.—Unless very special precautions are taken metallised valves are liable to become soiled when they are subjected to the fairly considerable amount of handling which is incidental to service-work. When appearance is important it will be desirable to clean these valves, which cannot be done by ordinary means. It will be found, however, that marks can be quickly removed by rubbing them with a particular type of rubber used by artists and known as " art gum." This material is a buff-coloured translucent substance and is made in three grades, the medium being suitable for this particular purpose.

Iron Cores.—There are various types of iron cores used in intermediate-frequency transformers and elsewhere to permit of trimming by permeability tuning. Generally speaking, the adjustment is accomplished by screwing them in or out ; some manufacturers use cores moulded in the form of a screw, while others use a bakelite moulded screw with the core attached. Should the two elements of the latter type become detached, they may be stuck together with fish glue ; on no account use an adhesive containing amyl acetate, as this substance will cause many types of core material to disintegrate.

Cleaning Television Tubes.—If a cathode-ray tube is removed from a television receiver, it is logical to clean the face of it before replacing it.

It is not always advisable, however, to clean the remaining portion of the glass, as some tubes are sprayed or smeared with a semi-conductive substance to discourage the formation of an uneven static charge.

If for any reason this coating is removed, the accumulation of a static charge will cause one or more edges of the picture to appear as though semicircular pieces have been cut out; this phenomenon is due to an uneven static charge and can be obviated by smearing the sides of the tube evenly with a mixture of glycerine and common salt in approximately equal portions.

CHAPTER 17

ACCUMULATOR CHARGING AND MAINTENANCE

BEFORE the inception of broadcasting the accumulator was scarcely known to the layman and could not, by any stretch of imagination, be regarded in the light of an item of domestic equipment. Radio has changed all this to such an extent that to-day the accumulator is so familiar that it is scarcely given a moment's thought or consideration, with the result that it receives no care and very little attention other than the essential recharging. To meet the demand for an accumulator that would give satisfactory service without proper care the responsible manufacturers produced the mass-type accumulator, which took the form of not less than two, occasionally three, solid plates, perhaps half an inch or more in thickness, in a moulded glass container. Such accumulators are very robust and will stand a remarkable amount of ill-treatment and are relatively cheap to replace, but, nevertheless, there are doubtless many readers who desire to give some care and attention to accumulators and others who charge their own accumulators for reasons of convenience. The following remarks on accumulator maintenance are provided for these readers and also for the guidance of those professionally engaged in radio engineering.

The Chemical Change.—Mention has been made of the accumulator earlier in this work, but it is desirable to add a few definite remarks purely relative to considerations of charging and maintenance. When the accumulator is fully charged, the active material in the positive plate is lead peroxide, and the negative plate is pure lead of a spongy texture, the electrolyte being dilute sulphuric acid. During discharge the active material of both the positive and negative plate tends to change to lead sulphate, the electrolyte loses certain of its constituents, and the specific gravity falls.

To charge the accumulator it is therefore necessary to change the lead sulphate back to lead peroxide in the positive plate and to pure lead in the negative plate. Apart from the fact that effecting this change may entail a certain amount of inconvenience and the provision of the necessary equipment, it would seem that the process is simplicity itself. This is only true providing the accumulator has not been discharged and so left for an appreciable time, since this delay in restoring the plates to their original condition produces the formation of a white lead sulphate that is usually incapable of being converted back to active material by the usual charging process. For the benefit of those who are quite unacquainted with accumulator charging it may be mentioned that this process consists of passing a direct current through the accumulator at an appropriate rate and period and in the right direction, that is to say, the positive terminal of the source of supply is connected to the positive terminal of the accumulator, the negative poles being similarly connected together. Considerations of the rate and duration of charge are dealt with below.

Sulphuric Acid.—If an accumulator is to give satisfactory service for a reasonable period it is essential that the initial charge be correctly carried out. This is particularly important with multi-plate accumulators. Assuming that the accumulator is supplied in a dry state, it will be necessary to fill the cell with pure sulphuric acid diluted with *distilled* water to the specific gravity appropriate for the particular make of accumulator, and which is invariably stated on the label.

It is convenient to purchase "accumulator acid" which is already diluted and, if necessary, dilute it a little more to obtain the particular specific gravity required. This procedure is very strongly advised, as concentrated sulphuric acid can only be described as a dangerous commodity. Quite apart from the fact it may cause blindness if splashed into the eye, it is capable of burning a hole in a wide variety of substances, among which are clothes and carpets. If for any reason the dilution of concentrated acid is undertaken, it is *absolutely imperative* that the distilled water be placed in a container and the acid added a few drops at a time; in other words, *always add acid to water*. If the reverse process is attempted and the water is poured on the undiluted acid, it will boil and very probably fly in the operator's face, who will be lucky if the damage is limited to a few bad burns. Strictly speaking, when it is necessary to add a little more distilled water to dilute acid, the latter should be poured into the former, but this is extremely inconvenient, as there is no means of knowing the quantity of water that will be required and it is, therefore, a commercial practice to add the water very gently to the *already diluted* acid, assuming, of course, that the diluted acid is, in fact, reduced to the weak state appropriate for use in accumulators.

Specific Gravity and the Hydrometer.—The specific gravity of a liquid can be described as its relative heaviness, and is conveniently determined by means of a hydrometer, a typical example of which is shown at Fig. 73. It will be seen that it consists of a rubber bulb and glass cylinder containing a calibrated float. By means of the rubber bulb the glass cylinder may be partially filled by drawing some of the acid out of the accumulator; the float will be partly immersed to an extent dependent on the specific gravity of the acid, which can be read directly on the calibrated scale. A hydrometer is the only entirely satisfactory means of ascertaining the charged and discharged state of an accumulator; a voltmeter is admittedly quite useful, and a low reading will always indicate that the accumulator is in a relatively discharged condition, but, unfortunately, a high reading is not an infalliable indication that the accumulator is in a charged condition.

The First Charge.—The procedure to be adopted will vary slightly with various types and makes of accumulators, but the following may be accepted as general practice:

(1) Fill the accumulator with dilute sulphuric acid of correct specific gravity. It is important that the specific gravity indicated on the label should be strictly adhered to. The acid should be about half an inch above the top of the plates.

(2) Allow the accumulator to stand for ten hours or so and then add sufficient acid of correct specific gravity, to make up for that which has soaked into the plates, so that the level is correct. Correct level is usually indicated by a line printed or moulded on the container, otherwise it should be about half an inch above the top of the plates. It is important that non-spillable accumulators should not be over-filled.

(3) Connect to a suitable source of direct current (*see* section entitled "Accumulator Chargers" at the end of this chapter) until the charge has been continued for the appropriate time and the specific gravity of the acid has remained constant for three hours and/or the voltage across the battery has remained constant for not less than three successive readings taken at intervals of one hour. When fully charged all the plates will be gassing freely.

(4) *Special Note.*—On no account should the temperature of the acid be allowed to rise above 100° F. for accumulators in celluloid containers, or 110° F. for cells in glass containers. Care should be taken not to bring a flame or even a lighted cigarette or pipe near an accumulator on charge, or immediately after charging has ceased, as hydrogen is given off which may become ignited and cause an explosion.

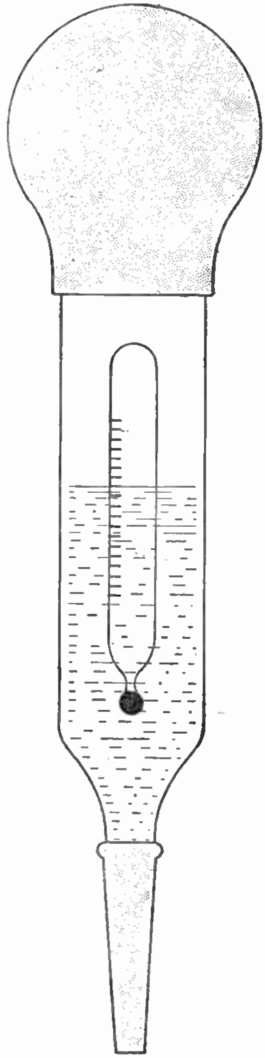


Fig. 73.—A hydrometer with acid drawn in, permitting its specific gravity to be read from the scale on the float.

(5) Measure the specific gravity by means of the hydrometer, and if this is more than ·005 above or below the correct figure, add stronger diluted acid or water as may be necessary to correct the electrolyte. If the specific gravity is too low, an attempt should be made to raise it by a further period of charge, and if this fails to bring about the necessary correction, then it is permissible to add acid, as above mentioned. If the specific gravity is too high, this may be ignored for the time being and rectified by topping up the battery on the occasion of the next charge with distilled water.

(6) Add to or withdraw the electrolyte, as may be necessary, to correct the level, making due allowance for the fact that the level will fall about a quarter of an inch when the gas bubbles have been allowed to escape.

It is imperative that the charging-rate as specified on the label be rigidly adhered to. If charging cannot be completed continuously, it should be given in periods of not less than twelve hours It is realised that this may be inconvenient in the case of commercial establishments who may have to work to an eight-hour day, and therefore a period of eight hours must, of necessity, be given.

If the accumulator is contained in a celluloid case, it is desirable that when giving the preliminary charge the acid be thrown away when the charge is nearly completed and the cell refilled with acid of the correct specific gravity.

(7) It is desirable that connection between the source of supply and accumulator be made by means of the accumulator terminals, which should be screwed down reasonably finger-tight in order to preclude the possibility of a spark. Many charging stations make a practice of connecting accumulators together with clips, which in all probability is satisfactory if they are well made and designed for the job, otherwise there is a danger of an electric spark igniting the hydrogen given off by the accumulator.

(8) *Applicable to Mass-type Accumulators Only.*—Mass-type accumulators differ from multi-plate types inasmuch as they are capable of functioning when filled with acid without an initial charge. This feature can be used to advantage in the case of an emergency, but it is very strongly recommended that when practicable a charge be given at the rate and for the period indicated on the accumulator label. Some mass-type cells are prone to excessive gassing towards the completion of charge, and also to excessive temperature-rise. An adequate watch should, therefore, be kept and the charging-rate reduced if necessary.

Recharging.—The process of recharging is, in principle, similar to the initial charge, except that, of course, the necessity does not arise for filling with electrolyte. The fact that the accumulator is in a discharged condition is most readily determined by the use of a hydrometer, the specific gravity below which the cells should not be permitted to fall will be stated on the accumulator label. Otherwise a voltage test may be taken, *while the accumulator is actually discharging.* If the voltage is below 1·8 volts, the accumulator should be recharged immediately ; as already mentioned, the accumulator should never be left in a discharged condition. It is useful to note that a considerable change takes place in the colour of the plates when the accumulator is discharged. The positive plate will lose its warm reddish-brown colour and the negative plate will become light in colour.

Almost invariably the rate of charge will be greater for recharging than for the initial charge, but here again the correct rate will be stated on the accumulator label and will vary with the type of accumulator and its ampère-hour capacity. As already intimated, these remarks are of a general nature, and it may be useful to mention that several accumulator manufacturers issue booklets giving definite details for the charging and maintenance of their particular manufactures; it is well worth while obtaining the booklet appropriate to the accumulator used.

Charging Methods.—Broadly speaking, there are two basic methods of controlling the charging-rate of accumulators, *i.e.* constant potential and constant current. The constant-potential system entails an arrangement whereby the source of supply is maintained at a constant voltage. With such an arrangement the accumulator when first connected is subjected to an abnormally heavy current, owing to the low E.M.F. and, as the internal resistance decreases and the E.M.F. rises, the charging current falls until it is almost negligible when the accumulator is fully charged. Constant-potential charging sets, intended for commercial use, are usually made so that they may charge a 12-volt car battery should occasion arise, and it is expected that accumulators to be charged should be grouped so that six cells are in series. In the hands of the inexperienced or careless such a charger is open to serious misuse, as an inadequate number of cells or, alternatively, the correct number of cells but of varying capacity may well result in the small-capacity cells passing such a heavy current that the positive plates disintegrate.

The alternative arrangement is constant-current charging, whereby the current flowing is regulated by a series resistance or other means, adjustment being made from time to time so that the charging-rate is kept approximately constant as the E.M.F. of the cells rise. For commercial purposes it is unfortunately unavoidable that the charging-time is speeded up, and as a compromise the constant-current arrangement may be modified so that the rate of charge is relatively high at the beginning and progressively reduced towards the end. In this way the average type of accumulator can be satisfactorily charged in from eight to ten hours. It should be understood that in mentioning the necessity for speeding up the charging-time for commercial purposes the author does not wish to condone the charging of accumulators at a destructive rate, but it is useless to avoid the tendency of users of battery receivers to take an accumulator to their charging-station early in the morning and insist on collecting it during the evening of the same day. While such speedy charging is not desirable from a purely theoretical standpoint, the fact remains that an accumulator may be charged in eight to ten hours in the manner described without shortening its effective life to any serious extent.

To summarise the merits of constant-potential and constant-current charging, it is apparent that constant-potential charging has the sole merit that it does not require any attention, but necessitates considerable care and discretion in grouping the cells and may prove extremely awkward if a comparatively small number of cells have to be charged which vary considerably in capacity. It therefore seems fair to say that this method is far from satisfactory. Constant-current charging, or the modified form of it described above, is generally accepted as satisfactory from the point of view of efficiency and proper care of the accumulators under charge, but requires a certain amount of care if charging is to be accomplished in eight to ten hours.

Accumulator Faults.—Accumulators are subject to various faults due to misuse occasioned by either incorrect charging, over-discharging, or by permitting the cell to stand in a discharged condition, and also due to old age or misadventure.

Loss of Capacity.—This may be due to sulphation rendering the accumulator incapable of taking a full charge, or due to an internal leak caused by a piece of plate having become detached and resting between the positive and negative plates. If the specific gravity falls about ·075 below the correct figure an internal short is indicated.

Disintegration of Positive Plate.—A space is provided at the bottom of an accumulator to receive a fine peroxide deposit which will fall during the life of the accumulator. This deposit will gradually turn white and is a practically normal happening. If lumps of material appear at the bottom of the cell this is due to over-discharge if signs of sulphation are present on the positive plates (which may be recognised as white patches) or, alternatively, due to an excessive rate of charging if the positive plate is black or blackish in colour.

Cracked Plates.—Cracks may appear in the plates either on the surface or from side to side to an extent that will eventually cause the plate to separate. This can be due to old age or to sulphation caused by over-discharge or, less probably, to a manufacturing defect.

Blisters on Negative Plate.—Blisters on the actual negative material or, alternatively, the appearance of a growth resembling fungus, is almost invariably due to the specific gravity of the acid being too high. This can easily be checked by means of a hydrometer, but should never occur if this instrument is used during charging, as obviously this abnormality would be noticed long before damage could occur.

Special Note.—If occasion arises to empty the accumulator, either as a preliminary step to withdrawing it from its case to effect a repair or to change the acid, it is imperative that the accumulator be fully charged before the acid is emptied out or the plates withdrawn. Should a short circuit occur due to a piece of active material having become detached and lodged between two plates, it may be possible to dislodge it by "washing the accumulator out." If this treatment be resorted to, it is imperative that only acid of approximately correct specific gravity be used; the practice of washing out with distilled water is strongly condemned, as it is liable to loosen the active material, which will probably result in several short circuits occurring within a very small space of time.

Accumulator Chargers.—Accumulator charging on D.C. mains is extremely simple, as it is only necessary to provide a suitable series resistance to limit the current to the required value. If a small number of cells is to be charged, this procedure is most uneconomical.

Suppose, for example, that the mains voltage is 250 volts, and twenty-five cells are to be charged at once, it is apparent that approximately 200 volts must be dropped across a resistance, which means that 80 per cent of the wattage consumed will be wasted. At one time simple devices made their appearance, consisting of a lampholder and leads for home charging on D.C. mains. Such a device was incredibly wasteful, and the charging of a 20-ampère-hour accumulator on 250-volt mains would result in the consumption of 5 to 6 units of electricity. At the time when these devices made their appearance it was not uncommon in remote country districts (where such a device would presumably appeal)

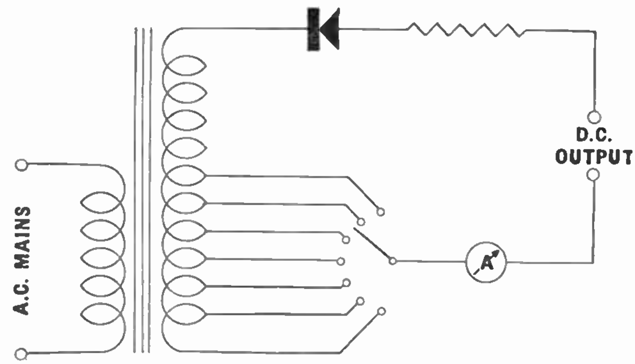


Fig. 74.—A simple accumulator charger using a metal rectifier.

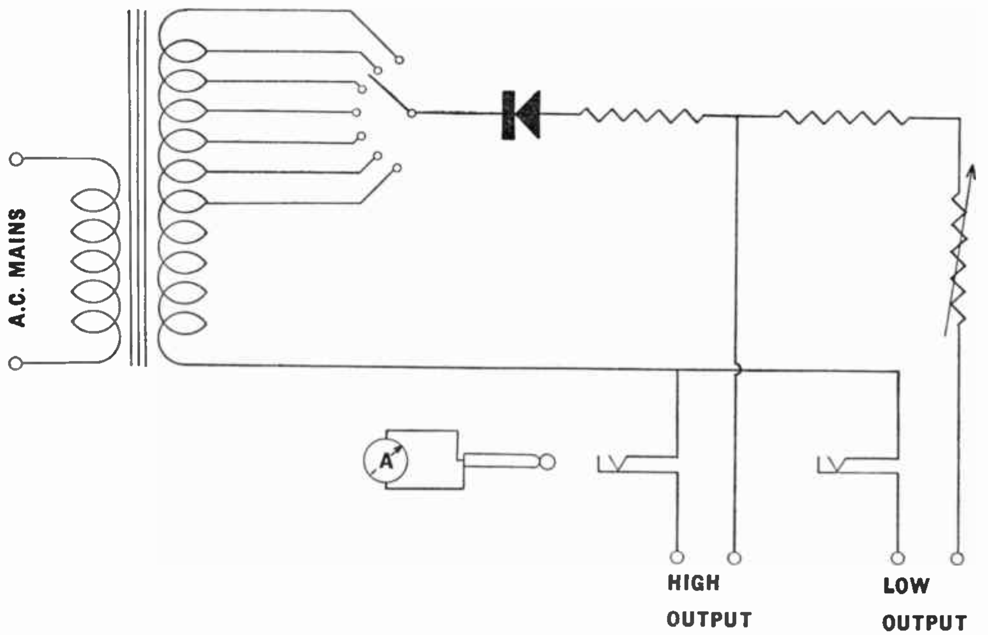


Fig. 75.—A more elaborate accumulator charger, allowing a group of large cells and a group of small cells to be charged simultaneously. The arrangement shown has a disadvantage that the current flowing through one circuit will vary the current flowing through the other, although any error can be corrected by means of the transformer tappings and variable resistance.

for electricity to cost 9*d.* per unit, thus the cost of charging this small accumulator works out at 4*s.* 6*d.* per charge. Unless a large number of cells will always be charged at one time it will be far more economical to convert the D.C. supply to A.C., usually by means of a converter, and step down the voltage by a transformer and then rectify.

When A.C. mains are available, charging is comparatively simple, and the circuit of a typical charger is shown at Fig. 74, the rate of charge being controlled by tappings on the secondary of the transformer, with a fixed resistance in series with the accumulator that has an ohmic value several times that of the internal resistance of the battery, to avoid slight changes of voltage having a profound effect on the rate of current flowing. If desired, the tappings on the secondary may be dispensed with and the resistance may be made variable, but it must be so arranged that an adequate proportion is always in circuit. This arrangement is wasteful, owing to the wattage dissipated in the additional resistance, but is otherwise perfectly satisfactory. Fig. 75 shows the circuit arrangement of a relatively elaborate charger having two charging circuits so that small accumulators can be grouped on one circuit and larger accumulators grouped on another circuit, each being regulated for an appropriate charging-current. It will be observed that in the interest of economy a single ammeter is used, which may be plugged in to other circuits by means of the jack provided. Obviously, by suitable arrangement, any number of charging-circuits can be provided.

APPENDIX I

(1) *Radio Mathematics.*—The mathematics used in this book are of the simplest possible nature consistent with imparting the requisite information; wherever possible a note is included showing the inference to be drawn from various formulæ for the convenience of those whose interest is superficial rather than directed to actual application.

Although only the simplest mathematical terms are used, it was thought worth while to include a short résumé of the rules used, to serve in the nature of a reminder to those who have not had occasion to handle formulæ perhaps since school days; on the other hand, those who are familiar with the use of simple formulæ will not desire to read this section (Appendix I) (1).

Take as an example the formula which expresses the reactance of an inductance, viz.:

$$X = 2\pi fL$$

In the section where the formula is first introduced the meaning of the several symbols will be given, together with the units to be used, in such terms as these: "when X equals reactance in *ohms*, π equals 3·141, f equals frequency in *cycles per second*, and L equals inductance in *henrys*."

It is obvious from the accompanying text matter that the formula is included to enable the reader to determine the reactance of an inductance; X is the symbol for reactance generally, but *inductive* reactance is sometimes written X_L. It is written as X in the text in question, as it is obvious that inductive reactance is being discussed.

In order to determine the required value (namely the value of X) it is necessary to resolve X; the word "resolve" may sound formidable, but it simply means substituting the several letters for relevant numbers and working out the resulting straightforward "sum." A glance will show that four characters are used, 2, π, f, and L, and it is important to remember that when characters follow each other without a sign (*i.e.* +, −, ÷) between them it is understood that they are to be multiplied together; thus the formula could be (but never is) written as follows:

$$X = 2 \times \pi \times f \times L$$

In so rewriting the formula no difference whatever has been made to it, the multiplication sign has merely been inserted where it is normally assumed. The next step is to substitute the characters for *known* quantities.

π. The Greek letter pronounced " pi " is a constant and has a value of 3·14159 etc., but for such purpose as finding the reactance of an inductance it will be sufficiently accurate for normal work to take its value as 3·14 or, if it happens to be more convenient, as $3\frac{1}{7}$.

f. It is apparent that the value of X will vary with frequency, and it must be decided at what frequency the value of X is required ; let it be assumed that the reactance of a smoothing choke is to be determined as a step towards ascertaining its efficiency as part of the mains pack. The frequency of hum ripple will be 100 cycles per second if the mains periodicity is 50 cycles per second, therefore, for the present purpose, f equals 100.

L " equals inductance in henrys." This is a piece of information about the choke that must be determined either by measurement, calculation, or by accepting the manufacturer's specification. Let it be assumed that it is a 30-henry choke; then L equals 30 (if appreciable direct current is flowing through the choke, the value must be that which obtains under such a condition).

The values of the characters are now known, so they can be substituted thus :

reactance (X) — a constant (2) — π (3·14) — frequency (100) — inductance (30)

$$X = 2 \times 3{\cdot}14 \times 100 \times 30$$

When 2, 3·14, 100, and 30 are multiplied together, the answer is 18,840; thus the reactance of a 30-henry choke at 100 cycles is 18,840 ohms.

Attention can now be directed to a slightly more complicated formula, if the use of the word " complicated " can be excused when applied to the very simple expression below, which is the formula for determining the stage gain of a valve working into a resistive load ; it is taken from the chapter on low-frequency amplification.

$$\text{Stage gain} = \frac{\mu \times R}{R + r_a}$$

when μ equals the amplification factor of the valve under working conditions, r_a equals the impedance of the valve under working conditions, and R is the effective resistance in the anode circuit.

For the purpose of this example assume that μ equals 20, r_a equals 10,000, and R equals 30,000. It is now possible to substitute the symbols directly :

$$\text{Stage gain} = \frac{\mu \times R}{R + r_a} = \frac{20 \times 30{,}000}{30{,}000 + 10{,}000}$$

By multiplying together the numbers above the line and adding together those below the line the calculation is still further simplified :

$$\frac{600{,}000}{40{,}000}$$

The presence of a simple horizontal line denotes that the expression above it is to be divided by the expression below it, but it is essential that each be reduced to a single expression before this is attempted, and in so doing it is imperative that all multiplication signs be worked out before any notice whatever is taken of + or − signs. To revert to the expression above, the answer could be determined by dividing 600,000 by 40,000, but the process is made very much less laborious by the normal operation of cancelling :

$$\frac{\overset{3}{\cancel{6}0\cancel{0},\cancel{0}\cancel{0}\cancel{0}}}{\underset{2}{\cancel{4}\cancel{0},\cancel{0}\cancel{0}\cancel{0}}} = \frac{30}{2} = 15 \text{ (the stage gain).}$$

It will be observed that the stage gain is 15, and it is apparent that the expression could possibly have been worked out mentally, but in practice it is unlikely that the several values would be in such convenient round figures.

In the chapter on alternating current there appears the formula :

$$Z = \sqrt{R^2 + X^2}$$

when Z equals impedance, R equals pure resistance, and X equals reactance.

For this example let it be assumed that R equals 10 ohms and X also equals 10 ohms. It is now possible to substitute :

$$Z = \sqrt{10^2 + 10^2}$$

It will be noted that in each case the figure 10 is followed by the index ^{2}, denoting that it has to be multiplied by itself or, in more correct terms, that it must be squared. Having done this the expression can then be written :

$$Z = \sqrt{100+100} = \sqrt{200}$$

The sign $\sqrt{}$ denotes that the square root has to be found, which, in the example under discussion, means that a number must be found that when multiplied by itself equals 200. For approximate purposes 14 can be taken as the answer, since $14 \times 14 = 196$, and in the present instance is determinable by inspection. If the square root must be determined accurately, or the number is too large for mental arithmetic, then the square root must be worked out.

The square root of a number is most easily determined by the use of a slide rule, and those who are not familiar with this invaluable adjunct to radio engineering, and calculations generally, are strongly advised to obtain one, together with an instructional booklet. If a square root is to be determined by arithmetic, the procedure is somewhat tedious; admittedly some whole numbers can be handled by means of factors, but as this appendix does not pretend to be a treatise on mathematics, a single method which is capable of finding the square root of *any* number must serve.

Before giving a resume of square root, it will be as well to establish one or two facts, even if they are, perhaps, rather obvious. $\sqrt{100} = 10$ and $\sqrt{10,000} = 100$. It is apparent, therefore, that each two digits in the original number give one additional digit in the square root.

Assume that it is desired to find the square root of 54,756. The number must first of all be split up into pairs of digits, beginning at the *right-hand* side; it is apparent that if there is an odd number of digits, a single one will occupy the extreme left-hand position. The number will be seen below set out in the conventional manner:

```
5,47,56|
```

The first step is to find the nearest square root of the first digit, or pair of digits, as the case may be. In the example this is obviously 2, which is placed on the right-hand side and forms the first digit of the ultimate answer; the digit is also squared and placed below the 5, and also doubled and placed on the left, as shown below. The subtraction is now made and the next two digits brought down:

```
     5,47,56|2
     4      |
4(?) 147    |
```

The next step is to find the figure which can be substituted for ? above, bearing in mind that the divisor as a whole must be multiplied by the selected figure, and still remain a suitable divisor. In the present example the required number is 3, which makes the divisor 43. The figure 3 therefore becomes the second digit of the answer, and the divisor is multiplied by 3, making 129, which is duly subtracted from the 147 and the remaining pair of digits is brought down:

```
  |5,47,56|23
  |4      |
43|147    |
  |129    |
  | 1856  |
```

Each time a new pair of digits is brought down a new divisor must be obtained by doubling that portion of the ultimate answer which has so far been obtained, which in this case will be 46. The next step is to determine the third figure of the divisor, which, as before, must be such that it may be multiplied by the divisor as a whole. In this example it is obviously 4, which forms the ultimate digit of the answer ; 464 is now multiplied by 4, giving 1,856, leaving no remainder :

```
    |5,47,56|234
    |4
    |-
 43 |147
    |129
    |---
464 | 1856
    | 1856
    | ----
    | ....
```

Occasion may arise when it is desired to find the square root of a decimal. It may be noted that if the decimal has an odd number of places it is necessary to add a nought, and it is *not* possible to determine the square root exactly. If the number is a pure decimal the procedure is perfectly straightforward, and may be followed from the example below. Note that the digits in the answer will always be preceded by a decimal point (when finding the square root of a *pure* decimal), since the square root of a number that is less than one will also be less than one.

In the example below the first pair of digits (00) is taken care of by a single nought in the answer ; it will be remembered that each pair of digits in the number results in one digit in the square root. This observation may be extended by drawing attention to the fact that each two decimal places in the number will result in one decimal place in the square root. The example below shows the manner of determining $\sqrt{\cdot000625}$:

```
   |·00,06,25|·025
   |      4
   |      -
45 |     225
   |     225
   |     ---
   |     ...
```

When determining the square root of a mixed number, the digits are marked off in pairs, left and right, from the decimal point ; if an odd number of places appear after the decimal point, a nought is added. The decimal point in the answer is put in immediately before the first pair of decimal digits is brought down. In the example below $\sqrt{408\cdot8484}$ is determined :

```
     |4,08·84,84|20·22
     |4
     |-
402  | 0884
     |  804
     |  ----
4042 |   8084
     |   8084
     |   ----
     |   ....
```

(2) ***The Interpretation of Graphs.***—Broadly speaking, a graph may be described as a convenient means of determining an indefinite number of relationships between two variables. The simplest type of graph is one in which the curve is a straight line, and it should be noted that the line drawn across the squares is known as a "curve," whatever its shape may be.

Suppose some liquid is to be sold at 5*s*. per pint. If it is to be sold in even quantities, such as quarter- and half-pints, it will be quite unnecessary to resort to graphical methods, but if a ready means of determining fractional quantities is required, it is conceivable that a graph would be worth while. Fig. 76 shows a piece of the usual squared paper which, it will be observed, is divided up into a number of major squares, which are in turn subdivided into tenths. As 5*s*. is sixty pence, it will be convenient to use six such squares, so that each square will represent ten pence and consequently each minor square will represent one penny. It is now necessary to distribute the pint along the vertical dimension; obviously each major square could represent one fluid ounce, but this would make the resultant graph ill-proportioned, which hampers accurate reading. It is therefore convenient to make each major square equal 5 fluid ounces, as shown. To draw the curve it is only necessary to mark off two known relationships, since the cost will be strictly proportional to the volume of liquid. These two points could conveniently be a pint at 5*s*., which will be placed where the horizontal 20-ounce line cuts the vertical 5*s*. line (*i.e.* sixty pence). This is indicated in Fig. 76 by a small circle. The other point could conveniently be one-fifth of the previous quantity, namely 4 ounces for one shilling, which is denoted by the lower small circle, and the two lines joined up and extended in either direction, as may be necessary.

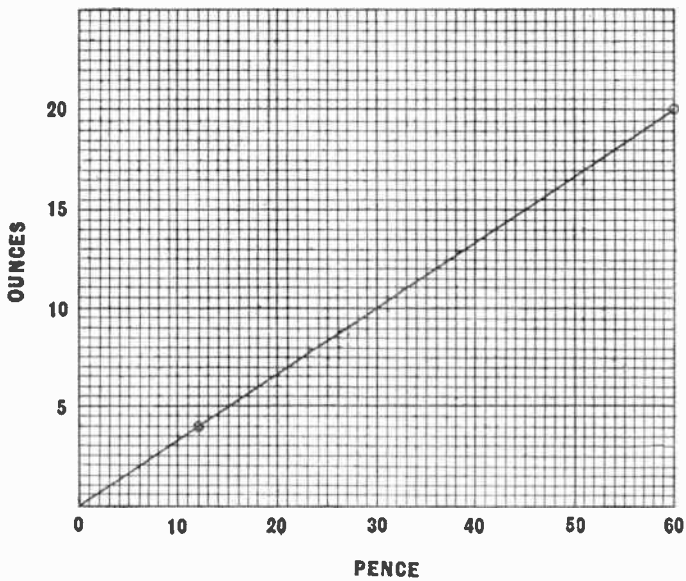


Fig. 76.—A simple example of a graph.

The real value of a graph is for determining relationships which are not proportional. Fig. 77 shows a curve which has been plotted from the following information, the actual points being indicated by small circles :

Volts.	*Cycles per second.*
0	0
2	666
3	1,333
3·5	2,000

If the nature of the phenomenon is fully understood, it will be safe to join the points shown at Fig. 77 so that the graph now appears as Fig. 78. The process of continuing a line between points is known as interpolation, a practice which can only be employed providing the nature of the phenomenon is such that a change of one variable has a reasonable effect on the other. To take an extreme case, the curve at Fig. 78 might be plotted in all good faith from a small series of known relationships, but the true curve might be as shown at Fig. 79 if more facts were known, as indicated by the crosses which denote additional points.

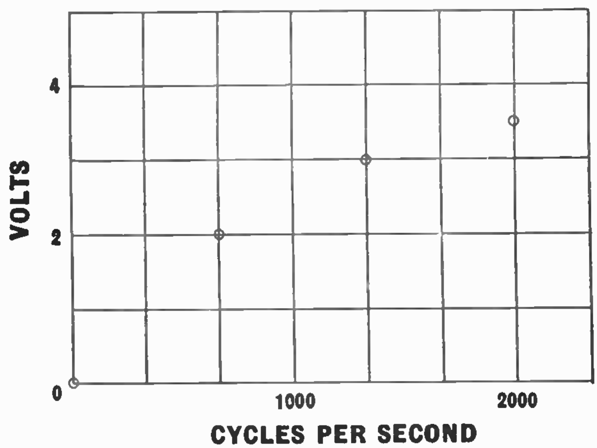


Fig. 77.—The first step in preparing a graph—marking off the points.

Certain curves are drawn on paper the divisions of which are non-linear in either or both directions. Generally speaking, such divisions follow a logarithmic law. This type of scale may be employed in order that the shape of the resultant curve shall convey a more appropriate mental impression of the phenomenon under observation. For example, a graph plotted between some variable in the horizontal direction and audio gain in a vertical direction would have linear divisions if the gain is expressed in decibels, but if it is expressed in terms of, say, voltage, it will be desirable to use a logarithmic scale in the vertical direction,

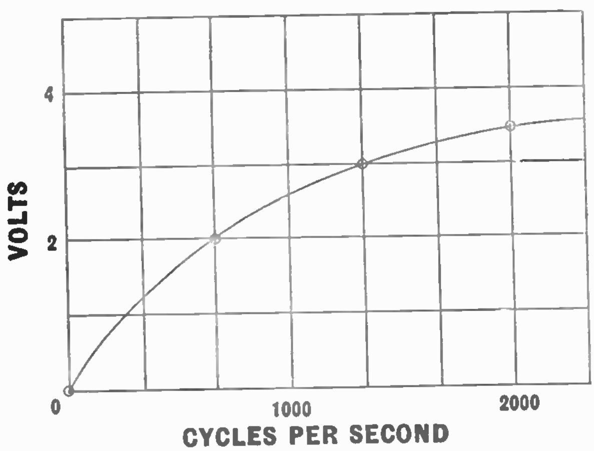


Fig. 78.—Second step in preparing a graph—joining up the points. It is essential that the number of points be adequate for the type of work.

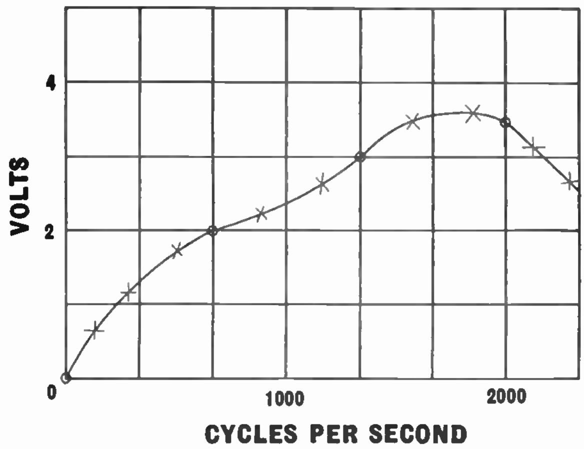


Fig. 79.—A graph showing the danger of insufficient points. Additional points might show that Fig. 78 is incorrect and should be as shown here.

so that deviation from the curve would give an idea of the apparent audible change in volume. It will be remembered that the response of the human ear to changes of volume follows approximately logarithmic law.

The use of a logarithmic scale is sometimes employed as a means of showing more clearly the behaviour of the curve that is straight for the greater part of its length.

When reading from logarithmic paper, care should be taken to avoid falling into the error of assuming that half a division is the geometrical half-way mark. The mathematical centre between two divisions bears the same relationship to the boundaries of the division in question as it bears to a complete logarithmic section.

(3) ***Reading Circuit Diagrams***.—There are several conventions for expressing the actual connections in circuit diagrams, in addition to innumerable minor and major differences in the actual symbols used to express various components. The accompanying illustrations, Figs. 80–83, show the extent of the variation as used by various responsible publications, associations, or manufacturers.

Fig. 80.—(left) Wires crossing, (right) a junction.

The variations in the expression of the actual connections are limited, and can therefore be referred to in detail. Throughout this work the author has adopted the convention of using a small loop when one wire crosses another without making contact, as shown at Fig. 80 (left), which shows two wires crossing but not making contact with each other. For indicating that two wires are in metallic connection with each other the author has adopted the convention of simply omitting the loop, as shown at Fig. 80 (right).

Some circuit diagrams use the loop, as shown at Fig. 81 (left), to express wires crossing each other, but employ a small spot at the junction of two wires that are connected together, as shown at Fig. 81 (right). Presumably this idea has arisen from the suggestion of a blob of solder holding the wires together.

Another convention which differs completely from that used in this book is to show wires that cross but that do not touch by simply drawing them across each other, as shown at Fig. 82 (left), and indicating wires that are in metallic connection by means of a spot at the point of junction (Fig. 82 (right)). It will be realised that a junction in the first-mentioned convention is the same as a cross-over in the third-mentioned convention. That such a state of affairs can exist is very unfortunate, and when a circuit diagram from an unknown source is read it is necessary to note which convention is used, deriving the information merely from the fact that the application of the wrong convention will show a ridiculous series of connections. It is apparent that some knowledge of circuit arrangements is necessary before it is possible to determine whether or not a particular pair of wires are in contact or otherwise.

Fig. 81.—A slightly modified convention: (left) wires crossing, (right) a junction.

Fig. 82.—An entirely different convention: (left) wires crossing, (right) a junction.

There is yet a further convention which uses straight lines drawn across each other with or without a spot to indicate a junction and a broken line as indicated at Fig. 83 to represent a cross-over. This arrangement is perhaps the best one to adopt if the loop convention as shown at Fig. 80 is objected to on account of the large number of loops that have to be drawn on an elaborate diagram. The author prefers the loop convention as, in his opinion, it permits a circuit arrangement to be more quickly grasped than is possible with any other convention. This is, however, purely a matter of opinion.

Fig. 83.—Yet another convention for wires crossing.

(4) ***Colour Codes and Customs.***—There are several colour codes which are standardised for various purposes. Some are strictly adhered to, but others are more often honoured in the exception rather than in the rule.

Resistances.—It will be observed from the foregoing that resistances are colour coded in a different way for those having leads at right angles to the main body as compared to those having leads in line with the main body, although the principle remains the same. Insulated resistances usually have the same colour code as those of the axial lead type irrespective of their construction.

It should be noted that the second digit may be indicated by the appropriate colour in the form of either a coloured band or a coloured tip. This is shown at Fig. 84*a* and Fig. 84*b* respectively. When the dot, tip (or band) is absent, it is assumed to be the same colour as the body.

RESISTANCE COLOUR CODE

Colour.	*Body and Tip.*		*Dot.*
Black	0		None.
Brown	1		0
Red	2		00
Orange	3		000
Yellow	4		0000
Green	5		00000
Blue	6		000000
Violet	7	U.S.A. only	0000000
Grey	8	U.S.A. only	00000000
White	9	U.S.A. only	000000000

EXAMPLES.

Body Colour.	*Tip or Band Colour.*	*Dot Colour.*	*Resistance.*
Brown	Red	Black	12 ohms.
Violet	Green	Brown	750 ohms.
Yellow	Black	Orange	40,000 ohms.
Black	Red	Blue	2 megohms.

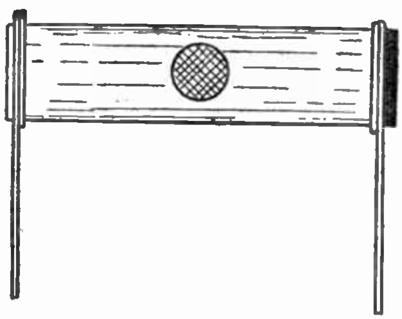


Fig. 84*a*.—The body colour denotes the first digit. The colour of the tip the second digit, and the colour of the spot the number of noughts.

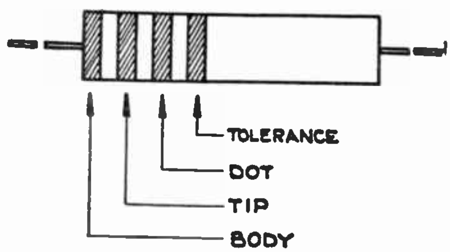


Fig. 84*b*.—The new modified colour code used for resistances with axial leads.

The tolerance of resistances is shown by a gold or silver tip or ring as appropriate, as follows :

Gold tip ± 5 per cent.
Silver tip ± 10 per cent. (Silver indicated ± 20 per cent. up to Spring 1944)
Not coded ± 20 per cent. (No indication was ± 10 per cent. up to Spring 1944)

Fuses.—Fuses are colour coded in accordance with the table below, but there are no regulations regarding the manner in which the colour shall be applied. It may take the form of paint, coloured-paper label, etc. Some manufacturers ignore this code and may, for decorative purposes, colour all values, say, blue. The code, however, is as follows:

Black 60 milliampères.
Grey 100 milliampères.
Red 150 milliampères.
Brown 250 milliampères.
Yellow 500 milliampères.
Green 750 milliampères.
Dark Blue 1 ampère.
Light Blue 1·5 ampères.
Purple 2 ampères.
White 3 ampères.
Black and white 5 ampères.

When interpreting the colour code of condensers it should be remembered that one micro-micro-Farad (μμF) is equal to one pico-Farad (pF).

Colour.	*A* *1st Digit.*	*B* *2nd Digit.*	*C* *Ciphers.*	*D* *Decimal Multiplier.*	*E* *Tolerance. Per cent.*	*F* *Type.*
Black	0	0	·0	1	—	*A*
Brown	1	1	0	10	—	*B*
Red	2	2	00	100	2	*C*
Orange	3	3	000	1,000	—	*D*
Yellow	4	4	0000	—	—	*E*
Green	5	5	00000	—	—	*F*
Blue	6	6	000000	—	—	*G*
Violet	7	7	0000000	—	—	—
Grey	8	8	00000000	—	—	—
White	9	9	000000000	—	—	—
Gold	—	—	—	0·1	5	—
Silver	—	—	—	0·01	10	—
Black	—	—	—	—	20	—

Note.—The tolerance colour dot E is sometimes replaced by a letter, in which case "G" = 2 per cent., "J" = 5 per cent., "K" = 10 per cent., and "M" = 20 per cent.

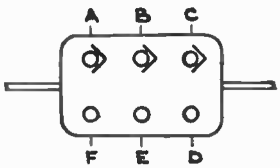


Fig. 85.—The condenser colour coding illustrating table above.

British Colour Code for Battery Connections.—The colour code for wander-plugs given below is honoured by some manufacturers and totally ignored by others; some of the latter hopelessly confuse the position by using coloured wander-plugs without conformity with the code.

Red	Highest positive H.T. voltage.
Yellow	Second highest positive H.T. voltage.
Green	Third highest positive H.T. voltage.
Blue	Fourth highest positive H.T. voltage.
Black	Common negative (L.T. − and/or H.T. − and/or G.B. +).
Pink	L.T. positive.
Brown	Maximum G.B. negative voltage.
Grey	Second highest G.B. negative voltage.
White	Third highest G.B. negative voltage.

Special Note.—Any additional leads are coloured violet and their purpose indicated in some other manner. A lead emanating from a centre tap is coloured white.

American Colour Code for Battery Connections.—It should be noted that the American colour code for battery connections is strictly adhered to and is determined by the colour of the *lead itself*, the colour of the actual wander-plug being ignored.

Red	Highest positive H.T. voltage.
Maroon and Red	Second highest positive H.T. voltage.
Maroon	Third highest positive H.T. voltage.
Black, red tracer	H.T. −.
Black, yellow tracer	L.T. −.
Yellow	L.T. +.
Green	G.B. +.
Black, green tracer	Maximum G.B. negative voltage.
Brown	Second highest G.B. negative voltage.

Special Note.—In America the high-tension battery is known as the B battery, thus H.T. + s +B. Similarly, the low-tension supply is called the A battery and grid-bias the C battery.

Multiple Block Condenser Leads.—When a block condenser has two wires only they are red and black irrespective of capacity or any other consideration, otherwise the following code applies :

Red	Highest capacity (positive).
Yellow	Second highest capacity (positive).
Green	Third highest capacity (positive).
Blue	Fourth highest capacity (positive).
Violet	Fifth highest capacity (positive).
Black	Principal negative.
Brown	Second negative.
Grey	Third negative.
White	Centre tap for voltage doubler.

Special Note.—If two sections are of the same capacity, the one with the higher voltage rating will have the higher code colour.

Markings in accordance with the following table may appear on condensers in addition to, or as an alternative from, the colour code above.

+ Common positive junction.
− Common negative junction.
± Series connection.
& Isolated section.

There are numerous other colour codings, including British conventions for transformer leads and American conventions for moving-coil loudspeaker leads. The codes and customs tabled above include those in general use and moderately frequent use, the rest being omitted, as they are so seldom employed that they result in confusion. A complete standardisation report has been published by the Radio Component Manufacturers Federation. Standardisation in other forms has been recommended by the British Radio Valve Manufacturers Association and other responsible bodies.

(5) ***Short-wave Reception.***—Reception of long-distance short-wave stations requires considerably more care and patience than is generally supposed. One is accustomed to receiving stations on the medium and long wavebands spaced at reasonable distances apart on the dial. When searching for short-wave stations it is important to remember that the change of frequency per degree of rotation is very considerable, so considerable in fact that on the 10-metre band fifty channels may easily

be covered by a quarter of an inch on an ordinary dial. These remarks are, of course, directed to those receivers which use the same variable tuning condenser for all wavebands.

Apart from the question of patience and care, the success of short-wave reception depends to a very large extent on knowing which band to use at various times of the day. A particular station may be easily received at midnight, but be utterly unobtainable at midday. Some stations transmit at times which make them practically unreceivable in this country, since they work on frequencies unsuited to their distance from this country. The wavebands which can be expected to yield the most long-distance stations change with the time of day, the seasons of the year, and the utterly unstable condition of the various refracting layers in the upper atmosphere. The most important factor in determining the time is sunrise and sunset, and the remarks on each band below are expressed in these terms in order that they shall be applicable all the year round within reasonable limits.

16-*metre Band.*—On this band distant reception is most easily accomplished when the entire path between transmitter and receiver is wholly in daylight. It is apparent, therefore, that stations in an easterly direction will be most easily received during the period two hours after sunrise until midday. American stations are most readily obtainable between midday and sunset, and European stations will be most consistent between sunrise and two hours after sunset.

19-*metre Band.*—Distant reception is most readily obtained on this band when the path between transmitter and receiver is largely, but not entirely, in daylight. Good conditions last until an hour or two after sunset at the receiving end. American stations are most readily received over a period extending about two hours on either side of sunset.

25-*metre Band.*—Distant reception is at its best when the transmitter is in daylight and the receiver is in darkness. American stations are usually received between one and five hours after sunset at the receiving end, while European stations are usually available during the afternoon and evening.

31-*metre Band.*—Distant reception is at its best when the transmitter is in darkness and the receiver in daylight, or *vice versa.* North and South American stations begin to come over at good strength about two hours after sunset, and will usually increase in strength until midnight or a few hours after. The best chance of obtaining Australian stations is often on this particular waveband between sunrise and two or three hours afterwards. European stations can be expected throughout all hours of the day.

49-*metre Band.*—Reception is best on this band when the path between the transmitter and receiver is wholly in darkness. American stations are best received from about five hours after sunset until daybreak, and European stations from two hours after sunset until daybreak.

Owing to the phenomenon of skip distance relatively near stations may be unobtainable when more distant stations are coming in well on the same band. When searching for short-wave stations an up-to-date schedule giving stations and frequencies should be available, as operating times and frequencies are subject to constant change. The above notes on the different wavebands can be summarised by the phrase, " the later the hour the longer the wavelength."

(6) ***Miscellaneous Valves.***—The following is a brief résumé of certain types of valves omitted from the main text to avoid confusion.

Electron Multiplier Valves.—A class of valve which utilises the phenomenon of secondary emission. The idea of applying what was hitherto regarded only as a drawback must be attributed to Farnsworth and Zworykin, who apparently worked on the idea independently and made their discoveries known at about the same time. The principle underlying the Electron Multiplier is amplification due to secondary emission. In practice, a number of anodes are employed, each being bombarded by a secondary electron from the previous anode, arrangements being made to accelerate progressively the electrons along the structure so that each anode gives off many more secondary electrons than primaries received. The principle has found practical application in television transmission in the form of the Farnsworth tube, certain special applications in high-frequency work, and in fields outside radio engineering.

Magnetron.—A special form of diode valve constructed so that the electron stream can be placed in the gap between the poles of a powerful magnet. When so arranged, it is capable of maintaining continuous oscillation or permitting anode current variation by magnetic means, and relies for its functioning on the somewhat obscure behaviour of a stream of electrons in a powerful field. Although the arrangement has great possibilities, the author is unaware of any practical application in the field of domestic radio engineering.

Multi-purpose Valve.—Twenty years ago a valve existed which possessed five grids in addition to the usual anode and cathode. It was so designed that the valve could fulfil any normal function by suitable connection or interconnection of its grids. In a suitable circuit arrangement, therefore, it could be used as high-frequency amplifier, frequency changer, oscillator, mixer, intermediate-frequency amplifier, detector, low-frequency amplifier, or output valve. From the point of view of the listener the system had one great advantage, namely, that a single spare valve would suffice as a replacement for any stage.

APPENDIX II

AN ABRIDGED TECHNICAL DICTIONARY

A. BATTERY.—American term for L.T. battery or accumulator.

ABSORPTION.—As applied to controlling the output of a transmitter or to a wave meter, whereby advantage is taken of the property of a tuned circuit "absorbing" power from another tuned circuit to which it is coupled.

A.C.—Abbreviation for Alternating Current.

ACCELERATION.—The rate of increase of velocity of electrons or a physical body. Acceleration and voltage are synonymous terms when applied to the flow of electrons.

ACCEPTOR CIRCUIT.—A tuned circuit which offers a minimum impedance at resonance.

ACCUMULATOR.—A secondary cell which converts chemical energy into electrical energy, and *vice versa*.

ACOUSTIC FEED-BACK.—The reintroduction of sound waves, *e.g.* sound waves from the loudspeaker actuating a pick-up head or microphone.

ACOUSTICS.—The science of sound.

ACOUSTIC WAVES.—Another term for sound waves.

ACTINIC VALUE.—The value of a light source for photography.

ADMITTANCE.—The reciprocal of impedance (Symbol Y).

AERIAL.—Speaking broadly, any device for collecting energy from electro-magnetic waves, whether specifically designed for this purpose or whether in some improvised form.

AERIAL (RESONANT).—An aerial of such dimensions that it has a natural frequency related to the frequency of the station which it is desired to receive. Such aerials are highly directional. If the transmitter is more than a few hundred miles distant, orientation must be determined from a globe or a great circle projection map. A map based on Mercator's Projection is useless for this purpose.

AERIAL CIRCUIT.—A vague term, but generally understood to mean everything between the aerial and the first valve.

AERIAL DIRECTOR.—A rod or wire placed between the transmitter and the aerial for the purpose of increasing the efficiency of the system.

AERIAL DOWNLEAD.—A vague term, but usually intended to convey the metallic connection between the receiver and the actual aerial. In the case of a standard inverted L aerial the downlead may collect more than 50 per cent. of the total energy.

AERIAL DUMMY.—A circuit including inductance and capacity and usually resistance, intended to have the same effect as a normal aerial on the input circuit of the receiver. The usual values are 25 Ω, 20 μH, and 200 μμF.

AERIAL FEEDER.—A downlead which is not intended to collect energy, its impedance is normally matched to the impedance of the aerial at the point of connection.

AERIAL HALF-WAVE.—An aerial with a natural wavelength equal to half that of the station to be received.

AERIAL INSULATION.—The resistance between the aerial and earth.

AERIAL REFLECTOR.—A rod or wire so placed that the aerial is between it and the transmitter for the purpose of increasing the efficiency of the system.

AFTER-GLOW.—The continuation of fluorescent light after electric bombardment has ceased from a fluorescent material such as the screen of a C.R.O. tube.

A.G.C.—See automatic gain control.

ALTERNATING CURRENT.—A current the direction of which reverses at regularly recurring intervals. The algebraic average value is zero.

ALTERNATOR.—A device for converting mechanical energy into A.C. electrical energy.

AMMETER.—Strictly an abbreviation for ampère meter. An instrument for measuring the rate of flow of electricity in terms of ampères.

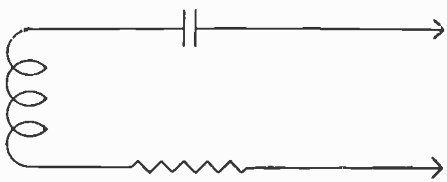


Fig. 86.—A standard dummy aerial circuit. The values are 25 Ω, 20 μH, and 200μμF.

AMPÈRE.—The practical quantitative unit of electrical current (Symbol A).

AMPÈRE HOUR.—A unit of quantity of electricity, equal to the flow of one ampère for one hour (Symbol Ah).

AMPÈRE METER.—*See* Ammeter.

AMPÈRE TURN.—A measure of magneto motive force expressed as the product of the number of turns in an electro-magnet and the current flowing through it.

AMPLIFICATION FACTOR.—A factor denoting the ratio between the effect of grid voltage and anode voltage on anode current in a valve (Symbol μ, a Greek letter which is pronounced " mu ").

AMPLIFIER.—A device for increasing the amplitude of a change of voltage or current; as normally used the word " amplifier " denotes a circuit containing a valve or valves for increasing the strength of a radio or other signal.

AMPLITUDE.—The peak voltage or the peak current of a waveform.

AMPLITUDE DISTORTION.—The presence of alien frequencies in the output waveform. *See also* Frequency Distortion.

ANODE.—The plate of a valve, *i.e.* the electrode that is farthest from the cathode. The electrode to which the electron stream flows.

ANODE A.C. RESISTANCE.—The differential resistance between cathode and anode of a thermionic valve (Symbol R_a, sometimes written r_a).

ANODE-BEND DETECTION, less correctly called Anode-bend Rectification.—A valve arranged to rectify by virtue of anode current being biased to sensibly zero.

ANODE CONVERTER.—A small combined rotary dynamo and motor giving high-tension supply from a low-tension input.

ANODE CURRENT.—The total current flowing in the anode circuit (Symbol I_a).

ANTENNA.—American for aerial.

ANTINODE.—The point at which voltage or current is at a maximum in an aerial or feeder ; the point on a diaphragm where displacement is a maximum.

APERIODIC AERIAL.—An aerial working directly into the grid of an amplifying valve which is not preceded by a tuned circuit.

APPARENT POWER.—The product of R.M.S. volts and R.M.S. ampères ; when voltage and current are exactly in phase the apparent power and the wattage dissipation are equal.

APPLETON LAYER.—An ionised refracting layer above the Kennelly-Heaviside layer.

ARC TRANSMITTER.—A wireless transmitter in which the " negative resistance " characteristic of a carbon/copper electric arc is utilised to produce continuous oscillations. An obsolete system.

ARCING.—Colloquially, a current passing between two conductors due to faulty insulation or inadequate spacing.

ARMATURE.—The inner (usually rotating) member of an electrical generating machine.

ARTIFICIAL AERIAL.—*See* Aerial Dummy.

ASTATIC COIL.—An inductance so wound that the external field is sensibly negligible.

ATMOSPHERICS.—Interference to wireless reception of natural origin such as radiation caused by lightning discharges and also radiation originating from outer space.

ATOM.—The smallest known particle of an element. An atom not having an electrical charge has equal numbers of positive and negative charges.

ATTENUATION.—The deliberate or incidental introduction of loss in a circuit.

ATTENUATOR.—An arrangement, usually of resistances, deliberately introduced to reduce the output from and input to a receiver, measuring instrument, or other piece of apparatus.

AUDIO FREQUENCY.—Wave periodicity within the compass of the human ear.

AUDIO-FREQUENCY TRANSFORMER.—A transformer so designed that it will handle audio frequency without causing undue frequency distortion.

AUTOMATIC GAIN CONTROL.—A circuit to hold a television signal at a chosen level independent of input variations.

AUTOMATIC VOLUME CONTROL.—A means of controlling the gain of a receiver by the amplitude of the signal input to counteract the effects of fading and/or to equalise the output on local and distant stations without manual adjustment.

AUTO-TRANSFORMER.—A transformer, the primary and secondary of which are virtually one winding.

B. BATTERY.—American for high-tension battery.

BACK E.M.F.—The voltage (or Electro-motive Force) which acts in opposition to the flow of current in an electrical circuit.

BAFFLE.—A mechanical obstacle between the front and back of a diaphragm to prevent the effect of the sound waves on either side of the diaphragm from tending to cancel each other.

BALANCED ARMATURE.—A type of loudspeaker movement, the armature of which is balanced both magnetically and mechanically.

BALLAST TUBE.—American for barretter.

BANDPASS FILTER.—An arrangement of tuned circuits designed to attenuate all but a single band of frequencies.

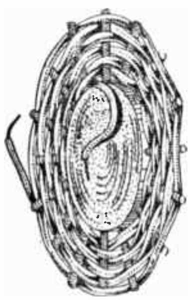


Fig. 87.—A typical basket coil.

BANDPASS TUNER.—A variable bandpass filter.

BANDSPREAD TUNING.—An arrangement for spreading out the tuning range so that a narrow shortwave band will cover the whole dial.

BARRETTER.—A device which appears to resemble an electric lamp designed so that it tends to keep the flow of current constant irrespective of a change of voltage.

BASKET COIL.—An obsolete type of inductance made by winding wire in and out of an odd number of pins arranged radially about a hub.

BATTERY.—Two or more cells connected in series.

BEAM CURRENT.—*See* Gun Current.

BEAM TRANSMISSION.—The system of directing the radiation from an aerial in one particular direction.

BEAT NOTE.—A third frequency caused by and being the difference between two other frequencies.

BEAT RECEPTION.—A system of making continuous wave transmission audible by heterodyning the incoming signal to produce an audible signal.

BEL.—A logarithmic unit of power ratio. The practical unit is the decibel, which is one-tenth of a bel.

BEVERAGE AERIAL.—A low aerial, the length of which is several times the wavelength to be received. It exhibits marked directional properties and has the advantage of favourable signal to noise ratio.

BIAS.—An initial voltage applied. usually to the grid of a valve, to determine its operating condition.

BLACK SCREEN.—Modern television tubes are darkened to allow greater room lighting. Some decrease of background "noise" is also achieved.

BLASTING.—A form of distortion, the nature of which is suggested by the term itself.

BLATTNERPHONE.—A device for recording music or speech by imparting magnetic variations to a tempered steel tape.

BLOCKING CONDENSER.—*See* D.C. STOPPER.

BLUE GLOW.—A phenomenon exhibited by a thermionic valve, the bulb of which contains an abnormal amount of residual gas. It is caused by the ionisation of the gas atoms resulting from collision with electrons.

BOBBIN.—Usually a reel-shaped former on to which an inductance is wound.

BORNITE.—A crystal that exhibits detecting properties when associated with zincite.

BRIDGE.—A circuit arrangement for quantitative electrical measurements.

BRIGHT EMITTER.—A valve requiring the filament to be raised to a relatively high temperature before normal emission takes place.

BUZZER WAVE METER.—A wave meter which functions as a miniature calibrated transmitter actuated by an oscillatory current produced by a buzzer.

BY-PASS CONDENSER.—Condenser connected across a resistance or impedance to offer reduced impedance to audio or high frequencies.

C. BATTERY.—American for grid-bias battery.

CAPACITANCE.—An alternative name for capacity.

CAPACITOR.—An alternative name for condenser.

CAPACITY (of an accumulator).—The number of ampère hours that a cell can deliver after being fully charged. Of a condenser or insulated body—a measure of ability to store electricity (Symbol *C*).

CAPACITY BRIDGE.—A balanced circuit arrangement for measuring capacity by determining its ratio to a known capacity.

CAPACITY COUPLING.—A term used when a coupling between two circuits relies upon a condenser, one plate of which is connected to each circuit.

CAPACITY REACTION.—Usually intended to mean magnetic reaction, the degree of which is controlled by a variable capacity. Strictly, the term means reaction due to energy fed from anode to grid by capacity coupling.

CARBON MICROPHONE.—A microphone which functions by virtue of variation in resistance between carbon contacts.

CARRIER.—A broad term used to indicate carrier wave, carrier current, or carrier voltage.

CARRIER FREQUENCY.—The fundamental frequency of a transmitter. *See also* Sidebands.

CARRIER SUPPRESSION.—A transmitting system in which the carrier wave is not radiated.

CARRIER WAVE.—A waveform modulated by a signal frequency enabling the latter to be transmitted through free space.

CASCADE.—A term used to denote that two or more pieces of apparatus, usually amplifiers, are so connected that the output of one is fed to the input of another. The valves in a receiver are said to be in cascade.

CATHODE.—An electrode from which electrons are emitted. The term is sometimes so used that it is peculiar to an indirectly heated valve.

CATHODE-RAY OSCILLOGRAPH.—A complete apparatus, comprising a cathode-ray tube, time base, and power pack.

CATHODE-RAY TUBE.—A thermionic device which reproduces current or voltage phenomena as a visible light trace.

CAT'S WHISKER.—A wire contact which forms a detector in conjunction with a suitable crystal.

CELL.—*See* Accumulator and Primary Cell.

CHARACTERISTIC CURVE.—A graph plotted to convey the peculiarities and electrical features of a piece of apparatus. In radio engineering the expression tends to be reserved for use in conjunction with thermionic valves.

CHOKE.—An inductance designed to have a large A.C. impedance but a relatively small D.C. resistance.

CHOKE CAPACITY COUPLING.—Similar to resistance capacity coupling, except that the anode resistance is replaced by a choke to increase the steady anode voltage of the valve.

CLASS A AMPLIFIER.—An amplifying valve so biased that anode current flows at all times unless the valve is over-loaded.

CLASS AB AMPLIFIER.—An amplifying valve so biased that anode current flows for more than half but less than the whole of one cycle of an A.C. input. This class of amplifier is sub-divided; when no grid current flows at full output it is Class AB_1. When grid current flows for some portion of the complete cycle at full output it is Class AB_2.

CLASS B AMPLIFIER.—An amplifier the grid bias of which will reduce the anode current to sensibly zero when no input is applied.

CLASS C AMPLIFIER.—An amplifier the grid bias of which is appreciably greater than that necessary to reduce the anode current to sensibly zero.

COEFFICIENT OF COUPLING.—A percentage indication of the mutual inductance between two coils.

COHERER.—An obsolete detector utilising the property of metal filings which make imperfect contact unless influenced by high-frequency current.

CONDENSER.—A component deliberately designed to possess capacity.

CONDENSER MICROPHONE.—A microphone which converts sound waves into change of capacity.

CONDUCTANCE.—The reciprocal of resistance. The unit is the mho, which is the reciprocal of an ohm. *See also* Mutual Conductance.

CONDUCTOR.—A substance which offers comparatively little resistance to the flow of current.

CONE.—A large cone-shaped loudspeaker diaphragm.

CONTINUOUS WAVES.—Undamped oscillations of constant amplitude; but, for signal purposes, broken up in the form of the Morse code. The incoming signal must be heterodyned to render it audible.

CONVERTER.—In television, a unit to enable a Band I receiver to also receive Band III.

CORRECTOR CIRCUIT.—Usually, but not necessarily, a resistance and condenser across an inductance to reduce frequency distortion.

COUNTERPOISE.—A wire supported underneath an aerial near to, and used instead of, the earth.

COUPLING.—Coupling is said to exist when an electrical change in one circuit produces an electrical change in another.

CROSS MODULATION.—A term used to describe the phenomenon resulting when two signals, one of which is of relatively high amplitude, are imposed on the grid of a screened tetrode, resulting in the modulation of one station superimposing itself upon the carrier of the other. When this condition obtains, both modulations are imposed on one carrier and the following tuned stages are powerless to separate them.

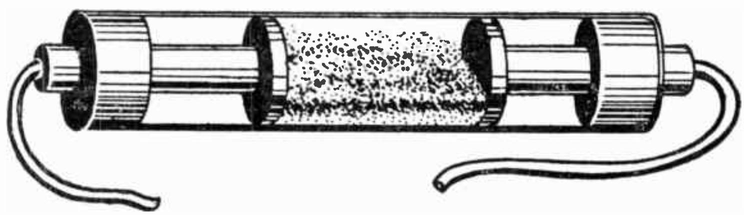


Fig. 88.—Drawing of a coherer taken from a museum collection.

CRYSTAL.—*See* Crystal Detector, or Quartz Crystal, as may be appropriate.

CRYSTAL DETECTOR.—A detector which takes advantage of the fact that some crystals exhibit the property of offering greater resistance to the flow of current in one direction than in the other.

CUMULATIVE GRID RECTIFICATION, OR DETECTION.—Another name for leaky grid detection.

CURRENT.—The movement of electrons along a conductor. As a matter of convenience the direction of flow is assumed to be in the opposite direction to the actual movement of electrons.

CUT-OFF.—The limit above or below which a microphone, loudspeaker, transformer, amplifier, etc., ceases to convey energy without undue attenuation.

CYCLE.—One complete sequence of a recurrent phenomenon.

DAMPING.—Strictly speaking, the rate at which a train of oscillations dies away. Colloquially, the deliberate or accidental introduction of resistance into a tuned circuit.

D.C. Stopper.—A condenser connected in a circuit to prevent the flow of direct current.

D.C.C.—Abbreviation of Double-cotton-covered.

Dead Beat.—A meter is said to be dead beat when the pointer comes to rest without oscillating.

Decibel.—One-tenth of a bel (Symbol db).

Deflector Plates.—The side plates in a cathode-ray tube which deflect the direction of the electron beam.

Delay (Voltage).—A voltage applied, usually to a diode, so that a circuit or part of a circuit is inoperative until the input reaches a predetermined level.

