Howard W. Sams

SECOND-CLASS RADIOTELEPHONE LICENSE COURSE

a comprehensive 20-lesson course
designed to broaden your knowledge of electronics
and serve as a study guide for the

SECOND-CLASS FCC LICENSE EXAMINATION

includes review questions and answers

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Lesson 1

Introduction to Communications Electronics

INTRODUCTION

Obtaining your 2nd-Class Commercial FCC License automatically qualifies you as an expert in electronics. Furthermore, it opens the door to the rapidly-expanding field of communications, including two-way and CB radio, marine radio, aviation electronics, etc. With a little further study, you can obtain a radar endorsement, permitting you to expand your services even further.

Even if you restrict your activities to servicing home electronics equipment such as TV, radio, hi-fi, you'll gain many benefits from a 2nd-Class license. First of all, it puts you in a professional class, in the eyes of the public. This can be used to good advantage in your advertising and promotional material. And, just as important, studying for the license helps to make you a better technician—even if it does no more than renew your acquaintance with basics you have long since forgotten.

In short, a 2nd-Class Commercial License is your "ticket" to a secure future in electronics.

This PHOTOFACT SECOND-CLASS LICENSE COURSE consists of 20 lessons, as outlined on the preceding page. It concentrates on the specific subjects which you, as a practicing serviceman, need training in to pass the FCC Exam. Most of the lessons include, as part of the text, questions typical of those asked on the Exam—and text-type answers which will give you the knowledge you need to answer similar questions correctly. In addition, review questions at the end of each lesson will permit you to test yourself on your knowledge of the most important points. The correct answers are included with the next month's lessons.

We suggest you make maximum use of these questions by actually writing out the answers, without going back to review the lesson material. Be fair to yourself by not referring to the text during any self-testing. Wait until you've actually written down the answers, so you'll know just what you need to study more thoroughly. With this approach, you should be able to pass the FCC Exam on your first try.

For your initial study of each lesson, we suggest you set aside about two to four hours each week. This is the average time—depending on how much you already know and how fast you learn. Additional study time will depend on how well you absorb the lesson material. You should be able to score 100% on the Review Questions.

What you get out of this Course will be strictly up to you. If you absorb everything contained in the 20 lessons, you'll have no problem in passing the 2nd-Class Exam. Good Luck!

Any electronic service technician entering the two-way radiocommunications field is advised to study for and obtain a second-class radiotelephone license, so that his knowledge and technical skills can be used more extensively in repairing, installing, adjusting, and operating radiocommunication systems.

One purpose of this course is to provide you with the technical knowledge required to pass the FCC second-class radiotelephone examination. A second and equally important purpose is to improve your working knowledge of radiocommunications systems. Thus, you will gain a clear understanding of two-way radio equipment and the services that the holder of a second-class radiotelephone license can perform. In particular, those two-way radio adjustments and measurements that must comply with FCC rules and regulations are emphasized. Such measurements must be made by a licensed operator.

In summary, the purpose of this course is to (1) aid you in securing your license, (2) disclose the responsibilities of such a license, and (3) familiarize you with the services you as a license holder can render.

To obtain a second-class radiotelephone license, you must pass Elements I, II, and III of the FCC commercial radio operator's examination. The first two elements encompass basic law and operating practices. Element I consists of 20 questions, with 5% credit given for each correct answer. Element II contains 50 questions, with 2% credit allowance.

The questions are subdivided so that you may select the subject — ship, coastal, or aircraft radiotelephony — for ten of them.

Element III is entirely technical, dealing with electronic terms and principles, tubes and transistors, power sources, transmitters, receivers, antennas, etc. It consists of 100 questions, with 1% credit for each correct solution. The passing grade *for each element* is 75%.

WHAT TO STUDY

If you are an experienced electronics technician and properly prepare yourself by studying these lessons, you will have no trouble passing the FCC examination. In fact, some of the questions in Element III are quite elementary. You probably know the answers to many of them, or will soon recall them after a little review. The questions in Element III fall into these categories:

Electronic Terms and Principles

A good review of common electronic terms such as resistance, power factor, conductance, etc., is in order. Know how to work simple Ohm's-law problems ($E = IR$, etc.). Refresh your memory about the important properties of resistors, capacitors, inductors, conductors, and insulators. Review frequency and wavelength relationships, plus frequency assignments and propagation characteristics.

Tubes and Transistors

Certainly you are already well up on tubes and transistors. However, a good review will help to recall some of the basic facts you may have forgotten. Refresh your memory on major tube characteristics and classes of amplifier operation, but don't worry too much about FCC transistor questions—they are quite basic.

Power Sources

Questions on power sources cover the fundamentals of dry cells and other storage batteries, rectifier power supplies, motors, and generators. You will probably have to spend more time reviewing battery and motor-generator supplies than half-wave and full-wave rectifiers using tubes or semiconductors. Review filter characteristics, and spend some time studying vibrators and special rectifier tubes.

Transmitters and Antenna Systems

Transmitters and antenna systems will probably be your most time-consuming study, unless you have been a radio amateur or have had other experience with transmitters. You must know the types of oscillators, and have a good knowledge of Class-C amplifiers. Tuning procedures are important, too. Become familiar with modulation and the various types of modulators. Interstage and antenna coupling systems must be understood, and a review of antenna fundamentals will also be of help. Use of meters in tuning and troubleshooting is important—not only on the exam, but later when you begin servicing transmitters.

Receivers

Questions on receivers will be "right down your channel." However, some of the questions are on types of detectors you may have thought no longer existed. Review their operation, and don't forget their schematic configurations.

Measurements and Regulations

Making measurements and using meters are subjects you know instinctively. Over the years, however, you may have forgotten how some of the basic meter movements function, or how to use meter shunts and series resistors.

The above topics will be covered in detail in the lessons that follow. Of course transmitter circuits and their functions will be stressed because this is the category likely to be the most troublesome for most electronics service technicians.

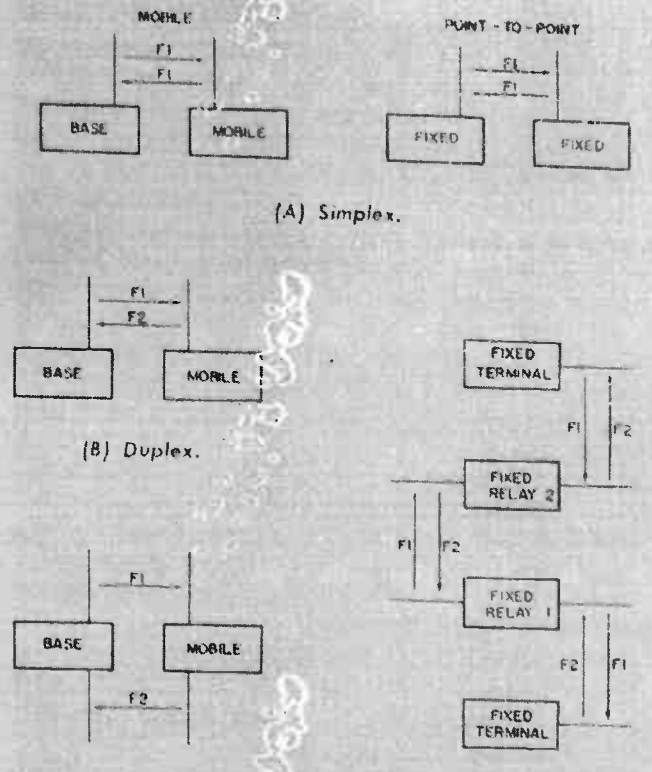
FUNDAMENTAL SYSTEMS

There are three major station classifications in the two-way radio services—mobile, base, and fixed. A mobile station is one associated with a truck, automobile, boat, aircraft, or other vehicle.

A base station is often referred to as a land station. It has a fixed position and is used for communicating with one or more mobile stations (and, on occasion, with other base or fixed dispatch stations). The great majority of two-way radio systems fall under the base-mobile classifications, usually consisting of a single base station and one or more associated mobile stations.

A fixed station has a permanent location and is used to communicate with other fixed stations only. This form of two-way radio is usually referred to as point-to-point communications. Normally, fixed stations have no facilities for communicating with mobile stations; their principal service is to convey information between two or more fixed locations. This differs from the base station, which is also permanently located, but communicates with mobile stations.

The most common arrangements of two-way radio stations are shown in Fig. 1. In the simplex arrangement, the base and mobile units operate on the same frequency. A sequential "on-off" communications is established—in other words, only one station can transmit at a time, but all other stations of the system can hear it. Each mobile station can hear both sides of a conversation between the base station and any other mobile station. Likewise, mobile sta-



(A) Simplex.

(B) Duplex.

(C) Full duplex.

(D) Full duplex, point-to-point.

Fig. 1. Two-way radio systems.

tions can talk to each other when within range. Although not common practice, a simplex arrangement can also be used in a point-to-point system.

The duplex arrangement in Fig. 1B is the most common two-way radio arrangement. The base station transmits on a different frequency than the mobile stations. Thus, the base station can communicate with all mobile stations, but the mobile stations cannot hear or communicate with each other.

Despite the fact that two transmitting frequencies are required, the duplex arrangement is usually more satisfactory than the simplex. The base station has better control over the mobile units, and individual mobile stations are not confused by signals from other mobile stations.

The duplex arrangement also uses "on-off" transmission. Quite often, the two frequencies are close together. In fact, each station customarily uses the same antenna for both transmitting and receiving, and a relay switches in the antenna between the transmitter and receiver. In addition, other segments of the station equipment may be used to both receive and transmit.

A full duplex arrangement is shown in Fig. 1C. Operating frequencies F_1 and F_2 are well separated; consequently, each station can transmit and receive at the same time. Each transmitter output is sufficiently isolated (separated in frequency) so that the input of its companion receiver is not blocked. With a full duplex arrangement, two stations can communicate with each other simultaneously, as in line telephone conversations. If there is more than one mobile station, it will usually be on a different transmit frequency. The base station can establish communications with other mobile stations over the same frequency or a different frequency can be used.

Full duplex is more common in point-to-point than in mobile systems. In the typical arrangement of four stations shown in Fig. 1D, the transmit and receive frequencies of the various fixed stations are staggered, each receiving on one frequency and transmitting on another. Highly directional antennas make it possible to establish duplex—and even full duplex—communication with minimum interference between stations. Notice that relay station 1 transmits on F_1 and receives on F_2, and that relay station 2 transmits on F_2 and receives on F_1. Point-to-point stations are usually assigned frequencies in the microwave or upper UHF spectrum. This is done to permit the use of antenna systems with the highly directional characteristics needed to prevent interference.

There are a variety of station assignments for land, marine, and aviation communications. Some provide communications between land vehicles and their respective base stations; others, between ships; and still others, between ships and fixed land stations. In the aviation services there are aircraft-to-ground stations and aircraft-to-aircraft communications. There are also special assignments that permit communications between aircraft and seagoing vessels. Likewise, one or more small planes are often part of a two-way radio system that also includes land vehicles.

RADIOCOMMUNICATION BANDS AND CHARACTERISTICS

Two-way radio, mobile, and point-to-point services are distributed throughout the entire frequency spectrum. The FCC assigns frequencies in accordance with the service to be rendered and the radio propagation characteristics suitable for this service. The radio-frequency spectrum is apportioned into the following subdivisions:

VLF (very low frequency)	Below 30 kc
LF (low frequency)	30 to 300 kc
MF (medium frequency)	300 to 3,000 kc
HF (high frequency)	3,000 to 30,000 kc
VHF (very high frequency)	30,000 kc to 300 mc
UHF (ultrahigh frequency)	300 to 3,000 mc
SHF (super high frequency)	3,000 to 30,000 mc
EHF (extreme high frequency)	30,000 to 300,000 mc

The two lowest frequency bands and a low-frequency segment of the medium-frequency band are used mainly by maritime and aeronautical services. Up to 550 kc, radiotelegraph transmissions are most common. Here information is transmitted via international Morse code, and operators are required to have a commercial radiotelegraph license. Airway beacons and other stations that send out navigational signals share sections of this frequency spectrum. The international distress frequency of 500 kc (600 meters) is also located here.

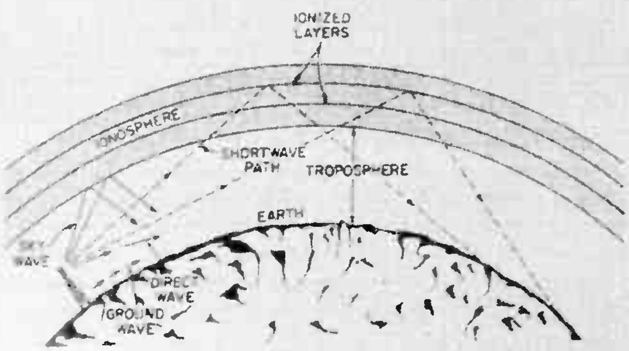


Fig. 2. Propagation of radio waves.

In this frequency spectrum, the ground wave dominates (Fig. 2). As a result, a very reliable transmission medium exists for both short and medium-distance communications.

With adequate transmitter power, a sensitive receiver, and a large, efficient transmitting antenna, very reliable long-distance communications can be established. In recent years much experimental work has been done, in this frequency spectrum, toward developing reliable world-wide communications. For example, very low frequencies will penetrate the ocean water more readily than higher-frequency waves. Thus they can be used for communicating with submarines.

In the medium-frequency spectrum (between 300 and 3,000 kc), both the ground wave and the sky wave contribute to the net signal delivered to a receiving location. At the low end of the low-frequency spectrum, however, the ground wave greatly dominates the sky wave. Consequently, reliable ground-wave communications can be established with only occasional limited interference from sky-wave components.

The radio broadcast band (AM) starts at 550 kc and extends to 1600 kc. The ground wave serves as a reliable local and regional transmission medium for most of the broadcast band. During the evening hours (especially in winter), strong sky-wave components return to the earth. At varying distances from the transmitter, fading occurs as the ground waves and sky waves interact, sometimes adding and sometimes subtracting. Ground-wave radiation is more reliable, over fairly short distances—more so at the high than the low end. Particularly at night, the local ground-wave components are subject to interference from sky-wave components originating at a substantial distance.

Atmospheric noises are predominant in this frequency spectrum. Summer transmission is plagued by lightning static, and in winter the interaction between the ground wave and sky wave makes reception a problem.

In the frequency spectrum between 1.6 and 5 mc, there are a variety of two-way radio assignments. It is here that small-boat radio assignments are made. The installation of radiotelephones aboard small boats has paralleled the accelerated interest in boating. As this growth continues, better traffic regulation will be needed in both coastal and inland waters. Don't forget that small-boat radio equipment must be installed, adjusted, and serviced by a second-class radiotelephone license holder.

The upper end of the medium-frequency spectrum provides reliable coverage up to 50 or 100 miles (and even farther under certain circumstances). The desired range for most two-way radios installed on small boats and in aircraft is substantially less than 50 miles. Consequently, reliable performance can be obtained from compact, low-power equipment.

Atmospheric noises are prevalent. In mobile installations, the problem of ignition interference also must be considered. Sky-wave components sometimes travel a great distance after bouncing off the ionized layers. Upon returning to earth, they are at a high enough level to interfere with more localized communications. In some point-to-point communications systems, however, sky-wave transmission is advantageous—it enables distances of up to several hundred miles to be covered on a reliable basis.

Long-distance point-to-point communications and other services are assigned to the short-wave frequency spectrum (between 3 and 30 mc). By using the sky-wave bounce from the ionized layers, the various bands of short-wave broadcast stations that utilize these frequencies make possible reliable world-wide communications.

The ionization of the various layers above the earth is continuously shifting. Careful observation and measurement over the years have permitted the development of consistent long-distance performance. Coupled with proper choice of frequency, time, power, and directive antenna systems, these long-distance communications services are able to pinpoint strong signals to almost every corner of the earth.

Atmospheric static is stronger at the low-frequency end of the short-wave spectrum, whereas

ignition interference increases in intensity toward the high-frequency end.

Sunspot activities and aurora borealis, along with the consequent magnetic storms, have a decided influence on short-wave performance. Sunspot activities, which occur in definite cycles over the years, affect the level and degree of ionization. This activity varies from day to night, season to season, and year to year. On occasion, magnetic storms are so severe that communication is impossible over large segments and sometimes over all the short-wave bands.

In addition to the point-to-point communications systems, many mobile services are crowded at the high-frequency end of the short-wave spectrum. Again, all equipment must be installed, adjusted, and serviced by or under the supervision of a second-class radiotelephone license holder. Many land-mobile systems are allocated frequencies between 25 and 50 mc, along with a limited number of maritime and aviation assignments.

The direct wave (Fig. 2) predominates at the high-frequency end of the short-wave spectrum. Here the ground wave is attenuated to an insignificant level only a short distance from the transmitter, and sky-wave reflections are more sporadic. Thus, most contacts are by way of direct-wave transmissions traveling in the immediate atmosphere between transmitter and receiver. Because of its reliability, the direct wave is ideal for two-way mobile systems. With proper facilities and sufficient power output, it is possible to extend the reliable maximum range to 75 miles.

Citizens-band assignments are made in the 27-mc range. Millions of mobile stations will eventually be licensed to operate in this popular band. As before, on-the-air power, modulation, and frequency checks must be made by a second-class radiotelephone license holder.

The VHF spectrum extends between 30,000 kc and 300 mc. In addition to many other, less-publicized services, this segment contains the television and FM broadcast-stations assignments. Two frequency bands are used extensively for mobile-radio systems, and a third band is assigned to point-to-point communications. All assignments except commercial broadcasting are under the jurisdiction of a second-class radiotelephone license holder. Aeronautical two-way radio systems and other aircraft and marine navigational services are also assigned space in the VHF spectrum.

Direct-wave propagation (Fig. 2) predominates in this spectrum. The ground wave drops to an insignificant value only a short distance from the transmitting antenna. The sky wave penetrates the atmosphere and the ionized layers before going off into space. In fact, the VHF and UHF spectrums are also used to transmit guidance and telemetering signals to missiles and satellites.

The lower half of the VHF spectrum is subject to some ionospheric reflection. Intense sunspot activity, and some reflection of VHF signals, will result in a dense ionosphere. Ignition and other sparking noises are strong at the low end of the VHF band, gradually decreasing toward the high end. Atmospheric noises seldom exist, or if they do, are very weak. Inherent receiver noises become significant in the VHF, UHF, and higher microwave spectrums. Most receivers are troubled by tube noise from the input stage. To overcome such noise, a crystal mixer is often used. The newly-conceived parametric amplifiers and masers are also employed because of their very low noise content.

The immediate atmosphere (troposphere) greatly influences the range and reliability of VHF transmission beyond the horizon. Customarily, VHF and UHF transmissions are considered to follow line of sight paths. However, the atmosphere does produce some bending of VHF waves. This refraction causes the wave to travel beyond the strictly optical line of sight. How far it travels depends on how much it is bent (Fig. 3). Many meteorological factors enter the picture—barometric pressure, temperature, and humidity, to name a few. Air-mass layers, temperature inversions in the upper atmosphere, or other irregularities also influence the degree of bending. In fact, under extreme conditions the radio wave is confined in duct-like fashion within these discontinuities and may be propagated hundreds or even thousands of miles before returning to earth.

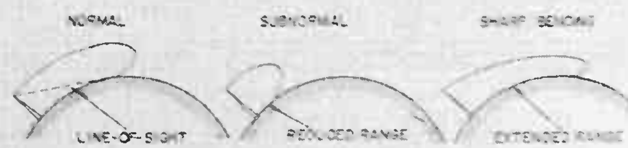


Fig. 3. VHF propagation and tropospheric bending

Although these propagation phenomena are interesting and unusual, they are unsuited for routine two-way radio communication. Consequently, communications systems are designed for line-of-sight operation, plus a reasonable extension based on an average minimum amount of atmospheric bending.

The UHF region (between 300 and 3,000 mc) represents an extension of the services provided in the VHF spectrum. (In common terminology, the portion above 1,000 mc is called the microwave region.) Similar two-way radio assignments for land, marine, and aviation are made in this region. UHF television assignments also occupy a good slice of this spectrum, together with radionavigational aids (such as radar). Assignments for point-to-point microwave relay systems are made at the high-frequency end of the spectrum.

In general, UHF has a shorter range than VHF. However, the UHF wave is more beamlike and thus can be reflected sharply by objects. For this reason, a UHF two-way radio system is often more satisfactory in metropolitan areas than its VHF counterpart—the signal can be bounced to a mobile unit surrounded by skyscrapers! On the other hand, VHF seems to operate better in suburban and rural areas because of its greater range.

The UHF wave can be concentrated into a pencil-like beam by the use of directional antennas. This is particularly true at the high-frequency end. Also, the physical dimensions of a highly-directional antenna are practical at higher frequencies. As a result, UHF frequencies are more advantageous in point-to-point communications systems.

Only two terminal stations are needed for transmission between two line-of-sight points. If the communications system is to extend along a lengthy right of way (oil or natural-gas line, turnpike, railroad line, truck route, etc.) manned or automatic intermediate relay stations can be used.

Microwave relay systems are being planned or are already in operation for many industrial and commercial services, representing more opportunities for the holder of a second-class radiotelephone license. Translators, which carry television signals into remote areas, use the UHF and microwave spectrums. Studio-transmitter links and remote-pickup equipment operate in this spectrum also. Some of this equipment can be operated by a second-class radiotelephone operator.

The SHF (super high frequency) spectrum extends between 3,000 and 30,000 mc. Radar and microwave relay services are assigned to this sector. However, much developmental work is being conducted to duplicate the services rendered in the UHF and VHF spectra, and some mobile operations already are being tested. Navigational devices in particular can take advantage of the very sharp radio beam that can be sent out by antennas of small physical dimensions. Licensing and technical requirements are somewhat more liberal on the many developmental frequencies. However, there is an important niche here for the second-class radiotelephone operator.

SUMMARY

The obvious distinction enjoyed by the holder of an FCC commercial license should be evident, if a collective view is given the topics discussed in this lesson. The expanded technical servicing qualifications are well worth the effort, considering that radiocommunications systems numbering in the millions are operated, installed, adjusted, and repaired by technicians holding first- or second-class radiotelephone licenses. You may already know that unlicensed personnel are permitted to make certain adjustments on Citizens-band transmitters, provided it meets the type-approval requirements of the Federal Communications Commission. However, on-the-air adjustments that influence the operating frequency or power input must be handled only by a technician who has a first- or second-class radiotelephone license.

The holder of a second-class radiotelephone license can adjust and service, or supervise the adjustment and servicing of, a wide variety of these radiocommunications systems. There are a few exceptions, but they are outside the realm of two-way equipment. For example, a second-class licensee may not adjust or service commercial broadcast equipment (AM, FM, or TV), certain marine equipment licensed to use telephony with power in excess of 100 watts, or stations which transmit by radiotelegraphy. However, the second-class permit does extend to the operation and maintenance of certain educational FM and TV stations, and certain broadcast relay facilities.

Many classes of two-way radio stations can be operated—but NOT SERVICED—by licensees of grades below second-class radiotelephone. Two such grades are the third-class and the restricted radiotelephone operator. While the questions in the third-class examination (Elements I and II) are nontechnical and have to do with basic radio laws and operating practices, you must be able to pass the third-class exam to achieve a second-class rating. Holders of a third-class permit may not adjust and service the station equipment in any way that would result in improper transmitter operation.

REVIEW QUESTIONS

1. Compare simplex and duplex operation. Which is used most often in two-way radio systems?
2. Where must the second-class radiotelephone operator's license be posted?
3. What is a verification card?
4. Why are frequency assignments made for the communication services on various bands throughout the electromagnetic spectrum?
5. Compare ground and sky waves.
6. What is meant by direct-wave propagation?
7. Compare the propagation characteristics of the HF, VHF, and UHF spectra.
8. How does the relative effect of atmospheric, man-made, and receiver input noises change with relation to frequency?

Answers to these questions will be included in PHOTOFACT Set No. 565.

Lesson 2

Services and Frequency Assignments — Frequency Bands

There are many opportunities in point-to-point and mobile communications systems for technicians who can install, operate, adjust, and maintain such equipment. Table 1 lists most of the two-way frequencies assigned to equipment which comes under the jurisdiction of second-class radiotelephone license holders. The symbols shown are used to identify the various bands.

Table 1. Major two-way radiotelephony bands.

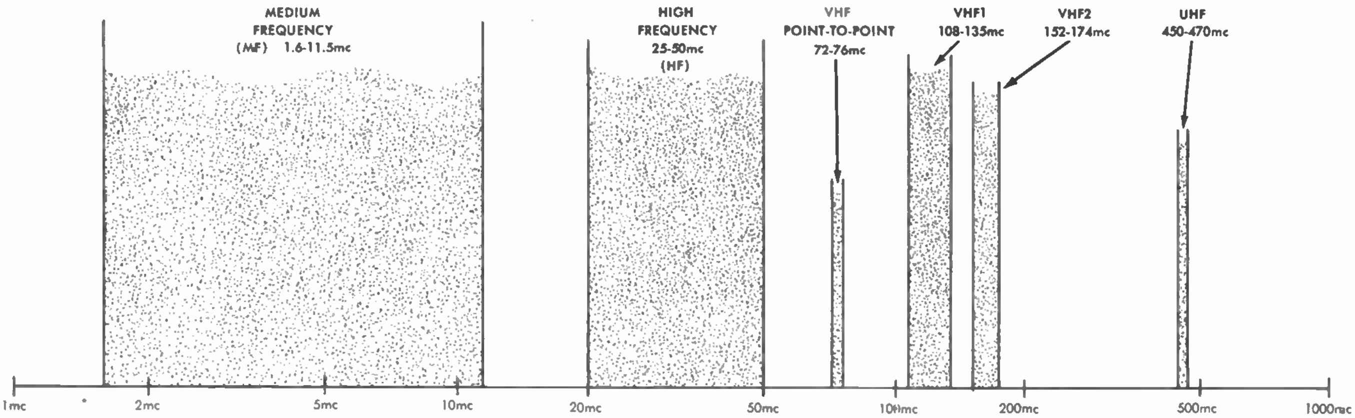
Medium frequency (MF)	1.6-11.5 mc
High frequency (HF)	25-50 mc
Very high frequency (VHF1)	108-135 mc
Very high frequency (VHF2)	152-174 mc
Ultrahigh frequency (UHF)	450-470 mc
VHF point-to-point	72-76 mc

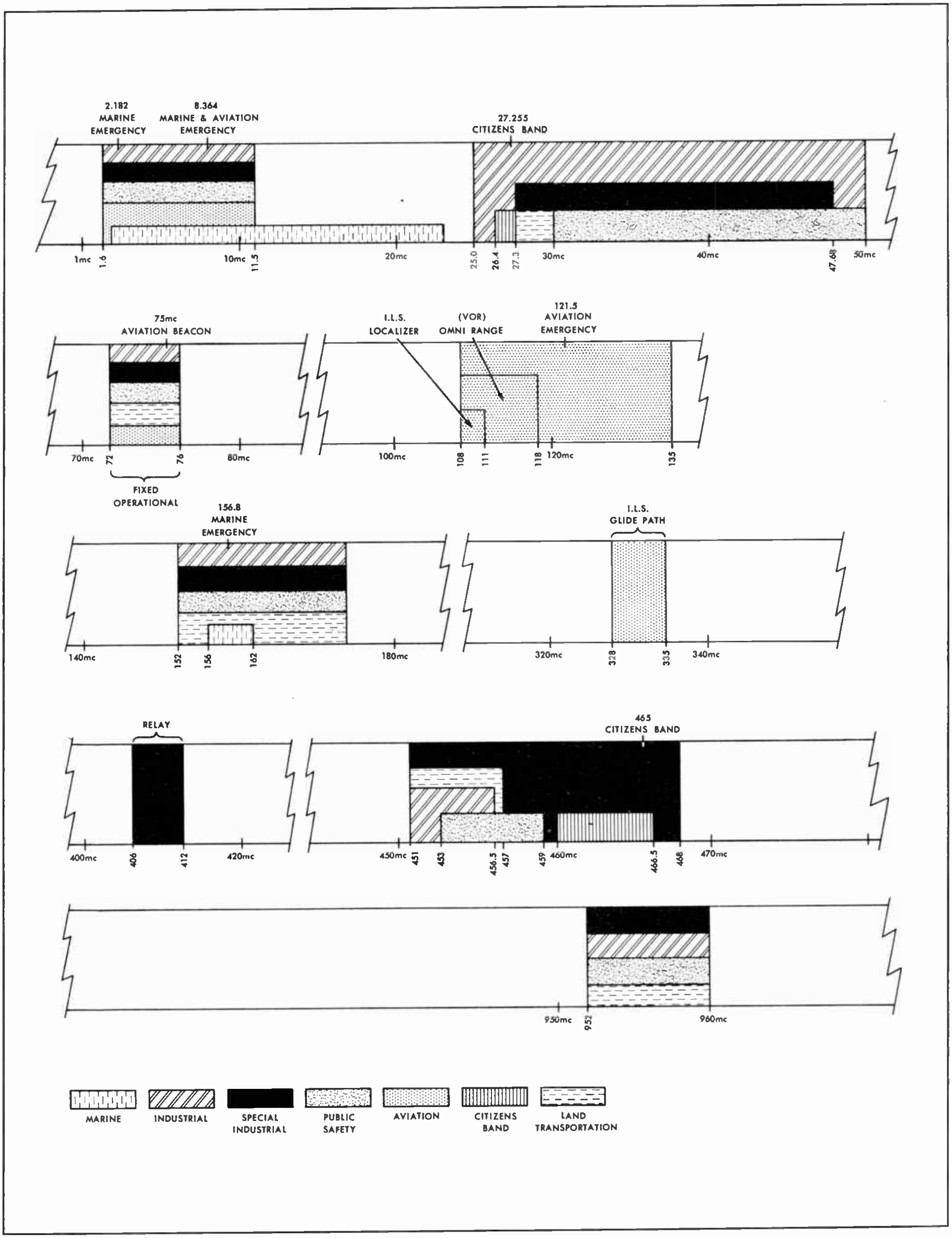
The major two-way radio assignments in the medium-frequency (MF) band are police radio, marine, and aviation (although there are some point-to-point relay and a limited number of land-mobile allocations). Because of the great interest in small boats, an increasingly active portion of the spectrum between 1.6 and 3.5 mc has been allocated to stations aboard small ships in coastal and inland waters. There are numerous aeronautical station assignments, largely for the benefit of passenger and cargo air-carrier services. Many such assignments, particularly for private aircraft and airdrome facilities, are in the VHF1 band.

The upper portion of the HF spectrum is crowded with mobile assignments. It includes not only the very active Citizens band but also a high percentage of the public-service and land-transportation services. Again, each transmitter must in some way be linked to a second-class radiotelephone licensee.

Similar assignments are made in the two VHF bands. The 72-76 mc band has been allocated largely for fixed-station operation. Point-to-point relay systems also have frequency assignments in this band. In time, most point-to-point allocations and some of the systems now operating on this band will use the super high frequency (SHF) and the upper end of the UHF bands. A high degree of stability and freedom from interference can be obtained more readily in the microwave spectrum. The alert second-class radiotelephone licensee will want to assist in the development and use of these microwave-relay assignments.

Aeronautical radio facilities dominate the VHF1 spectrum. The assignments on the VHF2 spectrum, however, are similar to those of the HF band. Land-




2.182
MARINE
EMERGENCY
8.364
MARINE & AVIATION
EMERGENCY
27.255
CITIZENS BAND
1mc
1.6
10mc
11.5
20mc
25.0
26.4
27.3
30mc
40mc
47.68
50mc
75mc
AVIATION BEACON
70mc
72
76
80mc
FIXED
OPERATIONAL
I.L.S.
LOCALIZER
(VOR)
OMNI RANGE
121.5
AVIATION
EMERGENCY
100mc
108
111
118
120mc
135
156.8
MARINE
EMERGENCY
140mc
152
156
162
180mc
I.L.S.
GLIDE PATH
320mc
328
335
340mc
RELAY
400mc
406
412
420mc
465
CITIZENS BAND
450mc
451
453
456.5
457
459
460mc
466.5
468
470mc
950mc
952
960mc
MARINE
INDUSTRIAL
SPECIAL
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SAFETY
AVIATION
CITIZENS
BAND
LAND
TRANSPORTATION

mobile radio assignments are predominant, although railroad radio and coastal radiomarine allocations are also prevalent.

The allocations on the UHF band are similar to those of the VHF and HF bands. An increasing number of fixed point-to-point allocations are becoming available, particularly at the high-frequency end of the UHF band. Also included in this band are a Citizens-band spectrum and an impressive array of allocations for land vehicle, marine, and aviation facilities. Radionavigational aids (including radar) for aeronautical and marine services are served by UHF and higher microwave frequency assignments.

The following information pertains to the three general classifications of land, aviation, and marine two-way radio assignments. It will give you an idea of the extensive use of radiocommunications equipment. Even more important, it will give you a glimpse of expansive avenues of growth open to you. As you will see, your second-class radiotelephone license will unlock many doors of opportunity.

CITIZENS RADIO SERVICE

The Citizens radio service has had a phenomenal growth, as attested to by the hundreds of thousands of transmitters now in operation. This service provides for private short-distance radiocommunications, radio signaling and the control of remote objects by radio. Any citizen is eligible to hold a license in the Citizens radio service, provided (1) the applicant for Class-A, -B, or -D station authorization is 18 years or older, (2) the applicant for a Class-C station authorization is 12 or more years of age. In addition, not more than one person shall be licensed to operate the same transmitting equipment. Citizens mobile-radio units can be installed in land vehicles, boats, and aircraft—but cannot be hired for public correspondence, of course.

Classes of Stations

There are four types of Citizens-band stations. Class-A stations are assigned an available frequency between 460.05 and 466.45 mc and are limited to a plate input power of 60 watts or less. They can be operated as either base or fixed stations, and normally are authorized to transmit radiotelephony only. However, they may transmit tone signals or use other signal devices, but only to establish and maintain voice communications.

Class-B stations are authorized to operate on a frequency of 465 mc with a plate input power of 5 watts or less. Normally they must be operated as mobile stations only; however, they may be operated at fixed locations in accordance with certain provisions. They may employ AM, FM, or on-off unmodulated carrier, and may be used for radiotelephony, to control remote objects by radio, or to remotely actuate devices used for attracting attention (for example, window displays). The frequency tolerance of the Class-B station is not as strict as for Class A. This is shown in Table 2.

Table 2. Citizens Band Power and Frequency Tolerances.

Class	Maximum Authorized Plate Power Input	Frequency Tolerance Base %	Frequency Tolerance Mobile%
A	3 watts or less	.001	.005
A	Over 3 watts......	.001	.001
B	3 watts or less		.5
B	Over 3 watts......		.3
C	5 watts or less		.005
C	Over 5 watts (27.255 mc only)		.005
D	5 watts or less		.005

Class-C stations that have a plate input power of 3 watts or less and are used solely for remote control of devices by radio (other than those used solely to attract attention) are permitted a frequency tolerance of 0.01%.

Class-C Citizens radio stations are authorized for control of remote objects by radio, or for remote actuation of devices used solely as a means of attracting attention. They are also authorized to operate as mobile stations, but may be operated at fixed locations in certain instances.

Class-C stations are authorized to use amplitude tone modulation or on-off unmodulated carriers. The frequency assignments are 26.995, 27.045, 27.095, 27.145, 27.195, and 27.255 mc. The power input is restricted to 5 watts or less, except on 27.255 mc, where up to 30 watts is permitted.

The very popular Class-D stations are assigned frequencies between 26.96 and 27.255 mc. The authorized plate input power is 5 watts or less for amplitude-modulated radiotelephony only. Class-D stations are authorized to operate as mobile stations only, but may be operated at fixed locations. They may not transmit any form of radiotelegraphy. However, tone signals or signaling devices may be used, but only to establish and maintain voice communications between stations.

The actual frequency assignments are given in Table 3, along with the channel numbers by which the various frequency assignments are customarily identified.

Table 3. Class-D Citizens Band Channel Frequencies.

Channel	Megacycles	Channel	Megacycles
1	26.965	12	27.105
2	26.975	13	27.115
3	26.985	14	27.125
4	27.005	15	27.135
5	27.015	16	27.155
6	27.025	17	27.165
7	27.035	18	27.175
8	27.055	19	27.185
9	27.065	20	27.205
10	27.075	21	27.215
11	27.085	22	27.225

PUBLIC-SAFETY RADIO SERVICES

Public-safety radio services are available for radiocommunications essential to the discharge of nonfederal governmental functions or to the alleviation of an emergency involving the endangerment of life or property. Authorizations are made for police, fire, forestry conservation, highway maintenance, special emergency, state guard, and local government. All transmitter adjustments or tests which may affect proper operation of the station must be made by, or under the supervision of, a first- or second-class radiotelephone or radiotelegraph operator. The license holder is responsible for the proper functioning of the station equipment. If Morse code is used, only a first- or second-class radiotelegraph operator is allowed to operate the station.

Unlicensed persons are not permitted to operate a mobile station transmitting on frequencies below 25 mc unless authorized to do so by a licensee, provided the station is associated with and under control of a base station of the same licensee. Likewise, an unlicensed person may not dispatch messages from a base or fixed station unless authorized to do so by a person holding a commercial radio operator's license or permit of any class, and only under his direct supervision.

Fire Radio

Authorization in the fire radio service is given to paid or volunteer fire departments or their personnel. Base, mobile, and fixed stations are authorized as follows:

1.63 mc—Base and mobile.
33.42-46.5 mc—Base, mobile, and fixed.
72.02-75.98 mc—Operational fixed.
153.77-170.150 mc—Base, mobile, and fixed.
453.050-458.950 mc—Base and mobile.
952-960 mc—Operational fixed.
Microwave—For all types of services.

Police Radio

Police radio stations are authorized to transmit communications essential to official police activities. Various frequencies are assigned to police base and mobile stations, fixed stations, and zone and interzone stations for communications both inside and outside their jurisdiction. Frequency assignments are made within the following frequency ranges:

1.611-7.935 mc—Base, mobile, zone, and interzone.
37.02-46.02 mc—Base and mobile.
72.02-75.98 mc—Operational fixed.
154.65-159.210 mc—Base and mobile.
453.050-458.950 mc—Base and mobile.
952-960 mc—Operational fixed.
Microwave—Assignments for all types of services are available.

Forestry Conservation Radio

Authorizations for forestry conservation stations are made only to persons or organizations charged with specific forestry conservation activities. Frequency assignments are as follows:

2.212-2.244 mc—Base and mobile.
30.86-46.82 mc—Base and mobile.
72.02-75.98 mc—Operational fixed.
151.145-172.375 mc—Base and mobile.
453.050-458.950 mc—Base and mobile.
952-960 mc—Operational fixed.
Microwave—All services.