Demodulation.—A phenomenon which occurs when a weak modulated signal is rendered inaudible by a relatively strong carrier on a nearby frequency. The actual demodulation can only occur in the detector valve.

Detector.—A valve or crystal combination arranged to cut off the upper or lower half of a modulated carrier.

Diaphragm (of a Loudspeaker).—Strictly, a disc or cone producing sound waves, but usually reserved for horn-type speakers.

Dielectric.—The insulator separating the plates of a condenser.

Dielectric Loss.—Loss of energy which occurs when a potential difference appears across a dielectric. The extent of the loss differs widely with different substances, and increases with frequency.

Differential Condenser.—A condenser with one set of moving vanes and two sets of fixed vanes so arranged that the average capacity is constant.

Diode.—A two-electrode thermionic valve incorporating an anode and cathode or filament.

Diplexer.—A device to enable separate Band I and III aerials to be connected to a television receiver with only one aerial socket. A device to enable a combined Band I and III aerial to be connected to a television receiver with separate sockets for Band I and III aerial feeders.

Direct Current.—A current the direction of which is continuous.

Direction Finder.—A wireless receiver with a special aerial array, or a loop aerial designed with the intention of determining the direction of a transmitter.

Discriminating Circuit.—A portion of an automatic-frequency control circuit which brings about a change of potential consequent upon a change of frequency.

Downlead.—*See* Aerial Downlead.

Driver.—A valve used in front of a class B output stage to supply the *power* used in the input circuit of the output valve due to the flow of relatively heavy grid current.

Dynamic Characteristics.—Curves usually, but not necessarily, of a thermionic valve, showing working performance, *e.g.* when anode and grid voltages are varying simultaneously.

Dynamic Loudspeaker.—Another name for moving-coil speaker.

DYNATRON.—A tetrode arranged to work as an oscillator by virtue of the property of the valve to generate continuous oscillation if the potentials applied are such that the valve works on its negative resistance characteristic.

EARTH POTENTIAL.—The electrical potential of the earth is considered as zero and various points of electrical apparatus are connected to earth for the purpose of preventing the building up of induced potentials.

EBONITE.—An insulating material made of vulcanised rubber and sulphur.

ECHO.—Reflection of sound causing one or more repetitions of a single original sound.

EDDY CURRENTS.—Currents induced in a conductor by a magnetic field.

EFFICIENCY DIODE.—An integral part of a line time base which incorporates flyback E.H.T.

ELECTROLYTE.—The liquid in the secondary cell, electrolytic condenser, etc.

ELECTROLYTIC CONDENSER.—A form of condenser in which the dielectric is a film of oxide formed by electrolysis set up by the current which flows through the condenser when the potential is first applied, and, to a lesser extent, during the whole of the time in which the condenser is in use. This type of condenser had a very favourable capacity to size ratio.

ELECTRO-MAGNET.—A magnet which is effective only when a current is passing through a coil which is placed round the iron core.

ELECTRO-MOTIVE FORCE.—The force that tends to bring about movement of electricity in a circuit (Symbol E).

ELECTRON.—The fundamental unit of negative electricity. The electron and proton are equal in charge but opposite in sign.

ELIMINATOR.—A device for supplying a radio receiver with high tension, low tension, and grid bias from the house-lighting system.

EMISSION.—The liberation of electrons from an electrode.

ETHER.—The name given to an asumed medium which at one time was thought necessary to permit the transmission of wave motion.

EXPONENTIAL HORN.—A loudspeaker horn so shaped that the progressive increase of diameter follows a logarithmic law.

FADER.—A tapped volume control permitting the mixing of two inputs or the gradual change from one input to another.

FADING.—Random fluctuations of aerial input due to changes in refracting layers in the upper atmosphere.

FARAD.—The unit of capacity. The practical unit is the microfarad, which is one millionth of a farad (Symbols F, μF).

FEED BACK.—The deliberate or accidental transference from a point in a circuit to another that is nearer to the input end.

FEEDER.—*See* Aerial Feeder.

FERRITE AERIAL.—A small aerial intended to be used inside a receiver cabinet made of a rod of the material Ferrite.

FIELD COIL.—Magnet energising coil of a moving-coil loudspeaker.

FIELD STRENGTH.—The strength of a transmitter at a given place.

FIELD OF VISION.—The area " seen " by the television camera.

FILAMENT.—A cathode which is directly heated.

FLUORESCENT SCREEN.—A chemical screen having the property of becoming luminous when bombarded by electrons.

FLUX DENSITY.—A measure of magnetic or electrostatic force shown as the number of lines per unit area.

FLYWHEEL SYNC.—A time base which resists the tendency of interference to make the vertical lines of a television picture ragged.

FOCUSING.—The adjustment of an electron beam so that its cross section is a minimum area at the point of impact on the fluorescent screen.

FRAME AERIAL.—A closed loop aerial wound as an exaggerated solenoid.

FRAME-HOLD.—A standardised term for the frame-synchronism adjustment of a television receiver.

FRAME TIME BASE.—That portion of a television receiver that controls the vertical deflection of a cathode-ray beam.

FREQUENCY.—The number of complete cycles which occur in a given time (Symbol f).

FREQUENCY CHANGER.—A circuit arrangement employing a valve, usually of special type, the main component in the anode circuit having a fixed frequency irrespective of the input frequency.

FREQUENCY DISTORTION.—Variation of amplitude for a constant input at various frequencies.

FREQUENCY MODULATION.—A system whereby audio frequency modulates the carrier by swinging the frequency instead of the amplitude, *see* Chapter 29, Volume I.

FULL-WAVE RECTIFICATION.—The conversion of alternating to direct current whereby both half-cycles are utilised.

FULL-WAVE RECTIFYING VALVE.—A valve containing a twin assembly of two diodes

FUNDAMENTAL FREQUENCY.—The lowest component frequency of a complex wave. The frequency of a fundamental alternating current or voltage (of an aerial), the lowest natural frequency of an aerial without the artificial addition of inductance or capacity (Symbol f_1).

FUSE.—A piece of relatively thin wire placed in a circuit. In the event of overload the fuse melts and prevents further damage.

GAIN.—The ratio of output to input of an amplifier.

GALVANOMETER.—A sensitive electrical indicating instrument.

GANGING.—The practice of mechanically uniting two variable components to achieve adjustment by means of a single knob.

GAS-DISCHARGE TRIODE.—A thermionic valve with a trace of residual gas to facilitate its operation as a time-base generator.

GASSING (of an Accumulator).—When an accumulator is on charge it gives off hydrogen and oxygen gases and when this phenomenon becomes readily apparent the cell is said to be gassing.

GAUSS.—A magnetic unit of flux density.

GRAMOPHONE PICK-UP.—A device for converting mechanical energy derived from the sound groove of a record into electrical energy.

GRAPH.—A curve allowing the relationships between two quantities to be readily determined.

GRID.—The name given to all electrodes between the cathode and anode of a thermionic valve.

GRID BIAS.—*See* Bias.

GRID CURRENT.—A flow of current from or to the control grid of a thermionic valve (Symbol I_g).

GRID DETECTION.—Another name for Leaky Grid Detector.

GRID LEAK.—A resistance so placed that the grid current flowing through it applies a potential to the valve grid.

GRID-PLATE TRANSCONDUCTANCE.—Another name for mutual conductance.

GUN.—The beam-forming electrodes of a cathode-ray tube.

GUN CURRENT.—The beam current of a cathode-ray tube.

HALF-WAVE RECTIFICATION.—*See* Full-wave Rectification.

HARD VALVE.—The valve is said to be hard when it has been exhausted to a very high degree of vacuum, in the process of which occluded gas must be driven from the surface of all metal and glass within the envelope.

HARMONIC AMPLIFIER.—An arrangement for producing harmonics by distorting a relatively pure waveform. If desired, one or more harmonics can be independently separated by means of filters.

HARMONICS.—Multiples of the fundamental frequency. Twice the fundamental frequency is a second harmonic, three times, the third harmonic, and so on.

HEATER.—A heating element placed inside, but insulated from, the cathode for the purpose of raising its temperature to produce electron emission.

HEAVISIDE LAYER.—*See* Kennelly-Heaviside Layer.

HENRY.—The unit of inductance (Symbol H).

HERTZIAN WAVES.—Another name for radio waves.

HETERODYNE RECEPTION.—*See* Beat Reception.

HETERODYNE WAVE METER.—The calibrated oscillator which is adjusted so that the beat note between wave meter and receiver is zero.

HIGH-DEFINITION TELEVISION.—The term used to distinguish the modern television system, which is made up of a relatively large number of lines, from the original experimental system made up of only 30 lines, and consequently giving very limited definition.

HIGH FREQUENCY.—A term without any clearly defined limits, but intended to include alternating-current phenomena above about 50 kilocycles per second.

HIGH-FREQUENCY AMPLIFIER.—*See* Radio-frequency Amplifier.

HIGH-FREQUENCY CHOKE.—*See* Choke.

HIGH-FREQUENCY RESISTANCE.—The resistance of a conductor to radio-frequency currents. It is always higher than D.C. resistance, but varies with frequency.

HIGH-PASS FILTER.—A filter circuit that is designed to pass all frequencies above a predetermined value.

HIGH TENSION.—The relatively high voltage supplied to the anodes of thermionic valves.

HIGH-TENSION BATTERY.—A number of dry cells or miniature accumulators arranged in one or more convenient units for supplying high-tension current to a radio receiver.

Fig. 89.—Enlarged drawing of a cathode cut away to show the insulated heater.

HONEYCOMB COIL.—Also known as wave-wound or duo-lateral coil. A machine-wound coil, the turns of which are wound from side to side, forming a continuous pattern not unlike a sinusoidal waveform.

HORIZONTAL FORM.—The linearity of a television picture in the horizontal or line direction; also called line linearity.

HOT-WIRE AMMETER.—A current-measuring instrument that depends for its action on the expansion of a wire consequent upon being heated by the passage through it of the current to be measured.

HYDROMETER.—Broadly, a device for measuring the specific gravity of a liquid. Suitable types are available for measuring the specific gravity of accumulator acid.

HYSTERESIS.—*See* Magnetic Hysteresis.

IMPEDANCE.—The opposition offered to alternating current by inductance, capacity, and resistance. *See also* Reactance, Anode A.C. Resistance (Symbol Z).

INDUCED VOLTAGE (OR CURRENT).—Energy in a conductor due to a magnetic field from another conductor.

INDUCTANCE.—The property of a conductor or coil to oppose a change in the flow of current. A straight wire possesses inductance, but the term is usually reserved for a coil deliberately intended to produce this phenomenon in some desired degree (Symbol L).

INDUCTANCE BRIDGE.—A balanced circuit arrangement for measuring inductance.

INDUCTIVE RESISTANCE.—A resistance wound in the form of an inductance so that its impedance is greater than its resistance.

INDUCTOR LOUDSPEAKER.—A moving-iron loudspeaker with a push-pull action designed to overcome the limitations imposed by the width of the magnet gap in the balanced-armature type of speaker.

INERT CELL.—A dry cell that does not become active until filled with water or some other solution. It may thus be stored in hot climates for a long period.

INERTIA.—The tendency of a body to resist a change of velocity.

INFRA-BLACK.—The term sometimes used in television to denote the signal amplitude that is below the black level.

INSULATION.—The property of reducing to negligible limits the flow of current between two conductors.

INSULATOR.—The opposite to a conductor, *i.e.* a substance that offers a very high resistance to the passage of current.

INTER-ELECTRODE CAPACITY.—The capacity existing between any pair or any set of electrodes in a thermionic valve. As colloquially used, it is sometimes implied that the term refers to the control grid/anode capacity of an H.F. tetrode or pentode.

INTERMEDIATE FREQUENCY.—As normally used, the term refers to the frequency of that portion of a superheterodyne receiver which is pretuned.

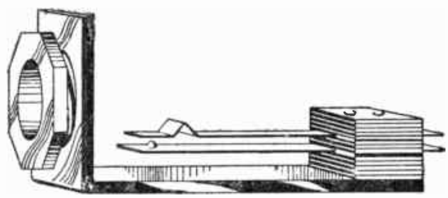


Fig. 90.—A typical example of a single-circuit jack.

INTERNAL IMPEDANCE.—Another term for impedance or anode A.C. resistance.

INTERRUPTED CONTINUOUS WAVE.—Continuous-wave transmission interrupted at audio frequency so that it may be received without the use of the autodyne or heterodyne system.

INTER-VALVE COUPLING.—The means by which the output of one valve is made to appear as a potential change between the grid and cathode of the succeeding valve.

ION TRAP.—A small electrode in the neck of a cathode-ray tube which, in conjunction with a small magnet, traps ions present in the tube, thus preventing them from striking and damaging the screen material.

IONISATION.—The act of splitting up the gas so that its atoms are short of or have an excess of electrons.

ISOCHRONOUS.—Two A.C. waveforms are said to be isochronous if they appear in the same circuit at the same frequency but are out of phase.

ISOLATING CONDENSER.—*See* D.C. Stopper.

JACK.—A device enabling connection to be made to one or more circuits and, if desired, the making or breaking of one or more circuits by the insertion of a plug to which an additional circuit is connected.

JAMMING.—Interference with a wanted station from other transmitters.

JAR.—A unit of capacity. Not now used in radio engineering.

JIGGER.—Obsolete name for a high-frequency transformer.

KATHODE.—Another spelling for cathode that is fast becoming obsolete.

KENNELLY-HEAVISIDE LAYER.—A layer of ionised particles of variable density and height, capable of refracting radio waves to an extent dependent upon the condition of the layer and the frequency of the wave.

KERR CELL.—A device in which the optical properties of the medium are controlled by an electric field. By suitable arrangement the intensity of a light can be controlled by a magnetic field.

KILOCYCLE.—One thousand cycles (Symbol kc).

KILOCYCLE/SECOND.—The number of kilocycles that occur in any second (Symbol kcs).

KILOVOLT.—One thousand volts (Symbol kV).

KILOWATT.—One thousand watts (Symbol kW).

KILOWATT HOUR.—The practical unit of quantity of electrical energy (Symbol kWh).

LAMINATED CORE.—A transformer or choke core made up with thin iron plates.

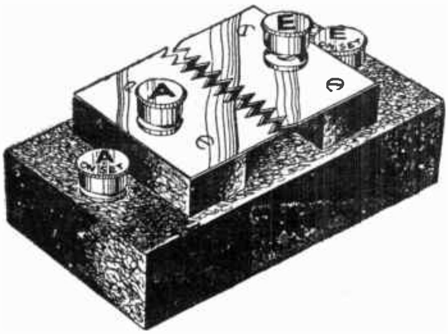


Fig. 91.—A simple form of lightning arrestor.

LIGHTNING ARRESTOR.—A form of spark-gap connected between aerial and earth to prevent the accumulation of a static charge upon the aerial. It does not, as popularly supposed, protect the receiver if the aerial is actually struck by lightning.

LIMITER.—A valve device in FM receivers to exclude AM modulation and prevent overload.

LINEAR AMPLIFICATION.—A condition that obtains when the output is proportional to the input in frequency and amplitude.

LINE FLYBACK E.H.T.—An arrangement whereby the change of voltage during the line flyback is stepped up and rectified to form the E.H.T. of a television receiver.

LINE HOLD.—The control on a television receiver that is adjusted to achieve line synchronism.

LINE IMPULSE.—A square waveform imposed on the modulation of a television transmitter to produce line synchronism at the receiving end.

LINE LINEARITY CONTROL.—An adjustment fitted to some television receivers permitting the velocity of the spot to be made constant for the length of its travel. Non-linearity causes an image to be broad or narrow, according to whether it appears on the right-hand or left-hand side of the picture.

LINE-SYNCHRONISING CONTROL.—*See* Line Hold.

LINE TIME BASE.—That part of a television receiver that causes the spot to travel in the horizontal dimension.

LOADING COIL.—An inductance connected in the aerial lead to extend the wavelength range without interference with the actual receiver.

LOCAL OSCILLATOR.—A valve oscillator as used in a superheterodyne receiver.

LOGARITHMIC HORN.—*See* Exponential Horn.

LOG LAW CONDENSER.—A variable condenser, the vanes of which are so shaped that the angle of rotation is proportional to the logarithm of the change in capacity.

LOOP AERIAL.—American for frame aerial.

LOOSE COUPLING.—Coils are said to be loose coupled when their mutual inductance is small when compared to their self inductance.

LOW FREQUENCY.—*See* Audio Frequency.

LOW TENSION.—The voltage applied to the filament or heater of a thermionic valve.

MAGNETIC FLUX.—The total number of lines of force radiating from the magnet or coil (Symbol Φ).

MAGNETIC HYSTERESIS.—Lagging of magnetic flux behind the magnetising force causing energy dissipation.

MAGNETIC REACTION.—Reaction achieved by inductive coupling between the anode and grid circuits of a thermionic valve.

MAGNETIC SCREEN.—A screen of iron, mu-metal, or rho-metal placed round a piece of apparatus to screen it from external magnetic field or, alternatively, to enclose a piece of apparatus so that its magnetic field does not affect the surrounding circuits.

MAGNETRON.—A special valve in a magnetic field which produces extraordinary values of peak output.

MAGNIFICATION FACTOR.—*See* Amplification Factor.

MAINS UNIT.—*See* Power Pack.

MEGACYCLE.—One million cycles (Symbol Mc).

MEGGER.—A meter with some source of potential for measuring high resistance.

MEGOHM.—One million ohms (Symbol $M\,\Omega$).

MERCURY-ARC RECTIFIER.—A rectifier which functions owing to the unidirectional conductivity of a metallic arc in a vacuum. D.C. voltage derived in this manner usually has an appreciable A.C. component, and the smoothing arrangements of D.C. receivers will often prove inadequate.

METAL RECTIFIER.—A rectifier made up of a number of copper plates, one side of each being oxidised.

METALLISING.—The metal covering on the *outside* of a thermionic valve.

MHO.—Unit of conductivity.

MICA.—A natural mineral much used as the dielectric material in small condensers.

MICROAMPÈRE.—One millionth of an ampère (Symbol μA).

MICROFARAD.—One millionth of a farad (Symbol μF).

MICROHENRY.—One millionth of a henry (Symbol μH).

MICROPHONE.—A device for converting sound waves into electrical energy.

MICROPHONE AMPLIFIER.—An amplifier used in conjunction with microphones having very small output; a complete amplifier is sometimes housed in the actual microphone head.

Microvolt.—One millionth of a volt (Symbol μV).

Milliampère.—One thousandth of an ampère (Symbol mA).

Millihenry.—One thousandth of a henry (Symbol mH).

Millivolt.—One thousandth of a volt (Symbol mV).

Mirror Galvanometer.—A sensitive measuring instrument in which the weight of a pointer is dispensed with by a minute mirror which throws a spot of light on the scale. If the scale is placed at a distance from the meter, a proportionate increase of deflection sensitivity is obtained.

Modulating Grid (of a Cathode-ray Tube).—The grid, usually the one nearest the cathode, which is intended to control the intensity of the beam (in a thermionic valve the grid to which a signal will normally be applied). Another name for control grid.

Modulation.—The imposition of one frequency upon another. As applied to radio transmission the imposition of audio frequencies on the carrier wave.

Molecule.—The smallest particle of a chemical compound which is distinguishable as that compound.

Monochromatic Sensitivity.—The sensitivity of a photo-electric cell to light of a given colour.

Motor-boating.—Instability in a radio receiver which produces a relatively low-frequency oscillation of a spurious character.

Moving-coil Ammeter (milliammeter, etc.).—A type of instrument which is actuated by the tendency of a coil in a magnetic field to align itself so that both fields are in line.

Moving-coil Loudspeaker.—A loudspeaker the diaphragm of which is actuated by a coil fixed at its apex and situated between the poles of a powerful magnet.

Moving-coil Microphone.—A microphone in which the diaphragm has a coil fitted to its apex, which is placed in the field of a powerful magnet so that movement of the coil produces an induced current in its winding.

Moving-iron Loudspeaker.—A general term denoting a loudspeaker the cone of which is actuated by an iron reed or armature in a magnetic field.

Mush.—Interference caused by natural and man-made static, unwanted transmitters, i.e., general background noise.

Mutual Conductance.—The power of the grid of a thermionic valve to control the anode current. It is usually quoted in terms of milliampères change of anode current per volt change of grid potential. (Symbol g_m).

Mutual Inductance.—The effect obtaining when two inductances are so arranged that the flow of current through one will produce a potential across the other (Symbol M).

Naperian Logarithm.—Logarithms calculated to the base 2·71828.

Natural Frequency or Natural Periodicity.—The frequency at which a circuit will oscillate by virtue of its own inductance and capacity (Symbol f_0).

NATURAL WAVELENGTH.—The wavelength at which an aerial will oscillate by virtue of its own inductance and capacity.

NEEDLE-ARMATURE PICK-UP.—A pick-up so constructed that the actual needle is also the armature.

NEGATIVE FEEDBACK.—Transference of energy from anode to grid circuit so that the fed back current or voltage is out of phase. Correctly applied, it is used to improve the quality of amplifiers and the stability of oscillators.

NEGATIVE POLE.—A point in a circuit at a potential lower than any other point in the circuit.

NEGATIVE RESISTANCE.—A condition when a *decrease* of voltage brings about an *increase of* current.

NEON LAMP (NEON TUBE).—A glass envelope filled with low-pressure neon gas containing two electrodes.

NEPER.—Continental unit of gain. One neper equals 8·68 decibels.

NEUTRAL WIRE (NEUTRAL MAIN).—The earthed wire of athree-phase A.C. system or of a three-wire D.C. system.

NEUTRODYNE RECEIVER.—A receiver employing a more or less obsolete principle in which the inter-electrode capacity of the amplifier is balanced out by an equal feed-back from another point in the circuit that is out of phase.

NICKEL IRON.—An iron-nickel alloy of a high permeability used for transformer cores.

NICROME.—A nickel-chrome alloy much used for valve grids, owing to the ease with which it may be freed from occluded gas.

Fig. 92.—A type of neon lamp that is equally adaptable for simple time bases or domestic purposes.

NIGHT EFFECT.—A general expression indicating phenomena affecting radio reception during the hours of darkness.

NODE.—The point at which voltage or current is at a minimum in an aerial or feeder. The point on a diaphragm where displacement is minimum.

NODON RECTIFIER.—A more or less obsolete form of rectifier, at one time used for such purposes as accumulator charging. It comprised an aluminium cathode and lead anode in ammonium phosphate.

NON-INDUCTIVE RESISTANCE.—A resistance so wound that its inductance is negligible, or made in the form of a solid composition rod which achieves the same purpose.

NOTE MAGNIFIER.—Obsolete term for audio-frequency amplifier.

OHM.—The basic unit of resistance (Ω).

OHMMETER.—An instrument for measuring resistance.

OHM'S LAW.—The inflexible and unchanging law that the flow of current is proportional to the potential difference across the circuit and inversely proportional to resistance.

OPEN CIRCUIT.—A circuit through which current cannot flow.

OPEN GRID.—Colloquial term used to imply an accidental disconnection isolating a valve grid from its cathode.

OSCILLATION.—The rhythmic change of current and voltage normally produced by feeding energy from an anode circuit back to its own grid circuit.

OSCILLATION VALVE.—An obsolete term at one time meaning triode.

OSCILLATOR.—A circuit, usually employing a valve, primarily intended for producing and maintaining oscillation at a predetermined frequency.

OSCILLOGRAPH.—*See* Cathode-ray Oscillograph.

PACKING.—The accidental rearrangement of carbon granules in a microphone resulting in reduced sensitivity, distortion, and decreased signal to noise ratio.

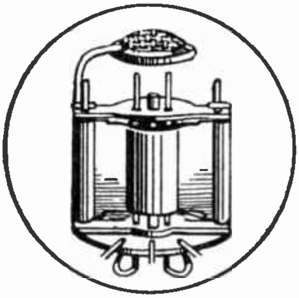


Fig. 93.—Electrode assembly of a "peanut" valve. The illustration is twice full size and the outer circle shows the proportionate size of a sixpenny piece.

PARAPHASE PUSH-PULL.—An output circuit so arranged that the output valves are driven in opposite phase by connecting the grids to the cathode and anode of the previous valve or from the anodes of two audio-frequency amplifying valves, the grid of one being driven from a tap on the anode resistance of the other.

PARASITIC OSCILLATION.—Spurious oscillation, due to a portion of a circuit oscillating at its natural frequency, *e.g.* the grid lead of an output valve.

PARKERISING.—A method of making iron and steel less liable to corrosion. Many modern chassis are finished in this way.

PEAK VALUE.—The maximum value of an alternating voltage or current.

PEAK VOLTAGE (CURRENT).—The maximum amplitude of an alternating phenomenon as distinct from the R.M.S. value.

PEANUT VALVE.—A general term embracing that class of valve which is contained in a *very* small bulb.

PENTODE.—A thermionic valve with five electrodes. The term is not generally used for frequency changers, although some do, in fact, have five electrodes.

PERCENTAGE MODULATION.—The ratio of the carrier and modulation amplitude expressed as a percentage.

PERIKON DETECTOR.—A crystal detector using bornite and zincite in contact as the element.

PERIODICITY.—Another word for frequency.

PERMANENT MAGNET.—A hard-steel magnet which retains its magnetism for a relatively indefinite period.

PERMEABILITY.—Magnetic conductivity of a material. The ratio of flux density to magnetising force (Symbol μ).

PERMEABILITY TUNER.—A system where tuning is effected by moving a dust-iron core in and out of a tuning coil.

PERSISTENCE.—The continuation of a phenomenon after the force producing it has ceased.

PERSISTENCE OF VISION.—A failing of the human eye, whereby it appears to see an object for a fraction of a second after the object is no longer visible. Without this failing television might never have been possible.

PHASE.—The relative progression of a periodic phenomenon.

PHASE ANGLE.—The angular relationship between two alternating phenomena of identical frequency (Symbol φ).

PHASE DETECTOR.—A type of frequency to modulation convertor used in FM receivers.

PHON.—A quantitative unit of noise.

PHOTO-ELECTRIC CELL.—A high-vacuum device that generates a minute current due to and proportional to light falling on its sensitive cathode.

Fig. 94.—A standard photo cell.

PICK-UP.—*See* Gramophone Pick-up.

PICTURE SYNCHRONISM (HOLD, SHIFT, ETC.).—*See* Frame Hold.

PILLAR.—American for synchronising impulse.

PILOT-LIGHT.—A small bulb so situated on the receiver that attention is drawn to it when switched on.

PLATE.—Another name for anode.

POLAR DIAGRAM.—Commonly a curve of the output of a transmitter, permitting the field strength in any particular direction for a given distance to be readily determined.

POLE (of a Magnet).—The apparent end of a magnet from which lines of force emanate.

POSITIVE POLE.—A point on a circuit that has a higher potential than any other point.

POST-OFFICE BOX.—A convenient adaptation of the Wheatstone bridge, used for highly accurate resistance measurement.

POTENTIAL DIFFERENCE.—Difference in potential between two points of a circuit.

POTENTIAL DIVIDER.—A tapped resistance, or the equivalent, used to tap off a predetermined fraction of a larger potential.

POTENTIOMETER.—A variable potential divider.

POWER FACTOR.—The ratio of watts to volt-ampères.

POWER GRID DETECTION.—A vague term denoting a leaky grid detector working with a low value of grid leak and high anode voltage.

POWER PACK.—That portion of a mains receiver that supplies the energy required by the receiving valves.

POWER VALVE.—A colloquial term denoting a triode valve intended for use in the output stage.

PRIMARY CELL.—A cell which relies on chemical action and which does not require charging.

PROGRESSIVE SCANNING.—*See* Sequential Scanning.

PROTON.—The smallest unit charge of positive electricity.

PULSATING CURRENT.—A uni-directional current whose amplitude varies periodically.

QUARTER-WAVE AERIAL.—An aerial having a natural wavelength equal to a quarter of the wavelength it is desired to receive.

QUARTZ CRYSTAL.—A natural crystal used for controlling frequency. Advantage is taken of the phenomenon that an alternating voltage applied to opposite faces of a quartz crystal of suitable thickness will cause the crystal to vibrate and by its own physical dimensions hold the electrical frequency constant within close limits.

RADIATION.—The projection of electro-magnetic waves into free space.

RADIO BEACON.—A transmitter with a directional aerial system, or otherwise, that radiates a signal to assist the navigation of ships or aeroplanes.

RADIO CHANNEL.—A band of frequencies of sufficient width to permit radio or television communication.

RADIO COMPASS.—A radio direction finder used for navigating.

RADIO FREQUENCY.—An undefined term intended to cover all frequencies used in radio transmission. The term is sometimes used in such a manner that it is intended to convey the idea of signal frequency as distinct from intermediate frequency.

RADIO-FREQUENCY AMPLIFIER.—An amplifying stage or stages tuned to the frequency of the incoming signal.

RATIO DETECTOR.—A type of frequency to modulation convertor used in FM receivers.

REACTANCE.—Opposition offered to an alternating current due to inductance or capacity or both. The total opposition offered by resistance, inductive reactance, and/or capacitative reactance is known as impedance (Symbol *X*).

REACTION.—The accidental or intentional transference of energy from an anode circuit to a grid circuit so that the feed-back current is in phase.

REACTION CONDENSER.—A variable condenser arranged to control the amount of energy fed-back in a reactive circuit.

RECTIFICATION.—The conversion of alternating current into uni-directional current.

RECTIFIER.—A device for rectifying alternating current. It usually consists of one or more diodes or a metal-oxide unit.

RECTIFYING VALVE.—A thermionic diode specially designed for rectifying alternating current.

REDIFFUSION.—The passing on of a received programme to a third party.

REFLECTION (of a Radio Wave).—The " bouncing back " of a wave occasioned by its striking a medium that it cannot penetrate. The bending of a wave caused by its inability to pass through a medium in a straight line, is more correctly described as refraction.

REFLECTOR.—One or more wires or rods placed behind a transmitting or receiving aerial to direct radiation or increase reception, as the case may be.

REFLEX CIRCUIT.—A circuit arrangement, now more or less obsolete in which one or more valves act as both high-frequency and low frequency amplifiers.

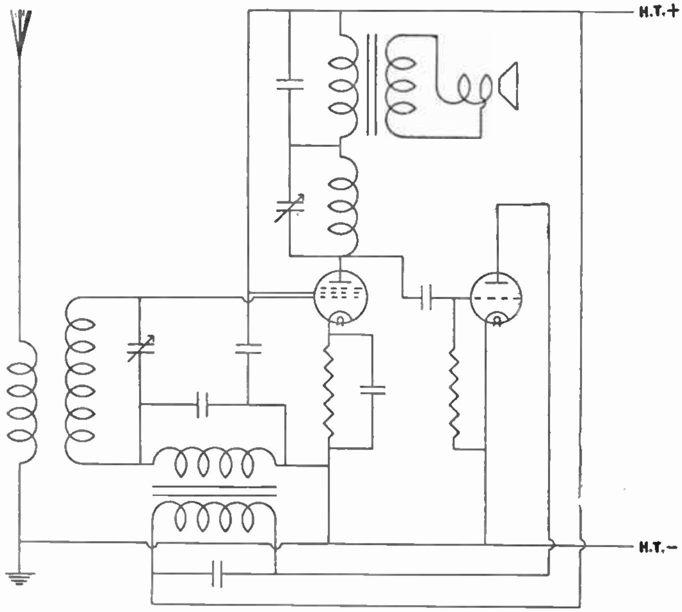


Fig. 95.—A typical reflex circuit.

REFRACTION.—*See* Reflection.

REGENERATION.—Reaction.

REINARTZ CIRCUIT.—A reactive detector controlled by capacity, so arranged that the reaction coil is also the aerial-coupling.

REJECTOR.—A tuned circuit designed to offer high impedance to a particular frequency.

RELUCTANCE.—The opposition offered to the passage of magnetic flux (Symbol S).

REMOTE CONTROL (in Radio Reception).—A device permitting the receiver to be more or less completely operated by means of extension controls.

RERADIATION.—The re-transmission of energy received from some external source; this phenomenon presents problems in direction finding

RESIDUAL MAGNETISM.—Magnetism in an iron core remaining after the magnetising force has ceased to function.

RESISTANCE.—The opposition of an electric circuit to the passage of current (Symbol R). *See also* Ohm's Law.

RESISTANCE-CAPACITY COUPLING.—A coupling arrangement between two thermionic valves. *See* appropriate chapter in general text.

RESISTOR.—A resistance in its physical form. More generally used in America than this country.

RESONANCE.—A phenomenon that occurs when alternating current flows through a circuit the natural frequency of which is equal to the frequency of the alternating current.

RESPONSE-CURVE.—The curve showing graphically the relationship between two characteristics, *e.g.* the voltage developed across the tuned circuit for various applied frequencies.

RHEOSTAT.—Another name for variable resistance.

RINGING (PICTURE).—A sort of visual echo forming one or more outlines displaced to the right of objects in a television picture.

RINGING (TIME BASE).—A series of vertical lines on the left-hand half of a television picture caused by the oscillatory characteristics of the line time base circuit.

ROTARY CONVERTER.—A machine for converting alternating to direct current, or *vice versa*.

R.M.S. VALUE (ROOT MEAN SQUARE VALUE).—The square root of the mean value of the squares of the instantaneous values for one complete cycle. The R.M.S. value is that which will perform the same work as direct current of equivalent amplitude. The effective value of an alternating phenomenon.

SATURATION (CURRENT).—The state when anode current cannot be increased irrespective of the voltage applied (magnetic). The state when flux density cannot be appreciably increased irrespective of the magnetising force applied.

SCANNING.—The process of building up a picture by traversing the area so that the whole is covered.

SCANNING DISC.—A disc used in early television which scanned by means of a series of holes placed at a progressively increasing distance from the centre.

SCREENED-GRID VALVE (SCREEN-GRID VALVE).—A tetrode, the outermost grid of which is so designed that control-grid to anode capacity is reduced to a minimum.

SECONDARY BATTERY.—Two or more secondary cells.

SECONDARY CELL.—A cell that requires charging before it is capable of discharging, *e.g.* an accumulator.

SECONDARY EMISSION.—Electrons emitted from a surface due to the impact of electrons from another source.

SELECTIVITY.—The power to select a particular frequency to the total or partial exclusion of all others.

SELENIUM CELL.—A cell exhibiting the peculiarity that its resistance varies according to the illumination intensity that falls upon it.

SELF-CAPACITY.—Capacity between a conductor and earth or between two or more points on the same conductor.

SEQUENTIAL SCANNING.—Television scanning in which each line is covered immediately following its predecessor.

SHIELD.—Another name for the modulating grid of a cathode-ray tube.

SIDEBANDS.—When a carrier wave is modulated, frequencies are present equal to the difference between and the sum of the carrier and modulation frequencies. Collectively known as the sidebands.

SINE WAVE.—A waveform which follows a sine law. *Note:* Sinusoidal is used as though it were the adjective of sine wave.

SINGLE SIDEBAND TELEPHONY.—A transmitter so designed that it transmits one sideband only. Reception is unintelligible until the missing sideband is reintroduced at the receiving end.

SKIN EFFECT.—The name given to the phenomenon exhibited by high-frequency currents which tend to travel on the surface of a conductor.

SKIP DISTANCE.—The area around a short-wave transmitter between direct ray and sky wave reception.

SMOOTHING CIRCUIT.—An arrangement comprising one or more shunt capacities and series inductance or resistance intended to convert a pulsating current into direct current of constant amplitude.

SOFTNESS (of a Valve).—The presence of gas in sufficient quantity to permit appreciable ionisation.

SPACE CHARGE.—A cloud of electrons emitted from a cathode and which are not immediately flowing to the anode.

SPIDER.—The centring device of a moving-coil loudspeaker cone.

SQUARE LAW DETECTOR.—A detector in which the output voltage is proportional to the square of the input voltage, *e.g.* an anode-bend detector.

STAGE GAIN.—The ratio of output voltage to input voltage of a stage of amplification.

STALLOY.—A silicon-iron which has fairly high permeability and low hysteresis. It is used for low-frequency and mains transformers.

STATIC.—Another name for atmospherics.

STEP-DOWN TRANSFORMER.—A transformer so designed that the secondary voltage is lower than the primary voltage.

STEP-UP TRANSFORMER.—A transformer which is so designed that the secondary voltage is higher than the primary voltage.

STOPPING CONDENSER.—*See* D.C. Stopper.

STORAGE BATTERY.—Another name for an accumulator.

SULPHATION.—A deposit of lead sulphate that appears on the plates of an accumulator due to being left in an uncharged state.

SUPER CASCODE.—An H.F. amplifier using two triodes virtually in series giving great gain, increased signal-to-noise ratio, and excellent stability even at very high frequencies; often used as the first stage of a television receiver.

SUPERHETERODYNE RECEIVER.—A circuit arrangement using a local oscillator which, when mixed with the incoming signal, produces a fixed frequency irrespective of signal frequency.

SUPER-REGENERATION.—A principle which entails the use of a quenching frequency which is above audio frequency, and used to interrupt a reactive detector so that the latter may be coupled beyond the normal threshold point.

SUPERSONIC FREQUENCY.—A frequency just above the range of the human ear.

SWINGING.—Momentary variation in frequency of the received wave.

SYNCHRONISM (in a Television Receiver).—The condition when the picture is at rest due to both time bases being in step with the transmitter time bases.

SYNCHRONOUS.—The condition which obtains when two alternating phenomena possess a common frequency and pass through all points of a cycle simultaneously.

TARGET.—The fluorescent electrode of a cathode-ray type tuning indicator.

TETRODE.—A four-electrode valve.

THERMIONIC CURRENT.—The rate of flow of electrons between cathode and anode.

THERMIONIC VALVE.—A vacuum tube containing two or more electrodes, one of which is intended to be maintained at a temperature which will cause it to emit electrons.

Fig. 96.—A toroidal coil.

THERMISTOR. — A composition-type resistance having the special property that its value increases as the current flowing through it tends to increase, thus preventing, within limits, a surge. Also used instead of a hot-wire barrettor.

THERMO-AMMETER.—A current-measuring instrument and a miniature thermo-couple; the high-frequency current to be measured heats the thermo-couple and the current thus generated deflects the meter.

TIGHT COUPLING.—When two circuits have a relatively large common impedance, or two inductances are so placed that most of the energy in one appears in the other, they are said to be tightly coupled.

TIME-BASE GENERATOR.—A circuit for producing a steadily increasing current or voltage followed by a rapid return to zero causing the cathode-ray beam to move across the screen at a predetermined velocity.

TIME-CONSTANT.—The time taken by current or voltage to rise to 63·4 per cent. of its ultimate value.

TOROIDAL COIL.—An inductance wound on a core, which may or may not be of ferrous material, shaped in the form of a ring. A coil wound in this manner has an extremely small external field.

TOTAL EMISSION.—The total number of electrons emitted from a cathode due to the influence of a voltage that will draw away all the electrons emitted.

TRANS-CONDUCTANCE.—A term sometimes used, particularly in America, for mutual conductance.

TRANSFORMER.—A device normally intended to convert energy in such a manner that voltage is increased or decreased, and current decreased or increased. A transformer may be so designed that the voltage is equal across primary and secondary and may be used as a means of passing alternating current while stopping direct current.

TRANSIENT.—A phenomenon which lasts only for a very short time.

TRICKLE CHARGER.—An accumulator charger of small output intended to charge during the night to make up for current used for operating a radio receiver.

TRIGGER CIRCUIT (in a Cathode-ray Oscillograph).—A circuit arrangement whereby the beam is held stationary or "blacked out" until released, usually by the phenomenon to be observed.

TRIODE.—A three-electrode valve.

TRUE POWER.—The actual wattage dissipated in a circuit, *i.e.* the product of volts and ampères multiplied by the power factor.

TUNED ANODE.—An inter-valve coupling in which the amplified output is built up across a tuned circuit directly in the anode circuit of the amplifying valve.

TUNED CIRCUIT.—A circuit containing inductance and capacity, the resonant frequency of which is, or has been, adjusted to some desired value.

TUNGSTEN.—A base metal employed for valve filaments, and heaters.

TUNING.—The adjusting of a tuned circuit.

TUNING COIL.—An inductance forming part of a tuned circuit.

TUNING CONDENSER.—A variable condenser forming part of a tuned circuit and usually providing the means of adjusting resonance to the required value.

TURRET TUNER.—An arrangement of coils which can be rotated so that the desired coil is made to register with a fixed pair of contacts; much used in television receivers.

UNDAMPED OSCILLATIONS (UNDAMPED WAVES).—A train of waves with constant amplitude.

UNI-LATERAL CONDUCTIVITY.—The property of allowing current to pass in one direction only or considerably more easily in one direction. Any rectifying device must necessarily possess this property.

UNTUNED AERIAL.—An input circuit that is not tuned to the frequency of the required signal. Sometimes called an aperiodic aerial.

VACUUM TUBE.—A vague term covering all types and sizes of sealed envelopes which contain electrodes but from which all gas has been withdrawn as far as practicable. In America the term is inclined to be reserved for the thermionic valve.

VALVE.—*See* Thermionic Valve.

VALVE RECTIFIER.—*See* Rectifier.

VALVE VOLTMETER.—An arrangement in which small potentials either A.C. or D.C. are measured by applying them to the grid/cathode circuit of a valve and noting the change in anode current.

Variable Condenser.—A condenser so designed that its capacity may be conveniently and constantly varied, as distinct from a pre-set condenser, which, although variable, is intended to be adjusted and left alone.

Variable-mu Valve.—A valve with a grid so constructed that the mutual conductance can be varied by a negative grid potential without introducing pronounced rectification properties.

Vario-coupler.—An arrangement by which the coupling between two tuning coils can be conveniently varied.

Variometer.—A variable inductance consisting of two coils connected in series and so arranged that the coupling can be conveniently varied. Variation of coupling produces variation of inductance.

Vernier Condenser.—A small condenser used in parallel with a large one to facilitate fine adjustment. The term has now become rather obsolete, and has been replaced by the misuse of the term "trimmer condenser."

Volt.—The fundamental unit of electrical pressure (Symbol V). *See also* Ohm's Law.

Volt-ampère.—The product of voltage and current. The apparent power in an alternating-current circuit. The true power or wattage dissipation is given by the product of volt-ampères and the power factor.

Voltage.—Potential difference measured in terms of the volt.

Voltage Amplification.—The ratio between output voltage and input voltage of an amplifier.

Voltage Divider.—A resistance usually with fixed tappings.

Voltage Doubler.—An arrangement of two rectifiers whereby the D.C. output is in the neighbourhood of double the A.C. input voltage.

Voltage Drop.—The potential difference across a resistance set up by the current passing through it.

Voltmeter.—An instrument for measuring electrical pressure in terms of the volt.

Volume Control.—An arrangement usually in the form of a variable resistance for manual adjustment of receiver output.

Volume Expansion.—A circuit arrangement which increases the volume of loud orchestration intended to off-set the reduced orchestration from a broadcasting station.

Watt.—Unit of electrical power (Symbol W).

Wattless Current.—Current that is precisely 90 degrees out of phase with the applied voltage.

Waveform.—The shape of the curve obtained by plotting the amplitude of an alternating phenomenon against time.

Wavelength.—The distance, usually measured in metres, between the crests of successive waves (Symbol λ).

Wavemeter.—An instrument for measuring wavelengths.

Wavetrap.—A rejector circuit or an acceptor circuit, or both, used to minimise interference from a powerful local transmitter.

WHEATSTONE BRIDGE.—An instrument for measuring resistance by balancing it against another one of known value.

WHITE-SPOT LIMITER.—A device used in television to prevent white spots caused by interference from exceeding the level of maximum white and thereby de-focusing the spot.

WIPE-OUT AREA.—The area immediately round a transmitter where it is impracticable or impossible to receive another station without interference.

WIRED WIRELESS.—A system of broadcasting using a modulated carrier-wave, which is conveyed to the receiver along a wire that is normally already in existence for another purpose, *e.g.* electric-light mains or telephone wires.

WOOD'S-METAL.—A lead-tin-bismuth and cadmium alloy with the low melting-point of 60 degrees Centigrade, used for fixing detector crystals in their cups.

X'S.—Another name for atmospherics.

X-RAYS.—Electro-magnetic waves of very high frequency, with considerable application in the medical field. X-rays are often present to a very small degree in radio valves which are pumped to a very high vacuum.

ZERO BEAT.—A term used to express a condition in beat reception when no beat note is produced, owing to the frequency of the incoming signal and local oscillator being identical.

ZERO POTENTIAL.—Another name for earth potential or, alternatively, the condition of no potential difference between two points.

ZINCITE.—An oxide of copper which forms an efficient detector in combination with bornite. The two together are known as a perikon detector.

INDEX

RADIO CIRCUITS AND DATA

BY

C. A. QUARRINGTON

A.M.Brit.I.R.E.

A recognised Authority on Radio and Television

THE CAXTON PUBLISHING COMPANY, LIMITED

LONDON · NEW YORK · MELBOURNE

TORONTO · WELLINGTON

First published	. *June*	1948
Reprinted	. *May*	1949
Reprinted	. *April*	1950
Reprinted	. *November*	1950
Reprinted	. *March*	1951
Reprinted	. *June*	1951
Reprinted	. *November*	1951
Reprinted	. *May*	1952
Reprinted	. *September*	1952
Reprinted	. *December*	1955
Reprinted	. *May*	1957

Various circuits, devices and principles described in this volume form the subject-matter of letters-patent or provisional protection

PRINTED AND BOUND IN ENGLAND BY
HAZELL WATSON AND VINEY LTD
AYLESBURY AND LONDON

FOREWORD

The absence, among contemporary works on radio engineering, of a concise data book has become increasingly more apparent. It is true that numerous text-books contain a few tables, formulæ or other matter, but a shelf of books is necessary before all normal information of this class is available, and even then, much valuable time can be wasted in finding it; when found it often leaves much to be desired, particularly from the point of view of covering modern needs or presenting facts and figures in a form that is immediately usable.

It is perhaps not unreasonable to form the conclusion that very little original work has been done on tabular data for more than a decade, old tables being published anew without being brought up to date or remoulded to suit changing needs.

The aim of this small volume has been twofold. Firstly, to present a very carefully selected series of circuits, data and formulæ; and secondly, to reshape information so that it covers present-day requirements, is freed from errors and inconsistencies of the past, and in addition, includes both English and American standards.

The very complete index which follows these remarks permits quick reference to the information required, since the cross indexing reveals the presence of any particular subject under any reasonable heading. The main subjects are, however, briefly described below.

(i) A representative selection of the circuits of receivers marketed by Britain's leading radio manufacturers during the last ten years is included primarily to illustrate changing design tendencies.

(ii) A selection of useful circuits designed to perform a variety of functions.

(iii) A selection of relatively simple test gear circuits with full component values.

(iv) Formulæ and data selected and presented in such a manner that considerable saving of time can be effected by regular use. Particular care has been taken to so devise tables that all related data are available in a single table. The author wishes to thank Mr. S. S. D. Jones, M.A., of St. Peter's Hall, Oxford, who checked the formulæ and made a number of useful suggestions.

(v) Valve equivalent tables and valve base connections.

This volume is essentially complementary to *Modern Practical Radio and Television*, since the latter is broad in its conception, whereas the former is precise in character and is intended for quick reference as opposed to systematic study.

C. A. QUARRINGTON.

INDEX

References to Circuit Diagrams are shown in italics

INDEX

INDEX

USEFUL CIRCUIT SECTION

The following forty-one pages contain a selection of useful circuits presenting a broad picture of commercial practice and contemporary design and also show, by a series of "unit" circuits, everyday alternatives and refinements associated with specialised rather than domestic equipment. The commercial circuits in this section will also be found helpful when fault-finding, since the task of tracing connections without the assistance of the appropriate circuit diagram is simplified by reference to a selection of typical arrangements. A close study of these circuits will suggest ideas for the systematic stage-by-stage isolation of a faulty receiver, a procedure so essential to efficient servicing; the use of the Information Bureau service for assistance when diagnosing a fault in a particular receiver is impracticable, since those who are able to select the appropriate facts and figures would not normally require such advice.

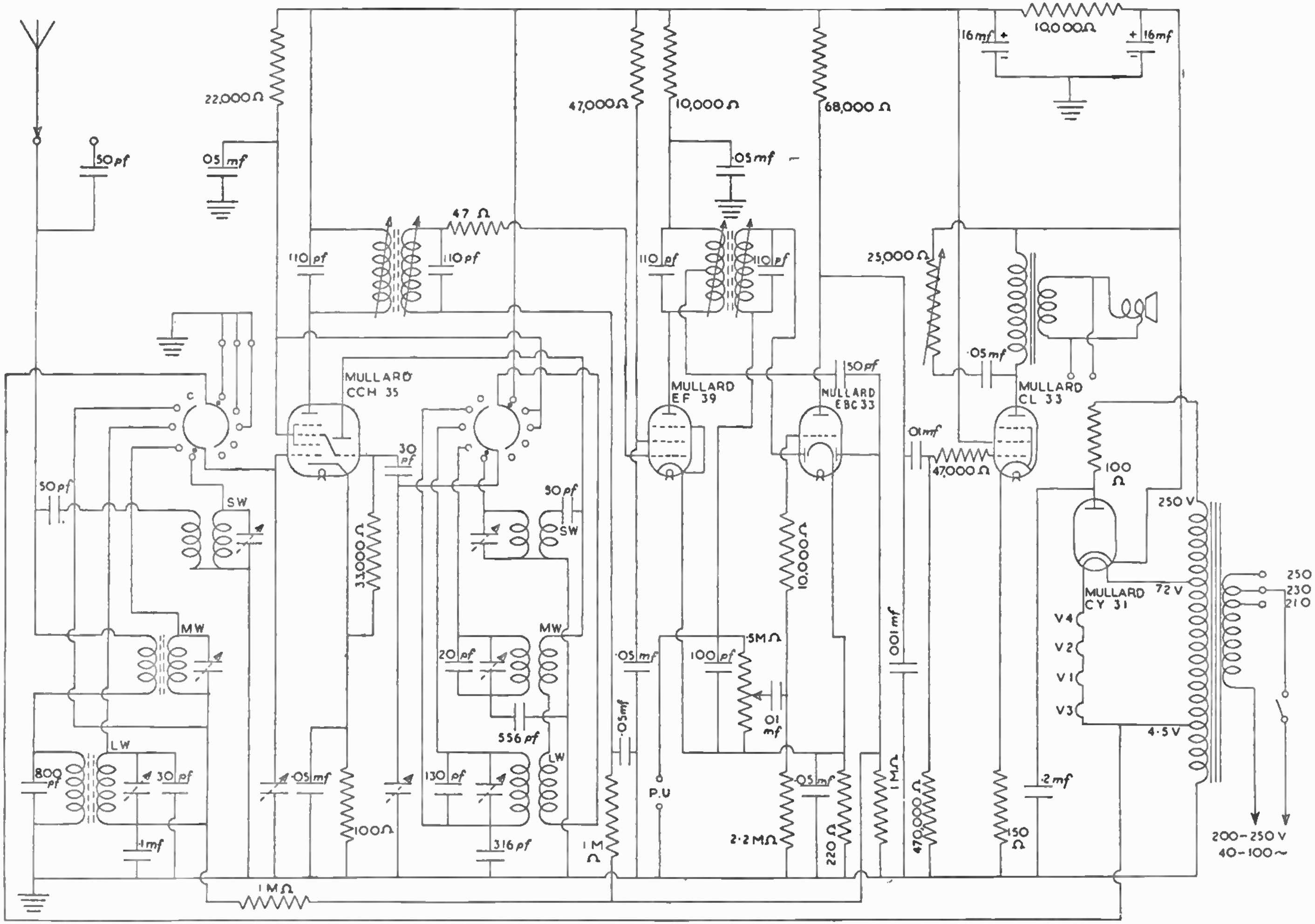
Commercial circuits which form the subject of pages 2–18 are followed by thirteen representative circuits; four of these circuits are rearrangements of those published in *Modern Practical Radio and Television*, Chapter 5, Volume II, with component values added. The rearrangement has been undertaken, since the original circuits were designed for the sole purpose of forming a basis for comment, and many functions were deliberately duplicated for the purpose of broadening discussions. These rearranged circuits can be regarded as an individual interpretation of the original circuits, and form a most interesting subject for comparison.

In the various circuits illustrated in the following pages values have, of necessity, been specified, since in certain cases component values are peculiar to the valves selected. The author desires to make it clear, however, that he considers valves made by any member of the British Valve Association to be satisfactory providing, of course, they are associated with suitable component values. In short, the selection of valves in the following pages has been almost entirely influenced by the types in the author's possession.

Pages 32–42 contain a variety of "unit" circuits useful when modifying or adding to existing equipment, and much thought and trouble has been expended in selecting circuits that will have wide appeal. One or two circuits have, however, been added on account of their intrinsic interest and originality.

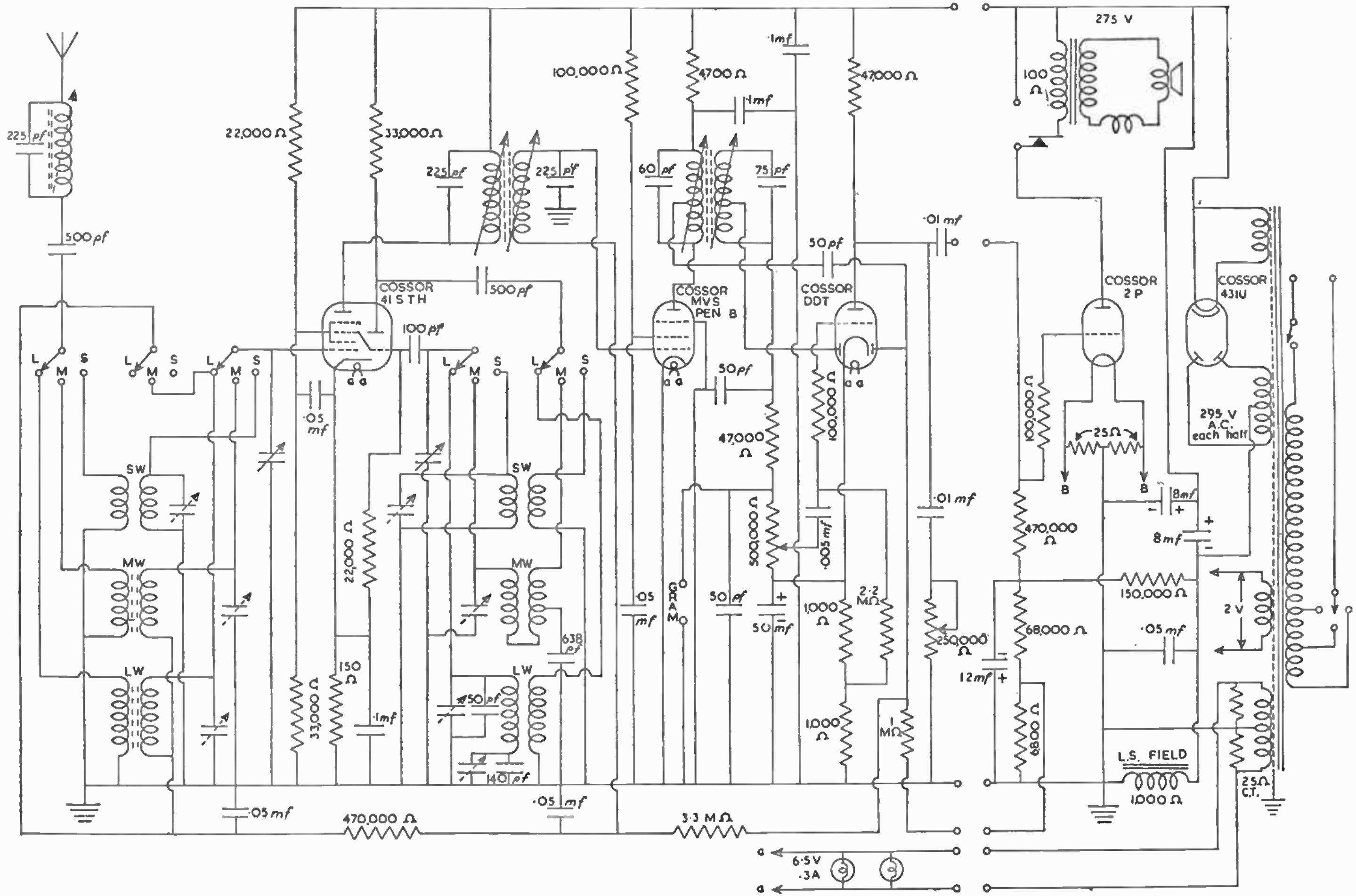
Component values have been specified in these "unit" circuits wherever possible. Where values are omitted, it is because they are influenced by the complete circuit of which these "unit" circuits are intended to form only a small part; in nearly every case, however, the missing value can be determined from studying the fundamental principles involved in the relevant section of *Modern Practical Radio and Television.*

The author welcomes suggestions for "unit" circuits, or indeed any other items for possible inclusion in future editions of this data book.



The Bush Model A.C.81

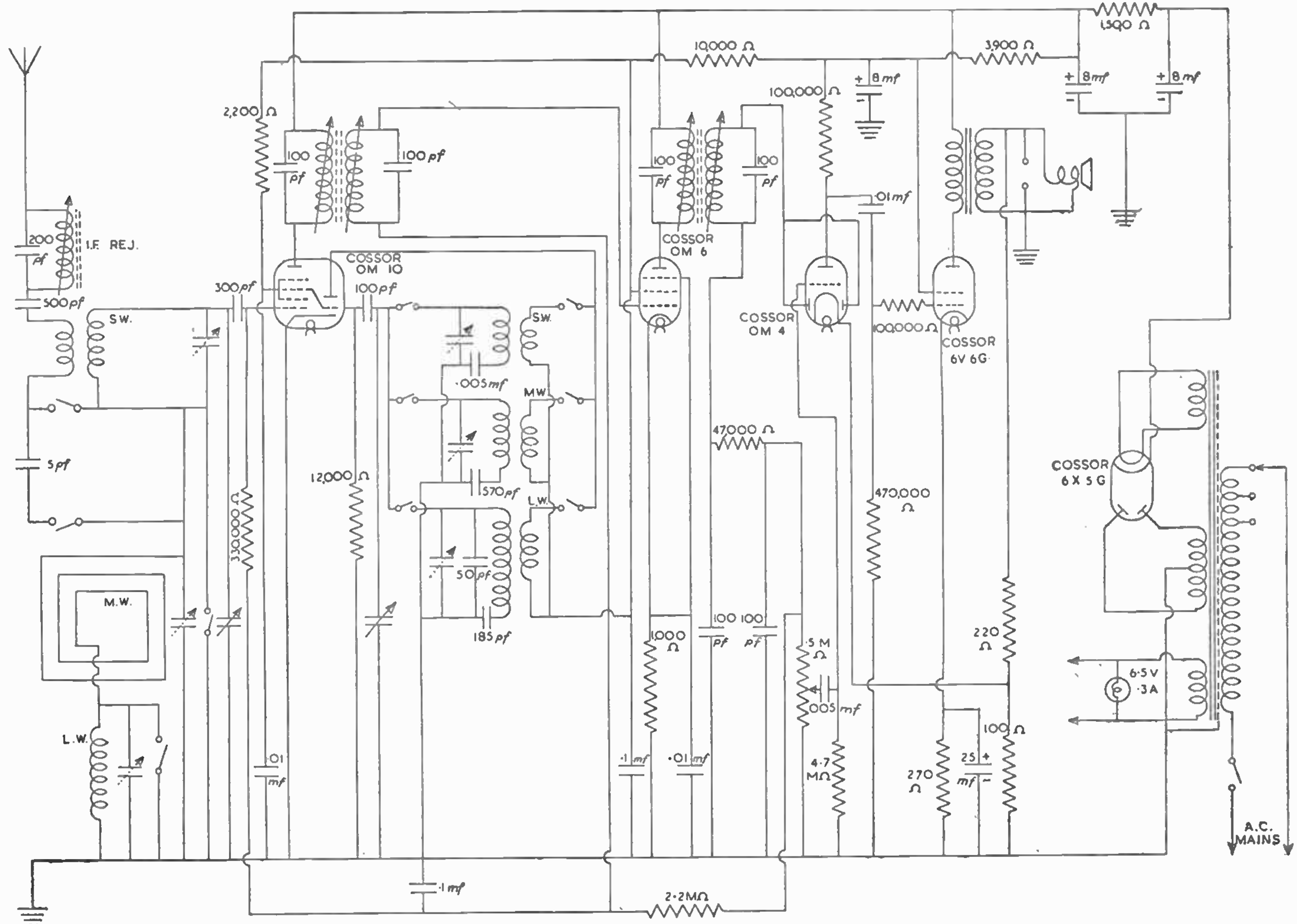
Attention is drawn to the output stage in which negative feedback is introduced by the omission of a cathode by-pass condenser; note that the output valve anode is fed from the unsmoothed side of the H.T. supply, also the parasitic stopper in the I.F. amplifier grid lead.



THE COSSOR MODEL 456 A.C.

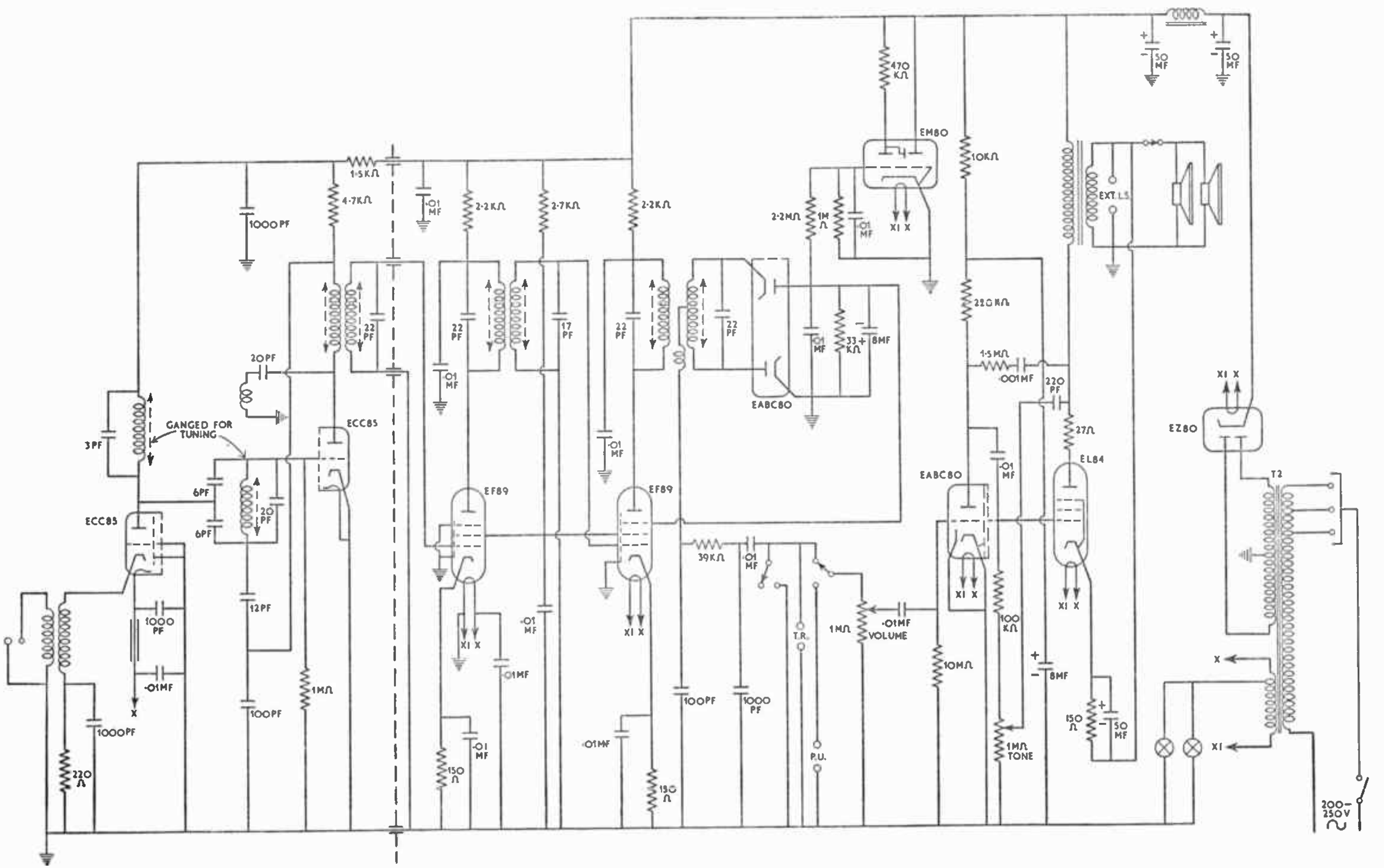
Note the directly heated low filament voltage output valve, the bias for which is developed across the loudspeaker field coil placed in the negative H.T. lead.

4



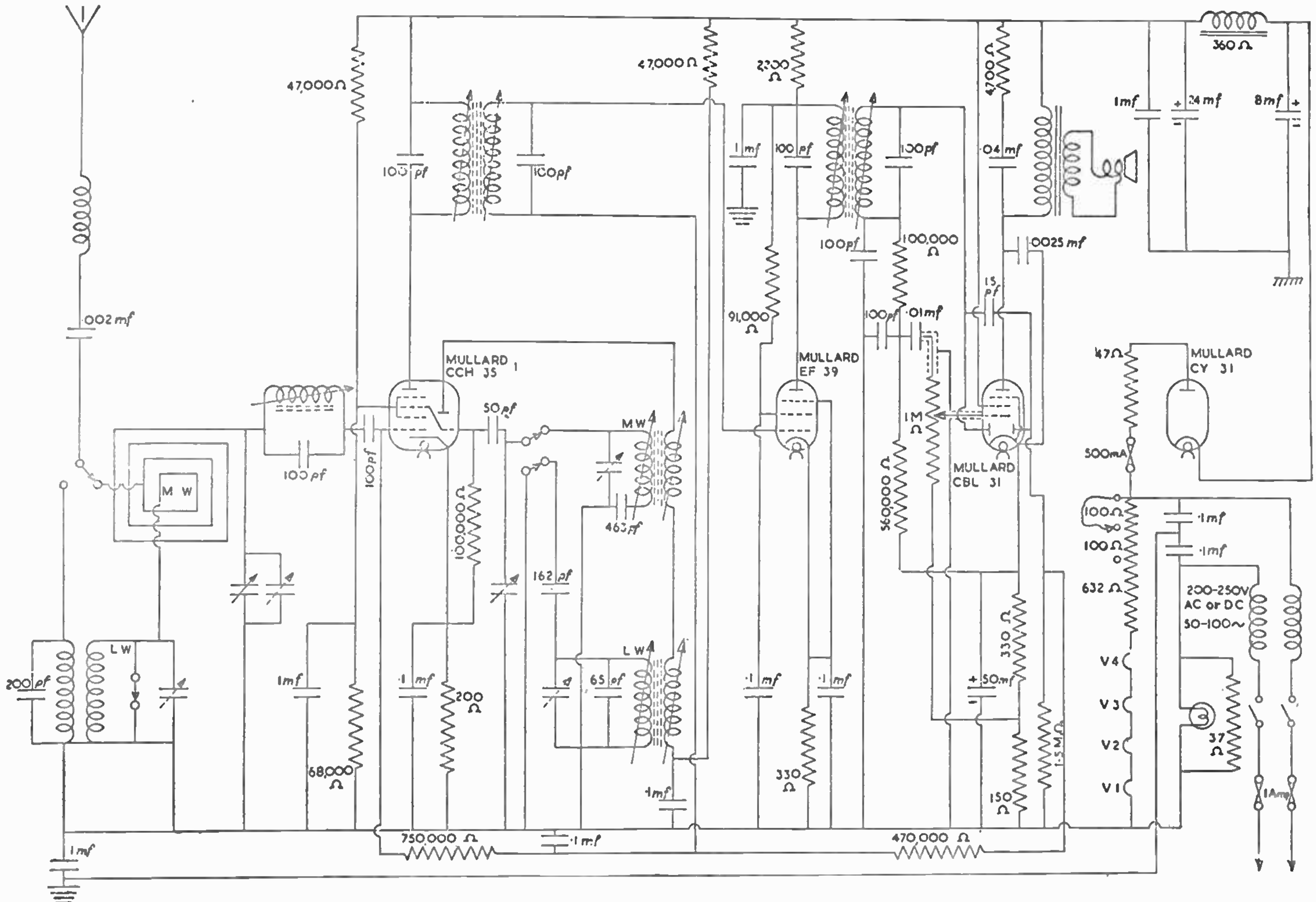
THE COSSOR MODEL 464

The aerial circuit arrangements are interesting and are worthy of careful study. Attention is also directed to the method of applying negative feedback and the resistance capacity two-stage H.T. smoothing.



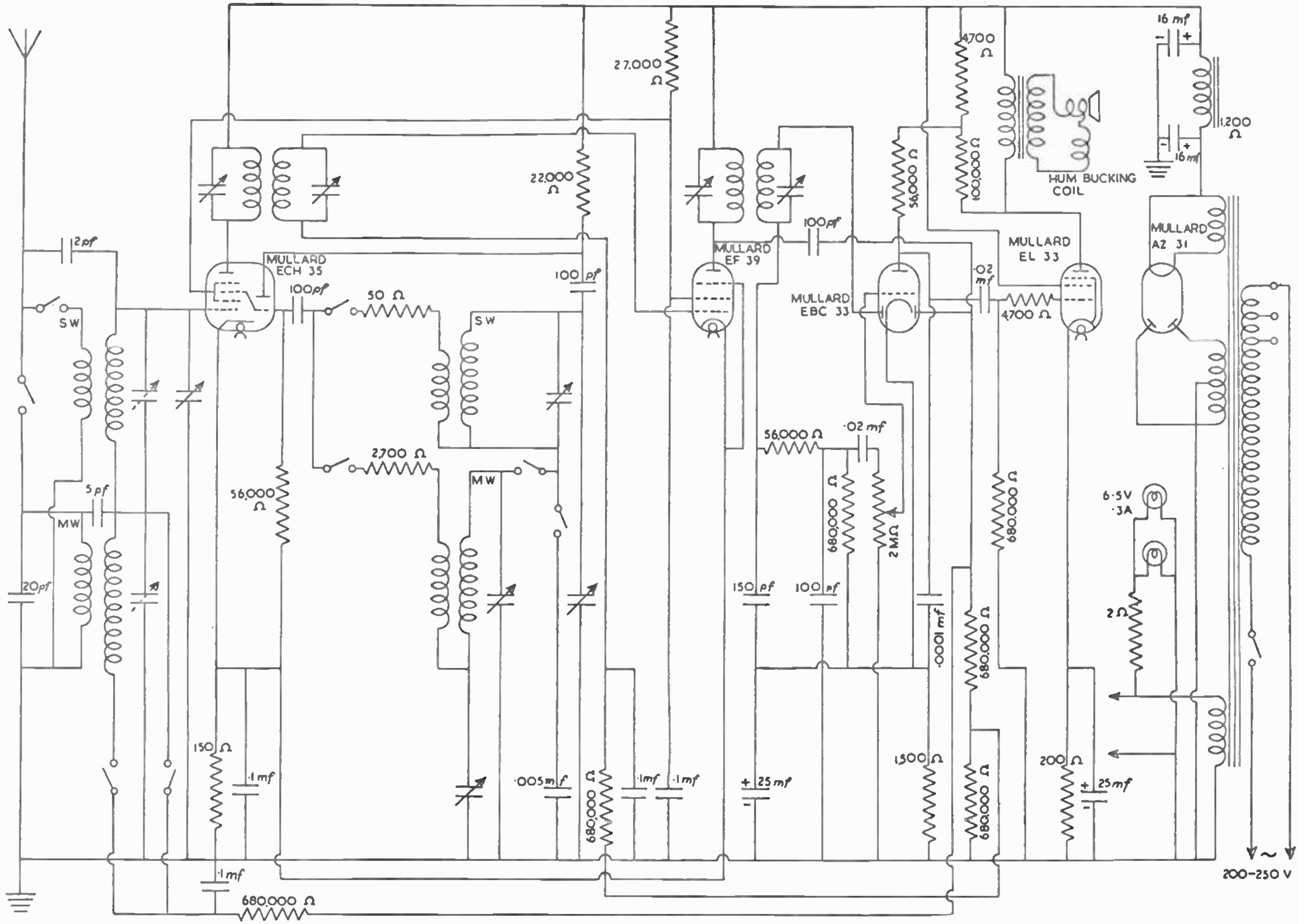
The Ekco FM Model A274

Points of interest are the oscillator coupling, the method of obtaining negative feedback, and the tape recorder connection.



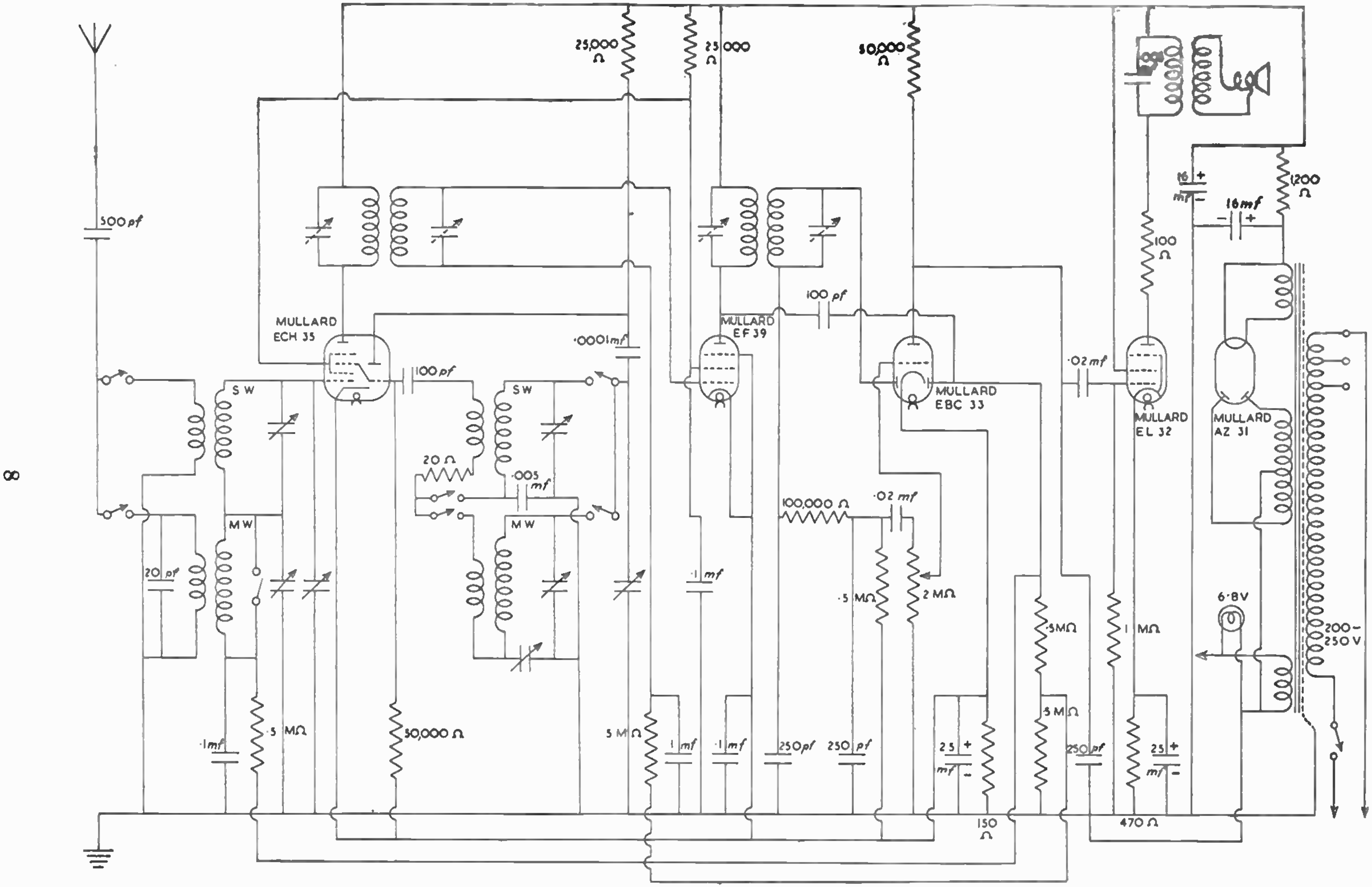
The Ekco Model U29

Note the rejector inductance in the aerial lead and the position of the I.F. rejector circuit between the frequency changer grid and aerial circuit. Observe that fuses are provided in both mains leads and rectifier anode lead, observe also the mains filter.



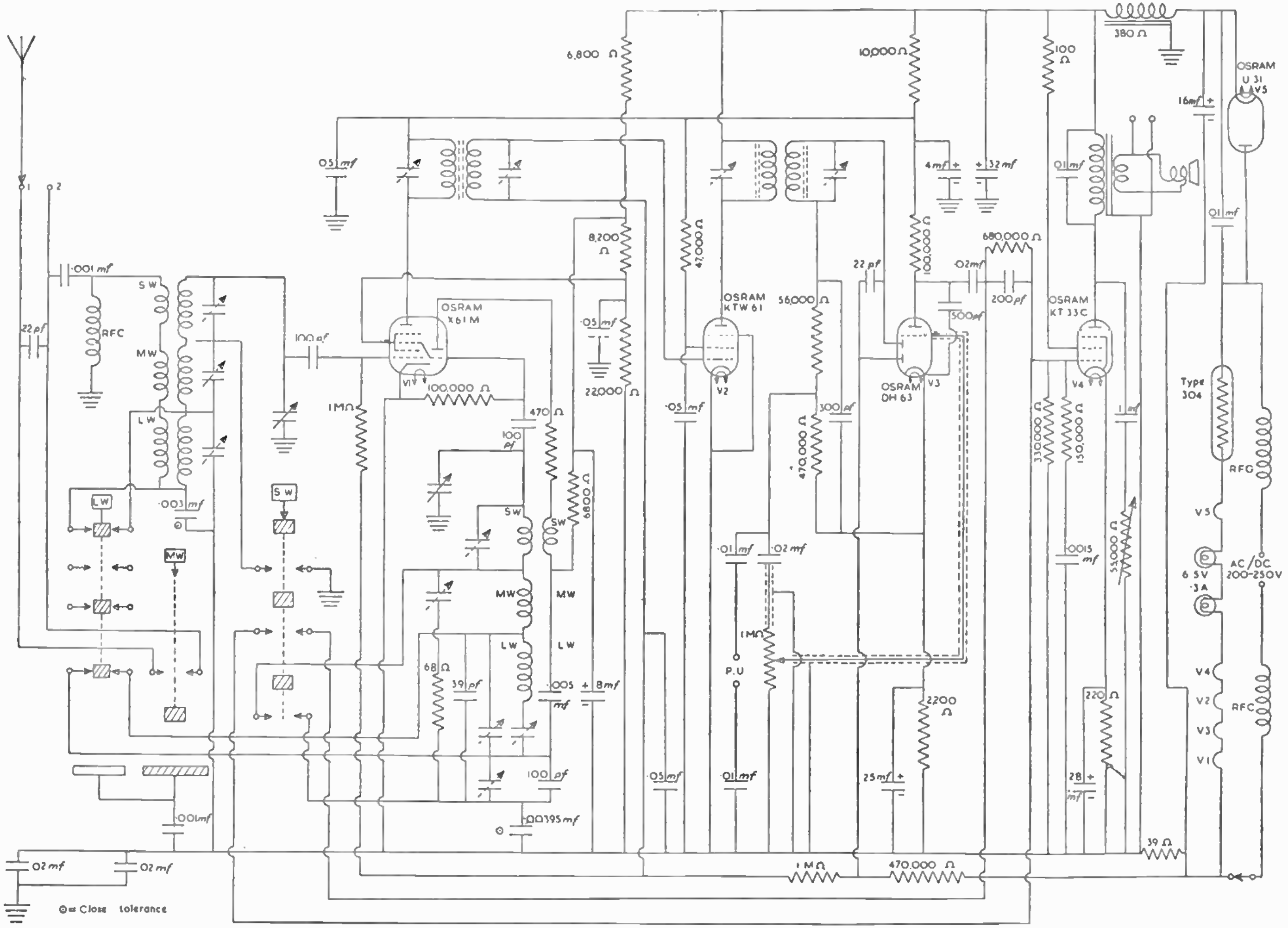
The Ferguson Model 450

Points of interest are the use of very small condensers in the design of the aerial couplings, anti-squegging resistance in the oscillator grid circuits and the series negative feedback arrangements.



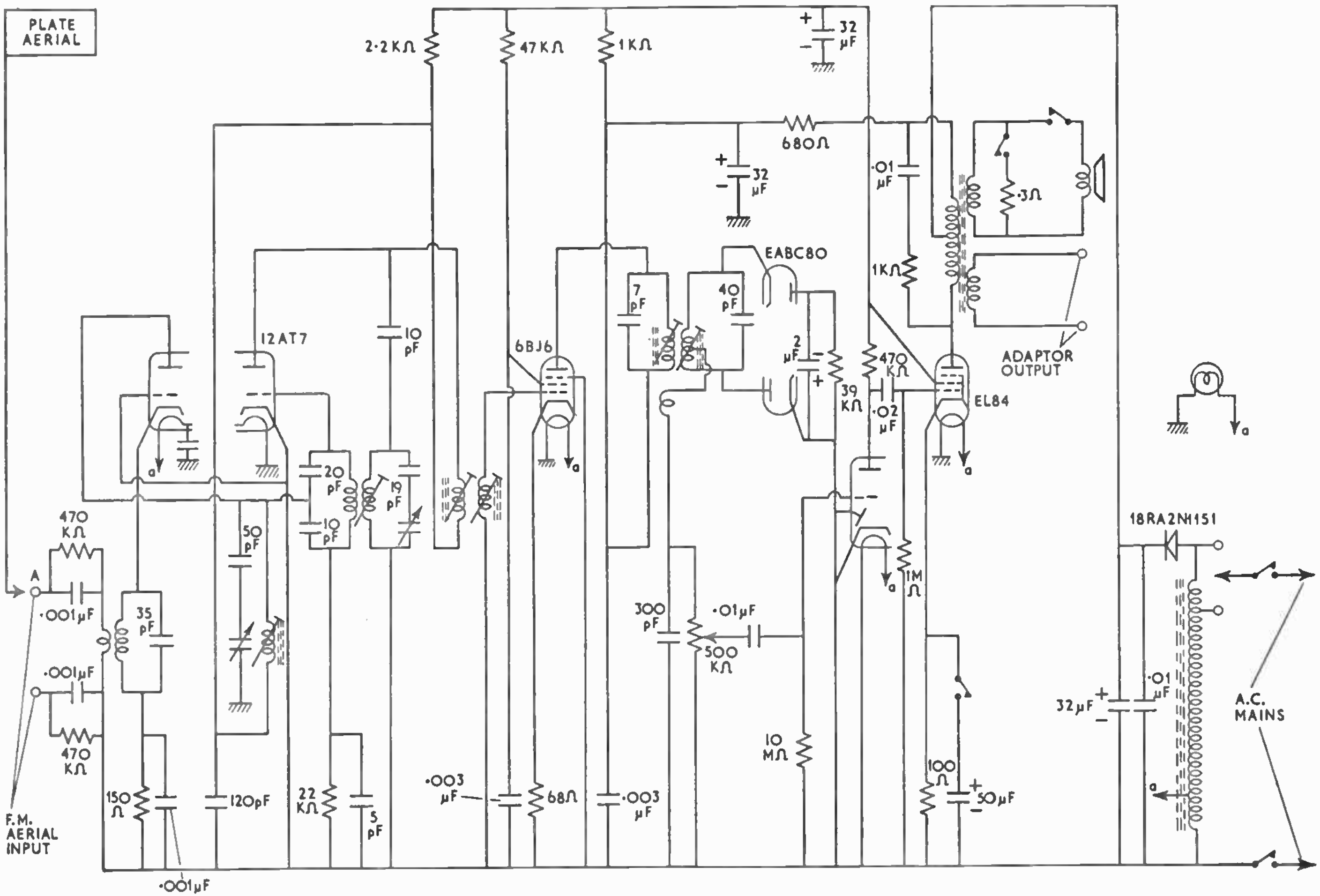
The Ferguson Model 910

Points to note are parasitic stoppers in the oscillator grid and output anode circuits, resistance capacity smoothing and the fact that A.V.C. is derived from the anode of the I.F. amplifier to reduce sideband shriek when tuning.



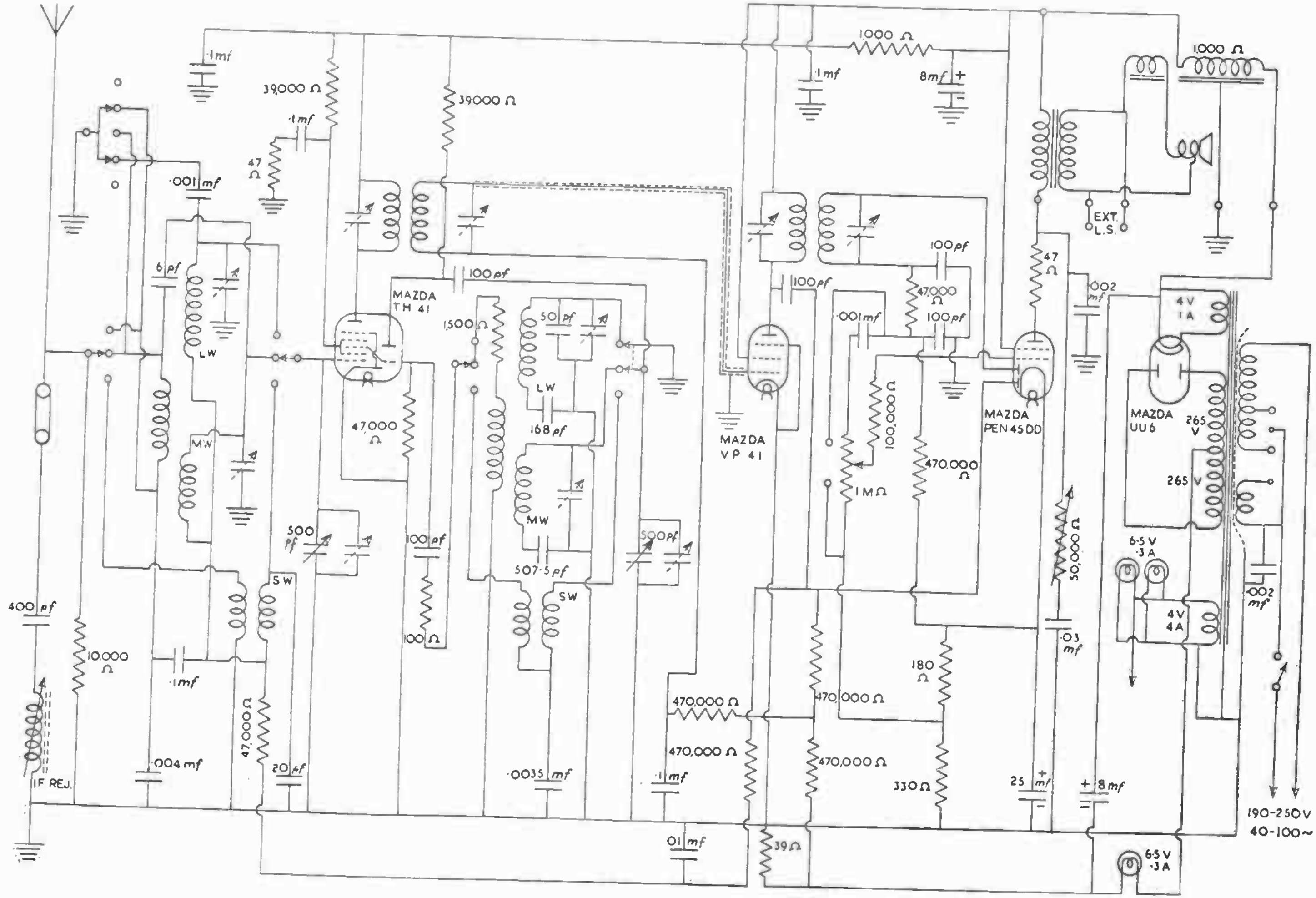
The G.E.C. Model BC4655

Both aerial and oscillator coupling is unusual, the medium and long wave sections have only single turn primary windings and rely on the common impedance of the condensers marked close tolerance. Attention is also drawn to the R.F. choke in the aerial circuit which eliminates any tendency to modulation hum.



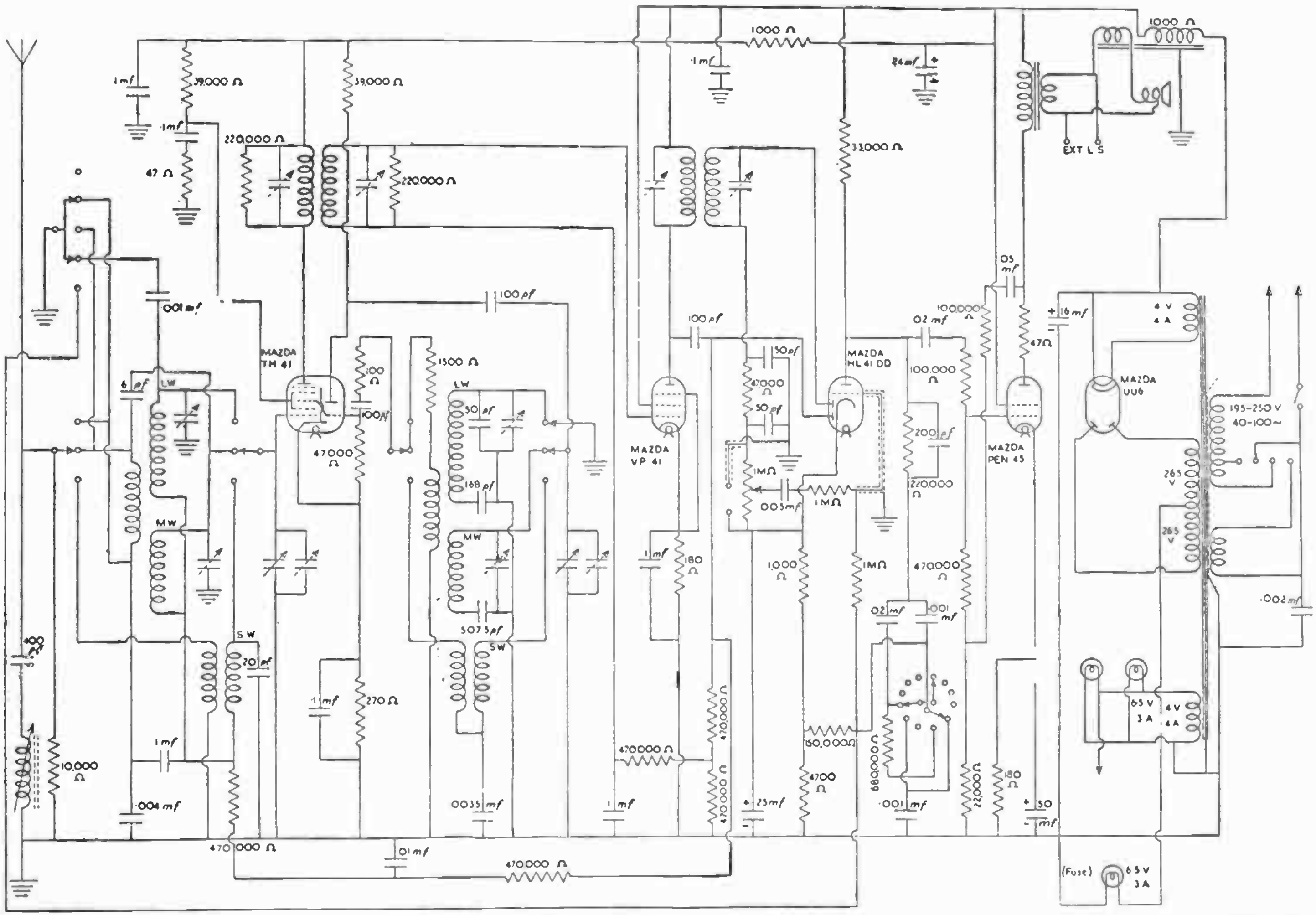
The Kolster-Brandes FM Model FB10FM

Note particularly the middle stage, which is reflexed, being an I.F. amplifier and a L.F. amplifier; the screen acts as the anode for the latter function.



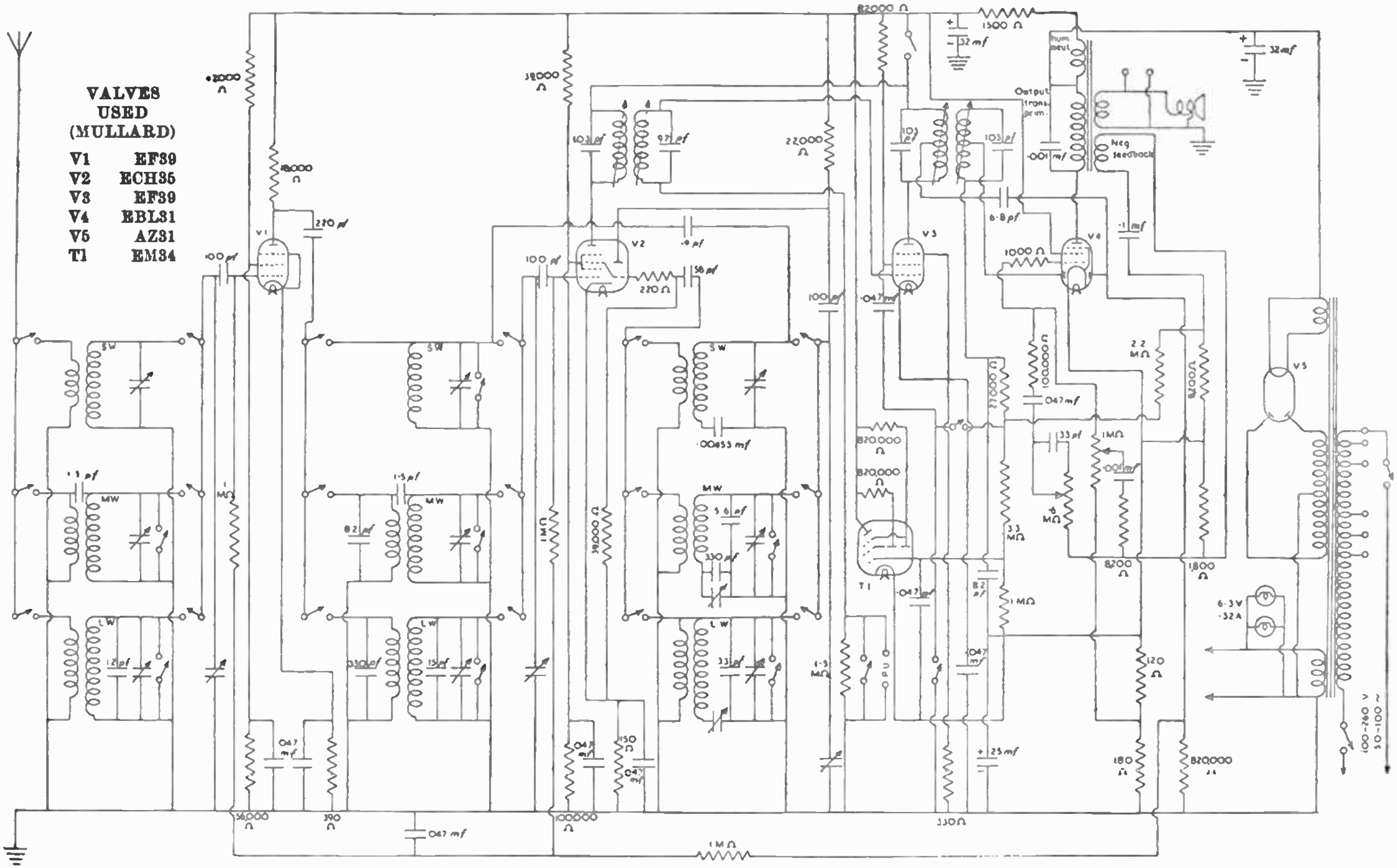
THE McMICHAEL MODEL 451

There are many detailed points of interest in this circuit, but attention is directed to the aerial circuit and switching, the output valve grid circuit and the mains transformer primary.



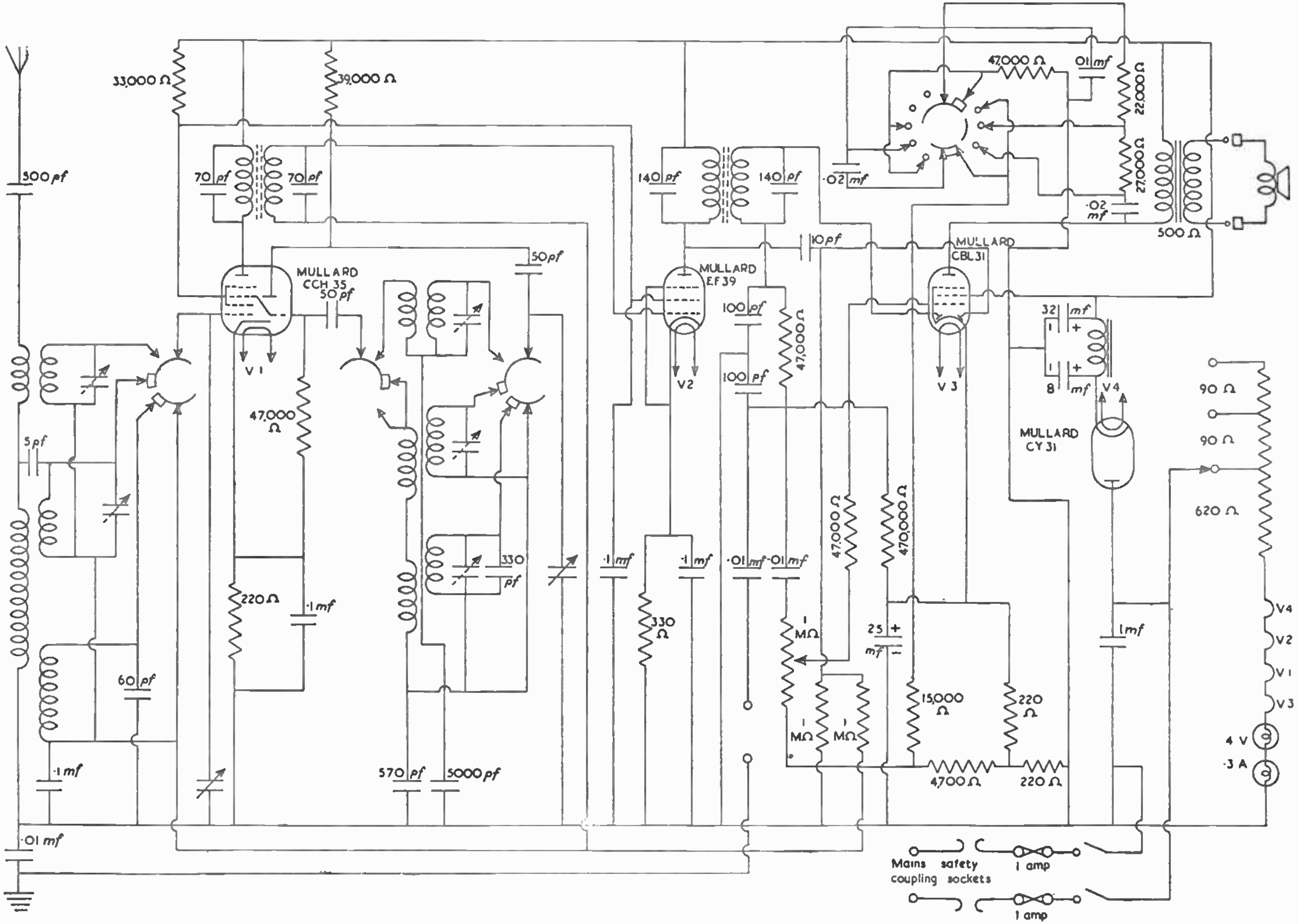
The McMichael Model 452

Note parasitic stoppers in the frequency changer screen lead and output valve anode lead, also anti-squegging resistance in the oscillator grid circuit. The resistance condenser combinations given by the four-position tone control are of interest ; note that negative feedback is employed.



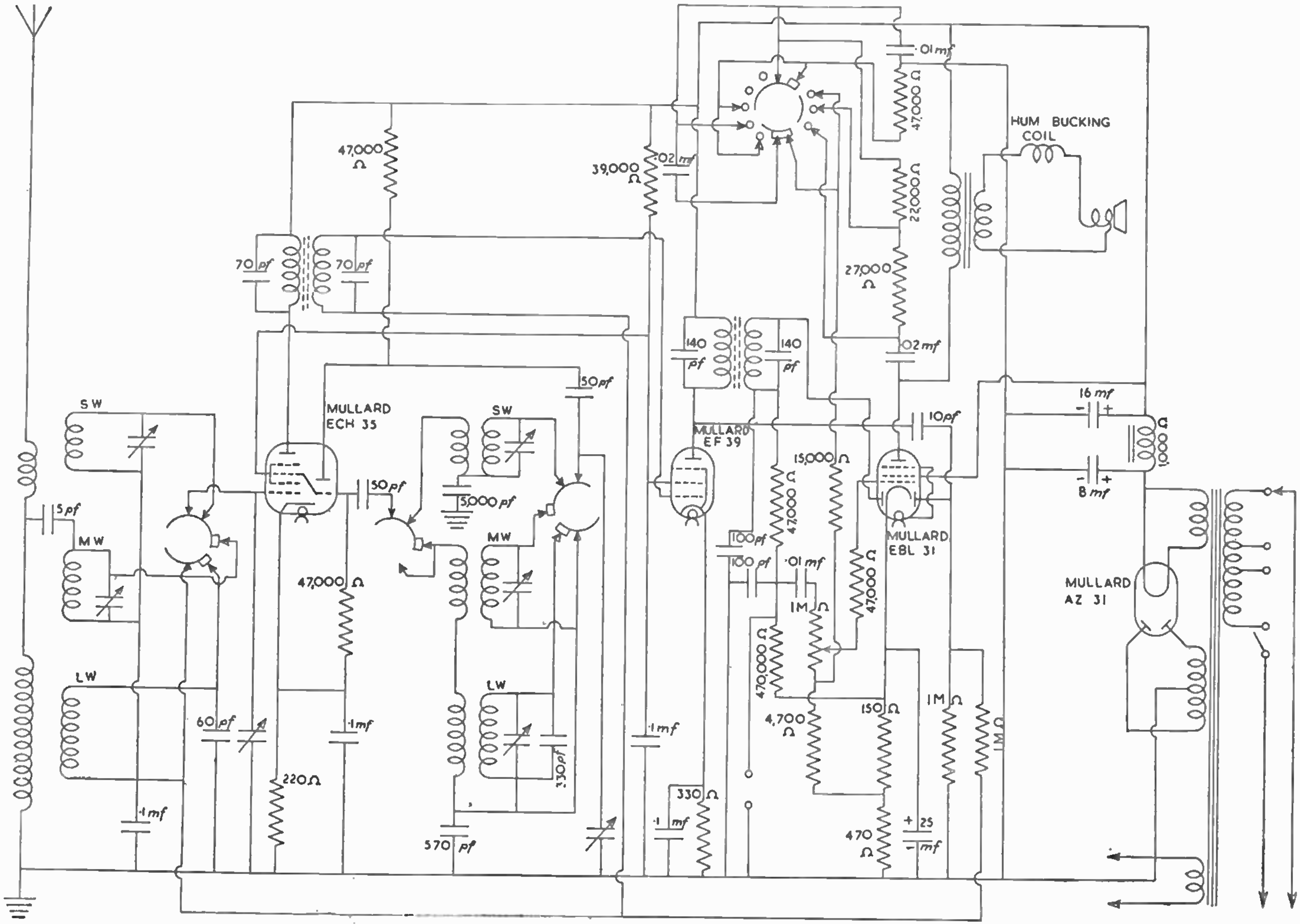
The Philips Model 170A

The negative feedback arrangements are an interesting object-lesson in circuit design; the volume control is compensated by automatically varying negative feedback and the tone control operates by varying the amount of negative feedback at higher frequencies. Note also the hum neutralising arrangements.



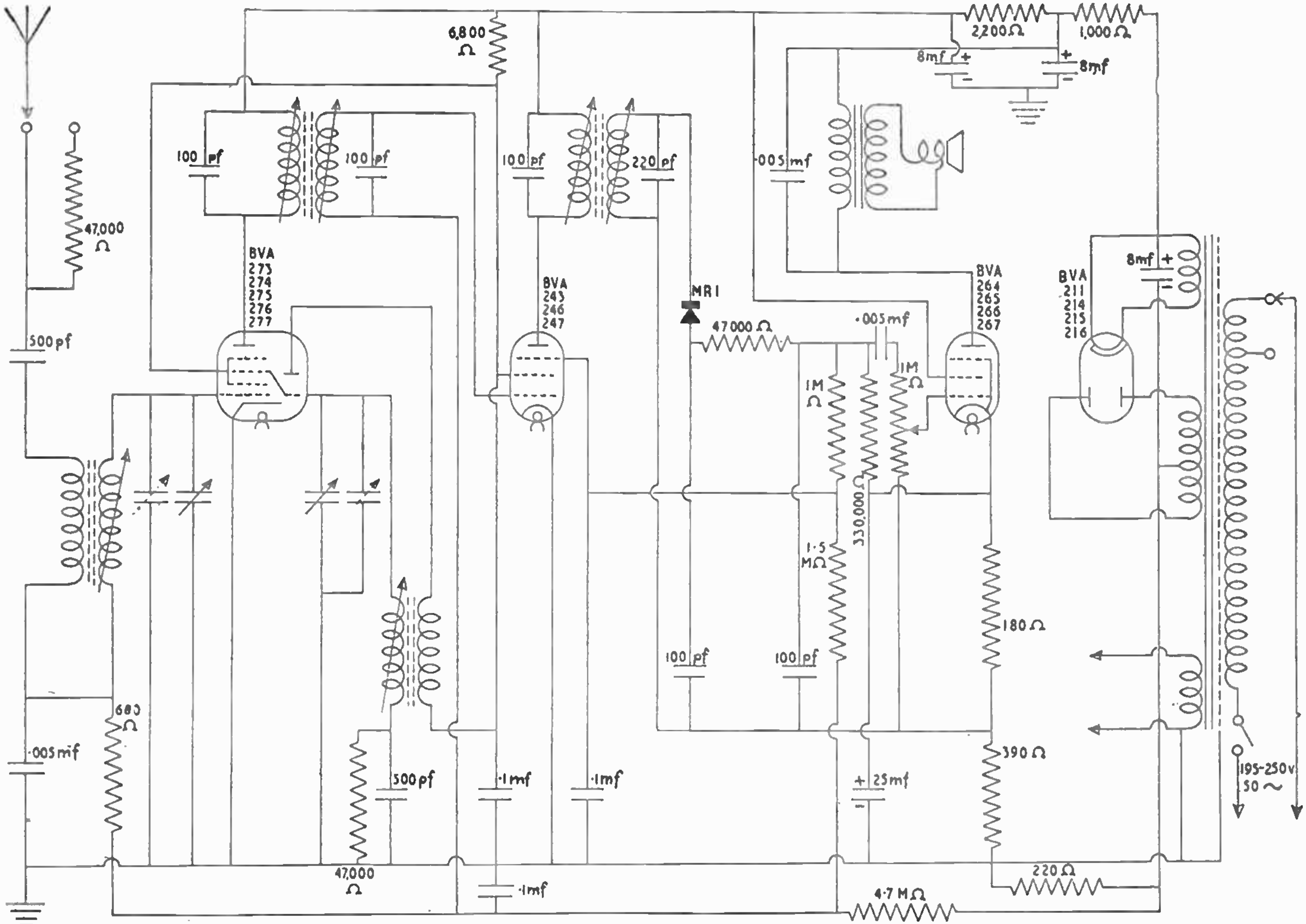
The Pye Model 45A

Like the model 15A, attention is drawn to the tone control arrangements. These two circuits form an interesting comparison between A.C. and D.C./A.C. working.



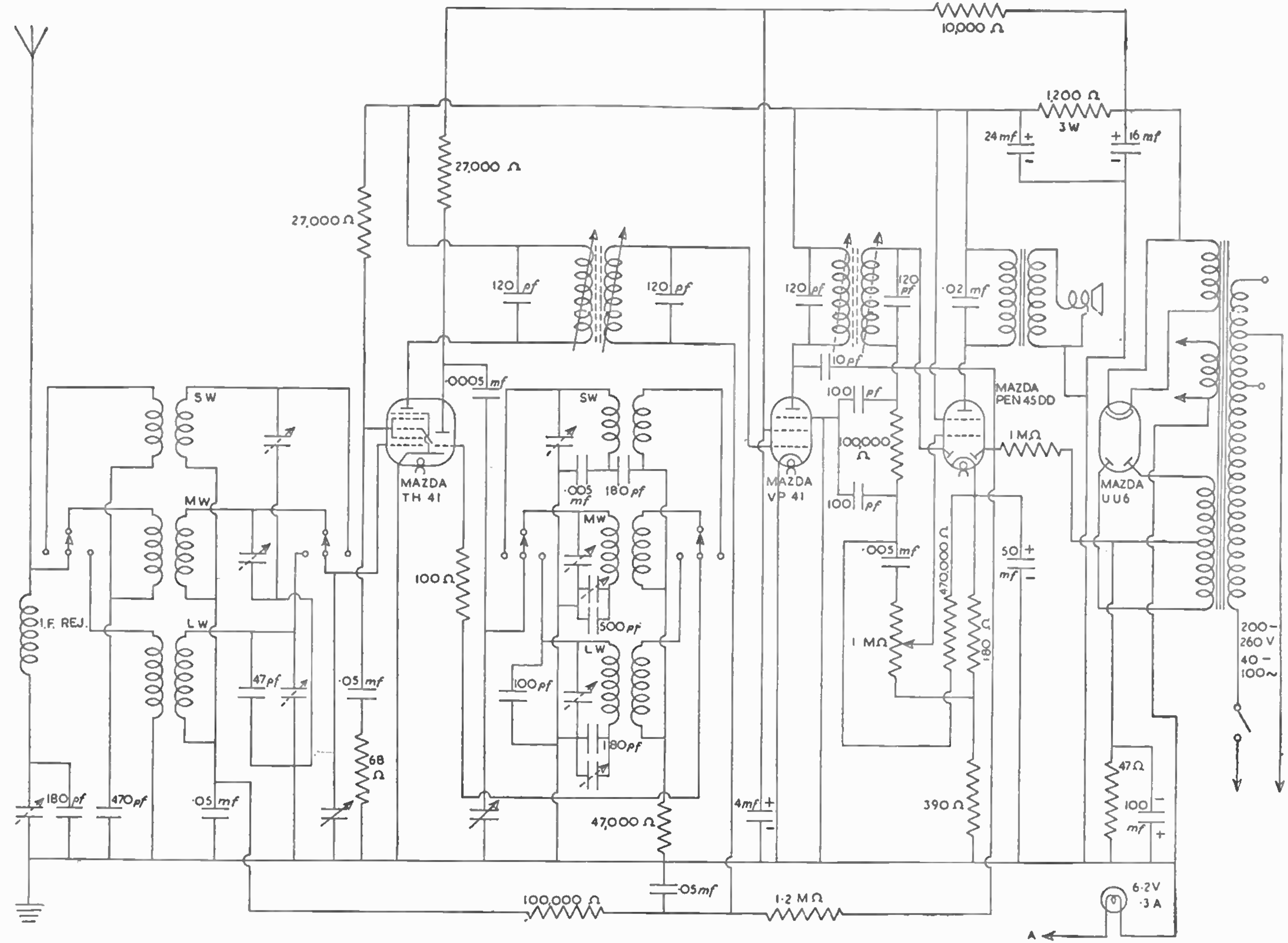
The Pye Model 15A

Attention is directed to the tone control switch, which has four positions. It is well worth following out the connections for each position.



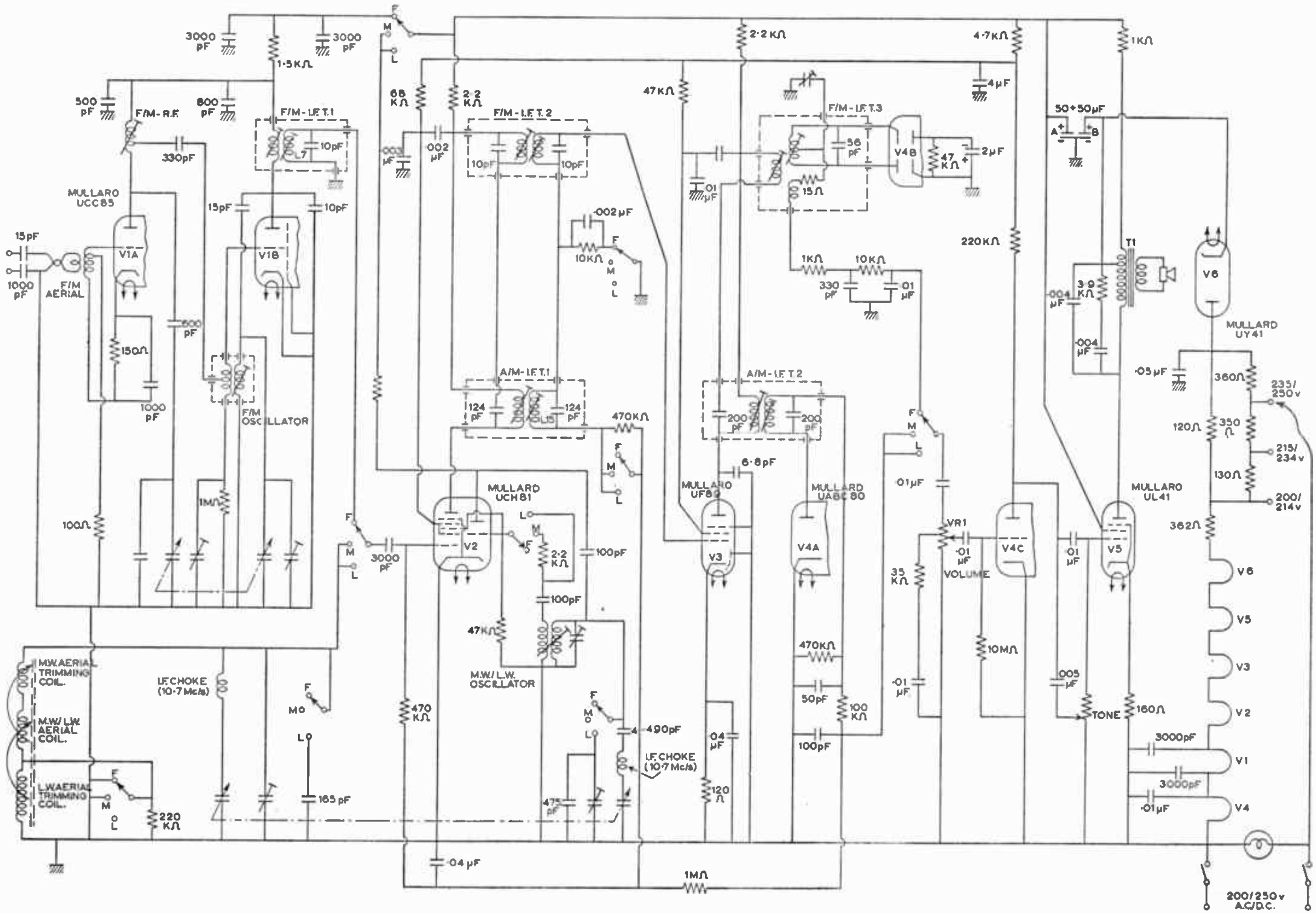
Standard War-time A.C. Receiver

This circuit is included as an example of austerity and because of certain ingenious features, notably the use of the I.F. amplifier suppressor (acting in conjunction with the cathode as a diode) to produce A.V.C. The MR1 is a metal oxide detector. This receiver was manufactured by a number of firms who introduced sundry variations, and a surprising number are still in use.



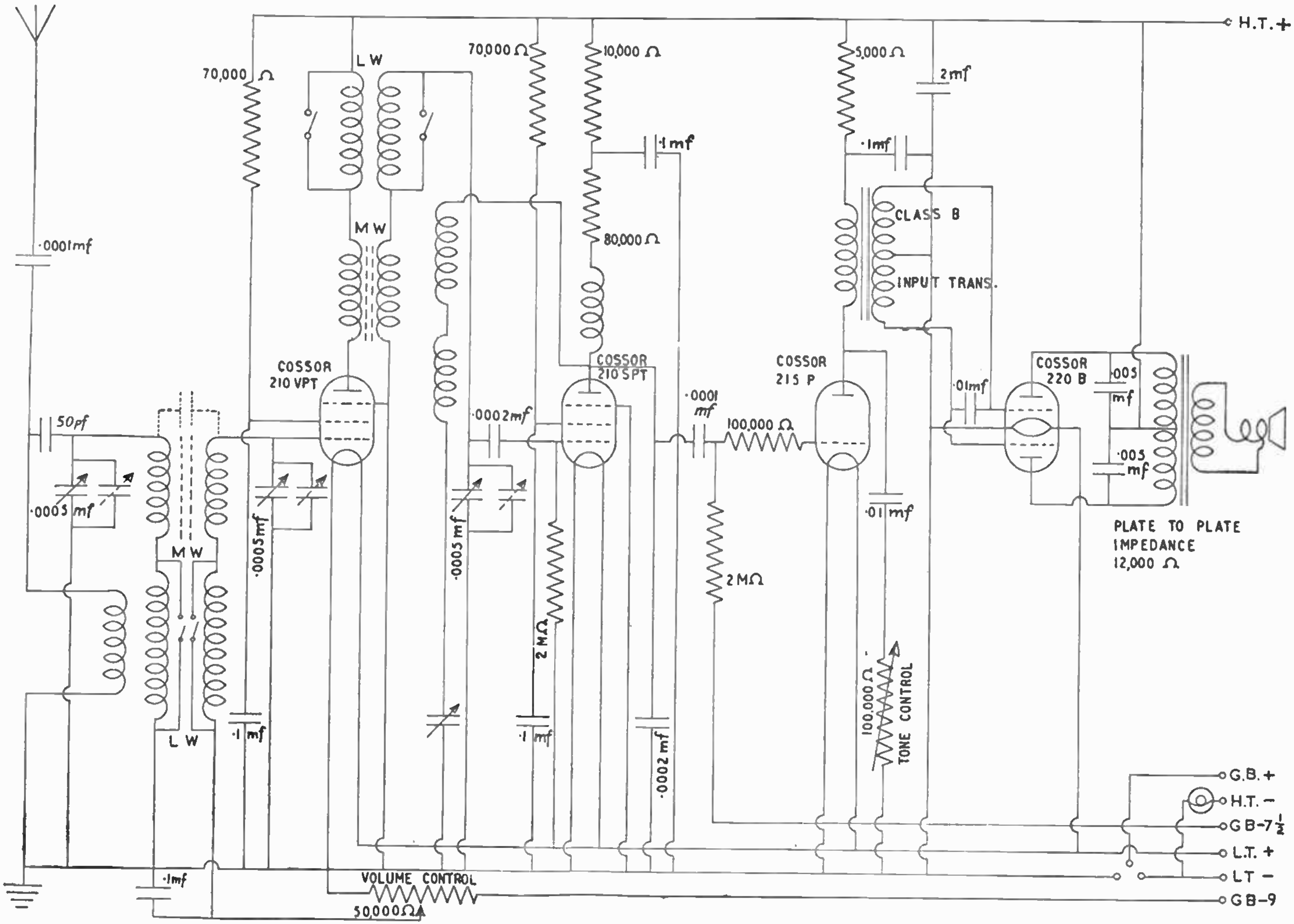
The Ultra Model T401

Note parasitic stopper in the frequency changer screen lead and anti-squegging resistance in the oscillator grid lead. The biasing of the frequency changer and I.F. amplifier and the A.V.C. delay arrangements are additional points of interest.



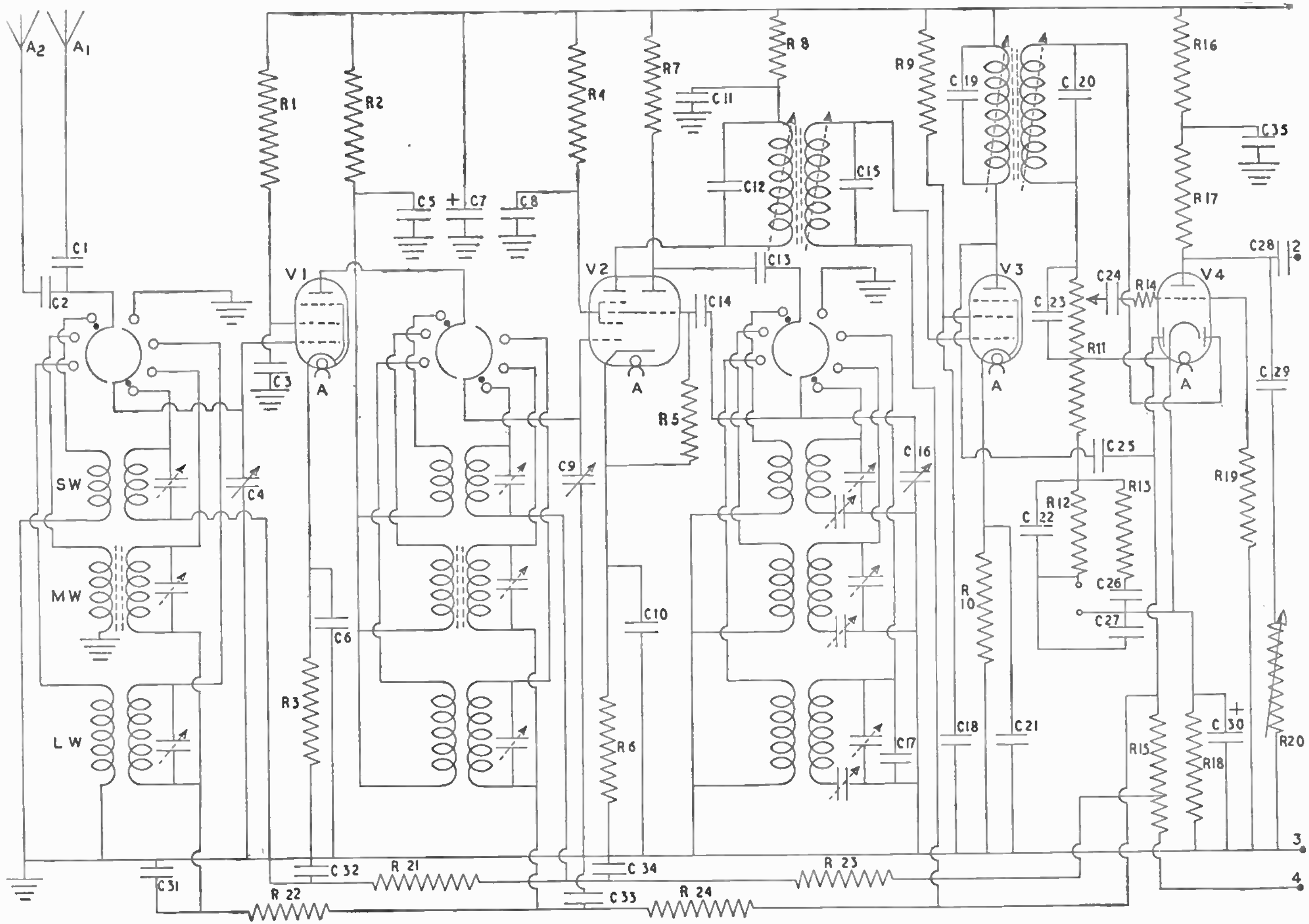
The Ultra AM–FM Model U930

Note separate oscillation for VHF and MW–LW bands, phase correction in ratio detector circuit and tone compensated volume control.



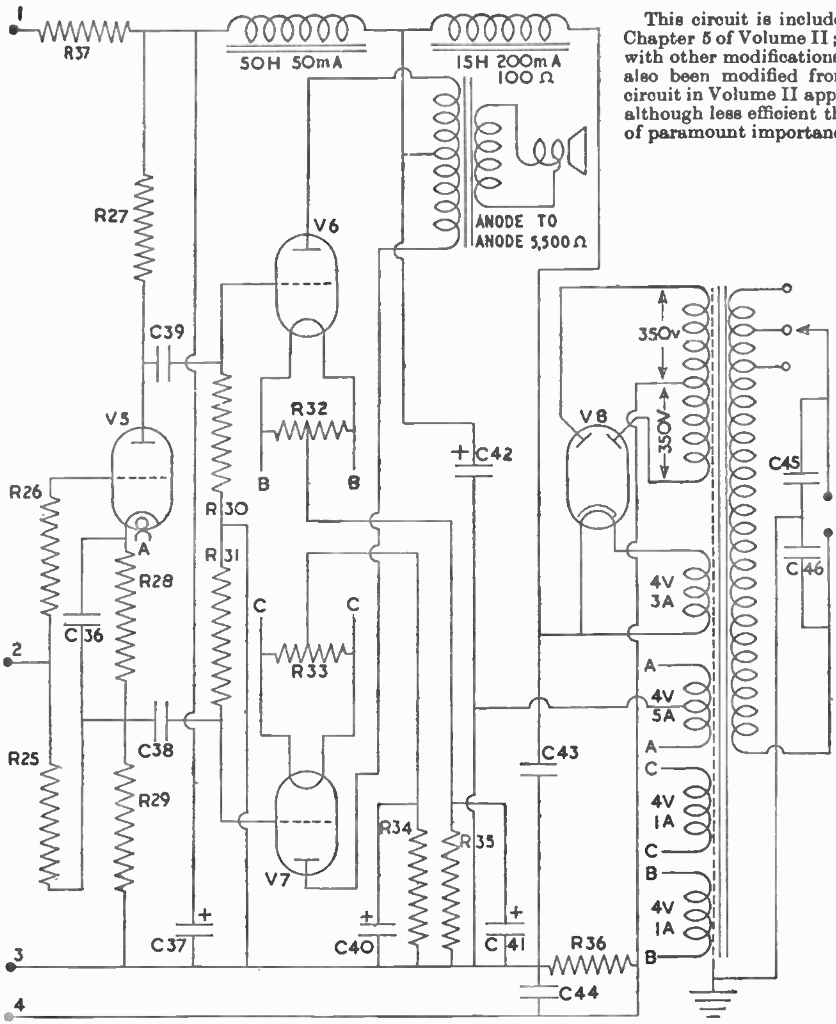
4V Class B Receiver

A slight rearrangement of the class B receiver, shown in Chapter 5, Volume II, but with component values added. The aerial circuit uses bandpass coils which sometimes require small additional capacitive coupling, usually about 5 pf, shown dotted in the above illustration.



7 + 1 Valve, 3-band Receiver

The output section and component values are on the facing page



7 + 1 Valve, 3-band Receiver
(12 watt, push-pull output)

This circuit is included in response to numerous requests for more details of the circuit shown in Chapter 5 of Volume II; it is presented, however, without the automatic frequency control circuit and with other modifications, so that non-standard components have been excluded. The output stage has also been modified from 8 to 12 watts. Much of the text matter which accompanies the 10-valve circuit in Volume II applies equally to the rearrangement herewith. Triode output valves are used, and although less efficient than tetrodes, they still enjoy considerable popularity where H.T. current is not of paramount importance.

Condensers

C1 = 100 pf	C13 = 100 pf	C25 = 75 pf	C37 = 16 mf
C2 = 15 pf	C14 = 50 pf	C26 = ·1 mf	C38 = ·075 mf
C3 = ·1 mf	C15 = IFTC	C27 = ·01 mf	C39 = ·075 mf
C4 = TC *	C16 = TC	C28 = ·03 mf	C40 = 25 mf
C5 = ·1 mf	C17 = Padder ‡	C29 = ·02 mf	C41 = 25 mf
C6 = ·2 mf	C18 = ·1 mf	C30 = 50 mf	C42 = 16 mf
C7 = 16 mf	C19 = IFTC	C31 = ·05 mf	C43 = 4 mf
C8 = ·2 mf	C20 = IFTC	C32 = ·03 mf	C44 = 1 mf
C9 = TC	C21 = ·1 mf	C33 = ·05 mf	C45 = ·1 mf
C10 = ·2 mf	C22 = ·01 mf	C34 = ·03 mf	C46 = ·1 mf
C11 = ·2 mf	C23 = 65 pf	C35 = ·5 mf	
C12 = IFTC †	C24 = ·02 mf	C36 = ·5 mf §	

Resistances (Ohms)

R1 = 15,000	R11 = ·5 + ·5 MΩ	R20 = 20,000	R29 = 3,600
R2 = 5,100	R12 = 10,000	R21 = 1 MΩ	R30 = 100,000
R3 = 100	R13 = 3,300	R22 = 1 MΩ	R31 = 100,000
R4 = 8,200	R14 = 47,000	R23 = 1 MΩ	R32 = 25
R5 = 33,000	R15 = 1 MΩ ¶	R24 = 1 MΩ	R33 = 25
R6 = 300	R16 = 20,000	R25 = 130,000	R34 = 510
R7 = 33,000	R17 = 56,000	R26 = 2,000	R35 = 510
R8 = 5,100	R18 = 2,000	R27 = 3,600	R36 = 10
R9 = 15,000	R19 = 1 MΩ	R28 = 330	R37 = 7,500
R10 = 100			

* Capacity of variable tuning condenser will depend on limits of bands to be covered and inductance of coils selected.

† Capacity as required to tune selected I.F. transformers to intermediate frequency to be used.

‡ Capacity as required to raise total padding capacity to required figure.

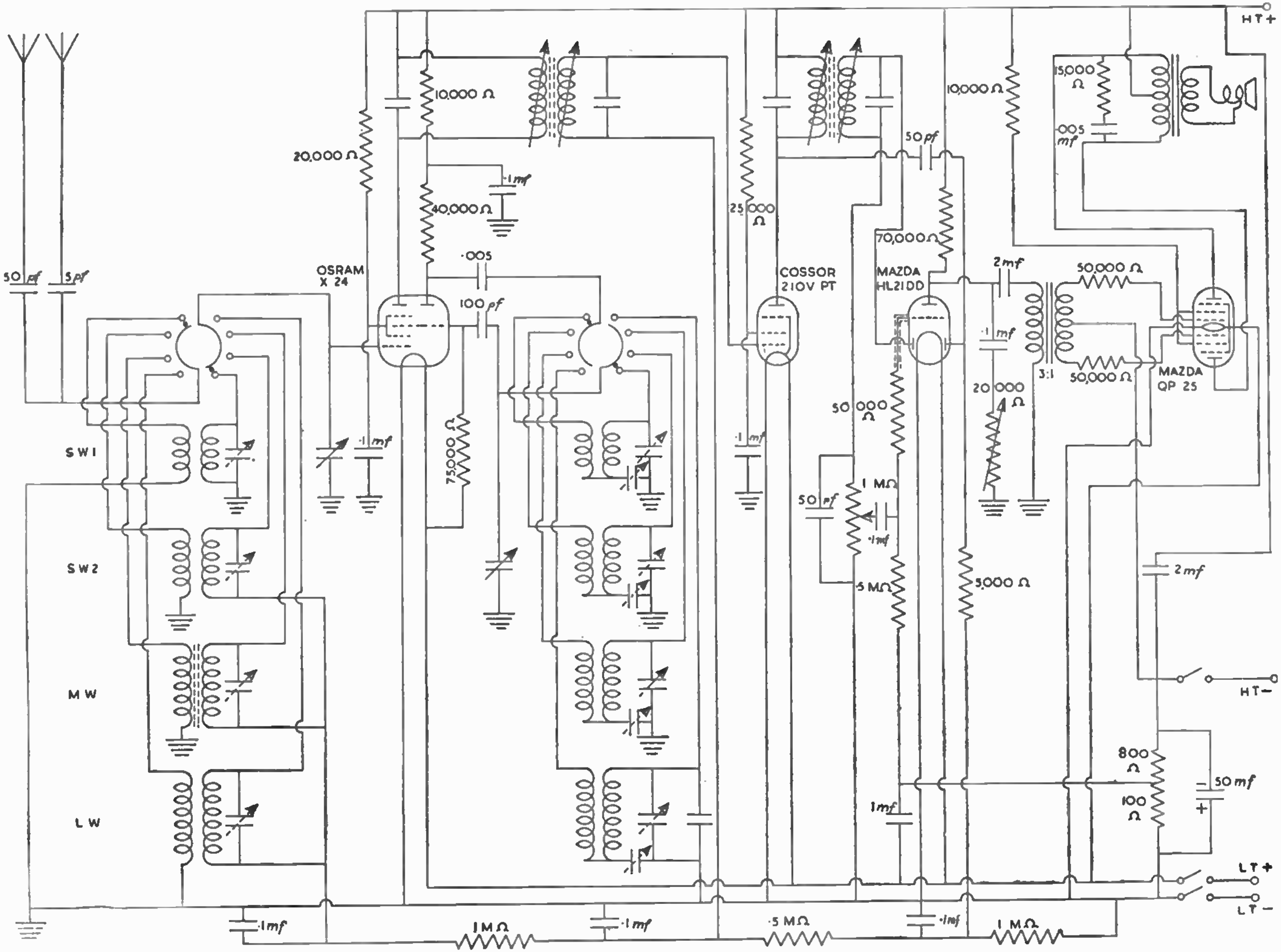
§ C36 may, with advantage, be connected across a portion only of R28 to provide a small amount of negative feed-back.

|| Values shown are preferred values: close non-preferred values can be used with discretion.