Highway Maintenance Radio

Authorizations for highway-maintenance stations are issued only to federal, state, local, etc., governments. Frequency assignments are as follows:

33.02-47.4 mc—Base and mobile.
72.02-75.98 mc—Operational fixed.
150.995-159.195 mc—Base and mobile.
453.05-458.95 mc—Base and mobile.
952-960 mc—Operational fixed.
Microwave—All services.

Special Emergency Radio Service

Disaster relief organizations, physicians and veterinarians, ambulance operators and rescue organizations, beach patrols, school buses, and other communications systems may use this service for emergencies, but on a standby basis only. Frequency assignments are as follows:

2-3 mc—Fixed.
2.726 mc—Base and mobile.
3.201 mc—Base and mobile.
33.02-47.66 mc—Base and mobile.
72.02-75.98 mc—Operational fixed.
453.050-458.950 mc—Base and mobile.
952-960 mc—Operational fixed.
Microwave—All services.

State Guard Radio

State-guard radio stations are authorized primarily to permit transmissions related directly to public safety and the protection of life and property, and secondarily to provide for essential nonemergency communications necessary for training and maintaining an efficient organization. Frequency assignments are as follows:

2.726 mc—Base and mobile.
2.505-3.5 mc—Used when a second frequency is required.

Local Government Radio

Stations in the local-government radio service are authorized to transmit communications essential to the official activities of the licensee. Frequency assignments are as follows:

45.08-45.64 mc—Base and mobile.
72.02-75.98 mc—Operational fixed.
153.755-158.955 mc—Base and mobile.
453.050-458.950 mc—Base and mobile.
952-960 mc—Operational fixed.
Microwave—All services.

INDUSTRIAL RADIO SERVICES

In the industrial radio services, parts of the radio spectrum are made available to various industrial enterprises which, for safety or other reasons, require radio transmitting facilities in order to function efficiently. Such radio facilities are not for hire and may not carry program material. The various industrial radio services are power radio, petroleum, forest products, motion picture, relay press, special industrial, business radio, industrial radiolocation, manufacturers, and telephone maintenance. Purposes and frequencies of the various services are as follows:

Power Radio

Assignments are made to persons engaged primarily in the generation, transmission, or distribution of electrical energy; the production, distribution, or storage of artificial or natural gas by means of pipelines; the collection, transmission, storage, or purification of water by pipeline, canal, or open ditch; and the generation or distribution of steam for use by the general public or a cooperative. Frequencies are:

1.605-4.65 mc—Base and mobile.
27.235-27.275 mc—Base, mobile, and operational fixed
37.46-48.54 mc—Base and mobile.
72.02-75.98 mc—Operational fixed.
153.41-173.35 mc—Base, mobile, and operational fixed
406.050-456.25 mc—Fixed relay and special.
952-960 mc—Operational fixed.
Microwave—All services.

Petroleum Radio

Assignments are made to persons engaged in prospecting for, producing, collecting, refining, or transporting petroleum or its products (including natural gas) by pipeline. Frequencies are:

25.02-49.5 mc—Operational fixed.
72.02-75.98 mc—Base and mobile.
153.05-173.35 mc—Base and mobile.
406.05-412.75 mc—Fixed relay.
451.55-456.75 mc—Base, mobile, and operational fixed.
952-960 mc—Operational fixed.
Microwave—All services.

Forest Products Radio

Assignments are made to persons engaged in tree logging, tree farming, or related woods operations. Frequencies are:

27.235-29.77 mc—Base and mobile.
48.56-49.5 mc—Base and mobile.
72.02-75.98 mc—Operational fixed.
153.05-173.35 mc—Base and mobile.
406.05-412.75 mc—Fixed relay.
451.55-456.75 mc—Base, mobile, and operational fixed.
952-960 mc—Operational fixed.
Microwave—All services.

Motion Picture Radio

Assignments are made to persons engaged in the production of motion pictures. Frequencies are:

27.235-27.275 mc—Base, mobile, and operational fixed.
72.02-75.98 mc—Operational fixed.
152.87-173.375 mc—Base and mobile.
952-960 mc—Operational fixed.
Microwave—All services.

Relay Press Radio

Many relay-press radio assignments are given to newspapers and press associations. Frequencies are:

27.235-27.275 mc—Base, mobile, and operational fixed.
72.02-75.98 mc—Operational fixed.
173.225-173.375 mc—Base and mobile.
952-960 mc—Operational fixed.
Microwave—All services.

SPECIAL INDUSTRIAL RADIO

Quite a few persons and organizations are eligible for assignment in the special industrial radio service, including those engaged in farming, ranching, heavy construction (roads, bridges, sewers, pipelines, airfields, and the production of water, oil, gas, or power), and mining (including the exploration for and development of mining properties). Persons rendering certain specialized services essential to industrial operations or public health are also eligible.

Eligibility is limited to those engaged in:

1. Plowing, soil conditioning, seeding, fertilizing, or harvesting for agricultural or forestry activities.
2. Spraying or dusting insecticides, herbicides, or fungicides in areas other than enclosed structures.
3. Livestock breeding.
4. Maintaining, patrolling, and repairing gas or liquid-transmission pipelines, tank cars, water or waste-disposal wells, industrial storage tanks, or distribution systems of public utilities.
5. Acidizing, cementing, logging, perforating, or shooting activities, and similar services incidental to the drilling of new oil or gas wells, or the maintenance of production from established ones.
6. Supplying of chemicals, mud, tools, pipe, and other unique materials or equipment to the petroleum production industry as the primary activity of the applicant—provided the delivery, installation, or application of these materials require the supplier to use specially fitted conveyances and unusual skills.
7. Delivering ice or fuel to the consumer in solid, liquid, or gaseous form for heating, lighting, refrigerating, or power-generation purposes by means other than pipelines or railroads.
8. Delivering and pouring of ready-mixed concrete or hot asphalt mix.

Frequency assignments are:

2.292-4.6375 mc—Base and mobile.
27.235-47.68 mc—Base, mobile, and fixed or operational fixed.
72.02-75.98 mc—Operational fixed.
151.505-171.975 mc—Base, mobile, and operational fixed.
406.05-456.95 mc—Base and mobile.
952-960 mc—Operational fixed.
Microwave—All services.

Business Radio

Authorizations are made in the business radio service to businesses, schools, philanthropic organizations, clergymen or ecclesiastical institutions, hospitals, clinics, and medical associations. Frequency assignments are:

27.235-43.0 mc—Base, mobile, and operational fixed.
72.02-75.98 mc—Operational fixed.
151.625-171.975 mc—Base, mobile, and operational fixed.
406.05-469.95 mc—Base, mobile, and operational fixed.
952-960 mc—Operational fixed.
Microwave—All services.

Industrial Radiolocation

Made to commercial or industrial enterprises which must establish a position, distance, or direction by means of radiolocation devices for purposes other than navigation; or to an organization furnishing a radiolocation service to such persons. This service is used primarily in geographical, geological, or geophysical activities. Frequency assignments are between 1.75 and 1.8 mc, at certain frequencies between 2.9 and 9.5 mc, and in the microwave spectrum.

Manufacturers Radio

Assignments are made to persons engaged in manufacturing, or to a subsidiary that will furnish a not-for-profit radiocommunications service. Plants, factories, shipyards, or mills where power-driven machines and materials-handling equipment are employed in the manufacture or assembly or the product are included in this category. Establishments engaged primarily in wholesale, retail, or service activities—even though they fabricate or assemble any or all of the commodities handled—are not considered manufacturers. Instead, they are classified under the Business radio service. Manufacturers radio assignments are:

27.235-27.275 mc—Base, mobile, or fixed.
153.05-158.43 mc—Base and mobile.
462.05-467.95 mc—Base and mobile.

Telephone Maintenance Radio

Telephone maintenance assignments are given to telephone companies and other common-carrier services employed primarily to render a wire-line and/or radiocommunications service to the public for hire. Frequency allocations are:

27.235-43.16 mc—Base, mobile, and fixed.
151.985-158.34 mc—Base and mobile.
451.3-456.5 mc—Base and mobile.

LAND TRANSPORTATION RADIO SERVICES

Part of the radio spectrum is reserved for certain land transportation communications. These radio facilities cannot be used for hire or to carry program material but are provided for motor carrier radio, railroads, taxicab companies, and automobile emergency.

Motor Carrier Radio

Authorization for stations in the Motor Carrier radio service is issued to bus lines, trucking companies, and moving and storage firms operating buses or trucks within a city, or from city to city. Frequency assignments are:

27.235-27.275 mc—Base, mobile, and operational fixed.
30.66-44.6 mc—Base and mobile.
72.02-75.98 mc—Operational fixed.
159.495-160.2 mc—Base and mobile.
452.65-457.85 mc—Base and mobile.
952-960 mc—Operational fixed.
Microwave—All services.

Railroad Radio

Authorization is given to railroads, including railway express companies owned wholly by the railroad. Frequency assignments are:

72.02-72.98 mc—Fixed.
160.215-161.565 mc—Base and mobile.
452.9-457.95 mc—Base and mobile.
Microwave—All services.

Taxicab Radio

Persons who carry passengers for hire—provided they do not follow a schedule or operate over a regular route or between established terminals—are eligible for this service. Frequency assignments are:

27.235-27.275 mc—Base, mobile, and operational fixed.
152.27-157.71 mc—Base and mobile.
452.05-457.5 mc—Base and mobile.
Microwave—All Services.

Automobile Emergency Radio

Associations, owners of private automobiles and public garages providing emergency road service are eligible for this service. Transmissions are restricted to the dispatching of repair trucks and cars to disabled vehicles for the purpose of saving lives or protecting property. Frequency allocations are:

27.235-27.275 mc—Base, mobile, and operational fixed.
150.815-157.5 mc—Base and mobile.
452.55-457.6 mc—Base and mobile.
Microwave—All services.

AVIATION RADIO SERVICES

The bulk of aeronautical radio-station assignments are between 118 and 135 mc, with additional assignments between 2.8 and 18 mc. Operational fixed stations are assigned between 72.02 and 75.98 mc, plus additional allocations in the microwave spectrum.

Some of the radionavigational frequency assignments are:

Localizer station—108.1-111.9 mc
Glide-path station—328.6-335.4 mc
Aeronautical marker beacon—75 mc
Radio range station—108.2-117.9 mc
Radio beacon station—200-400 kc
Microwave—Available for distance-measuring and other navigational functions.

Some key aircraft frequency assignments available to aircraft stations are:

375 kc—International direction-finding frequency for use outside the continental United States.

457 kc—International calling and distress frequency for ships and aircraft over the seas. Transmission on this frequency, except urgent and safety messages and signals, must cease twice each hour for three minutes beginning at 15 and 45 minutes past the hour, Greenwich civil time.

8364 kc—For lifeboats, life rafts, and other survival crafts communicating with maritime stations during rescue operations.

121.5 mc—Universal simplex emergency and distress frequency used by aircraft for emergency direction-finding purposes, to establish air-ground communications in emergencies, and for search and rescue operations by aircraft not equipped to transmit on 121.6 mc. This frequency will not be assigned to an aircraft unless other frequencies have been assigned to accommodate its normal needs.

121.6 mc—For air-to-air and air-to-ground communications with aeronautical search and rescue stations engaged in search and rescue operations.

121.60, 121.65, 121.70, 121.75, 121.80, 121.85, 121.90, and 121.95 mc—Airport utility frequencies. 121.60 mc can be used by aircraft radio stations for airport utility communications, provided they do not interfere with search and rescue communications.

118-134.95 mc—For air-traffic and airport control.

The calling and working frequency is 3117.5 kc for commercial and 3023.5 kc for private aircraft. Air-traffic control frequencies for private aircraft extend between 122.0 and 123.05 mc. Two specialized frequencies within this spectrum are 122.8 mc (assigned to aeronautical-advisory and private-aircraft stations, and also used for establishing communications between private aircraft in flight) and 123 mc (for contact between private aircraft and aeronautical advisory stations only).

MARINE RADIO SERVICES

Two-way radio equipment is mandatory on inland and coastal boats and all seagoing vessels however small, that carry more than six passengers for hire. As a result, there is a variety of land and shipboard radio stations requiring the services of licensed second- or first-class radiotelephone operators for the installation, adjustment, and maintenance of such marine stations.

All licensed radio operators, especially those who maintain marine and aviation equipment, should be familiar with the distress frequencies, priorities, and procedures.

The six key distress and emergency frequencies are:

500 kc—Ships and over-the-sea aircraft; radiotelegraphy.
8.364 mc—Survival craft; lifeboats and life rafts; rescue operations.
121.5 mc—Aeronautical emergency and distress frequency; emergency direction finding.

121.6 mc—Air-to-air and air-to-ground search and rescue operations.
2.182 mc—Maritime distress frequency; radiotelephony.
156.8 mc—Harbor safety and calling.

Small-boat installations are largely radiotelephones operating in the medium-frequency and VHF2 bands. Practically all stations operate on either 2.182 or 156.8 mc, or both, for distress and emergency calls. Shipboard stations using radiotelephony are assigned certain spot frequencies between 2 and 23 mc or 156 and 162 mc. Most small-boat frequency assignments, however, are between 1.605 and 2.85 mc.

Coastal stations open to public correspondence have a variety of frequency assignments between 2.182 and 22.716 mc. Additional assignments may also be allocated elsewhere, according to the needs and location of the station.

REVIEW QUESTIONS

1. What frequency band is most popular for small-boat two-way radio?
2. What frequency band is used extensively for private aviation two-way radio?
3. List the three frequency bands used for land vehicle communications.
4. Give the various categories of the land-transportation, industrial, and public safety radio service.
5. Give the frequency limits of the two Citizens radio bands.
6. List and compare the various classes of Citizens band radio.
7. What are the power requirements for Citizens band operation?
8. What operator license requirements apply below 25 megacycles?

Answers to these questions will be included in PHOTOFACT Set No. 565.

Lesson 3

Radiocommunications Systems

INTRODUCTION

In the previous lesson you learned of the various communication services and frequency assignments, the propagation characteristics of the various frequency bands, and how assignments are made according to the service to be rendered.

Transmitter power outputs depend on the distance to be covered and the propagation problems of a given area or service. Power output must be limited to a safe maximum to prevent interference to similar services which share the same frequency.

There are various types of approved modulation. Modulation, of course, is the method used to impress the information to be conveyed onto the radio-frequency carrier. The various types of emission, as recognized by the FCC, are given in Table 1. The basic type of emission and the supplementary characteristics of the particular modulation are dependent, too, on the service that the radiocommunications system must render, as well as on the assigned frequency and the type of information that the radio channel must carry. This lesson will introduce you to the more common forms of transmission employed in radiocommunications systems. In later lessons, the forms of modulation and demodulation used in modern radiocommunications systems will be discussed in detail.

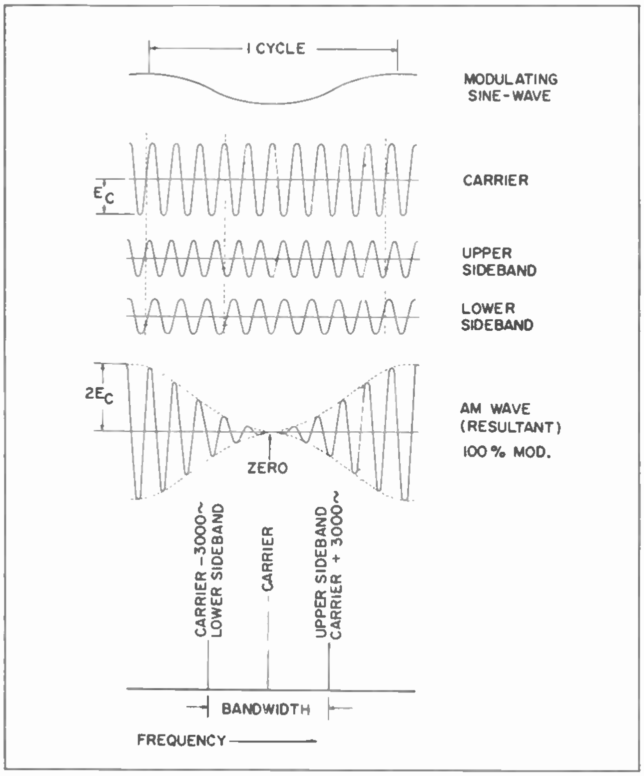

Fig. 1. The formation of an AM wave.

TYPES OF EMISSION AND MODULATION

The FCC classifies three major types of modulation. These are amplitude, frequency, and pulse. In the AM system (Fig. 1), the information is conveyed by varying the amplitude of the carrier. The amplitude-modulated wave consists of three signals—the original carrier, the upper sideband (equal to the carrier frequency plus the modulating frequency), and the lower sideband (the difference between the carrier and modulating frequencies).

Thus, it is apparent that the bandwidth occupied by an amplitude-modulated signal is limited by the highest modulating frequency. If this frequency is 3,000 cycles, for example, the total bandwidth will be twice as much, or 6 kc; if it is 10 kc, the total bandwidth required will be 20 kc, and so on.

In radio broadcast systems, the highest audio-frequency component transmitted lies between 8,000 and 12,000 cycles (although some high-fidelity stations transmit higher components). Thus, the bandwidth of broadcast stations lies between 15 and 25 kc.

In AM broadcasting, the frequency response is generally limited at the receiver. The IF system in an average broadcast receiver is designed to pass audio components up to approximately 5,000 cycles. This is done to minimize interference between stations operating on frequencies that are very close together.

The bandwidth of the average AM broadcast receiver is usually less than 10 kc.

The low- and high-frequency audio components are of significance in the transmission of music. For the most intelligible voice communications, however, a low-frequency limit between 300 and 350 cycles, and a high-frequency limit between 3,000 and 4,000 cycles, are the most satisfactory.

There are three advantages to confining the frequency response and bandwidth in voice communications. (1) With a narrow bandwidth at the transmitting and receiving ends, the communication is less subject to heterodyne and sideband interference from other stations on the same or adjacent channels. (2) The narrow-band signal does not radiate as many sidebands and is therefore less likely to interfere with other stations on the same or adjacent channels. (3) A narrow-band receiver discriminates against static and man-made noises, and thus its inherent noise level (tube and input) is usually lower.

In summary, a narrow-band system takes up less space in the frequency spectrum, minimizes interference, and has a lower noise level.

In voice transmission, few significant frequency components are present above 3,000 or 4,000 cycles. Even if they are, their amplitude is usually so low that they contribute little to intelligibility. It is true that these overtones and high-frequency components do determine voice quality and individualism. However, intelligibility is not reduced. This is why most voice-communications channels are limited at 3,000 to 3,500 cycles. By so doing, they occupy less space in the frequency spectrum, interference is reduced, and simpler equipment can be designed.

Voice-frequency components below 300 cycles determine the bass quality of a human voice. But again, they are not essential to intelligibility. The low-frequency components also represent the bulk of voice power. Equipment designed for good low-frequency performance must be capable of handling the higher power levels in the low-frequency voice components. If these components are eliminated during modulation, however, the available power can be utilized more effectively in the middle-frequency range. This is the range most important to voice intelligibility. The removal of lows permits more effective use of the desired audio range. It also permits more economical equipment design, because low-frequency performance and disturbances can be ignored.

The various types of transmission and emission are shown in Table 1. Notice that each is given an identifying symbol. These symbols are in common usage, particularly in FCC publications. For example, A3 is the symbol for regular AM double-sideband (DSB), full-carrier emission. A numerical prefix is often added to indicate the bandwidth. For example, 8A3 indicates double-sideband AM modulation which has a total bandwidth of 8 kc.

Table 1. Emission chart.

Type of modulation or emission	Type of transmission	Supplementary characteristics	Symbol
Amplitude	Absence of any modulation..	....	A0
	Telegraphy without the use of modulating audio frequency (on-off keying).	....	A1
	Telegraphy by the keying of a modulating audio frequency or audio frequencies or by the keying of the modulated emission (special case: an unkeyed modulated emission).	....	A2
	Telephony	Double sideband, full carrier.	A3
		Single sideband, reduced carrier.	A3a
		Two independent sidebands, reduced carrier.	A3b
	Facsimile	....	A4
	Television	....	A5
	Composite transmission and cases not covered by the above.	....	A9
	Composite transmissions	Reduced carrier	A9c
Frequency (or phase) modulated	Absence of any modulation..	....	F0
	Telegraphy without the use of modulating audio frequency (frequency shift keying).	....	F1
	Telegraphy by the keying of a modulating audio frequency or audio frequencies or by the keying of the modulated emission (special case: an unkeyed emission modulated by audio frequency).	....	F2
	Telephony	....	F3
	Facsimile	....	F4
	Television	....	F5
	Composite transmissions and cases not covered by the above.	....	F9
Pulsed emissions	Absence of any modulation intended to carry information.	....	P0
	Telegraphy without the use of modulating audio frequency.	....	P1
	Telegraphy by the keying of a modulating audio frequency or audio frequencies, or by the keying of the modulated pulse (special case: an unkeyed modulated pulse).	Audio frequency or audio frequencies modulating their pulse in amplitude.	P2d
		Audio frequency or audio frequencies modulating with width of the pulse.	P2e
		Audio frequency or audio frequencies modulating the phase (or position) of the pulse.	P2f
	Telephony	Amplitude modulated pulse.	P3d
		Width modulated pulse.	P3e
		Phase (or position) modulated pulse.	P3f
	Composite transmissions and cases not covered by the above.	....	P9

SUPPRESSED CARRIER

Some voice-communication circuits, mainly in point-to-point equipment, use suppressed-carrier transmission (Fig. 2). In AM modulation, the information to

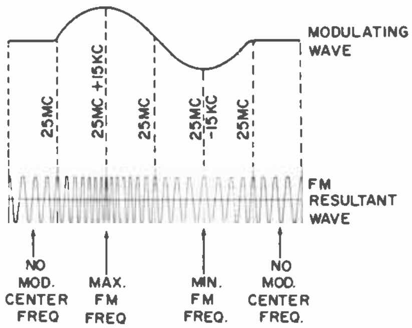

Fig. 2. Basic FM wave with a 25-mc carrier.

be conveyed is contained in each of the sidebands, not in the carrier itself. The carrier is therefore excess baggage, serving only as the vehicle for producing the transmission. While its presence simplifies receiver design, and it can be made to provide automatic volume or frequency control, it can be dispensed with, or at least transmitted at a reduced level.

In conventional AM systems with 100% modulation, two-thirds of the transmitted power is in the carrier; only one-third is contained in the useful sidebands. Even for modulation less than 100% (usually true except on peaks), the carrier still has substantially higher power than the sidebands. As a result, a lot of transmitter power is wasted on the carrier. Furthermore, under crowded conditions the carriers and sidebands interact and set up whistles and squeals. Thus, if the carrier can be removed or at least suppressed, there will be one less source of interference to worry about.

Two advantages of reduced-carrier transmission are: (1) Receiver design is simplified because a stable substitute for the carrier no longer must be generated within the receiver, and (2) All available power can be concentrated into the sidebands.

SINGLE SIDEBAND (SSB)

Another widely accepted form of AM transmission in point-to-point and amateur communications is single sideband (symbolized as A3a). The prefix *3* in the symbol 3A3a designates a bandwidth limit of 3,000 cycles. In single-sideband transmission, the carrier is removed or at least reduced substantially, and one sideband is also suppressed. As a result, the required bandwidth is cut in half. Hence, the total bandwidth of 3A3a transmission is the same as the high-frequency limit, or 3,000 cycles.

In addition to occupying less room in the frequency spectrum, single-sideband transmission requires less power and thereby reduces interference. In two-way radio systems, single-sideband transmission is used more frequently for fixed point-to-point services. However, it is used in some mobile installations. As a matter of fact, radio amateurs have already demonstrated its capabilities in mobile installations.

The power-saving feature of single-sideband transmission is obvious. Even with 100% modulation, each sideband contains only one-sixth of the total power. Nevertheless, all the information to be conveyed is also contained in each one of the sidebands. Thus, all the available power from the transmitter can be concentrated into that one sideband. Moreover, the narrow bandwidth and the absence of a carrier result in much lower interference.

Single-sideband transmission is less troubled by ionospheric variables and selective fading. (In selective fading, some of the frequency segments of the transmitted signal fade in and out. This condition produces intermodulation distortion in the receiver and is heard as garbled speech.)

FREQUENCY MODULATION

Frequency modulation has a number of advantages in two-way mobile-radio systems. The ignition system of any vehicle is a source of impulse noises which cause distortion by introducing amplitude variations in the incoming RF signals. When AM transmission is used, very little can be done to eliminate such noise without affecting the desired amplitude variations of the incoming signals. In a frequency-modulation system, the desired information is in the form of frequency deviations. Consequently, any amplitude variations can be reduced or eliminated without affecting the frequency.

The very nearness of the noise source to the receiver in a vehicle makes the frequency-modulation system attractive for mobile installations, especially in the UHF, VHF, and high HF bands. Although amplitude modulation is used in these bands, its use is much more common in the short-wave and on the low end of the high-frequency (HF) band.

In an FM system, the frequency of the transmitted wave increases sinusoidally during the positive alternation of the modulating sine wave. As the modulating sine wave swings toward the zero axis, the frequency decreases sinusoidally to the carrier (center) frequency. On the negative alternation, the frequency of the transmitted wave decreases below the center frequency. The greatest deviations from the center frequency occur at the crest of the positive and negative alternations (15 kc from the center frequency).

The frequency-change in the FM wave is the amount of deviation—in the example, 15 kc. In assigning a channel for FM transmission, the FCC specifies the maximum permissible deviation for the particular class of station. This deviation corresponds to the 100% modulation limit of an AM wave.

The maximum permissible deviation is not the same for each type of service. For FM broadcasting stations, it is 75 kc. For the FM sound signal associated with television broadcasting, it is only 25 kc. And for most two-way radio FM systems, it drops to either 15 or 5 kc, depending on the station classification. It is important for you, as a second-class radiotelephone operator, to know the maximum deviation permitted for the type of gear you will be called on to maintain.

In an FM system, you might assume that the total bandwidth is determined by the maximum deviation of the wave. This is not true, however. Like the AM wave, the FM wave is a composite of the carrier frequency and center frequency, plus several sidebands. Unlike the AM wave, however, the FM wave may have more than one pair of significant sidebands (see Fig. 3). The number of pairs (hence, the bandwidth of the FM transmission) is determined, by the *modulation index* at the highest modulating frequency.

The sideband pairs are displaced from the carrier by the frequency of the modulating wave and its harmonic multiples (2,3,4,5,etc.). Let's say that an FM wave for a given maximum deviation has three significant sideband pairs. The total bandwidth is then equal to two (the number of sidebands) times three (the number of significant sideband pairs) times the highest modulating frequency. Thus, 10 kilocycles, the total bandwidth required would be 60 kc (2 x 3 x 10,000). What happens if the highest modulating frequency is reduced to 3 kc? Now the total bandwidth required will be only 18 kc (2 x 3 x 3,000). It is significant, just as in AM, that reducing the audio frequency also reduces the bandwidth.

In FM broadcasting, particularly for high-fidelity transmission, the highest audio frequency is over 12 kc. In communications, however, the greatest intelligibility is obtained by limiting the audio frequency to 3,000 or 4,000 cycles. Consequently, the FM wave used for communications can be confined to a much narrower bandwidth.

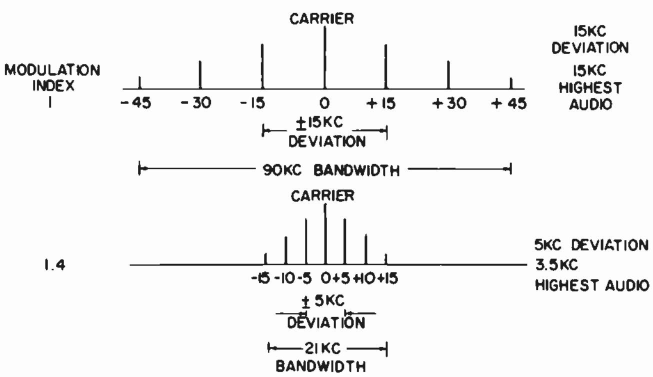

Fig. 3. FM sideband distribution as influenced by modulation index.

Another method of reducing the bandwidth of an FM transmission is to reduce the amount of deviation. In an FM system the best noise rejection is obtained when deviation is greatest. For this reason, the narrow-band system (NBFM) has poor noise rejection. However, the signal-to-noise ratio can be improved by reducing the audio frequency. Because the highest audio frequency for voice communications is much lower than that required in broadcasting, a much improved signal-to-noise ratio can be obtained, despite the more confined deviation of an NBFM system.

The symbols for FM emission are shown in Table 1. Two-way radio assignments are predominantly F3. A numerical prefix establishes the permissible bandwidth. For example, 18F3 signifies FM telephony with a total permissible bandwidth of 18 kc.

OTHER TYPES OF MODULATION

As an applicant for a second-class radiotelephone license, you should also be familiar with other common forms of transmission and their symbols.

A1 is the symbol for radiotelegraphy where the carrier is interrupted as in Fig. 4 to form a coded message (usually International Morse code).

Another form of radiotelegraphy, common on the low- and very-low-frequency ship bands, is A2. Here the carrier is transmitted continuously, and the coded message is formed by modulating an audio tone (heard as the familiar "dit" and "dah").

Symbols F1 and F2 represent methods of sending frequency-modulated coded messages. F4 and F5 represent frequency-modulated facsimile and television transmission, respectively. Where amplitude modulation is used, the respective symbols are A4 and A5. In television broadcasting, A5 is used for picture transmission and F3 for sound.

Various types of pulse modulation are symbolized in the last section of the chart. Pulse modulation is used in advanced multiplex and telemetering applications, and also in space communications.

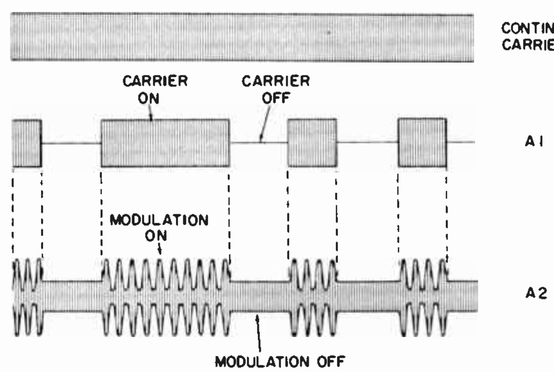

Fig. 4. A1 and A2 code transmission—Morse Code letter L as an example.

PREPARING FOR THE LICENSE EXAMINATION

Simple mathematics problems are a part of the FCC examination. They are based mainly on Ohm's law, frequency or power calculations and other easy problems. The formulas you should know when you take the exam are:

Ohm's Law

$$E = IR \qquad I = \frac{E}{R} \qquad R = \frac{E}{I}$$

where,
E is the voltage in volts,
R is the resistance in ohms,
I is the current in amperes.

AC Ohm's Law

$$E = IZ \qquad I = \frac{E}{Z} \qquad Z = \frac{E}{I}$$

where,
E is the voltage in volts,
Z is the impedance in ohms,
I is the current in amperes.

Power Law

$$P = I^2R \qquad P = I^2Z$$
$$P = E^2/R \qquad P = E^2/Z$$
$$P = EI \qquad P = EI$$

where,
P is the power in watts,
E is the voltage in volts,
I is the current in amperes,
R is the resistance in ohms,
Z is the impedance in ohms.

Resonance

$$f_o = \frac{1}{2\pi\sqrt{LC}}$$

where,
f_o is the resonant frequency in cycles,
L is the inductance in henrys,
C is the capacitance in farads,
π is a constant equal to 3.1416

Wavelength

$$\lambda = \frac{V}{f}$$

where,
λ is the wavelength in meters,
f is the frequency in cycles,
V is the velocity of the wave (300,000,000 meters per second).

Some sample problems follow:

1. *If a vacuum tube with a filament rated at 0.25 ampere and 5 volts is to be operated from a 6-volt battery, what value of series resistor is needed?*—To provide 5 volts across the tube, there must be a 1-volt drop across the series resistor. Since the same amount of current flows throughout a series circuit, 0.25 ampere also flows through the resistor. Consequently, its value, from Ohm's law, is:

$$R = \frac{E}{I} = \frac{1}{.25} = 4 \text{ ohms}$$

2. *If the voltage applied to a circuit is doubled and the circuit resistance is tripled, what will the final current be?*—According to Ohm's law, the current varies directly with the voltage and inversely with the resistance. For ease of figuring, assume the old current is 1 ampere. The new current will then equal:

$$\frac{2E}{3R} = \frac{2X1}{3X1} = 2/3$$

Hence, doubling the voltage and tripling the resistance causes the current to decrease to two-thirds its former value.

3. *A relay with a coil resistance of 500 ohms is designed to operate when a current of 0.2 ampere flows through the coil. What value of resistance must be connected in series with the coil when operated from a 110-volt DC line?*—The resistance must be such that the current flow is maintaned at 0.2 ampere. The relationship can be set up from Ohm's law as follows:

$$I \times R_{coil} = 0.2 \times 500 = 100 \text{ volts}$$

$$R = \frac{110 - 100}{I}$$

$$= \frac{10}{0.2} = 50 \text{ ohms}$$

4. *If the resistance in a circuit is doubled, what will happen to the power?*—It will be cut in half because the power varies inversely with the resistance (assuming the voltage across the resistance remains the same, of course).

5. *If the resistance in Question 4 is halved, what will the power dissipation be?*—It will be doubled, for the same reason.

6. *What is the minimum required power dissipation rating of a 20,000-ohm resistor connected across a potential of 500 volts?*—Using the power formula:

$$P = \frac{E^2}{R} = \frac{(500)^2}{20{,}000} = 12.5 \text{ watts}$$

It is customary, however, to select a resistor that will provide at least twice the minimum power dissipation required. So, a 25-watt resistor would be selected, to be on the safe side.

7. *What is the conductance of a circuit in which 6 amperes flows when 12 volts DC is applied?*—The

resistance of the circuit is determined from Ohm's law.

$$R = \frac{E}{I} = \frac{12}{6} = 2 \text{ ohms}$$

Since conductance is the reciprocal of resistance, its value would be:

$$\frac{1}{R} = \frac{1}{2} = 0.5 \text{ mho}$$

8. *If two 10-watt, 500-ohm resistors are connected in parallel, what is the power dissipation capability of the combination?*—Each resistor dissipates 10 watts, therefore the total would be 20 watts.

9. *What will be the dissipation, in watts, of a 20-ohm resistor through which a current of 0.25 ampere passes?*—From the formula:

$$P = I^2R = (.25)^2 \times 20 = 1.25 \text{ watts}$$

10. *What is the maximum rated current-carrying capacity of a 5,000-ohm, 200-watt resistor?*—From the formula:

$$P = I^2R$$

$$I = \sqrt{\frac{P}{R}} = \sqrt{\frac{200}{5{,}000}}$$

$$= \sqrt{.04} = 0.2 \text{ amp}$$

11. *What is the total resistance of a circuit consisting of one 10-ohm branch in parallel with another of 25 ohms?*—The formula for resistances in parallel is:

$$\frac{1}{R_T} = \frac{1}{R1} + \frac{1}{R2} + \cdots$$

$$R_T = \frac{1}{\frac{1}{R1} + \frac{1}{R2}}$$

$$R_T = \frac{1}{\frac{1}{10} + \frac{1}{25}} = 7.143 \text{ ohms}$$

12. *If resistors of 5, 3, and 15 ohms are connected in parallel, what is the total resistance?*—Again using the formula for parallel resistances:

$$R_T = \frac{1}{\frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3}} + \cdots$$

$$R_T = \frac{1}{\frac{1}{5} + \frac{1}{3} + \frac{1}{15}} = 1\tfrac{2}{3} \text{ ohms}$$

13. *What is the reactance of a .005 microfarad capacitor at a frequency of 1000 kilocycles?*—Using the formula:

$$X_c = \frac{1}{2\pi fC}$$

$$= \frac{1}{6.28 \times 1{,}000 \times 10^3 \times .005 \times 10^{-6}}$$

$$= 31.8 \text{ ohms}$$

14. *If 1-, 3-, and 5-microfarad capacitors are connected in parallel, what is their total capacitance?*—9 microfarads. The total value of capacitors connected in parallel is the sum of the individual capacitances:

$$C_T = C_1 + C_2 + C_3 = 1 + 3 + 5 = 9 \text{ mfd.}$$

15. *If 5-, 3-, and 7-microfarad capacitors are connected in series, what is the total capacitance?*—Using the formula:

$$C_T = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}}$$

$$= \frac{1}{\frac{1}{5} + \frac{1}{3} + \frac{1}{7}} = 1.48 \text{ mfd}$$

16. *Neglecting distributed capacitance, what is the reactance of a 5-millihenry choke coil at 1000 kilocycles?*—Using the formula:

$$X_L = 2\pi fL = 6.28 \times 1000 \times 10^3 \times 5 \times 10^{-3}$$

$$X_L = 31{,}400 \text{ ohms}$$

17. *If a circuit inductance has a reactance of 100 ohms and a resistance of 100 ohms, what will the phase angle of the current be with reference to the voltage?*—Using the formula:

$$\tan\theta = \frac{X_L}{R} = \frac{100}{100} = 1$$

$$\theta = 45°$$

18. *What is the impedance of a solenoid if its resistance is 150 ohms and a current of 0.3 ampere flows through the winding when 110 volts at 60 cycles is applied to the solenoid?*—The impedance of the solenoid is equal to the voltage across it divided by the current through it. Hence, the resistance and frequency can be ignored—we merely threw them in to see if you were on your toes! Using the formula:

$$Z = \frac{E}{I} = \frac{100}{0.3} = 366.6 \text{ ohms}$$

19. *If one complete cycle of a radio wave occurs in .000001 second, what is the wavelength?*—First we convert the length of one period into cycles per second:

$$f = \frac{1}{\text{period}} = \frac{1}{0.000001} = \begin{matrix}\text{1,000,000 cycles or} \\ \text{1,000 kilocycles}\end{matrix}$$

Then we use the formula for determining the wavelength when the frequency in kilocycles is known.

$$\lambda = \frac{V}{f}$$

$$= \frac{300{,}000}{\text{f (in kilocycles)}} = \frac{300{,}000}{1{,}000}$$

$$= 300 \text{ meters}$$

20. A series-resonant circuit has a resistance of 6.5 ohms and equal inductive and capacitive reactances of 175 ohms each. What is the voltage drop across the resistance if the applied potential is 260 volts?—260 volts. At series resonance, the out of phase reactances cancel and the impedance is equal to the resistance. As a result, the entire 260 volts is applied across the resistance.