¶ Tapped resistance gives any lesser degree of A.V.C. on shortwave band as desired. If very weak stations are required, move tap to top end of resistance and disconnect from grid of V1, when R3 should be 700 Ω.

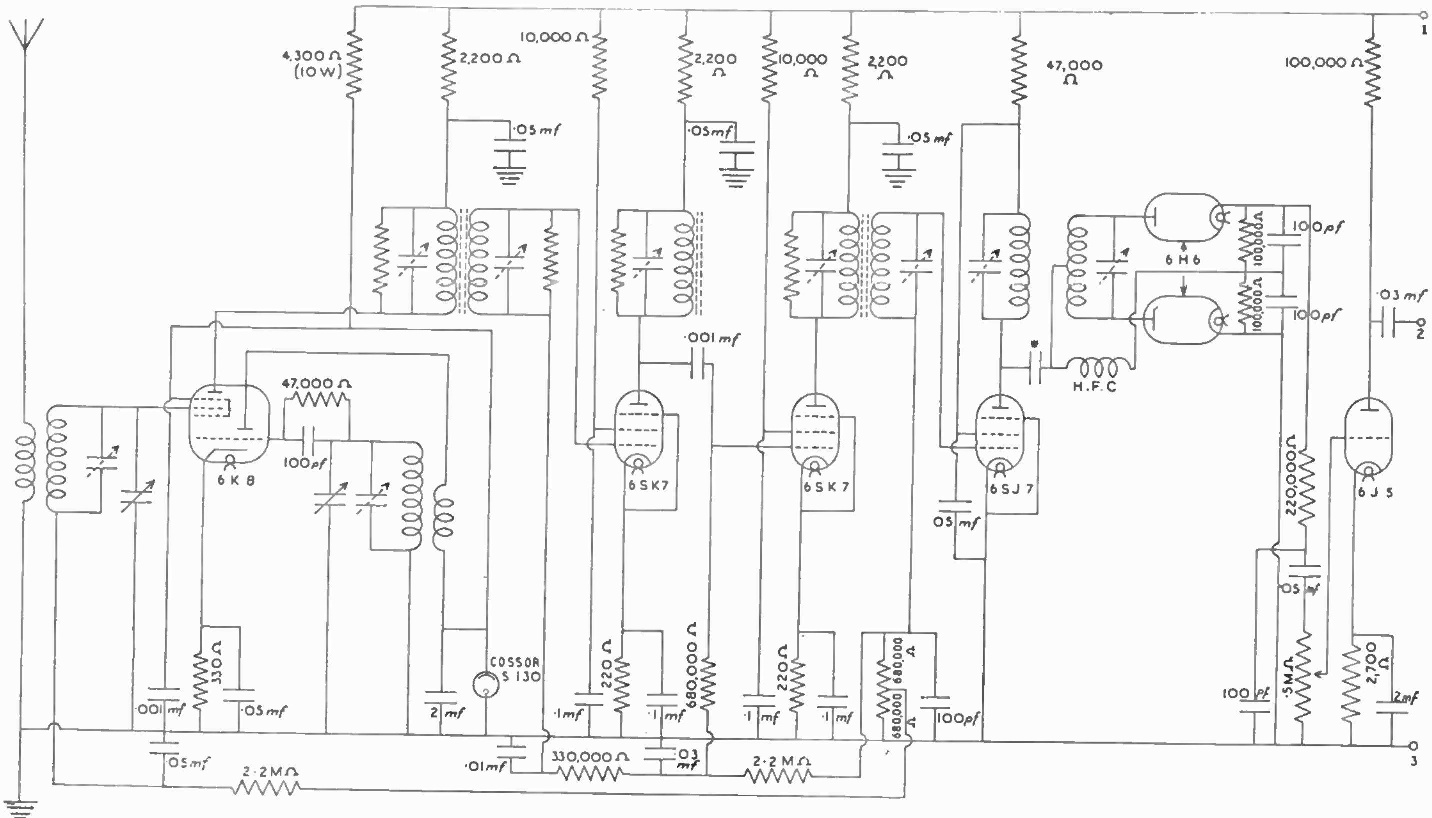
V1 Cossor MVS/Pen or MVS/Pen B	V5 Cossor 41MP **
V2 Cossor 41 STH	V6 Mazda PP5/400
V3 Cossor MVS/Pen or MVS/Pen B	V7 Mazda PP5/400
V4 Cossor DDT	V8 Mullard FW4/500

** The author has used a valve of this type for several years with complete success under conditions prevailing in this circuit; nevertheless, a considerable voltage difference exists between heater and cathode. It is advantageous, therefore, to supply the heater from a separate transformer winding, the centre tap being connected to chassis through a ·1 mf-condenser.



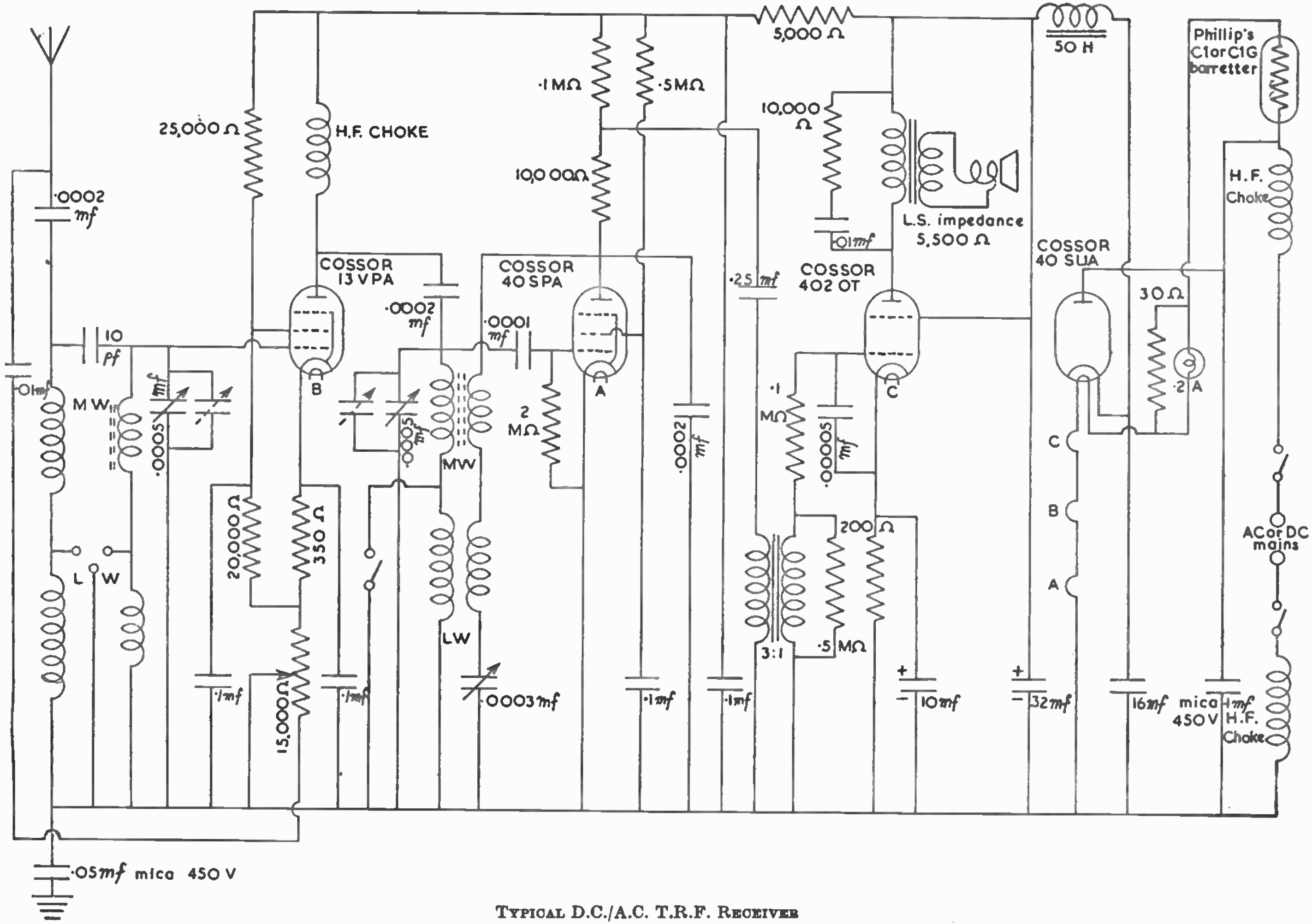
Q.P.P. Superhet Battery Receiver

A modification of the Q.P.P. receiver illustrated in Chapter 5, Volume II, but with typical values shown. Coils covering any desired number of wavebands can, of course, be used, and their selection will determine the values of the pre-set trimming and padding condensers. Should a frequency changer or I.F. amplifying valve be used of a type which passes grid current at zero grid volts, the lower end of the A.V.C. diode load resistance should be disconnected from L.T. – and connected to a point on the main bias resistance, which is just sufficiently negative to prevent the flow of grid current.



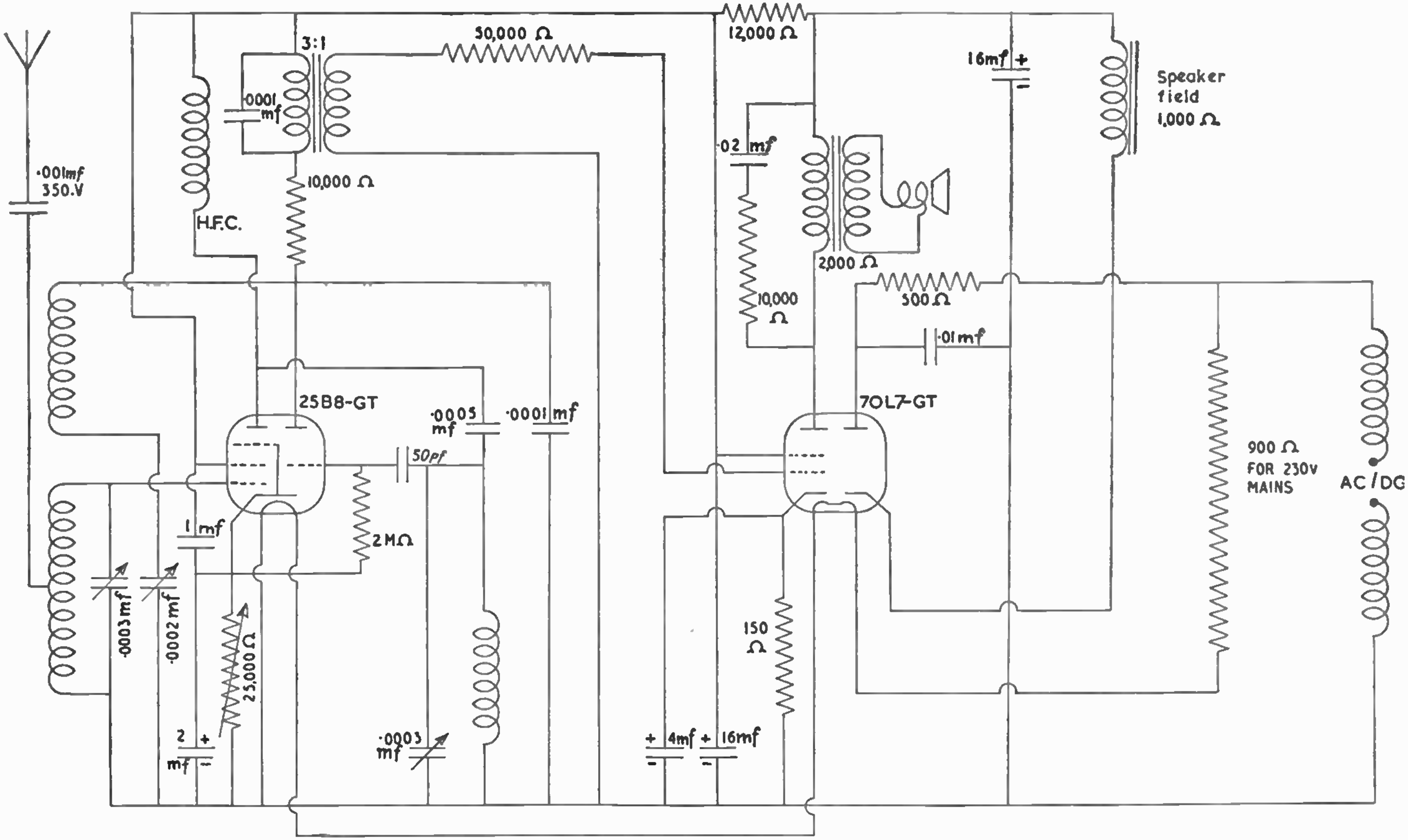
A Typical Wideband F.M. Receiver

This simple F.M. receiver is intended to be used with the output and power pack unit shown on page 21, which will need to be modified in the following way: Terminal 4, C44 and R36 are deleted and the points formerly bridged by R36 joined together; the value of R37 becomes 1,000 ohms. The H.F. and oscillator coils and the I.F. and discriminator coils will normally be part of a complete set designed for the waveband or bands to be covered; no value is shown for the condenser marked * as it will normally be an integral part of the discriminator coil assembly. The type of discriminator used has been selected because it is possible to align it with limited test equipment, otherwise the ratio detector on phase detector would be preferred.



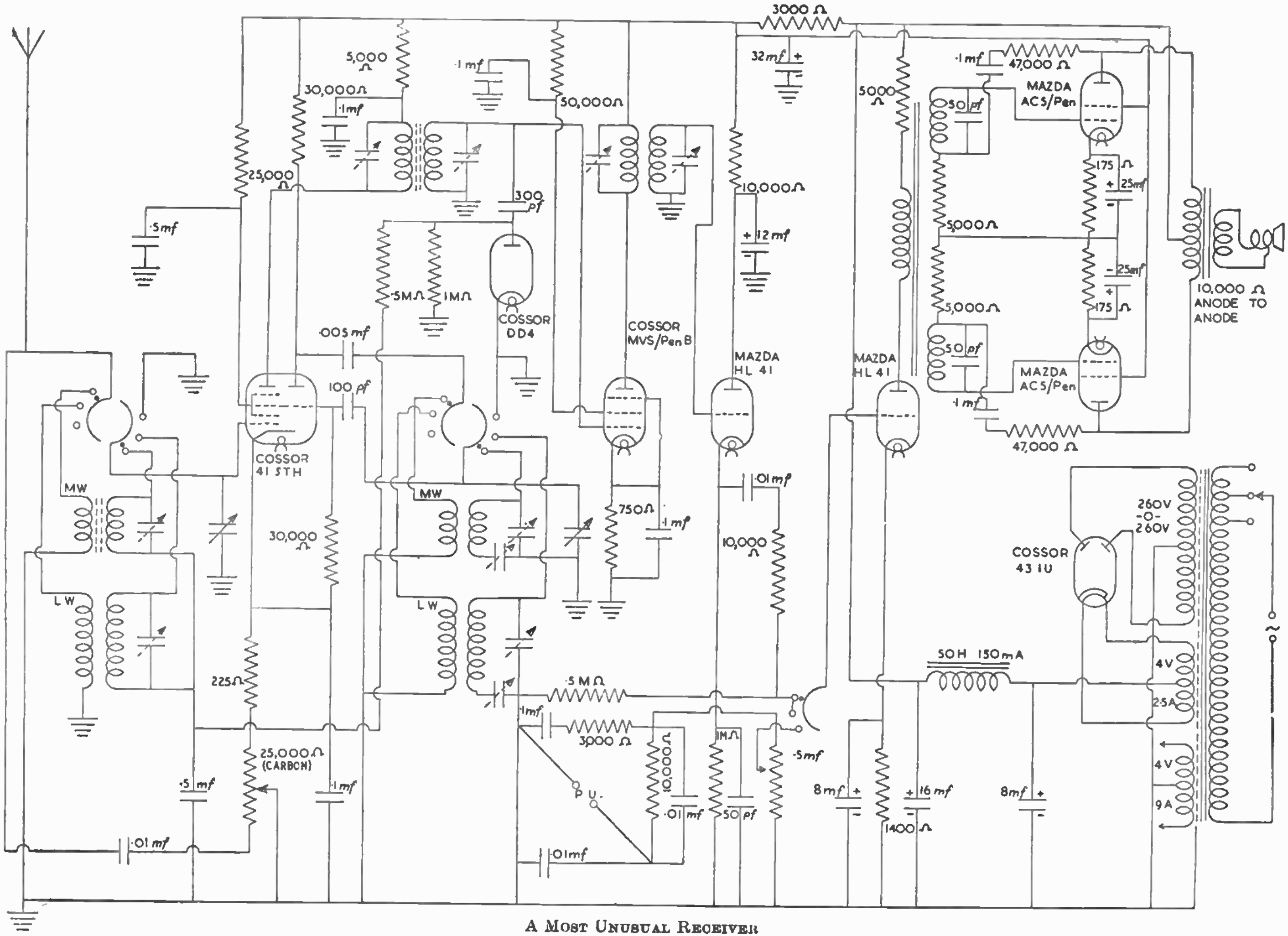
Typical D.C./A.C. T.R.F. Receiver

This circuit is generally similar to the D.C./A.C. circuit in Chapter 5, Volume II, but values are shown and some modifications have been introduced. Variable negative feed-back could be introduced by using a potentiometer for the resistance across the L.F. transformer secondary, the slider being connected through a 1 mf-condenser to the output anode.



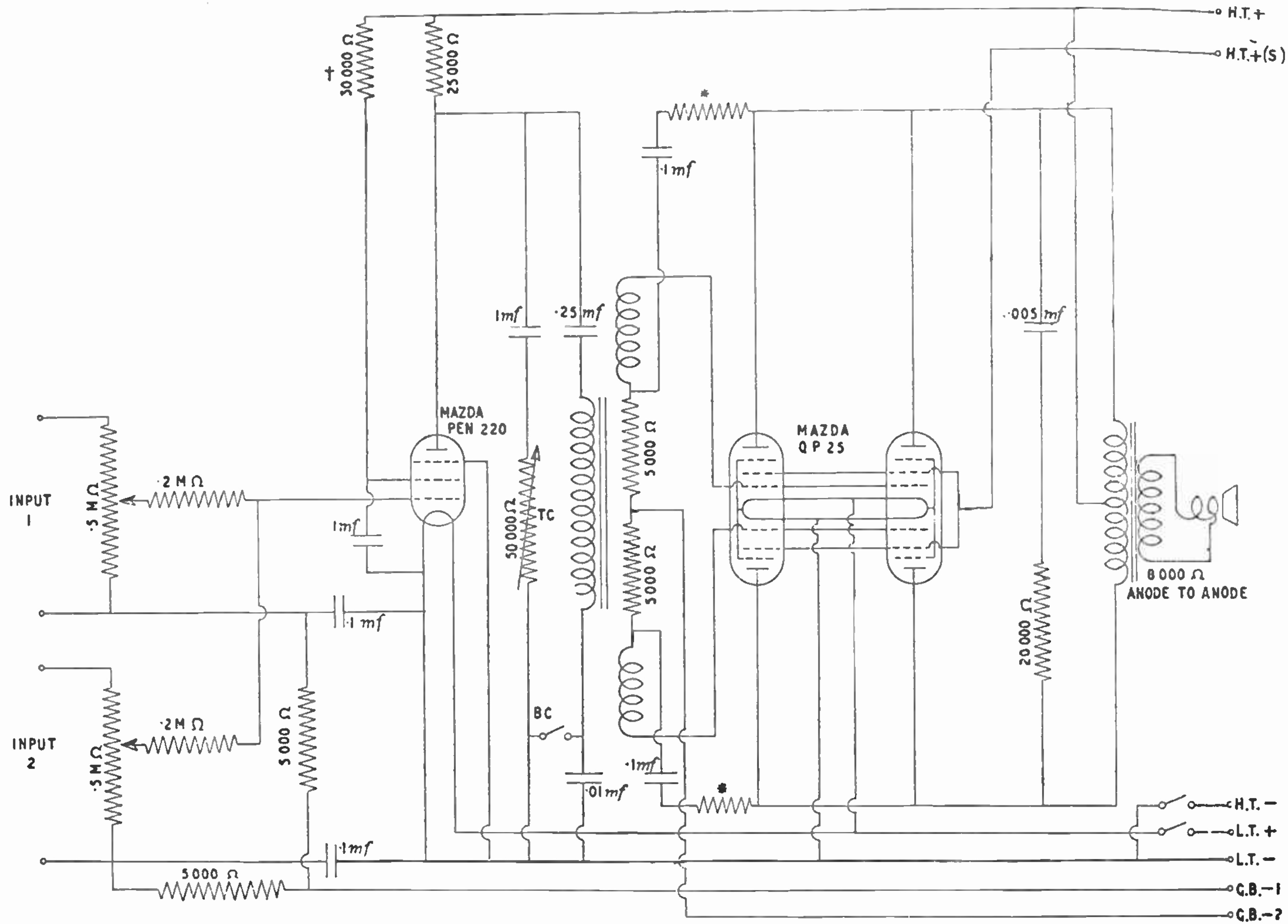
Typical T.R.F. Midget Receiver

This circuit is typical of many of the cheaper midget receivers manufactured in the U.S.A., and although fundamentally a 3 + 1 valve receiver, only two valves, are used, which are only $1\frac{1}{16}$ inches diameter and $3\frac{1}{16}$ inches long, including pins, making possible with the use of midget components a receiver of exceedingly small dimensions. The rectifier anode dropping resistance (500 Ω) assumes a L.S. transformer primary resistance of 350 ; these considerations are important as the 70L7–GT has a maximum anode voltage of 117 volts and the 25B8–GT has a maximum anode voltage of 100 volts.



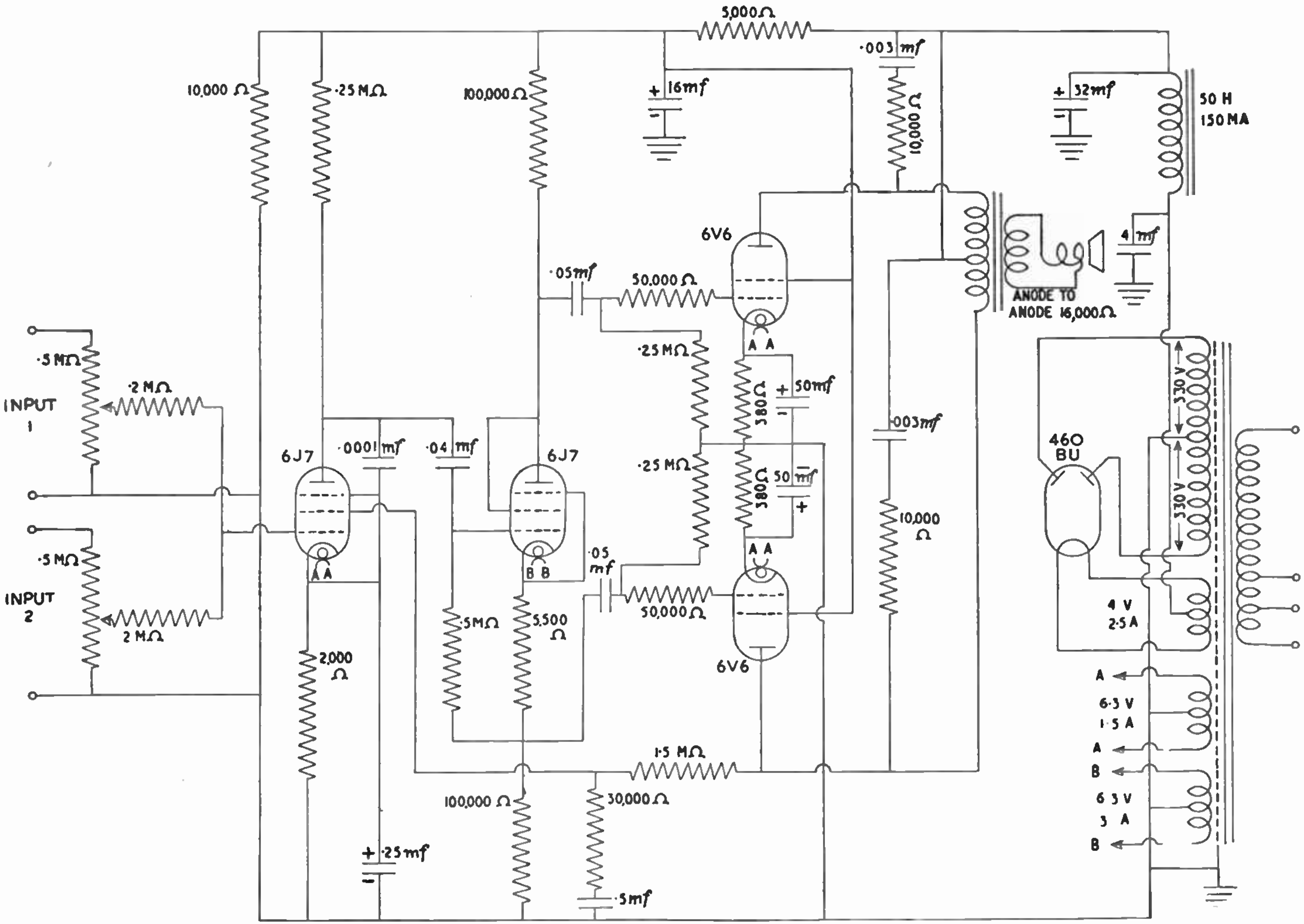
A Most Unusual Receiver

Circuits presented in a book of this character are necessarily orthodox, and this circuit is introduced as a measure of relief and to illustrate that good results can be obtained in more ways than one. The circuit was found by the author in use in a recreation room, where it gave really excellent quality on more or less local stations. The circuit arrangement is probably the result of a series of modifications carried out without regard to the circuit as a whole.



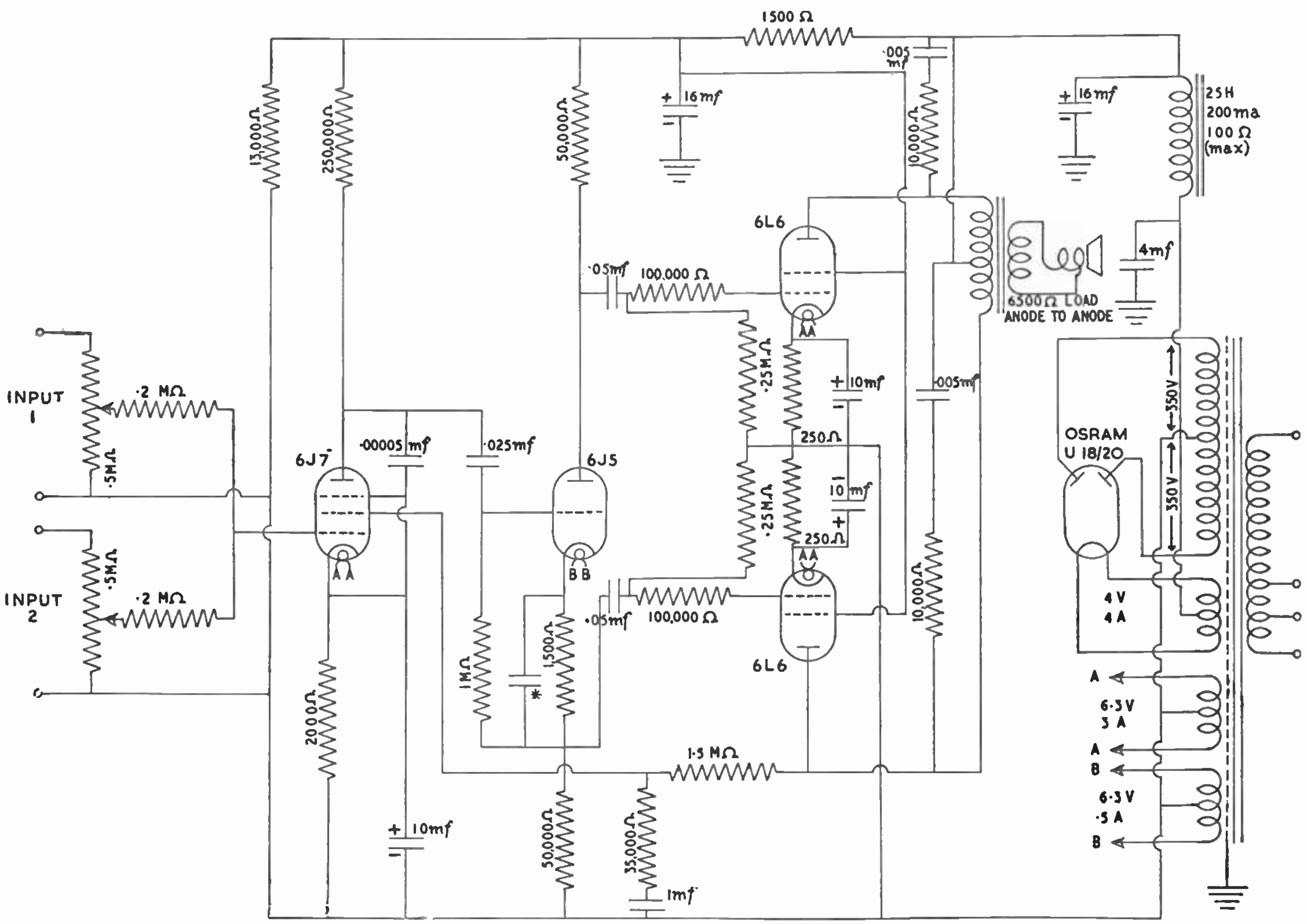
2½-WATT Q.P.P. BATTERY AMPLIFIER

A 2½-watt battery amplifier with a simple two-input mixer. The resistance marked † will normally require selection to ensure that the first amplifier works under optimum conditions. The negative feed-back resistances marked * are best determined by trial, 100,000 ohms being a convenient starting-point. A variable top cut control and a fixed bass cut device are fitted.



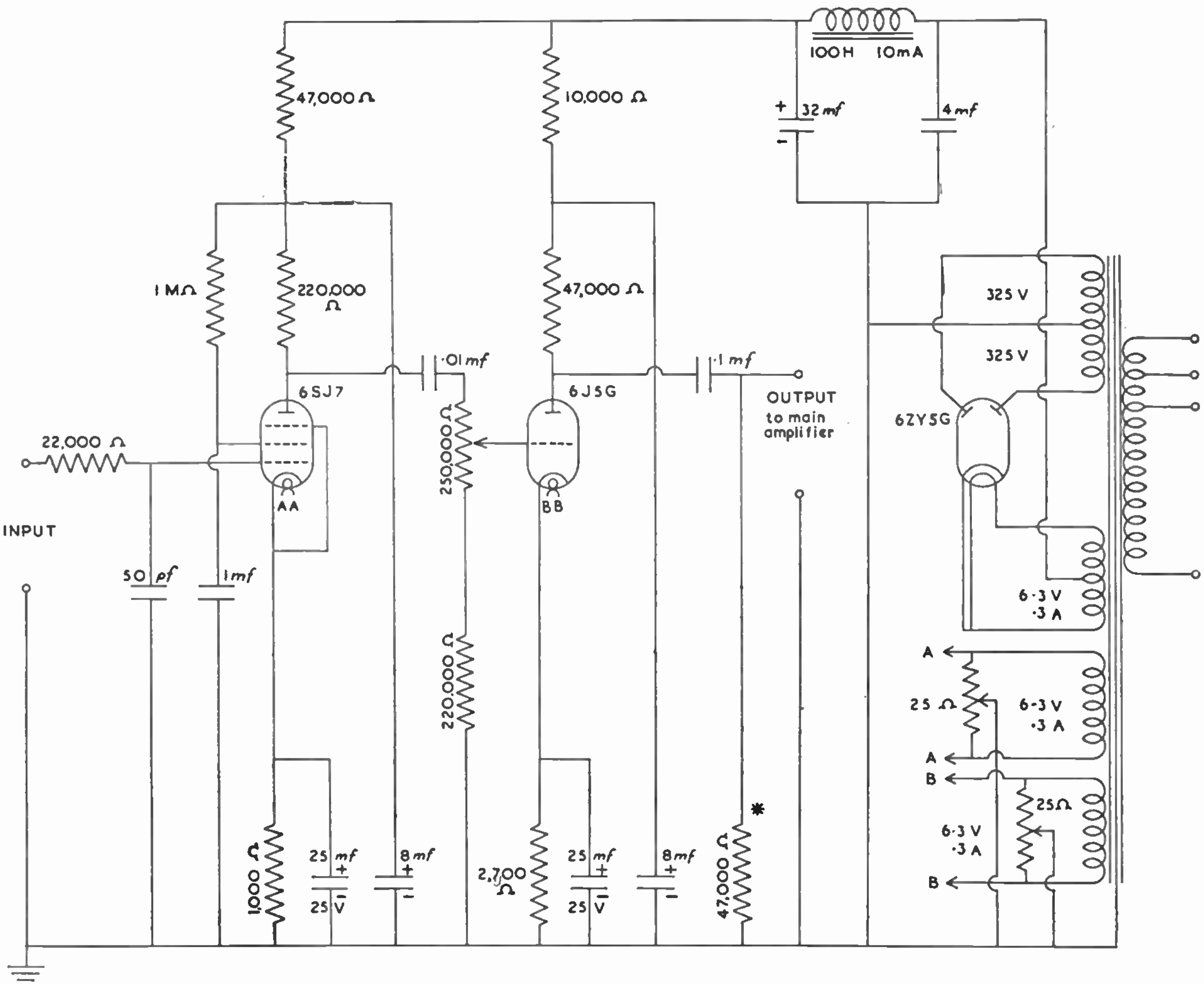
10-WATT A.C. MAINS AMPLIFIER

A conventional 10-watt amplifier employing negative feed-back over all stages. When using this form of negative feed-back it is essential that the two halves of the L.S. transformer primary are tightly coupled. Tone control is omitted as most users will prefer separate tone controls associated with each input



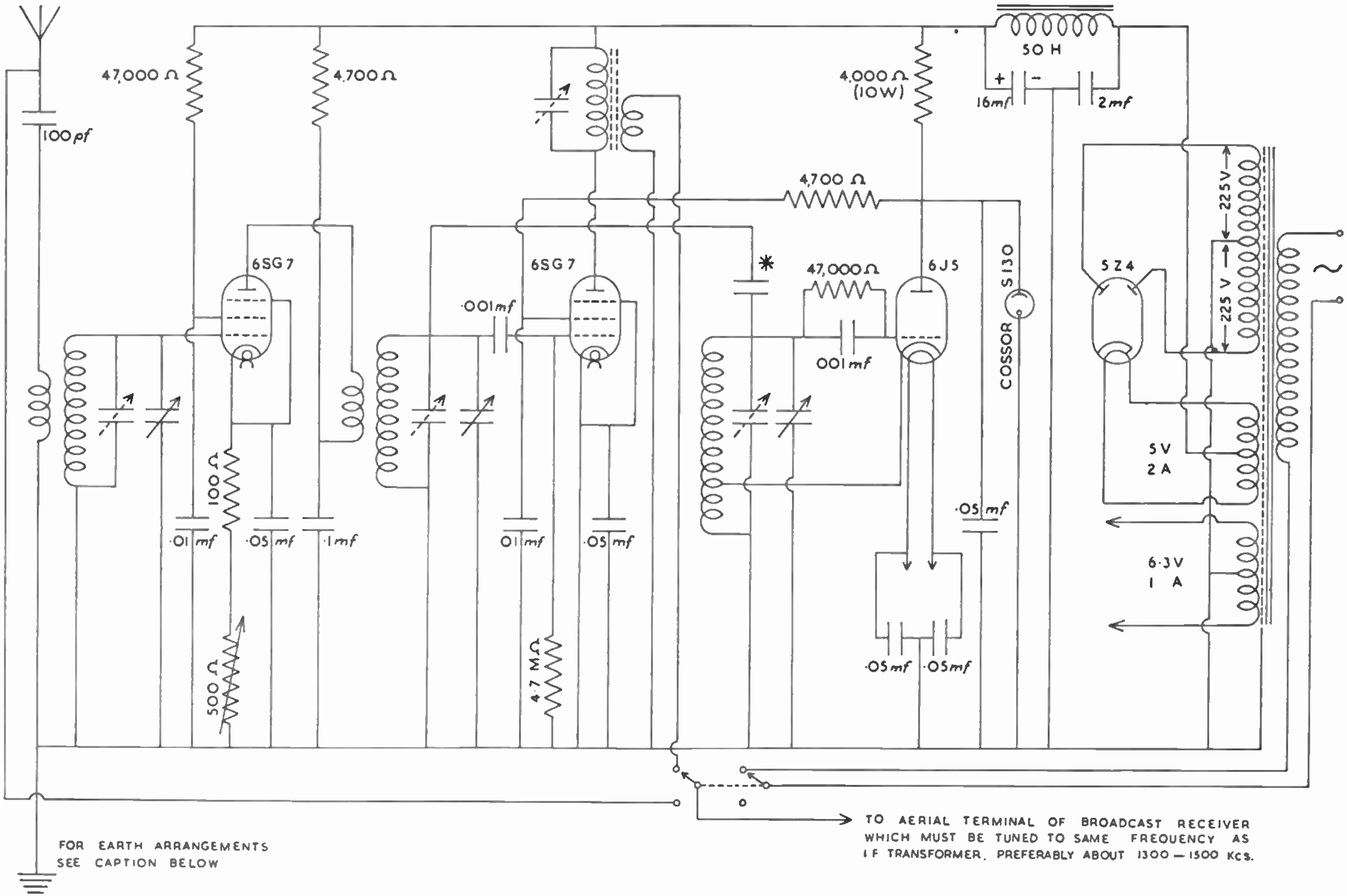
20-watt Amplifier

An amplifier similar to that shown on page 28, but having an output of 20 watts. The condenser marked with an asterisk was found to have a marked effect on stability in the original amplifier, the value being 10 pf. When using this sort of negative feed lock it is essential that the two halves of the L.S transformer primary are tightly coupled.



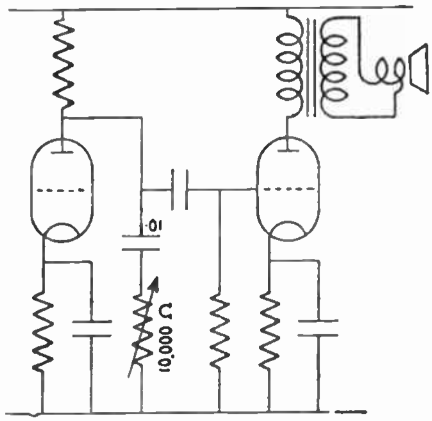
An A.C. Mains Preamplifier

A typical preamplifier for use with crystal or other low output microphones, with certain types it will be necessary to connect the appropriate resistive load across the input terminals; in any case a D.C. path must be provided for the grid of the first valve. Resistance marked * should be omitted when the main amplifier already has a D.C. connection to the grid of its first valve.

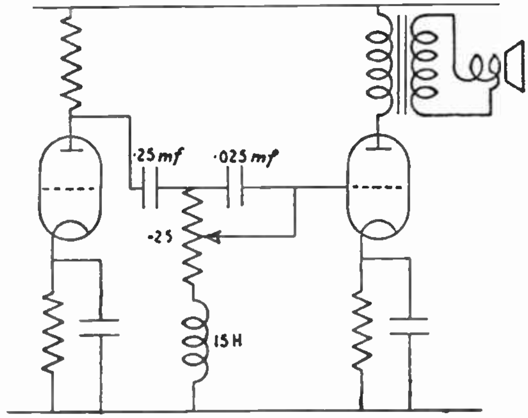


Shortwave Converter for A.C. Mains

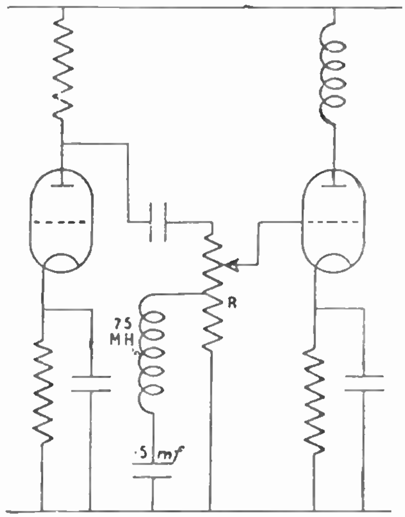
A particularly efficient shortwave converter with H.F. amplifier. The aerial coil and H.F. transformer can conveniently be ganged and the oscillator coil separately tuned or the three may be ganged together, in which case padding condensers can be introduced in the oscillator coil or coils. The condenser marked * may take the form of two wires twisted together or a small pre-set, and should be the subject of experiment to obtain maximum results. If the earth lead of the main receiver is short, earth the unit separately; if not, join the two earth terminals together and use a common earth lead. The I.F. transformer should preferably be about 1,300–1,500 kcs. and should have about two-thirds of the secondary removed.

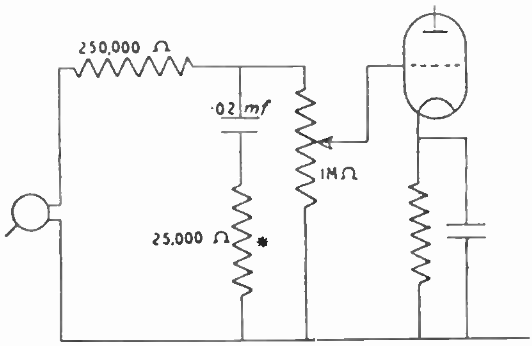


The conventional variable tone-control circuit for cutting the higher frequencies.



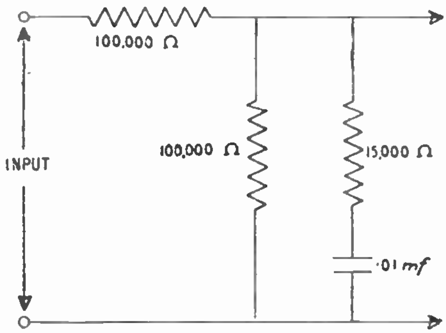
A variable tone-control circuit for cutting the lower frequencies.



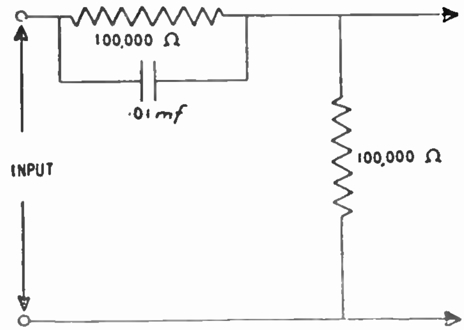


(Above) Bass boosting circuit suitable for use with an average magnetic pick-up. Resistance marked * may be variable, in which case it may be 50,000 Ω.

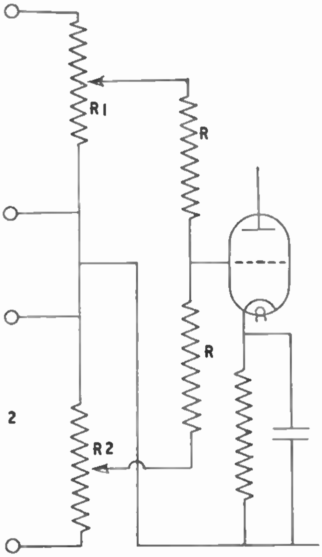
(Left) Compensated volume control avoiding the apparent serious change in frequency response when volume is varied. R should be 30,000 Ω, the upper portion being 24,000 Ω and the lower 6,000 Ω.

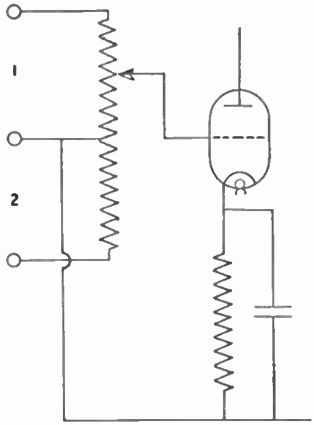


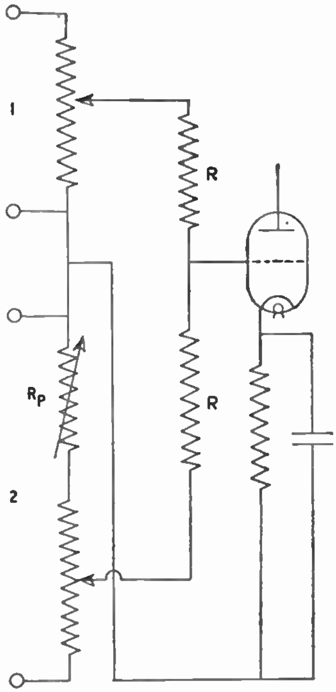
A filter giving a rapid decline in response from 50 to 1,000 cycles followed by a sensibly flat characteristic; useful when really heavy bass response is desired.



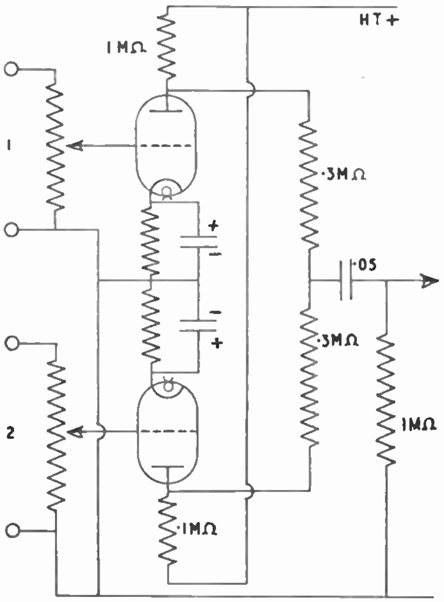
A filter giving sensibly level response up to 100 cycles followed by a rapid increase between 100 and 1,000 cycles, after which the increase tends to become progressively more gradual. Useful for boosting the middle frequencies and increasing the intelligibility of speech.



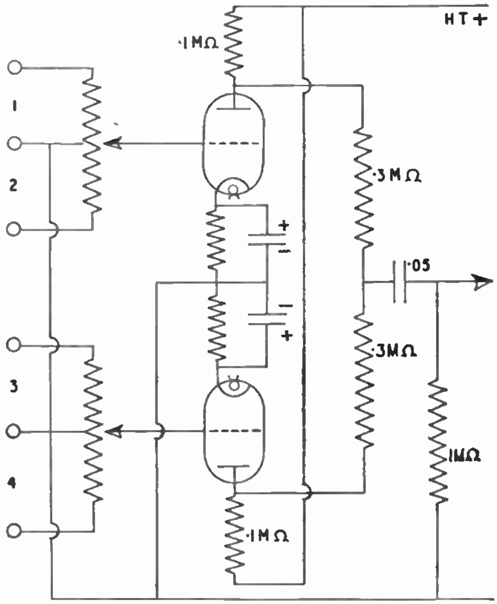




(Left) A mixing circuit which although simple has the disadvantage that adjustment of one input affects the other input. This is minimised by the resistances R, which should be twice the value of the variable resistances. (Centre) A simple fader circuit using a tapped volume control. (Right) A modified mixing circuit which includes a variable resistance Rp, allowing a pre-set limit to be imposed on input 2.

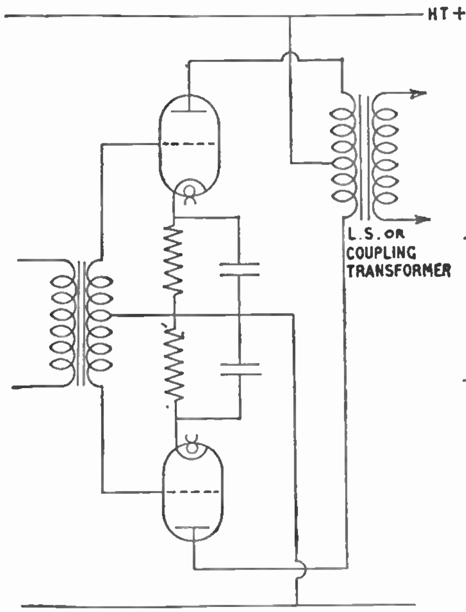


A twin-valve mixing circuit giving completely independent adjustment of both inputs. Values shown are suggested for a fairly high impedance triode.

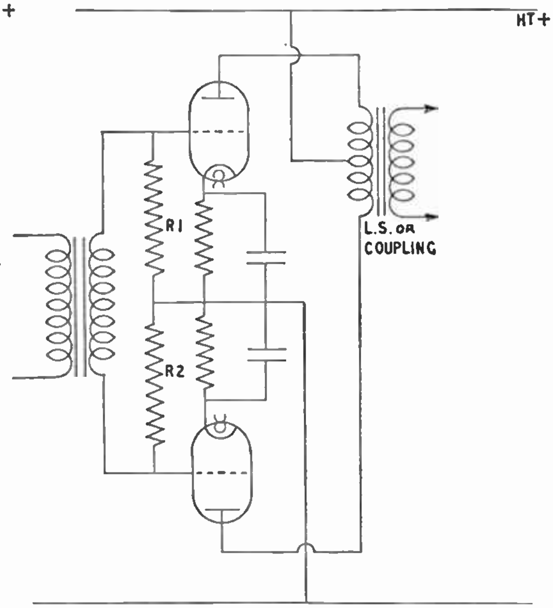


A similar arrangement to that shown (left), but giving combined fading and mixing for two pairs of inputs.

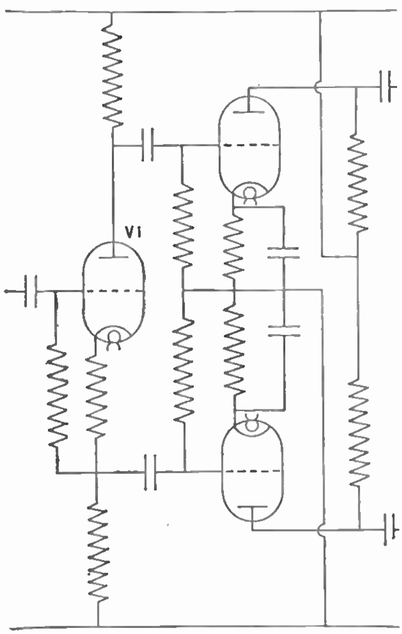
MIXING AND FADER CIRCUITS



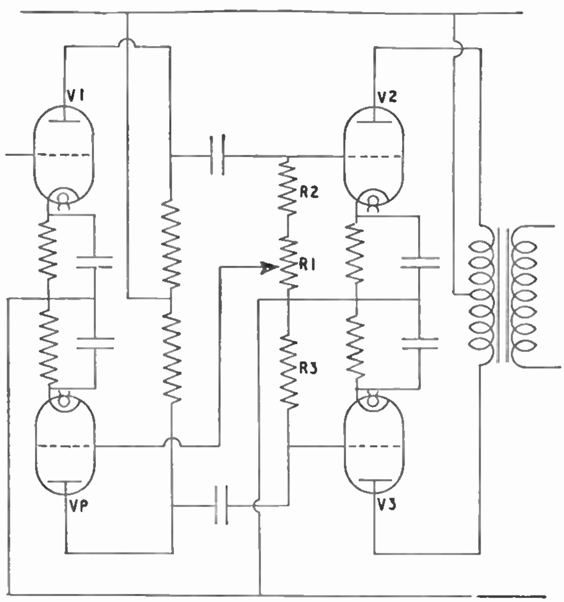
The simplest method of phase splitting, using an input transformer with centre-tapped secondary. Separate bias resistances are shown, but a common bias resistance can be used if desired.



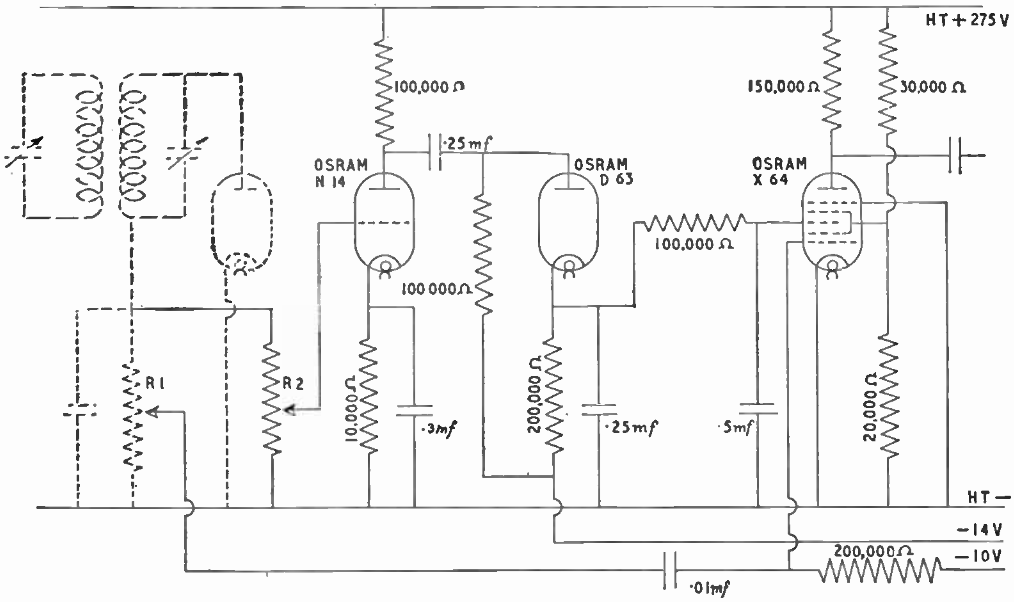
A variation of the circuit (left) sometimes advocated when a centre-tapped transformer is not available; it is a bad arrangement, since the value of R1 + R2 divided by the square of the transformer ratio appears as a reflected load in the anode circuit of the preceding valve.



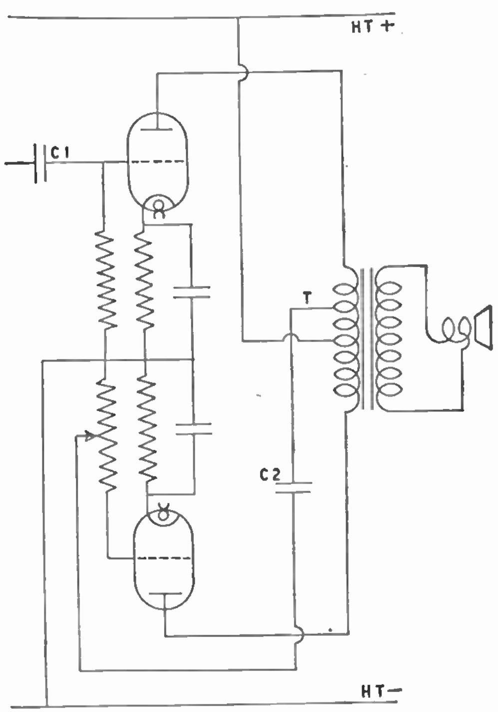
Probably the most popular phase-splitting arrangement; the anode load of V1 is halved, one half being placed between anode and H.T. +, the other between cathode and H.T. −.

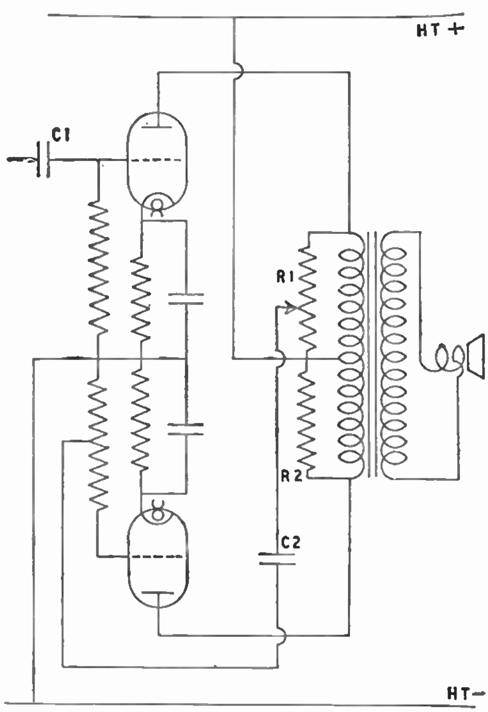


A very useful phase-splitting arrangement which offers a simple means of achieving balance. R1 + R2 should equal R3, R1 being just large enough to give the required input to the paraphase valve Vp. This valve makes no contribution to the stage gain of the amplifier.

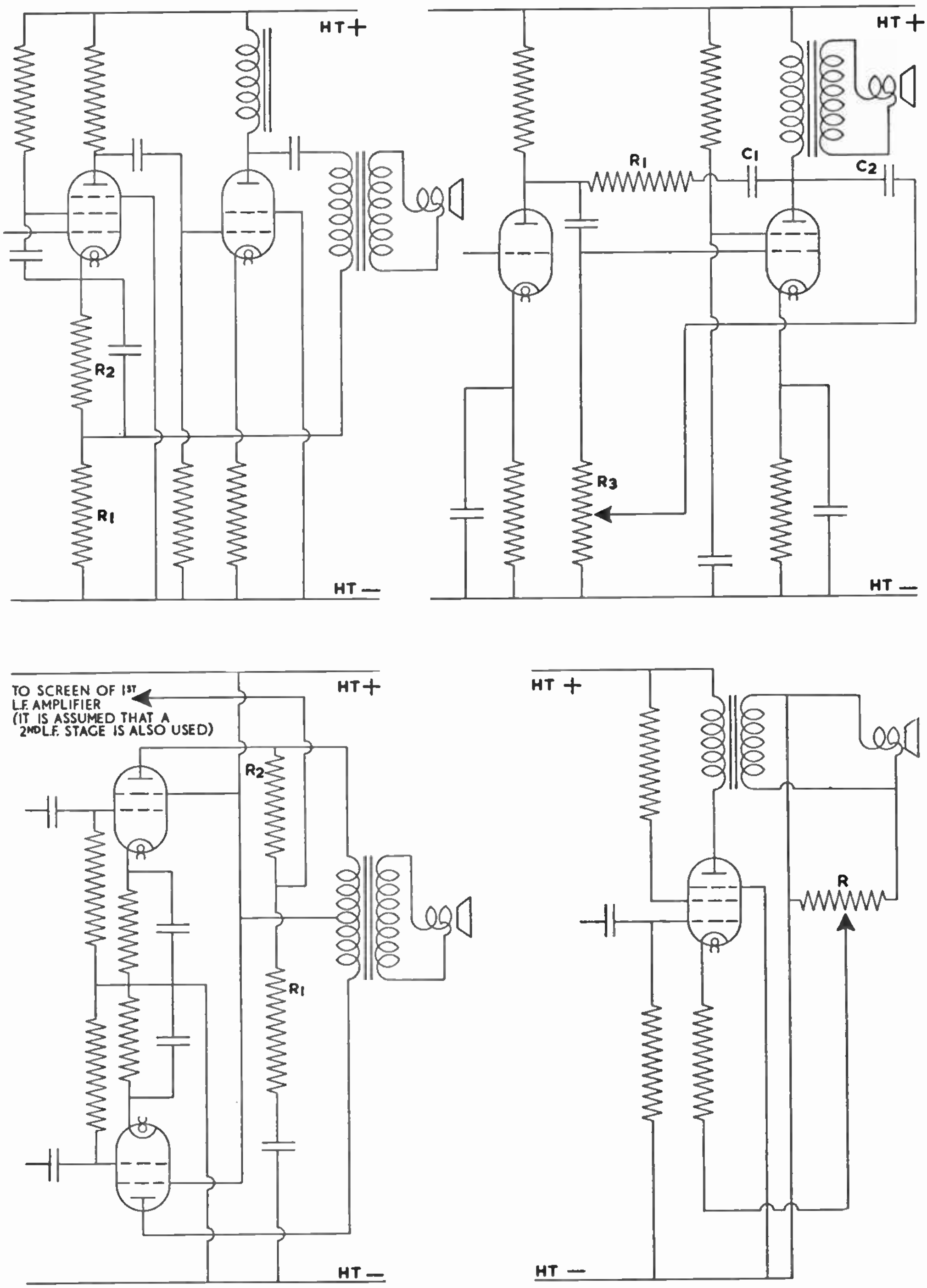


A typical volume expansion circuit, the shaded portion represents a norma diode detector. Considerable difficulty is usually experienced in getting volume expansion to function correctly, and some experiment is invariably necessary.



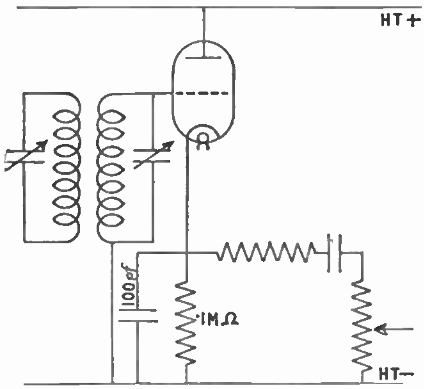


Two-phase splitting arrangements which have serious shortcomings but are very convenient when converting a single output stage to push-pull. The circuit (left) is preferable, but requires a spare tap T on the output transformer primary.The circuit (right) does not require a tap, R1 should be equal in value to R2, and together their resistance should be about ten times the primary impedance. In both circuits C1 is the coupling condenser and C2 the H.T. isolating condenser, and can be about ·1 mf and 1 mf respectively.

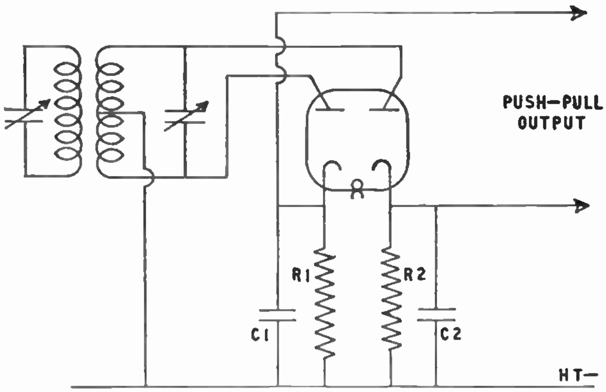


In these typical negative feed-back circuits, where resistances are so marked, feed-back increases as R1 increases in relation to R2. In the circuit (top left) R1 + R2 must equal the correct bias resistance value for the valve. R in the arrangement (bottom right) should be about five times the speech-coil impedance, which must be reasonably low; if positive instead of negative feed-back is obtained, reverse connections between speech coil and resistance R. In the circuit (top right) R1, C1 are the main negative feed-back components and C2, R3 provide negative feed-back top cut.

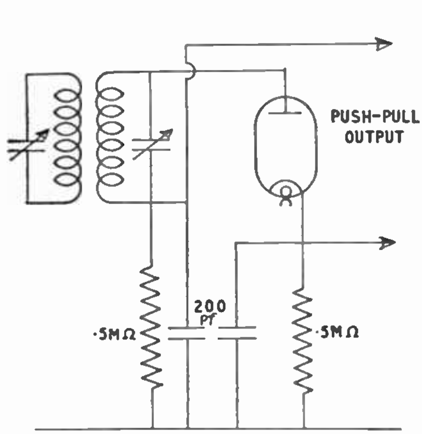
Typical Negative Feed-back Circuits



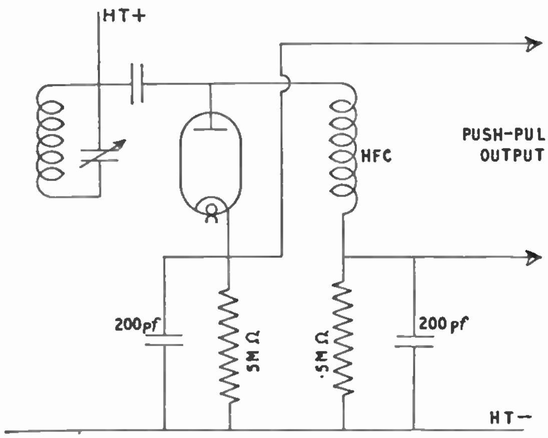
The infinite impedance detector. The volume control is usually about ·5 megohm; the unmarked resistance is intended as a filter and is usually about 10,000 ohms; a suitable value for the blocking condenser is ·1 mf.



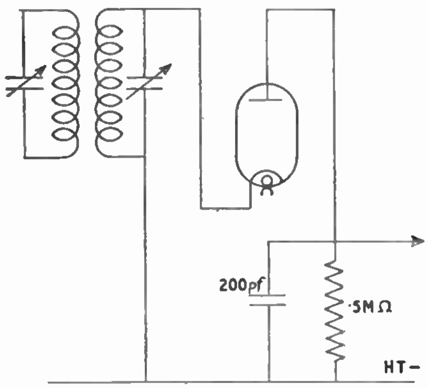
A double diode detector arranged to deliver a balanced output, for feeding a push-pull amplifier. R1, C1 and R2, C2 form the diode loads and may be of conventional values.



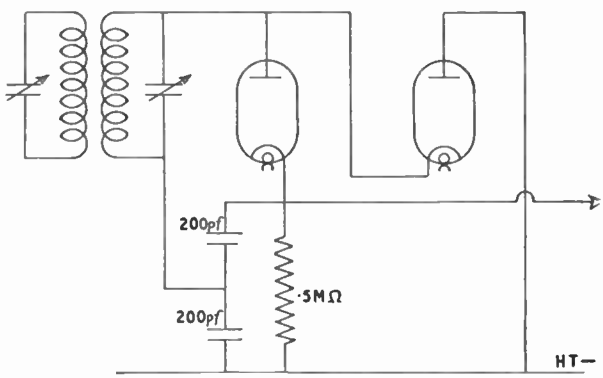
A single diode arranged to deliver a balanced output. It is, however, difficult to reduce mains hum to acceptable limits when using valves of normal construction.



An unusual arrangement giving a balanced output from a single diode for use when the tuned circuit must be isolated in so far as D.C. potential is concerned.

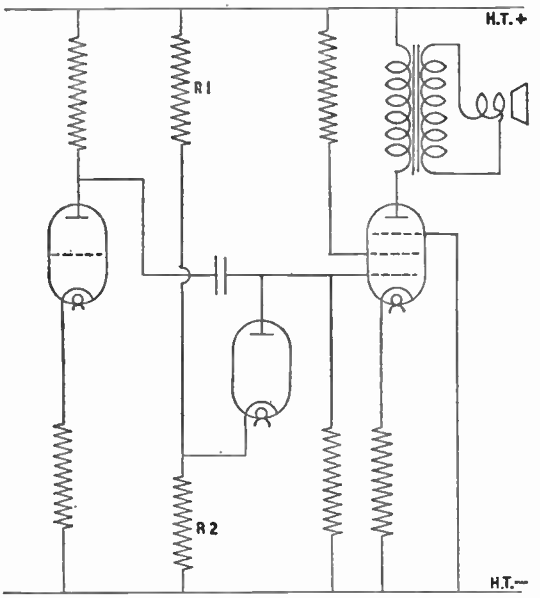


A diode detector so arranged that H.F. is virtually absent across the diode load.

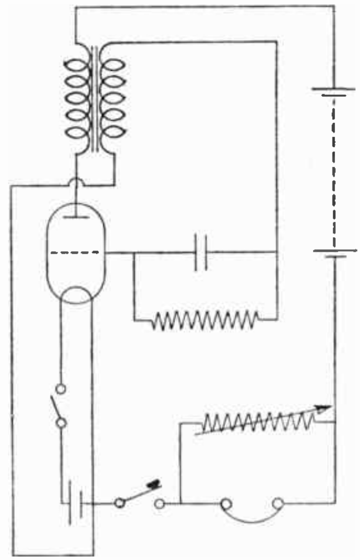


Two diodes arranged for voltage doubling which is sometimes useful in control circuits of various kinds.

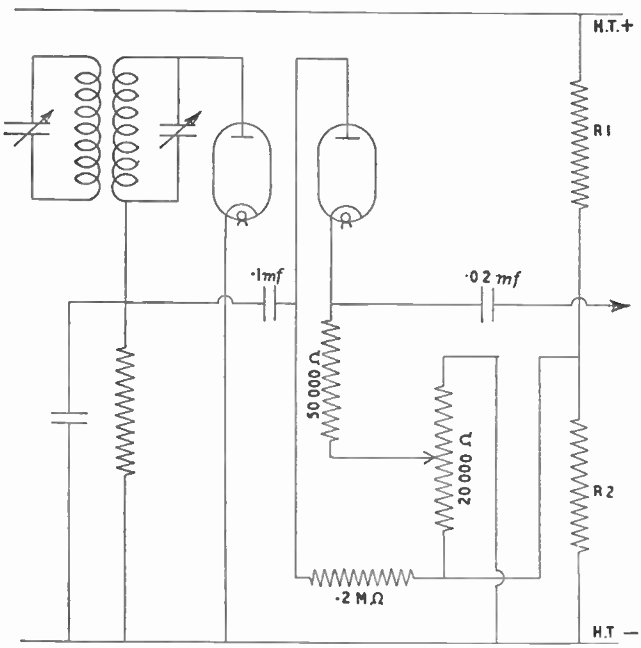
Infinite Impedance and Diode Detector Circuits

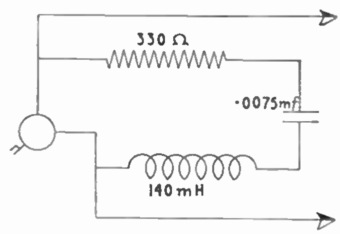


A simple noise-limiter circuit which will mitigate the effect of noise of short duration, the amplitude of which is greater than that of the desired signal. As R2 is increased in respect to R1, the voltage at which the diode commences to cut is increased.



A simple oscillator suitable for Morse-code practice. With the average triode, 12–20 volts H.T. is usually sufficient. Suggested values for grid leak and condenser are ·25 megohm and ·01 mf.

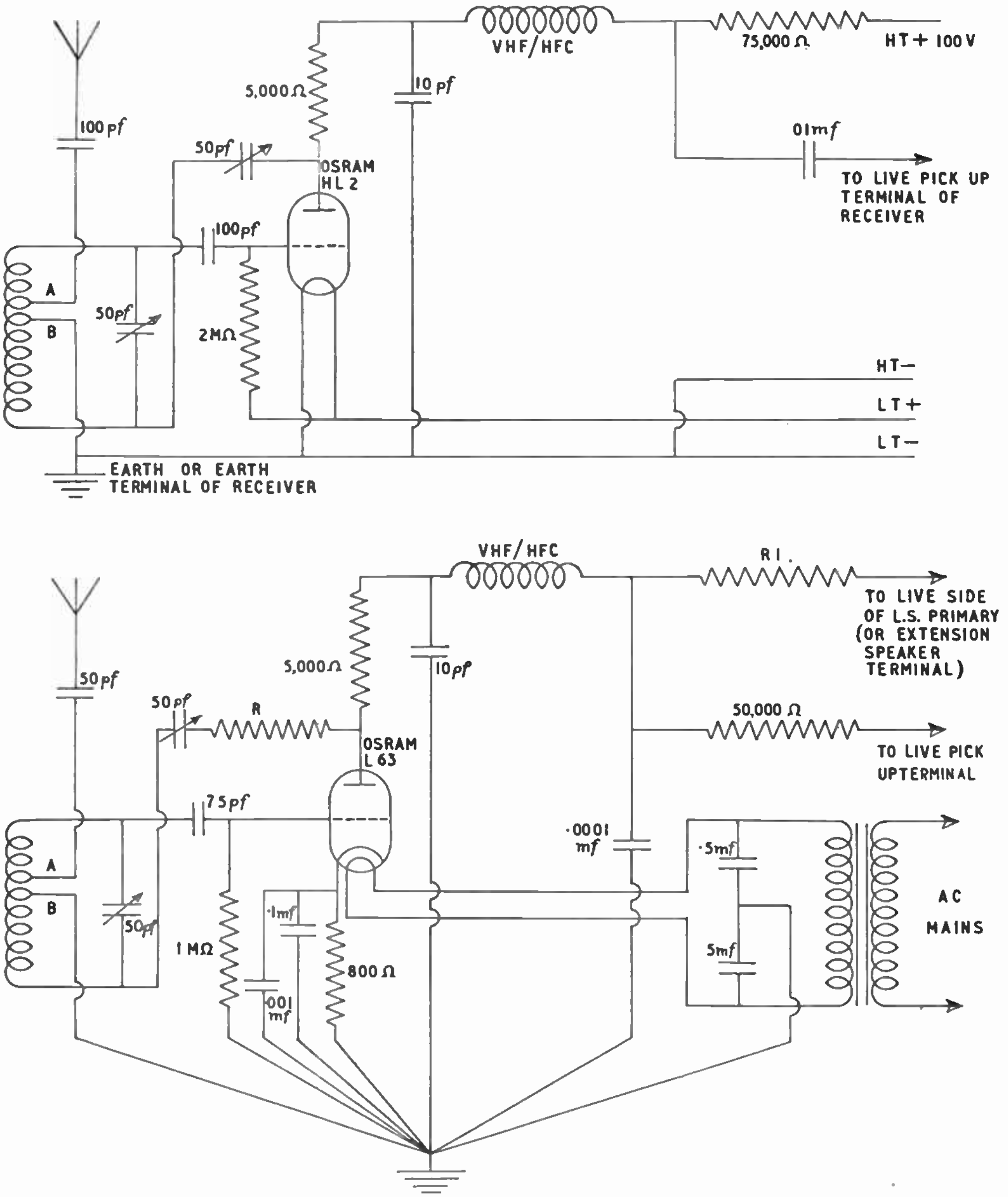




(Above) A tuned scratch filter suitable for use with the average magnetic pick-up. The resistance should have a value of 330 ohms *including* the D.C. resistance of the actual pick-up. If necessary, the condenser value shown can be obtained by connecting the following values in parallel : ·005 mf + ·002 mf + ·0005 mf.

(Left) An improved form of noise limiter, immediately following the detector. The variable resistance controls the amplitude at which limiting commences; R1 can have a value of 100,000 ohms for each 100 volts of H.T. supply; R2 is selected to give the required control.

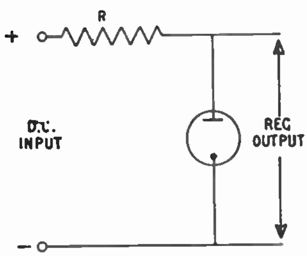
Noise Limiting and Scratch Filter Circuits

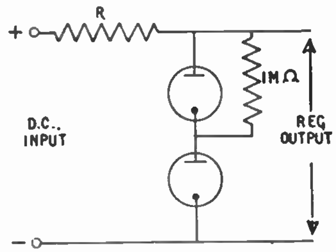


Television Sound Adapters (B.B.C. frequencies)

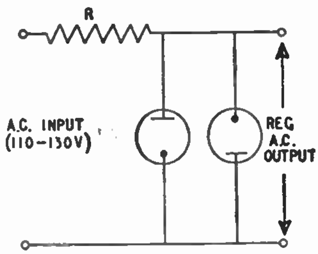
These adapters enable the sound which accompanies television broadcasts to be reproduced on receivers not provided with this facility. The arrangement (top) is for use with a battery receiver, but can also be used with a mains receiver if an accumulator is employed for heating the filament. The coil consists of five turns of 20 S.W.G. wire spaced equal to wire diameter and wound on a ⅜-inch diameter former, which should be removed, leaving the wire self-supporting. The top tap is two turns from the top and the lower tap between a half and one turn lower. These two units were designed to work on the B.B.C. London transmitter and some variation to inductance diameter turns may be necessary for other frequencies.

The A.C. mains version uses the same coil as the battery version and employs a transformer for heater supply; the secondary voltage should be 6·3 volts with the valve shown, or 4 volts if more convenient, when an Osram MHL4 may be employed. R1 should have such a value that the anode voltage is approximately 100; R is intended to smooth reaction, and its value should be found by trial.

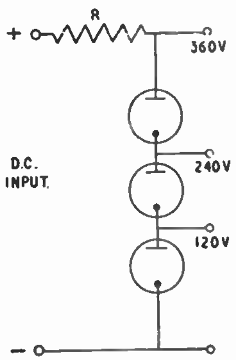




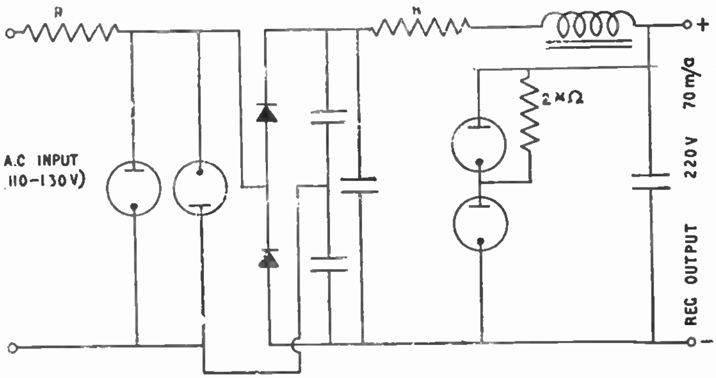
(Left) A simple circuit giving a sensibly constant voltage output irrespective of the current drawn within stated limits. Stabiliser tubes are made by various manufacturers, who publish curves from which the value of R may be determined. The controlled output voltage is usually 120/130 volts. (Right) In this arrangement two tubes are used to double the voltage output.



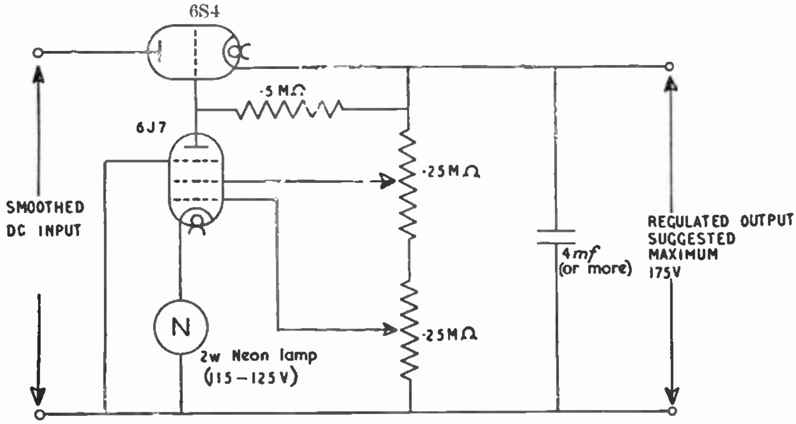
Two voltage stabiliser tubes in opposite sense, arranged to give a regulated A.C. output. The input voltage shown, 110/130 volts, is R.M.S. voltage, not peak voltage.



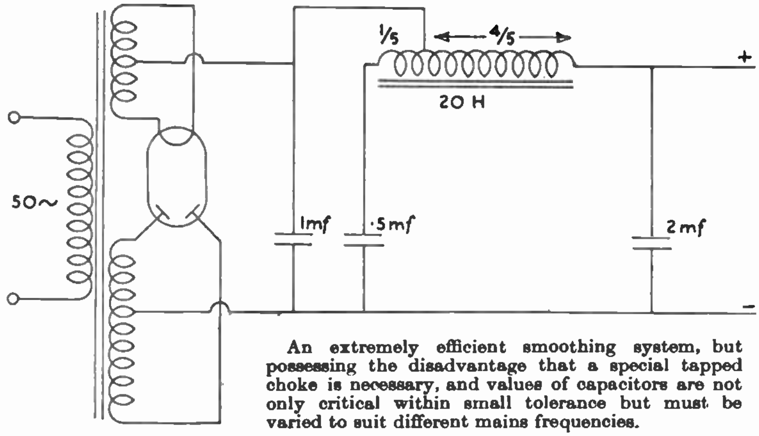
Stabiliser tubes arranged as a voltage divider. This circuit is only suitable where current drawn from the 120-V and 240-V tappings does not exceed about 2mA each.



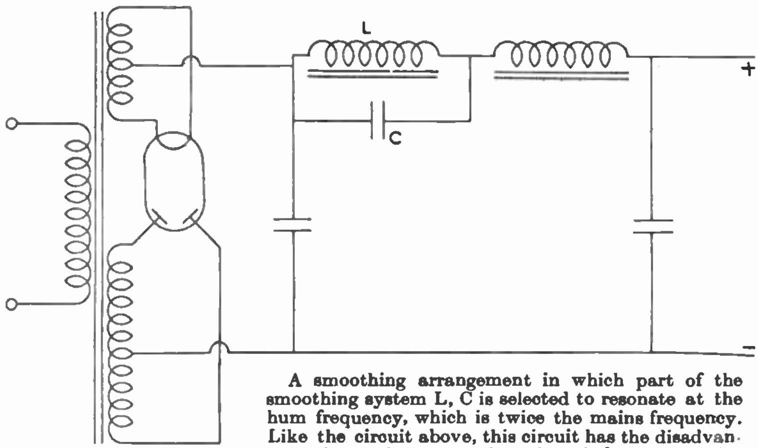
An elaborate arrangement in which voltage regulation is achieved in both A.C. and D.C. portions of the circuit. A voltage doubler is employed to compensate for the relatively low-voltage A.C. input. When the value of R in the D.C. circuit is determined, the D.C. resistance of the choke must be considered to be part of it.



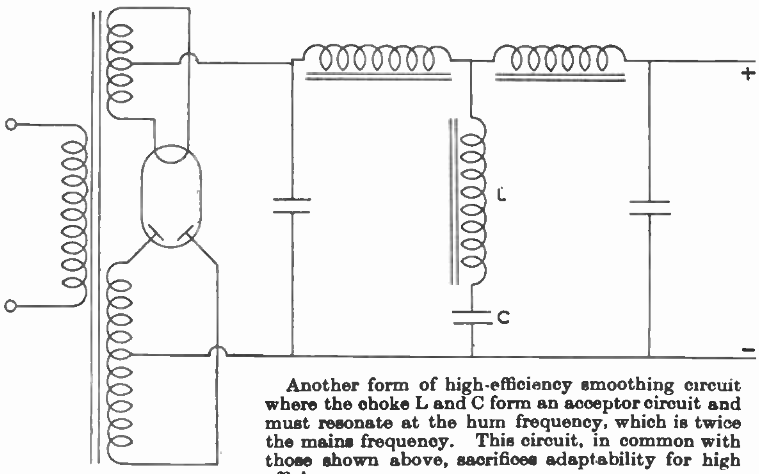
A valve voltage regulator circuit suitable for laboratory use which gives a remarkably constant output voltage; the maximum current output is about 25 m.a. but two or more S64 valves may be used in parallel as desired to increase output. In exacting conditions where the output voltage must be independenof ambient temperature, the neon lamp must be replaced by some source of D.C. bias such as the 24-volt accumulator.



An extremely efficient smoothing system, but possessing the disadvantage that a special tapped choke is necessary, and values of capacitors are not only critical within small tolerance but must be varied to suit different mains frequencies.

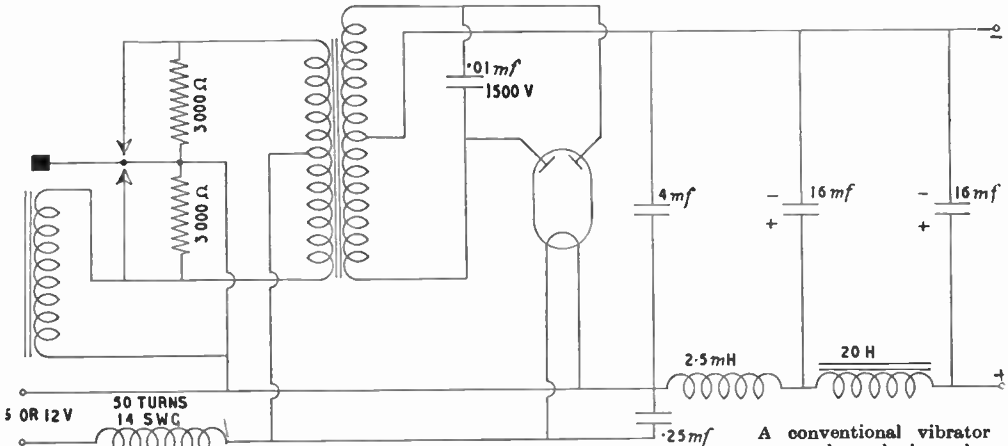


A smoothing arrangement in which part of the smoothing system L, C is selected to resonate at the hum frequency, which is twice the mains frequency. Like the circuit above, this circuit has the disadvantage that values must be selected for a particular mains frequency.

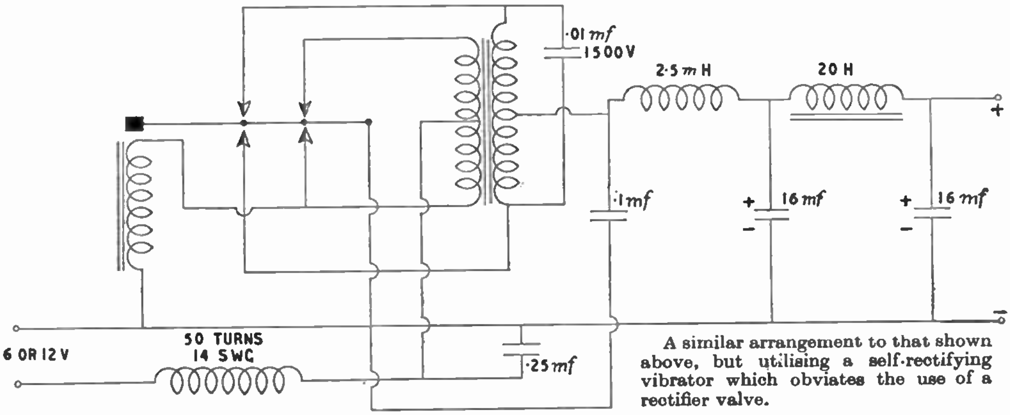


Another form of high-efficiency smoothing circuit where the choke L and C form an acceptor circuit and must resonate at the hum frequency, which is twice the mains frequency. This circuit, in common with those shown above, sacrifices adaptability for high efficiency.

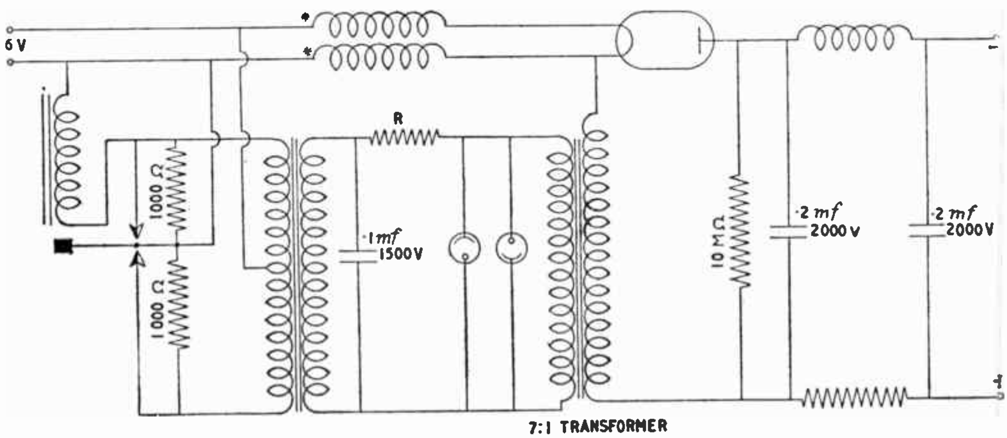
UNUSUAL SMOOTHING CIRCUITS



A conventional vibrator power pack employing valve rectification.



A similar arrangement to that shown above, but utilising a self-rectifying vibrator which obviates the use of a rectifier valve.



An interesting vibrator power pack used by the author for the E.H.T. supply of a portable oscillograph which worked from a 6-volt car battery. The author has used a similar circuit to obtain the E.H.T. supply for a television receiver converted for use on D.C. mains. H.F. chokes marked * should be inter-wound; R should be adjusted so that the neon stabiliser tubes only just glow. The 10MΩ resistance must be made up of several resistances in series, e.g. five resistances of 2MΩ each.

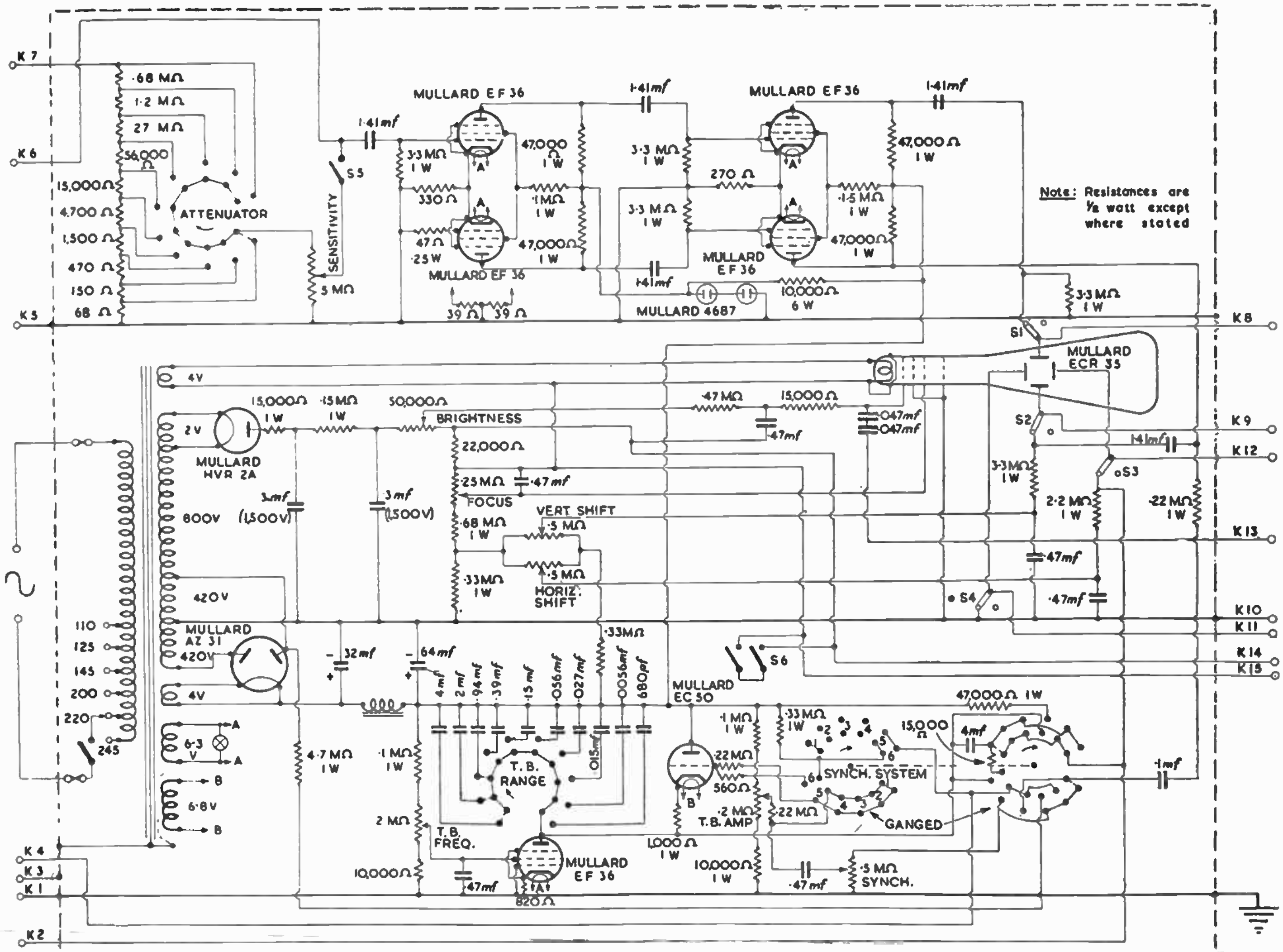
TEST GEAR AND SERVICING EQUIPMENT SECTION

PUBLISHED test gear circuits are very often idealistic in character but presented without component values; this is usually due to the fact that the individual or company responsible for the design feels disinclined to give away the result of weeks or months of patient development. With the exception of the oscilloscope on page 44, which is a laboratory designed commercial instrument, the circuits which form the subject of this section do not pretend to be idealistic, but have the compensating advantage that all component values are given; furthermore, they can be relied upon to function properly, since they are precise copies of miscellaneous pieces of test gear built by the author and used for varying numbers of years with the object of reducing wear and tear on precision laboratory instruments when the use of such accurate instruments is not essential.

Those who contemplate constructing one or more pieces of test gear must realise that a considerable amount of thought and care must be expended if such equipment is to be even moderately accurate. Components must be selected with great care, mechanical construction must be above criticism, while certain instruments such as signal generators and valve voltmeters must be efficiently screened.

Any component which controls or affects the calibration of a piece of test equipment must be a very great improvement upon the type of component used in the construction of the ordinary radio receiver. If this remark applies to any one type of component more than another, it is to the variable condenser, mass-produced examples of which cannot be relied upon to repeat the same capacity to within the required limits each time the moving section is rotated to the same position.

When constructing test gear, it must always be borne in mind that the assembly as a whole must possess sufficient mechanical rigidity to prevent calibration from being affected by normal rough handling or the position in which the equipment rests. In conclusion, let it be said that a piece of inaccurate or unreliable test gear is a most dangerous thing to have on the service bench or in the laboratory, and one of the greatest potential sources of wasted time, patience, and energy.



A Practical Oscilloscope

(See page 45 for description)

A Practical Oscilloscope

The circuit diagram on the facing page shows a typical oscilloscope, the Mullard E800, which is included as representative of present-day oscillograph practice. It is neither economical nor practicable to attempt the individual construction of such a comprehensive instrument, but by careful study the various functions can be dissected and the relative parts of the circuit used to form the basis of any workshop instrument that may be contemplated, or as a hookup with an existing oscilloscope that lacks some desired facility. Voltages of the order of 1,500 volts are normal with instruments of this type, and in the case of the example illustrated, two external sockets, K14 and K15, are at a potential of 1,250 volts with respect to earth.

Brief characteristics are: Time-base frequency range ·25—16,000 cps. Vertical deflection sensitivity 7V, A.C. (R.M.S.) per cm. or 21V, D.C. per cm. Horizontal deflection sensitivity 14V, A.C. (R.M.S.) per cm. or 42V, D.C. per cm. The voltage amplifier has a gain of 7,000 approx. with a frequency response from ·1—40,000 cps. flat within 2 db.

The synchronism system switch permits a choice of six systems; positions 1, 2, 3 and 5 use the internal time-base. Position 4 permits the use of an external time-base source, while position 6 is single stroke. Synchronism for positions 1, 2, 3 and 5 is derived as follows: (1) From vertical deflection amplifier. (2) From external source applied between K3, K4. (3) From 50-cycle mains. (5) By means of mechanical contact breaker S6; the gas discharge triode fires at "break."

There are fifteen external connections and four external links, which are intended for use in the following manner and give the facilities implied:

K1, K2. Time-base voltage outlet for external use; available when synchronising system switch is in positions 1, 2, 3, 5 or 6.

K3, K4. Same use as K1, K2, but for use when synchronising system switch is in position 4.

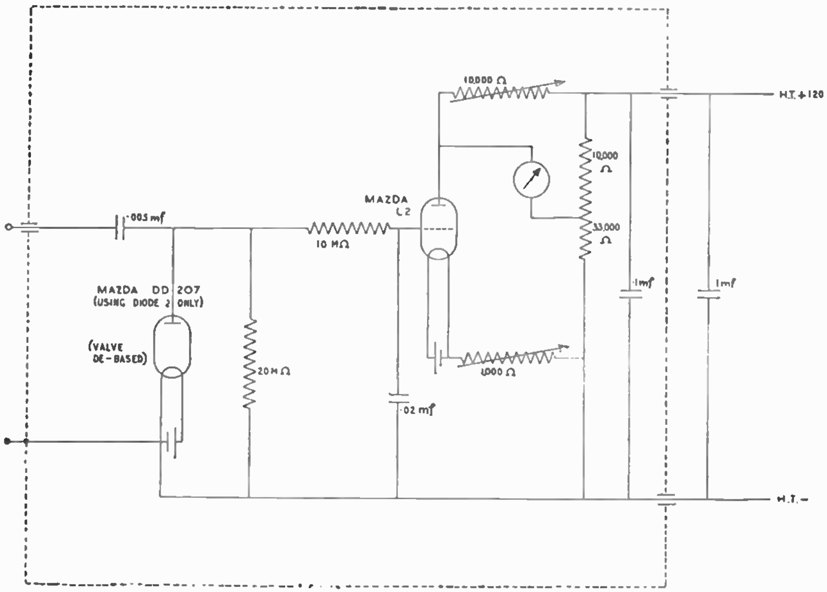
K5, K7. Inlet for voltage to be observed; when S5 is opened for high impedance input, K5 and K6 are used instead of K5 and K7.

K8, K9. Give direct access to vertical deflection plates, which can be freed from internal connection by opening the links S1, S2.

K11, K12. Give direct access to horizontal deflection plates, which can be freed from internal connection by opening the links S3, S4.

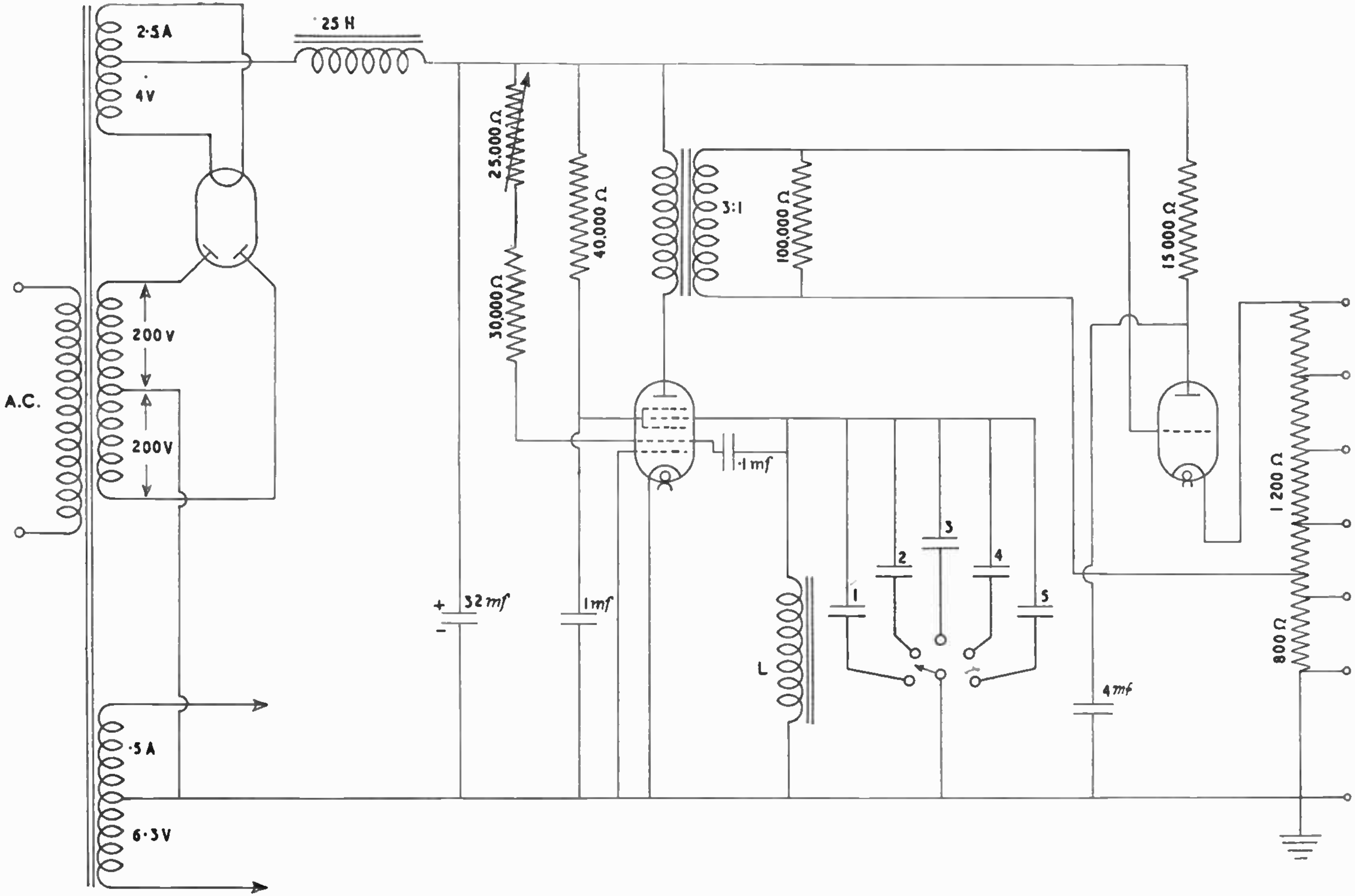
K10, K13. Inlet for grid modulation voltage.

K14, K15. Are for beam suppression by an external source; the beam is suppressed when K14, K15 are short-circuited.



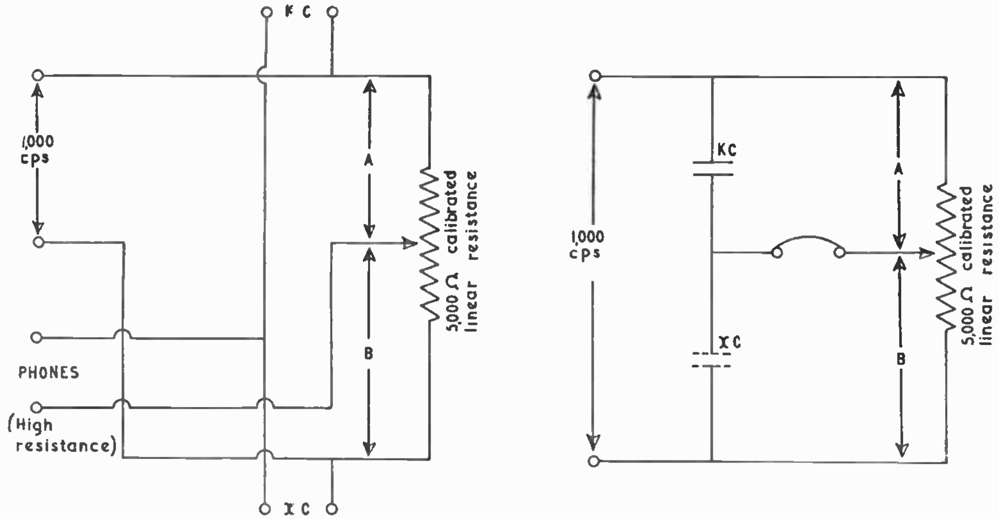
Valve Voltmeter

A simple, but highly efficient diode valve voltmeter with triode amplifier Note that a separate accumulator must be used for each filament and that they must be housed within the screen or in a separate screened compartment without exposed connecting wires. Resistance values shown are satisfactory when using a standard 250-μA meter, which will give full scale deflection with an input of only about 1·5 volts. If properly designed, calibration does not fall off unduly with frequencies up to 50 Mcs. The 10,000-Ω resistance is so adjusted that the meter reads zero after the 1,000-Ω bias resistance has been set so that the triode is working at the beginning of the straight portion of its characteristic. Larger input voltages can be accommodated by shunting the meter, but a limitation is imposed when the input is large enough to overload the triode.



A General-purpose Audio Oscillator

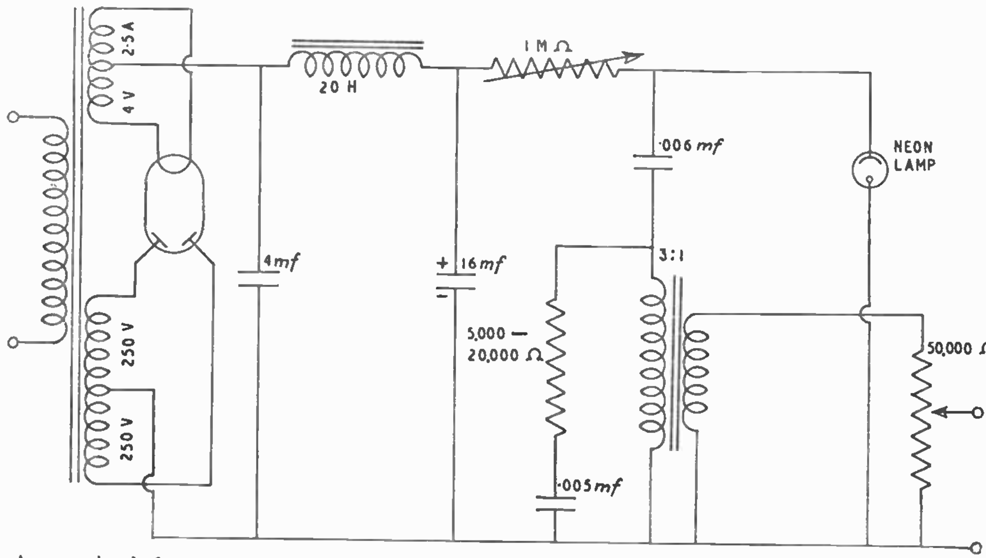
Originally constructed for general purposes, this oscillator has proved very satisfactory. The use of the L.F. transformer is open to criticism, but in practice it is quite satisfactory; an additional lead may be led out from the top end of the secondary if a high impedance output is desired. The L.F. transformer can, of course, be replaced by resistance capacity coupling, but output is thereby reduced. Suitable valves are: Rectifier U14 or UU5, Oscillator 6AB, Triode Output 6J5G. The output frequency is determined by the value of L and the values of the various condensers; for formula see page 52.



A simple capacity bridge, the accuracy of which is dependent on the accuracy of known condensers available and the calibration of a variable resistance which must be non-inductive. The diagram (left) is a practical wiring circuit, that on the right being a schematic arrangement to illustrate the following instructions. To find the capacity of an unknown condenser XC, connect a condenser of probable similar value at KC and adjust resistance until the injected 1,000-cycle note disappears or reaches a definite minimum, when

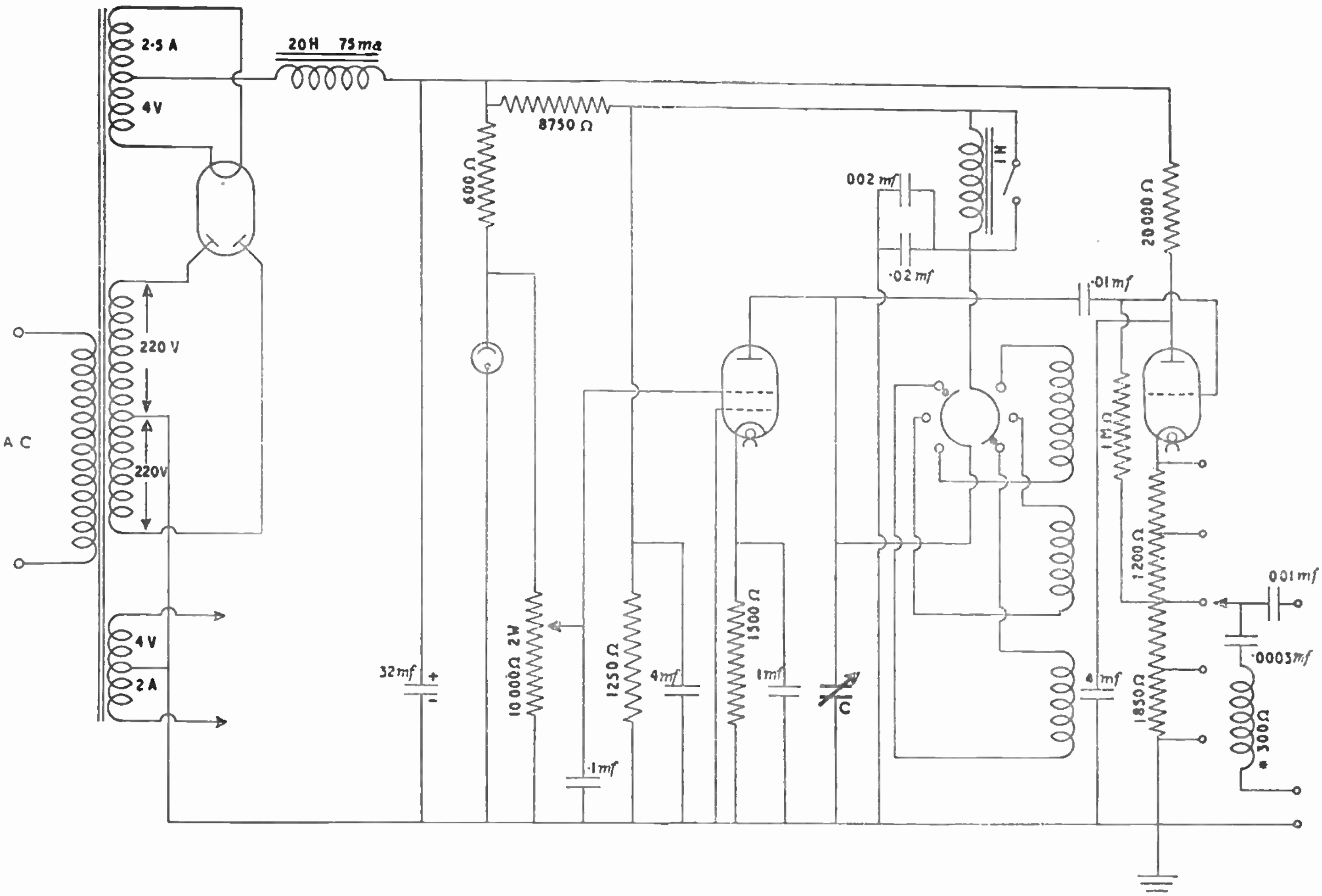
$$XC = \frac{R_A}{R_B} KC$$

when XC equals the unknown, and KC the known capacity and R_A is the portion of the resistance across KC and R_B is the portion across XC. If R_A is greatly dissimilar to R_B, greater accuracy can be obtained by selecting a condenser for KC which gives a better ratio.



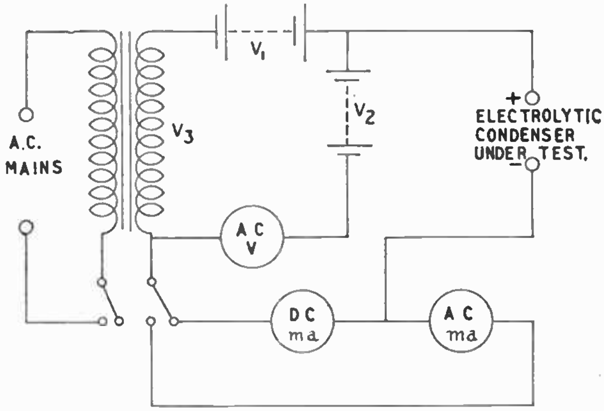
A very simple form of audio oscillator, useful where simplicity and economy are necessary and a bad waveform can be tolerated. An ordinary L.F. transformer is used, but connected to give a step-down ratio to increase output current at the expense of voltage; where higher voltage is desired at the expense of current the transformer can be reversed. A resistance and condenser in series are shunted across the transformer to limit changes of output at different frequencies. The presence of the transformer is not essential; it limits the frequency range and prevents ready calculaton of frequency, but improves the waveform for general purposes. Suitable rectifiers on 43IU, U14 or UU5.

Capacity Bridge and Simple Neon Audio Oscillator



A Dynatron Signal Generator

The signal generator shown above is not proof against criticism, but has the advantages of simplicity and robustness. The variable condenser C must be of impeccable design, and the whole unit must be built into a screening box from which the inductances must be spaced by a minimum of 2 inches. The inductance marked with an asterisk consists of a suitable length of resistance wire wound on a glass tube—or this component and the ·0003-mf condenser can be replaced by a standard dummy aerial. The coils must be so designed and constructed that they are adequately free from temperature and other changes. The output is modulated or not at will, the modulation frequency being approximately 1,000 cps. Suitable valves are: Rectifier 43IU or UU5, Oscillator AC/SG and Triode Output MHL4. The neon stabiliser is the S130.



This electrolytic-test set will give leakage current and approximate capacity under working conditions. With switch in position shown, leakage current may be read directly from D.C. milliammeter: V1 should equal D.C. working-voltage of condenser (V2 must exactly equal V1).

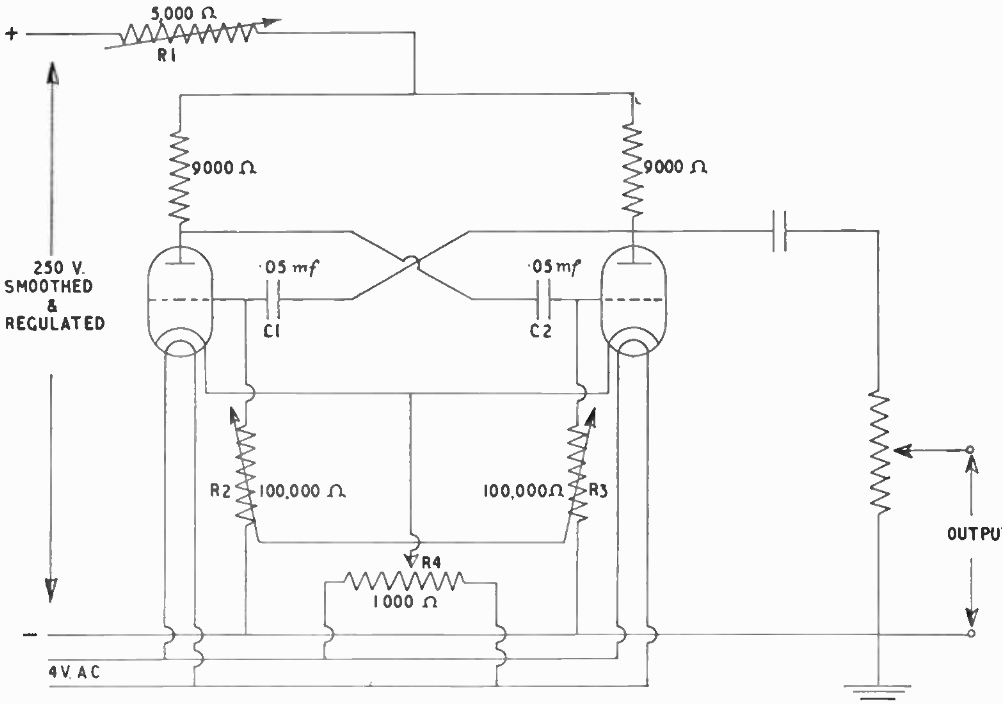
To measure capacity, throw switch and read A.C. volts and current.

$$C = \frac{159 \times I}{V \times f}$$

when {C is in mf, I is in milliamps; V is in volts (R.M.S.), f is mains periodicity in cycles.

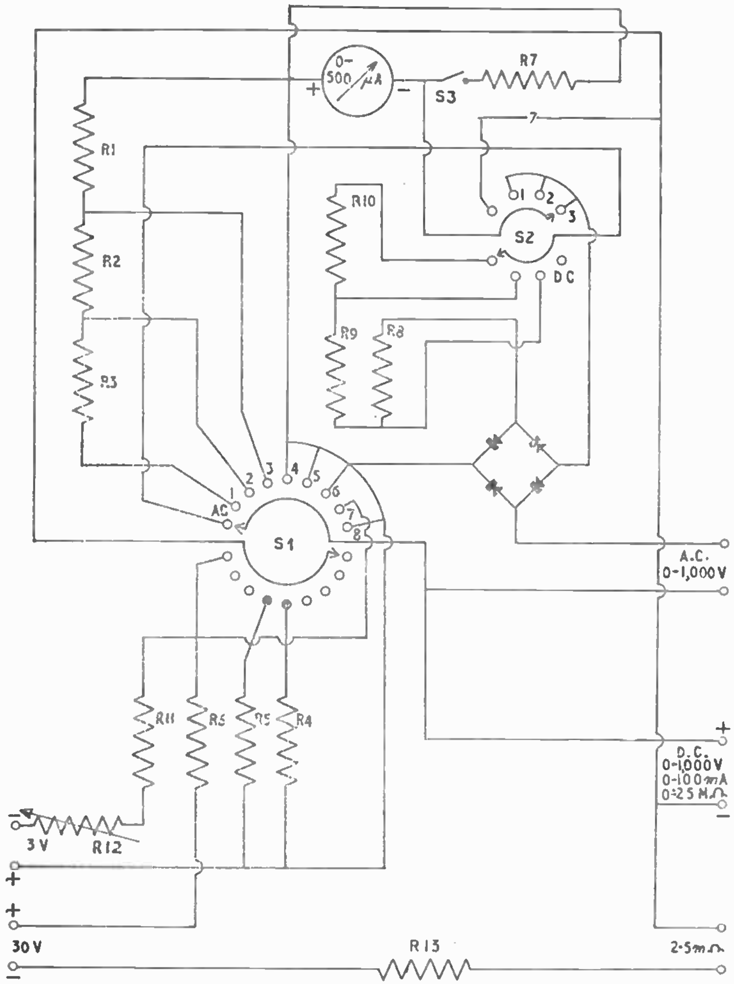
For capacity test, V1 and V2 must be exactly equal, V3 should be about 30 per cent. of V1, and V1 + V3 should preferably be about 75 per cent. of condenser working-voltage.

Warning: Bad connections on V1 or V2 may damage the meters.



This improved form of multi-vibrator has the advantages of wide frequency range and extreme simplicity; the multi-vibrator unfortunately, however, has a bad waveform, although with this particular arrangement some improvement can be made by careful adjustment of R1. The ganged variable resistances R2, R3 control the output frequency, R4 allows a small voltage at mains frequency to be used to lock the oscillator frequency at any desired multiple of the mains frequency.

Electrolytic Condenser Tester and Multi-vibrator



Switch Positions

S1

A.C. = Volts A.C.:
1 = 0–1,000 volts D.C.
2 = 0–100 volts D.C.
3 = 0–10 volts D.C.
4 = 0–100 mA D.C.
5 = 0–10 mA D.C.
6 = 0–1 mA D.C.
7 = 0–250,000 ohms.
8 = 0–500 ohms.

S2

D.C. = Ohms, D.C. volts and amps.
1 = 0–10 volts A.C. (R.M.S.)
2 = 0–100 volts A.C. (R.M.S.)
3 = 0–1,000 volts A.C. (R.M.S.)

Note 1.—When switch S1 is in positions 1–8 inclusive, switch S2 *must* be in position D.C. When switch S1 is in position A.C., switch S2 *must* be in position 1, 2 or 3 as appropriate.

Note 2.—When the switch S3 is closed, the *reading* on the meter is *halved*, thus doubling all D.C. current and voltage ranges and A.C. voltage ranges *except* 0–10 V. A.C.

Resistance Values

R1	= 20,000 − R_m ohms.	¼ W.
R2	= 180,000 ohms.	¼ W.
R3	= 1,800,000 ohms.	2 W.
R4	= $\frac{R_m}{199}$ ohms.	
R5	= $\frac{R_m}{19}$ ohms.	
R6	= 85,000 ohms.	¼ W.
R7	= R_m	
R8	= 17,000 ohms.	¼ W.
R9	= 162,000 ohms.	¼ W.
R10	= 1,620,000 ohms.	2 W.
R11	= 5,000 ohms.	¼ W.
R12	= 5,000 ohms (variable).	¼ W.
R13	= 54,000 ohms.	¼ W.

R_m = the resistance of the meter used, which must have a full-scale deflection of 0–500 μA; if the internal resistance of the meter selected is 50 ohms or less, R1 can be 20,000 ohms.

Rectifier unit—Westinghouse Type 1 mA bridge instrument rectifier.

Note.—If high accuracy is required on the 0–10 V. A.C. range, R8 should be varied to suit the individual characteristics of the rectifier used.

A Universal Test Set

(2,000 ohms per volt)

For ranges see table above, left. R1, 2, 3, 6, 8, 9, 10 must be of the high stability 1% tolerance type. R4, 5, 7, must be wire wound. R11, 12 may be normal resistances. In most cases the values shown will not be obtainable as a single component, but must be built up with two or more as required. Switch S1 must be of a type that does not short-circuit contacts when rotated; it may be a single two-pole, nine-way wafer or two one-pole, nine-way wafers; in either case an additional wafer should be ganged on the same spindle so that contacts shown black can be doubled up to reduce contact resistance. Separate scales should be used for range groups as follows: (1, 2, 3, D.C., 1, 2, A.C.), (3, A.C., (4, 5, 6), (7), (8). Calibration should be checked with the aid of a similar instrument of high accuracy. This instrument has its resistance range extended to 2·5 MΩ if a 30-volt battery is connected where shown; S1 must be in position 7 and readings taken from the ·25 MΩ scale multiplied by 10. If an H.T. battery is used to supply the necessary 30 volts, a zero reading can be obtained by adjustment of R12; after temporarily shorting the 2·5 MΩ terminals. If zero reading cannot be obtained, check H.T. battery for correct voltage.

USEFUL FORMULÆ AND DATA SECTION

The formulæ on these pages and the tables on the pages that follow are accurate to normal engineering standards and, where appropriate, they are selected for the special use of the radio engineer and are rationalised with due regard to raw materials, tolerances and ranges suitable for radio engineering.

Voltage, Current, Resistance and Power for D.C.

$$V = IR,\ R = \frac{V}{I},\ I = \frac{V}{R};\ W = IV,\ W = I^2R,\ W = \frac{V^2}{R}$$

when V = volts, I = amps., R = ohms and W = watts.

Voltage, Current, Impedance and Power for A.C.

$$V = IZ,\ Z = \frac{V}{I},\ I = \frac{V}{Z};\ W = I^2R,\ W = VI\cos\varphi$$

when V = volts, I = amps., Z = ohms and φ = phase angle between V and I.

Resistances in Series

$$R = R_1 + R_2 + R_3 + R_4, \text{ etc.}$$

Resistances in Parallel

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4}, \text{ etc.}$$

Specific Resistance

$$R = \rho\frac{B}{A}$$

Two Resistances in Parallel

$$R = \frac{R_1 \times R_2}{R_1 + R_2}$$

when ρ = specific resistance per centimetre cube, R = resistance in ohms, B = length in centimetres and A = area in square centimetres.

Condensers in Series

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \frac{1}{C_4}, \text{ etc.}$$

Condensers in Parallel

$$C = C_1 + C_2 + C_3 + C_4, \text{ etc.}$$

Two Inductances in Parallel

$$L = \frac{L_1 \times L_2}{L_1 + L_2}$$

Two Condensers in Series

$$C = \frac{C_1 \times C_2}{C_1 + C_2}$$

Inductances in Parallel

$$\frac{1}{L} = \frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3} + \frac{1}{L_4}, \text{ etc.}$$

Inductances in Series

$$L = L_1 + L_2 + L_3 + L_4, \text{ etc.}$$

Note.—Above inductance formulæ assume no mutual inductance.

Inductive Reactance

$$X_L = 2\pi fL$$

when f = cps. and L = henrys.

Capacitive Reactance

$$X_C = \frac{1}{2\pi fC}$$

when f = cps. and C = farads

Resistance and Capacity in Series

$$Z = \sqrt{R^2 + X_c^2}$$

$$V = I\sqrt{R^2 + \frac{1}{(2\pi fC)^2}}$$

$$I = \frac{V}{\sqrt{R^2 + X_c^2}}$$

Resistance and Capacity in Parallel

$$Z = \frac{1}{\sqrt{\frac{1}{R^2} + \frac{1}{X_c^2}}}$$

$$V = I\sqrt{\frac{1}{R^2} + (2\pi fC)^2}$$

$$I = \frac{V}{\sqrt{\frac{1}{R^2} + (2\pi fC)^2}}$$

when Z = impedance in ohms, R = ohms, V = volts, I = current in amps. and C = capacity in farads.

Resistance and Inductance in Series

$$Z = \sqrt{R^2 + X_L^2}$$

$$I = \frac{V}{\sqrt{R^2 + X_L^2}}$$

$$V = I\sqrt{R^2 + (2\pi fL)^2}$$

Resistance and Inductance in Parallel

$$Z = \frac{RX_L}{\sqrt{R^2 + X_L^2}}$$

$$I = V\sqrt{\frac{1}{R^2} + \frac{1}{(2\pi fL)^2}}$$

$$V = I\frac{RX_L}{\sqrt{R^2 + X^2}}$$

when Z = impedance in ohms, R = ohms, V = volts, I = amps. and L = henrys.

Resistance, Capacity and Inductance in Series

$$V = I\sqrt{R^2 + \left(2\pi fL - \frac{1}{2\pi fc}\right)^2}$$

$$Z = \sqrt{R^2 + (X_L - X_c)^2}$$

when Z = impedance in ohms, R = ohms, V = volts, I = amps., L = henrys and C = farads.

Frequency and Wavelength

$$f = \frac{1}{2\pi\sqrt{LC}}$$

when f = cps., L = henrys and C = farads.

$$\lambda = 1{,}884\sqrt{LC}$$

when L = μH, C = μF and λ = metres.

$$f = \frac{1{,}000{,}000}{2\pi\sqrt{LC}}$$

when f = kcs., L = μH and C = μF.

$$\lambda = 1{\cdot}884\sqrt{LC}$$

when L = μH, C = μμF and λ = metres.

$$f = \frac{300{,}000}{\lambda}$$

when f = kcs., λ = metres.

$$f = \frac{300}{\lambda}$$

f = mcs., λ = metres.

$$\lambda = \frac{300{,}000}{f}$$

when f = kcs., λ = metres.

$$\lambda = \frac{300}{f}$$

when f = mcs. λ = metres.

Dynamic Resistance at Resonance

$$R = 2\pi fLQ \text{ or } R = \frac{L}{Cr}$$

when L = henrys, C = farads and r = HF resistance at frequency concerned.

Magnification of a Tuned Circuit

$$Q = \frac{2\pi fL}{r}$$

when L = henrys, C = farads and r = HF resistance at frequency concerned.

Selectivity of a Tuned Circuit

$$\text{Voltage on tuned circuit} = \frac{100}{\sqrt{1 + 4Q^2\left(\frac{\delta f}{f}\right)}} \text{ \% of voltage at resonance}$$

when f = frequency of resonance in cycles, δf = amount of detuning in cycles, Q = magnification of tuned circuit.

Optimum Coupling

(for max. signal)

$$M = \frac{\sqrt{r_1 r_2}}{2\pi f}$$

when r_1 r_2 = HF resistance at resonance and f = frequency in cps. of resonance.

Coefficient of Coupling

$$k = \frac{M}{\sqrt{L_1 L_2}}$$

when M = mutual inductance, L_1, L_2 = inductance in henrys.

H.F. Transformer Ratio

$$n^2 = \frac{R}{R_a}$$

when n = ratio, R_a = valve impedance and R = dynamic resistance.

LC Constant

$$LC = \frac{25330}{f^2}$$

when L = μH, C = $\mu\mu$F and f = mcs.

Bandpass Tuning, Peak Separation

Inductive Coupling

$$\text{Peak separation} = \frac{\sqrt{(2\pi f)^2 M^2 -}}{2\pi L}$$

Capacity Coupling

$$\text{Peak separation} = \frac{\sqrt{\frac{1}{(2\pi f)^2 C_m^2}}}{2\pi L} - r^2$$

when M = mutual inductance in henrys, r = HF resistance in ohms, L = inductance in henrys and C_m = coupling capacity in farads.

Time Constants

RC = time in seconds for voltage across a discharging condenser to fall to 37% approx. of its original value

RC = time in seconds for a charging condenser to reach 63% approx. of its ultimate voltage

$\frac{L}{R}$ = time in seconds for current to reach 63% approx. of its ultimate steady value

$\frac{L}{R}$ = time in seconds for a current to fall from its maximum steady value to 37% approx. of that value

when R = ohms, L = henrys and C = farads.

H.F. Feeders

$$Z_0 = \sqrt{\frac{L}{C}}$$

when Z_0 = characteristic impedance. L = henrys and C = farads per unit length.

$$Z_0 \text{ of twin feeder} = \frac{276, \log_{10} \frac{2D}{d}}{\sqrt{K}}$$

when d = diam. of wire, D = mean distance between conductors, K = dielectric constant.

$$Z_0 \text{ of concentric feeder} = \frac{138, \log_{10} \frac{D}{d}}{\sqrt{K}}$$

when D = internal diam. of outer conductor, d = diam. of inner conductor and K = dielectric constant.

Aerials

$$\text{Length of } \tfrac{1}{2}\lambda \text{ aerial in feet} = \frac{468}{f(mcs.)}$$

$$\text{Length of } \tfrac{1}{4}\lambda \text{ aerial in feet} = \frac{234}{f(mcs.)}$$

$$\text{Length of long wire aerial in feet} = \frac{492(N - \cdot 05)}{f(mcs.)}$$

when N = number of $\frac{1}{2}$ waves on aerial.

Valve Characteristics

$$\text{Impedance} = \frac{\text{Change in anode volts}}{\text{Change in anode current}} \qquad \text{Slope} = \frac{\text{Change in anode current}}{\text{Change in grid volts}}$$

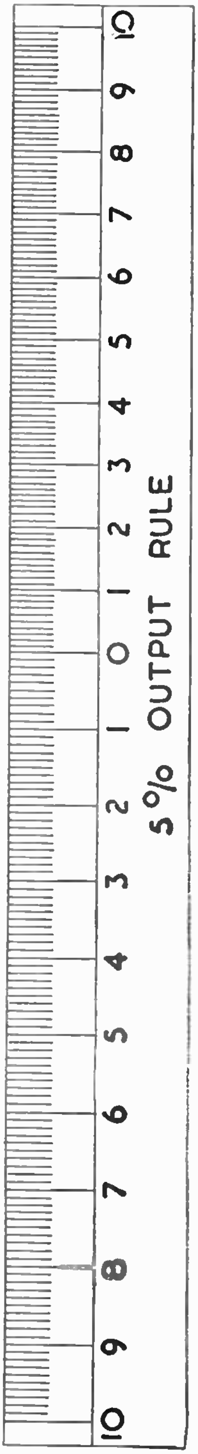
$$\text{Amp. factor} = \frac{\text{Change in anode volts}}{\text{Change in grid volts}} \qquad \text{Slope} = \frac{\text{Amp. factor}}{\text{Impedance}}$$

Relationship between impedance (R_a), amplification factor (μ) and slope (g_m) is:

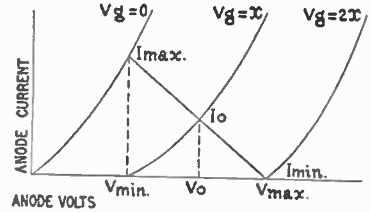
$$g_m = \frac{\mu}{R_a}, \quad \mu = g_m R_a \quad \text{and} \quad R_a = \frac{\mu}{g_m}$$

when units are volts, amps. and ohms and g_m is in amps. per volt.

Power Output and Distortion of Triode Valves



5% second harmonic distortion is present when the distance $I_{max} - I_o$ is $\frac{11}{9}$ of the distance $I_o - I_{min}$ (I_o is the operating or bias point). The use of a special ruler to satisfy this condition is explained on page 193, Vol. I, of *Modern Practical Radio and Television.* Suitable dimensions for making such a ruler are given on the left; any transparent material may be used, and great accuracy must be observed.



Diagrammatic representation of anode-volt/anode-current curve. I_o is the operating point.

$$\text{Output watts} = \tfrac{1}{8}(I_{max} - I_{min})(V_{max} - V_{min})$$

$$\text{Load resistance} = \frac{V_{max} - V_{min}}{I_{max} - I_{min}}$$

$$\%\ \text{2nd harmonic distortion} = \frac{\dfrac{I_{max} + I_{min}}{2} - I}{I_{max} - I_{min}} \times 100\%$$

when V = volts and I = current in amps.

Power Output, Optimum Load and Bias by Formulæ

$$\text{Watts output} = \cdot 041\,\mu k \left(\frac{V_a}{\mu}\right)^{\frac{5}{2}} \text{approx.}$$

when V_a = anode voltage in volts, μ = amplification factor and k = as below.

$$k = \frac{I}{\left(\dfrac{V_a}{\mu} - V_g\right)^{\frac{3}{2}}}$$

when V_a = anode voltage in volts, V_g = grid voltage in volts, I_a = anode current in amps.

$$\text{Optimum load in ohms} = 1{\cdot}9\,\frac{\mu}{k}\left(\frac{V_a}{\mu}\right)^{-\frac{1}{2}}$$

Units and value of the constant k are the same as those given, left.

$$\text{Approx. grid bias} = \frac{V_g \times 1{,}000}{(I_a + I_{sg})n}$$

when V_g = grid bias in volts, I_a = anode current in mA, I_{sg} = screen current in mA and n = number of valves using common bias resistor.

Voltage Amplification (Stage Gain)

$$\text{Stage gain} = \frac{\mu Z}{Z + R_a}$$

when Z = impedance of anode load, μ = amplification factor and R_a = valve impedance. (If Z is inductive or capacitive, Z and R_a must be added vectorially.)

Output Transformer Ratio

$$N = \sqrt{\frac{R_o}{Z}}$$

When N = transformer turns ratio, R_o = optimum load of valve and Z = loudspeaker impedance.