21. A series-resonant circuit has a resistance of 6.5 ohms and equal inductive and capacitive reactances of 175 ohms each. What is the voltage drop across the inductance when 260 volts is applied to the circuit?—The component values are the same as for Question 20. The current at resonance is:

$$I = \frac{E}{Z} = \frac{260}{6.5} = 40 \text{ amps}$$

The voltage across the inductor is:

$$E_L = IX_L = 40 \times 175 = 7{,}000 \text{ volts}$$

22. A series circuit has a resistance of 4 ohms, an inductive reactance of 4 ohms also, and a capacitive reactance of 1 ohm. The applied circuit emf is 50 volts. What is the voltage drop across the inductance?—The series impedance is:

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

$$= \sqrt{(4)^2 + (4-1)^2} = \sqrt{16+9} = 5 \text{ ohms}$$

The series current is:

$$I = \frac{E}{Z} = \frac{50}{5} = 10 \text{ amps}$$

The inductor voltage is:

$$E_L = IX_L = 10 \times 4 = 40 \text{ volts}$$

REVIEW QUESTIONS

1. What determines the bandwidth of the signal transmitted by an AM station?
2. What factors determine the bandwidth of an FM radio station?
3. What is meant by narrow-band frequency modulation (NBFM)?
4. Of what significance is the audio bandwidth in a NBFM system?
5. Give the advantages of single sideband transmission (SSB).
6. What are the advantages of a limited audio-frequency band?
7. What are the advantages of frequency modulation for vehicular communication?
8. Distinguish among A1, A2, and A3 emission.

Answers to these questions will be included in PHOTOFACT Set No. 565.

Lesson 4.

Laws, Licensing, and Operating Practice

RADIO LAW

The radio spectrum, being finite, must be regulated to provide space for the many services available. Frequencies must be allocated in segments according to the needs of the various services. Rules of procedure must be established and enforced.

The regulatory agency in the United States is the Federal Communications Commission (FCC), established under the Communications Act of 1934. The United States is also bound by certain international agreements, because radio waves do not observe boundaries in their travels.

Copies of the rules and regulations for the various radio services are available from the U. S. Government Printing Office, Washington 25, D.C. If your interest is in two-way radio, you should obtain Volume V, which covers aviation, public safety, industrial, and land-transportation radio services. If you have an additional interest in Citizens-band radio, Volume VI is available. Volume IV covers the regulations for the maritime services.

Elements I and II of the FCC exam are about the basic laws and operating practices. Typical questions and answers covering these elements are given at the end of this lesson.

Notice that safety and distress laws and procedures are stressed. You may never use this information, but if a distress situation which involves you does arise, it is extremely important that you know what to do.

LICENSING

Radio transmitters in the two-way radio services may not be operated without a station license, which is granted by the FCC. Application forms can be requested from the FCC in Washington, D.C., or from one of their district offices.

As the holder of a second-class radiotelephone license, you should be familiar with the rules and procedures for obtaining a station license. In addition, you should be prepared to help the potential user select the service most appropriate for his particular industrial, commercial, or professional need. You can also assist him in the selection of equipment and frequency. Finally, you can lend him a hand in completing the application, and provide the necessary guidance until the system is in operation. The second-class radiotelephone licensee who can follow through from the initial planning until the station goes on the air will be in the most advantageous position to attract new customers and users. He can also make himself indispensable in the maintenance and expansion of present systems. All of this requires the license holder to be familiar with the FCC rules and regulations.

After getting your license, you should become familiar with the various types of two-way radio equipment best suited for your area. A good way to start is to get on manufacturers' mailing lists. In this way, you can keep abreast of new developments and thus know what equipment is available and what it can do.

Before buying his equipment, the potential user must know the category of his intended communications activity. These categories were presented in Lesson 2, along with the various frequency assignments. It's a good idea to know them. Specific frequencies are listed in the appropriate rules and regulations, and the applicant must select a specific frequency.

The equipment used in most two-way radio systems must be FCC-approved and meet certain operating requirements. The Commission maintains a current list of equipment acceptable for licensing. This list can be inspected at FCC headquarters in Washington, D.C., or at any field office. Manufacturers of two-way radio equipment also have information regarding the type-acceptance of their models. If the prospective equipment is not on the list, much lengthier descriptions must be submitted along with the application for a station license.

LICENSE APPLICATION PROCEDURE

A sample station application form for the special radio services is shown in Fig. 1. So that you will know how to fill one out, let us consider each item individually.

The frequency is selected from those allocated to the particular radio service designated for the user's intended purpose. *It is up to the applicant to select a frequency that will not interfere with similar radio services in his area.* Any persons operating in the same local-interference range (15 kc above or below the frequency selected) must be notified.

Many areas, particularly those crowded with two-way assignments, have a local frequency-advisory committee usually composed of two-way radio equipment dealers and licensed operators.

Item 1C refers to the type of emission. For example, 20F3 refers to the use of frequency modulation with an assigned bandwidth of 20 kc and a maximum input power of 120 watts.

Items 2 and 3 are self-explanatory. They include the business address of the applicant and the location of the transmitter. (The two may or may not be the same.)

Item 4 lists the type of radio service and whether the application is for base, mobile, or both. Item 5 must be filled in if any mobile or fixed stations are being requested for less than one year. Data on the location of control point(s) more than 500 feet away from the transmitter must be presented in item 6. Antenna height above ground is inserted in item 7.

The eligibility requirements of the applicant are covered in items 8, 9, and 10. Item 11 is answered when the applicant intends to render a communications service to, or receive base-station service from, other persons. In item 12, additional information must be provided if the answer is no to either Part A or B. The applicant must make clear that he will have full freedom to operate the station in accordance with FCC rules and regulations.

A functional system diagram is requested in item 13; it must be submitted when there are two or more fixed stations at different locations. Such a diagram must show their locations, and should include the entire area over which communications are to be established. Item 14 must be answered more completely when the proposed equipment does not appear on the FCC List of Equipment Acceptable for Licensing.

Item 15 is a statement of eligibility. It must include a general description of the applicant's business or activity, how the radio service will be employed, and any other information the applicant believes will aid in determining his eligibility. Item 16 relates to the type of application being made.

Items 17 and 18 have to do with the antenna system. If the applicant intends to install more than one antenna on the same tower, the necessary information must be given in item 17. An appropriate form must also be submitted when the over-all antenna height above ground exceeds 170 feet, unless the antenna is mounted on a man-made structure and does not increase the over-all height by more than 20 feet. The special antenna form 401 must be completed if the proposed antenna structure will exceed the elevation of an established airport by more than one foot for each 200 feet from the nearest boundary of the landing area. Again, the form is not required when the antenna base is no more than 20 feet above the ground or the top of a man-made structure or natural formation.

In some services, the FCC grants the station license immediately; in others, a construction permit is issued first. The final license is then granted after the station has been completed and placed in operation, provided it complies with technical performance standards.

The local FCC district office must be notified when construction has been completed and the station is ready for testing. The main station license is posted at the fixed station, and separate transmitter identification cards should be filled in and attached to each *mobile* transmitter.

It will be your responsibility, as the holder of a second-class radiotelephone license, to keep an eye on the expiration date of your employer's or customers' transmitters. You should apply for license renewals two months before they expire. The renewal form is filled out in triplicate and submitted to the FCC.

OPERATING PRACTICE

Each radiotelephone operator should know and abide by the rules and accepted procedures of operation. Courtesy and consideration are very important in minimizing unnecessary interference and maintaining reliable communications on active channels. The second-class radiotelephone license holder should set an example for others, and should do everything possible to encourage proper operation.

An excellent summary of radiotelephone operating practice, suggested by the FCC, follows:

A licensed radio operator should remember that the station he operates must be licensed by the Federal Communications Commission. In order to prevent interference and to give others an opportunity to use the airways he should avoid unnecessary calls. He should remember that radio signals normally travel outward from the transmitting station in many directions and can be intercepted by unauthorized persons.

Before making a radio call, the operator should listen on the communications channel to insure that he will not interfere with communications already in progress. At all times the operator should be courteous.

Station identification should be made clearly and distinctly so that unnecessary repetition of call letters or names is avoided and to enable monitoring stations to clearly identify all calls.

FCC Form 400
July 1955

Form Approved
Budget Bureau No. 52-R132.2

United States of America
FEDERAL COMMUNICATIONS COMMISSION

This authorization permits the use of only such transmitters as are specified under "Special Conditions" and those appearing in the Commission's "List of Equipment Acceptable for Licensing" and designated for use in the particular radio service named in Item 4(a) of this application.

1 (a). Frequency (Mc)	1 (b). No. of transmitters: Base or Land	Mobile	Other	1 (c). Emission	1 (d). Maximum permissible power input (watts)

2 (a). Name (see instructions)

(b). Mailing address (number, street, city, zone, state)

3. Location of transmitter(s) at a fixed location
Number and street (or other indication of location)

City | County | State

Latitude ° ′ ″ | Longitude ° ′ ″

4 (a). Name of Radio Service

COMMISSION FILE COPY
FOR COMMISSION USE ONLY

(b). Class of station:
Base ☐ Mobile ☐
Other (Specify):

Call Sign

File Number

5. If mobile units, or other class of station at temporary locations, are included in this authorization, show area of operation

6. Location of control point(s)

7. Overall height above ground of tip of antenna feet.

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Antenna painting and lighting specifications:

Special Conditions:

Term of authorization: This authorization effective ________

and will expire 3:00 A.M. EST ________ and is subject to further conditions as set forth on reverse side. If the station authorized herein is not placed in operation within eight months this authorization becomes invalid and must be returned to the Commission for cancellation unless an extension of completion date has been authorized.

By direction of the FEDERAL COMMUNICATIONS COMMISSION

SECRETARY

FOLD HERE

8. Is applicant a representative of an alien or of a foreign government? If answer is "Yes", explain on the reverse of this page. Yes ☐ No ☐

9. State whether applicant is (Check one)
Individual ☐ Partnership ☐ Association ☐ Corporation ☐ Governmental Entity ☐
(If applicant is a non-governmental corporation fill out Item 19; if an unincorporated association fill out Item 20, on the reverse side of this page.)

10. If applicant is an individual, is applicant a citizen of the United States? Yes ☐ No ☐ | If applicant is a partnership, are all partners citizens of the United States? Yes ☐ No ☐

11. Is communication service to be received from or rendered to another person (see instructions)? If "Yes", name of person is Yes ☐ No ☐

12. Will the applicant own (a) The radio equipment? Yes ☐ No ☐ | (b) The property on which the Station will be located? Yes ☐ No ☐
(If the answer to either (a) or (b) is "No", see instructions.)

13. Attach functional system diagram showing details of proposed radio system and include such other supplementary data as required by specific rules.

14. If it is proposed to use a transmitter which does not appear on the Commission's "List of Equipment Acceptable for Licensing", or if the transmitter is listed but not designated for use in the radio service named in Item 4(a) of this application, describe such transmitter in detail. (See instructions)

15. Statement of eligibility

(Use space on the reverse of this page)

16 (a). Application for: (Check one)
New station ☐ Assignment of authorization ☐
Modification ☐
Reinstatement of expired authorization ☐ License to cover CP ☐

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(b) If for modification, state modification proposed

(c) If this application refers to a presently authorized station, give call sign | (d) Give points of communication (call signs)

(e) Are you presently authorized for any other stations in the service indicated in Item 4 (a)? Yes ☐ No ☐

17. If antenna will be mounted on an existing radio tower, give call signs of users

18. Will antenna extend more than 20 feet above the ground or natural formation, or more than 20 feet above an existing man-made structure on which it will be mounted? Yes ☐ No ☐

(a) Give height and type of existing structure on which antenna will be mounted (pole, mast, tower, building, chimney, etc., or combinations of these)

(b) Distance to nearest aircraft landing area feet. | (c) Elevation of ground, at antenna site, above mean sea level feet.

All the statements made in the application and attached exhibits (to , inclusive) are considered material representations, and all the exhibits are a material part hereof and are incorporated herein as if set out in full in the application.

The applicant certifies that he has a current copy of the Commission's Rules governing the radio service named in Item 4(a) above.

The applicant waives any claim to the use of any particular frequency or of the ether against the regulatory power of the United States because of the previous use of the same, whether by license or otherwise, and requests an authorization in accordance with this application.

Subscribed and sworn to before

me this _____ day of ________, 19____.

Notary Public ________ SEAL
(or name and title of other person competent to administer oaths)

My commission expires ________

Applicant (Must agree with name as shown in Item 2 (a)).

By ________
(Designate appropriate classification below)

☐ Individual Applicant
☐ Member of Applicant Partnership
☐ Officer of Applicant Corporation or Officer and Member of Applicant Association
☐ Official of Governmental Entity Competent under the Jurisdiction to Sign for the Applicant

(OVER)

Fig. 1. Typical radio-station application form.

To prevent tampering, a radio transmitter should at all times be either attended or supervised by a licensed operator, or should be made inaccessible to unauthorized persons.

A radio transmitter should not be on the air except when messages are being transmitted. The operator of a radiotelephone station should not press the push-to-talk button except when he intends to speak. Radiation from a transmitter may cause interference even when voice is not transmitted.

When radiocommunications at a station are unreliable or disrupted due to static or fading, it is not good practice for the operator to continuously call other stations in attempting to make contact, because his calls may interfere with the other stations that are not experiencing static or fading.

A radiotelephone operator should make an effort to train his voice for most effective radiocommunication. His voice should be loud enough to be distinctly heard by the receiving operator, and it should not be too loud since it may become distorted and difficult to understand at the receiving station. He should articulate his words and avoid speaking in a monotone. The working distance range of the transmitter is affected to some extent by the loudness of the speaker's voice; if the voice is too low, the maximum distance range of the transmitter cannot be attained, and if the voice is too loud the effective range may be reduced to zero because the signals are distorted beyond intelligibility.

Radiotelephone operators should use familiar words and phrases in order to insure accuracy and save time. Some radio operating companies, networks, associations, etc., select and adopt standard words and phrases for expediting and clarifying radiotelephone conversations. For example, in the aviation services, "Roger" means "I have received all of your last transmission"; "Stand by" means "Wait for another call or further instruction"; "Out" means "This conversation is ended and no response is expected"; "Over" means "My transmission is ended, and I expect a response from you"; "Break" indicates a separation between portions of a message; "Say again" means "Repeat," and "Words twice" is used to ask a station to send every phrase twice. The above procedure is often used in other communication services, too.

Often, in radiotelephone communications, a "phonetic alphabet" or word list is useful in identifying letters or words that may sound like other letters or words of different meaning.

In making a call by radio, the call signal or name of the called station is generally given not more than (3) times, followed by the call sign, or in some services the name, of the calling station not more than (3) times.

In testing a radiotelephone transmitter, the operator should clearly indicate that he is testing, and the station identification should clearly be given. Tests should be as brief as possible.

If a radio station is used only for occasional calls, it is a good practice to test the station regularly. Such tests may reveal defects which, if corrected immediately, may prevent delays when communications are necessary.

When a licensed operator in charge of a radiotelephone station permits another person to use the facilities of the station, the operator should remember that he continues to bear responsibility for the proper operation of the station.

Now let's review a few typical questions on Elements I and II of the FCC exam.

Preparation for License Examination

ELEMENT I—BASIC LAW

1. *Where and how is an operator license or permit obtained?*—Request an application form and examination schedule from the nearest FCC field office. Submit the application in the prescribed form, including all subsidiary forms and documents, properly completed and signed, in person or by mail, to the office of your choice (usually the closest one). This office will make the final arrangements.

2. *Must a person designated to operate a radiotelephone station post his operator license or permit, and if so, where?*—Yes. The original license of each station operator must normally be posted at the place where he is on duty. In the case of portable or mobile stations, or when the operator holds a restricted permit, he must have on his person either his operator license or an FCC verification card.

3. *How must a person who receives a notice of violation from the FCC reply?*—By sending a written answer directly to the FCC office from which the notice originated.

4. *How soon does the FCC require a response to a notice of violation?*—Within three days.

5. *If a person cannot respond to a notice of violation in the time prescribed by the FCC, is it necessary to explain the reason for any delay?*—Yes, at the earliest practical date.

6. *Should the answer to each notice of violation be complete and should reference be made to remedial action, if any is necessary?*—Yes. The answer to each notice should be complete and not be abbreviated by reference to other communications or answers to other notices. If the notice relates to violations that may be due to the physical or electrical characteristics of transmitting apparatus, the answer should

state fully what steps, if any, have been taken to prevent future violations.

7. To whom is a response to a notice of violation addressed?—The originating field office.

8. May the FCC suspend an operator license or permit for due cause?—Yes.

9. Can suspension of an operator license or permit take effect prior to notification?—No.

10. How soon after receiving notification of suspension of an operator license or permit does a suspension order become effective?—15 days.

11. May an operator who has received an order of operator license or permit suspension request a hearing?—Yes.

12. Is it prohibited by law to transmit superfluous signals? Are profane and obscene language prohibited?—Yes.

13. Does the government have authority to impose fines for failure to comply with the rules and regulations governing the use of radio on compulsory-equipped ships?—Yes.

14. What does a person do whose operator license or permit has been lost, mutilated, or destroyed?—Notify the Commission immediately.

15. In applying for a duplicate operator license or permit, what documentary evidence must be submitted?—The evidence of service obtained under the original license or permit.

16. Is it permissible to operate pending receipt of a duplicate operator license or permit after application has been made for reissue?—Yes.

17. What provision is made for operation without an actual operator license or permit pending receipt of a duplicate?—Operation is permitted, but a signed copy of the application must be exhibited.

18. Is the holder of a radiotelephone third-class operator permit authorized to make technical adjustments on the transmitter he operates?—No, except under the immediate supervision and responsibility of a person holding the appropriate first- or second-class commercial radio-operator license, either radiotelephone or radiotelegraph, as required for the class of station involved.

19. Must a radio station that is required to be operated by a licensed radio operator be a licensed radio station?—Yes.

20. Are communications bearing upon distress situations subject to the secrecy provisions of law?—No.

21. What penalty is provided by law for willful and knowing violation of regulations imposed by the Federal Communications Commission and of Radio Treaties?—A fine of $500 for each day such offense occurs, plus any other penalties provided by law.

22. What penalty is provided by law for willful and knowing violation of the radio laws?—A fine of $10,000 or imprisonment of not more than two years, or both.

23. Are radio stations subject to inspection by the Federal Communications Commission?—Yes.

24. In radiotelephony, what are the distress, urgency, and safety signals?—MAYDAY, PAN, and SECURITY, respectively, repeated three times.

ELEMENT II—BASIC OPERATING PRACTICE

General

1. If a radiotelephone operator desires to make a brief test of a transmitter, what would be a good choice of words?—The operator should clearly indicate that he is testing, and give the station identification. Tests should be as brief as possible. The operator could say, "This is station KXYZ testing . . . 1, 2, 3, testing . . . this is station KXYZ testing, etc."

2. Why is it important to avoid unnecessary calls by radio?—To give others an opportunity to use the channel, and to minimize interference.

3. Must a person listen on a channel before transmitting?—Yes.

4. Why is it advisable to listen on a channel before transmitting?—To avoid interfering with communications already in progress on the channel.

5. Why should a trial of the radiotelephone installation be made frequently?—To reveal defects which, if corrected immediately, may prevent delays when communications are necessary.

6. How can a radiotelephone installation be tested?—By placing it in operation under normal conditions. A radio check can be scheduled with another station. Base and mobile stations can conduct radio tests among units of the system.

7. Before placing the transmitting apparatus of a radio station in operation for a test, what precautions must be taken?—The operator should listen on the channel to insure that interference will not be caused. Tests should be as brief as possible.

8. What is the correct form for transmitting a distress call by radiotelephony?—The expression MAYDAY spoken three times, followed by the identification of the mobile station in distress. The distress call should be repeated three times, followed by the distress message.

9. Why is it good policy to be brief in radiotelephone conversations?—Because others may wish to use the channel.

10. What does the word CLEAR mean at the end of a radiotelephone communication?—The operator is through and expects no further reply.

11. Are there any ill effects to radiocommunications if the operator shouts into the microphone?—Yes. Shouting often causes overmodulation and severe speech clipping, which distorts the voice communication. Overmodulation can also interfere with stations on adjacent channels.

12. In a noisy location is it good practice, when speaking into the microphone, to shield it with the *hand?*—Yes. This reduces pickup of background noises by the microphone. However, one must not shout into the microphone, as explained in question 11.

13. In radiotelephone communications why should the operator use well-known words and phrases as much as possible?—To insure greater accuracy and prevent repetition.

14. What is the operator's responsibility upon hearing the word SECURITY repeated three times?—All stations hearing the safety signal must continue to listen on this frequency until satisfied the message is of no interest to them. Moreover, they must not make any transmissions likely to interfere with the message.

15. What must the operator do if told he is interfering with a distress signal?—Cease all transmissions immediately.

16. What is the significance of the word OVER when transmitted at the end of a radiotelephone communication?—"My transmission is ended and I expect a response from you."

17. What is indicated by the word OUT when transmitted at the end of a radiotelephone communication?—The conversation is ended and no response is expected.

18. Can a radio operator always consider his radiotelephone conversation completely confidential?—No. He should never forget that radio signals can be intercepted by others.

19. In calling a station by radiotelephony, how many times does the calling station generally repeat its call sign or name?—Usually, three times.

20. Would you listen on a shared channel before transmitting? Why?—Yes. To avoid interfering with communications already in progress.

21. Under normal conditions, would a transmission on a calling frequency be proper if the receiver for that frequency was inoperative?—No, unless the operator can advise the called station to transmit on another channel.

22. What is the difference between calling and working frequencies?—A calling frequency is used solely to secure the attention of another station or stations.

A working frequency is used to carry on communications for other than calling.

In several two-way radio services, notably marine, contacts are established on a calling frequency. Then the two stations switch over to a working frequency for message handling.

23. Why is it important to clearly give the station call signs?—To minimize repetition and possible interference. A clear call sign also assists a monitoring station in identifying calls.

24. Should radiotelephone equipment be tested each day?—Yes. (Refer to question 6.)

25. Should messages bearing upon safety, including weather information, be given priority over business messages?—Yes. Safety and weather data rank third and fourth in the priority list.

26. If a station is required by law to listen on a calling and distress frequency, when may the listening be discontinued?—When the station is communicating with another one.

27. Why should a radiotelephone transmitter be kept off the air when voice transmissions are not in progress?—Carrier radiation may cause interference and heterodyning with other communications on the channel, even when voice is not being transmitted.

28. Why is it beneficial for the transmitter of a radio station to be in constant readiness for making a call?—To avoid delays in making and answering calls and in conducting the station's function.

29. If a station is required to maintain effective listening on a distress frequency, why is it desirable for the equipment to return automatically to reception on the distress frequency immediately after it has been used on another frequency?—This procedure permits more effective monitoring of the distress frequency, reduces the time of changeover, and relieves the operator of the mechanics of changeover.

30. Why is rapid frequency change of the transmitter and receiver desirable?—Communications can be handled more quickly and efficiently. This is important when frequent changeovers are necessary between calling and working frequencies.

31. What would you do as radiotelephone operator if told that your voice was distorting?—Speak more softly or perhaps further away from the microphone, making certain to shield it from any external noises. Distortion can also be caused by off-frequency operation or equipment defects.

32. Under what conditions may a radiotelephone station employ a calling frequency as contrasted to a working frequency?—For calling and replying. Also, for distress, urgency, and safety calls.

33. In calling a station by radiotelephone, should the calling station repeat the call sign or name of the called station consecutively more than three times?—No.

34. Why should stations using a shared frequency leave an interval between calls?—To permit other stations to use the channel.

35. What is the operator's responsibility upon hearing a distress call in the mobile services?—He must immediately acknowledge receipt of the message. If the station in distress does not use the auto-alarm signal, the operator receiving the distress call may transmit it, provided he is given permission to do so by the person responsible for the receiving station. The operator receiving the distress calls must avoid interfering with transmission of the distress message or with information concerning it.

36. When routine radiocommunications are unreliable because of static or fading, should the operator continue transmitting, or wait for more favorable *conditions?*—Wait for more favorable transmission conditions, to avoid repetition and possible interference. However, this obviously does not apply to urgent messages.

37. What is the order of priority for radiotelephone communications?—Distress, urgency, safety, bearings, navigation and needs of ships and aircraft, meteorological information, government communications of priority, followed by all other communications.

Special

1. In making a ship-to-ship contact, except in an emergency involving safety, how long may a ship radiotelephone station continue calling in each instance?—Not more than 30 seconds, whether by voice or automatically.

2. Except in an emergency involving safety, if a ship radiotelephone station does not receive a reply after calling, how long must it wait before calling again?—One minute.

3. In regions of heavy traffic, how long may the ship-to-ship radiotelephone frequencies between 2000 and 3000 kilocycles be used for any one exchange of communications (other than distress and emergency communications)?—Five minutes.

4. How is a ship radiotelephone station required to be identified in connection with its operation?—The official call must be given in English at the beginning and end of each transmission, and every 15 minutes whenever transmission exceeds 15 minutes.

5. If a radiotelephone installation provided on board ship for safety purposes becomes defective, what action must the operator take?—Notify the master of the ship.

6. Who signs the radio log of a ship radiotelephone station, certifying to entries made therein?—The licensed operator or other person responsible for operation of the radiotelephone transmitting apparatus. The use of initials or signs in lieu of a signature is not authorized.

7. What are the requirements, with respect to listening watch in a ship radiotelephone station, during its hours of service in the 2000-3000-kilocycle band?—An efficient watch must be maintained for A3 transmission on 2182 kc. Insofar as possible, this watch should be maintained twice an hour for three minutes, beginning on the hour and half hour.

8. Who may operate the radiotelephone set aboard a vessel?—A licensed operator must be in control on frequencies below 30 mc. However, another person may speak over the microphone. An unlicensed but properly authorized person may operate a transmitter licensed exclusively for transmission on frequencies above 30 mc.

9. Is it necessary for all vessels having knowledge of distress traffic to follow the traffic, even if they do not take part in it?—Yes.

10. What is the proper form to use in acknowledging a distress message?—In telegraphy the proper form is to repeat the call sign of the mobile station in distress three times, followed by DE, the call sign of the station acknowledging three times, RRR, the distress signal, and AR.

In telephony the call sign of the station in distress is repeated three times, followed by THIS IS, the call sign of the acknowledging station three times, ROGER, MAYDAY, and OUT.

11. What information must be sent following acknowledgment of a distress message?—Every mobile station which acknowledges receipt of a distress message must—on the order of the master or person responsible for the ship, aircraft, or other vehicle—transmit as soon as possible its own name, position, and the speed at which it is proceeding toward the distressed ship, aircraft, or other vehicle.

Before sending this message, the station must be certain it will not interfere with other stations better situated to render immediate assistance to the station in distress.

12. Is it necessary to obtain the authority of the master or person responsible for the vessel prior to sending the information required, following acknowledgment of a distress call?—Yes.

13. Is it desirable, when acknowledging a distress message, not to interfere with other acknowledgments from vessels better able to assist?—Yes.

14. Is a vessel which hears a distress message, but is not in a position to assist, required to take all possible steps to attract the attention of stations which might be in a position to assist?—Yes.

15. If the radiotelephone ship installation is used during the day, is it necessary to make any special test communication for the purpose of trying the radio?—No. Normal daily operation proves the performance of the installation.

16. What radio channel is used for communicating with the United States Coast Guard?—On telegraphy, 500 kc. For telephony, 2.182 or 156.8 mc. For distress communications, an optional frequency of 2.67 mc is available except in the Great Lakes region, where the distress frequency is 2.182 mc. Except in emergencies, the Coast Guard station should not be called during silent periods or when it is handling traffic. At other times the Coast Guard station may be called, by sign or location, for not more than 30 seconds.

17. What procedure is used in contacting the United States Coast Guard?—Calling NCU or a specific Coast Guard station on the proper frequency.

18. What procedure would you use in contacting a coast station on 2182 kilocycles, and what would you say over the air?—Announce the call sign or approved geographical position of a particular coast station three times. The call is concluded with THIS

IS and the sign of the calling station repeated three times.

19. What attention should be given to the antenna tower light at a radio station?—Daily inspection plus a thorough check of all components every three months.

20. What should be done in case the antenna tower lights fail at a radio station?—If they cannot be repaired within 30 minutes, an airways communications station (Civil Aeronautics Administration) must be notified.

21. How should station identification be made at a coast station using radiotelephony?—The official call sign or approved geographic location is given in English at the beginning and end of each transmission.

22. If a licensed radio operator at the controls of a radio station hears obscene language being transmitted through the facilities of the station, what action should he take?—He should attempt to end the communication, even going so far as to take the station off the air. The activity should be reported in the log and the FCC notified.

23. If a coast station hears a distress call from a mobile station, what action, if any, should the operator on duty take?—The distress call has absolute priority over all other transmissions. All stations which hear it must immediately cease any transmission capable of interfering with the distress traffic, and must listen on the distress-call frequency. The distress call must not be addressed to a particular station, and must not be acknowledged before completed.

The coast-station operator acknowledges the distress message if in the vicinity, making certain he does not interfere with other stations in a better position to render assistance. He also has the benefit of land wires and other means of communicating with fixed stations in a position to render assistance.

24. When calling a mobile radiotelephone station but receiving no immediate reply, how often may a coast station using radiotelephony repeat the call?—At three-minute intervals. Station calls are limited to one minute if no reply is received. In an emergency this provision does not apply, of course.

25. What is meant by safety communication in the Maritime Mobile Service?—The transmission or reception of distress, alarm, urgent, or safety signals; any communication preceded by one of these signals; any communications which, if delayed in transmission or reception, may endanger life or property; and occasional test transmission or reception if necessary for determining whether the radio equipment is in working condition.

26. What are the requirements with respect to keeping a log at a coast station using radiotelephony?—An accurate radiotelephone log must be maintained during the hours of service. In general this information should include time, date, and signature of the operator on duty; all calls transmitted and received; data on distress, urgency and safety information; test transmission; interference conditions; equipment failure and performance characteristics, etc.

27. Under what conditions may a coast station intervene in a distress situation?—Any land station receiving a distress message must, without delay, advise those participating in the operation of the availability of rescue facilities.

28. To what extent may a coast station using radiotelephony communicate with other than ship stations?—Safety communications primarily, although it may communicate with other ship, aeronautical, and land stations in accordance with U. S. Government and International regulations.

29. For what purpose is the frequency 121.5 megacycles authorized for an aircraft radio station?—It is the simplex channel for emergency and distress communications.

30. In lieu of a call sign, how may a private aircraft telephone station be identified?—By its aircraft registration number.

31. What types of communications is an aircraft radiotelephone station authorized to transmit?—Only those necessary for safe aircraft operation. Normally, an airport should not be called unless the aircraft is within the area served by the station.

32. When must aircraft radio station and maintenance records be made available for inspection?—Upon request of an authorized representative of the Commission to the licensee or his representative.

33. How often should station identification be made at a base or land radiotelephone station?—At the end of each transmission or exchange of transmissions, or once each 30 minutes of operating time.

34. What entries must be made in the logs or records of radio stations required to have antenna tower lights?—Time of lights on and off, time of daily check, and record of any failure and times of CAA notification.

35. What precautions should be taken when a radio station is left unattended in a public place?—It should be locked, or otherwise made inaccessible, to prevent tampering by unauthorized persons.

REVIEW QUESTIONS

1. In what way can the second-class radiotelephone license holder assist a potential user in obtaining a station license?
2. List at least six rules of courtesy you would follow in operating a radio station.
3. What is a construction permit?
4. Distinguish between station and operator licenses.
5. When must an antenna form be submitted with a license application?

Answers to these questions will be included in PHOTOFACT Set No. 565.

ANSWER SHEET

For Questions in Lessons 1 through 4

LESSON 1—ANSWERS

1. In simplex operation, base and mobile stations operate on the same frequency. In duplex operation, the base station transmits on one frequency, while the mobile stations transmit on another. Simplex operation is the more common in commercial two-way radio services.
2. The license shall be posted at the station transmitter while service or maintenance work is being performed. In lieu of displaying his license, the licensee must carry either his license or a verification card on his person.
3. A card issued by the FCC, verifying that the holder has a valid license of the specified grade.
4. Frequency assignments are made according to the service to be rendered, and take into consideration the radio propagation characteristics most favorable to that particular service.
5. The ground wave travels directly over the surface of the earth between the transmitting and receiving points. A sky wave refers to a high-frequency radio wave that is reflected back to earth by the ionized layers in the atmosphere. The ground wave is steady and reliable except when it is interfered with by out-of-phase sky wave components. Sky wave propagation is less dependable and changes as a function of the height and density of the ionized layers.
6. Direct-wave propagation refers to the components of RF energy that travel in a direct path between transmitter and receiver via the troposphere.
7. At the low-frequency end of the HF spectrum, ground waves *and* sky waves are used. Ground wave communication is reliable but limited in range. Amazing distances can be covered with sky wave propagation in this frequency spectrum, but such propagation is subject to the variables of the ionosphere. Direct wave propagation is most useful at the high end of the HF spectrum. Two-way radio channel assignments abound in the range between the high-frequency end of the HF band, through the VHF band, and into the UHF band. Direct wave travel is the only really useful type of propagation in this great span of frequencies. As the frequency increases, the radio beam becomes more confined. A UHF wave can be confined into a beam more readily than a VHF wave. The wave travels in almost a straight line between transmitter and receiver, although there is some bending of the waves due to refraction in the troposphere. The degree of bending depends on atmospheric conditions.
8. Atmospheric noises are most predominant at frequencies beginning below the broadcast band and continuing up into the HF spectrum, diminishing in intensity in the VHF region. Man-made noises begin in the broadcast band and continue into the UHF region. Vehicular noises are particularly troublesome in the HF and VHF bands. Receiver input noises become significant in the VHF, UHF and microwave spectra. They are the major source of noise in the UHF and microwave regions.

LESSON 2—ANSWERS

1. 2 to 3 megacycles.
2. 118 to 135 mc.
3. 25-50 mc, 152-174 mc, and 450-470 mc.
4. In public safety there are police, fire, forestry conservation, highway maintenance, special emergency, and local government radio services. In industrial radio there are power, petroleum, forest products, motion picture, relay press, special industrial, business, industrial radiolocation, manufacturers, and telephone maintenance radio services. In land transportation there are motor carrier, railroad, taxicab, and automobile emergency radio services.
5. 460.05-466.45 mc and 26.96-27.225 mc.
6. There are four classes of Citizens band services. Class-A stations operate on frequencies assigned between 460.005 and 466.45 mc. These stations are used for radiotelephony only. Class-B stations are assigned a frequency of 465 megacycles. They operate at low power and with less strict technical requirements. Class-C stations are authorized for control of remote objects by radio, or for remote actuation of devices used to attract attention. They are assigned specific frequencies of 26.995, 27.045, 27.095, 27.145, 27.195, and 27.255 mc. Class-D station assignments fall between 26.96 and 27.255 mc. They are authorized for amplitude-modulated radiotelephony at low power.
7. Class-A, less than 50 watts; Class-B stations, less than 5 watts; Class-C stations, less than 5 watts (except up to 30 watts on 27.255 mc); and Class-D stations, 5 watts.
8. A licensed operator must be in control of the transmitter.

(continued)

LESSON 3—ANSWERS

1. The highest modulating frequency. In double-sideband transmission, the bandwidth is twice the highest modulating frequency.
2. The bandwidth of an FM station is determined by the maximum deviation and the highest modulating frequency.
3. In NBFM systems, the maximum deviation (100% modulation) is limited to 15 kilocycles.
4. In an NBFM communications system the audio-frequency range is limited to obtain better intelligibility and to improve noise and interference rejection.
5. Single-sideband transmission is more conservative of power, requires less bandwidth, is less subject to interference, and causes less interference to other services.
6. Lowered bandwidth and improved intelligibility.
7. Less subject to the vehicular impulse noises that plague the mobile services.
8. A1 is carrier-interrupted code transmission; A2 is AM tone-modulated code transmission; and A3 is amplitude-modulated radiotelephony.

LESSON 4—ANSWERS

1. He can help the user make a decision on the type of radio service that best meets his requirements, help select a frequency and fill out the necessary FCC forms, and help him through the initial troublesome period of getting a system into operation.
2. There are numerous rules of courtesy. Six of them are: Listen before you transmit, be brief and concise in your transmission, speak clearly, do not use abusive or profane language, and use simple and understandable wording.
3. A permit that authorizes the construction of a station and installation of equipment.
4. The station license has to do with the station and transmitter. Operators' licenses are issued to personnel qualified to operate or maintain transmitters.
5. It must be submitted if the antenna height is to be greater than FCC specified levels.

Lesson 5

Class-C Amplifiers

The Class-C radio-frequency amplifier is the mainstay of the RF section of a transmitter. It amplifies the radio-frequency carrier to the desired power level, and also serves as a buffer to isolate one radio-frequency stage from another (for example, the oscillator stage from a modulator or power amplifier). Class-C amplifiers are also used as frequency multipliers. In this application, the output is tuned to a harmonic of the input wave—usually the second.

The efficiency of the Class-C amplifier is higher than other amplifier classes, since it is biased beyond cutoff and plate current flows for considerably less than half the period of the input sine wave. The output current pulses shock-excite the tank circuit, which is tuned to the desired multiple. Oscillatory action forms a new signal which, in a straight Class-C amplifier, is essentially a sine wave.

A brief review of the other amplifiers will help you better understand the reasons why the Class-C amplifier is truly the mainstay of the RF section. In a Class-A amplifier, plate current flows for the entire input cycle. The amplifier is biased along the linear portion of its transfer curve, and the output voltage is therefore a replica of the input voltage. Plate efficiency is lower than for Class-B and -C operation, falling between 15 and 30 per cent. Normally, driving power is negligible because a Class-A amplifier draws no grid current.

A Class-B amplifier is biased right at cutoff (Fig. 1). Consequently, plate current flows for approximately half the input cycle. Class-B amplifiers are usually operated in push-pull, each tube conducting during opposite alternations of the input cycle. The two plate-voltage changes combine in the output to produce a replica of the input signal. Hence, two tubes operated Class B in a push-pull arrangement provide an undistorted output with an efficiency of 60% or higher. Push-pull Class-B amplifiers are used in high-powered audio amplifiers, as modulators in transmitter circuits, and as RF amplifiers.

The Class-C amplifier (Fig. 1) is biased beyond cutoff (often three or more times). Consequently, plate current flows for only a portion of the positive alternation of the input cycle, and efficiencies of 75% and higher can be obtained. The plate-current, plate-voltage changes at the output of a Class-C amplifier are highly distorted versions of the input cycle. Thus, the Class-C stage is not used in the amplification of audio or amplitude-modulated RF signals (although in a resonant circuit, it is an excellent amplifier of an unmodulated RF signal). The pulses of plate current, which supply energy to the output tank circuit, provide the energy needed for continued cycling of the resonant circuit. If a Class-C amplifier is operated with the proper bias, excitation, and tank-circuit constants and loading, a high-quality RF cycle will be developed in the output.

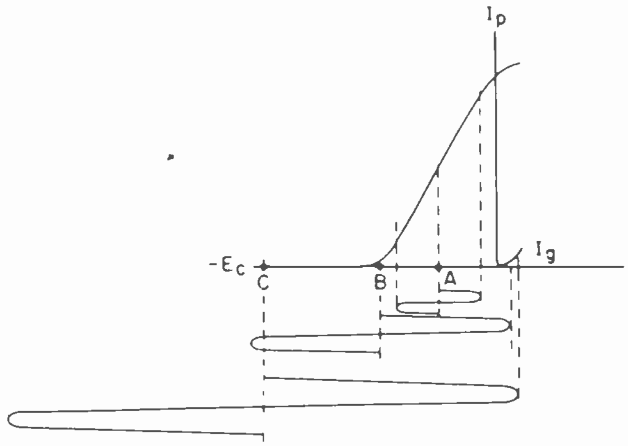


Fig. 1. Class-A, -B, and -C bias.

Class-C amplifiers are almost always signal-biased —that is, the flow of grid current during the positive crest of the input signal charges the grid capacitor to a high negative value (Fig. 2). Between pulses of grid current, this charge is held steady by the long time constant of the capacitor (Cc) and its associated grid-leak resistor (Rg). This time constant is longer than the sine-wave cycle applied to the control grid. As a result, the charge on the capacitor contributes all, or nearly all, of the DC bias on the grid of the amplifier. Each new burst of grid current recharges the capacitor, and therefore a constant Class-C bias is maintained.

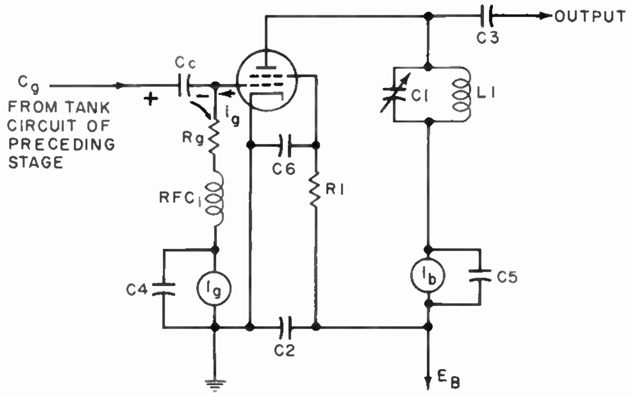


Fig. 2. Series-fed Class-C stage.

Some Class-C amplifiers employ an external grid-bias source to augment the charge on the grid capacitor. External bias is often used to prevent the tube from drawing excessive plate current should signal excitation no longer reach the grid. If suitable safety precautions are not taken, it is highly probable that tube or circuit components will be damaged by the excessive current.

The supply voltage for the plate can be fed in shunt or in series, as shown in Figs. 2 and 3. In a tetrode Class-C stage, the proper supply voltage must also be applied to the screen grid. Often this voltage is fed through a decoupling resistor-capacitor combination (R1-C6 in Figs. 2 and 3) which prevents signal currents from affecting the screen voltage.

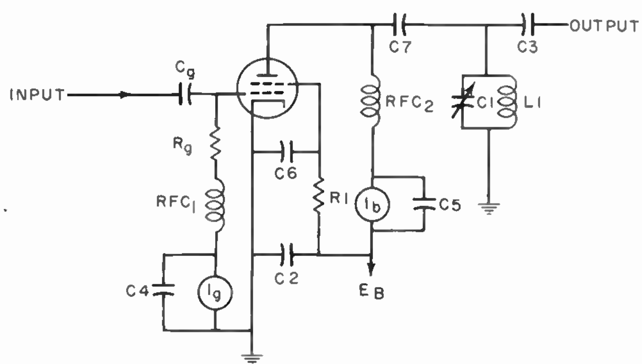


Fig. 3. Shunt-fed Class-C stage.

The energy developed in the plate tank circuit is coupled to the antenna system (or to another Class-C power stage). Some Class-C stages have built-in meters to permit continuous monitoring of grid and plate currents and plate voltage. RF chokes and shunt capacitors are used to prevent RF energy from passing through the meters. In low-powered transmitters and the early stages of a high-powered transmitter, meter-switching arrangements are more common. By switching the meter from one circuit to another, the operator is able to check the operation of several sequential stages.

These built-in meters can also be used to tune up the transmitter. Hence, only a minimum of accessory test equipment is required.

VOLTAGE AND CURRENT RELATIONSHIPS

Two voltages are applied to the control grid of the Class-C amplifier—the DC grid-bias voltage (Ec) and the RF signal voltage (Eg) from the previous Class-C amplifier or oscillator, as shown in waveform A of Fig. 4. As mentioned previously, Ec is usually the result of charging Cc during periods of grid current flow.

Waveform A of Fig. 4 is drawn with relationship to the cutoff voltage and the DC bias. The level at which grid current flows is also indicated. Waveform C is the grid current. Its average value can be measured by inserting a DC meter into the grid circuit.

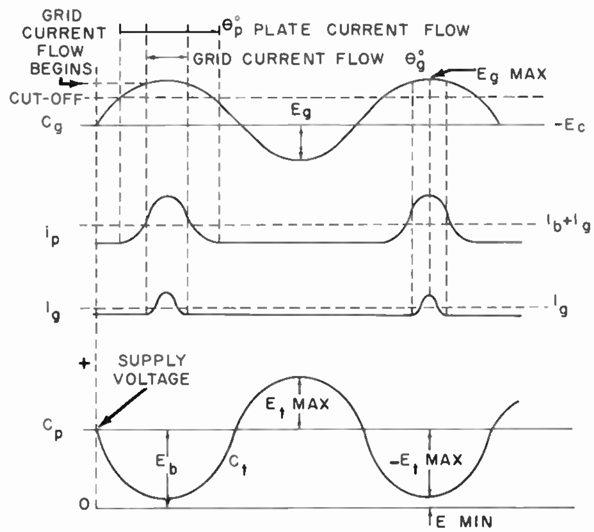


Fig. 4. Class-C waveforms.

The tube draws plate current each time the grid voltage rises above the cutoff level. Waveform B shows the burst of plate current which flows during each cycle of the impressed sine wave. A DC meter can be inserted into the plate circuit to read the average DC current drawn from the power supply for the stage.

Observe from waveform D that supply voltage Eb is the DC reference level for the tank circuit signal; hence, at any instant plate voltage Ep is equal to supply voltage Eb plus tank circuit voltage Et.

For efficient operation, a Class-C stage should be carefully adjusted until the peak value of alternating voltage across the tank circuit approaches the DC value of the power-supply voltage. Ideally, the plate voltage would swing from zero to twice the supply voltage. However, certain other optimum operating conditions must be established. In addition, a certain minimum plate-voltage drop is always present across the tube during periods of peak plate current. Consequently, the tank-circuit voltage is always something less than the supply voltage. The useful output power of a Class-C stage is a result of the current circulating in the tank circuit. If another inductor or a resonant circuit is placed near the tank coil, energy will be transferred to the second circuit. Because any such coupling results in a transfer of power, the energy in the tank circuit must be replaced. Otherwise there would not be enough to sustain oscillation throughout a complete cycle, and a series of damped or decaying waves would be developed.

Since the amount of energy supplied to the plate tank circuit depends on tube current, proper operation becomes a function of plate-circuit loading, grid bias, and the maximum power available from the B+ supply. Grid bias controls the "turn-on" time of the amplifier, and therefore determines the duration of current pulses. The amount of plate current which flows depends on the voltage across the tube, which is a function of the supply voltage. These two factors must be coordinated with the power requirements of the load.

A DC plate-current meter is a good indicator of tube and tank-circuit performance. When the load on a Class-C amplifier is increased, more energy is drawn from the tank circuit. To maintain oscillations of the same strength, more current must be drawn through the amplifier. This increase in power demand is indicated by a rise in the plate-current meter reading. Thus the meter not only indicates that the plate tank is tuned to resonance, but is also helpful in establishing the proper load conditions.

EFFICIENCY AND POWER

The energy from the plate power supply divides between the resonant circuit and the tube. The power to the tube is wasted as heat. On the other hand, the power to the tank circuit is available for producing an output. The average power input, output, and plate loss are a function of the average instantaneous levels of the waveforms in Fig. 4.

As you will recall, the efficiency of a Class-C stage is greatest when its conduction period is shortest. You will also recall that during the period of tube conduction, the voltage drop between plate and cathode is lowest (equal to the plate-supply voltage minus the maximum voltage drop across the tank circuit). Thus, it is apparent that as the amplitude of the tank-circuit voltage approaches that of the supply voltage, plate voltage becomes lower when plate current is drawn. Inasmuch as the power dissipated by the plate is a function of both plate voltage and plate current, less power is dissipated in the tube when both plate current and plate voltage are at a minimum.

Although these conditions permit the most efficient operation of a Class-C stage, there is a limit to the maximum power that can be derived from the output. Reducing the plate dissipation to a minimum limits the power that can be extracted from the tank circuit. In a practical Class-C amplifier, therefore, a compromise must be made between best efficiency and highest output. Ideally, plate current should flow for approximately 120 to 150 degrees of the cycle.

The grid circuit of a Class-C amplifier also dissipates certain amount of power. As noted earlier, the grid draws current from the cathode during the crest of the input cycle. Thus, part of the energy delivered to the Class-C stage is dissipated in the grid and the grid-leak resistance. It is apparent that the lower the grid current, the lower the power dissipation of the input circuit. However, it is the strong, momentary grid drive that permits a strong peak of plate current to be drawn. This peak establishes the minimum plate voltage. Again there is an optimum operating condition—the grid excitation must be sufficient to provide optimum operation of the plate circuit. Thus, ample power to drive the grid circuit must be made available at the output of the preceding stage. By the same token, the grid circuit must not be overdriven. To do so will cause excessive grid current and consequent loss of power.

OPTIMUM OPERATION OF A CLASS-C STAGE

The factors which must be considered in establishing optimum operation of a Class-C stage are:

1. The maximum instantaneous grid potential, usually referred to as the amount of excitation.
2. The portion of the cycle during which the grid draws current, usually indicated in electrical degrees.
3. The instantaneous maximum plate current drawn at the positive crest of the input cycle. This peak current determines the amount of energy to the tank circuit.
4. The portion of the cycle during which plate current is dissipated, usually given in electrical degrees.
5. The minimum instantaneous plate voltage, which determines the maximum RF voltage developed across the tank circuit during the peak of plate current flow and thus the division of power between the tank circuit and the tube.

The maximum grid-signal excitation and grid bias are selected to provide optimum peak plate current at the desired minimum plate voltage. However, the maximum grid voltage must never exceed the absolute value of the minimum plate voltage. Otherwise, the grid will draw excessive current, not only reducing the current available to the plate but also increasing grid dissipation.

Suppose the "hoped-for" peak plate current, maximum grid potential, and minimum plate potential have been established within the tolerances of the tube. Now the period of plate-current flow will determine the efficiency of the stage.

As mentioned previously, increasing the period of plate-current flow increases both the input and output dissipation. Thus, the angle of flow is usually adjusted so that maximum output is delivered without exceeding the rated plate dissipation of the tube. Remember, however, that this is not the operating condition for which peak efficiency is obtained. If greater efficiency and more conservative operation of the tube is desired, the conduction angle can be reduced. The required driving power must be increased as the angle of conduction is decreased, so the only way efficient plate-circuit operation can be attained is to use more grid power. When this is done, over-all efficiency of the stage begins to fall.

The plate-supply voltage has a very significant influence on the output power and hence the operating efficiency of a Class-C stage. An increase in this voltage will increase the peak RF voltage across the tank circuit for any minimum plate voltage. In fact, the available power output increases almost directly with an increase in the plate supply voltage. The maximum recommended plate voltage is determined by the tube rating, and this value should not be exceeded. In some transmitters, power output can be controlled over a limited range by raising or lowering the plate voltage of one or more stages.

The selection of DC grid bias, maximum grid potential (determined by the amplitude of the grid excitation), and plate-supply voltage have much to do with the power output and efficiency of a triode Class-C stage. In a tetrode or pentode Class-C stage, there is considerable latitude in their selection. The desired peak plate current can be obtained by controlling the screen voltage. In fact, screen voltage can be used to adjust the power output to a specific level.

In order to obtain the most output with the desired efficiency, it is customary to use a screen voltage that is considerably higher than the maximum grid potential and lower than the plate voltage. In this way, screen dissipation—which could be high because of the high screen current drawn during the minimum plate-voltage interval—is kept within safe limits. If the screen voltage is not made greater than the maximum grid voltage, the grid-circuit losses will become too great. As in a triode stage, the minimum plate voltage must not be too high because plate dissipation will be excessive. Conversely, it must not be too low because too many electrons would be attracted to the screen and screen dissipation would therefore be excessive.

LOADED AND UNLOADED PLATE TANK CIRCUITS

The plate tank circuit plays a very important part in the function of a Class-C amplifier. It is tuned to the resonant frequency of the signal to be amplified and coupled to the load. Resonant tuning of the tank circuit permits the greatest voltage drop to be developed (the parallel-resonant circuit has a maximum impedance at resonance).

The tank circuit has such a low impedance off the resonant frequency that it discriminates against spurious signal components and harmonics. To provide adequate discrimination against harmonics, however, the Q of the resonant circuit should be reasonably high. The higher the Q, the more the oscillating voltage will approach a pure sine wave. If there is inadequate energy storage (too low a Q), the oscillating voltage will contain harmonic components which can be passed on to the output. According to the type of transmitter, the FCC requires that the harmonic radiation of a transmitter be held to a certain minimum level. Usually, special coupling arrangements are included in transmitter output stages to minimize the transfer of harmonics to the antenna system.

The selection of the Q of a resonant circuit is again a compromise. For the reason mentioned above, the Q may not be too low. A high Q tank circuit stores considerable reactive energy. Therefore, the voltage breakdown and current-carrying capabilities of the resonant circuit must be high, and this means more expensive components will be required.

A tank circuit has two values of Q—loaded and unloaded. The Q of a tank circuit is higher when the load is disconnected. The change in Q under load determines the tank-circuit efficiency and how effectively power is transferred between the tank circuit and the load. In fact, the total power transferred from the tank circuit to the load is a measure of the tank-circuit efficiency.

Tank circuit Q under load is typically 10 to 12. In some very high power transmitter stages, an even lower Q is used to reduce voltage breakdown and to minimize cost. Greater attention must be given to the use of suitable networks to minimize harmonic output to the antenna system.

In summary, too low a tank-circuit Q provides less efficient operation of the Class-C stage, more difficulty with coupling to the load, and a higher harmonic content. Likewise, too high a tank-circuit Q results in a high circulating tank current and a greater resistive loss in the tank-circuit inductor.

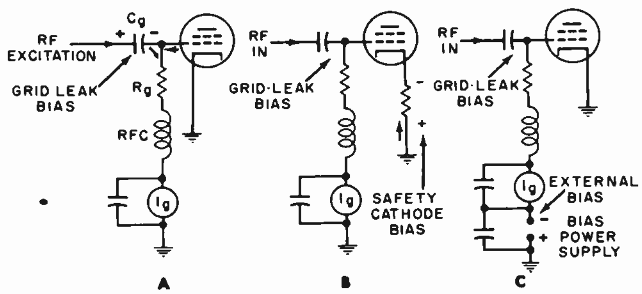


Fig. 5. Class-C bias methods.

GRID-LEAK BIAS

A grid capacitor and grid-leak resistor are most often used to provide grid bias, as shown in Fig. 5A. In higher-powered stages, a combination of grid-leak and external bias is often used, as in Fig. 5B. With some external bias, loss of grid excitation will not result in damage to the high-powered tube and its associated circuit components. In addition, high-powered stages often employ safety components to protect the stage when the excitation fails. A warning system informing the operator of such a deficiency is sometimes included.

In Fig. 5C, the loss of grid bias will increase the plate current and thus raise the voltage drop across the cathode resistor. The added bias from the cathode resistor prevents the plate current from rising to the danger point.

In the grid-leak bias combination, grid current flows when the tube is driven positive. As a result, a negative charge is placed on the grid capacitor. The magnitude of this charge is determined by the amount of grid current and by the value of grid resistance. When the grid-leak resistance is high, a large bias will be developed. It follows, then, that the grid excitation must be high in amplitude. Otherwise, the tube will be unable to draw the desired peak plate current at the crest of the grid-voltage waveform (See Fig. 6). In this mode of operation, the angle of plate-current flow will be low.

A decrease in grid-leak resistance causes a lower Class-C bias to be developed. Thus, a lower exciting voltage is needed to drive the grid to the point where the desired peak plate current is drawn. However, the conducting angle will be longer and the plate-circuit efficiency will be lower.

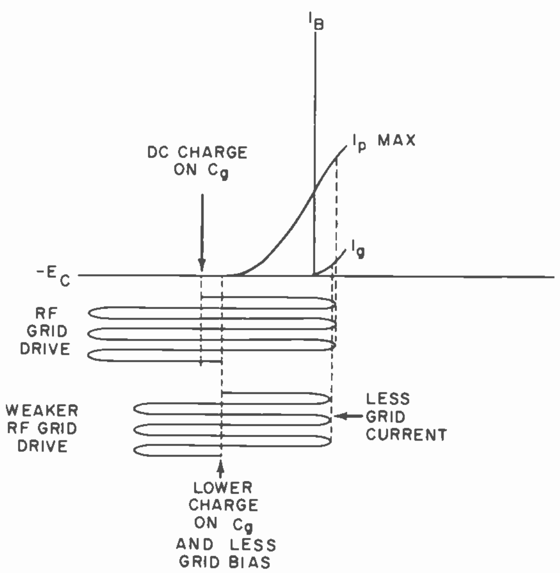


Fig. 6. Development of Class-C grid bias.

An optimum value of grid-leak bias must be established for the most effective transfer of power to the load. The most desirable efficiencies lie between 60 and 80 per cent.

The grid-leak capacitor should have a substantially higher value than the grid-to-cathode capacitance of the tube. The capacitor must have a low reactance at the operating frequency; otherwise, the grid-excitation signal will be impeded. In conjunction with the grid-leak resistor, the time constant must be long enough for the capacitor to hold a charge between positive peaks of the excitation signal.

The grid-leak combination affords a simple method of obtaining Class-C bias, in addition to being more or less self-adjusting. Small changes in the amplitude of the exciting voltage have a substantial influence on grid current and bias. These changes are such that peak grid voltage remains essentially constant. Therefore, the peak plate current will not be altered, and the output will be held reasonably constant in spite of reasonable changes in the amplitude of the grid signal.

NEUTRALIZATION

Class-C amplifiers must often be neutralized to prevent them from oscillating. While triodes, tetrodes, and pentodes are all used as RF power-amplifiers, beam-power tetrodes are most common. Multigrid tubes are preferred because less grid excitation is required for a given power output.

A triode Class-C amplifier must be neutralized because the plate and grid signals are of the same frequency and are linked by the grid-to-plate capacitance of the tube. Without proper neutralization, a triode becomes a tuned-plate, tuned-grid oscillator. Screen-grid tubes normally do not require neutralization, because the shielding action of the screen substantially reduces the grid-to-plate capacitance.

When an RF stage is incorrectly neutralized, spurious signals are radiated. In addition, it is difficult to modulate such a stage correctly.

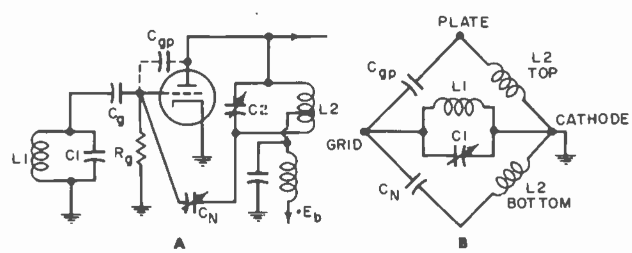


Fig. 7. Plate neutralization of a triode.

In the neutralization of a Class-C triode (Fig. 7), an out-of-phase signal (Cn) is fed back from the plate circuit to the grid. This neutralizing signal is 180° out of phase with the feedback through the interelectrode capacitance. Its amplitude is adjusted to cancel out the regenerative feedback. The method shown in Fig. 7 is referred to as plate neutralization.

In action the neutralization system is a balanced-bridge arrangement, as shown in Fig. 7B. When the bridge is balanced correctly, the plate-circuit currents flowing in the inductive and capacitive legs of the bridge will be balanced. Consequently, the variations in plate voltage produce no current flow through the center of the bridge, and no plate-voltage variation appears across the grid-tank circuit.

SCREEN-GRID NEUTRALIZATION

Under most conditions, a screen-grid Class-C stage does not require neutralization. However, at very high frequencies or with tubes of high power sensitivity, a small amount of feedback can start spurious oscillations. To insure stable operation, therefore, it is necessary to load the tuned-grid circuit or utilize some other simple method of neutralization. Except in wide-band Class-C amplifiers, it is not always advisable to use a resistive load in the grid circuit, because this will necessitate an increase in grid driving power. Instead, simple inductive or capacitive feedback links can be established, as shown in Fig. 8.

In the capacitive stabilization arrangements, feedback amplitude is determined by the ratio of capacitors Cl and Cn. In a practical neutralization arrangement, a capacitive bridge with the following ratio is set up:

$$\frac{Cn}{Cl} = \frac{Cgp}{Cin}$$

In the alternate circuit (dotted lines in Fig. 8), an inductive link feeds back a small amount of energy from the plate to the grid. The polarity of the link determines the phase of the feedback, and the positioning of the link determines the magnitude.

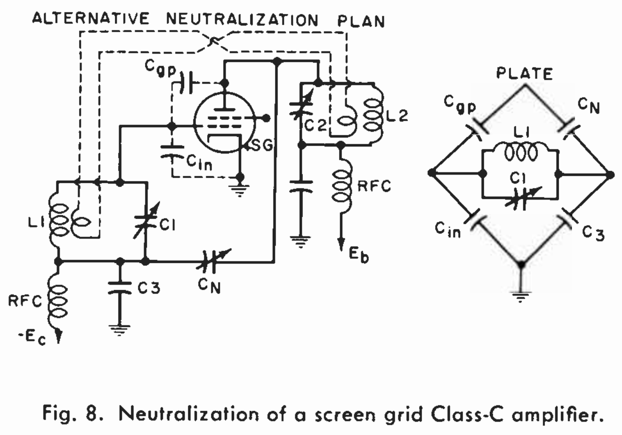


Fig. 8. Neutralization of a screen grid Class-C amplifier.

LICENSE EXAM QUESTIONS AND ANSWERS

1. *Describe the three classes of amplifier operation.*—Class A, in which the stage is biased for continuous operation along the linear portion of its Eg-Ip curve; Class B, in which the stage is biased at cutoff and conducts only during positive swings of the input signal; Class C, in which the stage is biased below cutoff and conducts for less than half the period of the input signal.

2. *Describe the characteristics of a vacuum tube operating as a Class-C amplifier.*—The grid bias is set substantially beyond cutoff. Consequently, plate current flows for substantially less than 180 degrees of the input cycle. The plate-current pulse is not a replica of the input cycle, but a parallel-resonant circuit in the plate circuit serves as an energy-storing network which is capable of forming a sine wave output when supplied with current pulses. Because of its high efficiency, a Class-C amplifier can deliver a large amount of output power with a small amount of input power.

3. *During approximately what portion of the excitation-voltage cycle does plate current flow in a Class-C amplifier?*—Only for a portion of the time when the grid signal is positive, usually between 90 to 150 degrees of the input cycle.

4. *Is the plate-circuit efficiency of an RF amplifier higher or lower when operated Class C as opposed to Class B? Why?*—Higher. In Class-C operation, plate current flows for a shorter time. Plate-circuit efficiency is equal to the power output divided by the power input; thus:

$$\text{efficiency in } \% = \frac{\text{power out}}{I_b E_b} \times 100$$

The average value of the plate current is low because, although of high peak value, it flows for only a short interval and only when the plate voltage is low. Therefore, only a limited amount of input power is dissipated at the plate, most of it being delivered to the tank as output.

5. *What is the primary purpose of grid-leak action in a vacuum-tube transmitter?*—The grid-leak resistor of an RF oscillator or amplifier is used to develop grid bias. Grid current charges the grid-leak capacitor, which then discharges through a resistor. The capacitor and resistor act as a filter to maintain an essentially constant DC grid level between positive alternations of the grid cycle.

6. *What is meant by a blocked grid?*—One with such a high bias that plate current does not flow.

7. *What is the purpose of an RF choke?*—A radio-frequency choke (RFC) presents a high impedance to RF energy. It has two primary functions—to prevent RF energy from entering certain DC circuits, and to introduce DC voltage into an RF circuit without affecting the normal signal path. The choke has practically no resistance to DC current, but a very high resistance (impedance) to RF current.

8. *Why are Class-C amplifiers not suited for audio-frequency amplification?* — Since a Class-C

stage is biased substantially beyond cutoff, plate current will not be representative of the grid signal. Thus, serious distortion will occur.

9. *What are the advantages of using a cathode resistor to provide bias for a Class-C amplifier?*—While a cathode resistor cannot provide Class-C bias, it will limit tube current and plate dissipation, which would become excessive in the absence of a grid-excitation signal.

10. *Explain the purpose of neutralization in RF amplifiers? How is neutralization achieved?*—Triode, and sometimes tetrode or pentode, RF amplifiers must be neutralized to prevent them from breaking into oscillation. Neutralization is achieved by offsetting the effect of grid-to-plate feedback with a signal of opposite polarity.

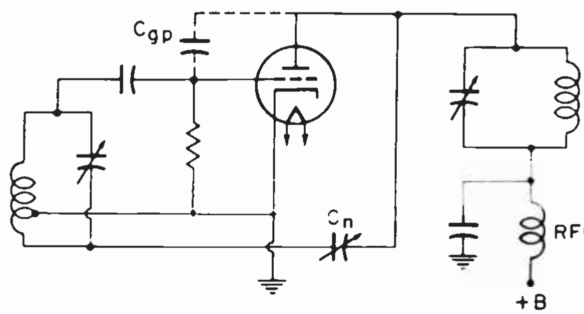


Fig. 9. Grid-neutralization triode RF stage.

11. *Explain how to neutralize a triode RF amplifier.* — Place the filament circuit in operation and supply a signal to the control grid from the preceding stage. Turn off the plate and screen voltages. If the stage is being neutralized for the first time, set the neutralizing capacitor for minimum capacitance.

Adjust the grid tank circuit for resonance, as indicated by a maximum indication on a grid-current meter. Tune the plate tank capacitor over its range. If the stage is not neutralized, the needle of the grid-current meter will jump whenever the plate tank circuit is tuned through resonance. Likewise, there will be an indication of output when an RF indicator is placed close to the plate tank circuit. Continue to increase the capacitance of the neutralizing capacitor slightly, and to tune the plate tank circuit through resonance, until no change is indicated by the grid meter. The stage is properly neutralized if the plate tank capacitor can be tuned through resonance without changing the grid-current meter reading.

As a final check, supply power to the stage at a reduced voltage. Tune the plate tank circuit for its resonant dip, and place a load on the output. Supply the maximum plate voltage, and adjust the plate-tank and output-coupling circuits for optimum operation.

12. *What tests will determine if an RF amplifier stage is properly neutralized?* — Remove the plate power, leaving the excitation and filament power normal. If it is possible to vary the plate tank capacitor through resonance without obtaining an RF output indication or causing the grid-current meter needle to kick, the stage is properly neutralized.

13. *Why does a screen-grid tube normally require no neutralization when used as an RF amplifier?*—A screen grid reduces grid-to-plate interelectrode capacitance, and the feedback path is of such a high impedance that self-oscillation is not likely to occur. When the input and output stages of a tetrode or pentode stage are properly isolated and shielded, neutralization is not required.

14. *What is the purpose of a buffer amplifier in a transmitter?*—To provide isolation. In a transmitter, a buffer amplifier often isolates high power RF stages, the modulated amplifier, or the keyed stage from the oscillator. Such isolation prevents changes in operating conditions in later stages from affecting the frequency stability or operating characteristics of a preceding stage.

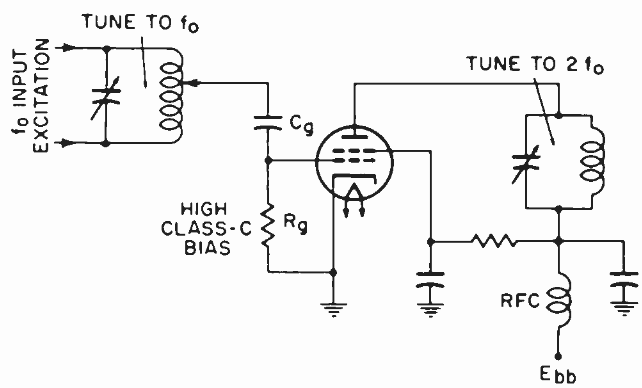


Fig. 10. Radio-frequency doubler.

15. *Draw the circuit of a frequency doubler and explain its operation.* — A typical doubler stage is shown in Fig. 10. It is biased for Class-C operation, and the output tank circuit is resonant at twice the frequency of the RF signal at its grid. Bias is somewhat greater than for a straight-through Class-C amplifier. The operating characteristics of the stage and output tank circuit are designed to emphasize the second-harmonic output.

16. *For what purpose is a doubler amplifier used?*—To produce an output signal having double the frequency of the input signal. When a series of doubler or multiplier stages are used, the signal frequency supplied by a low-frequency crystal oscillator can be increased to provide the desired high-frequency carrier.

17. *What class of amplifier is appropriate as an RF doubler stage?*—Class-C, because it can be operated to provide an output waveform which includes a strong second harmonic.

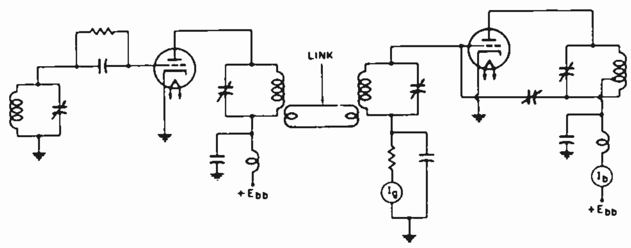


Fig. 11. TPTG oscillator link-coupled to a neutralized RF amplifier.

18. *What is meant by link coupling, and why is it used?*—Link coupling is a method of transferring energy between two resonant circuits without using direct magnetic coupling. In Fig. 11, link coupling with transmission-line characteristics is used. Because the low-impedance link has minimum radiation, it is able to couple energy over a considerable distance with a minimum of capacitive and radiation losses. Link coupling is often used between the final stage and the antenna coupling or tuning system.

19. *What is meant by unity coupling?*—It is a tight coupling method that permits maximum transfer of energy between resonant circuits. The coefficient of unity coupling is 1, but this is never quite reached in practice.

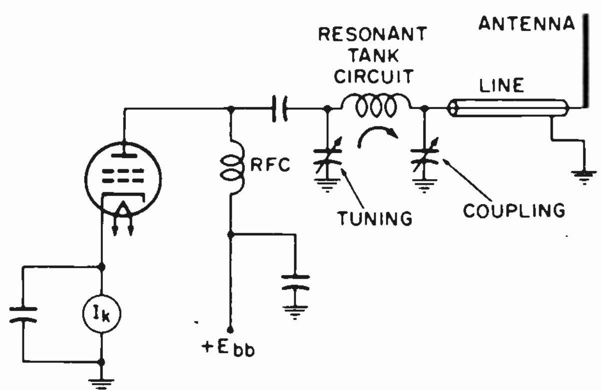


Fig. 12. Pi-network tank circuit and coupling to an antenna system

20. *How can the production of harmonic energy be minimized in a vacuum-tube RF amplifier?*—By correct choice of operating bias and grid drive, and use of a high-*Q* plate tank circuit, correct loading, and a pi-network tank circuit (as in Fig. 12). Push-pull RF amplifiers minimize even harmonics. Additional low-pass tuned circuits and filters can be used to minimize the transfer of harmonic components between stages.

21. *Define parasitic oscillation.*—Parasitic oscillations are undesired harmonics. They are the result of self-excitation of some portion of a circuit, and usually have a frequency quite removed from the desired operating frequency.

22. *What may be the result of parasitic oscillations?*—They can lower efficiency and stability by causing the radiation of spurious signal components which affect the modulation quality of the desired carrier.

23. *What are some possible indications of a defective transmitter tube?*—A drop in power output; abnormal or erratic meter readings; optimum performance of the stage cannot be achieved despite careful tuning. Examination of the tube may reveal an unlighted filament, a blue haze within the elements, arcing between electrodes, or serious overheating.

24. *What are some possible causes of overheated vacuum-tube plates?*—A failing tube, off-resonance tuning, improper operating voltages (plate voltage and bias), spurious oscillations, loss of grid excitation, and improper loading.

25. *What would be the result of a shorted choke coil in the plate circuit of an RF amplifier?*—In a shunt-fed, plate-voltage arrangement, a shorted choke will bypass the tank circuit. As a result, no RF voltage will be developed. In a series-fed arrangement, RF energy may be present in supply lines and other circuits normally at RF ground potential. Neutralization or stability also could be adversely affected.

REVIEW QUESTIONS

1. What are the three basic classes of amplifiers? Describe the characteristics for each.
2. What factors determine the efficiency of a Class-C amplifier?
3. What is meant by Class-C grid-leak bias?
4. Distinguish between the loaded and unloaded Q of a tank circuit.
5. What action prevents the development of a damped wave across the Class-C output tank circuit?
6. Describe the oscillatory action of a parallel resonant circuit.
7. Why does a Class-C amplifier draw more plate current when load-coupling is increased?
8. What is meant by the excitation of a Class-C amplifier?

Answers to these questions will be included in PHOTOFACT Set No. 569

Lesson 6

Oscillators and Multipliers

In radio transmitters, the two most common frequency generators are the crystal and electron-coupled oscillators. Both have the excellent reliability and frequency stability required to hold the carrier frequency within the tolerances specified by the FCC.

The crystal oscillator is very stable, the only frequency drift occurring as a result of temperature changes. For very strict frequency requirements, crystals are often enclosed in an oven which is automatically kept at a constant operating temperature. In recent years, crystals have been very much improved, and certain types with a very minimum of temperature drift are now available. Consequently, in many services it is no longer necessary to use a crystal oven.

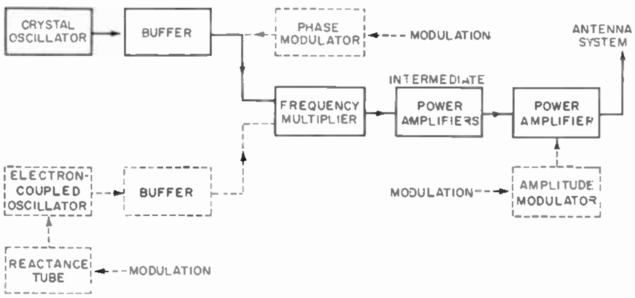


Fig. 1. Functional plan of typical transmitter.

The power output of a typical crystal oscillator in a transmitter is on the order of a few milliwatts. In a typical transmitter, as shown in Fig. 1, the oscillator is well-isolated from higher-powered stages by buffers and intermediate amplifiers. In almost all HF, VHF, and UHF radiocommunication services, the oscillator operates on a frequency which is substantially lower than that of the radiated carrier. Thus, as mentioned in earlier lessons, the buffer and other intermediate amplifier stages function as frequency multipliers, increasing the rate of the oscillator signal to obtain the desired carrier frequency.

A given crystal confines transmitter operation to a single output frequency. If the transmitter is to be operated on more than one frequency, either a crystal-switching arrangement or separate crystal oscillators are required. For mobile service, the switched crystal plan is the most common. Two or more operating frequencies can then be selected according to system needs.

The electron-coupled oscillator can also be made to have a high order of frequency stability in a carefully designed circuit. Circuit design is more critical than for a crystal type, and some means must be incorporated to provide for accurate frequency calibration. One major advantage of an electron-coupled oscillator is that any specific frequency within range of the oscillator adjustment can be selected for use in the development of the carrier frequency. Therefore, the electron-coupled oscillator, or variable-frequency oscillator (VFO) as it is called, is common in equipment requiring a vernier adjustment of the carrier frequency over a substantial range.

The addition of a suitable reactance tube permits the electron-coupled oscillator to be frequency-modulated in a convenient manner. As you learned, frequency modulation is popular in many radiocommunication services. This does not mean that a crystal oscillator cannot be used in an FM transmitter. In most services, narrow-band frequency modulation is used and, as shown in Fig. 1, a phase modulator can be used to alter the crystal oscillator signal after it has passed through the buffer stage. Such a modulation system becomes quite complex when a wide-band deviation is to be obtained. However, with narrow-band modulation only a simple phase modulator is needed.

HARTLEY OSCILLATOR

In addition to the electron-coupled and crystal-controlled oscillators, there are a variety of other types you should have some knowledge about in preparing for the FCC license examination. In this lesson, the Hartley circuit is used to explain the basic principles of oscillator operation.

Fundamentally, almost all forms of transmitter oscillators are Class-C amplifiers with a feedback link. The purpose of the feedback path is to supply a regenerative signal from the output back to the input in order to sustain generation.

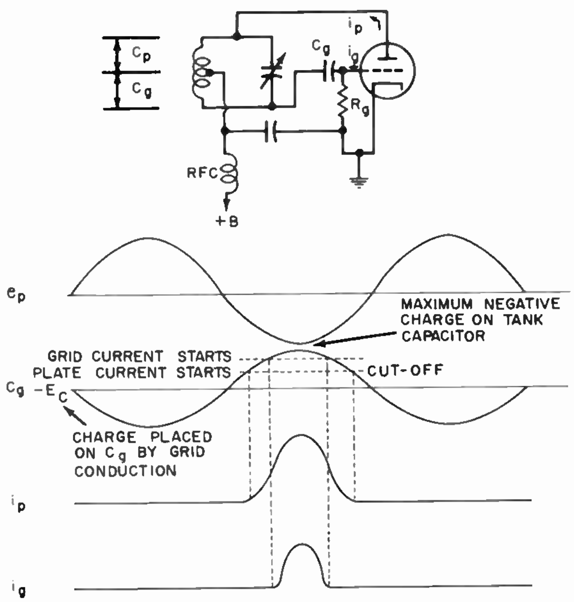


Fig. 2. Series-fed Hartley circuit and its associated waveforms.

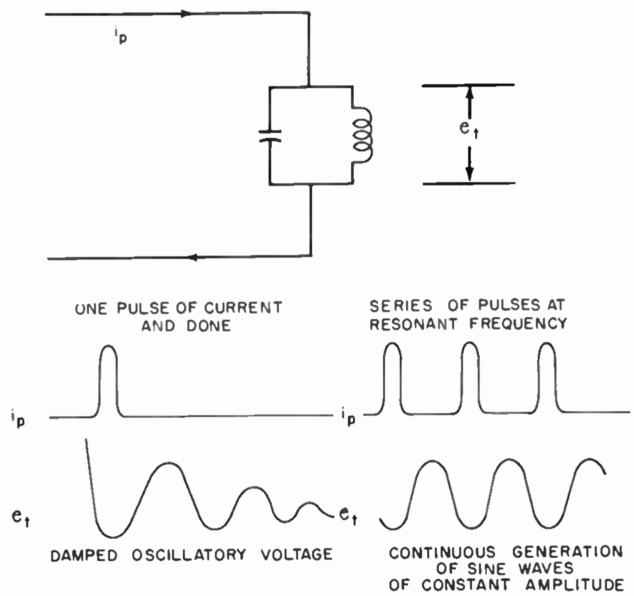


Fig. 3. Excitation of a resonant circuit by a pulse of current.