R.C. Coupled A.F. Amplifier Design

Stage gain at medium frequencies $= \dfrac{\mu R}{R + R_a} = A_{mf}$

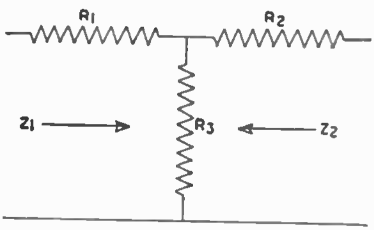
Stage gain at low frequencies $= \dfrac{A_{mf}}{\sqrt{1 + \dfrac{1}{(2\pi f)^2 C_2^2 \rho^2}}}$

Stage gain at high frequencies $= \dfrac{A_{mf}}{\sqrt{1 + (2\pi f)^2 C_1^2 r^2}}$

when $R = \dfrac{R_1 R_2}{R_1 + R_2}$ $\quad r = \dfrac{RR_a}{R + R_a}$ $\quad \rho = R_2 + \dfrac{R_1 R_a}{R_1 + R_a}$

and when R_a = valve impedance, R_1 = anode load resistance in ohms, R_2 = grid leak resistance in ohms, C_1 = total shunt capacity in farads, C_2 = coupling capacity in farads, μ = valve amplification factor, A_{mf} = see top left, ρ = see bottom right.

Attenuation Network Design

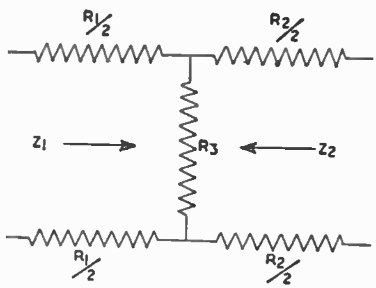


Unbalanced T type

$$R_1 = Z_1\left(\frac{N+1}{N-1}\right) - R_3$$

$$R_2 = Z_2\left(\frac{N+1}{N-1}\right) - R_3$$

$$R_3 = \frac{2\sqrt{NZ_1Z_2}}{N-1}$$



Balanced H type

when Z = impedance in ohms, R = resistance in ohms and N = the ratio of power absorbed (by the attenuator) from the source of the power to the output power delivered.

Turns Required for a Given Inductance and Size of Coil Former

Multi layer $\dfrac{L\,(3{\cdot}5D + 8l)}{{\cdot}2D^2} \times \dfrac{D}{(D - 2{\cdot}25d)} = N^2$

Single layer $\dfrac{L\,(3.5D \times 8l)}{{\cdot}2D^2} = N^2$

Inductance of a Single or Multi-layer Coil

$$L = \frac{{\cdot}2N^2D^2}{3{\cdot}5D + 8l} \times \left(\frac{D - 2{\cdot}25d}{D}\right)$$

Note.—For single layer coil omit all in brackets

when N = number of turns; D=outside diameter of coil; l = length of coil; d = depth of coil (i.e. ½ times outside minus inside diameter); L = μH (measurements in inches).

Capacity of a Fixed Condenser

$$C = \frac{{\cdot}0885AK\,(n-1)}{d}$$

when A = overlapping area of metal plates in square centimetres, K = dielectric constant, n = number of metal plates. d = distance between plates in centimetres.

GREEK LETTERS.—Greek letters used in these pages of formulæ are pronounced as follows: ρ = rho, φ = phi, π = pi, λ = lambda, μ = mu and δ = delta.

READY-WORKED FREQUENCY—WAVELENGTH CONVERSION TABLE

f in Mcs.	Metres	*f* in Mcs.	Metres	*f* in Kcs.	Metres	*f* in Kcs.	Metres	*f* in Kcs.	Metres
100	3	14	21·43	3,000	100	830	361·4	505	594·1
98	3·06	13·5	22·22	2,950	101·7	820	365·8	500	600
96	3·12	13	23·08	2,900	103·5	810	370·7	495	606
94	3·19	12·5	24	2,850	105·3	800	375	490	612·3
92	3·26	12	25	2,800	107·1	790	379·7	485	618·6
90	3·33	11·5	26·08	2,750	109·1	780	384·9	480	625
88	3·41	11	27·27	2,700	111·1	770	389·6	475	631·6
86	3·49	10·5	28·57	2,650	113·2	760	394·8	470	638·3
84	3·57	10	30	2,600	115·4	750	400	465	645·2
82	3·66	9·5	31·58	2,550	117·7	745	402·9	460	652·2
80	3·75	9	33·33	2,500	120	740	405·4	455	659·3
78	3·85	8·5	35·29	2,450	122·5	735	408·2	450	666·7
76	3·94	8	37·5	2,400	125	730	411	440	681·8
74	4·05	7·75	38·71	2,350	127·7	725	413·8	430	697·7
72	4·2	7·5	40	2,300	130·4	720	416·7	420	714·3
70	4·29	7·25	41·38	2,250	133·3	715	419·6	410	731·8
68	4·41	7	42·86	2,200	136·4	710	422	400	750
66	4·55	6·75	44·46	2,150	139·5	705	425·5	390	769·8
64	4·69	6·5	46·15	2,100	142·9	700	428·6	380	789·5
62	4·84	6·25	48	2,050	146·4	695	431·7	370	810·8
60	5	6	50	2,000	150	690	434·8	360	833·4
58	5·17	5·9	50·85	1,950	153·9	685	438	350	857·2
56	5·36	5·8	51·73	1,900	157·9	680	441·2	340	882·5
54	5·56	5·7	52·63	1,850	162·2	675	444·5	330	909·1
52	5·71	5·6	53·57	1,800	166·7	670	448·8	320	937
50	6	5·5	54·55	1,750	171·4	665	451·1	310	967·7
48	6·25	5·4	55·55	1,700	176·5	660	454·6	300	1,000
46	6·52	5·3	56	1,650	181·8	655	458	295	1,017
44	6·82	5·2	57·69	1,600	187·5	650	461·5	290	1,034·5
42	7·14	5·1	58·83	1,550	193·6	645	465·1	285	1,052·6
40	7·5	5	60	1,500	200	640	468·5	280	1,071·4
39	7·7	4·9	61·23	1,450	206·9	635	472·4	275	1,090·9
38	7·9	4·8	62·5	1,400	214·3	630	476·2	270	1,111·1
37	8·11	4·7	63·83	1,350	222·2	625	480	265	1,132
36	8·33	4·6	65·22	1,300	230·8	620	483·9	260	1,153·8
35	8·57	4·5	66·66	1,250	240	615	487·8	255	1,176·5
34	8·82	4·4	68·18	1,200	250	610	491·8	250	1,200
33	9·09	4·3	69·77	1,150	260·9	605	495·9	245	1,224·5
32	9·37	4·2	71·43	1,100	272·7	600	500	240	1,250
31	9·68	4·1	73·18	1,050	285·7	595	504·2	235	1,276·6
30	10	4	75	1,000	300	590	508·5	230	1,304·3
29	10·35	3·9	76·98	990	303	585	512·8	225	1,333·3
28	10·71	3·8	78·95	980	306·2	580	517·2	220	1,363·6
27	11·11	3·75	80	970	309·3	575	521·7	215	1,395·4
26	11·54	3·7	81·08	960	312·5	570	526·3	210	1,428·5
25	12	3·65	82·19	950	315·8	565	531	205	1,463·5
24	12·5	3·6	83·34	940	319·2	560	535·7	200	1,500
23	13·04	3·55	84·39	930	322·9	555	540·5	195	1,538·5
22	13·64	3·5	85·72	920	326·1	550	545·5	190	1,579
21	14·29	3·45	86·96	910	329·7	545	550·6	185	1,621·6
20	15	3·4	88·25	900	333·3	540	555·6	180	1,666·7
19	15·79	3·35	89·56	890	337·1	535	560·8	175	1,714·3
18	16·67	3·3	90·91	880	340·9	530	566	170	1,764·7
17	17·65	3·25	92·31	870	344·9	525	571·4	165	1,818·2
16	18·75	3·2	93·7	860	348·9	520	576·9	160	1,875
15	20	3·1	96·77	850	352·9	515	582·5	155	1,935·5
14·5	20·69	3	100	840	357·1	510	588·3	150	2,000

READY-WORKED COIL WINDING TABLES

MEDIUM WAVES

Former Diam. (inches)	175 Microhenrys *				200 Microhenrys †				225 Microhenrys ‡			
	S.W.G.	Type	Turns	Length (inches)	S.W.G.	Type	Turns	Length (inches)	S.W.G.	Type	Turns	Length (inches)
1·25	32	S.S.C.	85	1·05	32	S.S.C.	94	1·15	32	S.S.C.	104	1·26
1·25	30	D.S.C.	93	1·38	30	D.S.C.	103	1·53	30	D.S.C.	112	1·72
1·5	30	D.S.C.	74	1·1	30	D.S.C.	82	1·22	30	D.S.C.	90	1·35
1·75	30	D.S.C.	63	·95	30	D.S.C.	68	1	30	D.S.C.	76	1·15
1·75	28	D.S.C.	67	1·16	28	D.S.C.	73	1·25	28	D.S.C.	80	1·4
2	30	D.S.C.	54	·8	30	D.S.C.	59	·89	30	D.S.C.	65	·97
2	28	D.S.C.	58	1	28	D.S.C.	64	1·15	28	D.S.C.	70	1·25
2·25	28	D.S.C.	52	·93	28	D.S.C.	57	1	28	D.S.C.	62	1·1
2·25	26	D.C.C.	70	1·95	26	D.C.C.	77	2·1	26	D.C.C.	87	2·39
2·5	28	D.S.C.	47	·84	28	D.S.C.	51	·9	28	D.S.C.	56	1
2·5	24	D.C.C.	58	1·85	24	D.C.C.	65	2·05	24	D.C.C.	72	2·25

Note.—* For normal broadcast coverage where a trimmer is employed, use 175 μH with ·0005 mf.
† Use with ·0005 mf. for normal broadcast coverage.
‡ Use with ·0004 mf. for normal broadcast coverage.

LONG WAVES

Former Diam. (inches)	2,100 Microhenrys *				3,000 Microhenrys †			
	S.W.G.	Type	Grooves‡	Turns per groove	S.W.G.	Type	Grooves‡	Turns per groove
1	36	Enamel	4	92	36	Enamel	5	95
1	36	Enamel	5	80	36	Enamel	6	85
1·5	36	Enamel	3	80	36	Enamel	3	96
1·5	34	Enamel	5	60	36	Enamel	4	78
2	34	D.S.C.	4	51	36	D.S.C.	4	60
2	34	D.S.C.	5	45	36	D.S.C.	5	53

Note.—* For normal long-wave coverage use ·0005 mf.
† For normal long-wave coverage use ·0004 mf.
‡ Grooves must be ⅛-inch deep, $\frac{1}{16}$-inch wide and be ⅛-inch apart; such formers may be purchased ready-made in ebonite or other suitable insulating material.

READY-WORKED L × C CONSTANTS FOR RADIO AND AUDIO FREQUENCIES

Radio Frequencies L in μH and C in μF		Radio Frequencies—continued		Audio Frequencies L in H and C in μF	
F in Kcs.	L × C	F in Kcs.	L × C	F in cps.	L × C
30,000	·0000282	680	·05477	25	40·545
15,000	·0001129	660	·05815	50	10·136
10,000	·000253	640	·06184	100	2·533
7,300	·0004753	630	·06382	200	·633
6,000	·000704	620	·06484	400	·158
5,000	·001014	610	·06807	600	·07
1,000	·02533	600	·07036	800	·04
950	·02806	590	·07276	1,000	·025
900	·03127	580	·07529	2,000	·0063
875	·03308	570	·07796	3,000	·0028
850	·03506	560	·08076	4,000	·0016
825	·03721	550	·08373	4,500	·00125
800	·03957	465	·11715	5,000	·001
780	·04163	300	·28145	6,000	·0007
760	·04385	250	·40545	7,000	·0005
740	·04625	200	·63325	8,000	·0004
720	·04891	170	·87646	9,000	·00031
700	·05149	150	1·1258	10,000	·00025

Note.—Many formulæ incorporate $\sqrt{L \times C}$; above figures are L × C, the square-root of which can be taken when necessary.

COPPER WIRE TABLE

Imperial or British Standard Wire Gauge	*U.S.A. Wire Gauge*	*Diameter in inches*	*Diameter in millimetres*	**Ohms per thousand feet*	*Feet per lb.*	*† Turns per inch*					
S.W.G.	*A.W.G. (B. & S.)*	—	—	—	—	*Bare*	*Enam.*	*S.C.C.*	*D.C.C.*	*S.S.C.*	*D.S.C.*
10	—	·128	3·25	·6219	20·16	7·81	7·63	7·35	7·04	—	—
11	—	·116	2·946	·7570	24·55	8·62	8·33	8·07	7·69	—	—
—	9	·1144	2·906	·7921	25·23	8·74	8·58	8·23	7·91	—	—
12	—	·104	2·64	·942	30·54	9·62	9·26	8·93	8·48	—	—
—	10	·1019	2·558	·9989	31·82	9·81	9·61	9·26	8·85	—	—
13	—	·092	2·337	1·204	39·01	10·87	10·42	10·00	9·43	—	—
—	11	·09074	2·304	1·26	40·12	11·02	10·7	10·4	9·98	—	—
—	12	·08081	2·053	1·588	50·59	12·37	12·00	11·6	11·07	—	—
14	—	·080	2·03	1·592	51·60	12·50	11·90	11·36	10·64	—	—
15	13	·0720	1·828	2·000	63·80	13·89	13·33	12·29	12·08	—	—
16	—	·064	1·63	2·488	80·65	15·59	14·81	14·08	13·16	14·93	14·71
—	14	·06408	1·628	2·525	80·44	15·61	15·1	14·4	13·59	—	—
—	15	·05707	1·450	3·184	101·4	17·52	16·9	16·1	15·00	—	—
17	—	·056	1·422	3·249	105·4	17·86	16·95	15·87	14·71	16·95	16·67
—	16	·05082	1·291	4·016	127·9	19·68	18·9	17·9	16·5	18·9	18·2
18	—	·048	1·22	4·422	143·3	20·83	19·72	18·18	16·95	20·0	19·61
—	17	·04526	1·150	5·064	161·3	22·1	21·2	19·8	18·2	21·1	20·2
—	18	·04030	1·024	6·385	203·4	24·8	23·7	22·0	20·0	23·6	22·5
19	—	·040	1·016	6·368	206·4	25·0	23·47	21·28	19·61	23·81	23·26
20	—	·036	·914	7·860	254·8	27·78	25·97	23·81	21·28	26·32	25·64
—	19	·03589	·9116	8·051	256·5	27·8	26·5	24·4	22·0	26·3	25·0
21	—	·032	·8138	9·950	322·6	31·25	29·15	26·32	23·26	29·41	28·57
—	20	·03196	·8118	10·15	323·4	31·3	29·5	27·0	24·1	29·4	27·7
—	21	·02846	·7230	12·80	407·8	35·1	33·1	29·8	26·3	32·7	30·7
22	—	·028	·711	12·997	421·2	35·71	33·33	29·41	25·64	33·33	32·26
—	22	·02535	·6438	16·14	514·2	39·4	37·0	33·5	29·5	36·6	34·1
23	—	·024	·6096	17·69	573·4	41·67	38·91	34·48	29·41	38·46	37·04
—	23	·02257	·5733	20·36	648·4	44·3	41·4	36·9	32·1	40·6	37·5
24	—	·022	·559	21·05	682·6	45·45	42·37	37·04	31·25	42·55	40·00
—	24	·0201	·5106	25·67	817·7	49·7	46·5	40·6	34·9	45·2	41·4
25	—	·020	·508	25·47	825·8	50·00	46·51	40·00	33·33	46·51	43·48
26	—	·018	·457	31·45	1,019	55·56	51·55	43·48	35·71	51·81	48·78
—	25	·0179	·4547	32·37	1,031	55·8	52·0	44·6	37·8	50·0	45·6
27	—	·0164	·4165	37·88	1,229	60·98	56·50	46·73	37·88	56·50	52·91
—	26	·01594	·4049	40·81	1,300	62·7	58·4	49·0	40·9	55·8	50·0
28	—	·0148	·376	46·52	1,508	67·57	62·50	50·51	40·32	62·11	57·80
—	27	·0142	·3606	51·47	1,639	70·4	65·3	53·4	44·0	61·7	54·9
29	—	·0136	·3454	55·09	1,786	73·53	67·57	53·76	42·37	67·11	62·11

* Resistance of U.S.A. gauges measured at 68° F. and S.W.G. gauges at 60° F.
† Apparent inconsistencies in turns per inch between similar British and U.S.A. gauges are due to differences in thickness of insulation.

COPPER WIRE TABLE (*contd.*)

Imperial or British Standard Wire Gauge	*U.S.A. Wire Gauge*	*Diameter in inches*	*Diameter in millimetres*	**Ohms per thousand feet*	*Feet per lb.*	*† Turns per inch*					
S.W.G.	*A.W.G. (B. & S.)*	—	—	—	—	*Bare*	*Enam.*	*S.C.C.*	*D.C.C.*	*S.S.C.*	*D.S.C.*
—	28	·01264	·3211	64·90	2,067	82·8	73·5	58·4	47·3	68·4	60·2
30	—	·0124	·315	66·27	2,148	80·65	74·63	57·47	44·64	72·99	67·11
31	—	·0116	·2946	75·7	2,455	86·21	79·37	60·24	46·30	77·52	70·92
—	29	·01126	·2859	81·83	2,607	88·8	81·0	63·2	50·5	75·1	65·3
32	—	·0108	·274	87·4	2,832	92·59	85·47	63·29	48·0	82·64	75·19
33	—	·01	·2540	101·9	3,302	100·0	91·74	66·67	50·0	88·50	80·0
—	30	·01003	·2546	103·2	3,287	99·7	92·5	68·9	54·0	83·3	71·4
34	—	·0092	·234	120·4	3,901	108·0	99·0	70·42	52·08	95·24	85·47
—	31	·00893	·2268	130·1	4,145	112·0	103·0	74·6	57·4	91·7	77·5
35	—	·0082	·2082	144·4	4,682	119·0	110·0	80·65	57·47	103·0	91·74
—	32	·0079	·2019	164·1	5,227	125·8	114·0	80·0	60·0	100·0	83·3
36	—	·0072	·193	176·4	5,718	131·6	118·0	86·21	60·25	112·5	99·0
—	33	·0071	·1798	206·9	6,591	141·2	129·0	86·2	64·1	109·0	90·0
37	—	·0068	·1727	220·4	7,143	147·0	135·0	99·21	63·29	123·5	107·5
—	34	·0063	·1601	260·9	8,310	158·6	144·0	92·5	67·5	120·0	97·0
38	—	·006	·152	283·0	9,174	166·7	148·5	100·0	66·67	137·0	118·0
—	35	·0056	·1426	329·0	10,480	178·0	161·0	99·9	70·9	131·0	104·0
39	—	·0052	·1320	376·8	12,210	192·3	175·4	108·7	70·42	153·8	130·0
—	36	·0050	·1270	414·8	13,210	200·0	181·0	111·0	76·9	142·0	111·0
40	—	·0048	·122	442·2	14,330	208·0	185·7	113·6	72·46	164·0	137·0
41	—	·0044	·1117	526·3	17,060	227·0	206·0	—	—	178·6	151·5
—	37	·00445	·1131	532·1	16,660	224·0	204·0	117·0	80·0	153·0	117·0
42	—	·004	·102	636·8	20,640	250·0	222·0	—	—	192·3	161·2
—	38	·00396	·1007	659·6	21,010	252·0	227·0	125·0	83·3	166·0	125·0
43	—	·0036	·0914	786·3	25,480	277·8	255·0	—	—	208·3	172·3
—	39	·00353	·0897	831·8	26,500	283·0	256·0	133·0	86·9	181·0	133·0
44	—	·0032	·081	995·0	32,260	312·5	277·7	—	—	227·3	185·2
—	40	·00314	·0799	1,049·0	33,410	318·0	285·0	140·0	90·0	196·0	140·0
45	—	·0028	·0711	1,299·7	42,120	357·1	315·1	—	—	250·0	200·0
—	41	·00275	·0698	1,370·0	43,700	363·0	327·0	—	—	—	—
—	42	·0025	·0635	1,660·0	52,800	400·0	378·0	—	—	—	—
46	—	·0024	·061	1.769·0	57,340	416·7	368·3	—	—	277·7	217·4
—	43	·00225	·0571	2,050·0	65,300	444·0	421·0	—	—	—	—
47	—	·002	·0504	2,547·0	82,580	500·0	435·5	—	—	312·5	238·0
—	44	·002	·0504	2,600·0	82,600	500·0	471·0	—	—	—	—
—	45	·00175	·0404	3,390·0	107,900	571·0	523·0	—	—	—	—

* Resistance of U.S.A. gauges measured at 68° F. and S.W.G. gauges at 60° F.
† Apparent inconsistencies in turns per inch between similar British and U.S.A. gauges are due to differences in thickness of insulation.

MISCELLANEOUS WIRE TABLES

FUSE-WIRE TABLE

Fusing Current in amps.	Tin		Tin Alloy (75% Lead, 25% Tin)		Tinned Copper		Lead	
	Diameter in inches	S.W.G.	Diameter in inches	S.W.G.	Diameter in inches	S.W.G.	Diameter in inches	S.W.G.
1	·0072	37	·0084	35	—	—	·0084	35
2	·0113	31	·0136	29	—	—	·0124	30
3	·0148	28	·0164	27	—	—	·0164	27
4	·018	26	·02	25	—	—	·02	25
5	·02	25	·024	23	—	—	·024	23
6	·024	23	·032	21	—	—	—	—
10	·032	21	·048	18	·01	33	·036	20
15	·044	—	·064	16	·0136	29	·048	18
20	·056	17	—	—	·0146	27	·056	17
25	·064	16	—	—	—	—	·072	15
30	·072	15	—	—	·022	24	·08	14

The above figures are approximate owing to the desirability of using S.W.G. and round figures in amps.; they are, however, sufficiently accurate for practical purposes. Sixty per cent. may be taken as the safe normal current.

FLEX

Description	Sectional Area in sq. ins. (nominal)	Maximum Current in amps.	Description	Sectional Area in sq. ins. (nominal)	Maximum Current in amps.
14/·0076	·0006	2	70/·0076	·003	10
23/·0076	·001	3	110/·0076	·0048	15
40/·0076	·0017	5	162/·0076	·007	20

RESISTANCE WIRE

S.W.G.	Diameter (inches)	Eureka* (ohms per yard)	Nichrome † (ohms per yard)	S.W.G.	Diameter (inches)	Eureka * (ohms per yard)	Nichrome † (ohms per yard)
10	·128	·053	·125	30	·0124	5·633	12·982
12	·104	·08	·189	31	·0116	6·436	14·285
13	·092	·1023	·242	32	·0108	7·427	17·102
14	·08	·1353	·32	33	·01	8·662	19·960
15	·072	·1671	·395	34	·0092	10·23	23·57
16	·064	·2115	·486	35	·0084	12·27	28·277
17	·056	·2762	·636	36	·0076	15	34·563
18	·048	·376	·865	37	·0068	18·74	43·166
19	·04	·541	1·246	38	·006	24·05	55·374
20	·036	·668	1·539	39	·0052	32·03	73·722
21	·032	·846	1·957	40	·0048	37·6	86·485
22	·028	1·105	2·546	41	·0044	44·74	100·15
23	·024	1·504	3·463	42	·0040	54·13	124·7
24	·022	1·789	4·118	43	·0036	66·68	153·875
25	·02	2·166	4·979	44	·0032	84·61	194·94
26	·018	2·673	6·156	45	·0028	110·5	254·6
27	·0164	3·221	7·422	46	·0024	150·4	346·3
28	·0148	4·119	9·107	47	·002	216·6	497·89
29	·0136	4·684	10·793	48	·0016	338·4	779·52

* Values are approximate and are based on an alloy of 40% nickel and 60% copper. This wire should not be used above 575° F. (300° C.). It has an extremely low temperature coefficient.

† The resistance of nichrome varies considerably; figures given are the average of several different manufacturers, all being alloys of approximately 80% nickel and 20% chromium. Alloys containing a small percentage of iron have a slightly lower resistance; temperature coefficient is low, averaging + 0·0001 per C°.

READY-WORKED VOLTAGE, CURRENT AND RESISTANCE TABLE

VOLTAGE DROP IN VOLTS

Current in Milliamps	1	2	4	6	8	10	14	18	22	26	30	34	38	42	46	50	60	70	80	100
1	1,000	2,000	4,000	6,000	8,000	10,000	14,000	18,000	22,000	26,000	30,000	34,000	38,000	42,000	46,000	50,000	60,000	70,000	80,000	100,000
2	500	1,000	2,000	3,000	4,000	5,000	7,000	9,000	11,000	13,000	15,000	17,000	19,000	21,000	23,000	25,000	30,000	35,000	40,000	50,000
3	333	667	1,332	2,000	2,664	3,333	4,667	6,000	7,333	8,667	10,000	11,333	12,667	14,000	15,333	16,667	20,000	23,333	26,667	33,333
4	250	500	1,000	1,500	2,000	2,500	3,500	4,500	5,500	6,500	7,500	8,500	9,500	10,500	11,500	12,500	15,000	17,500	20,000	25,000
5	200	400	800	1,200	1,600	2,000	2,800	3,600	4,400	5,200	6,000	6,800	7,200	8,400	9,200	10,000	12,000	14,000	16,000	20,000
6	167	333	667	1,000	1,333	1,667	2,333	3,000	3,667	4,333	5,000	5,667	6,333	7,000	7,667	8,333	10,000	11,667	13,333	16,667
7	143	283	572	857	1,143	1,430	2,000	2,571	3,142	3,714	4,286	4,857	5,429	6,000	6,571	7,143	8,571	10,000	11,429	14,286
8	125	250	500	750	1,000	1,250	1,750	2,250	2,750	3,250	3,750	4,250	4,750	5,250	5,750	6,250	7,500	8,750	10,000	12,500
9	111	222	444	667	889	1,111	1,556	2,000	2,444	2,889	3,333	3,778	4,222	4,667	5,111	5,556	6,667	7,778	8,889	11,111
10	100	200	400	600	800	1,000	1,400	1,800	2,200	2,600	3,000	3,400	3,800	4,200	4,600	5,000	6,000	7,000	8,000	10,000
12	83	167	333	500	667	833	1,167	1,500	1,833	2,167	2,500	2,833	3,167	3,500	3,833	4,167	5,000	5,833	6,667	8,333
14	71	143	283	428	572	714	1,000	1,286	1,571	1,857	2,143	2,429	2,714	3,000	3,286	3,571	4,286	5,000	5,714	7,143
16	63	125	250	375	500	625	875	1,125	1,375	1,625	1,875	2,125	2,375	2,625	2,875	3,125	3,750	4,375	5,000	6,250
18	56	111	222	333	444	556	778	1,000	1,222	1,444	1,667	1,889	2,111	2,333	2,556	2,777	3,333	3,889	4,444	5,556
20	50	100	200	300	400	500	700	900	1,100	1,300	1,500	1,700	1,900	2,100	2,300	2,500	3,000	3,500	4,000	5,000
22	45	91	182	273	364	455	636	818	1,000	1,182	1,364	1,545	1,727	1,909	2,091	2,273	2,727	3,182	3,636	4,545
24	42	83	167	250	333	417	583	750	917	1,083	1,250	1,417	1,583	1,750	1,917	2,083	2,500	2,917	3,333	4,167
26	39	77	153	231	308	385	538	692	846	1,000	1,154	1,308	1,462	1,615	1,769	1,923	2,308	2,692	3,077	3,846
28	36	71	143	214	286	357	500	643	786	929	1,071	1,214	1,357	1,500	1,643	1,786	2,143	2,500	2,857	3,571
30	33	67	133	200	267	333	467	600	733	867	1,000	1,133	1,267	1,400	1,533	1,667	2,000	2,333	2,667	3,333
32	31	63	125	188	250	313	437	561	688	813	938	1,063	1,188	1,313	1,438	1,563	1,875	2,188	2,500	3,125
34	29	59	118	176	235	294	412	529	647	765	882	1,000	1,118	1,235	1,353	1,471	1,765	2,059	2,353	2,941
36	28	56	111	167	222	278	389	500	611	722	833	944	1,056	1,167	1,278	1,389	1,667	1,944	2,222	2,778
38	26	53	105	158	211	263	368	474	578	684	789	895	1,000	1,105	1,211	1,316	1,579	1,842	2,105	2,632
40	25	50	100	150	200	250	350	450	550	650	750	850	950	1,050	1,150	1,250	1,500	1,750	2,000	2,500
42	24	48	95	143	190	238	333	429	524	643	714	810	905	1,000	1,095	1,190	1,439	1,667	1,905	2,381
44	23	45	91	136	182	227	318	409	500	591	682	773	864	955	1,045	1,136	1,364	1,591	1,818	2,273
46	22	43	87	130	174	217	304	391	478	565	652	739	826	913	1,000	1,087	1,304	1,522	1,739	2,174
48	21	42	83	125	167	208	292	379	458	542	625	708	792	875	958	1,042	1,250	1,458	1,667	2,083
50	20	40	80	120	160	200	280	360	440	520	600	680	760	840	920	1,000	1,200	1,400	1,600	2,000
52	19	38	77	115	154	192	269	346	423	500	577	653	731	808	885	962	1,154	1,346	1,538	1,923
54	19	37	74	111	148	185	259	333	407	81	556	630	704	778	852	926	1,111	1,291	1,481	1,852
56	18	36	71	107	143	179	250	321	393	464	536	607	671	750	821	893	1,071	1,250	1,429	1,786
58	17	34	69	103	138	172	241	310	379	457	517	586	655	724	793	862	1,034	1,207	1,379	1,724
60	17	33	67	100	133	167	233	300	367	433	500	567	633	700	767	833	1,000	1,167	1,333	1,667

¼ Watt · ½ Watt · 1 Watt · 2 Watts · 3 Watts · 4 Watts · 5 Watts · 6 Watts

READY-WORKED RESISTANCE COLOUR CODE

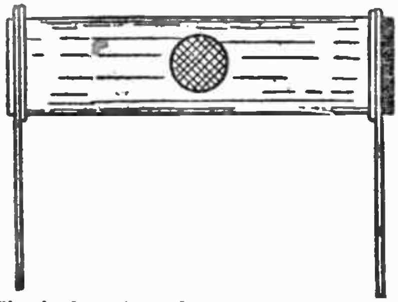
Ohms	*Body*	*Tip*	*Dot*	*Ohms*	*Body*	*Tip*	*Dot*
10	Brown	Black	Black	820	Grey	Red	Brown
11	Brown	Brown	Black	910	White	Brown	Brown
12	Brown	Red	Black	1,000	Brown	Black	Red
13	Brown	Orange	Black	1,100	Brown	Brown	Red
15	Brown	Green	Black	1,200	Brown	Red	Red
16	Brown	Blue	Black	1,300	Brown	Orange	Red
18	Brown	Grey	Black	1,500	Brown	Green	Red
20	Red	Black	Black	1,600	Brown	Blue	Red
22	Red	Red	Black	1,800	Brown	Grey	Red
24	Red	Yellow	Black	2,000	Red	Black	Red
27	Red	Violet	Black	2,200	Red	Red	Red
30	Orange	Black	Black	2,400	Red	Yellow	Red
33	Orange	Orange	Black	2,500	Red	Green	Red
36	Orange	Blue	Black	2,700	Red	Violet	Red
39	Orange	White	Black	3,000	Orange	Black	Red
43	Yellow	Orange	Black	3,300	Orange	Orange	Red
47	Yellow	Violet	Black	3,500	Orange	Green	Red
50	Green	Black	Black	3,600	Orange	Blue	Red
51	Green	Brown	Black	3,900	Orange	White	Red
56	Green	Blue	Black	4,000	Yellow	Black	Red
62	Blue	Red	Black	4,300	Yellow	Orange	Red
68	Blue	Grey	Black	4,500	Yellow	Green	Red
75	Violet	Green	Black	4,700	Yellow	Violet	Red
82	Grey	Red	Black	5,000	Green	Black	Red
91	White	Brown	Black	5,100	Green	Brown	Red
100	Brown	Black	Brown	5,600	Green	Blue	Red
110	Brown	Brown	Brown	6,000	Blue	Black	Red
120	Brown	Red	Brown	6,200	Blue	Red	Red
130	Brown	Orange	Brown	6,800	Blue	Grey	Red
150	Brown	Green	Brown	7,000	Violet	Black	Red
160	Brown	Blue	Brown	7,500	Violet	Green	Red
180	Brown	Grey	Brown	8,000	Grey	Black	Red
200	Red	Black	Brown	8,200	Grey	Red	Red
220	Red	Red	Brown	9,000	White	Black	Red
240	Red	Yellow	Brown	9,100	White	Brown	Red
250	Red	Green	Brown	10,000	Brown	Black	Orange
270	Red	Violet	Brown	11,000	Brown	Brown	Orange
300	Orange	Black	Brown	12,000	Brown	Red	Orange
330	Orange	Orange	Brown	13,000	Brown	Orange	Orange
350	Orange	Green	Brown	15,000	Brown	Green	Orange
360	Orange	Blue	Brown	16,000	Brown	Blue	Orange
390	Orange	White	Brown	18,000	Brown	Grey	Orange
400	Yellow	Black	Brown	20,000	Red	Black	Orange
430	Yellow	Orange	Brown	22,000	Red	Red	Orange
450	Yellow	Green	Brown	24,000	Red	Yellow	Orange
470	Yellow	Violet	Brown	27,000	Red	Violet	Orange
500	Green	Black	Brown	30,000	Orange	Black	Orange
510	Green	Brown	Brown	33,000	Orange	Orange	Orange
560	Green	Blue	Brown	35,000	Orange	Green	Orange
620	Blue	Red	Brown	36,000	Orange	Blue	Orange
680	Blue	Grey	Brown	39,000	Orange	White	Orange
700	Violet	Black	Brown	40,000	Yellow	Black	Orange
750	Violet	Green	Brown	43,000	Yellow	Orange	Orange

READY-WORKED RESISTANCE COLOUR CODE (*contd.*)

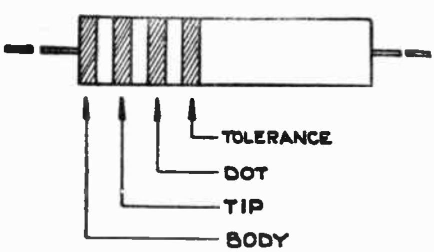
Ohms	*Body*	*Tip*	*Dot*	*Ohms*	*Body*	*Tip*	*Dot*
47,000	Yellow	Violet	Orange	390,000	Orange	White	Yellow
50,000	Green	Black	Orange	400,000	Yellow	Black	Yellow
51,000	Green	Brown	Orange	430,000	Yellow	Orange	Yellow
56,000	Green	Blue	Orange	450,000	Yellow	Green	Yellow
60,000	Blue	Black	Orange	470,000	Yellow	Violet	Yellow
62,000	Blue	Red	Orange	500,000	Green	Black	Yellow
68,000	Blue	Grey	Orange	510,000	Green	Brown	Yellow
70,000	Violet	Black	Orange	560,000	Green	Blue	Yellow
75,000	Violet	Green	Orange	600,000	Blue	Black	Yellow
82,000	Grey	Red	Orange	620,000	Blue	Red	Yellow
91,000	White	Brown	Orange	680,000	Blue	Grey	Yellow
100,000	Brown	Black	Yellow	750,000	Violet	Green	Yellow
110,000	Brown	Brown	Yellow	820,000	Grey	Red	Yellow
120,000	Brown	Red	Yellow	910,000	White	Brown	Yellow
130,000	Brown	Orange	Yellow	1 MΩ	Brown	Black	Green
150,000	Brown	Green	Yellow	1·1 MΩ	Brown	Brown	Green
160,000	Brown	Blue	Yellow	1·2 MΩ	Brown	Red	Green
180,000	Brown	Grey	Yellow	1·3 MΩ	Brown	Orange	Green
200,000	Red	Black	Yellow	1·5 MΩ	Brown	Green	Green
220,000	Red	Red	Yellow	1·6 MΩ	Brown	Blue	Green
230,000	Red	Orange	Yellow	1·8 MΩ	Brown	Grey	Green
240,000	Red	Yellow	Yellow	2 MΩ	Red	Black	Green
250,000	Red	Green	Yellow	2·2 MΩ	Red	Red	Green
270.000	Red	Violet	Yellow	2·4 MΩ	Red	Yellow	Green
280,000	Red	Grey	Yellow	2·7 MΩ	Red	Violet	Green
300,000	Orange	Black	Yellow	3 MΩ	Orange	Black	Green
330,000	Orange	Orange	Yellow	4 MΩ	Yellow	Black	Green
350,000	Orange	Green	Yellow	5 MΩ	Green	Black	Green
360,000	Orange	Blue	Yellow	10 MΩ	Brown	Black	Blue

THE RESISTANCE COLOUR CODE (British and U.S.A.)

Colour	*Body*	*Tip*	*Dot*	*Colour*	*Body*	*Tip*	*Dot*
Black	0	0	·0	Green	5	5	00000
Brown	1	1	0	Blue	6	6	000000
Red	2	2	00	Violet	7	7	0000000 (U.S.A. only)
Orange	3	3	000	Grey	8	8	00000000 (U.S.A. only)
Yellow	4	4	0000	White	9	9	000000000 (U.S.A. only)



The body colour denotes the first digit, the colour of the tip the second digit, and the colour of the spot the number of noughts after the second digit.



The modified colour code used for resistances with axial leads.

READY-WORKED REACTANCE TABLE (in ohms)

A.F. INDUCTIVE

Inductance in Henrys	30 *cps.*	50 *cps.*	100 *cps.*	400 *cps.*	1,000 *cps.*	3,000 *cps.*	5,000 *cps.*
100	18,800	31,400	62,800	251,000	628,000	1,880,000	3,140,000
75	14,130	23,550	47,100	188,400	471,000	1,413,000	2,355,000
50	9,420	15,700	31,400	126,000	314,000	942,000	1,570,000
25	4,710	7,850	15,700	62,800	157,000	471,000	785,000
10	1,880	3,140	6,280	25,100	62,800	188,000	314,000
1	188	314	628	2,510	6,280	18,800	31,400
·1	18·8	31·4	62·8	251	628	1,880	3,140
·01	1·88	3·14	6·28	25·1	62·8	188	314
·001	·188	·314	·628	2·51	6·28	18·8	31·4

A.F. CAPACITIVE

Capacity	30 *cps.*	50 *cps.*	100 *cps.*	400 *cps.*	1,000 *cps.*	3,000 *cps.*	5,000 *cps.*
50 pf.					3·18 MΩ	1·06 MΩ	637,000
100 pf.				3·98 MΩ	1·59 MΩ	531,000	318,000
250 pf.			6·37 MΩ	1·59 MΩ	637,000	212,000	127,000
300 pf.		10·6 MΩ	5·31 MΩ	1·33 MΩ	531,000	174,000	106,000
500 pf.	10·6 MΩ	6·37 MΩ	3·18 MΩ	796,000	318,000	106,000	63,700
·001 mfd.	5·3 MΩ	3·18 MΩ	1·59 MΩ	398,000	159,000	53,100	31,800
·005 mfd.	1·06 MΩ	637,000	318,000	79,600	31,800	10,600	6,370
·01 mfd.	531,000	318,000	159,000	39,800	15,900	5,310	3,180
·02 mfd.	265,000	159,000	79,600	19,900	7,960	2,650	1,590
·025 mfd.	212,000	127,000	63,700	15,900	6,370	2,120	1,270
·03 mfd.	174,000	106,000	53,100	13,300	5,310	1,740	1,060
·05 mfd.	106,000	63,700	31,800	7,960	3,180	1,060	637
·1 mfd.	53,100	31,800	15,900	3,980	1,590	531	318
·25 mfd.	21,200	12,700	6,370	1,590	637	212	127
·5 mfd.	10,600	6,370	3,180	796	318	106	63·7
1·0 mfd.	5,310	3,180	1,590	398	159	53·1	31·8
2·0 mfd.	2,650	1,590	796	199	79·6	26·5	15·9
25·0 mfd.	212	127	63·7	15·9	6·37	2·12	1·27
50·0 mfd.	106	63·7	31·8	7·96	3·18	1·06	·637

R.F. INDUCTIVE

Inductance	100 *Kcs.*	250 *Kcs.*	465 *Kcs.*	500 *Kcs.*	1,000 *Kcs.*	1,500 *Kcs.*	5,000 *Kcs.*
·1H	62,800	157,000	292,000	314,000	628,000	943,000	3,140,000
·01H	6,280	15,700	29,200	31,400	62,800	94,300	314,000
1,000 μH	628	1,570	2,920	3,140	6,280	9,430	31,400
200 μH	126	315	484	630	1,260	1,890	6,300
100 μH	62	157	292	314	628	943	3,140
50 μH	31	78	146	157	314	476	1,570

R.F. CAPACITIVE

Capacity	100 *Kcs.*	250 *Kcs.*	465 *Kcs.*	500 *Kcs.*	1,000 *Kcs.*	1,500 *Kcs.*	5,000 *Kcs.*
10 pf.	159,000	636,000	34,200	31,800	15,900	10,600	3,180
50 pf.	31,800	12,720	6,850	6,360	3,180	2,120	636
100 pf.	15,900	6,360	3,420	3,180	1,590	1,060	318
500 pf.	3,180	1,272	685	636	318	212	63·6
·001 mfd	1,590	636	342	318	159	106	31·8
·005 mfd	318	127·2	68·5	63·6	31·8	21·2	6·36
·01 mfd	159	63·6	34·2	31·8	15·9	10·6	3·18
·05 mfd	31·8	12·72	6·85	6·36	3·18	2·12	·636
·1 mfd	15·9	6·36	3·42	3·18	1·59	1·06	·318
·25 mfd	6·36	2·544	1·37	1·272	·636	·424	·127
·5 mfd	3·18	1·272	·685	·636	·318	·212	·064
1·0 mfd	1·59	·636	·342	·318	·159	·106	·032

READY-WORKED DECIBEL TABLE

LOSS		db	GAIN	
Current or Voltage Ratio	*Power Ratio*		*Current or Voltage Ratio*	*Power Ratio*
1	1	0	1	1
·989	·977	·1	1·012	1·023
·977	·955	·2	1·023	1·047
·966	·933	·3	1·035	1·072
·955	·912	·4	1·047	1·096
·944	·891	·5	1·059	1·122
·933	·871	·6	1·072	1·148
·923	·851	·7	1·084	1·175
·912	·832	·8	1·096	1·202
·902	·813	·9	1·109	1·23
·891	·794	1	1·122	1·259
·871	·759	1·2	1·15	1·32
·851	·724	1·4	1·17	1·38
·832	·692	1·6	1·2	1·44
·813	·661	1·8	1·23	1·51
·794	·631	2	1·26	1·58
·750	·562	2·5	1·34	1·78
·708	·501	3	1·41	1·99
·668	·447	3·5	1·5	2·24
·631	·398	4	1·59	2·51
·596	·355	4·5	1·68	2·82
·562	·316	5	1·78	3·16
·531	·282	5·5	1·88	3·55
·501	·251	6	1·99	3·98
·473	·224	6·5	2·11	4·47
·447	·199	7	2·24	5·01
·422	·178	7·5	2·37	5·62
·398	·158	8	2·51	6·31
·376	·141	8·5	2·66	7·08
·355	·126	9	2·82	7·94
·335	·112	9·5	2·98	8·91
·316	·1	10	3·16	10
·282	·079	11	3·55	12·6
·251	·063	12	3·98	15·8
·224	·05	13	4·47	19·9
·199	·04	14	5·01	25·1
·158	·025	16	6·31	39·8
·126	·016	18	7·94	63·1
·1	·01	20	10	100
·056	·00316	25	17·78	316
·032	·001	30	31·62	1,000
·0178	·000316	35	56·23	3,160
·01	·0001	40	100	10,000
·0056	·0000316	45	177·8	31,600
·00316	·00001	50	316	100,000
·002	·00000316	55	562	316,000
·001	·000001	60	1,000	1,000,000
·0006	·000000316	65	1,770	3,160,000
·000316	·0000001	70	3,160	10,000,000
·0002	·0000000316	75	5,620	31,600,000
·0001	·00000001	80	10,000	100,000,000
·00006	·0000000032	85	17,800	316,000,000
·0000316	·000000001	90	31,600	1,000,000,000
·00002	·0000000003	95	56,200	3,160,000,000
·00001	·0000000001	100	100,000	10,000,000,000

Station	*Channel*		*Polar*[1]	*Vision : mcs.*[2]	*Sound : mcs.*[2]	*Dip.*[3]	*Ref.*[3]	*Space*[4]
Crystal Palace	1	Band I	V	45	41·5	128	133	32
Divis	1		H	45	41·5	128	133	32
Dover Area[5]	2		H	51·75	48·25	111	115·5	27·75
Holme Moss	2		V	51·75	48·25	111	115·5	27·75
Londonderry	2		H	51·75	48·25	111	111·5	27·75
North Hessary Tor	2		V	51·75	48·25	111	115·5	27·75
Rosemarkie	2		H	51·75	48·25	111	115·5	27·75
Truleigh Hill	2		V	51·75	48·25	111	115·5	27·75
Blaen Plwy	3		H	56·75	53·25	101	105	25·25
Kirk o' Shotts	3		V	56·75	53·25	101	105	25·25
Norwich	3		H	56·75	53·25	101	105	25·25
Row Ridge	3		V	56·75	53·25	101	105	25·25
Channel Isles	4		H	61·75	58·25	93	97	23·25
Meldrum	4		H	61·75	58·25	93	97	23·25
Sandale	4		H	61·75	58·25	93	97	23·25
Sutton Coldfield	4		V	61·75	58·25	93	97	23·25
Isle of Man	5		V	66·75	63·25	86	89·5	21·5
Pontop Pike	5		H	66·75	63·25	86	89·5	21·5
Wenvoe	5		V	66·75	63·25	86	89·5	21·5
Litchfield	8	Band III	V	189·75	186·25	30	31·25	7·5
Croydon	9		V	194·75	191·25	29	30	7·25
Winter Hill	9		V	194·75	191·25	29	30	7·25
Blackhill	10		V	199·75	196·25	28	29·25	7
Emley Moor	10		V	199·75	196·25	28	29·25	7
South Wales	10		V	199·75	196·25	28	29·25	7

[1] Polarisation ; V = Vertical, H = Horizontal. [2] Some transmitters are offset by 6·75 kcs. Vision and 20 kcs. Sound to avoid mutual interference. [3] Length of dipole and reflector in inches. [4] Spacing between dipole and reflector. [5] A transmitter may be erected near Dover if Thanet is not adequately served when Crystal Palace is on maximum power.

INSULATING MATERIALS

DIELECTRIC CONSTANTS (*K*)

Substance	*Dielectric Constant**	*Substance*	*Dielectric Constant**
Air	1	Micanite, non-flexible	7
Bakelite	4·4–7·8	Mycalex	8·5
Casein	6·1–6·8	Nylon	3·5–3·7
Celluloid	4–15	Paper, varnished	2–3
Celluloid, photographic	6·6–6·7	Paraffin	2·1–2·4
Cellulose acetate	4·5–5·4	Paraffin oil	2·1–4·7
Cellulose acetate, moulded	3–6	Paraffin wax	2–2·5
Cellulose acetate, sheet	3–4·5	Paraffined paper	2–3·5
Dilectene 100	3·6–3·75	Polyethylene	2·5
Ebonite	2–3·3	Polystyrene	2·5–2·59
Ebonite, P.O. standard	2·8	Polyvinyl chloride	6–12
Empire cloth	2	Porcelain	5·5–6·8
Ethyl cellulose	2–2·9	Pyrex (glass)	4·5–5
Fibre (red)	2·5–4·8	Rubber	2–3·5
Glass	5·1–9·9	Shellac	2·9–3·7
Glass, common window	7·9–8·2	Steatite	6·1
Glass, photographic	7·5	Trolitul	2·2–2·25
Isolantite	6–6·1	Urea-formaldehyde resin	6·6–7·6
Mica	2·5–7·5	Vinylite	3–3·4
Mica, first-quality Indian	6·2–6·7	Wood (dry)	2·5–7·7

* Figures are average, but exceptions will be found outside the tolerances quoted. Temperature and frequency also introduce variation ; above figures are at 1 mcs. with the exception of cellulose, rubber, shellac and wood.

ELECTRICAL CONVERSION TABLE

(For Mechanical Conversion Table, see page 69)

MULTIPLE AND SUB-MULTIPLE CONVERSION

To Convert	*Into*	*Multiply by*	*Conversely, multiply by*
Amps	Milliamps	1,000	·001
Amps	Microamps	1,000,000	·000001
Cycles	Kilocycles	·001	1,000
Cycles	Megacycles	·000001	1,000,000
Farads	Microfarads	1,000,000	·000001
Farads	Micromicrofarads (pf)	1,000,000,000,000	·000000000001
Henrys	Millihenrys	1,000	·001
Henrys	Microhenrys	1,000,000	·000001
Kilocycles	Megacycles	·001	1,000
Millivolts	Microvolts	1,000	·001
Mhos	Micromhos	1,000,000	·000001
Microfarads	Picafarads (pf)	1,000,000	·000001
Ohms	Micro-ohms	1,000,000	·000001
Ohms	Megohms	·000001	1,000,000
Volts	Millivolts	1,000	·001
Volts	Microvolts	1,000,000	·000001
Volts	Kilovolts	·001	1,000
Watts	Milliwatts	1,000	·001
Watts	Microwatts	1,000,000	·000001
Watts	Kilowatts	·001	1,000

INTER-UNIT CONVERSION

Horsepower	Watts	746	·0034
Horsepower	Force de Cheval	1·0139	·986
Horsepower	B.T.U. per minute	42·4	·02357
Micromicrofarads	Centimetres (capacity)	1·1	·9
Microfarads	Centimetres (capacity)	1,100	·0009
Atmospheres	Inches of Mercury	29·92	·03342
Atmospheres	Centimetres of Mercury	76	·01316

PREFIXES USED IN RADIO NUMEROLOGY

Prefix	*Abbreviation*	*Definition*
centi	c	one-hundredth of
mil or milli	m	one-thousandth of
micro	μ	one-millionth of
micromicro	mm or $\mu\mu$	one-millionth of a millionth of
pica	p	one-millionth of a millionth of
kilo	k	one thousand times
meg or mega	M	one million times

SIGNIFICANCE OF INDICES

Expression	*Simple Equivalent*	*Expression*	*Simple Equivalent*
10^1	10	10^{-1}	·1
10^2	100	10^{-2}	·01
10^3	1,000	10^{-3}	·001
10^4	10,000	10^{-4}	·0001
10^5	100,000	10^{-5}	·00001
10^6	1,000,000	10^{-6}	·000001
10^7	10,000,000	10^{-7}	·0000001
10^8	100,000,000	10^{-8}	·00000001
10^9	1,000,000,000	10^{-9}	·000000001
10^{10}	10,000,000,000	10^{-10}	·0000000001

TWIST DRILL SIZES

Drill Number	Dia. (in.)	Drill Number	Dia. (in.)
1	·2280	41	·0960
2	·2210	42	·0935
3	·2130	43	·0890
4	·2090	44	·0860
5	·2055	45	·0820
6	·2040	46	·0810
7	·2010	47	·0785
8	·1990	48	·0760
9	·1960	49	·0730
10	·1935	50	·0700
11	·1910	51	·0670
12	·1890	52	·0635
13	·1850	53	·0595
14	·1820	54	·0550
15	·1800	55	·0520
16	·1770	56	·0465
17	·1730	57	·0430
18	·1695	58	·0420
19	·1660	59	·0410
20	·1610	60	·0400
21	·1590	61	·0390
22	·1570	62	·0380
23	·1540	63	·0370
24	·1520	64	·0360
25	·1495	65	·0350
26	·1470	66	·0330
27	1440	67	·0320
28	·1405	68	·0310
29	·1360	69	·0293
30	·1285	70	·0280
31	·1200	71	·0260
32	·1160	72	·0250
33	·1130	73	·0240
34	·1110	74	·0225
35	·1100	75	·0210
36	·1065	76	·0200
37	·1040	77	·0180
38	·1015	78	·0160
39	·0995	79	·0145
40	·0980	80	·0135

FRACTIONS—DECIMAL—MILLIMETRE EQUIVALENTS

Fraction of inch	Decimal of inch	Millimetre	Fraction of inch	Decimal of inch	Millimetre
1/64	·0156	·397	33/64	·5156	13·097
1/32	·0313	·794	17/32	·5313	13·494
3/64	·0469	1·191	35/64	·5469	13·891
1/16	·0625	1·588	9/16	·5625	14·287
5/64	·0781	1·985	37/64	·5781	14·684
3/32	·0938	2·381	19/32	·5938	15·081
7/64	·1094	2·778	39/64	·6094	15·478
1/8	·1250	3·175	5/8	·6250	15·875
9/64	·1406	3·572	41/64	·6406	16·272
5/32	·1563	3·969	21/32	·6563	16·668
11/64	·1719	4·366	43/64	·6719	17·065
3/16	·1875	4·762	11/16	·6875	17·462
13/64	·2031	5·159	45/64	·7031	17·859
7/32	·2188	5·556	23/32	·7188	18·256
15/64	·2344	5·953	47/64	·7344	18·653
1/4	·2500	6·350	3/4	·7500	19·050
17/64	·2656	6·747	49/64	·7656	19·447
9/32	·2813	7·144	25/32	·7813	19·843
19/64	·2969	7·541	51/64	·7969	20·240
5/16	·3135	7·937	13/16	·8125	20·637
21/64	·3281	8·334	53/64	·8281	21·034
11/32	·3438	8·731	27/32	·8438	21·430
23/64	·3594	9·128	55/64	·8594	21·827
3/8	·3750	9·525	7/8	·8750	22·224
25/64	·3906	9·922	57/64	·8906	22·621
13/32	·4063	10·319	29/32	·9063	23·018
27/64	·4219	10·716	59/64	·9219	23·415
7/16	·4375	11·120	15/16	·9375	23·812
29/64	·4531	11·509	61/64	·9531	24·209
15/32	·4688	11·906	31/32	·9688	24·606
31/64	·4844	12·303	63/64	·9844	25·003
1/2	·5000	12·700	1	1·0000	25·400

WHITWORTH SCREWS

Size (in.)	Turns per inch	Tapping Drill
1/8	40	41
3/16	24	29
1/4	20	12
5/16	18	1/4"
3/8	16	5/16"
1/2	12	13/32"
5/8	11	17/32"
3/4	10	5/8"
1	8	7/8"

B.S.F. SCREWS

Size (in.)	Turns per inch	Tapping Drill
7/32	28	13/64
1/4	26	7/32
9/32	26	17/64
5/16	22	9/32
3/8	20	11/32
7/16	18	13/32
1/2	16	3/8
9/16	16	7/16
5/8	14	1/2

B.A. SCREWS

B.A. Number	*Diameter*	*Core Diam.*	*Turns per inch*	*Clearing Drill*	*Tapping Drill*
0	·2362	·189	25·4	¼"	9
1	·2087	1661	28·2	2	17
2	·185	·1469	31·4	10	24
3	·1614	·1268	34·8	18	29
4	·1417	·1106	38·5	25	32
5	·126	·098	43·0	29	37
6	·1102	·085	47·9	32	43
7	·0984	·0756	52·9	37	46
8	·0866	·0661	59·1	42	50
9	·0748	·0563	65·1	46	53
10	·0669	·0504	72·6	49	54
11	·0591	·0445	81·9	52	56
12	·0512	·0378	90·7	54	60
13	·0472	·0354	101·0	55	63
14	·0394	·0283	110·0	58	68
15	·0354	·0256	121·0	62	70

Tapping Drill sizes are recommended for brass. For soft substances use the next smaller size drill.

WOOD SCREWS

Gauge Number	*Shank Diam.*	*Clearing Drill*
1	·066	48
2	·080	43
3	·094	38
4	·108	32
5	·122	29
6	·136	26
7	·150	21
8	·164	17
9	·178	14
10	·192	9
11	·206	4
12	·220	1
13	·234	¼"

Where danger of splitting is great, use next larger size drill.

AMERICAN SCREWS

(As used in Radio Manufacture)

Size Number	*Diameter*	*Tapping Drill*
2–56	·0860	49
3–48	·0990	44
4–40	·1120	43
5–40	·1250	36
6–32	·1380	33
8–32	·1640	28
10–24	·1900	23
10–32	·1900	20
12–24	·2160	17
¼–20	·2500	7

MECHANICAL CONVERSION TABLE

To Convert	*Into*	*Multiply by*	*Conversely, multiply by*
Centigrade	Fahrenheit	$(C^{\circ} \times \frac{9}{5}) + 32$	$(F^{\circ} - 32) \times \frac{5}{9}$
Cubic inches	Cubic centimetres	16·39	·06102
Gallons (British)	Gallons (U.S.A.)	1·20094	·83268
Grams	Grains	15·432	·0648
Grams	Ounces (a.d.p.)	·03527	28·35
Inches	Centimetres	2·54	·3937
Inches of mercury	Lbs. per sq. in.	·49116	2·0360
Knots	Miles	1·152	·86836
Litres	Pints	1·76	·5682
Metres	Feet	3·2808	·3048
Metres	Yards	1·094	·9144
Metres per minute	Feet per minute	3·281	·3048
Miles per hour	Feet per minute	88	·01136
Miles per hour	Feet per second	1·467	·6818
Sq. inches	Sq. centimetres	6·452	·1550
Watts	B.T.U. per minute	·05688	17·58
Watts	Horse-power	·00134	745·7

READY-WORKED METER SHUNT AND SERIES RESISTANCE TABLE

The table below gives values of shunt resistance for increasing the current range of a milliammeter and the values of series resistance for converting a milliammeter into a voltmeter to cover various ranges. A practical example of this technique is given on page 50. The internal resistance of the milliammeter is a controlling factor. The average 0–1 milliammeter, for example, has an internal resistance of something less than 50 ohms; in drawing up the tables below the author intends that the resistance of the meter shall either be made up to 100 ohms by the use of a suitable series resistance, or, preferably, be made up to 50 ohms with an additional 50 ohms added, the latter being provided with a press-button shorting switch, so that its depression will double the meter reading when desired. By incorrect switching arrangements, serious errors can be introduced by switch contact resistance; attention is therefore drawn to page 12, Vol. III, of *Modern Practical Radio and Television.*

Required Voltage Range (volts)	*Series Resistance in Ohms for Milliammeter with range as below*				
	1 mA	*2 mA*	*3 mA*	*5 mA*	*10 mA*
2	*1,900	*900	566	300	*100
3	2,900	1,400	*900	500	200
5	*4,900	2,400	1,560	*900	*400
10	*9,900	*4,900	3,230	*1,900	*900
15	15,000	7,400	*4,900	2,900	1,400
20	*20,000	*9,900	6,560	3,900	*1,900
30	30,000	15,000	*9,900	5,900	2,900
50	*50,000	25,000	16,600	*9,900	*4,900
100	*100,000	*50,000	33,300	*20,000	*9,900
150	150,000	75,000	*50,000	30,000	15,000
200	*200,000	*100,000	66,600	40,000	*20,000
300	300,000	150,000	*100,000	60,000	30,000
500	*500,000	250,000	166,000	*100,000	*50,000
1,000	*1,000,000	*500,000	333,000	*200,000	*100,000

Note.—The above resistance values have been adjusted to convenient values so far as possible consistent with a maximum error not exceeding 1 per cent. Figures marked with asterisk indicate ranges that read conveniently on the meter scale.

SHUNT RESISTANCE IN OHMS FOR MILLIAMMETER WITH TOTAL RESISTANCE OF 100 OHMS

Multiplying Factor		*Multiplying Factor*		*Multiplying Factor*		*Multiplying Factor*	
2	100	10	11·11	60	1·695	400	·251
4	33·33	20	5·26	80	1·266	500	2
5	25	30	3·45	100	1·01	600	·167
6	20	40	2·56	200*	·503	800	·125
8	14·29	50	2·04	300	·334	1,000	·1

* It is inadvisable to attempt multiplication factors above 100 unless fully conversant with test gear and very low resistance shunts.

COMPARATIVE RESISTANCE

Material	*Relative Resistance*
Copper	1
German silver	11·7–18·5
Eureka	30 average
Nichrome	55 average
Silver	·94
Silicon bronze	1·5
Aluminium	1·6
Nickel	4·3
Phosphor bronze	4·4
Manganin	27

RESISTIVITY, ρ OF METALS

Material	*μ Ohms per cu. cm. at 0° C.*
Copper, standard	1·589
Copper, hard-drawn	1·6
Eureka	48 average
Nichrome	112 average
Silver	1·47
Aluminium	2·67
Nickel	12·32
Manganin	42 average
German silver	21 average
Iron, annealed	9·07

SULPHURIC ACID TABLE

(Quantities by Volume)

1·350 Sp. Gr.	= 1 part acid to	2·3	parts distilled water.
1·300 ,, ,,	= 1 ,, ,, ,,	2·8	,, ,, ,,
1·250 ,, ,,	= 1 ,, ,, ,,	3·6	,, ,, ,,
1·200 ,, ,,	= 1 ,, ,, ,,	5·0	,, ,, ,,
1·150 ,, ,,	= 1 ,, ,, ,,	7·0	,, ,, ,,

Note.—Above table assumes undiluted acid to be 1·840 Sp. Gr. Always add acid to water; the reverse procedure is most dangerous.

ACCUMULATOR DISCHARGE TABLE *

Fully charged	= 1·250 Sp. Gr.	at 60° F.
,, ,,	= 1·246 ,, ,,	,, 70° F.
,, ,,	= 1·242 ,, ,,	,, 80° F.
Half discharged	= 1·180 ,, ,,	,, 60° F.
,, ,,	= 1·176 ,, ,,	,, 70° F.
,, ,,	= 1·173 ,, ,,	,, 80° F.
Discharged	= 1·110 ,, ,,	,, 60° F.
,,	= 1·107 ,, ,,	,, 70° F.
,,	= 1·105 ,, ,,	,, 80° F.

* Varies slightly with different makers.

ESTIMATION OF TEMPERATURE BY COLOUR

Black red	= 900° F.	= 500° C.
Deep red	= 1,000° F.	= 525° C.
Red	= 1,400° F.	= 775° C.
Brilliant red	= 1,550° F.	= 850° C.
Vivid orange	= 1,725° F.	= 950° C.
Yellow	= 1,825° F.	= 1,000° C.
Whitish yellow	= 1,975° F.	= 1,100° C.
White	= 2,200° F.	= 1,200° C.
Blinding white	= 2,800° F.	= 1,500° C.

ESTIMATION OF SOUND INTENSITY

0 db = Threshold of normal hearing.
10 db = Very quiet but unmistakable sound.
20 db = Kettle boiling at 6 ft. away.
30 db = Sewing machine in adjoining room (door open).
40 db = Moderate radio set in adjoining room.
50 db = Traffic noise on main road with closed windows.
75 db = Very busy suburban main road.
100 db = Road drill other side of road.
125 db = Shattering noise, e.g. unsilenced motor-engine fully revved in small confined space; feeling of discomfort begins to be apparent.
over 125 db At noise-levels 130–140 db, pain rather than hearing is experienced.

Note.—The above indications of sound-intensity are obviously wide approximations; they are the result of measurement in a South-west London suburb, using a microphone. The ear, however, will be greatly influenced by the nature of the sound, e.g. a person singing out of tune may give the impression of being louder than a more pleasing sound of equal intensity; also the human ear is not linear to frequency.

CLIMATIC DATA

Miscellaneous information useful when considering overseas requirements or when erecting large aerial masts.

TEMPERATURES

British Isles	= Max. 100° F.	Min. 4° F.
Europe (excluding U.S.S.R.)	= ,, 125° F.	,, − 50° F.
Africa	= ,, 136° F.	,, 0° F.
Australia	= ,, 127° F.	,, 19° F.
Asia	= ,, 125° F.	,, − 90° F.
North America	= ,, 120° F.	,, − 70° F.
New Zealand	= ,, 95° F.	,, 23° F.
South America	= ,, 115° F.	,, − 25° F.
U.S.A.	= ,, 134° F.	,, − 66° F.
U.S.S.R.	= ,, 110° F.	,, − 90° F.

WIND VELOCITY AND PRESSURE

10 m.p.h.	= ·23 lb. per sq. ft.	on cylindrical surface
20 ,,	= ·8 ,, ,, ,, ,,	,, ,,
30 ,,	= 1·7 ,, ,, ,, ,,	,, ,,
50 ,,	= 4·2 ,, ,, ,, ,,	,, ,,
75 ,,	= 8·7 ,, ,, ,, ,,	,, ,,
100 ,,	= 14·5 ,, ,, ,, ,,	,, ,,
125 ,,	= 21·9 ,, ,, ,, ,,	,, ,,
150 ,,	= 30·9 ,, ,, ,, ,,	,, ,,
175 ,,	= 41·4 ,, ,, ,, ,,	,, ,,
200 ,,	= 53·5 ,, ,, ,, ,,	,, ,,
10 ,,	= ·4 lb. per sq. ft.	on flat surface
20 ,,	= 1·3 ,, ,, ,, ,,	,, ,,
30 ,,	= 2·8 ,, ,, ,, ,,	,, ,,
50 ,,	= 9·7 ,, ,, ,, ,,	,, ,,
75 ,,	= 14·5 ,, ,, ,, ,,	,, ,,
100 ,,	= 24·3 ,, ,, ,, ,,	,, ,,
125 ,,	= 36·9 ,, ,, ,, ,,	,, ,,
150 ,,	= 51·9 ,, ,, ,, ,,	,, ,,
175 ,,	= 69·5 ,, ,, ,, ,,	,, ,,
200 ,,	= 89·8 ,, ,, ,, ,,	,, ,,

HUMIDITY

Humidity varies so widely in relatively small areas that brief data is meaningless, but in certain parts of the world humidity is as high as 99 per cent. Its effect on radio receivers may be controlled by spraying with nitrocellulose lacquer. For use in non-built-up areas about 2 per cent. of pentachloral-phenol may be added as a fungus deterrent.