The Hartley circuit in Fig. 2 typifies this design. The feedback signal is developed across the lower end of the plate-tank inductance. Oscillations occur when the phase of the plate signal is shifted 180 degrees so as to be in phase with the grid voltage. In the Hartley oscillator, the necessary phase reversal is achieved by proper connection of the tube elements to the resonant tank coil.

The oscillations in the tank circuit are initiated and sustained by bursts of Class-C plate current. Thus, a sine wave signal is generated by the tank circuit. The frequency of this sine wave is determined by the capacitance and inductance of the tank circuit, and is determined by the familiar formula:

$$Fo = \frac{1}{2\pi\sqrt{LC}}.$$

You should anticipate there being at least one question based on this formula in the FCC examination.

If energy from the power supply were not continuously reapplied to the tuned circuit of an oscillator in the form of plate current pulses, the oscillations would gradually die out and a so-called damped wave would be generated (Fig. 3). The function of the feedback link is to swing the grid voltage in the positive direction once each cycle, thus providing a new burst of plate current for each cycle to be generated. The periodic supply of a constant amount of energy to the resonant circuit produces a continuous train of oscillations of the same amplitude. The magnitude of the feedback voltage must be such that the grid is driven far enough positive each cycle to cause the same amount of plate current to flow each time.

Referring back to Fig. 2, it can be seen that a portion of the signal across the tank circuit (Eg) is applied between the grid and cathode of the oscillator tube. This represents the input sine wave voltage of the oscillator. Notice that the grid is supplied from the low end of the tank; therefore, the polarity of the signal it receives (Eg) is opposite to that at the plate (Ep). As a result, the necessary phase reversal is accomplished. The position of the tap determines the magnitude of the feedback, and determines the efficiency and stability of the oscillator. As discussed in Lesson 5, the amount of grid signal is one of the factors that control the efficiency of a Class-C stage. In this instance, instead of receiving its grid signal from a preceding stage, the Hartley oscillator obtains regenerative energy from its own tank circuit.

It might seem as though the oscillator is an example of electrical perpetual motion, which we know is not possible. Remember, however, that the renewal energy supplied to the tank circuit is the result of current bursts drawn from the power source through the tube.

Most types of oscillators employ grid-leak bias, utilizing a resistor-capacitor combination with a short charge time and long discharge time. In this respect, oscillators are again similar to a basic Class-C amplifier. When the grid draws current, at the crest of each positive alternation in the feedback signal, the grid capacitor charges. The time constant of Rg-Cg is long enough to maintain that charge between cycles. In other words, the capacitor discharges an insignificant amount between periods of grid conduction, recovering the charge each time the grid signal goes positive.

The amount of grid-leak bias developed is a function of the capacitor and resistor values and the amount of grid current drawn, which in turn is related to the magnitude of the feedback voltage. Constants are chosen to provide the amount of bias required to operate the oscillator at the desired efficiency; the factors are much the same as for a Class-C amplifier.

One advantage of grid-leak bias is that it is self-regulated. When a circuit or supply voltage variation occurs, it will influence the feedback magnitude. Any such change affects the grid current flow and the charge on the grid capacitor. The direction of the change is always such that a compensating influence results. For example, if there is a tendency for the output oscillations to decrease, there will be a drop in the magnitude of the feedback. Consequently, there will be a less negative bias on the grid capacitor, which causes an increase in the amplitude of the plate current pulses and in the magnitude of the tank signal. The net result is a reasonably constant output which is more or less self-regulating.

ELECTRON-COUPLED OSCILLATOR

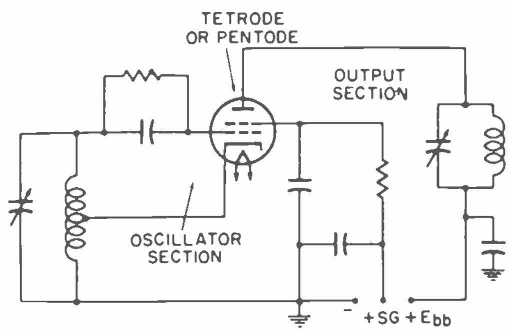


Fig. 4. Basic electron-coupled oscillator (ECO).

The electron-coupled oscillator, as shown in Fig. 4, is basically a triode stage which utilizes the interelectrode capacitance of the tube to provide energy feedback. In this configuration, the screen grid actually functions as the plate of a Hartley triode oscillator.

The screen grid is operated at RF ground potential, and therefore serves as a shield between the oscillator section and the plate output circuit. This isolation minimizes the interaction between the plate and oscillator circuits. Changes in load or operating constants thus have a lesser influence on the operating characteristics of the oscillator, as compared to the basic Hartley circuit. In pentode versions of the electron-coupled oscillator, the suppressor grid is usually operated at ground potential and serves as the shield.

As shown in Fig. 5, several types of output circuits are commonly used with electron-coupled oscillators. A resistor or an inductor can serve as the plate circuit load. If maximum output is desired, the tank circuit can be used. However, if the plate tank circuit is tuned to the same frequency as the oscillating section, there is a greater possibility of some mutual interaction between the output and the frequency-control elements of the oscillator. For the most stable operation, the non-resonant output circuit is preferred.

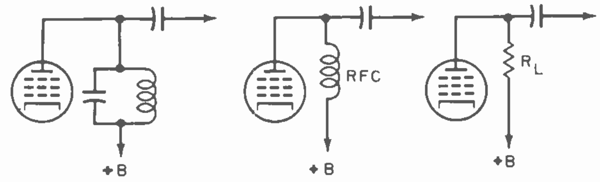


Fig. 5. ECO output circuits.

This does not mean that resonant circuits are never used at the output of an electron-coupled oscillator. As a matter of fact, resonant circuits are used frequently, but in most cases they are tuned to some multiple of the oscillator frequency. Usually, the output circuit is tuned to a frequency which is twice that of the oscillator (although higher harmonics are used on occasion). When tuned to twice the frequency, the circuit is referred to as an oscillator-doubler.

When the plate tank circuit is tuned to a different frequency, there is less possibility of mutual interaction and instability. At the same time, it provides one step in the process of multiplying the oscillator frequency to obtain the desired carrier frequency.

The untuned output circuit is advantageous when the transmitter is to be operated over a rather wide range of frequencies. If the output is untuned, it is only necessary to change the tuning of the oscillating section when making a frequency change.

CRYSTAL OSCILLATORS

Certain crystalline materials produce a voltage when under mechanical stress. One such material is quartz, which is used in the manufacture of transmitting crystals. If the pressure on such a crystal is varied, an alternating voltage will be developed. Conversely, when an alternating voltage is applied across a crystal, a physical vibration is set up. Quartz crystal vibrates freely and is very stable. Most important, it vibrates at a particular frequency determined by its size and structure.

If such a crystal is inserted into an oscillator stage which is tuned near its natural frequency, it will vibrate strongly. In fact, a potential difference, much like the resonant voltage across a tank circuit, will develop across the crystal. Thus, the frequency of the oscillator will be determined by the natural frequency of the crystal.

A typical crystal circuit is shown in Fig. 6 along with its electrical equivalent. Notice that the crystal is represented by a tuned circuit. The feedback between the output and the input is provided by the grid-to-plate capacitance of the tube. In some crystal oscillators—depending on the tube type, frequency, and circuit design—some external capacitance is connected between plate and grid to establish the most favorable feedback conditions.

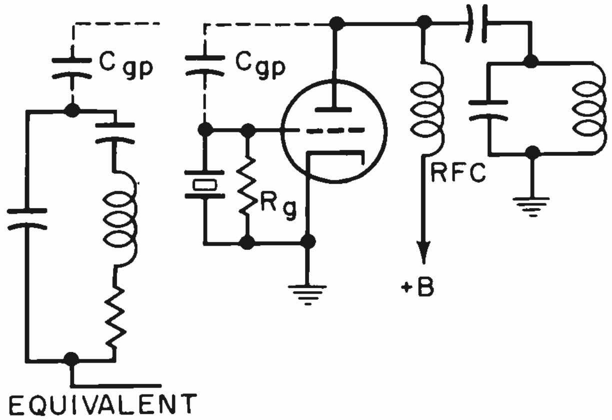


Fig. 6. Triode crystal oscillator and crystal equivalent.

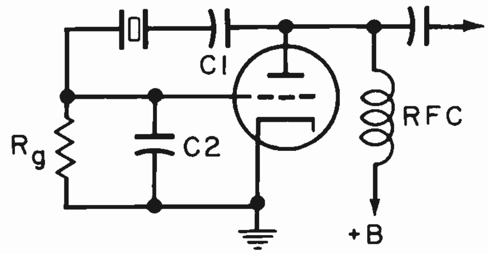


Fig. 7. Pierce crystal oscillator.

An actual transmitting crystal is extremely thin, having the appearance of a tiny slab of frosted window glass approximately ¼ to 1 inch square. The smaller the physical size of the crystal, the higher its resonant frequency will be. The mounted crystal is held tightly between two flat metal plates, each brought out to a terminal connection.

Some capacity is introduced by the plates of the crystal holder. This capacity is effectively in shunt with the crystal, and has some influence on its operating frequency. In some cases this capacity is made adjustable by the use of a small capacitor in shunt or series with the crystal. By so doing, it is possible to tune the circuit, over a narrow range, to some precise frequency slightly displaced from the natural crystal frequency.

A crystal oscillator need not employ a grid-leak capactior because the crystal circuit itself is capacitive and able to hold the grid-current charge. The value of the grid-leak resistance is chosen to provide the necessary time constant to maintain a constant bias between intervals of grid current flow.

It is important to realize that average plate current is maximum when a crystal stage is not oscillating. With no oscillations present, no grid current will flow and no grid-leak bias will be developed. As the plate circuit is tuned to resonance, the tank circuit will begin to oscillate. Some of its energy is fed back to the grid circuit, serving to excite the crystal and causing it to vibrate at its natural frequency. In so doing, the necessary grid drive signal is developed. The flow of grid current during positive peaks of the grid voltage charges the crystal capacity and builds up the grid bias. As the circuit is tuned to resonance average plate current will dip to a minimum value. Resonant operation is not always the most stable for a crystal circuit. It is usually preferable to tune slightly off the minimum plate current point.

A crystal stage must be operated at low power level. Too much feedback from plate to grid can result in excessive current which will damage the crystal. Thus, it is customary to operate a triode crystal oscillator at a rather low value of plate voltage.

A common type of crystal oscillator is the Pierce circuit shown in Fig. 7. Notice that it does not use a tuned output circuit. The crystal itself serves as the one and only tuned circuit, and is connected between the plate and grid of the tube. The small capacitor C1 is used to prevent DC voltage from reaching the crystal circuit. Capacitor C2 develops a feedback voltage of proper magnitude between grid and cathode, and at the same time functions as the grid-bias capacitor. For high-frequency operation, C2 may not be a physical unit, but represented by the interelectrode capacitance of the tube.

The Pierce oscillator has a low output but is highly stable. Also, there is less danger of a damage to the crystal by excessive current.

Tetrode and pentode crystal oscillators are common. They not only provide a higher output, but also improved stability because of the additional isolation between the output load and the oscillating section. Furthermore, there is less possibility of damage to the crystal because of the limited amount of energy that can be fed back through the relatively lower grid-to-plate capacitance. Crystal current is

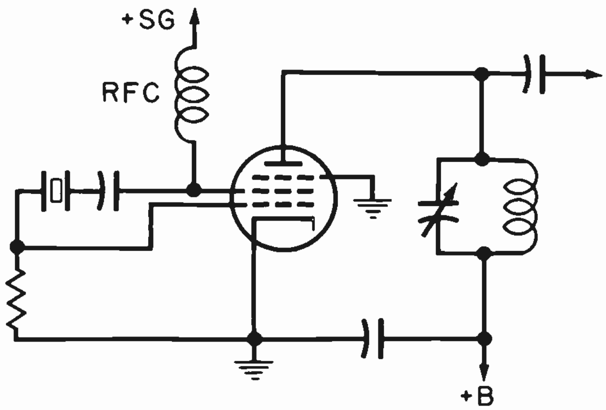


Fig. 8. Pentode crystal oscillator.

therefore kept low, permitting a stronger oscillation to be developed in the plate circuit.

In the circuit of Fig. 8 the cathode, control grid, and screen function as a Pierce-type oscillator. RF variations are coupled through the interelectrode capacitance to the plate circuit. As in an electron-coupled oscillator, the output tank can be tuned to the fundamental frequency of the crystal or to some higher harmonic. In the latter case the stage serves as both an oscillator and a frequency multiplier.

Crystals can be cut to operate strongly on a harmonic frequency. They can be made to vibrate freely on third, fifth, and even higher order harmonics. For example, a seven megacycle overtone crystal may be constructed to emphasize its fifth harmonic, and will vibrate strongly at 35 megacycles. These so-called overtone crystals are widely used in radio-communications equipment operating in the VHF and UHF ranges. Overtone crystal oscillator circuits operate between 30 and some 100 megacycles.

Some overtone crystal oscillator circuits have special arrangements to provide somewhat higher than normal feedback. However, overtone crystals have been developed which will "take-off" readily in most conventional crystal circuits.

TRANSISTOR CLASS-C AMPLIFIERS AND OSCILLATORS

The transistor has been a boon to the mobile radio services and other radiocommunications systems. A number of transistors have been developed to function well as oscillators and Class-C amplifiers, permitting the design of compact, cool, and light-weight transmitter stages. Frequencies up into the hundreds of megacycles can be utilized in these applications. All-transistor communications receivers are widely available. Transistors are used in the audio and RF exciter sections of many mobile transmitters, and has practically obsoleted the vibrator in mobile power supplies.

The transistor functions well as a stable low-power Class-C amplifier. It can be also operated as a fundamental amplifier and as a frequency multiplier. A sequence of transistor stages functions ideally as a carrier generator, phase modulator, and multiplier chain. Thus, in mobile radio services, for which a frequency multiplication of 12 to 24 times is quite common, transistors are ideal components.

A typical Class-C transistor amplifier is shown in Fig. 9. The common emitter circuit is used widely, and is comparable to a conventional grounded-cathode vacuum-tube stage. Grounded-base circuits, which can be compared with grounded-grid vacuum-tube stages, are used for VHF operation up to several hundred megacycles. Conventional and pi-network tank circuits can be used. The base-emitter impedance of a transistor is quite low, and even the output impedance in the collector circuit is not high in

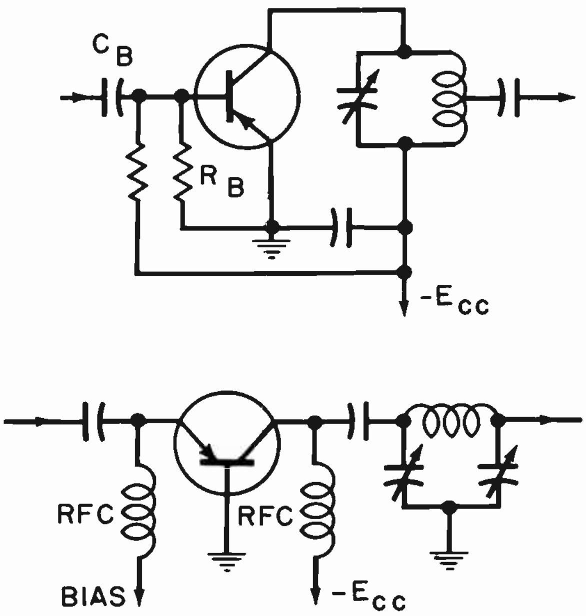


Fig. 9. Basic Class-C transistor amplifiers.

comparison to that of a vacuum tube. This factor must be considered when matching input and output impedance of a transistorized Class-C stage. As shown in Fig. 9, tapped-inductor or capacitive-divider matching arrangements are common.

As in vacuum-tube circuits, the transistor stage can be signal-biased. In this arrangement, the current in the base-emitter circuit provides the necessary "grid-leak" bias. A combination of external and self-bias can also be used. The external bias can be adjusted for the best operating conditions for a given magnitude of applied drive signal. As with tube circuits, a higher supply voltage permits a greater RF output to be developed.

A transistor stage makes a fine transmitter oscillator, providing both compactness and stability. It may be self-excited or crystal-controlled, connected in Hartley and other basic oscillator circuits and, utilizing a tetrode transistor, operated as an electron-coupled oscillator. In the Hartley arrangement of Fig. 10, the stage appears as a basic Class-C amplifier, except that a tapped inductor provides the necessary feedback. The coil is tapped at a point

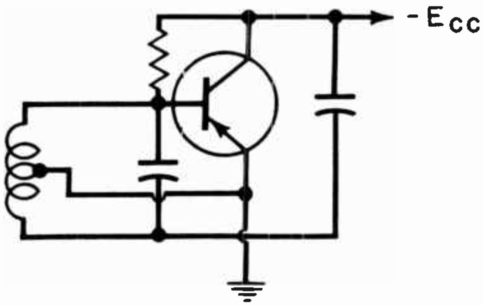


Fig. 10. Transistor Hartley oscillator.

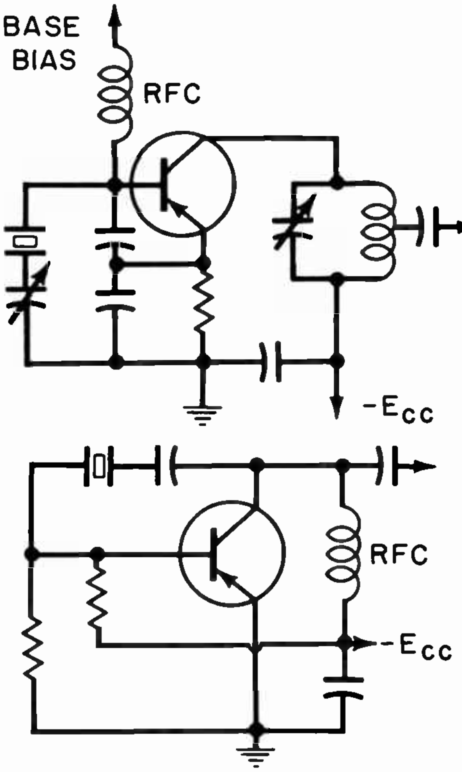


Fig. 11. Transistor crystal oscillators.

which results in a feedback current that is in phase with the base-emitter current and that sustains oscillations.

Two typical crystal oscillators are shown in Fig. 11. The circuit in 11A uses a split capacitor arrangement to establish optimum feedback. A small trimmer capacitor is connected in series with the crystal to permit precise setting of the oscillator frequency. A high Q output circuit is obtained by connecting the collector to a low-impedance point on the tank circuit, reducing the loading effect of the collector on the resonant tank.

A Pierce-type oscillator is shown in Fig. 11B. Notice that both crystal stages use some external base bias. Use of external bias provides more stable operation and minimizes frequency drift with temperature changes.

PREPARATION FOR LICENSE EXAMINATION

A considerable number of the FCC exam questions are devoted to oscillators. The samples which follow are typical of the material you should know. The answers will give you a fine review of oscillator theory and practice.

1. *Draw a simple schematic showing a Hartley triode oscillator with shunt-fed plate.*—See Fig. 12.

2. *Describe the fundamental principles of a vacuum-tube oscillator.*—The vacuum-tube and its associated components (which usually include a resonant circuit) are combined to form an amplifier with a feedback arrangement capable of utilizing DC

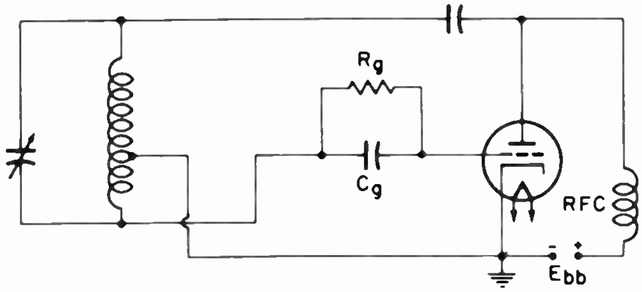


Fig. 12. Shunt-fed Hartley oscillator.

power to generate continuous RF variations. Referring to Fig. 13, oscillations will occur when the feedback energy is of the proper amplitude and phase. Because of the 180-degree phase reversal which occurs between grid and plate in the usual amplifier, the feedback arrangement must provide an additional 180-degree phase change to bring the output voltage back in phase with the input voltage. This in-phase condition, called positive or regenerative feedback, replaces the energy dissipated in the input circuit. As a result, self-sustained and continuous oscillations can be generated. All types of oscillators use this fundamental feedback principle.

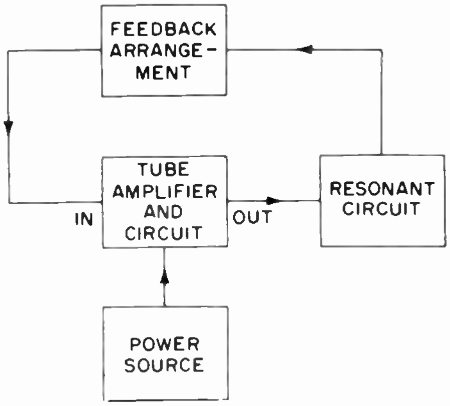


Fig. 13. Block diagram of a basic oscillator.

3. *Describe grid-leak action and how it is used to achieve Class-C operation of a vacuum-tube stage.*—A capacitor connected in the grid circuit of an oscillator or amplifier is charged when grid current flows during the positive peaks of an excitation signal. In an oscillator, this signal is fed back from the plate circuit, whereas an amplifier receives the signal from another stage. The charge across the capacitor increases the bias on the stage. If sufficiently high, this charge will bias the stage into cutoff for Class-C operation. A resistor is used to provide a discharge path for the capacitor, usually from grid to ground. The voltage developed across the resistor serves to maintain bias on the stage as the capacitor discharges. To achieve Class-C operation, the amplitude of the excitation signal and the value of the capacitor must be such that the resultant capacitor charge will bias the

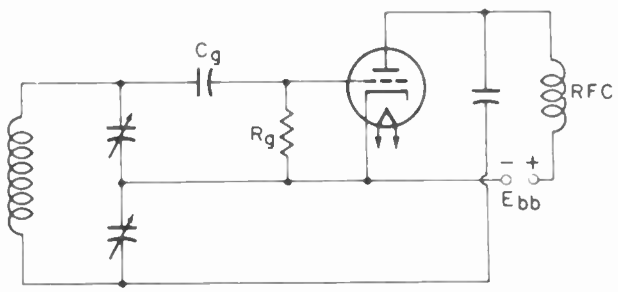


Fig. 14. Shunt-fed Colpitts oscillator.

stage beyond cutoff. Further, the time constant of the capacitor and grid-leak resistor must be long enough to maintain this cutoff bias until the excitation signal again passes through its positive peak. At this time, the stage will conduct and grid current will flow, replenishing the charge on the capacitor.

4. *Draw a simple schematic showing a Colpitts triode oscillator with shunt-fed plate.*—See Fig. 14.

5. *What is the difference between the Colpitts and Hartley oscillator?*—The Hartley and Colpitts oscillators are quite similar except for the way feedback is obtained. In the Hartley, a tapped (divided) inductance arrangement is used. The Colpitts oscillator uses a capacitive-divider network.

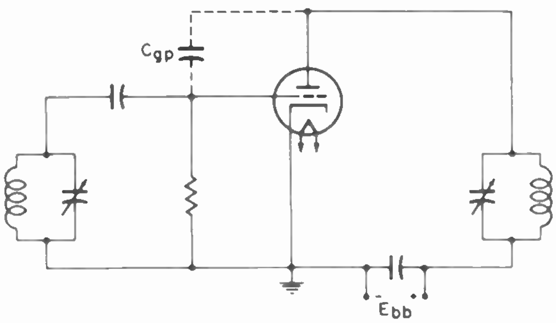


Fig. 15. TPTG oscillator with series-fed plate.

6. *Draw a simple schematic showing a tuned-plate, tuned-grid oscillator with series-fed plate.*—See Fig. 15.

7. *Draw a simple schematic showing a tuned-plate, tuned-grid triode oscillator with shunt-fed plate.*—See Fig. 16.

8. *How is feedback coupling obtained in a tuned-plate, tuned-grid oscillator?*—Via the grid-to-plate capacitance (Cgp) of the tube. The net feedback capacitance is also influenced by wiring and component capacities.

9. *Draw a simple schematic showing a tuned-grid Armstrong triode oscillator with shunt-fed plate.*—See Fig. 17.

10. *Draw a simple schematic showing a tuned-grid Armstrong triode oscillator with series-fed plate.*—See Fig. 18.

11. *Draw a simple schematic of an electron-coupled oscillator*—See Fig. 4.

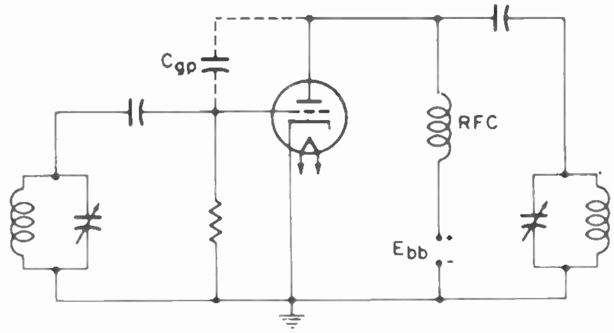


Fig. 16. TPTG oscillator with shunt-fed plate.

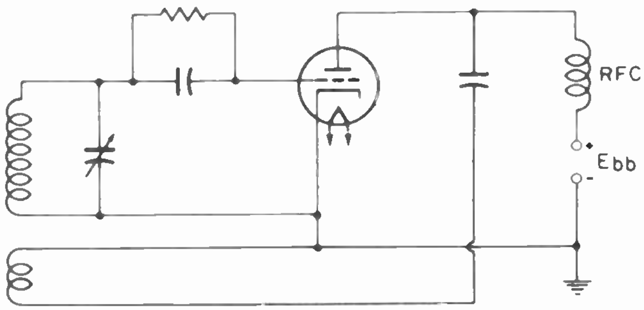


Fig. 17. Shunt-fed Armstrong oscillator.

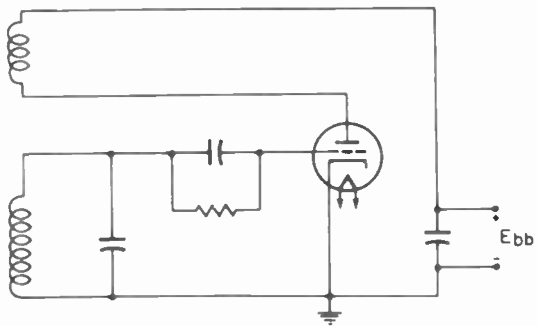


Fig. 18. Series-fed Armstrong oscillator.

12. *Why is a high capacitance-to-inductance ratio employed in the grid circuits of some oscillators?*—To improve oscillator stability; a more constant operation is provided during a changing oscillator load. Also, with a high-value tank capacitance, variation in the stray capacitances will have less effect on oscillator frequency.

13. *Describe the characteristics of an electron-coupled oscillator.*—An electron-coupled oscillator, as compared with other types, provides greater isolation between the load and frequency-controlling sections. Hence, load and supply-voltage variations have less effect on output and frequency. The ECO circuit has good frequency stability, high efficiency, and good output. Tetrode or pentode tubes must be used.

14. *Draw a simple schematic of a crystal-controlled vacuum-tube oscillator.*—See Fig. 6.

15. *What is the advantage of using a quartz crys-*

tal in a radio transmitter?—A crystal provides excellent frequency control of the transmitter oscillator.

16. *What are the principal advantages of the crystal-controlled oscillator over the tuned-circuit design?*—The crystal-controlled circuit has greater frequency stability. In addition, the crystal is more compact than the usual tuned circuit. A non-crystal oscillator must be more carefully tuned.

17. *Draw a simple schematic of a crystal-controlled vacuum-tube oscillator using a pentode tube.* —See Fig. 8.

18. *What crystalline substance is widely used in crystal oscillators?*—Quartz.

19. *What will occur if a DC potential is applied across the two parallel surfaces of a quartz crystal?*—A reasonable amount of DC voltage will deform the crystal; an excessive amount could permanently damage it. An AC voltage causes the crystal to vibrate or oscillate at its resonant frequency, the Q being determined by the characteristics of the crystal.

20. *Why is the crystal in some oscillators operated at a constant temperature?*—To prevent frequency drift. The resonant frequency of a crystal changes with temperature; thus, when a close tolerance must be maintained, the ambient temperature must be kept relatively constant.

21. *What is meant by the negative temperature coefficient of a quartz crystal?*—A negative temperature coefficient means the crystal frequency decreases as the temperature increases. Temperature coefficient is given in terms of frequency change per degree centigrade.

22. *What is meant by the expression "positive temperature coefficient," as applied to a quartz crystal?*—A crystal with a positive temperature coefficient increases in frequency as its temperature increases.

23. *What is meant by the expression "low temperature coefficient," as applied to a quartz crystal?* —A crystal having a low temperature coefficient exhibits only a small frequency change when subjected to temperature variations.

24. *What may result if a high degree of coupling exists between the plate and grid circuits of a crystal-controlled oscillator?*—Too much feedback to the crystal circuit. Excessive crystal current may cause frequency instability, and overheating which can fracture the crystal.

25. *Why is a separate source of plate power desirable for the crystal-oscillator stage in a radio transmitter?*—A separate power supply minimizes the influence of loading, and variations in the power demands of other transmitter sections have less effect on the frequency stability.

26. *What is the approximate range of temperature coefficients to be encountered with X-cut quartz crystals?*—The range of X-cut crystals falls between approximately −10 to +25 cycles per megacycle per degree centigrade, depending on the design and operation of the oscillator.

27. *Is it necessary or desirable that the surfaces of a quartz crystal be clean? If so, what cleaning agents will not adversely affect the operation of the crystal?*—Yes. Oscillating reliability and frequency stability require that the crystal be clean. Carbon tetrachloride, or even soap and water and a soft tissue or cloth can be used to clean the crystal surfaces. A dusty or oily crystal may be erratic, or refuse to oscillate at all.

28. *Do oscillators operating on adjacent frequencies have a tendency to synchronize or drift apart in frequency?*—Crystal oscillators tend to synchronize with each other. This problem often arises when one crystal is used as a standard to check another. To prevent lock-in between crystals, there should be minimum coupling between their circuits.

29. *Draw a simple schematic of a dynatron oscillator, indicating the circuit element necessary to identify this form of oscillatory circuit.*—See Fig. 19.

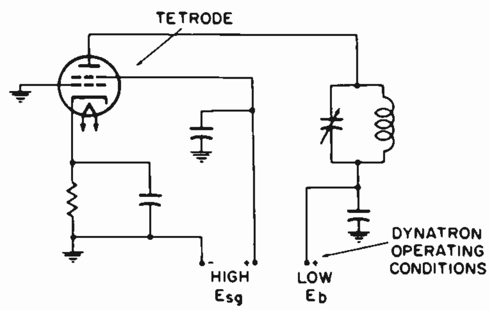


Fig. 19. Dynatron oscillator.

30. *Upon what characteristic of a vacuum tube does a dynatron oscillator depend, and why?*—On the high secondary emission of a tetrode, which produces a negative-resistance characteristic. In the negative-resistance region, plate current decreases as plate voltage increases. Using this inverse relationship along with a resonant circuit, continuous oscillations can be produced.

REVIEW QUESTIONS

1. Name the two advantages of electron-coupled oscillators.
2. Name two advantages of a crystal oscillator.
3. How is it possible to change the frequency of a crystal oscillator?
4. Of what use is a frequency multiplier?
5. Briefly explain the operation of a frequency doubler.
6. What is a self-excited oscillator?
7. Why is an oven sometimes used with a crystal oscillator?
8. Of what use is a buffer stage?

 Answers to these questions will be included in PHOTOFACT Set No. 569

Lesson 7

Antenna Systems

The antenna system makes an important contribution to the efficient operation of any radio-communications system. There are several practical limitations on the power output of a communications transmitter—for example, battery drain (in mobile equipment), cost, size, and FCC restrictions. Therefore, the proper type of antenna must be used if the installation is to give peak performance. Most antenna types stem from the basic half-wave (Hertz) and quarter-wave (Marconi) designs shown in Fig. 1. The impedance of a basic Hertz half-wave dipole is 72 ohms. The Marconi has a 36-ohm impedance and is in effect a half-wave type with ground or a large metallic surface (called a ground plane) serving as the second quarter-wave section.

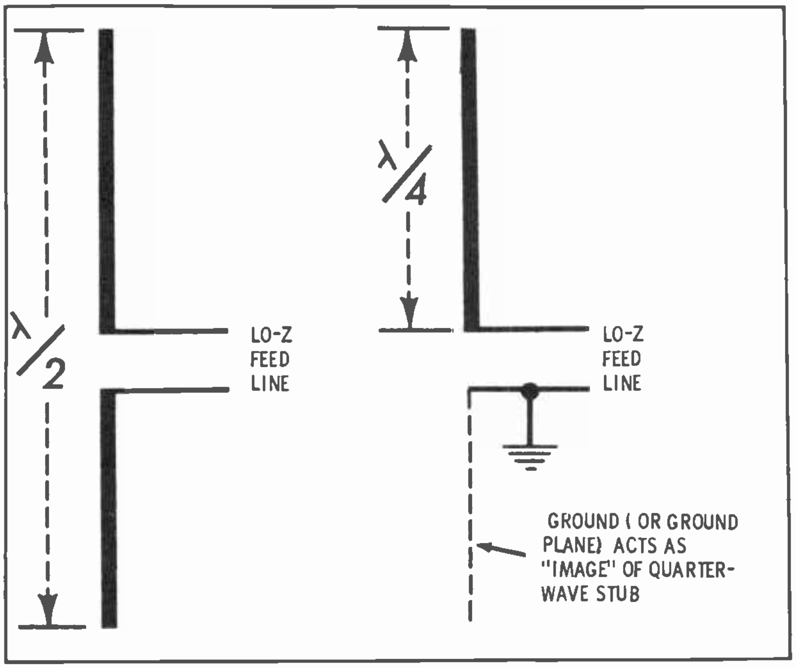


Fig. 1. Basic half-wave Hertz and quarter-wave Marconi antennas.

The physical length of an antenna element depends on the radio band in which the antenna is used. The most popular bands are given in Table I, together with a free-space quarter-wavelength measurement for the center frequency of each range. Notice how greatly this dimension differs from band to band.

The receiver and transmitter will not operate at peak efficiency unless the antenna is brought into exact resonance. Most antennas are supplied in the full length required to resonate at the low-frequency end of a given communications band. For best operation at some other frequency, it is necessary to shorten the antenna. Antennas must be cut to the exact length, although telescoping arrangements can be used.

MOBILE INSTALLATIONS

Practically all two-way mobile units employ vertical antenna polarization. Such polarization provides more reliable communications when the antenna height is limited. Also, vertical-antenna systems are best suited for producing the omnidirectional horizontal-radiation pattern which most mobile systems require. Furthermore, a vertical antenna directs the

Fig. 2. Mobile antenna mounting arrangements.

bulk of its radiated energy horizontally, instead of sending it upward into the atmosphere.

The quarter-wave and shortened quarter-wave are by far the most popular whip antennas for moving vehicles. The vehicle body itself serves as ground, thus permitting quarter-wave operation. The long antennas for the 25-50 mc band are usually mounted on the bumper or along the side of the vehicle, whereas the shorter VHF and UHF antennas are mounted in the center of the roof.

Many antennas are hinged so they can be swiveled out of the way when not in use, even when the base is mounted on a sloping surface. The longer, heavier antennas used in HF systems are generally connected to the base through a spring, to prevent damage to the mount when the antenna brushes against obstacles. Antennas are often connected to the transmitter through coaxial lines, with standard coaxial fittings at both sides. Coaxial lines are preferred because of their excellent shielding characteristics. Solder lugs may be used, at the antenna end, for connection to the terminals beneath the base.

Antennas for the HF range are sometimes cut shorter than an exact quarter wavelength to make them more manageable. When this is done, however, the antenna will display a capacitive reactance to the source of signal. The more the antenna is shortened from a quarter wavelength, the higher its capacitive reactance and the lower its radiation resistance will be. This effect makes proper resistive loading of the transmitter impossible, and as a result, its efficiency and output drop off. However, it is possible to present a reasonable load to a transmitter

Table 1. Quarter-Wave Dimensions for Popular Two-Way Radio Bands

Band	(MC)	Center Frequency (MC)	$\lambda/4$ Dimension in Inches
HF	25-50	37.5	78.7
VHF1	72-76	74	39.9
VHF2	150-174	162	18.2
UHF	450-470	460	6.41

Freq. MC	Free-Space $\lambda/4$ in Inches	Whip Length Considering End Effect and Spring	Whip Length When Using Loading Coil
27	109	102	92.8
29	102	95.6	84.5
31	95.2	89	78
33	89.4	83.5	72.5
35	84.3	78.6	66.2
37	79.8	74.2	61.5
39	75.7	70.2	56.5
41	72.1	66.5	52
43	68.7	63.3	47.5
45	65.7	60.3	42.5
47	62.7	57.4	—
49	60.3	55	—

Table 2. Practical Lengths of HF Whip Antennas.

if the capacitive reactance is offset with an inductance, usually a coil mounted at the base.

While the use of a loading coil permits efficient operation even though the antenna is shorter than a quarter wavelength, less energy radiation is obtained than with a true quarter-wave dimension. In achieving maximum antenna efficiency, there are other factors which must also be considered. For example, the mounting hardware has an effect on the resonant frequency. As shown in Table II, the actual rod length is less than the theoretical "free-space" quarter-wave dimension because of end effect, the inductive action of the spring, and the influence of other mounting elements. The third column shows how the length can be further reduced by adding a loading coil. Notice that the antenna can be shortened by as much as 20 inches and still be resonant at the desired frequency.

BASE INSTALLATIONS

Base-station antennas can be more elaborate and thus more efficient than mobile types, since their size and height above ground are not as restricted. The simplest base-station antenna is fundamentally a vertical quarter-wave. However, since such an antenna is normally mounted too high to utilize actual ground as its lower quarter-wave section, some kind of artificial ground surface (called a ground plane)

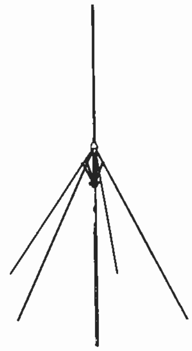


Fig. 3. Vertical antenna and ground plane.

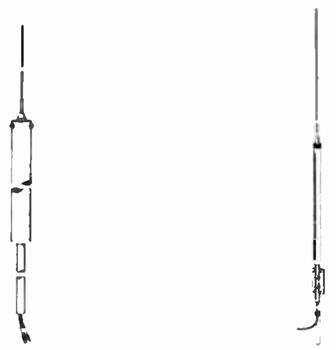


Fig. 4. Coaxial skirt antennas.

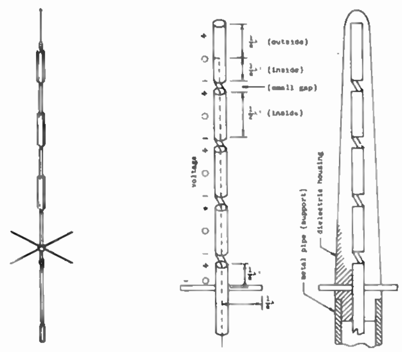


Fig. 5. Details of vertical collinear antenna structure.

must be used to insure reliable operation and proper impedance matching.

A typical ground plane appears in Fig. 3. Usually it consists of several radial elements, each a quarter wavelength and positioned horizontally beneath the vertical element. Above all, the ground plane provides uniform antenna performance; in other words, it does not permit the antenna characteristics to vary with ground conditions, environmental changes, and height above ground. In addition, a good low-angle (close-to-the-horizon) vertical-radiation pattern can be maintained. In effect, the latter characteristic permits more effective use of the radiated energy.

The freedom from size limitations of base-stations antennas makes possible the use of higher-gain types using extended elements, or a group of radiating elements positioned one above the other. By making more effective use of transmitter power, such antennas increase the reliable transmission range of the system.

In one popular extended type, the coaxial half-wave antenna shown in Fig. 4, the transmission line (coax) is fed upward through the center of a tubular quarter-wave "skirt." The inner conductor is connected to the bottom of a smaller-diameter quarter-wave section extending above the skirt, and the outer (grounded) conductor is connected to the top of the skirt. By minimizing the RF currents on the outer conductor, such an arrangement increases the signal radiation at low vertical angles.

Additional vertical-pattern directivity and gain can be obtained by extending a half-wave antenna to five-eighths of a wavelength. At the center feed point, such an antenna displays a low enough impedance and reactance that it can be matched to a transmission line. Five-eighths of a wavelength is about the limit to which a single antenna element can be extended. Beyond this dimension, additional vertical lobe patterns develop and more of the radiated energy is directed upward, which is of little benefit for ordinary two-way radiocommunications.

An antenna with even higher gain is the vertical

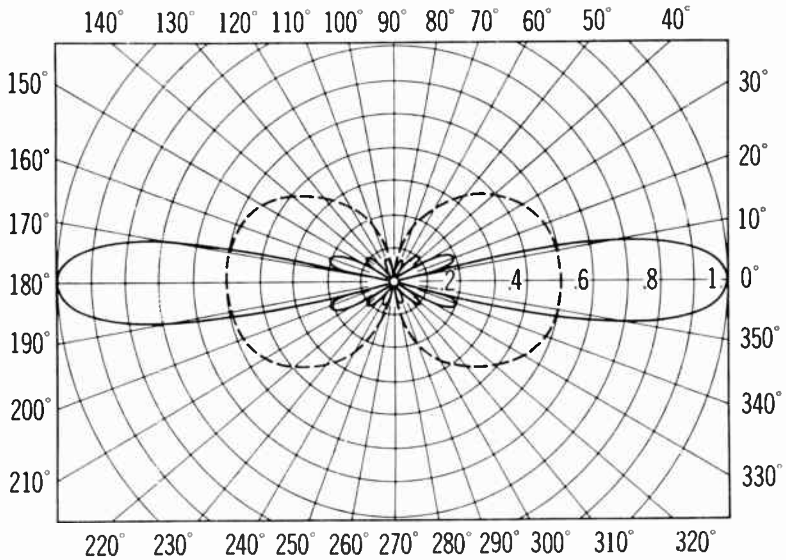


Fig. 6. Vertical-directivity pattern of a typical collinear array (solid lines) compared with pattern of a whip antenna (dotted lines).

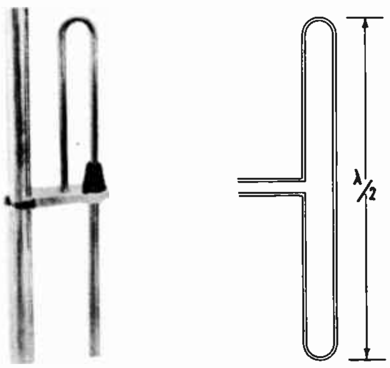


Fig. 7. Wide-band antenna styles.

collinear type in Fig. 5. Here a number of half-wave antenna elements are stacked and fed in phase. A vertical collinear arrangement maintains a fully omnidirectional horizontal pattern, and a narrow vertical-directivity pattern (Fig. 6). The resultant gain is determined by the number of collinear elements used. Gains as high as 10 db can be obtained from this type of system.

Single-element vertical antennas have a rather narrow bandwidth. As mentioned previously, they must be designed for the assigned frequency, either by cutting them or by using a telescoping arrangement. If several transmitting frequencies are used and they are widely separated, it is necessary to use individual narrow-band antennas, or else to compromise by making a median cut between the two frequencies.

One alternative is to use an antenna in which the quarter-wave element is folded or has a large cross-sectional area (Fig. 7). Either feature helps present a higher and more constant impedance to the transmission line over a wider band of frequencies.

POINT-TO-POINT COMMUNICATIONS

Directional antennas are often employed in fixed point-to-point communications services. This type of operation is also suitable for some base stations which communicate with several mobile stations, provided the communications are all in the same

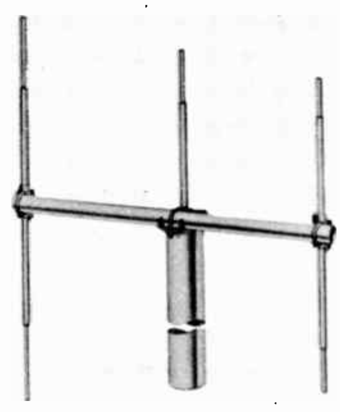


Fig. 8. Typical yagi-style antennas.

general direction from the base location. Antennas are made directional by using parasitic elements or by feeding groups of elements in phased arrangements. Yagi antennas, similar to the cut-to-channel types used for TV reception, are among the most common directional designs (Fig. 8). Directivity increases in proportion to the number of parasitic elements used.

Antenna design is an important factor in compensating for differences in radio-wave propagation at various frequencies. For example, the short wavelength dimensions at UHF make it practical to build a very high-gain multielement antenna for this band. Such an antenna helps to lengthen the inherently short UHF transmission range. Similar antennas would be too unwieldy to be practical on the longer-wave HF band, but the limited gain of HF antennas is compensated for by the longer distances over which HV waves will carry.

The objectives of any two-way communications system—cost, convenience, and wise use of the air waves—all dictate that a highly efficient system be used. Therefore, all components chosen must fulfill the requirements of the job as closely as possible.

PREPARATION FOR LICENSE EXAMINATION

The following questions and answers are representative of the information you should know about antennas in preparing for the second-class radiotelephone license examination.

1. *What is the velocity of propagation of radio-frequency waves in space?*—Free space velocity is 300 million meters, or approximately 186,000 miles, per second.

2. *What is the relationship between the electrical and physical lengths of a Hertzian antenna?*—The physical length is slightly shorter than its electrical length.

3. *What factors determine the resonant frequency of an antenna?*—The physical length of the antenna is the main factor. Electrically, a typical antenna may be a half wavelength; however, to make it resonant at a given frequency, its physical length would have to be slightly shorter.

Element diameter, proximity of other antenna elements and surrounding objects, and the presence of insulators also determine the exact resonant frequency of an antenna.

4. *What is the effect, on the electrical length, of connecting an inductor in series with an antenna?*—The inductor increases the electrical length, and permits a physically shorter antenna to be used for a given frequency.

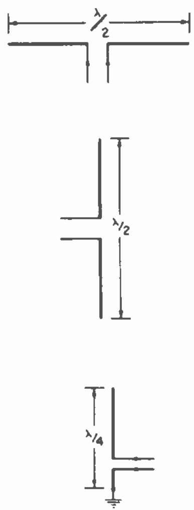
5. *What is the effect, on the resonant frequency, of adding a capacitor in series with an antenna?*—The resonant frequency increases because the series capacitor shortens the electrical length of the antenna.

6. *What will be the effect on the resonant frequency of a Hertzian antenna which is shortened physically?* — Its resonant frequency will be increased.

7. *How is it possible to operate on a frequency lower than the resonant frequency of an available Marconi antenna?*—By adding an inductor in series with the antenna.

8. *Describe the directional characteristics of the following antennas: horizontal Hertz, vertical Hertz, vertical loop, horizontal loop, and vertical Marconi.* —First, let's review directivity. The two kinds, horizontal and vertical, are shown in Fig. 9. Horizontal directivity is the compass direction in which radiation occurs; vertical directivity is the vertical angle of radiation, expressed in degrees with respect to ground. The horizontal directivity of a horizontal Hertz antenna follows the shape of a figure-8 pattern, and its maximum radiation is broadside to the direction of the antenna element. Its vertical directivity is a function of height, surroundings, and soil conditions. In free space it is considered circular; in other words, the same amount of energy is radiated upward, downward, and to the sides.

Horizontal directivity of a vertical Hertz antenna is circular (i.e., omnidirectional). Vertical directivity, which is again a function of height and surroundings, is usually low (i.e., almost parallel to ground).



(A) Horizontal Hertz.

(B) Vertical Hertz.

(C) Vertical Marconi.

Fig. 9. Hertz and Marconi antennas.

A vertical Marconi also has an omnidirectional directivity and a rather low vertical angle of radiation. Again, the vertical angle is a function of height and the soil conditions beneath the antenna.

A vertical loop antenna has a figure-8 horizontal pattern, but the maximum radiation is parallel with instead of broadside to the plane of the loop.

A horizontal loop antenna is omnidirectional and has characteristics similar to those of a vertical Hertz antenna.

9. *Which type of antenna has a minimum of directional characteristics in the horizontal plane?* — A single-element vertical antenna such as the Hertz or Marconi types.

10. *What is meant by radiation resistance?*—The value of resistance required to dissipate the same amount of power normally radiated by the antenna.

11. *If the resistance and current at the base of a Marconi antenna are known, what formula is used to determine the power in the antenna?*—Power in an antenna is computed using the formula $P = I^2R$.

12. *What is meant by horizontal and vertical polarization of a radio wave?*—The direction of the electric vector of a propagated wave determines its polarization. For example, the electric vector of a horizontal Hertz antenna is horizontal; hence, the antenna is said to radiate a horizontally-polarized wave. A vertical Hertz antenna radiates a vertically-polarized wave because its electric vector is vertical.

13. *How should a transmitting antenna be designed if a vertically polarized wave is to be radiated, and how should the receiving antenna be designed for best reception of the ground wave from such a transmitting antenna?*—The antenna should be vertical to radiate a vertically polarized wave. The receiving antenna should also be mounted vertically to extract the most signal from the vertically polarized radiation.

14. *Show by a diagram how a two-wire radio-frequency transmission line can be connected to feed a Hertz antenna.*—See Fig. 10.

15. *Draw a simple schematic showing how a single tube employed as a radio-frequency amplifier is coupled to a Hertz antenna.*—Refer to Fig. 10.

16. *Draw a simple schematic of a push-pull, neutralized radio-frequency amplifier stage coupled to a Marconi antenna system.*—See Fig. 11.

17. *What is the purpose of a Faraday screen between the final tank inductance and the antenna inductance of a transmitter?* — The Faraday screen presents a low impedance to ground for any harmonics and other spurious-frequency components present in the final tank circuit. The desired signal passes unimpeded between the final tank circuit and the resonant antenna system. (See Fig. 11.)

18. *What material is best suited for use as an an-*

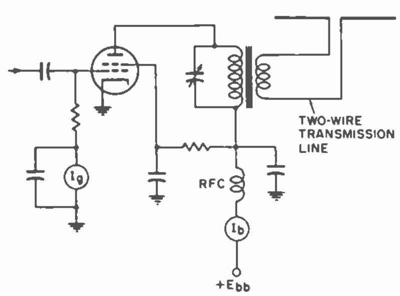


Fig. 10. Two-wire line feed to a Hertz antenna.

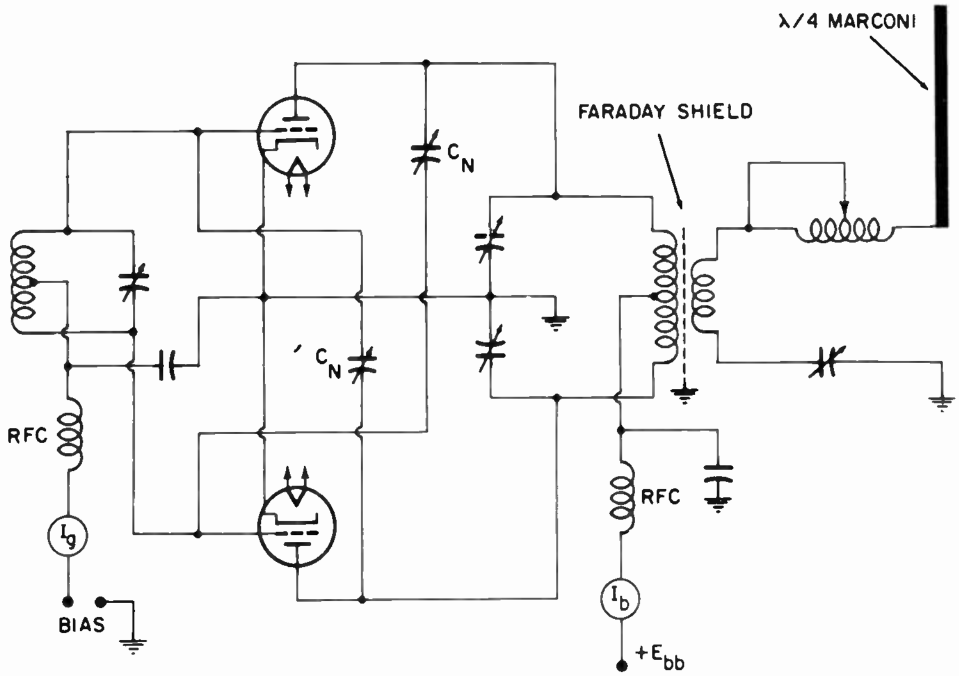


Fig. 11. Push-pull RF amplifier coupled to Marconi antenna.

tenna strain insulator which is exposed to the elements?—Glazed porcelain or other ceramic materials, which have low RF losses and are least affected by environment.

19. *Why are insulators sometimes placed in antenna guy wires?*—To insulate the radiating element from the supporting guy wires, and to break up the guy wires into segments of a substantially shorter electrical lengths than the transmitted wavelength so they will have less influence on the radiating section of the antenna system.

20. *What is the effect of a swinging antenna on the output of a simple oscillator?*—When an antenna swings, its load resistance, and hence the reactance presented to the oscillator, varies. As a result, the oscillator frequency and its output amplitude change. When an antenna is fed directly from an oscillator, its variations and their influence on the oscillator must be minimized.

21. *What is a dummy antenna and what is its purpose?*—A dummy antenna is made up of one or more resistive elements which will dissipate the energy normally supplied to the antenna. When fed from the output of a transmitter for tune-up and test purposes, the transmitter can be operated without radiating a signal that could cause interference.

22. *What is a wave guide? Cavity resonator?*—A wave guide is a transmission line that permits efficient transfer of microwave energy between a microwave generator and a load. A typical wave guide is a hollow cylinder or rectangular tube in which the walls guide the radio-frequency energy from generator to source. The energy is not conveyed by the tube, but is merely confined within its boundaries. This results in minimum loss, which is further reduced by using a highly conductive internal surface to minimize attenuation at the points where the microwave energy comes in contact with the tube.

The wave guide is more efficient in transferring microwave energy than transmission line. The frequency at which a wave guide is effective is a function of its physical dimensions—the larger its cross section, the lower the frequency at which it is more efficient. Wave guides cannot be used at low frequencies because their size would be prohibitive.

Like a section of transmission line, a section of wave guide can serve as a resonant circuit. When used in this manner, the wave guide is called a cavity resonator. A microwave cavity resonator can have an exceptionally high Q, and will be quite stable with relation to its surroundings. Usually, the cavity resonator is either spherical or cubical and is completely enclosed except for the injection points where the signal is inserted or removed.

23. *Describe briefly the purpose of a wave guide. What precautions should be taken, in the installation and maintenance of a wave guide, to insure proper operation?*—The function of a wave guide is to efficiently transfer microwave energy between a source and a load.

Wave guides, like transmission lines, must be matched to insure efficient transfer of energy. Junctions and insertions for take-off points must be planned carefully in order not to upset the matching. The sections must be joined correctly to minimize losses, and sharp bends and breaks must be avoided.

REVIEW QUESTIONS

1. How can the electrical length of an antenna be increased?
2. Give the advantages of a ground plane.
3. Of what importance is the horizontal-radiation pattern of a communications antenna?
4. Why is the vertical-radiation pattern of importance in two-way radio systems?
5. In what way does the antenna radiation of a mobile radio station differ from that of a point-to-point communications station?
6. What is the difference between the vertical radiation characteristics of a quarter-wave vertical and a collinear vertical?
7. What is the relative difference in the length of a quarter-wave antenna at 150 megacycles?
8. Why is vertical polarization usually more suitable for vehicular two-way radio?

Answers to these questions will be included in PHOTOFACT Set No. 569

Lesson 8

Microphones and Audio Amplifiers

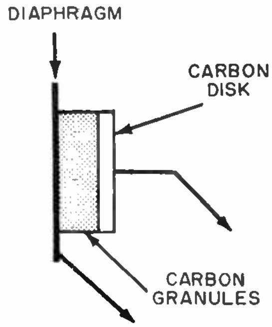


Fig. 1. Basic construction of a carbon microphone.

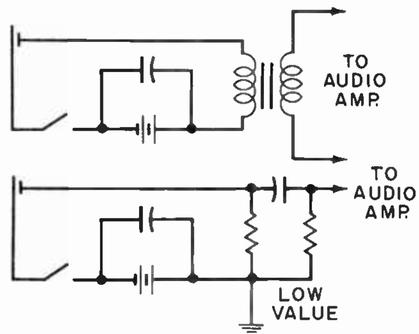


Fig. 2. Carbon microphone circuits.

This lesson contains considerable basic electronic theory and practice, with which you should already be familiar but may have forgotten. It has been selected and presented in a manner that will be most useful in preparing for the FCC license examination. A knowledge of these fundamentals is important to you because it will help you answer more examination questions correctly. Two basic audio systems constitute a part of each radiocommunications station. The first is a speech amplifier, which builds up the microphone signal before it is applied to the modulator. The stages used for this purpose are fundamentally voltage amplifiers. The modulator itself is more often a power amplifier, and is not too different from the power-output stages of a high-fidelity amplifier or PA system. Modulator circuits will be dealt with in detail in lessons 9 and 10.

A second audio amplifier system follows the demodulator stage of the receiver. Its purpose is to amplify the detected signal so it can drive a speaker or headset. In small mobile, portable, and hand-held units, the same amplifier used in the audio system of the receiver is often used as the speech amplifier and modulator of the transmitter. Such a transmitter-receiver combination is called a transceiver.

MICROPHONES

The three most common types of microphone movements used in radiocommunications are carbon, crystal or ceramic, and dynamic. As shown in Fig. 1, the carbon microphone consists of a small container called a carbon button, which is attached to a diaphragm. The button is connected to a battery or other source of DC voltage. As sound vibrations strike the diaphragm, the carbon granules within the button are compressed and expanded. This movement changes the resistance and, in turn, the amount of current flowing in the external circuit. These variations in microphone current develop a changing voltage across the primary of a step-up transformer and to the grid of an audio-amplifier stage, as shown in Fig. 2.

Instead of using a transformer to step up the voltage, the modern carbon microphone has such a high output that it often supplies signal directly to the the first audio amplifier input. A low-value resistor serves as the load for the inherent low impedance of a carbon microphone. The R-C coupling into the grid isolates the DC components in the microphone circuit from the grid of the amplifier.

One disadvantage of the carbon microphone is that current must be supplied from a battery or other source of DC voltage. Another is that the carbon microphone is occasionally troubled with granule packing, which results in a hissing background noise. It also has a limited frequency response; however, this is not a disadvantage in two-way communications systems, since response is usually limited to the frequencies most important to voice transmission.

One advantage of the carbon microphone is its

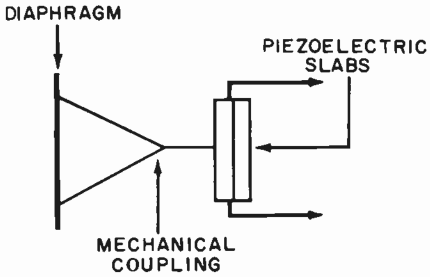


Fig. 3. Construction of a crystal or ceramic microphone.

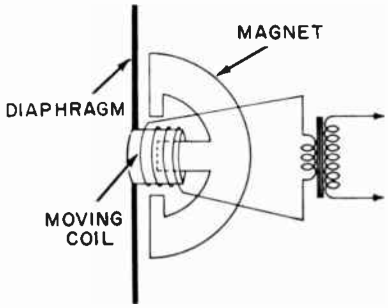


Fig. 4. Basic construction of a dynamic microphone.

very high output level. This is important in the design of small compact units, where only limited audio amplification is available before the signal is supplied to the modulator.

Crystal and ceramic microphones operate on the piezoelectric principle, in which certain crystals or ceramic materials develop an output voltage under pressure (Fig. 3). When sound vibrations are applied to a diaphragm linked mechanically to one of these piezoelectric elements, the variations of mechanical pressure will vary the output voltage of the element in proportion to the changes in sound pressure.

A crystal microphone is sensitive and develops a strong output, although not as strong as provided by a typical carbon microphone. It has a high output impedance, however, and can therefore be connected directly to the high-impedance grid circuit of a vacuum-tube stage. No source of DC current is required.

In a second type of piezoelectric construction, a number of very small elements or cells serve as the diaphragm, and the individual outputs are combined to develop the total output of the microphone. Better frequency response and a higher output can be obtained from such a multiple-element combination.

The high impedance of the piezoelectric microphone limits the length of microphone cable that can be used, because of the noise and hum to which any high-impedance circuit is susceptible. Again, this is no serious disadvantage in radiocommunications because only a short length of line is usually required between the audio amplifier and microphone.

The dynamic microphone employs the moving-coil principle, in which a wire coil attached to a diaphragm is positioned in a strong magnetic field (Fig. 4). When sound waves strike the diaphragm, movement of the coil results. The turns of the coil cut the lines of force of the magnetic field and induce a voltage in the coil.

The ends of the coil are connected to a transformer in the microphone. This transformer can provide either a low- or a high-impedance output, depending on the microphone design. Often the microphone includes a suitable tapping arrangement that provides a choice of low- or high-impedance outputs. Output voltage is substantially higher on the high-impedance position, sufficiently so that the microphone can be connected directly into the grid circuit of a vacuum-tube stage. High-impedance dynamic microphones are used for most radiocommunications applications. In general, dynamic microphones which have a high output level also have limited frequency response. Since only a limited frequency response is needed for the usual radiocommunications service, a high-impedance and high-output dynamic microphone can be employed. When a low-impedance dynamic microphone is used, a step-up voltage transformer must be added between the microphone output and the amplifier input.

Many radiocommunications microphones are differential types, which are designed for close talking. Such microphones develop a strong output when held close to the lips, but have a low sensitivity to sounds arriving from a distance. The differential microphone has two apertures leading to the diaphragm. When the microphone is close-talked, the sound enters only one aperture before striking the diaphragm. However, sound arriving from a distance of several feet enters both apertures and cancels out, causing the output to drop very low.

The ability of a microphone to reject background noise is important in radiocommunications. Often there are many distracting noises from operating machinery, conversations, traffic, etc. A microphone with good close-talk performance permits the voice signals to come through loud and clear.

The radiocommunications microphone in Fig. 5 is a hand-held type used mostly in mobile applica-

Fig. 5. Typical hand-held microphone for mobile use.

Fig. 6. Desk-stand microphones for use in base and fixed stations.

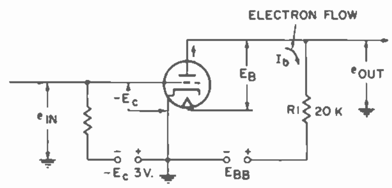
tions. The built-in switch lets the operator alternate between transmit and receive operations.

The desk stand microphone in Fig. 6 is popular in base stations and point-to-point communications. This model includes a grasp-to-talk switch. To transmit, the operator merely squeezes the microphone stand. When he releases the switch, the transmitter is turned off automatically and the receiver is turned on. The goose-neck mounting shown in Fig. 7 permits the operator to swivel the microphone to the most advantageous position in terms of use and background noise.

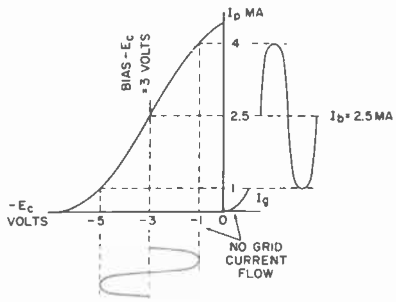
Many radiocommunications microphones are designed to handle any of the three basic microphone movements (piezoelectric, carbon, or dynamic). Microphones can also be selected according to the output level and impedance requirements. In fact, microphones may look the same outwardly, yet their elements may have different characteristics and even different movements. Thus it isn't always possible to install a substitute microphone just because it "looks like" the original.

A transistor amplifier can be built into the microphone case to increase the output. The microphone itself is usually a magnetic type and develops an output comparable to that of a carbon microphone. Consequently, magnetic microphones can be substituted in carbon-microphone circuits to nullify hiss, aging of the carbon element, and other problems that develop in carbon microphones as a result of vibration and high noise.

Fig. 7. Gooseneck microphone for base station use.



(A) Circuit.



(B) Transfer curve.

Fig. 8. Basic vacuum-tube amplifier.

AUDIO AMPLIFIERS

The speech-amplifier section of a transmitter increases the amplitude of the weak microphone signal. A basic vacuum-tube amplifier is shown in Fig. 8A, and 8B shows the transfer curve. Note that the stage operates on the linear portion of the curve.

The operation is as follows: The positive DC voltage supplied to the plate attracts the electrons emitted from the cathode. The number of electrons reaching the plate and flowing out of the tube through plate load resistor R1 is determined by the amount of negative voltage supplied to the control grid (here, —3 volts). Over the linear portion of the curve (between —1 and —5 grid volts), the plate current changes linearly with respect to the grid voltage. With this grid bias of —3 volts on the vacuum-tube stage, the DC component of plate current will be 2.5 milliamperes.

To better understand the operation of the triode as an amplifier, assume that an AC sine wave of 2 volts peak is being supplied to the control grid. As the sine wave goes positive, the grid bias decreases and plate current increases. At the crest of the positive alternation, the instantaneous grid voltage is —1 volt and the plate current is 4 milliamperes.

On the negative alternation of the grid-voltage signal, the plate current decreases because of the greater retarding influence of the grid. At the crest of the negative alternation, the instantaneous grid voltage is —5 volts and the plate current is only 1 milliampere.

It is important to recognize that the plate-current change follows the grid-voltage change. As the grid voltage swings between peaks, it changes between —1 and —5 volts. At the same time, the plate current also changes between the limits of 4 milliamperes and 1 milliampere. Thus, the peak AC plate current change is 1.5 milliamperes. This current flows through the plate load resistor R1. The plate-voltage change can be determined by multiplying values for the plate current and the plate load resistor, or:

$$E_p = I_p \times R_L$$
$$E_p = .0015 \times 20{,}000 = 30 \text{ volts}$$

The plate-voltage change is 30 volts peak. Since the initial grid-voltage change was 2 volts peak, the amplifier has a gain of 30 divided by 2, or 15.

We have reviewed how a triode vacuum-tube stage functions as a voltage amplifier. By correct selection of tube and operating conditions, a vacuum-tube stage can also be made to operate as a power amplifier.

In a voltage amplifier, a rather high value of plate resistance is normally used in order to develop a high voltage output from a limited change in current. In the power amplifier, however, it is usually necessary to develop a certain amount of power across a rather small load such as a modulation transformer or the audio-output transformer that drives the speaker. The power-amplifier tube is designed to produce a substantial change in current when excited by a moderate to high input-signal voltage. The function of the voltage amplifier or speech amplifier of a transmitter is to build up the microphone voltage sufficiently to drive the audio power-output stage, or the modulator.

VACUUM-TUBE CHARACTERISTICS

The three characteristics that tell the most about the operation of a vacuum tube are its amplication factor (μ), mutual conductance (Gm), and plate resistance (Rp).

The amplification factor is a measure of the ability of a tube to cause a greater change in plate voltage for a given change in grid voltage. If a tube has an amplification factor of 20, the change in plate voltage will be 20 times greater than the change in grid voltage. Thus, the amplification factor provides an indication of how well the tube produces a plate-voltage change when a signal is supplied to its input.

The mutual conductance, or Gm, often referred to as the figure of merit, indicates the capability of the tube as a power amplifier or one that must develop a signal across a rather low ohmic value of load resistor. The Gm indicates the extent of the plate-*current* change for a given change in grid voltage—in other words, how much the plate current will change with a given applied signal voltage.

The plate resistance (Rp) of a tube is the ratio of the plate-voltage change to plate-current change. This ratio has much to do with determining the degree to which a tube loads down its associated circuit. In a voltage-amplifier tube, this resistance limits the voltage gain of its associated stage.

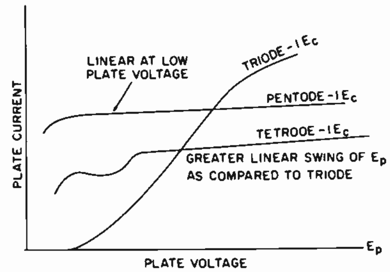


Fig. 9. Characteristics of triode, tetrode, and pentode tubes.

Triode vacuum tubes are characterized by a low plate resistance and a rather limited μ (depending on physical construction). A triode is often referred to as a constant-voltage generator because its plate voltage is fairly independent of plate current for a constant grid bias. Referring to Fig. 9, notice that the triode curve is more vertical, indicating that the plate voltage changes only slightly with a substantial change in plate current.

The triode has a fine fidelity as an audio amplifier when operated on the linear portion of its transfer curve. It does have a significant second-harmonic component which limits its efficiency if second-harmonic distortion must be held to a minimum, as in a power amplifier. However, the second harmonic can be suppressed by using two triodes in a push-pull arrangement.

When used as a Class-C radio-frequency amplifier, a triode requires neutralization because of its low-impedance feedback path from plate to grid. Moreover, a triode requires more drive signal than the tetrode or pentode in an audio or Class-C stage.

The tetrode has a high plate resistance, and can have a high Gm. It also provides more effective shielding between plate and grid, minimizing the necessity for neutralization. The constant-current characteristics of tetrodes and pentodes are compared in Fig. 9 with those of a triode. Notice how slightly the plate current changes for a wide expanse of plate-voltage change. Tetrode and pentode tubes are referred to as constant-current generators because their plate currents remain relatively constant with changes in plate voltage. Compared with a triode, a tetrode will exhibit a much greater change in plate current and output for an equivalent change in grid voltage. In Class-C operation, a good tetrode normally requires no neutralization except perhaps at very high frequencies, and even here, only a limited amount.

A pentode has an additional electrode, called the suppressor grid, between the screen grid and plate. Its primary function is to counteract secondary emission at the plate. The plate voltage of a tetrode, if permitted to drop below that applied to the screen during a portion of the input cycle, will cause secondary electrons to become dislodged from the plate and attracted to the screen.

Thus at a low plate voltage, there is a limit to the range over which the plate voltage can be permitted to change with a given input signal. However, since the suppressor grid in a pentode is held at or near ground potential, it is much more negative than the plate and is able to retard the emission of secondary electrons, causing them to cloud around the plate. As a result, the plate voltage can swing to a rather low positive value — substantially lower, in fact, than the screen potential.

A pentode has a very high plate resistance, and it can be made with a very high Gm as well. Thus, a substantial change in both plate current and voltage can occur with only a small grid-signal drive. The curves in Fig. 9 show that, compared to the tetrode, a pentode is linear over a much greater portion of its curve.

A beam-power tube (Fig. 10) is basically a tetrode but has characteristics more like those of a pentode. Beam-forming electrodes are inserted between the screen and plate to concentrate the electrons into a beam. Because these plates are at cathode potential, they have a focusing action similar to that performed by the suppressor grid. Such a tube has high plate efficiency and power sensitivity. It is very popular in audio power and radio-frequency stages of a transmitter.

PREPARATION FOR LICENSE EXAMINATION

The following questions and answers cover material you should know about microphones and audio amplifiers in preparing for the second-class radiotelephone license examination.

1. *What form of energy is contained in a sound wave?*—Mechanical, in the form of vibrations of the air particles.

2. *What characteristics determine the pitch of a sound?*—The pitch of a sound is usually determined by its fundamental frequency, which would pinpoint its position in a musical scale. Sometimes, however, the term pitch is used in defining harmonic qualities or loudness levels.

3. *Draw a diagram of a single-button carbon-microphone circuit, including the microphone transformer and source of power.*—See Figs. 1 and 2.

4. *What may cause packing of the carbon granules in a carbon-button microphone?*—A severe jar during a moment of strong current flow or excessive sound pressure may cause the carbon granules to stick together tightly, even after the sound pressure has been removed.

5. *What precautions should be observed in using a double-button carbon microphone?*—It should be connected in a balanced circuit (one in which equal and proper amounts of current flow in each side).

6. *What precautions should be observed when storing a crystal microphone?*—It should be stored in a dry, cool location because it is susceptible to environmental extremes (particularly to high temperature and humidity).

7. *What is the purpose of a preamplifier?*—A preamplifier is used to increase the level of an audio signal prior to its application to a power amplifier. For example, a preamplifier is often fed from a low-sensitivity microphone which is positioned some distance from the regular amplifier. Preamplifiers are generally mounted near the signal source in order to amplify the signal before it has a chance of being subjected to noise distortions.

8. *Draw a simple schematic showing a method of resistance coupling between two triode vacuum tubes in an audio-frequency amplifier.*—See Fig. 11.

9. *What will be the effect of a shorted coupling capacitor in a conventional resistance-coupled audio amplifier?*—Some of the DC plate voltage of the first stage will appear at the grid of the second stage. Consequently, the second stage will be biased improperly and will operate on the nonlinear portion of its transfer curve. The sound will be distorted, and the tube may even be driven into saturation, which will reduce stage gain.

10. *If the value of a coupling capacitor in a resistance-coupled audio amplifier is increased, what effect may be noted?*—The capacitor will present a lower reactance to low-frequency signal components, and their amplitudes at the grid of the succeeding stage will increase. The low-frequency response will thus be increased.

11. *What circuit and vacuum-tube factors influence the voltage gain of a triode audio-frequency amplifier stage?*—The plate voltage, grid bias, and output load resistance or impedance must be proper with respect to the desired frequency response and to

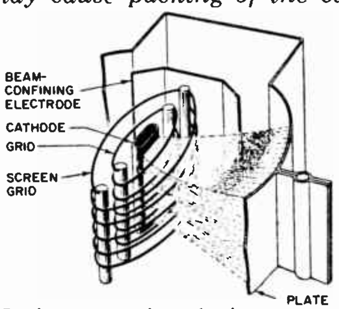


Fig. 10. Basic construction of a beam-power tube.

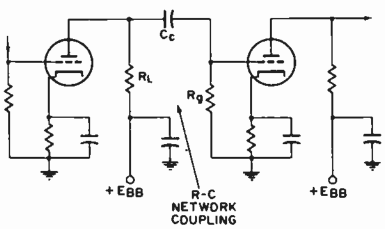


Fig. 11. Resistance-coupled triodes.

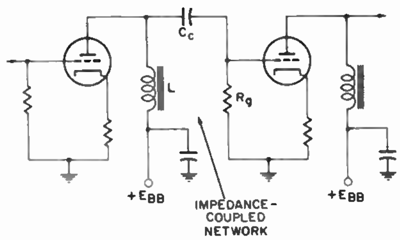


Fig. 12. Impedance-coupled triodes.

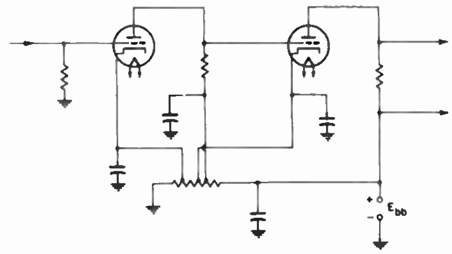


Fig. 14. Loftin-White DC coupling.

the characteristics of the particular tube used in the stage. The mutual conductance (Gm) and the amplification factor (μ) control the attainable voltage gain of the tube.

12. *What is the purpose of a bias voltage on the grid of an audio-frequency amplifier tube?* — The bias voltage determines the class of operation. In Class-A audio amplifiers, the bias is selected for operation on the linear portion of the transfer curve, considering the maximum peak-to-peak signal that will be applied to the grid.

13. *What will be the effect of incorrect grid bias in a Class-A audio amplifier?*—The tube will operate on the nonlinear portion of its transfer curve. As a result, the output voltage will not be an exact replica of the input-signal variation. In addition, the stage may draw grid current or excessive plate current, and stage gain will be reduced.

14. *Draw a simple schematic showing a method of impedance coupling between two vacuum tubes in an audio-frequency amplifier.*—See Fig. 12.

15. *Draw a simple schematic showing a method of transformer coupling between two triode vacuum tubes in an audio-frequency amplifier.*—See Fig. 13.

16. *Draw a diagram illustrating direct, or Loftin-White, coupling between two stages of an audio-frequency amplifier.*—See Fig. 14.

17. *Draw a simple schematic of a triode vacuum-tube audio-frequency amplifier coupled inductively to a speaker.*—See Fig. 15.

18. *Draw a simple schematic showing a method of coupling a high-impedance speaker to an audio-frequency amplifier tube without using a transformer or causing plate current to flow through the speaker windings.*—See Fig. 16.

19. *Draw a diagram of a microphone circuit, complete with two stages of audio amplification.*—See Fig. 17.

20. *What means are used to prevent interaction*

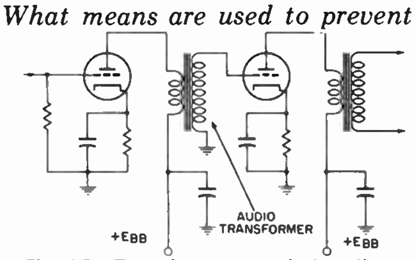


Fig. 13. Transformer-coupled audio stages.