READY-WORKED NUMERICAL VALUES

$\pi = 3{\cdot}1416$	$2\pi = 6{\cdot}2832$
$\pi^2 = 9{\cdot}8696$	$\frac{1}{2\pi} = {\cdot}1592$
$\frac{1}{\pi} = {\cdot}3183$	$\sqrt{2} = 1{\cdot}4142$
$\frac{1}{\pi^2} = {\cdot}1013$	$\sqrt{3} = 1{\cdot}7321$
$\sqrt{\pi} = 1{\cdot}7725$	$\frac{1}{\sqrt{2}} = {\cdot}7071$
$\frac{1}{\sqrt{\pi}} = {\cdot}5642$	$\frac{1}{\sqrt{3}} = {\cdot}5773$

Area of circle	$= \pi r^2$
Area of triangle	$= \text{Base} \times \frac{1}{2}H$
Area of cylinder	$= 2\pi rH$
Volume of sphere	$= \frac{4}{3}\pi r^3$
Volume of cylinder	$= \pi r^2 H$
Volume of cone	$= \frac{\pi r^2 H}{3}$

VARIATIONS IN WORLD TIME

Local time is given in considerable detail below owing to its great value when identifying foreign stations. Up-to-date information of this kind and up-to-date frequency changes are given in the *Short-Wave News*, published by The Amalgamated Short-Wave Press Ltd., 57 Maida Vale, W.9.

Country	*To G.M.T.* ADD *Hrs. Mins.*	*From G.M.T.* TAKE *Hrs. Mins.*
Aden	3 00	—
Afghanistan	4 00	—
Albania	1 00	—
Algeria	No	change
Argentine	—	4 00
Australia, N.S.W., Victoria	10 00	—
,, Queensland	9 30	—
,, Western	8 00	—
Bahamas	—	5 00
Barbados	—	4 00
Bechuanaland	2 00	—
Belgian Congo (Leopoldville)	1 00	—
,, ,, (Stanleyville)	2 00	—
Belgium	No	change
Bermuda	—	4 00
Bolivia	—	4 33
Borneo, North	8 00	—
,, Dutch	7 30	—
Brazil	—	3 00
British Guiana	—	3 45
British Honduras	—	6 00
Bulgaria	2 00	—
Burma	6 30	—
Canada:		
New Brunswick, Nova Scotia	—	4 00
Quebec, Ontario	—	5 00
Manitoba	—	6 00
Alberta, Saskatchewan	—	7 00
British Columbia	—	8 00
Yukon Territory	—	9 00
Ceylon	5 00	—
Chile	—	4 00
China, Eastern	8 00	—
,, Central and Western	7 00	—
Colombian Republic	—	5 00
Costa Rica	—	5 00
Cuba	—	5 00
Cyprus	2 00	—
Czechoslovakia	1 00	—
Denmark	1 00	—
Ecuador, Guayaguil	—	5 19
,, all other parts	—	5 14
Egypt	2 00	—
El Salvador	—	6 00
Estonia	2 00	—
Ethiopia	3 00	—
Finland	2 00	—
France	No	change
French Cameroons	1 00	—
,, Equatorial Africa	1 00	—
,, Guiana	—	4 00
,, Indo-China	7 00	—
Gambia	—	1 00
Germany	1 00	—
Gold Coast	No	change
Greece	2 00	—
Greenland	—	3 00
Hawaiian Islands	—	9 30
Honduras	—	6 00
Hungary	1 00	—
India	5 30	—
Iran	3 00	—
Iraq	3 00	—
Italy	1 00	—
Jamaica	—	5 00
Japan	9 00	—
Java	7 30	—
Kenya	2 30	—
Korea	9 00	—
Latvia	2 00	—
Liberia	—	44
Libya	1 00	—
Lithuania	1 00	—
Madagascar	3 00	—
Malay States	7 20	—
Malta	1 00	—
Manchukuo	8 00	—
Mexico	—	6 00
Mongolia	7 00	—
Mozambique	2 00	—
Netherlands	20	—
Newfoundland	—	3 30
New Guinea (Dutch)	9 00	—
,, ,, (British)	10 00	—
New Zealand	11 30	—
Nigeria	1 00	—
Norway	1 00	—
Palestine	2 00	—
Panama	—	5 00
Paraguay	—	4 00
Peru	—	5 00
Poland	1 00	—
Portugal	No	change
Rhodesia, North	2 00	—
,, South	2 00	—
Rumania	2 00	—
Saudi Arabia	3 00	—
Senegal	—	1 00
Sierra Leone	—	1 00
Solomon Islands	10 00	—
Somaliland (Fr. and Brit.)	3 00	—
South-West Africa	2 00	—
Spain	No	change
Sudan	2 00	—
Sweden	1 00	—
Switzerland	1 00	—
Syria	2 00	—
Tanganyika	3 00	—
Thailand	7 00	—
Transjordan	2 00	—
Trinidad and Tobago	—	4 00
Tunisia	1 00	—
Turkey	2 00	—
Union of South Africa	2 00	—
U.S.S.R., European	3 00	—
,, Ukraine (Kiev)	4 00	—
,, Ural Area (Sverdlovsk)	5 00	—
,, Usbek (Tashkent)	6 00	—
,, Siberian Area (Novo-Sibursk)	7 00	—
,, Siberian Area (Irkutsk)	8 00	—
,, Asiatic Repb. (Chita, etc.)	9 00	—
,, Asiatic Repb. (Vladivostok)	10 00	—
U.S.A., Atlantic Coast	—	5 00
,, Central States	—	6 00
,, Mid-Western States	—	7 00
,, Pacific Coast	—	8 00
Uruguay	—	3 30
Venezuela	—	4 30
Yugoslavia	1 00	—

SYMBOLS

Note.—Symbols used are those in daily use and are not necessarily idealistic.

GENERAL SYMBOLS

Admittance	Y, y	Magnetic field	H
Ampere	A	Magnetic flux	Φ
Amplification factor	μ, m	Magnetic flux density	B
Angular velocity ($2\pi f$)	ω	Magneto motive force	F
Anode A.C. resistance (impedance)	R_a	Magnification of tuned circuit	Q
Anode current	I_a	Mutual inductance	M
Anode current inductance	L_a	Number of plates, turns, etc.	N, n
Anode voltage	V_a	Ohm	Ω
Capacity	C	Period	T
Conductance	G. g	Permeability	μ
Conductivity	γ	Phase displacement or angle	ϕ
Current (instantaneous)	i	Power output	P_o
Current (R.M.S.)	I	Reactance	X
Dielectric constant	K	Reactance, capacitive	X_c
E.M.F.	E	Reactance, inductive	X_L
E.M.F. (instantaneous)	e	Reluctivity	v
Energy	W	Resistance	R
Farad	F	Resistance, H.F.	r
Frequency	f	Resistivity	ρ
Grid circuit inductance	L_g	Susceptance	b
Grid current	I_g	Time	t
Grid voltage	V_g	Velocity	v
Henry	H	Volt	V
Impedance	Z	Watt	W
Inductance	L	Wavelength	λ

VALVE SYMBOLS *

Amplification factor	μ m	Conversion conductance	g_c
Anode current	I_a	Filament current	I_f
Anode impedance	R_a	Filament voltage	V_f
Anode voltage	V_a	Grid current	I_g
Capacity, anode cathode	C_{ac}	Grid input impedance	Z_g
Capacity, anode output	C_a	Grid voltage	V_g
Capacity, grid anode	C_{ga}	Optimum load	R_o
Capacity, grid cathode	C_{gc}	Screen current	I_{sg}
Capacity, grid input	C_g	Screen voltage	V_{sg}
Cathode current	I_c	Slope	g_m
Cathode voltage	V_c	Transconductance (U.S.A.)	g_m

* A new system of valve symbolisation has been introduced by the B.V.A. and will doubtless pass into general usage in due course; that shown has been in use for many years and, with slight variation, will be found in most text-books.

MATHEMATICAL SYMBOLS

Is equal to	$=$	Less than	$<$
Is not equal to	$\neq$	Not less than	$\nless$
Is approx. equal to	$\doteqdot$	The sum of	Σ
Is the same as	$\equiv$	General symbol of an angle	θ
The difference between	$\sim$	A small difference	δ
Varies as; is proportional to	$\propto$	Angle	$\angle$
Greater than	$>$	An unknown quantity	x
Not greater than	$\ngtr$	Angular velocity; $2\pi f$	ω

C.G.S. MECHANICAL SYMBOLS

Length	(cm.)	l	Force	(dyne)	F
Mass	(gm.)	m	Work	(erg)	W
Time	(sec.)	t	Energy	(erg)	W
Surface	(sq. cm.)	A	Power	(erg per sec.)	P
Volume	(cu. cm.)	V	Pressure	(dynes per sq. cm.)	p
Velocity	(cm. per sec.)	v	Angle	(radian)	ϕ
Acceleration	(cm. per sec.)	a	Angular velocity	(radians per sec.)	ω

DIRECTORY OF RADIO AND ELECTRICAL INSTITUTIONS AND ASSOCIATIONS

BRITISH INSTITUTION OF RADIO ENGINEERS
General Secretary : G. D. Clifford, F.C.C.S., 9 Bedford Square, London, W.1. (Museum 1901–3.)

INSTITUTION OF ELECTRICAL ENGINEERS
Secretary : W. K. Brasher, Savoy Place, Victoria Embankment, London, W.C.2. (Temple Bar 7676.)

THE TELEVISION SOCIETY
Joint Secretary : G. Parr, 68 Compton Road, London, N.21. (Laburnum 4123.)

INCORPORATED RADIO SOCIETY OF GREAT BRITAIN
Secretary : J. Clarricoats, O.B.E., New Ruskin House, Little Russell Street, London, W.C.1. (Holborn 7373.

INSTITUTION OF RADIO ENGINEERS, AUSTRALIA
Secretary : N. S. Gilmour, Box 3120, G.P.O., Sydney, Australia.

INSTITUTE OF RADIO ENGINEERS (INC.)
330 West 42nd Street, New York.

RADIO TRADES' EXAMINATION BOARD
9 Bedford Square, London, W.1. (Museum 1901–3.)

CITY AND GUILDS OF LONDON INSTITUTE
Dept. of Technology, 31 Brechin Place, South Kensington, S.W.7. (Freemantle 1121.)

RADIO INDUSTRY COUNCIL:

BRITISH RADIO EQUIPMENT MANUFACTURERS' ASSOCIATION
59 Russell Square, London, W.C.1. (Museum 6901–5.)

BRITISH RADIO VALVE MANUFACTURERS' ASSOCIATION
Piccadilly House, 16 Jermyn Street, London, S.W.1. (Regent 5168.)

RADIO COMMUNICATION AND ELECTRONIC ENGINEERING ASSOCIATION
59 Russell Square, London, W.C.1. (Museum 6901-5.)

RADIO COMPONENT MANUFACTURERS' FEDERATION
22 Surrey Street, Strand, London, W.C.2. (Temple Bar 6740.)

RADIO AND TELEVISION RETAILERS' ASSOCIATION
18 Woburn Square, London, W.C.1. (Museum 3987.)

SCOTTISH RADIO RETAILERS' ASSOCIATION
4 Forres Street, Edinburgh 3.

NORTHERN IRELAND RADIO RETAILERS' ASSOCIATION
20 Victoria Street, Belfast. (Belfast 26631 and 21109.)

WIRELESS DEALERS' ASSOCIATION
29–30 Dame Street, Dublin. (Dublin 71693.)

INSTITUTE OF PUBLIC ADDRESS ENGINEERS
18 Woburn Square, London, W.C.1. (Museum 3987.)

BRITISH STANDARDS INSTITUTION
28 Victoria Street, London, S.W.1. (Abbey 3333.)

BRITISH "WIRELESS FOR THE BLIND" FUND
226 Great Portland Street, London, W.1. (Euston 5251.)

VALVE BASES AND CONNECTIONS

Every care has been taken in compiling the information given below; it will be realised that the author is dependent, in many cases, upon information received from various sources; errors may therefore exist and no liability can be accepted.

The valves listed are "current" and "replacement" types catalogued by selected valve manufacturers and used in both radio and television receivers. The symbols in the diagrams are largely self-explanatory but are listed below for convenience. When there is more than one *similar* electrode, they are, when necessary, distinguished by a dash; for example, the symbols a′ a″, k′ k″ imply that anode a′ is associated with cathode k′ whereas anode a″ is associated with cathode k″.

a	anode	ic	internal connection
bp	beam-forming plates	k	cathode
def	target deflector	m	metalising
f	filament	s	internal shield
g	grid	t	magic eye target
h	heater	ts	target screen

An *isolated* figure indicates that a pin so marked is connected internally to the pin corresponding to the number used; valve pins are deemed to be numbered starting with No. 1 at the bottom centre, but when there is no pin in this position numbering starts at 7 o'clock. These numbers must not be confused with subscript numbers such as g_3 used to denote the positions of grids in a multi grid valve; in line with usual practice, such grids are numbered starting with No. 1 nearest to the filament or cathode. For example, the grids of a pentode are numbered in the following manner. Control grid g_1, screening grid g_2 and suppressor grid g_3. Reference to Volume 1, page 105, will help to illustrate these symbols.

In addition to the main symbols shown above, there are four subscripts used to distinguish between similar electrodes used for different purposes. For example, a_t means the anode of the triode section of a multi-valve.

d	diode	t	triode
p	pentode	tap	tapping on heater or filament.

Where appropriate, the usual signs are used to denote positive and negative. For example, f(—) denotes that the pin so marked must be used for the negative filament connection.

BRIMAR

S.G. and R.F. Pens.

Current Types

DAF96	73
DF96	70
1AH5	73
1AJ4	70
1L4	70
1S5	73
1T4	70
1U5	64
6AM6	80
6BA6	67
6BH6	76
6BJ6	76
6BR7	303
6BS7	298
6BW7	285
6DA6	304
6N8	287
8D3	80
9D6	80
12AV6	67
12BA6	67
5749	67
6059	303
6064	80
6065	80

Replacement Types

EF41	190
EF80	285
1LD5	221
1LN5	223
6B8	180
6BX6	285
6C6	339
6D6	339
6J7	111
6K7	111
6U7	111
7B7	212
7H7	212
7R7	219
8D2	45
9D2	45
12C8	180
12J7	111
12K7	111
14H7	212
14R7	219
77	339
78	339

Frequency Changers

Current Types

DK96	93
ECF82	308
PCF82	308
1AB6	93
1AC6	93
1R5	71
6BE6	79
6U8	308
9U8	308
12AH8	294
12BE6	79
5750	79

Replacement Types

ECH42	185
UCH42	185
1LA6	224
6A7	346
6A8	115
6F7	345
6K8	128
7S7	215
12K8	128
14S7	215
15A2	41
15D2	41
20D2	42

Diodes, Triodes and Diode Triodes

Current Types

EABC80	289
ECC84	306
ECC85	312
ECL80	300
HABC80	289
PCC84	306
6AB8	300
6AF4	92
6AK8	289
6AL5	69
6AT6	98
6BM8	322
6BQ7A	312
6CW7	306
6C4	66
6SL7	164
6SN7	164
6T8	289
7AN7	306
12AT7	288
12AT6	98
12AU7	288
12AX7	288
12BH7	288
13D1	164
13D2	164
13D3	288
19T8	289
5726	69
6057	288
6058	69
6060	288
6158	288

Replacement Types

EBC41	192
UBC41	192
4D1	53
6H6	123
6J5	167
6N7	165
6Q7	152

Diodes, Triodes and Diode Triodes

REPLACEMENT TYPES

7B6	211
7C6	211
7K7	220
10D1	27
11D3	46
11D5	46
12Q7	152
12SL7	164
14B6	211
75	343

Efficiency Diodes

CURRENT TYPES

EY83	302
PY81	302
PY83	302
6U4	143

REPLACEMENT TYPES

PY81-17Z3	302

Output Valves, Sound and T.V.

CURRENT TYPES

DL96-3C4	62
ECL80-6AB8	300
ECL82-6BM8	322
EL84-6BQ5	291
G-50C5	78
HL84	291
PCL82	322
PL81-21A6	292
3V4	62
6AK6	67
6AM5	87
6AQ5	84
6BW6	297
6CD6	121
6CH6	297
6L6	162
7D9	87
9BW6	297
19AQ5	84
50C5	78
50CD6	121
807	338
5763	286
6061	297
6062	286
6132	297

REPLACEMENT TYPES

EL41	186
UL41	190
1A5	147
1S5	72
2A3	336
3D6	222
3Q4	74
3S4	74
6A3	336
6AG6	162
6B4	179
6BG6	121
6F6	162
6K6	162
6V6	162
7A2	30
7A2	54
7A3	54
7C5	217
7D3	54
7D5	54
7D6	54
7D8	54
12A6	162
18	341
19BG	6121
25A6	162
25L6	162
35A5	217
35L6	162
42	341
43	341
50A5	217
50L6	162

Thyratrons

2D21	86

Rectifiers

CURRENT TYPES

EZ80-6V4	317
R10	81
R11	13
R12	Wires
R17	307
R18	307
R19-1X2B	318
5R4	177
5U4	177
5V4	175
5Y3	177
5Z4	175
6X4	75
35W4	100
35Z4	174
83	335
6063	75
6157	307
6443	307

REPLACEMENT TYPES

EZ40	195
OZ4	172
R2	15
R3	15
UY41	189
1D5	31
1D6	340
5Z3	335
6X5	124
7Y4	210
7Z4	210
25Z4	137
35Z3	218
80	335

Tuning Indicators

CURRENT TYPES

EM85	313

REPLACEMENT TYPES

EM71	232
6E5	342
6U5-6G5	342
6U5G	171
12U5	171
1629	171

COSSOR

S.G. and R.F. Pens.

CURRENT TYPES

OM5B	111
OM5C	111
OM6	111
1S5	73
1T4	70
6AM5	87
6AM6	80
6BX6	285
6BY7	285
6F33	80
7B7	212
61SPT	170
62VP	190
63SPT	331
171DDP	287
210VPA	43

REPLACEMENT TYPES

MS/PEN	44
MS/PEN/B	45
MVS/PEN	44
MVS/PEN/B	45
1N5	146
4TSA	58
6J7	111
6K7	111
6SG7	166
6SH7	166
6SK7	160
6SS7	160
12SG7	166
13SPA	45
13VPA	45
41MPT	44
41MTS	51
42MPT	44
42PTB	45
42SPT	44
210SPT	43
210VPT	43
215SG	11
202VP	44
202VPB	45

Frequency Changers

CURRENT TYPES

1R5	71
6AJ8	290
7S7	215
8A8	308
9U8	308
14S7	215
62TH	185
141TH	185

REPLACEMENT TYPES

OM10	127
1A7	145
4THA	42
13PGA	41
41MPG	41
41STH	42
210PG	40
210SPG	40
202MPG	41
202STH	42
203THA	42
220TH	57
302THA	42

Diodes, Triodes and Diode Triodes

CURRENT TYPES

SD6	99
SD61	20
6AB8	300
6AK8	289
6AL5	69
6AQ8	312
6J6	68
6SN7	164
7AN7	306
7C6	211
12AT7	288
12AU7	288
62DDT	192

REPLACEMENT TYPES

DDL4	27
OM4	152
6C5	167
6H6	123
6J5	167
6Q7	152
6SL7	164
12H6	123
12SC7	163
12SR7	154
41MTL	25
202DDT	46

Efficiency Diodes

CURRENT TYPES

17Z3	302

Output Valves, Sound and T.V.

CURRENT TYPES

3A4	60
3S4	74
6AB8	300
6BQ5	291
6CH6	297
6L6	162
6V6	162
7C5	217
16A5	291
21A6	292
35A5	217
62BT	120
67PT	190
142BT	162
451PT	190
807	338

REPLACEMENT TYPES

MP/PEN	54
PT10	54
PT41	29
1C5	147
2P	10
4XP	10
6K6	162
41MPT	44
41MXP	25
42MP/PEN	54
42MPT	44
61BT	120
185BTA	120
215P	10
220OT	29
220P	10

COSSOR—*continued*

Output Valves, Sound and T.V.

Replacement Types	
220PA	10
220PT	29
240QP	48
332Pen	162
402PenA	49

Thyratrons

Replacement Types	
GDT4B	32
GDT4C	32

Rectifiers

Current Types	
SU2150A	13
SU61	Wires
6V4	317
6W2	Wires
7Y4	210
19Y3	293
35Z3	218
43IU	12
52KU	175
53KU	175
54KU	175
66KU	195
311SU	187

Replacement Types	
OM1	174
SU25	119
SU2150	13
4-100BU	12
5U4	177
5Z4	175
6X5	124
27SU	144
40SUA	31
80	335
225DU	56
405BU	12
451U	12
506BU	12

Tuning Indicators

Current Types	
EM81	310
64ME	161
65ME	310

Replacement Types	
63ME	171

EMITRON

S.G. and R.F. Pens.

Current Types	
EF80-6BX6	285
EF85-6BY7	285
1S5	73
1T4	70
6AM6	80
6BA6	67
7B7	212
7H7	212

Frequency Changers

Current Types	
ECH81-6AJ8	290
PCF80-9A8	308
1R5	71
6BE6	79
7S7	215
14S7	215

Diodes, Triodes and Diode Triodes

Current Types	
EABC80-6AK8	289
ECC81-12AT7	288
ECC85-6AQ8	312
ECL80-6AB8	300
PCC84-7AN7	306
6AL5	69
6AT6	98
7C6	211

Efficiency Diodes

Current Types	
PY80-19X3	293
PY81-17Z3	302

Output Valves, Sound and T.V.

Current Types	
ECL80/6AB8	300
EL84/6BQ5	291
PL81/21A6	292
3A4	71
3S4	74
6AM5	87
6AQ5	84
6L6	162
7C5	217
16A5	291
185BT	120
185BTA	120
35A5	217
807	338

Rectifiers

Current Types	
EZ80-6V4	317
PY82-19Y3	293
SU45	81
SU2150A	16
U709-EZ81	317
6W2	Wires
6X4	75
7Y4	210
35Z3	218

Replacement Types	
SU25	119
6X5	124
27SU	144
43IU	12
45IU	12
52KU	175

Tuning Indicators

Current Types	
EM80	310

FERRANTI

S.G. and R.F. Pens.

Current Types	
DAF96-1AH5	73
DF96-1AJ4	70
DF97	91
DP61	65
EAF42-6CT7	188
EFB80-6N8	287
EF41-6CJ5	190
EF42	191
EF80-6BX6	285
EF85-6BY7	285
EF86	296
EF89-6DA6	303
UBF42	188
UBF80	287
UF41	190
UF85	285
UF89	303
1S5	73
1T4-DF91	70
6AG5	65
6AK5	65
6AM6-EF91	80

Replacement Types	
SPT2	43
SPT4A	44
VPT2	11
VPT2	43
VPT4	26
1N5	146
6AB7	160
6AC7	160
6B8	180
6C6	339
6D6	339
6J7	111
6K7	111
6SG7	166
6SH7	166
6SJ7	160
6SK7	160
6SS7	160
6U7	111
7H7	212
7R7	219
12C8	180
12J7	111
12K7	111
12SJ7	160
12SK7	160

Frequency Changers

Current Types	
ECH42-6CU7	185
ECH81-6AJ8	290
1AB-DK96	93
1AC6-DK92	93
1R5-DK91	71
6BE6-EK90	79
9A8-PCF80	308
9U8-PCF82	308

Replacement Types	
VHT2A	40
VHT4	41
6A7	346
6A8	115
6K8	128
6SA7	151
6SA7	110
7S7	215
12K8	128

Diodes, Triodes and Diode Triodes

Current Types	
DD6	69
EABC80	289
EBC41	192
PCC84-7AN7	306
PCC85-9AQ8	312
UBC41	192
UCC85	312
6AL5-EB91	69
6J6	68
6SL7	164
6SN7	164
12AT7-ECC81	288
12AU7-ECC82	288
12AX7-ECC83	288

Replacement Types	
D4	25
EB41	193
H2D	28
H4D	46
HL2	10
L2	10
1G6	130
1H5	133
6A6	344
6C5	167
6F8	151
6J5	167
6N7	165
6Q7	152
6SQ7	154
7C6	211
7K7	220
12Q7	152
12SC7	163
12SL7	164
12SQ7	154
6116	123

Output Valves, Sound and T.V.

Current Types	
DL96/3C4	62
ECL80/6AB8	300
EL41	186
EL42	190
EL84/6BQ5	291
EL85/6BN5	309
PCL82	322
PCL83	305
PL36-25E5	148
PL81-21A6	292
PT2	29
UL41	190
UL84	291
1A5	147
1C5	147
3Q5	113
3S4	74
3V4-DL98	62
6AM5-EL91	87
6AQ5-EL90	84

FERRANTI—*Continued*

Output Valves, Sound and T.V.

REPLACEMENT TYPES

L4	25
LP4	10
PT4	54
PT4D	47
6C4	66
6F6	162
6K6	162
6V6	162
6Y6	162
7C5	217
12A6	162
25L6	162
35L6	162
50L6	162

Thyratrons

CURRENT TYPES

EN30	117
GK10	94
GK20	94
GL1	118
GL2	158
GN10	116
GN20	116
3C23	337

REPLACEMENT TYPES

GK3	17

Rectifiers

CURRENT TYPES

EY51-6X2	Wires
EY86-6S2	319
EY91	85
EZ80-6V4	317
EZ90-6X4	75
GZ32	175
HR2	81
HR3	81
HR6	165
HR8	142
HR9	157
HR11	126
PZ30	169
UY85	323
5RU	177

REPLACEMENT TYPES

EZ40	195
HR2	Wires
OZ4	172
R42	15
R43	12
R52	175
UY41	189
5U4	177
5V4	175
5Y3	177
5Z4	175
6W2	Wires
6X5	124
7Y4	210
7Z4	210
35Z4	174
35Z5	168
80	335

Tuning Indicators

CURRENT TYPES

DM70/1M3	240
EM80/6BR5	310
EM81	310

REPLACEMENT TYPES

VFT6	171
1629	171

MARCONI

S.G. and R.F. Pens.

CURRENT TYPES

W142	204
W143	225
W145	191
W147	111
W148	212
W149	212
W150	199
WD142	188
Z142	191
Z145	198
Z150	191
Z152	285
ZD152	287

Frequency Changers

CURRENT TYPES

X142	185
X143	230
X145	185
X147	127
X148	215
X150	185

Diodes, Triodes and Diode Triodes

CURRENT TYPES

B152	288
D152	69
DH142	192
DH147	152
DH149	231
DH150	192
DL145	192
LN152	300

Efficiency Diodes

CURRENT TYPES

U152	293
U153	302

Output Valves, Sound and T.V.

CURRENT TYPES

DN143	226
KT44/45	59
LN152	300
N142	203
N144	95
N145	190
N147	162
N148	227
N150	203
N151	201
N152	292
N153	301

Rectifiers

CURRENT TYPES

U70	124
U142	202
U143	177
U145	187
U147	124
U149	210
U150	200
U154	293

MARCONI OR OSRAM

S.G. and R.F. Pens.

CURRENT TYPES

QA2400	80
QA2403	80
W17	70
W77	80
W107	81
W719-EF85	285
W727-6BA6	67
W729	285
WD709-EBF80	287
Z77	80
Z309	295
Z319	316
Z719	285
Z729	296
Z759	311
ZD17	73

REPLACEMENT TYPES

KTW63	112
MS4B	26
MSP4	26
MSP4	44
W21	11
W61	111
W76	111
W81	212
W101	212
Z14	146
Z22	43
Z63	111
Z66	111
Z90	331

Frequency Changers

CURRENT TYPES

X17	71
X18	93
X79	299
X109	299
X719-ECH81	290
X727-6BE6	79

REPLACEMENT TYPES

X14	145
X22	40
X61M	127
X65	127
X76M	127
X78	77
X81	215
X101	215

Diodes, Triodes, Diode Triodes and A.F. Pentodes

CURRENT TYPES

B36	164
B65	164
B309	288
B319	306
B329-12AU7	288
B33-12AX7	288
D77	69
DH63	152
DH77-6AT6	98
DH107	98
DH179-EABC80	289
L63	167
L77	66
LN309	305
QA2401	66
QA2404	69
QA2406	288
QA2408	164
Z729	296

REPLACEMENT TYPES

D41	27
D63	123
DH76	152
DH81	213
DH101	213
DL63	152
DL82	213
H63	156
HD14	133
HL2	10

Efficiency Diodes

CURRENT TYPES

U152	293
U309	293
U329	302

Output Valves, Sound and T.V.

CURRENT TYPES

A1834	164
A2134	100
HN309	305
KT33C	178
KT36	120
KT61	162
KT66	162
LN309	305
N18	74
N19	90
N37	87
N77	87
N78	87
N108	87
N309-PL83	301
N329	291
N339	292
N349	292
N709	291
N727-6AQ5	84
PX4	10
QA2402	87
Z759	311

MARCONI OR OSRAM—*Continued*

Output Valves, Sound and T.V.

Replacement Types	
KT2	29
KT24	29
KT32	162
KT63	162
KT76	162
KT81	217
KT101	217
LP2	10
MKT4	54
N14	147
N16	113
N17	74
PX25	10

Thyratrons

Current Types	
GT1B	25
GT1C	25

Rectifiers

Current Types	
GU50	13
QA2407	75
U18/20	12
U19	13
U31	174
U37	Wires
U41	173
U43	Wires
U45	Wires
U50	177
U52	177
U54	175
U78	75
U107	63
U319	293
U709	317

Replacement Types	
MU14	12
U10	12
U14	12
U19/23	13
U33	13
U35	126
U76	174
U81	228
U82	210
U84	228
U101	229

Tuning Indicators

Current Types	
Y61	171
Y63	171

MAZDA

S.G. and R.F. Pens.

Current Types	
1F1	96
1F3	70
1FD1	97
1FD9	73
1S5	73
6F1	198
6F11	191
6F12	80
6F12ANR	80
6F14	191
6F15	191
6F18	193
6F33	80
10F1	198
10F9	191
10F18	285
20F2	191
30FL1	320
30F5	285

Replacement Types	
AC/SG/VM	26
AC/VP1	44
AC/VP2	45
SP41	256
SP42	256
SP61	256
SP181	256
V453	256
VP23	250
VP41	256
VP133	256
VP210	43
VP1321	44
VP1322	45
1F2	70
1L4	70
1T4	70
6F13	191
6F16	199
6F32	256
10F3	191

Frequency Changers

Current Types	
1C2	93
1C3	93
6C9	185
6C10	185
10C1	185
10C2	197
30C1	308

Replacement Types	
AC/TH1	42
AC/TP	281
TH41	257
TH233	257
TH2320	42
TH2321	42
TP22	280
TP25	264
TP2620	281
1C1	71
1R5	71
6C31	127

Diodes, Triodes and Diode Triodes

Current Types	
6/30L2	312
6D2	69
6F1	198
6F11	198
6F12	191
6L1	80
6L18	194
6L19	194
6L34	83
6LD3	192
10D2	69
10F1	198
10LD3	192
10L1	83
20D1	69
20L1	194
30F5	285
30FL1	320
30L1	306
30PL1	305

Replacement Types	
AC/HL	25
AC/HLDD	46
AC/2HL	25
D1	20
DD41	260
HL23	251
HL23DD	253
HL41	263
HL41DD	255
HL42DD	255
HL133DD	255
P41	263
P61	263
V312	33
6D1	20
6D3	85
6F13	191
6LD20	192
10LD11	192

Efficiency Diodes

Current Types	
U191	141
U251	302
U301	141
U801	135

Replacement Types	
U281	174
U282	131
U403	259

Output Valves, Sound and T.V.

Current Types	
Pen46	261
1P1	62
1P11	62
3V4	62
6P1	162
6P25	162
6P28	120
10P13	190
10P14	162
12E1	120
20P3	162
20P4	120
20P5	190
30PL1	305
30P4	148
30P12	291

Replacement Types	
AC/Pen	54
AC/2Pen	54
AC/2PenDD	47
AC/4Pen	54
AC/5Pen	54
AC/5PenDD	47
PenDD4020	47
Pen25	252
Pen44	265
Pen45	265
Pen45AN	265
Pen45DD	262
Pen220	29
Pen383	265
Pen384	265
Pen453DD	262
PP3/250	10
PP5/400	10
1P10	74
20P1	120
3S4	74

Thyratrons

Current Types	
20A2	361
20A3	89

Replacement Types	
T41	263
6K25	167

Rectifiers

Current Types	
U25	Wires
U26	321
U404	189
U801	155
UU9	195
UY41	189
19G3	125
19G6	81
19H1	13
19H4	173

Replacement Types	
U22	258
U24	119
UU4	15
UU5	15
UU6	254
UU7	254
UU8	254
UU10	15
U201	174
U281	174
U403	259
U4020	31

Tuning Indicators

Current Types	
1M1	240
6M2	159
10M2	140

Replacement Types	
ME41	266
ME91	626
ME920	50
6M1	171
10M1	171

MULLARD

S.G. and R.F. Pens.

CURRENT TYPES

DAF70	243
DAF91	73
DAF96	73
DF61	23
DF62	24
DF64	23
DF73	244
DF91	70
DF92	70
DF96	70
DF97	91
E180F	315
EBF80	287
EBF89	287
EF70	247
EF71	248
EF72	248
EF73	245
EF80	285
EF85	285
EF89	304
EF91	80
EF92	80
EF93	67
EF95	65
HF93	67
KF35	129
M8083	80
M8100	65
M8101	67
M8121	248
M8122	245
M8125	247
M8126	80
UBF80	287
UBF89	287
UF80	285
UF85	285
UF89	304
6AS6	76

REPLACEMENT TYPES

DF33	146
DF66	22
DF72	244
EAF42	287
EF9	273
EF22	212
EF36	111
EF37A	111
EF39	111
EF40	196
EF41	190
EF42	191
EF50	331
EF54	332
EF55	331
PM12M	11
SP2	43
SP2B	55
SP4	44
SP4B	45
SP13	273
SP13C	45
VP4B	45
UAF42	188
UF41	190
UF42	191
1N5	146
6J7	111
6K7	111
6SK7	160
12J7	111
12K7	111
12SK7	160
78	339

Frequency Changers

CURRENT TYPES

DF97	91
DK91	71
DK92	93
DK96	93
ECF80	324
ECH81	290
EK90	79
HK90	79
PCF80	308
UCF80	308
UCH81	290

REPLACEMENT TYPES

CCH35	127
DK32	145
ECF82	324
ECH3	271
ECH21	230
ECH35	127
ECH42	185
EK2	272
EK32	115
FC2	40
FC2A	40
FC4	41
FC13	272
FC13C	41
KK32	145
PCF82	324
TH21C	42
UCH21	230
UCH42	185
1A7	145
12A7	346
12A8	115
12K8	128

Diode Triodes and A.F. Pentodes

CURRENT TYPES

DCC90	61
EABC80	289
EAC91	82
EBC41	192
EBC90	98
EC90	66
EC91	83
ECC81	288
ECC82	288
ECC83	288
ECC85	312
ECC91	68
ECL80	300
EF86	296
EY51	Wires
EY86	319
HBC90	98
HBC91	98
M8081	68
M8097	82
M8099	66
M8136	288
M8137	288
PCC84	306
UABC80	289
UCC84	306
UCC85	312

REPLACEMENT TYPES

DAC32	133
EBC33	152
EC52	333
EC92	66
ECC32	164
ECC33	164
ECC34	164
ECC35	164
ECC40	194
EF37A	111
HL13	275
HL13C	53
KBC32	114
PM2HL	10
TDD2A	28
TDD4	46
UBC41	192
UC92	88
6C5	167
6J5	167
6Q7	152
6SN7	164

Efficiency Diodes

CURRENT TYPES

PY81	302

REPLACEMENT TYPES

PY31	174
PY80	293
PZ30	169

Output Valves, Sound and T.V.

CURRENT TYPES

DL64	23
DL69	23
DL70	246
DL73	246
DL92	74
DL93	60
DL94	62
DL96	62
DL620	22
ECL80	300
ECL82	322
EL34	149
EL42	190
EL81	292
EL84	291
EL85	309
EL90	84
EL91	87
EL821	297
EL822	297
HL92	78
M8082	87
PCL82	322
PCL83	305
PL36	148
PL81	292
PL82	291
PL83	301
UCL83	305
UL84	291

REPLACEMENT TYPES

CBL1	274
CBL31	180
CL4	276
CL33	162
DL33	113
DL35	147
DL66	22
DL68	22
DL75	246
EBL1	214
EBL21	214
EBL31	180
EL2	270
EL31	122
EL32	112
EL33	162
EL37	162
EL38	122
EL41	186
KL35	147
PENA4	54
PENB4	54
PEN4DD	52
PEN428	54
PL33	162
PL38	122
PL820	292
PM22A	29
PM22D	29
PM24A	29
PM24M	29
PM202	10
UL41	190
UL44	198
UL46	190
1C5	147
3Q5	113
6F6	162
6L6	162
6V6	162
25A6	162
25L6	162
35L6	162
42	162
43	162
50L6	162

Thyratrons

CURRENT TYPES

EN32	134
EN70	241
EN91	86
EN92	89
Z300T/1267	139

REPLACEMENT TYPES

AN1	25
EN31	138

Rectifiers

CURRENT TYPES

DY70	Wires
EY51	Wires
EY70	242
EY84	307
EY86	319
EZ40	200

MULLARD—*Continued*

Rectifiers

CURRENT TYPES

EZ41	200
EZ80	317
EZ81	317
EZ90	75
GZ32	175
GZ33	176
GZ34	175
HY90	100
PY32	153
PY82	323
RG1-240A	13

REPLACEMENT TYPES

AZ31	177
CY31	174
DW4-350	12
DW4-500	12
EZ35	124
FW-500	12
FW4-800	12
GZ30	175
HVR2	16
IW4-350	15
IW4-500	15
PY31	174
PZ30	169
UR1C	31
UY1N	132
UY41	189
5U4	177
5V4	175
5Y3	177
5Z4	175
6X5	124
25Z4	174
25Z6	123
35Z4	174
35Z5	168
80	335

Tuning Indicators

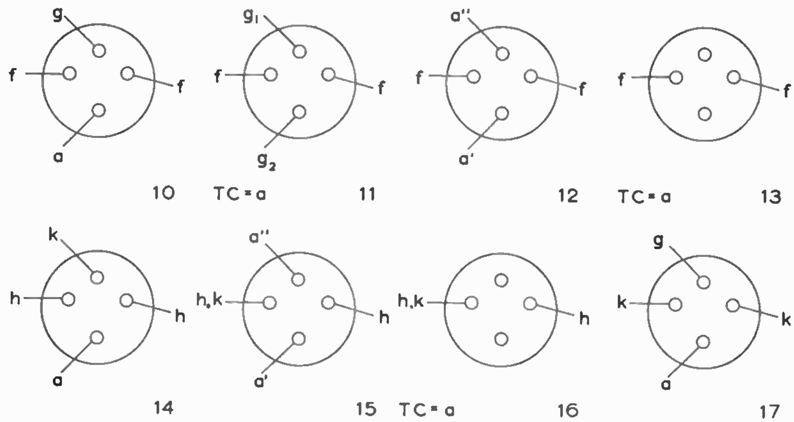
CURRENT TYPES

DM70	240
EM80	310
EM81	310
UM4	159
UM81	310

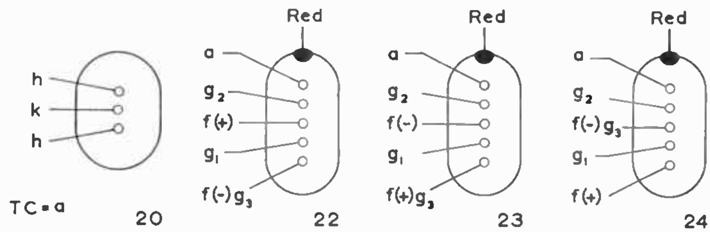
REPLACEMENT TYPES

EM34	161
UM34	161

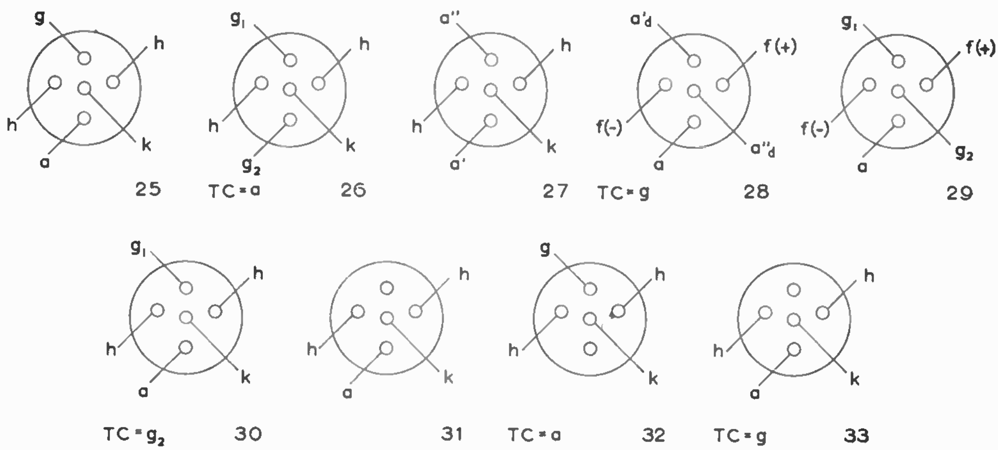
B4 BASES



B3G and B5A BASES



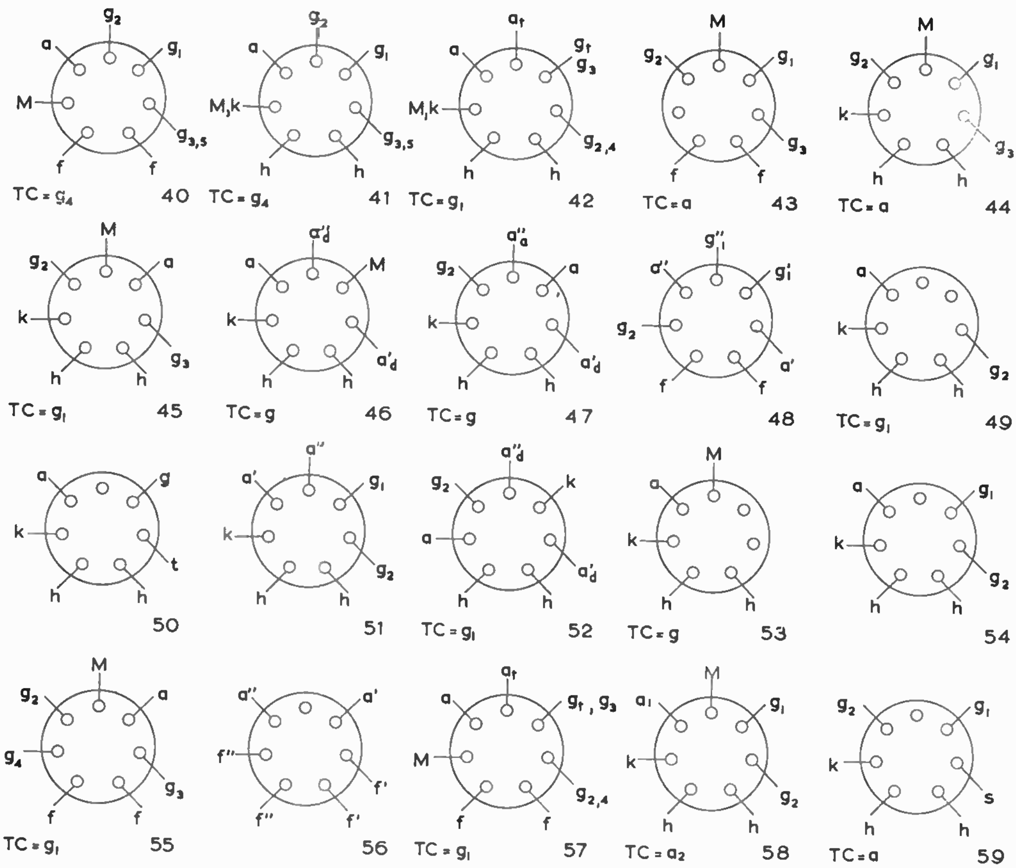
B5 BASES



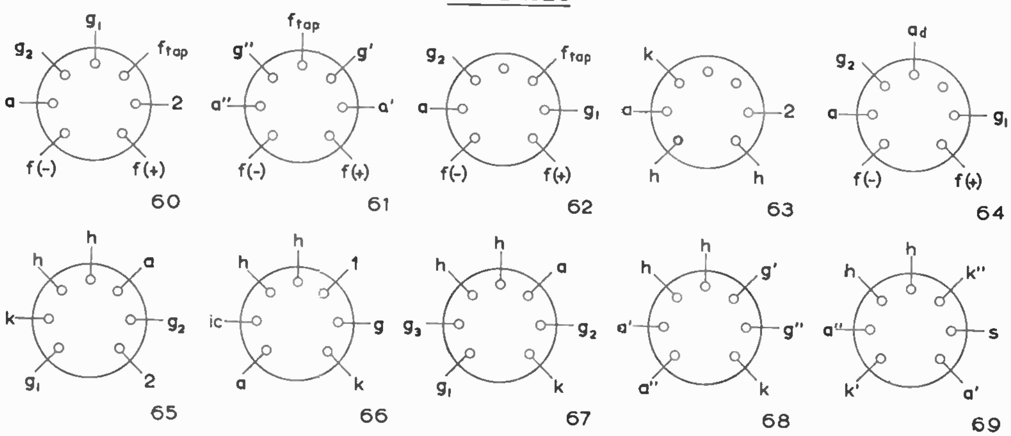
Note.—All connections are as viewed from underside of valve bases.

B7, B7G Bases

B7 BASES

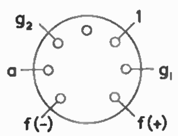


B7G BASES

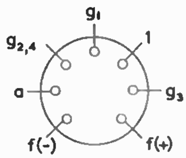


Note.—All connections are as viewed from underside of valve bases.

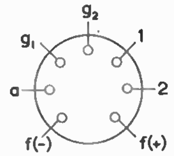
(B7G continued)



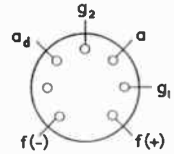
70



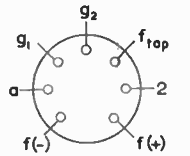
71



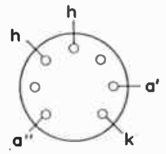
72



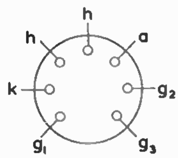
73



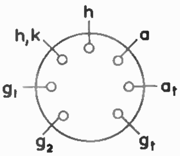
74



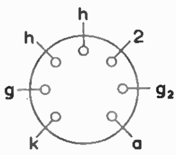
75



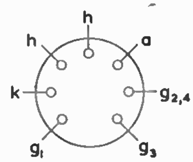
76



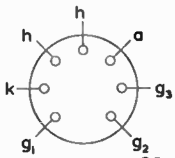
77



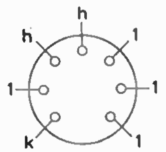
78



79

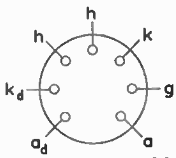


80

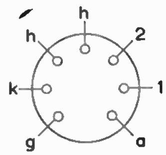


TC=a

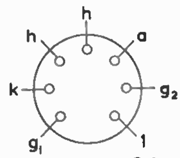
81



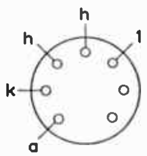
82



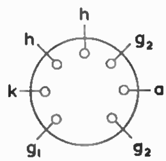
83



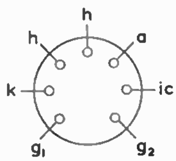
84



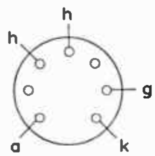
85



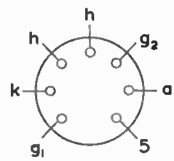
86



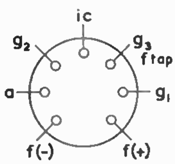
87



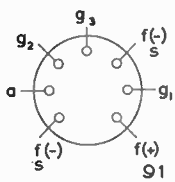
88



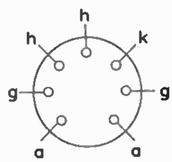
89



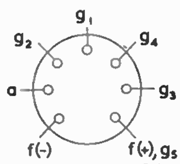
90



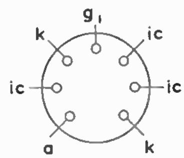
91



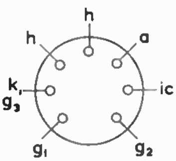
92



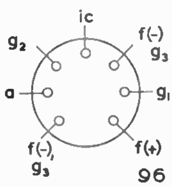
93



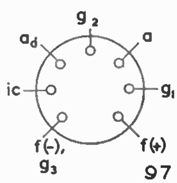
94



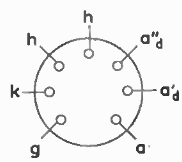
95



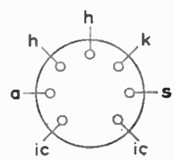
96



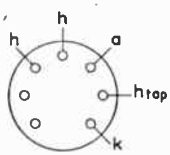
97



98



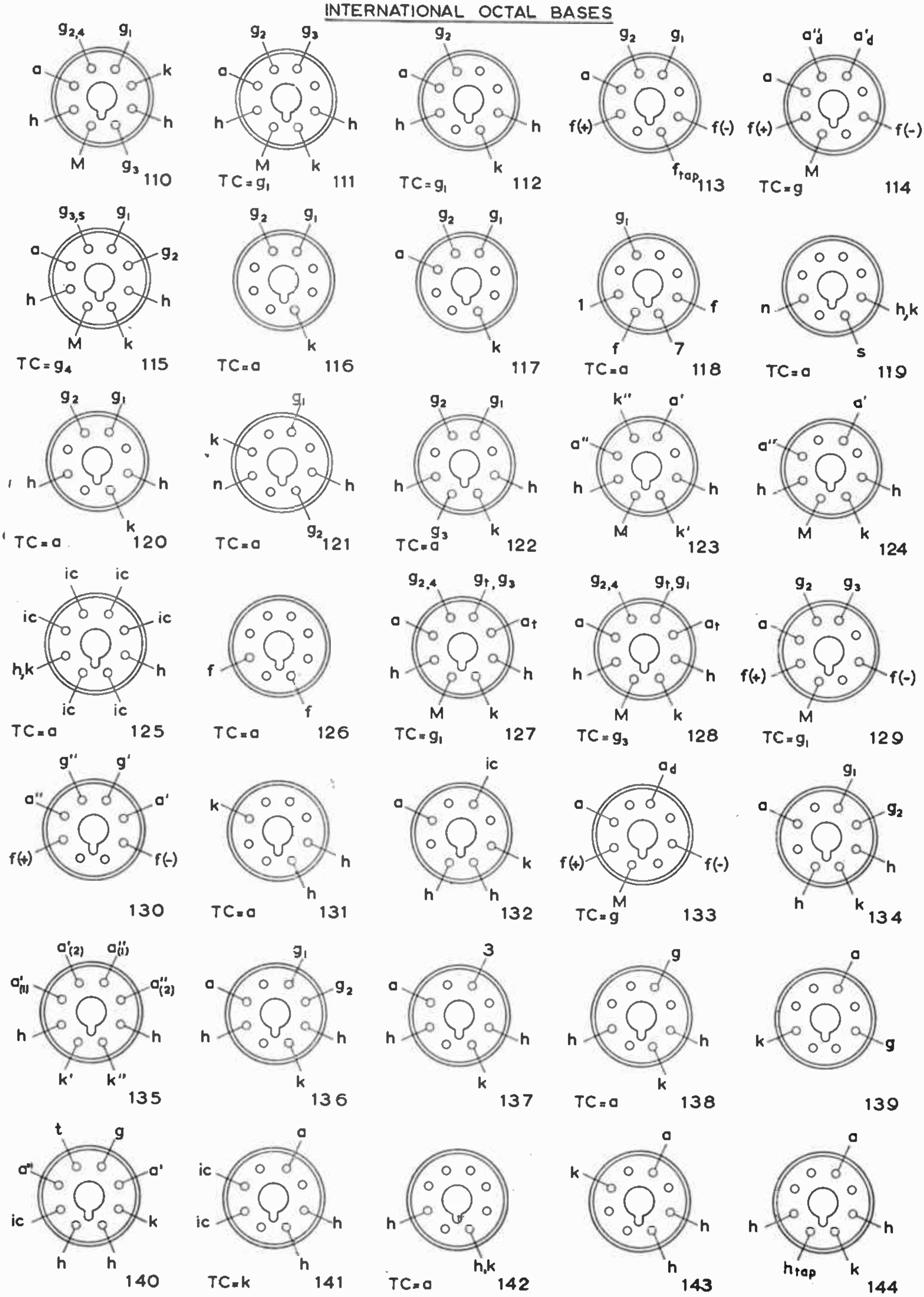
99



100

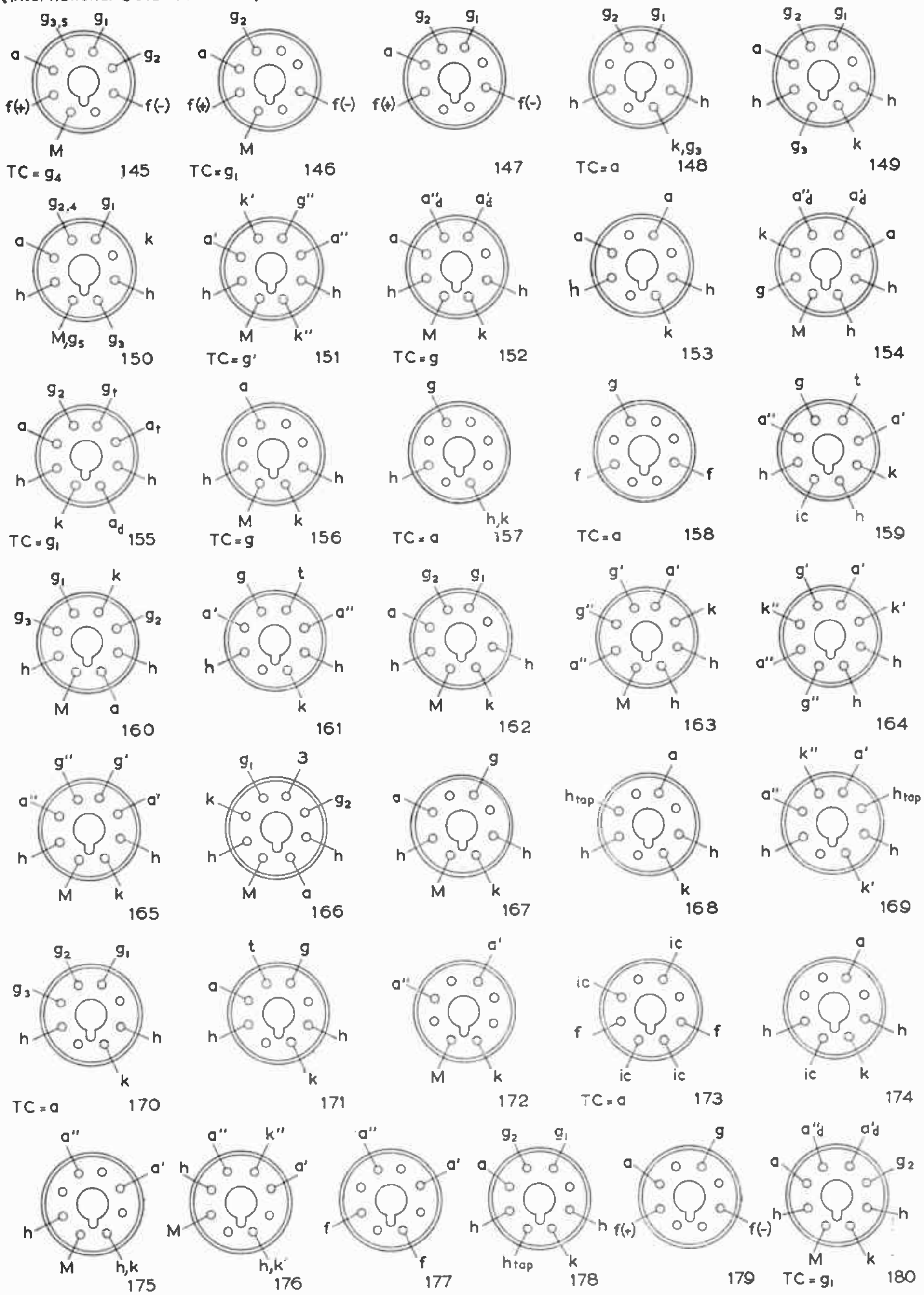
Note.—All connections are as viewed from underside of valve bases.

INTERNATIONAL OCTAL BASES



Note.—All connections are as viewed from underside of valve bases.

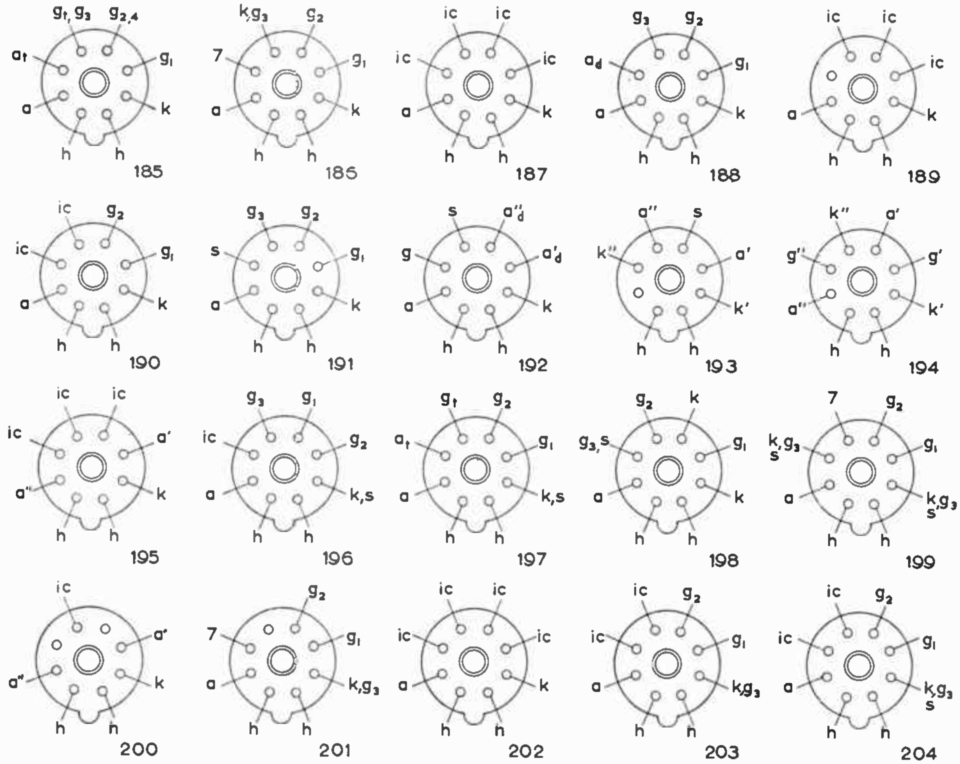
(International Octal continued)



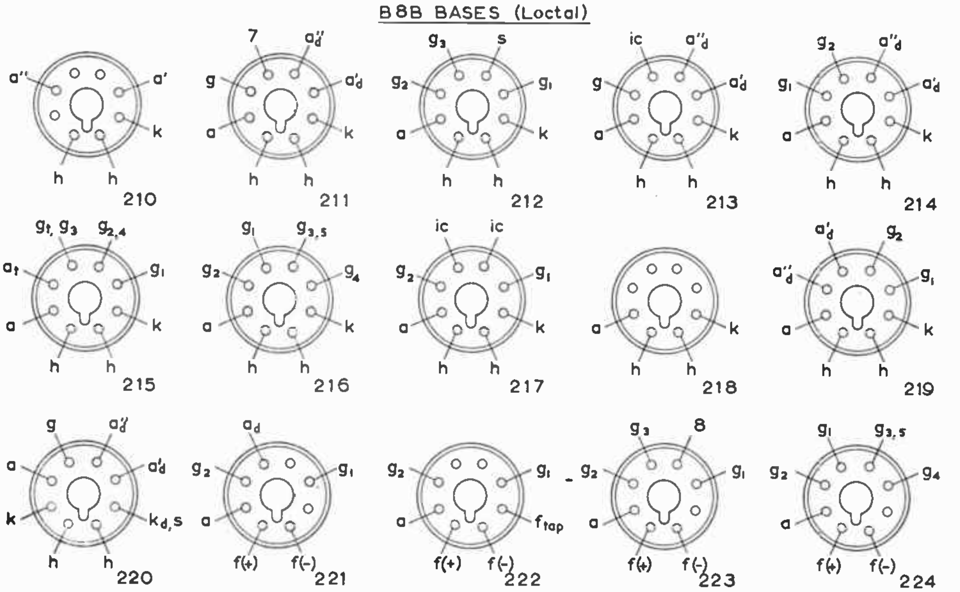
Note.—All connections are as viewed from underside of valve bases.

B8A, B8B (Loctal) Bases

B8A BASES

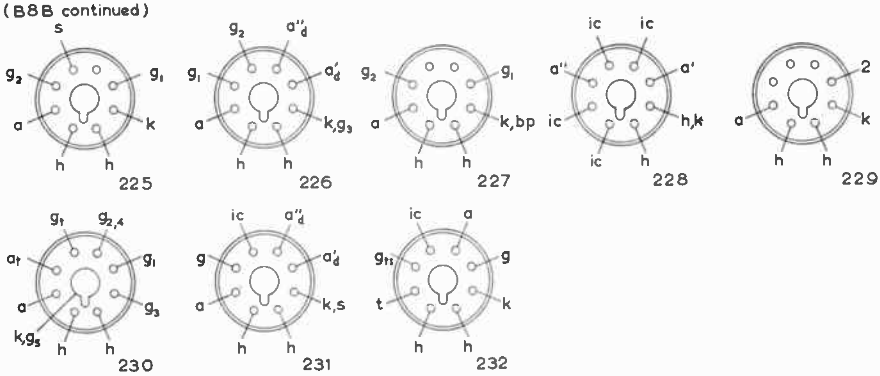


B8B BASES (Loctal)

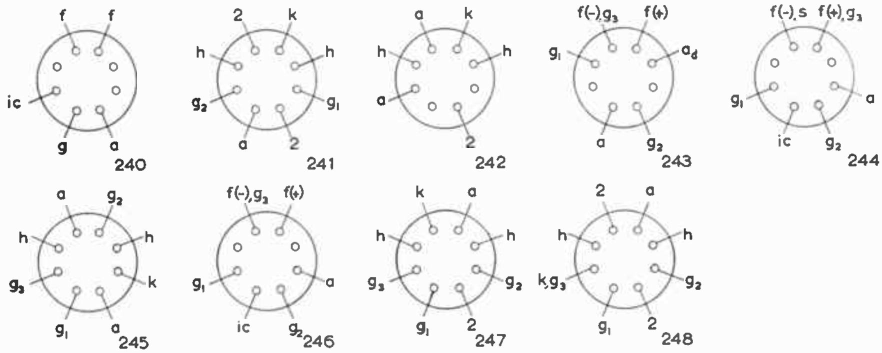


Note.—All connections are as viewed from underside of valve bases.

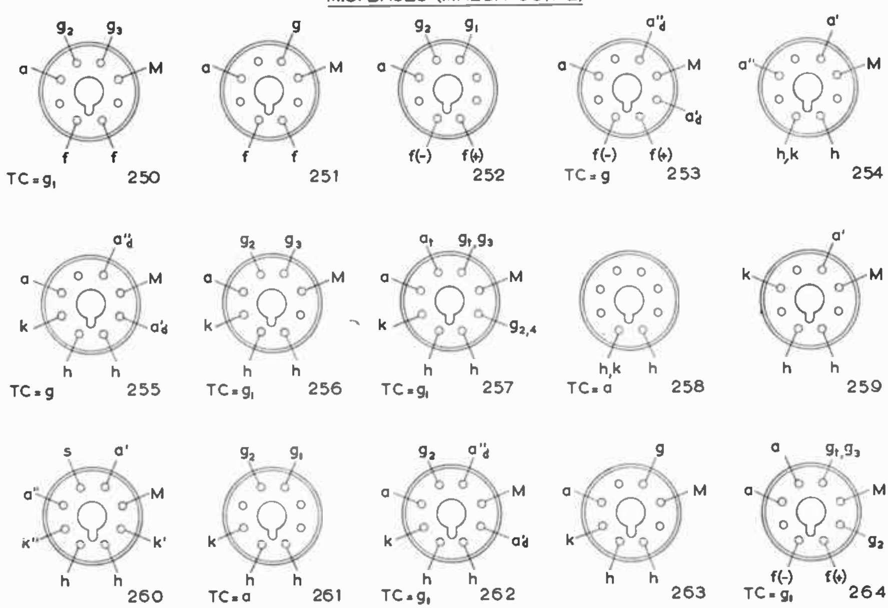
(B8B continued)



B8D BASES

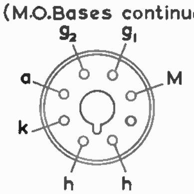


M.O. BASES (MAZDA OCTAL)

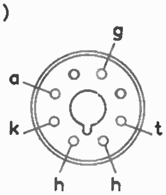


Note.—All connections are as viewed from underside of valve bases.