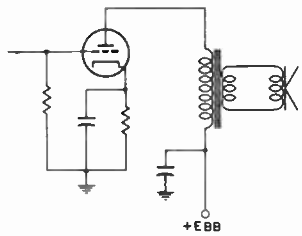


Fig. 15. Transformer-coupled audio-output stage.

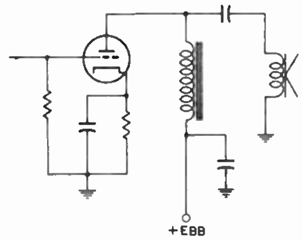


Fig. 16. Coupling to a high-impedance speaker.

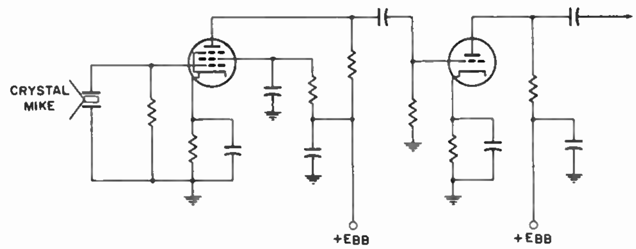


Fig. 17. Crystal microphone in two-stage amplifier.

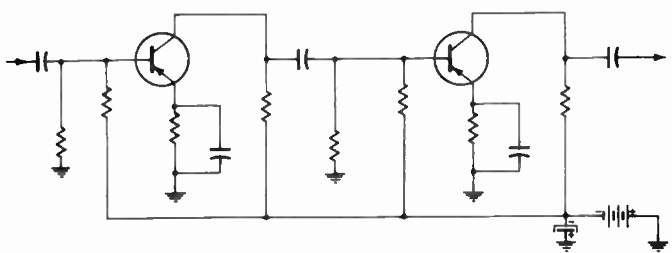


Fig. 18. Transistor two-stage audio amplifier.

between the stages of an audio-frequency amplifier?—Use of proper decoupling networks, usually resistor-capacitor combinations in the plate and screen supply-voltage lines. Such networks effectively decouple the individual stage current and voltage variations from the common impedance of the power supply, which is linked to all stages of the amplifier.

Proper shielding of stages and correct layout of wiring and components are also important. In particular, the very weak signal input circuit should be isolated from the high-magnitude output circuit.

21. *What may cause self-oscillation in an audio amplifier?*—Improper decoupling and bypass circuits, open DC coupling capacitors and defective components in feedback networks, or any spurious feedback paths that cause an output-signal component to reappear in phase with the grid signal of some preceding stage.

22. *What may cause low plate current in a vacuum-tube amplifier?*—An increase in bias, or a decrease in the plate or screen supply voltage. Loading and excitation to an RF amplifier will also influence the plate current.

23. *List some causes of distortion in a Class-A audio-frequency amplifier.*—Improper bias, plate or screen voltage, or load impedance; too strong an input signal; a defective tube.

24. *Why are pairs of wires carrying AC heater current in audio amplifiers twisted together?*—To reduce the strength of radiated fields and minimize the likelihood of hum pickup.

25. *What are the advantages of using two tubes in push-pull instead of in parallel in an audio-frequency amplifier?*—(1) More output can be obtained because each stage need amplify only one polarity of the input signal. (2) Even harmonics are canceled. (3) Hum is reduced. (4) A more economical transformer can be designed because DC core saturation is not as great a problem.

26. *Discuss the input-circuit requirements for the grid circuit of a Class-B audio-frequency amplifier.*—(1) The power dissipated in the grid circuit must come from the driving stage. (2) The input transformer must provide a match between the output of the driving stage and the low-impedance input circuit of the grid. (3) The driving stage and grid-bias source must have good regulation; otherwise, the output will be nonlinear.

27. *Draw a simple schematic of a two-stage audio amplifier using PNP transistors.*—See Fig. 18.

REVIEW QUESTIONS

1. When is a close-talk microphone advisable for use in two-way radio applications?
2. What is a differential microphone?
3. How important is frequency response in selecting a communications microphone?
4. Name the major advantage of a carbon microphone.
5. What is the principle of operation of a dynamic microphone?
6. What is the purpose of a speech amplifier in a transmitter?
7. What type of microphone requires a battery or a source of DC voltage?
8. What type of microphone can be connected directly to the grid of a vacuum-tube amplifier?

Answers to these questions will be included in PHOTOFACT Set No. 569

ANSWER SHEET

For Questions in Lessons 5 through 8

LESSON 5—ANSWERS

1. Classes A, B, and C. The Class-A amplifier is biased to operate on the linear portion of the transfer curve. Plate current flows during the entire period of the grid signal voltage. In Class-B operation, the tube is biased at cutoff, and plate current flows for approximately one-half of the duration of the grid signal voltage (during the positive alternation). In a Class-C amplifier, the tube is biased below cutoff so that plate current flows for only a small portion of the positive alternation of the input waveform.
2. The efficiency of a Class-C amplifier is influenced by the grid bias, the amplitude of the input signal, the duration of conduction, and the characteristics of the load.
3. The self-bias developed by current flow in the grid-leak circuit.
4. The unloaded Q of a resonant circuit is high in comparison to its Q under load. The power drawn by the next stage or the antenna system introduces additional effective circuit resistance; consequently, the Q of the resonant circuit (loaded Q) drops to a value lower than when the circuit is unloaded.
5. The bursts of plate current which supply energy to the tuned circuit.
6. In a resonant circuit, energy in transferred back and forth between the inductive and capacitive components. The initial flow of current builds up a magnetic field about the coil. When the current starts to decrease, the field begins to collapse; in so doing, it causes an induced current flow which charges the capacitor. The capacitor can charge only to a level determined by the available energy in the circuit; once charged, the capacitor then begins to discharge, causing electron flow in the opposite direction. The current flow again builds up a magnetic field about the coil, which rises to its limit and then collapses to start a new cycle of activity. The energy is transferred back and forth in this manner until it is dissipated in the circuit resistance. This can be the actual resistance in the circuit, or the load resistance reflected from an antenna system or the next stage.
7. It draws more plate current because energy is being taken from the resonant circuit by the load. Consequently, more energy must be delivered to the stage from the power supply.
8. This is the RF drive voltage supplied from the preceding stage.

LESSON 6—ANSWERS

1. They are more frequency-stable and have a stronger, more constant output than simpler types of self-excited oscillators. Their frequencies can be varied.
2. Fixed operating frequency and minimum frequency drift with changes in loading and operation.
3. A small adjustable capacitor can be placed across, or in series with, the crystal to permit a very limited adjustment of oscillator frequency.
4. A multiplier stage or a series of stages is used to raise the frequency of the oscillator to the desired transmitting frequency.
5. In a frequency-doubler circuit, the output circuit is tuned to twice the frequency of the exciting signal. A burst of plate current is drawn through the tank circuit for each positive alternation of the incoming excitation. Since the tank circuit is tuned to twice the frequency of the incoming signal, two cycles of oscillatory action are generated in the tank circuit for each burst of plate current. The constants of the resonant circuit are chosen so that the loss in amplitude of the single cycle, occurring between plate-current bursts, is insignificant.
6. A circuit that generates a continuous stream of oscillations without the application of external excitation. The circuit provides its own feedback to sustain oscillations. No external device such as a crystal is used to maintain the frequency of operation; the oscillating frequency is determined by the tuned circuit.
7. To a limited extent the frequency of a crystal is influenced by the ambient temperature. By mounting the crystal in an oven, the oscillator will not drift with ambient temperature changes.
8. A buffer stage is often inserted between the oscillator and a later stage to minimize the influence on the oscillator frequency of operating changes in succeeding stages.

(continued)

LESSON 7—ANSWERS

1. By adding series inductors.
2. Minimizes the influence of variable ground conditions and surrounding objects on the radiation pattern of the antenna. A ground plane contributes a gain improvement because it permits the vertical radiation pattern to be concentrated at more favorable angles.
3. The horizontal radiation pattern determines the direction in which the signal is radiated (compass angle). Antennas must be designated and oriented in a manner that provides favorable radiation and reception of signals between stations.
4. The vertical radiation pattern is important in concentrating the RF energy at the angles necessary to direct the signals between the stations in a system.
5. In the case of a mobile radio station the horizontal radiation patterns should be in all directions (omnidirectional), since the direction of the base station from the mobile unit continually changes. For point-to-point communications, a highly directional antenna can be used because the stations are permanent.
6. A collinear vertical has a sharper vertical radiation pattern than a quarter-wave vertical. All of the energy made available from the transmitter is concentrated and beamed at a very low vertical angle.
7. A quarter-wave antenna designed for 450 megacycles is approximately one-third the length of a quarter-wave antenna cut for 150 megacycles.
8. Vertical polarization is usually preferred because an omnidirectional horizontal radiation pattern can be obtained with a simple antenna construction. Furthermore, at the low height of vehicular antennas, vertically-polarized signals are less influenced by their close proximity to the earth.

LESSON 8—ANSWERS

1. In areas of high noise levels. A close-talk microphone has a strong output when held close to the mouth, but rejects surrounding noises.
2. It is designed to cancel out noise and other vibrations which arrive at the microphone from any point except directly in front. Sound vibrations from the front are emphasized, and develop a strong signal output.
3. It is preferable that the frequency response of the microphone correspond to the intelligible voice-frequency range. A rejection of very low and very high frequencies is desirable because this improves the ratio between desirable voice frequencies and other distracting noises.
4. The carbon microphone has a very high signal output.
5. The dynamic microphone operates on the moving coil principle. Voice vibrations move a small coil (attached to a diaphragm) in the field of a permanent magnet. The mechanical motion of the coil within the magnetic field causes a corresponding electrical variation to be induced into the coil. This induced coil voltage is coupled to the input of a speech amplifier.
6. The speech amplifier increases the voltage amplitude of the low level microphone signal.
7. A carbon microphone.
8. A crystal or ceramic microphone, because of the high impedance characteristics they exhibit.

Lesson 9

FM Modulation Principles

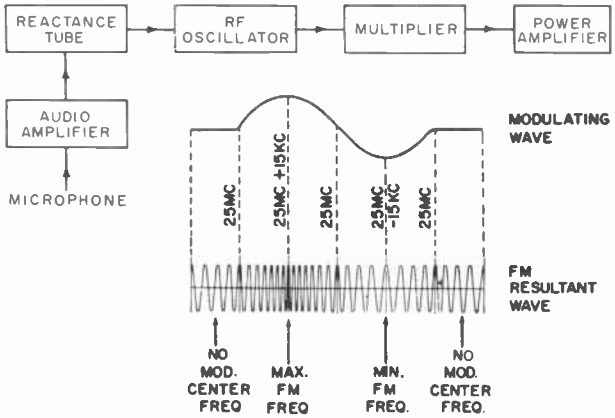


Fig. 1. Block diagram of a direct-FM system.

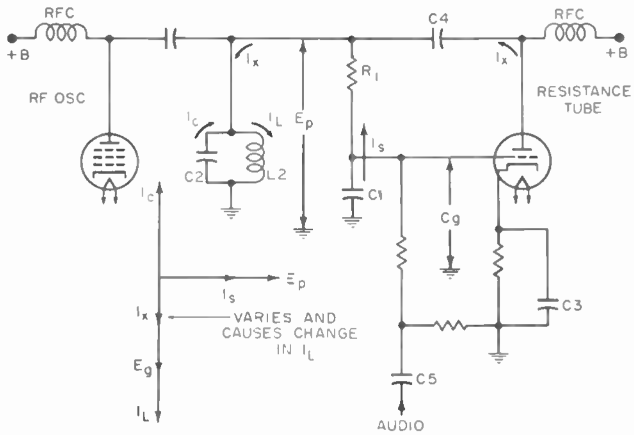


Fig. 2. Simplified schematic of a basic reactance-tube circuit.

Two basic methods are used to frequency modulate an RF carrier. One system is called direct-FM; the other is known as indirect-FM, or phase modulation. In the direct-FM process, the carrier frequency is changed by varying the resonant frequency of an oscillator tank circuit (see Fig. 1). This is accomplished by using a vacuum-tube or transistor circuit, called a reactance stage, which acts as a variable capacitor, inductor, or combination of both.

A typical reactance-tube circuit is shown in Fig. 2. The function of the reactance tube is to introduce a reactive component of current into the oscillator tank circuit. A reactance-tube circuit can be designed to deliver current which is in phase with the normal capacitive current in the resonant tank circuit. The reactance tube then can serve as a variable capacitor. It is also possible to design a reactance-tube circuit that will furnish current which is in phase with the inductive current, in which case the stage can be used as a variable inductor. In the circuit shown in Fig. 2, the reactance tube is acting as an inductance. Let us find out why.

In a reactance tube stage, a portion of signal voltage Ep, developed across the oscillator tank circuit, is applied to the grid of the reactance tube through phase-shifting network, R1 and C1. The resistance of R1 is many times greater than the reactance of C1 at the oscillator frequency, so series current I is in phase with voltage Ep. The network of R1-C1 appears as almost a pure resistance to the output of the oscillator.

As would be expected, the voltage across capacitor C1 lags the series current by 90 degrees. Consequently, RF signal voltage Eg, at the grid of the reactance tube, lags oscillator output voltage Ep by 90 degrees.

The RF grid signal results in a corresponding plate current I. This signal current is coupled via capacitor C4 back to the oscillator tank circuit. Plate current Ix is in phase with grid voltage Eg, with the result that the plate current fed back to the tank circuit through capacitor C4 lags the plate voltage Ep of the oscillator by 90 degrees.

Next, let us consider the relationship between this feedback signal and the capacitive and inductive currents (Ic and IL) of the oscillator tank circuit. RF current I, in the capacitive leg of the tank circuit, leads the tank circuit voltage Ep by 90 degrees. Likewise, inductive current I lags Ep by 90 degrees. Note that the latter phase relationship is the same as that which exists between plate current I (fed back from the reactance tube) and plate voltage Ep. Consequently, the feedback component Ix is in phase with the normal inductive current IL in the oscillator tank circuit. In effect, the reactance tube is acting as an inductor because it is introducing a lagging current into the oscillator tank circuit.

How can the reactive current I, contributed by the reactance tube, vary the frequency of the oscillator tank circuit? This is accomplished by varying the amplitude of the RF current component fed back by the reactance tube. The resonant frequency formula, $F = \frac{1}{2\pi LC}$, tells us that the resonant frequency of a tank circuit can be increased by decreasing the inductance. A decrease in inductance lowers the inductive reactance of the tank circuit and permits a higher inductive current flow. The same thing is done when an additional inductive current component is introduced into the resonant tank circuit. By changing the cycle-by-cycle amplitude of this RF current component, we are, in effect, changing the amount of inductance inserted by the reactance tube. In fact, if we vary the amplitude of the RF feedback current at an audio rate, we can cause the frequency of the tank circuit and its associated oscillator stage to vary with the audio information. This is frequency modulation.

The RF plate current Lx is made to vary in amplitude by applying the audio signal to the control grid of the reactance tube as shown in Figs. 1 and 2. To understand the influence the audio signal has on the amplification of the radio-frequency component, one can consider the audio wave as changing the grid bias of the reactance tube at an audio rate. This causes a change in gain and, therefore, variations in the amplitude of the RF output current Ix.

In the earlier study of vacuum-tube characteristics, you learned about mutual conductance Gm. Gm is the ratio of a change in plate current to a change in grid voltage, or:

$$G_m = \frac{I_P}{E_G}$$

In the reactance tube circuit, the amplitude of the RF grid voltage Eg is constant, and it is necessary to change the Gm of the tube in order to develop a change in plate RF-current amplitude. For a reactance stage, tube operation is essentially linear. Thus, the audio signal on the grid of the reactance tube causes its conduction to vary correspondingly.

The RF plate current varies in amplitude because the Gm of the tube is being changed at an audio rate. Changes in the inductive current component in the oscillator tank circuit follow, and cause a variation in the resonant frequency of the tank circuit at the audio frequency rate. Thus, the oscillator frequency deviates above and below its normal resting frequency with the positive and negative alternations of the audio signal applied to the control grid of the reactance tube.

Usually a triode, or a pentode connected as a triode, is used in a reactance tube circuit. A tube is selected which provides an essentially uniform change in mutual conductance over a wide range. By so doing, a more linear deviation of the oscillator frequency can be obtained.

In a direct-FM system, the frequency of the RF carrier is varied directly, at an audio rate, as shown in Fig. 1. This is accomplished by varying the actual resonant frequency of the carrier oscillator. In the example, the frequency is highest on the positive alternation and falls to a minimum at the crest of the negative alternation. The *amount* the carrier frequency departs from the center frequency is called the deviation, and depends on the amplitude of the audio signal.

In broadcast FM, maximum permissible deviation is 75 kilocycles, which corresponds to 100% modulation. In the sound transmission associated with television broadcasting, the maximum permissible deviation is 25 kilocycles. In most radiocommunications services, the maximum permissible deviation is either 15 kilocycles or 5 kilocycles. A signal of greater amplitude will cause a wider deviation of the oscillator frequency than one of lower amplitude. The *rate* at which the oscillator frequency changes depends on the frequency of the audio applied to the reactance tube. The higher the audio-signal frequency, the more rapidly the oscillator will change from its center-frequency to maximum deviation, then to minimum, and back to center frequency.

There are other types of phase-shifting networks used between the carrier oscillator and the reactance-tube grid. Each performs the same basic function, introducing a leading or lagging component into the grid circuit of the reactance-tube. The one shown in Fig. 3 causes a leading current component in the plate circuit; therefore, the reactance-tube appears as a variable capacitance across the oscillator tank circuit.

In this network the reactance of capacitor C1 is much greater than the resistance of R1. Since the reactance dominates the resistance, series current I

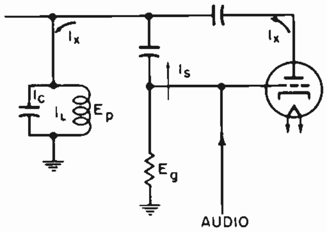


Fig. 3. Basic capacitive-reactance tube circuit.

leads plate voltage Ep by approximately 90 degrees. Since the current through and the voltage across the resistor are in phase, the grid voltage Eg at the reactance tube will lead the oscillator output voltage Ep by 90 degrees. The reactance tube plate current is in phase with the grid voltage; therefore, the RF plate current component I will also lead the plate voltage Ep of the oscillator. This plate current component, when fed back through capacitor C2 to the oscillator tank circuit, will be in phase with the capacitive current in the tank circuit. Therefore, the feedback current will alter the frequency of the oscillator by effecting a capacitive variation.

MODULATION INDEX

The ratio of frequency deviation to modulating frequency is called the modulation index, and is written as follows:

$$\text{modulation index} = \frac{\text{deviation}}{\text{modulating frequency}}$$

With a given audio frequency, the bandwidth of the FM wave is determined largely by the modulation index. As mentioned in an earlier lesson, if one were to break down the complex FM wave for analysis, it would be found to consist of a carrier frequency with an upper and a lower sideband for each harmonic of the modulating frequency, sometimes to the tenth harmonic. The higher the modulation index, the greater will be the number of sideband pairs created and the wider the bandwidth occupied by the FM wave.

The formula tells us that with a greater deviation, the modulation index becomes higher; with a decrease in the modulating audio frequency there will also be an increase in the modulation index. If the modulation index is permitted to exceed the design limit of 5, additional sidebands are created as a result of the interaction between the usual sideband pairs. This causes an increase in the required bandwidth and lowers the noise-rejection characteristics of the system. However, the relationship between bandwidth and modulation index is not a linear one, because when the modulating frequency decreases there is a slight decrease in the bandwidth, due to closer spacing of the sideband pairs, while at the same time the modulation index is rising in value.

In FM systems we are particularly concerned with the modulation index at the highest audio frequency. The modulation index determines the maximum deviation permissible while transmitting the highest audio frequency component at maximum amplitude deviation. The working formula for this is stated as follows:

$$M = \frac{\text{Maximum Deviation}}{\text{Highest Modulating Frequency}},$$

where M must remain not more than 5.

The greater the modulation index and the higher the audio frequency limit, the greater the bandwidth needed. Relatively wide channels are needed to transmit broadcast-FM signals, and even the sound signals associated with television broadcasting. In the communications services the channel widths are limited by reducing the deviation and the maximum audio frequency. As mentioned previously, in most communication services the deviation is limited to 15 kilocycles or less, while the maximum audio is seldom greater than 3,000 cycles. These limitations do not seriously harm the noise rejection characteristics of FM transmission, since the modulation index remains at the practical level. Noise in a radio communication system is related to bandwidth; maintaining a low modulation index in the communications services, good noise rejection characteristics exist even though the bandwidth is more confined than in broadcast FM.

INDIRECT FM

Frequency modulation can also be obtained using an indirect method. In the process shown in Fig. 4, the RF carrier is phase-modulated. In most indirect-FM systems the RF oscillator is crystal-controlled. In the phase-modulation process, individual RF cycles in the modulator are caused to lead or lag the original RF cycles (from the oscillator) in accordance with audio variations. In so doing, the duration of the individual cycles are stretched out or compressed; in other words, the time required to complete each cycle is increased or decreased.

The frequency of a wave is related to the time (period) required to complete a cycle. If a cycle is "stretched out" in time (period), a lower-frequency wave results. If the time period is shortened, a higher frequency wave results. Hence, by shifting the phase of the RF cycles at an audio rate, a frequency-modulated wave results (an FM signal has been obtained by indirect modulation).

Phase or angle-modulation can be accomplished in a number of ways. The basic system shown in Fig. 4, was developed by Armstrong. The center-frequency signal is supplied to a buffer-amplifier and to a balanced-modulator stage. The audio signal also is applied to the balanced modulator. The balanced

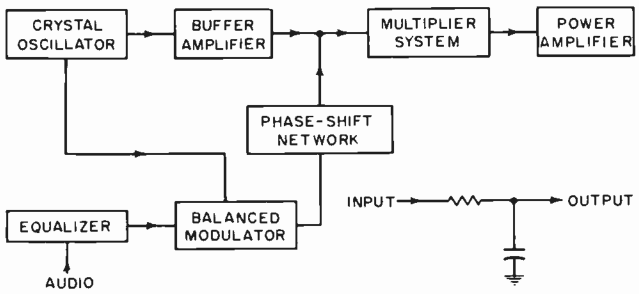


Fig. 4. Block diagram of a basic phase-modulation system.

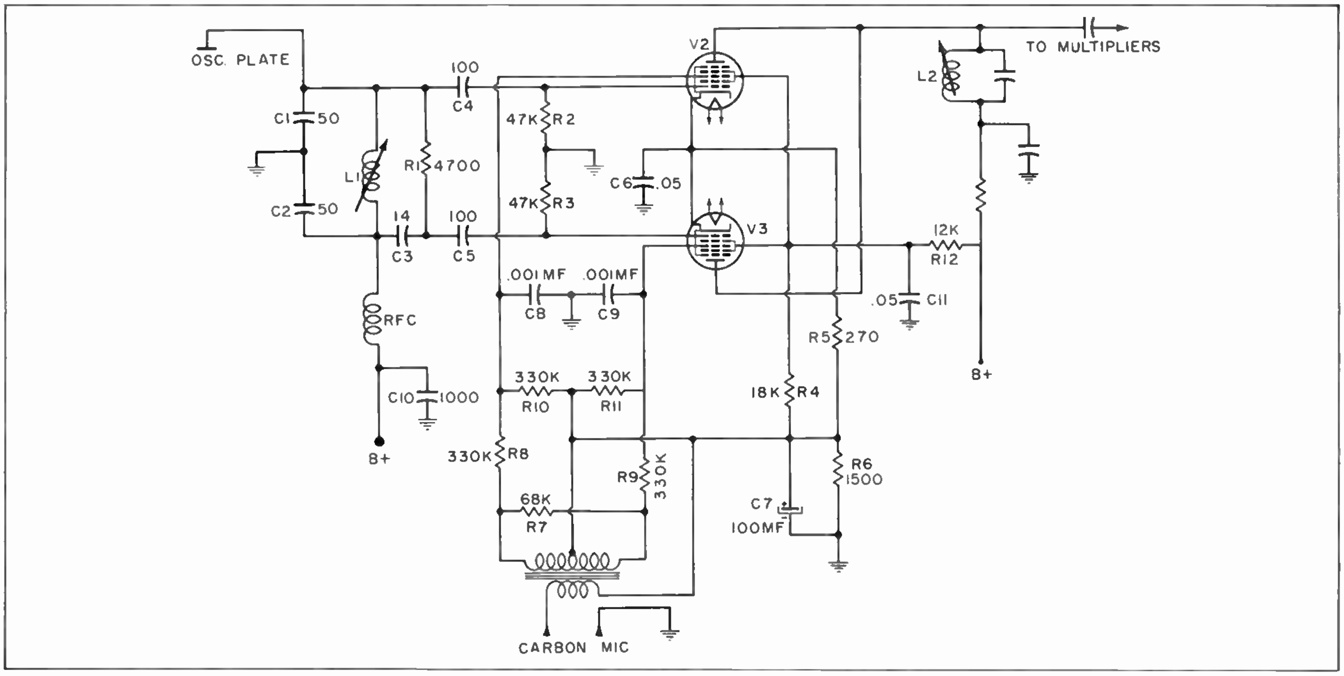


Fig. 5. Typical modern balanced modulator circuit.

modulator produces two amplitude-modulated sideband components without a center-frequency component. Thus, the output of the balanced modulator consists of two sidebands similar to those which might be obtained using amplitude modulation at a low modulation percentage, but with the center-frequency signal removed.

The sideband components are then applied to a network which produces a 90-degree phase shift, after which the sideband frequencies are recombined with the center-frequency component that has passed through the buffer amplifier. The buffer amplifier serves to assure that the mixed signals will have no effect on the crystal oscillator. In the mixing process, a phase-modulated resultant is obtained. The presence of the sidebands, with their 90-degree phase shift, shifts the phase of the resultant signal with respect to the original center-frequency signal at a rate equal to the audio-signal variations. The continually changing phase shift results in a phase-modulated wave.

There is one fundamental difference between frequency and phase modulation. In a pure FM system the deviation is constant for a given amplitude of audio, regardless of the audio frequency. The modulation index formula tells us that a change in audio frequency will cause a change in the modulation index if the deviation remains fixed. Thus, in a frequency modulation system the modulation index changes with the audio frequency.

In a phase modulation system it is the modulation index which remains constant for a given audio amplitude regardless of audio frequency. Inasmuch as the modulation index is constant, the deviation must vary somewhat with the audio frequency. In practice the higher the audio frequency of a given amplitude, the greater the resulting frequency deviation when using phase modulation. This nonlinear deviation characteristic of phase modulation systems is usually compensated by some form of equalizing network which is inserted between the audio source and the balanced modulator, as indicated in Figure 4. In communications FM systems, this nonlinearity is negligible due to the narrow range of audio frequencies utilized (300 to 3,000 cycles—only a 10-to-1 ratio of highest-to-lowest frequency). So, in modern communication transmitters, such as the balanced-modulator system shown in Fig. 5, the normal deviation limiting devices and circuits take care of any slight tendency of the modulator efficiency to be affected by the frequency of the modulating audio frequency.

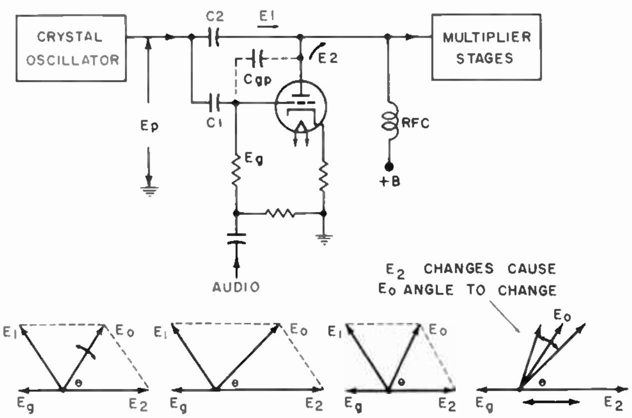


Fig. 6. Vector analysis of a narrow-band phase modulator.

NBFM PHASE MODULATOR

In FM radiocommunications, the maximum permissible deviation is much less than permitted in FM broadcasting. Consequently, a simpler form of phase modulator can be used. A common type of narrow-band phase modulator is shown in Fig. 6. Most communications FM transmitters use this type of modulator.

The RF oscillator output voltage Ep follows two paths—one to the control grid of the phase modulator through capacitor C1 and the other directly to the plate circuit of the modulator through C2. Hence, part of the modulator plate RF voltage is fed directly from the oscillator while the other portion is developed through amplification in the phase modulator tube.

Since a tube produces a polarity reversal of the signal, it would seem that the two components present in the plate circuit would be 180° out of phase. This is not the case, however, because capacitors C1 and C2 have low values, chosen to establish a desirable phase relationship between the two RF voltage components in the plate circuit of the phase modulator. The direct component E_1 and the component that arrives through tube action E_2 are indicated in the vector diagrams associated with Fig. 6.

It would also seem that E_2 should be greater than E_1 because of amplification by the phase modulator tube. However, the values of C1 and C2, and the operating voltages of the phase modulator, are chosen to keep the two components at a comparable voltage level. In some phase modulator circuits, a small amount of degenerative feedback (in Fig. 6 the cathode is unbypassed) assists the phase modulator in maintaining E_1 and E_2 at equal levels.

Two out-of-phase components of the RF voltages are present in the plate circuit of the phase modulator. In the phase modulation process, the amplitude of RF voltage E_2 is varied by the audio signal being applied at the grid. Its amplitude varies in relation with the constant amplitude of the direct oscillator voltage component E_1.

The audio signal applied to the grid circuit of the phase modulator and varies the phase modulator grid voltage at an audio rate. When a proper tube and bias have been chosen for the phase modulator, these variations produce a linear change in the mutual conductance of the tube.

Since the Gm of the tube is changed by the audio variation, the E_2 voltage developed at the output of the phase modulator varies in amplitude at an audio rate.

However, there are two components of RF voltage in the plate circuit, E_1 and E_2. The output voltage furnished to the grid of the next radio-frequency stage is the vector sum of E_1 and E_2. This resultant voltage is Eo, shown in the vector diagrams. Notice in Fig. 6 how the phase angle of Eo also changes as the amplitude of E_2 varies with the applied audio. The higher the amplitude of the applied audio, the greater the phase deviation. The higher the frequency of the applied audio, the more often the angle swings between its extremes.

Of course, the amplitude of the resultant Eo also varies. So in the phase-modulation process some amplitude modulation is also introduced. However, the succeeding multiplier stages of the transmitter tend to smooth out these amplitude variations, leaving only the frequency-modulated wave. In this respect, their action can be compared to that of the limiters in an FM receiver.

PRE-EMPHASIS AND DE-EMPHASIS

A major advantage of an FM transmission system is that it can be designed to reject noise components. Since most noise signals of the amplitude-varying type, an FM system displays favorable signal-to-noise characteristics. This rejection of AM components is particularly important in vehicular installations, where ignition noises are present.

However, noise and interference also produce FM components, so FM systems are not completely noise free. Steps are taken to assure that the modulation deviations of the FM signal are much greater than random deviations caused by noises and interference.

In an FM system such as shown in Fig. 7, noise interference has less effect when it exists at low audio frequencies, since audible interference consists largely of higher audio frequencies. Thus, the noise-rejection characteristics of an FM system decrease when the noise frequencies are higher.

The noise-rejection characteristics can be improved by using pre-emphasis. Pre-emphasis, as shown in Fig. 8, is inserted in the audio-amplifier section of the transmitter. The pre-emphasis network provides attenuation with decreasing audio frequency. Consequently, higher-frequency audio causes a greater deviation of the transmitter than

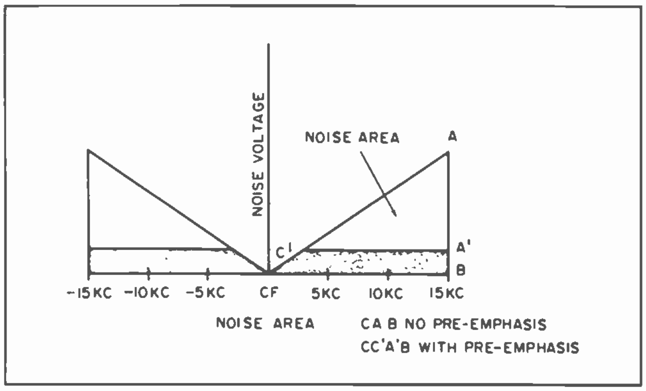


Fig. 7. Noise as related to separation from center frequency.

lower-frequency audio of the same amplitude. In this way, the system is made less subject to noise interference because of the more favorable relationship between desired and undesired high frequencies in the FM signal. This reduction in high-frequency noise susceptibility produces a better over-all signal-to-noise ratio as shown in Fig. 7.

In FM radiocommunications the auditor range usually extends between about 300 cycles and 3,000 cycles. Thus, pre-emphasis affects only this audio range. Above this high-frequency limit, the response of the system is attenuated very sharply so as not to transmit higher-frequency audio components. Likewise, high-frequency noise components originating in the transmitter are attenuated severely and the noise rejection characteristic of the over-all FM system is again improved.

The audio-frequency response of the FM system is restored to a linear relationship by the use of a de-emphasis network in the receiver. Refer again to Fig. 8. This network has a frequency characteristic equal to but opposite that of the transmitter pre-emphasis circuit. The de-emphasis network in the receiver reduces the amplitude of the high-frequency

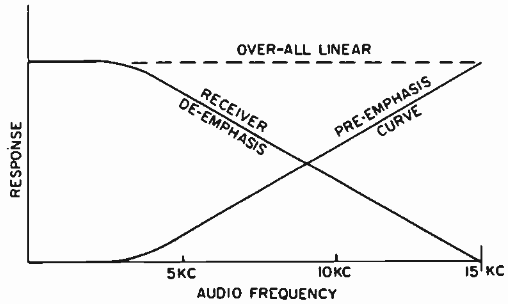


Fig. 8. Over-all frequency response made linear by de-emphasis in the receiver.

audio components returning them to the proper level relative to the lower audio frequencies. Consequently, any received noise components are reduced a like amount.

In summary, the use of pre-emphasis and de-emphasis permits a linear transmission response with respect to the desired audio frequency range. In addition it helps the signal-to-noise and signal-to-interference ratios, improving on the inherently good noise and interference rejection characteristics of FM transmission.

MULTIPLIER FUNCTION

The amount most practical direct or indirect FM systems can vary the frequency of the oscillator output is limited. The oscillator deviation is usually only a small fraction of the maximum required for the transmitted frequency. In the interest of frequency stability, a low oscillator frequency is used in both radiocommunications and broadcast FM transmitters. A series of frequency-multiplier stages are used to raise the oscillator frequency to the transmitted frequency. Fortunately the multiplier stages multiply not only the carrier or center frequency but the deviation as well.

In the phase modulation system used in broadcast FM, only a very limited deviation of the oscillator frequency can be permitted if low distortion is to be maintained. A crystal frequency of only several hundred kilocycles is used and a total multiplication of more than 800 is required to obtain the very-high frequency and 75-kc deviation of broadcast FM.

In radiocommunications, however, the required amount of multiplication is much less because of the more limited deviation. Multiplications between 12 and 36 are common. Crystal oscillators are in the 6- to 12-mc range. A 10-mc oscillator signal need be deviated only 1,000 cycles to produce a ±15-kc swing of a 150-mc transmitter frequency. In this case the total multiplication would be 15 (15 x 10 mc and 15 x 1 kc).

TYPICAL PHASE MODULATOR SYSTEM

The phase modulation system used in the Aerotron communications transmitter (Fig. 9) is shown schematically in Fig. 10. A crystal oscillator stage is used to supply RF drive to the control grid of the phase modulator, through capacitor C211, and to the phase modulator plate circuit through capacitor C212. Inductor L212 is an RF choke. The phase modulator output drives the succeeding buffer and multiplier stages.

The microphone signal is coupled through capacitor C201 to pre-emphasis network R202-C202-R203 and on to the grid of the triode section of tube V201. As audio frequency increases, the microphone signal sees a lower and lower reactance path

Fig. 9. Typical vehicular two-way radio.

through capacitor C202, while lower-frequency audio must take the path through R202. Therefore, a greater percentage of the higher audio frequencies are developed across resistor R203 and impressed on the grid of the tube. Lower frequency components, attenuated by resistor R202, develop less voltage across grid resistor R203.

The audio-frequency range of this speech circuit is 300 to 3,000 cycles. The pre-emphasis network has a rating of 6 db per octave. This means there is a 6 db increase (equivalent to a voltage gain of 2) in modulation level each time the frequency is doubled. For example, if two equal frequency components of 1,000 and 2,000 cycles are applied to the input of the network, the 2,000-cycle note would be emphasized 6 db above the 1,000-cycle note at the output of the pre-emphasis network.

To obtain a correct over-all response in the FM system, it is necessary to use a de-emphasis network at the output of the FM demodulator in the receiver. Such a network is shown in Fig. 11. If correct frequency compensation is to be obtained, the attenuation characteristics of the de-emphasis network must also be 6 db per octave over the 300-to-3,000-cycle range, but in the opposite direction. In other words each time the frequency is doubled there would be an additional 6 db of *attenuation*. In this case, a 2,000-cycle note would incur a loss 6 db greater than a 1,000-cycle note when passing through the de-emphasis network. Under this condition 1,000- or 2,000-cycle notes at the output of the de-emphasis network would be restored to the same relative amplitude they had just ahead of the pre-emphasis network in the transmitter.

The pre-emphasized microphone signal is amplified by the triode section of tube V201, Fig. 10. The signal is then applied to a symmetrical diode clipper. The function of the clipper is to remove negative and positive audio peaks beyond a given level so as not to overmodulate the transmitter; the circuit is called an automatic deviation control.

For normal signal levels, both diodes conduct and the signal is transferred through the clipper and via capacitor C210 to the phase modulator. Refer to Figs. 10 and 12. If there is an excessive *positive peak* applied to resistor R207, cathode 3 will become more positive than plate 6. Consequently, the left diode cuts off and prevents the transfer of the positive peak to the output. A *negative peak* will pass through the conducting left diode and will appear on the common plates of the diodes. However, if the negative peak is excessive it will make plate 1 negative with respect to cathode 2. Thus, the right diode will cut off when a strong negative peak is present.

In other words, as shown in Fig. 12 the two diodes are effectively in series with the signal path. If either is cut off, the signal will be blocked from the output. This is the condition that occurs when a strong positive peak cuts off the left diode, or a strong negative peak cuts off the right diode.

The amplitude of audio signal applied to the grid of the phase modulator is controlled by potentiometer R215, which is called the modulation deviation control. Its operation is similar to a volume or gain control but its adjustment is more specific. Recall that the amplitude of audio signal at the phase modulator grid determines the angular deviation of the resulting phase-modulated wave and, therefore, the extent of the frequency deviation. To properly adjust R215, audio signal from the microphone must be sufficient to cause some clipping by the automatic deviation control circuit on modulation peaks. When such a signal is being supplied, deviation control R215 is adjusted for proper transmitter deviation (± 5 kc or ± 15 kc depending on FCC assignment).