(M.O. Bases continued)

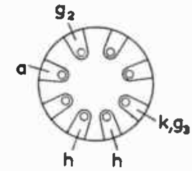


265

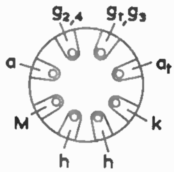


266

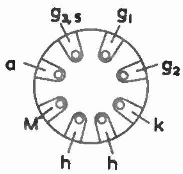
CT8 BASES. (Side Contact)



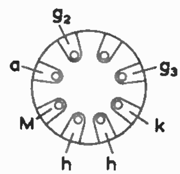
TC = g_1 270



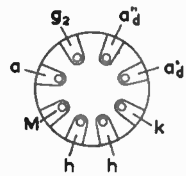
TC = g_1 271



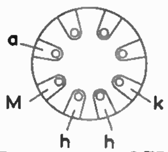
TC = g_4 272



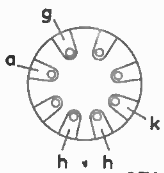
TC = g_1 273



TC = g_1 274

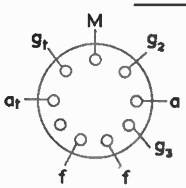


TC = g 275

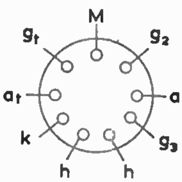


TC = g_1 276

B9 BASES

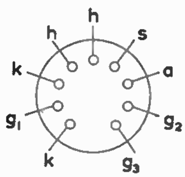


TC = g_1 280

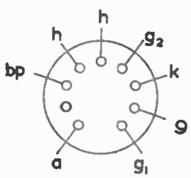


TC = g_1 281

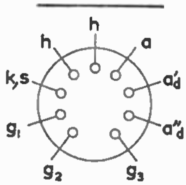
B9A BASES



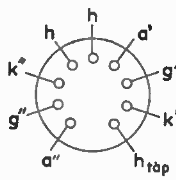
285



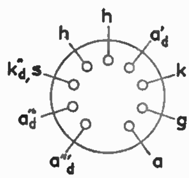
286



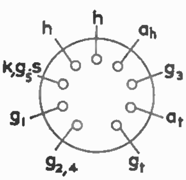
287



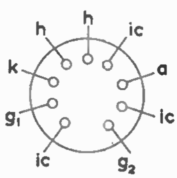
288



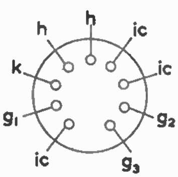
289



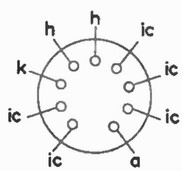
290



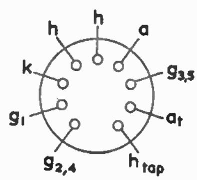
291



TC = a 292



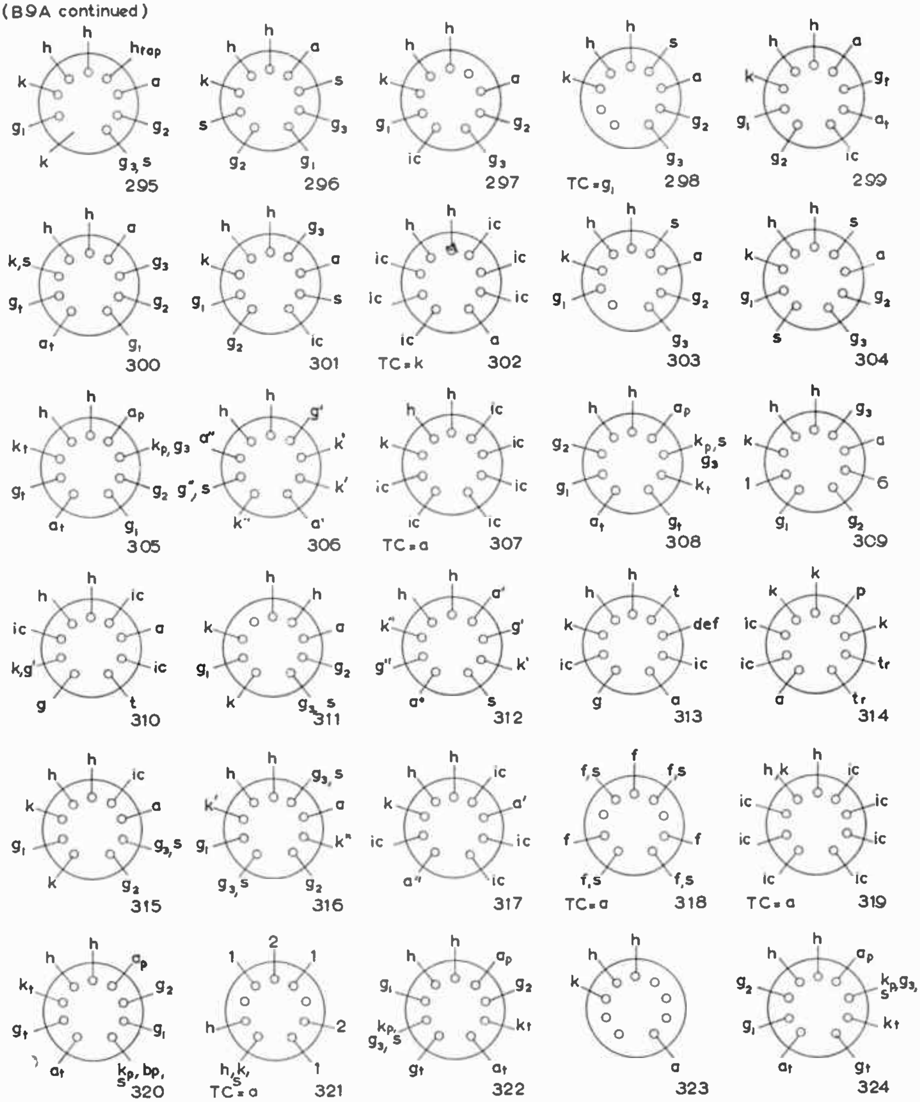
293



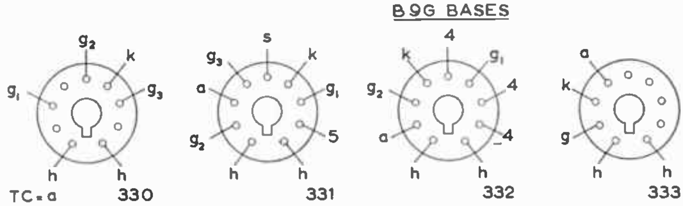
294

Note.—All connections are as viewed from underside of valve bases.

(B9A continued)

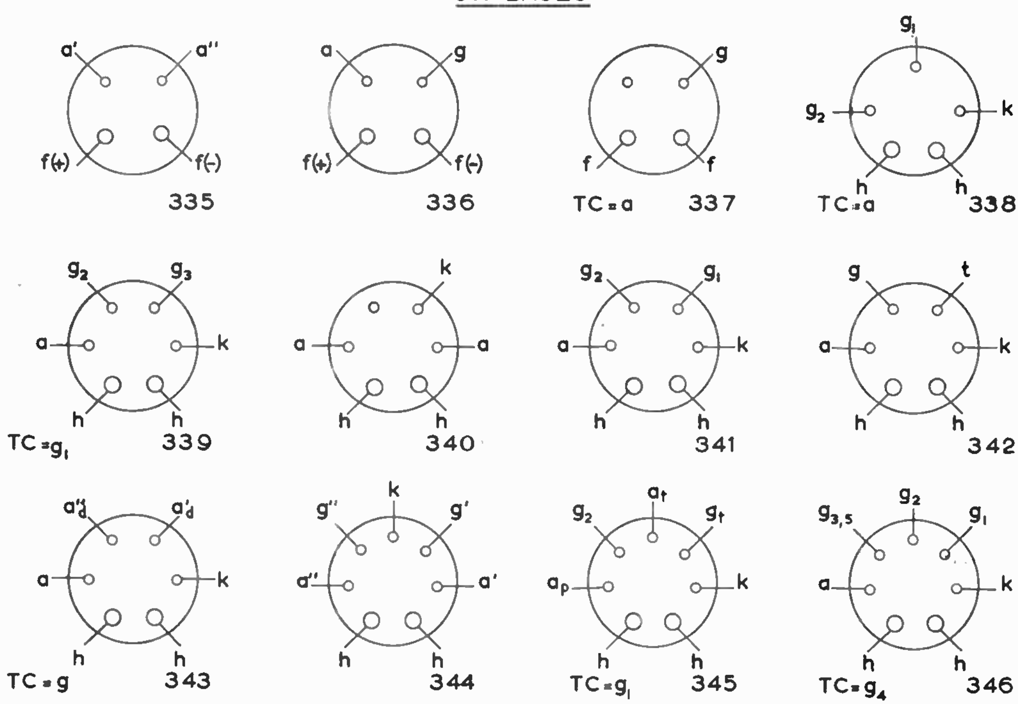


B9G BASES



Note.—All connections are as viewed from underside of valve bases.

UX BASES



Note.—All connections are as viewed from underside of valve bases.

VALVE EQUIVALENTS GUIDE

The following suggestions for valve substitution are given in good faith, but no liability can be accepted as it is realised that errors and omissions may exist since sources of information may, on occasion, be inaccurate. Some valves are unobtainable but are included for the information of those who possess or wish to replace such types.

The valves listed below include direct "plug in" alternatives and near equivalents, and are intended as suggestions only ; before effecting a replacement, thought should be given to the function that the valve is required to fulfil and any unusual conditions peculiar to the receiver in which it is to be used. Two output pentodes, for example, could be satisfactory counterparts in the output stage of a radio set, yet incompatible or even harmful when used as a time-base amplifier in a television set.

Type	*Brimar*	*Cossor*	*Emitron*	*Ferranti*	*Marconi or Osram*	*Mazda*	*Mullard*
A11B	R2	—	—	R42	—	UU5	IW4/350
A11C	R3	44IU	—	R43	—	UU5	IW4/500
A11D	R2	—	—	R42	—	UU5	IW4/350
A20B	—	—	—	H40	—	V914	—
A23A	11A2	—	—	—	—	AC/HL/DD	TDD4
A27D	—	—	—	—	—	—	Pen4DD
A30B	—	—	—	D4	—	AC2/HL	—
A30D	HLA2	—	—	D4	—	AC/HL	—
A36A	—	—	—	SPT4A	—	—	—
A36C	—	—	—	—	—	AC/TH1	—
A40M	—	—	—	—	—	AC/SG/VM	—
A50A	8A1	—	—	—	—	—	SP4
A50B	—	—	—	—	—	—	SP4B
A50M	9A1	—	—	VT4A	—	AC/VP1	—
A50N	—	MVS/Pen	—	MT4B	—	—	—
A50P	—	—	—	—	—	AC/VP2	VP4B
A70B	7A2	—	—	—	—	AC/Pen	—
A70C	7A3	42MP/Pen	—	PT4	—	AC2/Pen	PenA4
A70D	—	42OT	—	PT4	—	AC2/Pen	PenA4
A70E	—	42OT	—	—	—	AC4/Pen	PenB4
A80A	15A2	41MPG	—	VHT4	—	—	FC4
A430N	—	MH4	—	D4	—	AC/HL	—
ABC1	—	—	—	H4D	—	—	—
AC/DDT	—	—	—	H4D	MH4D	AC/HLDD	TDD4
AC/HL	HLA2	41MHL	—	D4	MH4	AC/HL	354V
AC/HLDD	11A2	—	—	H4D	MHD4	AC/HLDD	TDD4
AC/HP	—	MSPen	—	SPT4A	—	—	SP4
AC/P	—	41MP	—	L4	—	AC/P	—
AC/Pen	7A2	42OT	—	—	MKT4/7	AC/Pen	—
AC/SG	8A1	—	—	SPT4A	—	AC/SG	—
AC/SGVM	9A1	MVSG	—	—	—	AC/SGVM	—
AC/SH	—	—	—	—	MS4B	—	—
AC/SL	—	MS/Pen	—	SPT4A	MS4B	—	—
AC/S2	—	MS/Pen	—	SPT4A	MS4B	—	—
AC/S2Pen	8A1	—	—	—	MSP4	—	—
AC/TH1	2DA1	—	—	—	X41	—	—
AC/VP	—	MVS/Pen	—	VPT4B	—	—	—
AC/VPB	—	—	—	—	—	AC/VP2	VP4B
AC/VP1	9A1	—	—	VPT4	—	—	VP4
AC/VP2	—	MS/PenB	—	—	W42	AC/VP2	VP4B
AC/Z	7A3	420OT	—	PT4	—	AC2/Pen	PenA4
AC/ZDD	—	42OTDD	—	PT4D	—	AC2/PenDD	—
AC/2HL	HLA2	41MHL	—	D4	MH41	—	354V
AC/Pen	7A3	42MP/Pen	—	PT4	KT41	—	PenA4
AC2/PenDD	—	42OTDD	—	PT4D	DN41	—	—
AC4/Pen	—	—	—	—	—	AC4/Pen	PenB4
AC5/Pen	—	PT10	—	—	—	AC5/Pen	—

Type	*Brimar*	*Cossor*	*Emitron*	*Ferranti*	*Marconi or Osram*	*Mazda*	*Mullard*
ACO42	—	—	—	LP4	—	—	—
ACO44	—	4XP	—	LP4	PX4	PP3/250	—
AC104	—	—	—	LP4	—	PP3/250	—
APP4A	7A2	MP/Pen	—	—	MKT4/7	AC/Pen	Pen4VA
APP4B	—	42MP/Pen	—	PT4	KT41	AC2/Pen	PenA4
APP4E	—	—	—	—	—	AC4/Pen	PenB4
APV4	—	—	—	—	MU14	UU5	IW4/350
AX50	—	—	—	R43	—	—	—
AZ31	—	—	—	—	U143	—	AZ31
B36A/B/C	12SN7GT	—	—	—	B36	TH2321	12SN7GT
B65	6SN7GT	—	—	6SN7GT	B65	—	—
B152	12AT7	—	—	ECC81	B309	—	ECC81
B228	—	210HL	—	HL2	K30K	—	PM2HL
B309	12AT7	—	—	ECC81	B309/12AT7	—	ECC81
B319	7AN7	—	—	PCC84	B319/PCC84	30L1	30L1
B329	12AU7	12AU7	—	ECC82	B329	—	—
B339	12AX7	—	—	ECC83	B339/12AX7	—	—
B719	—	6AQ8	—	ECC85	B719/ECC85	—	—
C10B	1D5	—	—	—	—	—	UR1C
C20C	10D1	—	—	—	—	—	—
C30B	4D1	—	—	—	—	—	HL13C
CC2	—	—	—	—	—	—	HL13
CE311	—	—	—	3C23	—	—	—
CF1	—	—	—	—	—	—	SP13
CF7	—	—	—	—	—	—	SP13
CK1	—	—	—	—	—	—	FC13
CL33	—	332Pen	—	—	—	—	CL33
CY1C	—	—	—	—	—	—	UR1C
CY31	—	OM1	—	—	—	—	CY31
D4	HLA2	41MHL	—	D4	MH4	AC/HL	354V
D63	6H6G	—	—	—	—	—	—
D77	6AL5	DD6	—	EB91	—	6D2	—
D152	6AL5	DD6	—	EB91	D77	6D2	—
D400	—	—	—	—	D41	—	—
DA	4D1	—	—	DA	—	—	—
DA90	—	1H5GT	—	—	—	1D13	DA90
DAC32	1H5G	—	—	1H5GT	HD14	—	1H5G
DAF91	1S5	1S5	1S5	DAF91	ZD17	1FD9	DAF91
DAF96	—	—	—	—	—	1FD1	—
DC90	3AF	—	—	—	—	—	—
DD4	—	DDL4	—	—	D41	V914	—
DD6	6AL5	DD6	—	DD6	D77	6D2	EB91
DD6G	6AL5	DD6	—	DD6	D152	6D2	EB91
DDA1	—	DDL4	—	—	D41	—	2D4A
DDL4	—	DDL4	—	—	D41	V914	2D4A
DDPP4B	—	420TDD	—	PT4D	DN41	AC2/PenDD	—
DDPP4M	—	—	—	—	DN41	—	Pen4DD
DDT	11A2	DDT	—	—	MH4D	AC/HLDD	—
DD2D	—	—	—	—	H2D	—	TDD2A
DDT2	—	210DDT	—	H2D	—	—	TDD2A
DDT4	—	—	—	H4D	MHD4	AC/HLDD	TDD4
DDT6S	6Q7	6Q7	—	6Q7	—	—	6Q7
DDT13	—	202DDT	—	—	—	—	—
DDT220	—	210DDT	—	H2D	—	—	TDD2A
DF33	1N5GT	1N5	—	1N5GT	ZD14	—	DF33
DF91	1T4	1T4	1T4	DF91	W17	1F3	DF91
DF92	1L4	—	—	—	—	1F2	—
DF96	1AJ4	1AJ4	—	DF96	—	1F1	DF96
DF97	1AN5	—	—	DF97	—	—	DF97
DH42	—	—	—	—	—	AC/HLDD	TDD4
DH63	6Q7G	6Q7	—	—	DH63	—	6Q7G
DH81	7B6	—	—	7C6	DH81	—	—
DH142	—	—	—	—	—	10LD3	UBC41
DH147	—	OM4	—	—	—	—	EBC33
DH149	7C6	—	—	7C6	—	—	—
DH150	—	—	—	—	—	6LD3	—
DH151	—	62DDT	—	EBC41	—	6LD3	—

Type	Brimar	Cossor	Emitron	Ferranti	Marconi or Osram	Mazda	Mullard
DH719	6T8	—	—	EABC80	—	—	—
DK32	1A7G	1A7GT	—	1A7GT	X14	—	DK32
DK33	1N5GT	1N5GT	—	1N5GT	—	—	—
DK91	1C1	1R5	—	DK91	X17	1C1	DK91
DK92	1AC6	1AC6	—	DK2	X18	1C2	DK92
DK96	1C3	—	—	DK96	—	1C3	DK96
DL33	3Q5G	—	—	3Q5G	N16	—	DL33
DL35	1C5G	1C5GT	—	1C5GT	N14	—	DL35
DL63	6R7G	—	—	6R7G	—	—	—
DL74M	6Q7GT	—	—	6Q7GT	—	—	—
DL92	3S4	3S4	3S4	DL92	N17	1P10	DL92
DL93	—	3A4	3A4	—	—	—	DL93
DL94	3V4	—	—	DL94	N19	1P11	DL94
DL95	3Q4	—	—	—	N18	—	—
DL96	DL96	—	—	DL96	—	1P1	DL96
DL145	—	—	—	—	—	10LD11	—
DM70	—	—	—	DM70	—	1M1	DM70
DM71	—	—	—	DM70	—	1M1	—
DN41	—	420TDD	—	PT4D	—	AC2/PenDD	—
DO24	—	—	—	LP25	PX25	PP5/400	—
DO30	—	—	—	—	DA30	—	—
DO42	—	—	—	—	—	—	Pen4DD
DP61	—	—	—	DP61	—	—	EF95
DT41	—	—	—	H4D	—	AC/HLDD	TDD4
DT215	—	—	—	—	—	HL23D	—
DT436	—	—	—	H4D	—	AC/HLDD	TDD4
DT1336	—	202DDT	—	—	—	—	—
DW2	R1	506BU	—	R41	U10	—	DW2
DW3	R2	442BU	—	R4	U14	—	DW4/350
DW4	R3	—	—	R43	U14	—	—
E235	—	—	—	—	—	—	PM202
E446	—	MS/Pen	—	SPT4A	MS4B	—	—
EA50	—	SD61	—	—	—	SD1	EA50
EABC80	6T8	6AK8	6AK8	EABC80	DH719	6LD12	EABC80
EAF42	—	—	—	EAF42	—	—	EAF42
EB91	6AL5	DD6	6AL5	EB91	D77	6D2	EB91
EBC33	—	OM4	—	—	DH147	—	—
EBC41	—	62DDT	—	EBC41	—	6LD3	EBC41
EBC90	6AT6	—	—	EBC90	DH77	—	EBC90
EBF80	6N8	—	—	EBF80	WD709	—	—
EBL21	—	—	—	—	DN143	—	EBL21
EC90	6C4	—	—	EC90	—	—	—
EC91	—	—	—	EC91	—	6L34	EC91
ECC81	12AT7	12AT7	ECC81/12AT7	ECC81	B309	—	ECC81
ECC82	12AU7	12AU7	—	ECC82	B329	—	ECC82
ECC83	12AX7	—	—	ECC83	B339	—	ECC83
ECC85	ECC85	6AQ8	ECC85/6AQ8	ECC85	B719	6L12	—
ECC91	—	6J6	—	—	—	—	ECC91
ECH21	—	—	—	ECH21	X143	—	—
ECH35	—	OM10	—	—	X61M	—	—
ECH42	—	62TH	—	ECH42	X150	6C10	ECH42
ECH81	6AJ8	6AJ8	6AJ8	ECH81	X719	6C12	ECH81
ECL80	—	6AB8	ECL80/6AB8	ECL80	LN152	—	—
EF22	—	—	—	—	W143	—	EF22
EF36	—	OM5B	—	—	—	—	EF36
EF37A	—	OM5B	—	—	—	—	EF37A
EF39	—	OM6	—	—	W147	—	EF39
EF41	—	62VP	—	EF41	W150	6F15	EF41
EF42	—	—	—	EF42	Z150	6F13	EF42
EF50	—	63SPT	—	—	Z90	—	EF50
EF80	6BX6	6BX6	EF80/6BX6	EF80	Z719	ECL80	EF80
EF85	6BY7	—	EF80/6BY7	—	W719	EF85	EF85
EF86	—	—	—	EF86	Z729	—	EF86
EF89	—	—	—	EF89	—	—	EF89
EF91	6AM6	6AM6	6AM6	EF91	Z77	6F12	EF91
EF92	9D6	VP6	—	—	W77	—	EF93
EF95	—	—	—	6AK5	—	—	—

Type	*Brimar*	*Cossor*	*Emitron*	*Ferranti*	*Marconi or Osram*	*Mazda*	*Mullard*
EK90	—	—	6BE6	EK90	X727	—	EK90
EL33	6AG6G	—	—	—	KT61	SP25	—
EL37	—	—	—	—	KT66	—	EL37
EL41	—	67PT	—	—	N150	—	EL41
EL84	—	6BQ5	EL84/6BQ5	EL84	N709	6P15	EL84
EL90	—	—	6AQ5	EL90	N727	—	EL90
EL91	6AM5	6AM5	6AM5	EL91	N77	—	EL91
EL821	6CH6	6CH6	—	—	—	—	EL821
EM34	—	64ME	—	—	EM34	6ME	EM34
EM80	—	65ME	EM80	EM80	EM80	EM80	EM80
EY51	R12	SU61	—	EY51	U43	—	EY51
EY81	—	EM81	—	—	U709	—	—
EZ35	6X5GT	6X5	6X5	EZ35	U147	—	6X5GT
EZ40	—	66KU	—	EZ40	U150	—	EZ40
EZ80	EZ80	6V4	6V4	EZ80	—	—	EZ80
EZ81	—	—	—	—	EZ80	UU12	EZ81
EZ90	6X4	—	6X4	EZ90	U78	—	EZ90
FC2	—	210PG	—	VHT2A	X22	—	FC2
FC4	15A2	41MPG	—	VHT2	MX40	—	FC4
FC13C	15D1	—	—	—	—	—	FC13C
FW4/500	—	4/100BU	—	R43	U18/20	—	FW4/500
FW4/800	—	—	—	—	U18/20	—	FW4/800
FY	—	PT41	—	—	—	—	PM24M
G431	—	506BU	—	R41	—	—	DW2
G470	—	—	—	R41	—	—	—
G2080	—	—	—	—	—	—	CY1
G4120	—	—	—	R43	—	—	DW4/500
G4120N	R3	43IU	—	R42	MU14	UU5	IW4/500
GN24	—	506BU	—	R41	—	—	DW2
GZ30	5Z4G	5Z4G	—	5Z4G	—	—	GZ30
GZ31	5U4G	—	—	5U4G	—	—	—
GZ32	—	54KU	—	GZ32	—	—	GZ32
GZ33	53KU	53KU	53KU	—	U54	—	GZ33
H2	—	210HL	—	HL2	—	—	PM2HL
H2D	—	210DDT	—	H2D	—	—	TDD2A
H4D	11A2	DDT	—	—	MH4D	AC/HLDD	—
H210	—	210HF	—	HL2	—	—	PM2HL
HAD	11D3	—	—	HAD	—	—	—
HBC90	12AT6	—	—	—	—	—	HBC90
HD14	1H5G	—	—	1H5GT	HD14	—	1H5G
HD22	—	—	—	H2D	—	—	TDD2A
HD23	—	210DDT	—	H2D	—	—	TDD2A
HD24	—	210DDT	—	H2D	—	HL21DD	TDD2A
HF93	12BA6	—	—	—	—	—	HF93
HL2	—	210HL	—	HL2	HL2	HL2	PM2HL
HL2K	—	—	—	—	—	—	PM2HL
HL4G	—	MH4	—	D4	MH4	—	—
HL13C	—	—	—	DA	—	—	—
HL20	—	—	—	HL22	—	—	—
HL21	—	—	—	HL22	—	—	—
HL22	—	—	—	HL22	—	—	—
HL21DD	—	210DDT	—	H2D	—	—	TDD2A
HL92	50C5	—	—	—	—	—	HL92
HL210	—	210HL	—	HL2	—	—	PM2HL
HL1320	4D1	—	—	DA	—	—	HL13C
HLA1	HLA1	41MH	—	—	MH4	AC2/HL	—
HLA2	—	41MHL	—	D4	—	AC/HL	354V
HLB1	—	210HF	—	HL2	—	HL2	BM2HL
HLDD1320	11D3	—	—	HAD	—	—	—
HP2	—	220B	—	HP2	—	—	—
HP135	—	—	—	—	—	—	VP13A
HP210	—	—	—	SPT2	Z21	—	—
HP4101C	—	MS/PEN	—	SPT4A	—	—	SP4
HP4105	—	MVS/PEN	—	VPT4	—	VM4P	VPT4
HP4106	—	MVS/PEN	—	VPT4	—	VM4P	VPT4
HR1	R10	—	—	HR1	—	—	—
HR210	—	210HF	—	HL2	—	—	PM2HL

Type	*Brimar*	*Cossor*	*Emitron*	*Ferranti*	*Marconi or Osram*	*Mazda*	*Mullard*
HY90	35W4	—	—	—	—	—	HY90
IW2	R1	—	—	R42	—	UU5	—
IW3	R2	—	—	R42	MU14	UU5	IW4/350
IW4	R3	43IU	43IU	R42	MU14	UU5	IW4/500
IW4/350	—	43IU	43IU	R42	MU14	UU5	IW4/350
IW4/500	—	43IU	43IU	R43	MU14	UU5	IW4/500
K3	—	—	—	GK3	—	—	—
K3A	—	—	—	GK32	—	—	—
K3F	—	—	—	GK40	—	—	—
K23B	—	210DDT	—	H2D	—	—	TDD2A
K30A	—	210HL	—	HL2	—	—	PM2HL
K30G	—	220PA	—	L2	—	—	PM2A
K30K	—	210HF	—	HL2	—	—	PM2HL
K33A	—	220B	—	HP2	—	—	—
K40N	—	215SG	—	VS2	—	VP210	VP12M
K50M	—	—	—	VPT2	—	VP210	—
K70B	—	220OT	—	PT2	—	Pen/220	PM22A
K70D	—	—	—	—	—	—	PM22D
K77A	—	—	—	QPT2	QP21	—	—
K77B	—	240QP	—	—	—	—	QP22B
K80A	—	210PG	—	VHT2A	X22	—	FC2
K80B	—	—	—	—	—	—	FC2A
K435/10	—	4XP	—	LP4	PX4	PP3/250	—
KD21	—	OA3	—	KD21	—	—	—
KD24	—	OC3	—	KD24	—	—	—
KD25	—	OD23	—	KD24	—	—	—
KT2	—	220T	—	PT2	KT24	Pen220	PM22A
KT24	—	220OT	—	PT2	KT2	Pen220	PM22A
KT41	7A3	42OT	—	PT4	KT41	AC2/Pen	—
KT42	7A2	MP/Pen	—	—	MKT4	AC/Pen	—
KT61	6AG6G	50L6	—	—	KT61	6P25	—
KT81	7C5	7C5	7C5	7C5	KT81	—	—
KTW74M	12K7GT	12K7	—	12K7GT	—	—	—
L2	—	220PA	—	L2	—	—	PM2HL
L2/B	—	210HF	—	HL2	—	—	PM2HL
L4	—	41MP	—	L4	—	AC/P	—
L21	—	210HL	—	HL2	—	—	PM2HL
L21/DD	—	210DDT	—	H2D	—	—	TDD2A
L63	6J5G	6J5	—	6J5G	L63	—	6J5G
L77	6C4	—	—	6C4	L77/6C4	—	—
L210	—	210LF	—	—	—	—	PM1LF
LL2	—	210HF	—	HL2	—	—	PM2HL
LL4	—	41MP	—	L4	—	AC/P	—
LN152	ECL80	6AB8	ECL80/6AB8	—	—	—	ECL80
LN309	—	—	—	PCL83	LN309/PCL83	—	—
LP2(F)	—	230XP	—	LP2	—	—	PM202
LP2(MO)	—	—	—	L2	—	P220	PM2A
LP4	—	4XP	—	LP4	PX4	PP3/250	—
LP25	—	—	—	LP25	PX25	PP5/400	—
LP220	—	—	—	L2	—	P220	—
LZ319	8A8	—	8A8	PCF80	LZ319	30C1	PCF80
MH4	—	41MH	—	D4	MH41	AC/HL	354V
MH41	HLA2	41MH	—	D4	MH41	AC2/HL	354V
MH4105	—	41MPG	—	VHT4	MX40	—	—
MHD4	11A2	DDT	—	HD4	MH4D	AC/HLDD	—
MHL4	—	—	—	—	MHL4	AC/HL	—
MKT4	7A2	MP/Pen	—	—	MKT4	AC/Pen	—
ML4	—	41MP	—	—	ML4	AC/P	—
MM4V	—	—	—	—	—	AC/SG/VM	—
MP/Pen	7A2	MP/Pen	—	—	MKT4	AC/Pen	Pen4VA
MPT4	7A2	MP/Pen	—	—	MPT4	AC/Pen	Pen4VA
MS4B	—	—	—	SPT4A	MS4B	—	—
MSG/HA	—	MSG/HA	—	SPT4A	MS4B	AC/SG	—
MSG/LA	—	MSG/LA	—	—	—	AC/S2	—
MSP4	8A1	MS/Pen	—	SPT4A	SP4	—	SP4
MS/Pen	8A1	MS/Pen	—	SPT4A	—	AC/SG	SP4
MS/PenA	—	—	—	SPT4A	—	AC/SG	—

Type	Brimar	Cossor	Emitron	Ferranti	Marconi or Osram	Mazda	Mullard
MS/PenB	—	MS/PenB	—	—	SP4B	—	—
MU12	R2	—	—	R42	MU12	UU5	IW4/350
MU12/14	R2	—	—	R42	MU12	UU5	IW4/500
MU14	R3	—	—	R42	MU14	UU5	IW4/500
MVSG	—	MVSG	—	—	—	AC/SG/VM	—
MVS/Pen	9A1	MVS/Pen	—	VPT4B	—	AC/VP1	—
MVS/PenB	—	MVS/PenB	—	—	—	AC/VP2	—
MX40	15A2	41MPG	—	VHT4	MX40	—	—
N14	1C5G	1C5	—	1C5GT	N14	—	DL35
N16	3Q5GT	—	—	3Q5JT	N16	—	DL33
N17	3S4	—	—	3S4	N17	1P10	DL92
N18	3Q4	—	—	—	N18	—	—
N19	3V4	—	—	3V4	N19	1P11	DL94
N30	7D4	—	—	PTA	N30	—	—
N31	—	—	—	PTS	N31	—	—
N40	7A2	—	—	—	N4D	—	—
N41	7A3	42OT	—	PT4	N41	AC2/Pen	PenA4
N66	7A3	—	—	—	N66	—	EL37
N77	6AM5	—	—	6AM5	N77	—	EL91
N142	—	—	—	UL41	N142	—	—
N144	6AM5	—	—	6AM5	N77	—	EL91
N145	—	—	—	—	N145	10P13	—
N147	6AG6G	—	—	—	N147	6P25	EL33
N150	—	—	—	EL41	N150	—	—
N151	—	—	—	EL42	N151	—	EL42
N152	PL81	—	—	PL81	N359	—	PL81
N153	—	—	—	PL83	N309	—	PL83
N154	—	16A5	16A5	PL82	N329	—	PL82
N309	—	—	—	PL83	N309	—	PL83
N329	—	16A5	16A5	PL82	N154	—	PL82
N339	PL81	—	—	PL81	N339	—	—
N359	—	21A6	—	PL81	N339/PL81	—	—
N709	—	6BQ5	EL84/6BQ5	EL84	N709	—	EL84
N727	—	—	6AQ5	6AQ5	N727	—	EL90
O202	—	210PG	—	—	X22	—	FC2
O406	—	41MPG	—	VHT4	—	—	FC4
O1307	—	—	—	VHTA	—	—	FC13C
OA3	VR75/30	—	—	KD21	—	—	—
OB3	VR105/30	—	—	KD24	—	—	—
OC3	VR105/30	—	—	KD25	—	—	—
OC3/VR150	—	—	—	KD24	—	—	—
OD3/VR105	—	—	—	KD25	—	—	—
OG3	—	—	—	—	—	—	85A2
OM1	—	OM1	—	—	—	U201	CY31
OM4	—	OM4	—	—	—	—	EBC33
OM5	—	OM5B	—	—	—	—	EF36
OM5A	—	OM5B	—	—	—	—	EF37A
OM5B	—	OM5B	—	—	—	—	EF37A
OM6	—	—	—	—	W147	—	EF39
OM7	—	OM6	—	—	W147	—	EF39
OM9	—	—	—	—	—	—	EL32
OM10	—	OM10	—	—	X147	—	ECH35
OP41	—	—	—	—	—	ACH/Pen	PenB4
OP42	—	—	—	PT4	—	AC2/Pen	PenA4
P2	—	230XP	—	LP2	P2	—	PM202
P4	—	4XP	—	LP4	PX4	—	ACO44
P12/250	—	4XP	—	LP4	PX4	PP3/250	ACO44
P27/500	—	—	—	LP25	PX25	PP5/400	—
P220A	—	—	—	LP2	P2	—	PM202
P225	—	—	—	PT2	KT24	Pen220	PM22A
P240	—	—	—	LP2	P2	—	MM202
P435	—	PT41	—	—	—	—	PM24M
P460	—	4XP	—	LP4	PX4	—	ACO44
P495	7A7	42OT	—	PT4	—	AC2/Pen	PenA4
PA1	—	41MXP	—	—	—	—	—
PA20	—	2P	—	—	—	—	—
PABC80	—	—	—	PABC80	—	—	—

Type	Brimar	Cossor	Emitron	Ferranti	Marconi or Osram	Mazda	Mullard
PB1	—	220PA	—	L2	—	—	—
PCC84	7AN7	PCC84/7AN7	PCC84/7AN7	PCC84	B319	30L1	PCC84
PCF80	—	8A8	PCF80/9A8	PCF80	LZ319	30C1	PCF80
PCF82	PCF82/9U8	9U8	—	PCF82	PCF82	PCF82	PCF82
PCL83	—	—	—	PCL83	LN309	—	PCL83
PD22DA	—	—	—	HP2	—	—	—
PD220	—	220B	—	HP2	—	—	—
Pen4VA	7A2	MP/Pen	—	—	MKT4	AC/Pen	—
Pen4VB	7A3	42OT	—	PT4	KT41	AC2/Pen	PenA4
Pen13C	7D8	—	—	PTA	—	—	—
Pen36C	7D6	—	—	—	—	—	—
Pen220	—	220OT	—	—	KT2	Pen220	PM22A
Pen231	—	—	—	—	—	—	PM22D
Pen1340	7D8	—	—	PTA	—	—	—
PenA1	—	PT41	—	—	—	—	PM24M
PenA4	7A3	42OT	—	PT4	K41	AC2/Pen	—
PenB1	—	220OT	—	PT2	KT2	Pen220	PM22A
PenB4	—	—	—	—	—	AC4/Pen	PenB4
Pen3520	7D6	—	—	—	—	—	—
PL81	—	21A6	PLA81/21A6	—	N359	—	PL81
PL82	—	16A5	16A5	PL82	N329	30P16	PL82
PM1A	—	210HL	—	HL2	—	—	PM1A
PM1HF	210HF	—	—	HL2	—	—	PM2HL
PM1HL	—	210HL	—	HL2	—	—	PM2HL
PM2	—	220P	—	—	P2	—	PM2
PM2A	—	220PA	—	L2	—	—	PM2A
PM2B	—	220B	—	HP2	—	—	PM2B
PM2DL	—	210HL	—	HL2	—	—	PM2DL
PM2HL	—	210HL	—	HL2	—	—	PM2HL
PM12	—	215SG	—	—	Z21	—	PM12
PM12A	—	215SG	—	—	Z21	Pen220	PM12A
PM12M	—	220VSG	—	VS2	W21	—	PM12M
PM22	—	220PT	—	—	—	—	PM22
PM22A	—	220OT	—	PT2	KT2	Pen220	PM22A
PM22C	—	220PT	—	—	—	Pen220A	PM22C
PM24M	—	PT41	—	—	—	—	PM24M
PM202	—	220PA	—	LP2	P2	—	PM202
PP2	—	220OT	—	—	KT2	Pen220	PM22A
PP3/250	—	4XP	—	LP4	PX4	PP3/350	ACO44
PP4	—	—	—	—	—	—	PM24M
PP5/400	—	—	—	LP25	PX25	PP5/400	—
PP6A	—	—	—	—	—	—	EL2
PP6BG	—	—	—	—	—	—	EL33
PP220	—	—	—	—	—	—	PM202
PP222	—	220OT	—	PT2	KT2	Pen220	PM22A
PT2	—	220OT	—	PT2	KT2	Pen220	PM22A
PT4(F)	7A3	42MP/Pen	—	PT4	—	AC2/Pen	PenA4
PT4(MO)	—	PT41	—	—	PT4	—	Pen24M
PT4D	—	42OTDD	—	PT4D	—	AC2/PenDD	—
PT10	—	PT10	—	—	—	AC5/Pen	—
PT41	—	PT41	—	—	—	—	PM24M
PTA	7D8	—	—	PTA	N30	—	—
PTS	—	—	—	PTS	KT31	—	—
PV4	—	442BU	—	R42	—	—	DW4/350
PV495	—	—	—	R41	—	—	—
PV4200	—	—	—	R43	U14	—	DW4/500
PX4	—	4XP	—	LP4	PX4	PP3/250	ACO44
PX25	—	—	—	LP25	—	PP5/400	—
PX41	—	4XP	—	LP4	PX4	PP3/250	ACO44
PX230	—	220PA	—	LP2	P2	—	PM202
PY80	—	—	PY80/19X3	—	U152	—	PY80
PY81	—	17Z3	PY81/1723	PY81	U153	—	PY81
PY82	—	19Y3	PY82/1973	PY82	U154	—	PY82
PZ30	R14	—	—	PZ30	—	—	PZ30
QP21	—	240QP	—	—	—	—	—
QP22B	—	—	—	—	—	QP230	QP22B
QPT2	—	—	—	QPT2	—	QP230	—

Type	*Brimar*	*Cossor*	*Emitron*	*Ferranti*	*Marconi or Osram*	*Mazda*	*Mullard*
R1	R1	—	—	R41	U10	UU5	—
R2	R2	43IU	43IU	R42	MU14	UU5	IW4/350
R3	R3	—	—	—	MU14	UU5	IW4/500
R4	R2	442BU	—	R4	MU14	UU5	DW4/350
R4A	R3	—	—	—	MU14	UU5	—
R10	—	—	—	HR2	—	—	—
R12	6X2	SU61	—	EY51	U43/EY51	—	EY51
R12A	—	—	—	EY51	—	—	EY51
R14	R14	—	—	PZ30	—	—	PZ30
R16	R16/1T2	—	—	—	U37	—	—
R41	R41	—	—	R41	U10	—	DW4/500
R42	R2	43IU	43IU	R42	—	UU5	IW4/350
R43	—	—	—	—	—	—	FW4/500
R52	5Z4	5Z4	—	R52	—	—	GZ30
RL7	—	—	—	EF54	—	—	EF54
RL16	—	—	—	EC52	—	—	EC52
RL37	—	—	—	EC54	—	—	EC54
RV120/350	—	442BU	—	R4	U14	—	DW4/350
RV120/500	—	—	—	R4A	U14	UU5	DW4/500
RV200/600	—	—	—	—	U18/20	—	FW4/800
RZ	1D5	—	—	RZ	—	—	UR1C
S2	—	220SG	—	S2	—	—	PM12M
S4VA	—	MS/Pen	—	—	MS4B	—	—
S4VB	—	MS/Pen	—	—	MS4B	—	—
S11A	R1	506BU	—	R41	—	—	—
S11D	R2	442BU	—	R4	—	—	DW4/350
S30C	—	4XP	—	LP4	PX4	PP3/250	ACO44
S208	—	220SG	—	VS2	—	—	PM12M
S213	—	220SG	—	VS2	W21	—	PM12M
S215VM	—	220SG	—	VS2	W21	—	PM12M
S218	—	—	—	—	Z22	—	SP2
S420	—	—	—	VPT4B	—	—	VP4B
S435N	—	—	—	SPT4A	—	—	SP4
SD2	—	210HL	—	HL2	—	—	PM2HL
SD61	—	SD61	—	—	—	6D1	EA50
SE211C	—	220SG	—	VS2	—	—	PM12M
SG215	—	215SG	—	—	—	—	PM12M
SG215A	—	215SG	—	VS2	—	—	PM12M
SP2	—	210SPT	—	SPT2	221	—	SP2
SP4(M)	8A1	MS/Pen	—	SPT4A	MS4B	—	SP4
SP4B	—	MS/PenB	—	—	—	—	SP4B
SP6	8D3	—	—	6AM6	Z77	6F12	EF91
SP13B	—	13SPA	—	SPTA	—	—	SP13C
SP13C	—	13SPA	—	SPTA	—	—	SP13C
SP210	—	210SPT	—	SPT2	—	—	—
SP215	—	—	—	—	Z21	—	—
SP220	—	—	—	LP2	—	—	PM202
SP1320	—	—	—	SPTA	—	—	SP13C
SPT4A	—	MS/Pen	—	SPT4A	MS4B	—	SP4
SPTA	8D2	13SPA	—	SPTA	—	—	—
SU45	—	—	SU45	—	—	19G6	—
SU61	R12	SU61	—	2Y51	U43/EY51	—	EY51
T4D	—	—	—	—	—	D1	T4D
T6D	—	—	—	—	—	—	EA50
TDD2A	—	210DDT	—	H2D	HD24	HL21DD	TDD2A
TDD4	11A2	DDT	—	H4D	MHD4	AC/HLDD	TDD4
TH2	—	220TH	—	—	X24	—	7H2
TH4	20A1	41STH	—	—	X41	—	—
TH4A	—	—	—	—	—	AC/TH1	—
TH4B	—	—	—	—	—	AC/TH1	—
TH21C	—	202STH	—	—	—	TH2321	TH21C
TH22C	—	302THA	—	—	—	TH2321	—
TH29	—	302THA	—	—	—	TH2321	—
TH30	—	302THA	—	—	—	TH2321	—
TH30C	—	302THA	—	—	—	TH2321	—
TH2321	—	302THA	—	—	—	TH2321	—
TP2	—	—	—	—	—	AC/TP	—

Type	*Brimar*	*Cossor*	*Emitron*	*Ferranti*	*Marconi or Osram*	*Mazda*	*Mullard*
TT4	—	41MP	—	L4	—	AC/P	—
TT4A	—	41MP	—	L4	—	AC/P	—
TX4	—	—	—	—	X41	AC/TH1	—
TX21	—	202STH	—	—	—	TH2321	—
U10	R1	506BU	—	—	U10	UU5	DW2
U12	R2	442BU	—	R4	U12	—	DW4/350
U12/13	—	—	—	—	U12/13	—	DW4/350
U14	R3	—	—	R3	U14	—	DW4/500
U18/20	—	—	—	R43	U18/20	—	FW4/500
U31	25Z4G	—	—	—	U31	—	—
U37	IT2/R16	—	—	—	U37	—	—
U43	R12/R12A	SU61	—	EY51	U43/EY51	—	EY51
U50	5Y3G	—	—	5Y3GT	U50	—	—
U70	6X5G	—	—	6X5GT	U147	—	—
U78	6X4	—	—	6X4	U78/6X4	—	EZ90
U82	7Z4	—	—	7Z4	U82	—	—
U142	—	—	—	UY41	U142	—	UY41
U143	—	—	—	—	U143	—	AZ31
U145	—	—	—	—	U145	U404	—
U147	6X5G	—	—	6X5GT	U147	—	EZ35
U149	7Y4	—	—	7Y4	U82	—	—
U150	—	66KU	—	EZ40	U150	UU9	EZ40
U151	R12	—	—	—	U43	—	EY51
U152	—	—	—	—	U152	—	PY80
U153	PY81	17Z3	RY81/17Z3	17Z3	U153	U153	PY82
U154	—	—	—	—	U154	—	PY82
U202	—	—	—	—	U202	—	CY1
U251	—	—	—	PY81	U329	—	—
U329	—	—	—	—	U329	—	—
U404	—	—	—	—	U145	U404	—
U709	—	—	U709/EZ81	—	U709	—	EZ81
U4020	1D5	40SUA	—	—	U709	U4020	—
UBC41	—	—	—	UBC41	—	10LD3	UBC41
UBF80	—	171DDP	—	UBF80	—	—	UBF80
UCC85	—	—	—	UCC85	—	UCC85	UCC85
UCH82	—	141TH	—	—	X142	—	UCH82
UD2	—	—	—	LP2	—	—	PM202
UL41	—	451PT	—	UL41	N142	UL41	UL41
UR1	—	—	—	—	—	—	CY1
UR1C	1D5	40SUA	—	RZ	—	U4020	UR1C
UU2	R2	—	—	R41	—	—	—
UU3	R2	—	—	R42	MU14	—	IW4/350
UU4	R2	—	—	R42	MU14	—	IW4/350
UU5	R3	—	—	R4A	MU14	UU5	IW4/350
UU9	—	—	—	EZ40	—	UU9	EZ40
UU60/250	R2	—	—	R42	—	—	IW4/350
UU120/350	R2	—	—	R42	MU14	—	IW4/350
UU120/350A	—	—	—	R42	—	—	IW4/350
U120/500	R3	—	—	R43	—	—	—
UY41	—	311SU	—	UY41	—	UY41	UY41
V20	—	—	—	—	—	—	UR1C
V20s	—	—	—	—	—	—	CY1
V312	—	41MTL	—	D4	—	—	—
V503	—	—	—	—	DA30	—	—
VHT2	—	—	—	VHT2	X22	—	FC2
VHT2A	—	—	—	VHT2A	—	—	FC2A
VHT4	15A2	—	—	VHT4	MX40	—	FC4
VHTA	15D1	13PGA	—	VHTA	—	—	—
VMP4	—	—	—	VPT4	—	—	—
VMP4G	9A1	MVS/Pen	—	VPT4B	—	—	—
VMS4B	—	—	—	—	—	AC/SG/VM	—
VO2	—	—	—	—	X22	—	FC2A
VO4	—	—	—	VHT4	MX40	—	FC4
VO6s	—	—	—	—	—	—	EK2
VO13	—	—	—	VHTA	—	—	FC13C
VO13s	—	—	—	—	—	—	FC13
VP2	—	210VPT	—	VP2A	VP21	VP210	VP2

Type	*Brimar*	*Cossor*	*Emitron*	*Ferranti*	*Marconi or Osram*	*Mazda*	*Mullard*
VP4	9A1	MVS/Pen	—	VPT4	—	AC/VP1	—
VP4A	9A1	MVS/Pen	—	VPT4A	—	AC/VP1	—
VP4B	—	MVS/PenB	—	—	—	AC/VP2	VP4B
VP6	—	VP6	—	—	W77	—	EF92
VP13C	9D2	13VPA	—	—	—	VP1322	—
VP21	—	—	—	VPT2	—	VP210	—
VP210	—	210VPT	—	VPT2	W21	VP210	—
VP215	—	—	—	VPT2	W21	—	—
VP1322	9D2	—	—	—	—	VP1322	—
VPT2	—	—	—	VPT2	—	VP210	—
VPT4	9A1	MVS/Pen	—	VPT4	—	AC/VP1	—
VPT4B	—	—	—	VPT4B	—	AC/VP1	—
VS2	—	—	—	VS2	W21	—	PM12M
VS24	—	—	—	VS2	—	—	PM12M
VS210	—	220VSG	—	VS2	W21	—	PM12M
VS215	—	220VSG	—	VS2	W21	—	PM12M
VSGA1	—	—	—	—	—	AC/SG/VM	—
VX2	—	—	—	—	—	—	VT2B
W17	1T4	—	—	1T4	W17	1F3	DF91
W21	—	—	—	VPT2	W21	VP210	—
W42	—	MVS/PenB	—	—	—	AC/VP2	—
W63	6U7G	—	—	6U7G	W63	—	—
W76	12K7GT	—	—	12K7GT	W76	—	—
W77	9D6	—	—	—	W77/9D6	—	EF92
W81	7H7	—	—	7H7	W81	—	—
W142	—	—	—	UF41	W142	—	UF91
W143	—	—	—	—	—	—	EF22
W145	—	—	—	—	W145	10F9	—
W147	—	—	—	—	W147	10F9	—
W148	7H7	—	—	7H7	W148	—	EF39
W149	7B7	—	—	—	W149	—	—
W150	—	—	—	EF41	W150	—	EF41
W719	—	—	—	EF85	W719	—	EF85
W727	—	—	—	—	W727/6BE6	—	EF93
W729	—	—	—	EF85	W729	—	—
WD142	—	—	—	UAF42	WD142	—	UAF42
WD150	—	—	—	EAF42	—	—	EAF42
WD709	—	—	—	EBF80	WD709	—	EBF80
X14	1A7G	—	—	1A7GT	X14	—	1A7G
X17	1R5	—	—	1R5	X17/1T4	1C1	DK91
X18	1AC6	—	—	1AC6	X18/1R5	1C2	DK92
X21	—	—	—	VHT2A	—	—	FCA2
X22	—	—	—	—	X22	—	FC2
X24	—	220TH	—	—	X24	—	—
X41	21A1	41STH	—	—	X41	AC/TH1	—
X42	15A2	—	—	—	X42	—	—
X63	6A8G	—	—	6A8G	X63	—	6A8G
X64	6L7G	—	—	6L7G	X64	—	—
X65	6K8G	—	—	6K8G	X65	—	—
X71M	12K8GT	—	—	12K8GT	X71M	—	—
X76M	12K8GT	—	—	12K8GT	X76M	—	—
X77	6BE6	—	—	6BE6	X77	—	—
X81	7S7	—	—	7S7	X81	—	—
X142	—	—	—	UCH42	X142	—	UCH42
X143	—	—	—	—	X143	—	ECH21
X145	—	—	—	—	—	10C1	—
X147	—	—	—	—	X147	—	ECH35
X148	7S7	—	—	7S7	X148	—	—
X150	—	—	—	ECH42	X150	6C10	ECH42
X719	—	—	—	ECH81	X719	—	ECH81
X727	—	—	—	6BE6	X727	—	EK90
Y61	6U5G	—	—	VFT6	—	6M1	—
Y62	—	—	—	VFT6	—	—	—
Y63	6U5G	—	—	VFT6	—	6M1	—
Y220	—	—	—	PT2	KT2	—	—
Z14	1N5G	—	—	1N5GT	Z14	—	1N5G
Z22	—	—	—	SPT2	Z22	—	SP2

Type	*Brimar*	*Cossor*	*Emitron*	*Ferranti*	*Marconi or Osram*	*Mazda*	*Mullard*
Z63	6J7G	—	—	6J7G	Z63	—	6J7G
Z77	6AM6	—	—	6AM6	Z77/EF91	6F12	EF91
Z90	—	—	—	—	—	—	EF50
Z142	—	—	—	UF42	Z142	—	UF42
Z145	—	—	—	—	Z145	10F1	—
Z150	—	—	—	EF42	Z150	—	EF42
Z152	6BW7	—	—	EF80	Z719	—	EF80
Z719	6BW7	—	—	EF80	Z719	—	EF80
Z729	—	—	—	EF86	Z729/EF86	—	DAF91
ZD	10D1	—	—	ZD	—	10D1	—
ZD14	—	—	—	1N5GT	ZD14	—	—
ZD17	1S5	—	—	1S5	ZD17	1FD9	—
ZD152	—	—	—	EBF80	ZD152	—	—
0A3/VR75	—	—	—	KD21	—	—	—
0B2	—	—	—	—	—	—	108C1
054V	PA1	4MXP	—	—	—	—	054V
1A3	—	—	—	—	—	—	DA90
A7G	—	1A7G	—	—	X14	—	1A7G
1A7GT	—	—	—	1A7GT	—	—	DK32
1AB6	—	—	—	1AB6	—	1C3	DK96
1AC6	—	1AC6	—	1AC6	X18	1C2	DK92
1AH5	1AH5	1AH5	—	1AH5	—	1FD5	—
1AJ4	—	—	—	1AJ4	—	1F1	DF96
1C1	1R5	—	—	1R5	X17	1C1	DK91
1C2	1AC6	—	—	A1C6	X18	1C2	DK92
1C3	—	—	—	DK96	—	1C3	DK96
1C5G	—	—	—	—	—	—	DL35
1D5	—	40SUA	—	RZ	—	U4020	—
1D13	—	—	—	—	—	—	DA90
1F1	—	—	—	1AJ4	—	1F1	DF96
1F2	1L4	—	—	—	—	1F2	DF92
1F3	1T4	—	—	1T4	W17	1F3	DF91
1FD1	—	—	—	1AH5	—	1FD1	DAF96
1FD9	1S5	—	—	1S5	ZD17	1FD9	DA91
1H5GT	—	1H5GT	—	1H5GT	HD14	—	DAC32
1L4	1L4	—	—	—	—	1F2	—
1M1	—	—	—	DM70	—	1M1	DM70
1M3	—	—	—	1M3	—	1F1	—
1N5G	—	1N5GT	—	—	Z14	—	1N5G
1N5GT	—	—	—	1N5GT	—	—	DF33
1N5VG	—	—	—	1N5GT	Z14	—	DF33
1P1	—	—	—	3C4	—	1P1	DL96
1P10	3S4	3S4	3S4	3S4	N17	1P10	DL92
1P11	3V4	—	—	3V4	N19	1P11	DL94
1R5	1R5	1R5	1R5	1R5	X17	1C1	DK91
1S5	—	1S5	1S5	1S5	ZD17	1FD9	DAF91
1T2	R16	—	—	—	—	—	—
1T4	—	1T4	1T4	1T4	W17	1F3	DF91
2D4A	—	DDL4	—	—	—	V914	—
2D13C	10D1	—	—	—	—	—	—
3A4	—	—	—	—	—	—	DL93
3A5	—	—	—	—	—	—	DCC90
3C4	—	—	1A4	3C4	—	1P1	DL96
3Q4	—	—	—	—	N18	—	—
3Q5G	—	—	—	—	N16	—	DDL3
3Q5GT	—	—	—	3Q5GT	N16	—	3Q5GT
3S4	—	—	3S4	3S4	N17	1P10	DL92
3V4	—	3V4	—	3V4	N19	1P11	DL94
4/100BU	—	—	—	R43	U18/20	—	FW4/500
4D1	—	—	—	DA	—	—	—
4THA	—	4THA	—	—	—	AC/TH1	—
4XP	—	4XP	—	LP4	PX4	PP3/250	—
5T4	—	—	—	5U4G	—	—	—
5U4G	5U4G	5U4G	5U4G	5U4G	U52	—	5U4G
5Y3GT	—	—	—	5Y3GT	U50	—	—
5Z4	—	—	—	5Z4G	—	—	GZ30

Type	*Brimar*	*Cossor*	*Emitron*	*Ferranti*	*Marconi or Osram*	*Mazda*	*Mullard*
6A8G	—	—	—	6A8G	X63	—	6A8G
6AB4	—	—	—	—	—	—	EC92
6AB8	ECL80	—	—	6AB8	—	—	ECL80
6AG6	—	—	—	—	KT61	—	EL33
6AJ8	—	—	—	6AJ8	—	—	ECA81
6AK5	—	—	—	6AK5	—	—	EF95
6AL5	—	—	6AL5	6AL5	D77	6D2	EB91
6AM5	—	—	6AM5	6AM5	N77	—	EL91
6AM6	8D3	—	6AM6	6AM6	Z77	6F12	EF91
6AQ4	—	—	—	EC91	—	—	EC91
6AQ5	—	—	6AQ5	6AQ5	N727	—	EL90
6AQ8	—	—	—	6AQ8	—	—	ECC85
6AT6	6AT6	—	6AT6	6AT6	DH77	—	EBC90
6AV6	—	—	—	—	—	—	EBC91
6BA6	—	—	—	—	W727	—	EF93
6BE6	—	—	6BE6	6BE6	X727	—	EK90
6BJ5	—	—	—	—	N78	—	—
6BL8	—	—	—	—	—	—	ECF80
6BQ5	—	—	—	6BQ5	—	—	EL84
6BR5	—	—	—	EM80	—	—	EM80
6BT4	—	—	—	6BT4	—	—	EZ40
6BX6	6BW7	—	—	6BX6	Z719	—	EF80
6BY7	—	—	—	6BY7	W719	—	EF85
6C10	—	62TH	—	ECH42	X150	6C10	ECH42
6CA7	—	—	—	—	—	—	EL34
6CD7	—	—	—	—	—	—	EM34
6CH6	—	—	—	—	—	—	EL821
6CJ5	—	—	—	6CJ5	—	—	EF41
6CJ6	—	—	—	—	—	—	EL81
6CK5	—	—	—	6CK5	—	—	EL41
6CN6	—	—	—	—	—	—	EL38
6CQ6	—	—	—	—	—	—	EF92
6CT7	—	—	—	6CT7	—	—	EAF92
6CU7	—	—	—	6CU7	—	—	ECH42
6CV7	—	—	—	6CV7	—	—	EBC41
6CW7	—	—	—	—	—	—	ECC84
6D1	—	6D1	—	—	—	6D1	EA50
6D2	6AL5	—	—	EB91	D77	6D2	EB91
6F5G	—	—	—	—	H63	—	—
6F6G	—	—	—	6F6G	KT63	—	6F6G
6F12	6AM6/8D3	—	—	6AM6	Z77	6F12	EF91
6F16	—	62VP	—	EF41	—	—	EF41
6G5G	—	—	—	—	—	6M1	—
6J5G	—	6J5G	6J5G	6J5G/GT	L63	—	6J5G
6J6	—	—	—	6J6	—	—	ECC91
6J7G	—	—	—	6J7G/GT	Z63	—	6J7G
6K8	—	—	—	6K8G/GT	X65	—	—
6L34	—	—	—	EC91	—	6L34	EC91
6LD3	—	62DDT	—	EBC41	DH150	6LD3	EBC41
6N8	—	—	—	6N8	WD709	—	EBF80
6Q7G	6Q7G	6Q7G	—	6Q7G/GT	DH63	—	6Q7G
6R7	—	—	—	6R7/G	DL63	—	—
6T8	6AK8	—	—	EABC80	DH719	—	EABC80
6U7G	—	—	—	6U7G	W63	—	6K7G
6U8	—	—	—	—	—	—	ECF82
6V4	—	6V4	—	6V4	—	—	EZ80
6W2	R12A	6W2	6W2	6W2	—	—	—
6X2	R12	SU61	—	6X2	—	—	EY51
6X5G	—	6X5G	6X5	6X5GT	—	—	EZ35
7A2	—	MP/Pen	—	—	MKT4	AC/Pen	Pen4VA
7A3	—	42MP/Pen	—	PT4	KT41	AC2/Pen	PenA4
7AN7	—	7AN7	7AN7	7AN7	B319	30L1	PVC84
7B6	—	—	—	7C6	DH81	—	—
7B7	—	7B7	7B7	—	W149	—	—
7C5	—	7C5	7C5	7C5	N148	—	—
7C6	—	7C6	7C6	7C6	DH149	—	—
7D9	—	—	—	6AM5	N77	—	EL91

Type	*Brimar*	*Cossor*	*Emitron*	*Ferranti*	*Marconi or Osram*	*Mazda*	*Mullard*
7D10	—	—	—	—	—	—	EL821
7H7	—	—	7H7	7H7	W148	—	—
7J7	—	—	—	7S7	—	—	—
7S7	—	7S7	7S7	7S7	X148	—	—
7Y4	—	7Y4	7Y4	7Y4	U82	—	—
8A1(5p)	—	MS/Pen	—	—	MSP4	AC/SG	—
8A1(7p)	—	MS/Pen	—	SPT4A	MSP4	—	SP4
8A8	—	8A8	—	9A8	LZ31	30C1	PCF80
8D2	—	13SPA	—	SPTA	—	—	—
8D3	—	—	—	6AM6	Z77	6F12	EF91
9A1	—	MVS/Pen	—	VPT4	—	AC/VP1	—
9A3	—	—	—	VPT4	—	—	—
9A8	—	—	PCF80/9A8	9A8	—	—	—
9D2	—	13VPA	—	—	—	VP1322	—
9D6	—	—	—	—	W77	—	EF92
9U8	9U8	9U8	—	9U8	—	PCF82	—
10C1	—	—	—	—	X145	10C1	—
10F1	—	—	—	—	Z145	10F1	—
10F9	—	—	—	—	W145	10F9	—
10LD3	—	—	—	UBC41	DH142	10LD3	UBC41
10LD11	—	—	—	—	DL145	10LD11	—
10P13	—	—	—	—	N145	10P13	—
11A2	—	DDT	—	H4D	MHD4	AC/HLDD	—
12AC5	—	—	—	UF41	—	—	UF41
12AT6	—	—	—	—	—	—	HBC90
12AT7	—	12AT7	12AT7	12AT7	B309	—	ECC81
12AU7	—	12AU7	—	12AU7	B329	—	ECC82
12AX7	—	—	—	12AX7	B339	—	—
12BA6	—	—	—	—	—	—	HF93
12BE6	—	—	—	—	—	—	HK90
13DHA	11D3	13DHA	—	HAD	—	—	—
13PGA	15D1	13PGA	—	VHTA	—	—	—
13SPA	8D2	13SPA	—	SPTA	—	—	—
13VPA	9D2	13VPA	—	—	—	VP1322	—
14KL	—	—	—	UCH42	—	—	UCH42
14L7	—	—	—	UBC41	—	—	UBC41
15A2	—	41MPG	—	VHT4	MX40	—	—
15A6	—	—	—	15A6	N309	—	PL83
16A5	—	16A5	16A5	16A5	N329	—	PL82
17Z3	PY81	17Z3	—	17Z3	U153	—	PY81
19D8	—	—	—	UCH81	U153	—	UCH81
19X3	—	—	—	—	U309	—	PY80
19Y3	—	19Y3	—	19Y3	U319	—	PY82
20A1	PL81	41STH	—	—	X41	AC/TH1	—
21A6	—	21A6	—	21A6	N359	—	PL81
25E5	—	—	—	25E5	—	—	PL36
25L6	—	—	—	25L6GT	KT32	—	—
30C1	9A8	—	—	PCF80	LZ319	30C1	PCF80
30L1	7AN7	—	—	PCC84	B319	30L1	PCC84
30P4	—	—	—	PL36	—	30P4	—
31A3	—	—	—	UY41	—	—	UY41
35W4	—	—	—	—	—	—	HY90
40PPA	7D3	40PPA	—	—	—	—	—
40SUA	1D5	40SUA	—	—	—	U4020	—
41FP	—	41FP	—	—	—	AC/P	—
41MH	HLA2	41MH	—	—	41MH	AC2HL	—
41MHF	—	41MHF	—	D4	—	MH4	—
41MHL	—	41MHL	—	D4	—	—	—
41MP	—	41MP	—	L4	P41	—	—
41MPG	15A2	41MPG	—	VHT4	MX40	—	FC4
41MSG	—	41MSG	—	SPT4A	—	AC/SG	
41MTL	—	41MTL	—	D4	MH4	AC/HL	354V
41MXP	PA1	41MXP	—	—	—	—	—
41STH	20A1	41STH	—	—	X41	AC/TH1	—
42MP/Pen	7A3	42MP/Pen	—	PT4	KT41	AC2/Pen	—
42OT	—	42OT	—	—	KT41	AC2/Pen	PenA4
42OTDD	—	42OTDD	—	—	DN41	AC2/PenDD	—

Type	*Brimar*	*Cossor*	*Emitron*	*Ferranti*	*Marconi or Osram*	*Mazda*	*Mullard*
43IU	R2	43IU	43IU	R42	MU14	UU5	IW4/350
44IU	R3	44IU	—	R42	MU14	UU5	IW4/500
50C5	—	—	—	—	—	—	HL92
50L6GT	—	—	—	50L6GT	KT71	—	50L6GT
52KU	—	52KU	52KU	R52	—	—	—
53KU	—	53KU	53KU	—	U54	—	—
54KU	—	54KU	—	GZ32	—	—	GZ32
62DDT	—	62DDT	—	EBC41	DH150	6LD3	EBC41
62TH	—	62TH	—	ECH42	X150	6C10	ECH42
62VP	—	62VP	—	EF41	W150	—	EF41
63ME	—	63ME	—	UFT6	—	6M1	—
64ME	—	64ME	—	—	—	6M2	EM34
66KU	—	66KU	—	EZ40	U152	—	EZ40
67PT	—	67PT	—	EL41	N150	—	EL41
104V	—	41MP	—	L4	ML4	AC/P	—
121VP	—	—	—	UF41	W142	—	UF41
141DDT	—	—	—	UBC41	DH142	10LD3	UBC41
141TH	—	141TH	—	UCH42	X141	—	UCH42
164V	—	—	—	—	MHL4	—	—
171DDP	—	—	—	UBF80	—	—	UBF80
202STH	—	202STH	—	—	—	TH2321	TH21C
210DDT	—	210DDT	—	H2D	HD24	—	TDD2A
210HF	—	210HF	—	HL2	HL2	HL2	PM2HL
210HL	—	210HL	—	HL2	HL2	HL2	PM2HL
210PG	—	210PG	—	VHT2A	X22	—	FC2
210SPG	—	210SPG	—	VHT2A	X22	—	FC2
210SPT	—	210SPT	—	SPT2	Z22	SP210	Z22
210VPT	—	210VPT	—	VPT2	W21	VP210	—
215SG	—	215SG	—	S2	Z21	—	PM12M
220HPT	—	220OT	—	PT2	KT2	PEN220	PM22A
220OT	—	220OT	—	PT2	KT2	PEN220	PM22A
220PA	—	220PA	—	—	LP2	—	—
220SG	—	220SG	—	—	Z21	—	—
220TH	—	220TH	—	—	X24	—	—
220VS	—	220VS	—	VS2	W24	—	—
220VSG	—	—	—	—	W21	—	—
230XP	—	230XP	—	—	—	—	PM202
240B	—	240B	—	HP2	—	—	—
240QP	—	240QP	—	QPT2	QP21	QP230	QP22B
244V	—	244V	—	D4	MH4	AC/HL	—
302THA	—	302THA	—	—	—	TH2321	—
354V	41MH	—	—	D4	MH4	AC/HL	354V
408BU	R1	506BU	—	R41	—	—	DW2
415PH	—	—	—	—	X41	—	—
42OT	—	42OT	—	PT4	KT41	AC2/PEN	—
42OTDD	—	—	—	PT4D	DN41	AC2/PEN DD	—
442BU	R12	—	—	R4	U14	UU5	DW4/350
451PT	—	—	—	UL41	N141	—	UL41
460BU	R3	460BU	—	R41	U10	UU3	DW2
904V	HLA2	—	—	—	—	—	—
1561	—	442BU	—	R4A	U14	—	DW4/500
1821	—	—	—	R41	U10	—	DW2
1851	—	—	—	6AC7	—	—	—
1861	R2	43IU	43IU	R43	MU14	UU5	IW4/500
1867	R2	43IU	43IU	R42	MU14	UU5	IW4/350