The network composed of C209, C214, R214, and R215 form the equalizer network mentioned earlier. Equalization is necessary when phase modulation is used, so as to derive a true FM signal. This equalizer network acts as a low-pass filter with a 12 db-per-octave attenuation characteristic. Thus, equal-amplitude audio signals cause the same frequency deviation of the RF carrier regardless of audio frequency.

In practical radiocommunications systems using direct-FM modulation, pre-emphasis is used at the transmitter and de-emphasis at the receiver. In phase modulation systems which develop an FM signal by indirect means, both are used at the receiver. The function of the transmitter equalizer is to form the same complex wave generated in a direct-FM system, even though using the phase- or angle-modulation process.

LICENSE EXAMINATION PREPARATION

1. *What are the merits of a frequency-modulation communications system compared with an amplitude-modulation system?*—An FM system has better signal-to-noise and signal-to-interference ratios. FM systems are better suited for mobile operation because they are less susceptible to the impulse noises generated by ignition systems generators, and they are able to suppress AM components. (Most noise sources produce strong AM components.)

2, *What effect, if any, does modulation have on the amplitude of the antenna current of a frequency-modulated transmitter?*—The antenna current does not change. In frequency modulation, the frequency —not the amplitude—of the radiated wave changes with the modulation.

3. *In an FM radiocommunications system, what is the meaning of modulation index? Of deviation ratio?—What values of deviation ratio are used in an FM radiocommunications system?*—The modu-

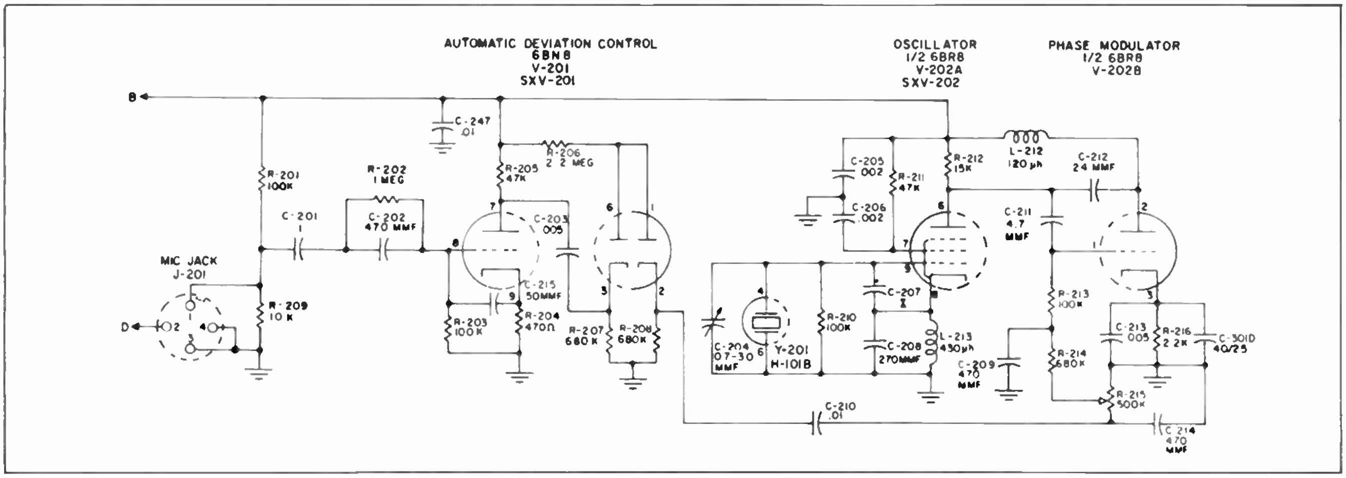


Fig. 10. NBFM phase modulation system of Aerotron transmitter.

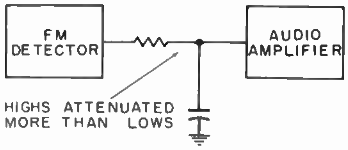


Fig. 11. Simple FM receiver de-emphasis network.

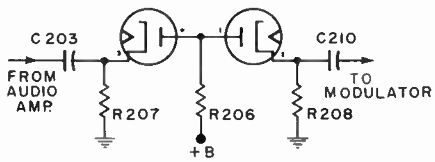


Fig. 12. Simplified schematic of an audio peak clipper.

lation index of an FM signal is the ratio of the frequency. The modulation index when a 2,000-cycle note deviates the carrier 10 kc is 5 (10 kc divided by 2 kc).

In the two-way radio services, the maximum deviations permitted are 15 kc or 5 kc. With a high-frequency audio limit of 3,000 cycles, the deviation ratios would be 5 and 1.67, respectively.

4. *Why is narrow-band rather than wide-band frequency modulation used in radiocommunications systems?*—Narrow-band frequency modulation (NBFM) requires a much narrower span of frequencies. Hence, stations can be allocated nearer each other in the frequency band. Since only a limited portion of the audio frequencies are of significance, the bandwidth can be limited. Moreover, the signal-to-noise and signal-to-interference ratios do not suffer as greatly as those of a wide-band FM system. Of course, other simplifications are possible, particularly in the modulation system of the transmitter and in the RF and IF systems of the receivers.

5. *What is the purpose of a squelch circuit in a radiocommunications receiver?*—Normally, the receiver operates at all times, to monitor the channel. When no signal is being picked up, particularly in an FM communications receiver, there is a high level of inherent circuit noise. To alleviate this disturbance, squelch circuits are included to keep the audio circuits inoperative until a signal is received. In an FM system, the incoming carrier is effective in reducing receiver noises; when the carrier is not being received, the inherent noise is very objectionable when squelching is not used.

6. *What type of modulation is largely contained in static and lightning radio waves?* — Amplitude modulation. Lightning and static radio waves produce sharp impulses of noise which generate components over a wide range of frequencies.

7. *What type of radio receiver tends to suppress static interference?*—The FM receiver, because of its AM-suppression characteristics.

REVIEW QUESTIONS

1. What is the purpose of equalization in an FM system?
2. When does a reactance tube display the characteristics of a capacitor?
3. Why is pre-emphasis used in an FM system?
4. How does the modulation index influence the band of frequencies occupied by FM signals?
5. What constitutes 100% modulation in an FM system?
6. Compare frequency and phase modulation.
7. How does Gm influence the operation of a phase modulator?
8. Give the technique for preventing overmodulating in an FM system.

Answers to these questions will be included in PHOTOFACT Set No. 573

Lesson 10

Amplitude Modulation Principles

Amplitude modulation is used in a variety of radiocommunication services from international shortwave broadcasting to Citizens band radio. AM is employed almost exclusively on the 2-3 megacycle marine band, and is used for communications in the aeronautical services between 108-135 megacycles. Single-sideband transmission (a variety of amplitude modulation) has become very popular in the entire spectrum between 2-40 megacycles. Conventional double-sideband AM is the oldest form of carrier modulation and is still widely used.

In an AM system, the intensity or amplitude of the carrier wave is varied by the information to be transmitted. In contrast to a frequency modulated wave, which can have more than one pair of significant sidebands, the amplitude-modulated wave contains only one pair of sidebands; these are separated from the carrier frequency by the frequency of the modulating wave. When a carrier is modulated by an audio signal, three RF components are created to form the resultant AM wave—the carrier, carrier plus modulating frequency, and carrier minus modulating frequency. The actual carrier frequency does not itself vary in amplitude. Rather it is the combining of the carrier with the two sidebands which produce the resultant AM wave.

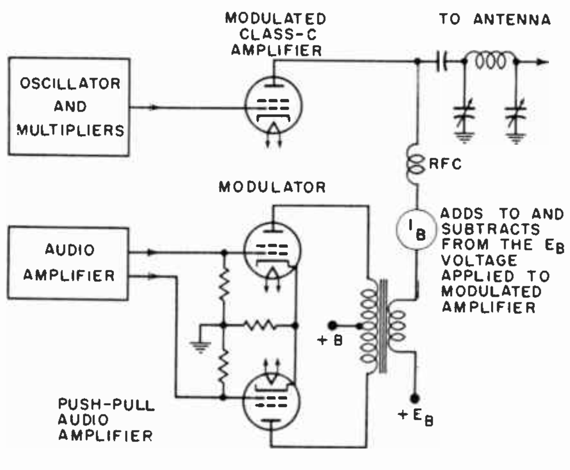


Fig. 1. Diagram of a basic plate modulation system.

PLATE MODULATION

By far the most common method of amplitude modulation is plate modulation, as shown in Fig. 1. In this system the plate voltage of a Class-C amplifier, called the modulated amplifier, is made to vary in accordance with the audio signal amplitude. The stage that provides the audio signal is called the modulator. In the lesson about Class-C amplifiers you learned of the influence plate voltage exercises on the output of an RF amplifier. Since the output of a Class-C amplifier can be made to vary in linear fashion over a substantial range of plate voltages, the technique of changing the plate voltage with the modulating signal is an ideal method of modulating the carrier.

How does the plate voltage affect the amplitude of the RF cycle? In the Class-C amplifier lesson you learned that plate current flow is in bursts which result from the positive peaks of RF excitation applied to the control grid. The magnitude of the plate-current pulse in the tank circuit determines the amplitude of the cycle formed by the resonant circuit. The higher the peak plate current, the greater the magnitude of the RF cycle.

The DC plate voltage determines the peak amplitude of the plate current for a given amount of grid excitation and bias. The higher the plate voltage, the higher the peak plate current and the greater the RF cycle formed in the tank circuit.

In the plate modulation system, the DC plate voltage is made to vary in accordance with the audio modulation. As a result the RF energy in the tank circuit varies with the plate voltage change.

In practice, a fixed amount of DC plate voltage Eb is applied to the modulated Class-C amplifier. This DC plate voltage is applied through the secondary of a modulation transformer. Voltage in the secondary adds to and subtracts from the applied plate voltage. Consequently, the plate voltage supplied to the modulated amplifier varies with the amplitude and frequency of the modulating waves. The result is a corresponding change in the magnitude of the RF energy in the tank circuit of the Class-C amplifier.

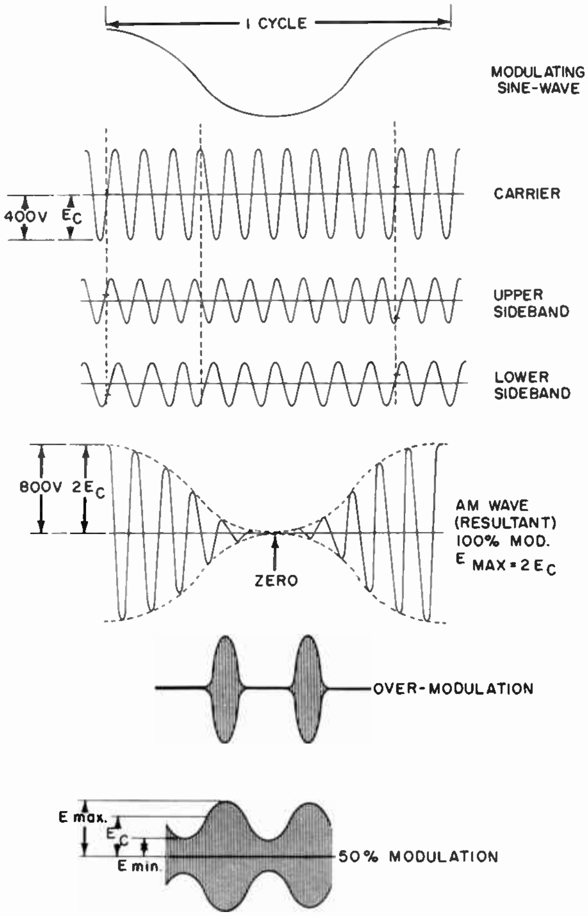


Fig. 2. Examples of AM modulation waveforms.

The *rate* at which the RF changes in magnitude depends on the frequency of the applied modulation; the magnitude of the modulating wave determines the variation of the RF amplitude. This latter change is more often spoken of as the degree or depth of modulation.

An AM wave is said to be modulated 100% when the magnitude of the RF signal varies from zero to twice the unmodulated amplitude as shown in Fig. 2. In the example it can be seen that the peak voltage of an unmodulated RF signal has been assigned a value of 400 volts. When the AM wave is 100% modulated, by a modulating voltage of sufficient amplitude across the secondary of the modulation transformer, the amplitude of the RF cycle at the crest of the modulating voltage is 800 volts peak (2 x 400). In the trough of the modulation, the amplitude of the RF cycle is zero.

It is not advisable to allow modulation in excess of 100% (as demonstrated in Fig. 2b) because distortion results and the band-width of the transmitted signal becomes excessive. Thus, it is necessary to limit the amplitude of the modulating voltage to a level that will not cause modulation in excess of 100%. Usually some form of audio clipper, similar to that used in the FM communications system, limits the peak amplitude of the modulating wave so as not to produce modulation in excess of 100%.

Of course, modulating waves of lower magnitudes produce lower modulation percentages. For example, if the modulating voltage increases the peak amplitude of the RF cycle only 50% at its crest, the AM wave is said to be 50% modulated—as in Fig. 2c. The formula for modulation percentage is as follows:

$$\%\ \text{Modulation} = \frac{\text{Emax} \times \text{Emin}}{2\ \text{Ecarrier}} \times 100$$

POWER AND IMPEDANCE RELATIONS

Just as the output transformer of a radio receiver or high-fidelity amplifier must match the impedance of the loud-speaker system, the modulation transformer must match the output impedance of the audio power amplifier (modulator) to the input impedance of the modulated Class-C amplifier. The approximate impedance of the RF amplifier is determined by its plate voltage and plate current. For example, if the DC plate voltage Eb is 400 and DC plate current Ib is 100 ma, the modulation transformer must match the output of the modulator to an impedance of:

$$R_{\text{IN}} = \frac{\text{Ib}}{\text{Eb}} = \frac{400}{.1} = 4{,}000 \text{ ohms}$$

How much audio power must be made available to modulate this Class-C stage? The *unmodulated* power input can be determined by using one of the following formulas:

$$P_{\text{IN}}\ (\text{unmod}) = \text{EbIb} = \frac{(\text{Eb})^2}{R_{\text{IN}}} = (\text{Ib})^2 R_{\text{IN}}$$

$$P_{\text{IN}}\ (\text{unmod}) = 400 \times .1 = 40 \text{ watts}$$

This amount of power is being supplied continuously to the Class-C amplifier, whether or not it is modulated, from the power supply. The additional power needed to obtain modulation must be in the form of audio power supplied by the modulator. To double the plate voltage Eb applied to the stage in attaining 100% modulation, it is necessary that the modulating voltage also have a peak amplitude of 400 volts. The modulating voltage must be changed to RMS value for calculating AC sine wave power. The audio power needed is as follows:

$$P = \frac{E^2}{R}$$

$$P_{\text{MOD}}\ (\text{output}) = \frac{(.707 E_{\text{P MOD}})^2}{R_{\text{IN}}}$$

$$P_{\text{MOD}}\ (\text{output}) = \frac{(.707 \times 400)^2}{4000} = \text{approx. } 20 \text{ watts}$$

In summary, to obtain 100% modulation when using the plate system it is necessary that the audio power output equal ½ the normal unmodulated DC power input to the modulated amplifier stage. Of course, for a lower modulation percentage, less audio power output is required. In the AM radio communication services, it is necessary to modulate the transmitter as fully as possible. The higher the modulation percentage, the greater the transmitter range. However, to prevent distortion and the radiation of signals outside of the assigned bandwidth, it is also necessary to prevent overmodulation.

This could be difficult with nontechnical persons operating the radio equipment. Consequently, some foolproof method must be used which will cause the transmitter to be modulated in depth without the hazards of overmodulation. This is the responsibility of the audio clipper, which permits a high average modulation, at the same time preventing overmodulation peaks.

MODULATED POWER OUTPUT

The actual power output of a modulated transmitter is somewhat less than the power input. Let us assume that the modulated RF amplifier has an efficiency of 60%. This would mean that when the unmodulated power input is 40 watts, as in our example, the unmodulated power output of the transmitter will be 24 watts.

$$P_{OUT}\ (\text{unmod}) = \text{EFFICIENCY} \times P_{IN}\ (\text{unmod})$$

$$P_{OUT}\ (\text{unmod}) = .6 \times 40 = \text{watts}$$

This is the carrier power output of the transmitter whether or not it is modulated.

When the transmitter is fully modulated, an additional 20 watts of input power is supplied from the modulator. This makes an additional 12 watts of power output available. However, this power goes into the sidebands of the transmitter. Since there are two sidebands, each sideband has a power of 6 watts. The power in the carrier is unchanged from its unmodulated value. It is apparent that with 100% modulation there is a 50% increase in the power output of the transmitter. Furthermore, all of this increase, which goes into the generation of the two sidebands, is supplied by the modulator.

The two sidebands are identical except one is above the carrier frequency and one is below the carrier frequency. Both contain the same audio information. It is apparent that conventional amplitude modulation is a rather wasteful method of communication transmission; in our example a total power output of 36 watts is radiated to convey the information that is present in a single 6-watt sideband.

It is anticipated that within a few years more AM systems will be operated at improved efficiency. Single-sideband systems and suppressed-carrier operation of double-sideband transmission systems will become more and more commonplace. In our example, a single-sideband system would radiate only 6 watts of power; only half the spectrum bandwidth would be needed and there would be less likelihood of interference to other services. As mentioned in an earlier lesson, however, both transmitter and receiver must be of more critical design and, in certain applications, would be more costly to build and maintain.

OTHER AMPLITUDE MODULATION METHODS

Plate modulation is by far the most common form of amplitude modulation. Two other forms of AM are shown in Fig. 3. Grid modulation is used because it requires only a small amount of audio power to modulate a Class-C amplifier of substantially greater power output.

With grid modulation, the grid bias is varied at an audio rate. The varying bias causes the RF plate current to be varied in accordance with the applied modulation. The higher the bias, the lower the peak plate current and the weaker the RF generated in the plate tank circuit. On the other hand, a decrease in the Class-C bias causes a higher plate current and RF of a higher magnitude is developed in the tank circuit.

In a grid-modulated stage, it is customary to use external bias instead of grid-leak bias. The amount of bias made available from this grid-bias supply determines the unmodulated condition and the carrier output power of the grid-modulated RF amplifier.

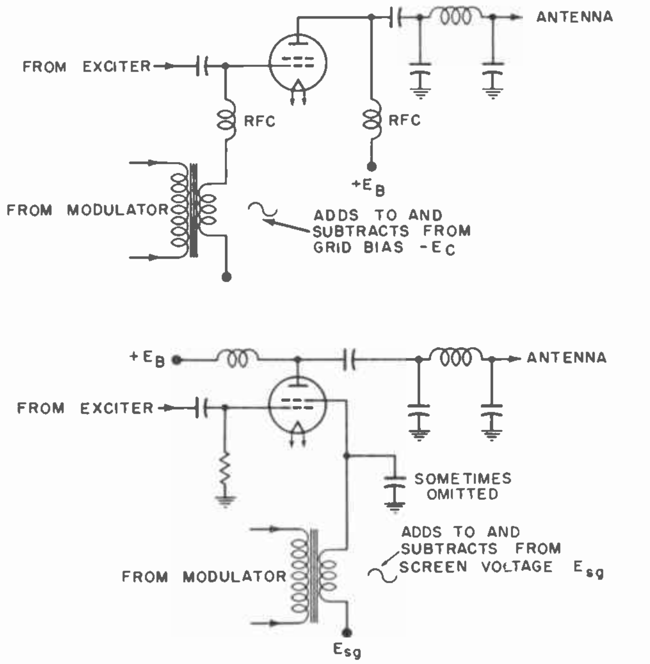


Fig. 3. Other basic AM modulation methods.

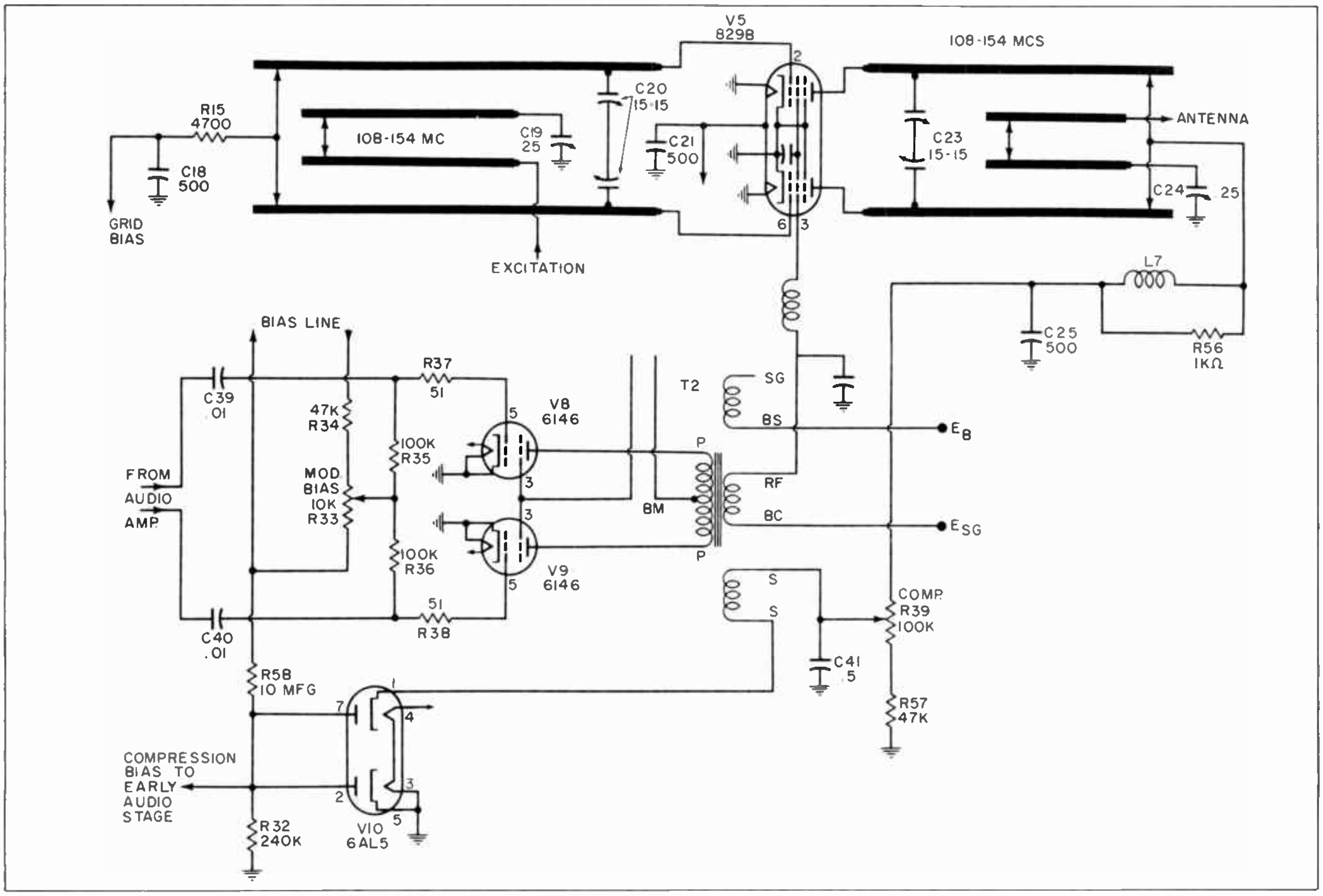


Fig. 4. Modulator and modulated amplifier of transmitter.

Fig. 5. Aerocom aeronautical base station transmitter.

The audio signal from the modulator adds to and subtracts from the fixed bias. Thus, the Class-C bias varies with the audio voltage. At minimum bias, corresponding to the positive alternation of the modulating wave, a high plate current is drawn and high-amplitude RF is generated. During the negative sweep of the modulating signal, plate current is less than the average value. Consequently, weaker RF cycles are developed in the plate tank circuit.

The same variations in amplitude of the RF output result as with plate modulation. However, these changes in the amplitude of the RF cycles can be made to occur with a small change in the grid bias voltage, as compared with the large change in plate voltage needed to produce an equivalent depth of modulation. Grid modulation takes advantage of the amplification contributed by the modulated amplifier stage itself. For this reason, much less audio power is needed to provide a given modulated power output. However, the modulated Class-C amplifier cannot be operated at as high an efficiency as is possible with plate modulation. A grid-modulated Class-C amplifier is more difficult to design and much

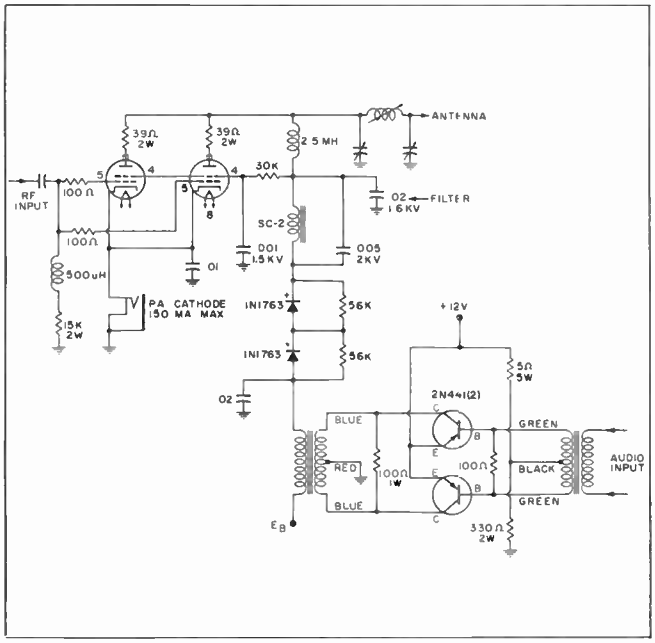


Fig. 6. Modulator and circuits for radiomarine transmitter.

more critical to adjust for a linear modulation characteristic.

SCREEN-GRID MODULATION

As you learned in an earlier lesson, the screen grid of a tetrode or pentode tube has greater influence on the plate-current flow than the plate voltage itself. Thus, it is possible to control the magnitude of Class-C plate current by varying the screen voltage. The screen grid voltage derived from the screen power supply determines the unmodulated RF amplitude. With modulation the screen voltage varies above and below the unmodulated value in accordance with the audio variations. There will be corresponding changes in the plate current; the higher the screen voltage (positive alternation of the modulating wave) the greater the plate current and the higher the amplitude of the RF in the plate tank circuit.

The characteristics of screen-grid modulation lie somewhere between those of plate modulation and control-grid modulation. For example, much less audio power is needed as compared to plate modulation, but the power requirements are greater than for control-grid modulation. In communications gear, screen-grid modulation has been found to be more stable and adjustment less critical; therefore, it is used more often than grid modulation. However, plate modulation continues to be the most popular form, since distortion is very high in the other types. Many transmitters use a combination

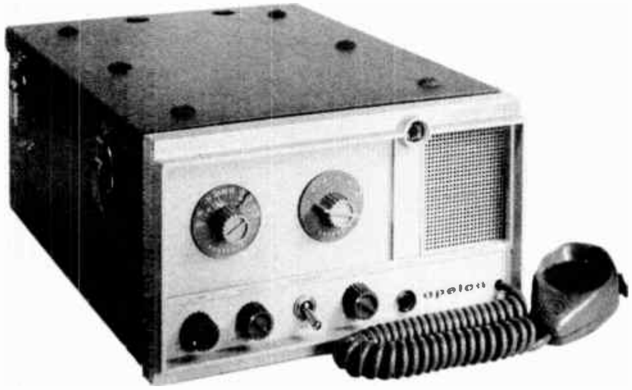


Fig. 7. APELCO radiomarine transmitter-receiver.

of plate and screen modulation to attain greater efficiency and improved modulation characteristics.

TYPICAL MODULATORS AND MODULATED AMPLIFIERS

The modulator and modulated amplifier for a 50-watt aeronautical base station transmitter are shown in Fig. 4. The Aerocom transmitter (Fig. 5) operates in the 108-135 mc spectrum. A dual beam-power pentode tube is used as the modulated Class-C amplifier. Resonant lines tune the input grid and output plate circuits. The modulator is a Class-AB_1 push-pull audio amplifier.

The modulation transformer has three secondary windings. The center secondary winding is connected in the plate circuit of the modulated RF amplifier. By so doing the plate voltage is modulated at the audio rate. The top secondary winding is connected in the screen-grid circuit and causes the screen-grid voltage also to vary with the modulation. When a tetrode or pentode tube is used as the modulated Class-C amplifier, it is possible to modulate both plate and screen grid to obtain higher efficiency and a more linear modulation characteristic.

The third winding of the modulation transformer supplies signal to a modulation-compression circuit. When the output of the modulator exceeds a predetermined level, the voltage is rectified in V10 and used to apply a controlling bias to one of the early audio stages. This negative bias, which is very much like AVC in action, cuts down the gain of the speech amplifier to prevent overmodulation of the transmitter. In practice, the compression level is set so the rectifier begins to conduct at 85% to 90% modulation, and will prevent overmodulation even though the audio input level is increased as much as 20 db. The modulation-compression system permits a high average level of modulation, at the same time preventing peaks which might overmodulate the transmitter.

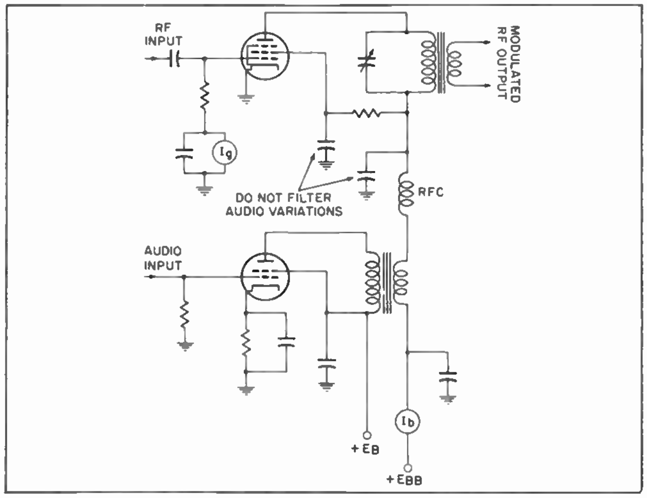


Fig. 8. Simplified plate-modulation circuit.

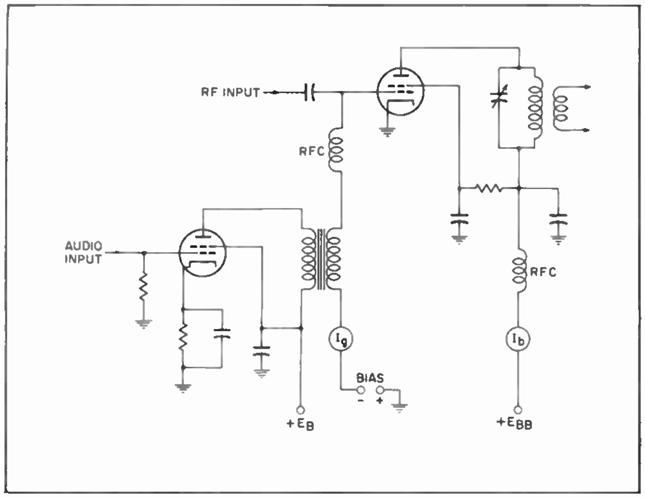


Fig. 9. Simplified grid-modulation system.

The modulator and modulated Class-C amplifier in an Apelco radiomarine transmitter is shown in Fig. 6. The modulator consists of two transistors connected in a Class-B push-pull stage. Clipping is accomplished by an especially-designed modulation transformer which saturates when the audio level is too high and, by clipping audio peaks, prevents overmodulation.

A low-pass filter is inserted in the modulated B-plus line. Filters of this type have two functions. They can be used to cut off all frequency components above 3,000 cycles. As you learned, the audio spectrum from 300 to 3,000 cycles is favored in communications because of greater intelligibility. The output filter is also helpful in reducing any waveform distortion that might arise because of the limiting process. Most types of limiting or clipping tend to produce some spurious high-frequency audio components; these are removed by the filter network.

When overmodulation occurs, the positive alternation of the modulating wave causes the peak amplitude to rise to a level of more than twice the unmodulated-carrier amplitude. However, it is the negative peak of the modulating wave that causes the greater amount of trouble. It swings so far negative that the carrier is cut off momentarily. This cutoff is particularly objectionable because it generates spurious frequency components that fall on frequencies substantially removed from the bandpass assigned to the station. Any negative modulation peak in excess of 100% also introduces serious audio distortion.

Therefore, it is particularly important that negative modulation peaks be prevented. In the Apelco transmitter, two silicon diodes prevent this possibility. If the negative cycle of the modulator output voltage has a peak value greater than the DC plate voltage on the modulated amplifier, the polarity across the modulator output reverses. If this occurs, the two silicon diodes are so polarized that they remove the negative peak and prevent the plate voltage from dropping to a level which would cut off the carrier.

LICENSE EXAMINATION PREPARATION

1. *Draw a simple schematic showing a method of coupling a modulator tube to an RF power amplifier to produce plate modulation of the RF energy.* —See Fig. 8.

2. *Draw a simple schematic showing a method of coupling a modulator tube to an RF power amplifier to produce grid modulation of the RF energy.*—See Fig. 9.

3. *What is meant by grid modulation? Plate modulation?*—In grid modulation, the modulating wave is introduced into one of the grid circuits. The modulating wave causes the negative grid bias to vary with the modulation. Consequently, the RF power output of the stage will also vary.

In plate modulation, the modulating wave is introduced into the plate circuit in such a manner that it varies the DC plate voltage applied to the RF amplifier. This causes the RF output to vary in step with the modulation.

4. *What is high-level modulation?*—The plate modulation of the final RF amplifier stage of a transmitter.

5. *What is low-level modulation?*—Modulation at the control grid of the final RF power amplifier or any preceding stage.

6. *If a 1500-kc radio wave is modulated by a 2,000-cycle sine-wave tone, what frequencies are contained in the modulated wave?*—A 1500-kc carrier, an upper sideband at 1502 kc (1500 kc plus 2 kc), and a lower sideband at 1498 kc (1500 kc minus 2 kc).

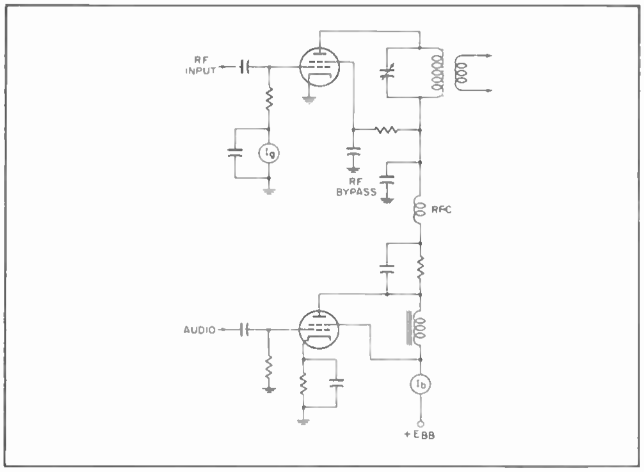


Fig. 10. Basic circuit for Heising plate modulation.

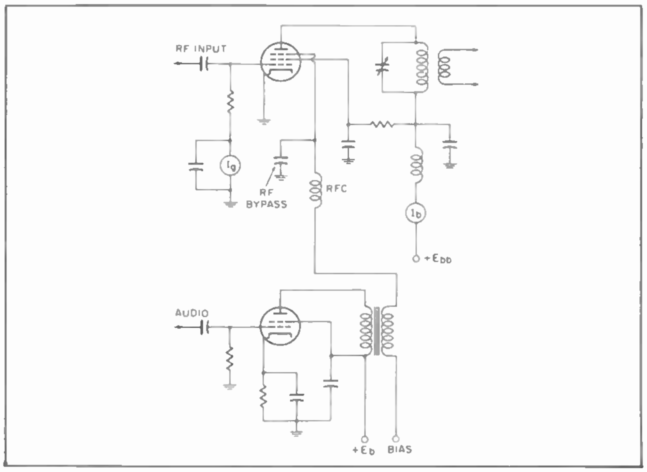


Fig. 11. Circuit designed for suppressor-grid modulation.

7. *Draw a simple schematic showing a Heising modulation system capable of producing 100% modulation. Indicate power-supply polarity where necessary.*—See Fig. 10.

8. *Draw a simple schematic showing a method of suppressor-grid modulation of a pentode tube.*—See Fig. 11.

9. *Draw a simple schematic showing the proper method of obtaining DC screen-grid voltage from the plate supply of a modulated pentode Class-C amplifier.*—Refer to Fig. 8.

10. *What is meant by frequency shift or dynamic instability with reference to a modulated radio-frequency emission?*—Any change in frequency of the carrier during modulation.

11. *Draw a diagram of a carrier-wave envelope modulated 50% by a sinusoidal wave, and indicate the dimensions from which the percentage of modulation is determined.*—See Fig. 12.

12. *What is the relationship between the average power output of the modulator and the plate-circuit input of the Class-C amplifier under 100% sinusoidal plate modulation?* — To attain 100% modulation, the audio-power output of the modulator must equal half the DC plate-power input of the plate-modulated Class-C amplifier.

13. *Why is a high percentage of modulation desirable?*—The higher the percentage of modulation, the greater the average power output of the transmitter. Inasmuch as the desired information to be conveyed is contained in the sidebands and not in the carrier, greater range and more reliability are obtained when strong sidebands are radiated as the result of a high percentage of modulation.

14. *What are some of the results of overmodulation?*—Overmodulation distorts the modulated wave and causes spurious signal components to be radiated at frequencies substantially removed from the carrier frequency, often overlapping into adjacent channels and beyond.

15. *What might decrease the antenna current of a high-level, amplitude-modulated radiotelephone transmitter when modulation is applied?*—Inability of the modulator or modulated amplifier to follow the positive modulation crest. Incorrect grid bias or insufficient excitation could prevent generation of the high peak power necessary to convey the modulation crest. A defective modulated Class-C amplifier tube or poor power-supply regulation could also cause the antenna current to decrease. Too-heavy loading of the modulated RF amplifier output might cause the same disturbance.

16. *Should the average plate current of a modulated Class-C amplifier vary or remain constant under normal modulation conditions? Why?*—Remain constant. The plate voltage changes symmetrically with modulation, and the instantaneous plate current should increase and decrease by equal amounts on each side of its unmodulated DC value. Because of this symmetrical plate-current change, the average DC current should remain the same.

17. *What is the effect of carrier shift in a plate-modulated Class-C amplifier?*—Carrier shift (fluctuation of average DC plate current with modulation) produces a distorted output and, if severe, the generation of sideband components outside the normal channel.

18. *What are possible causes of negative carrier shift in a linear RF amplifier?*—Some of the causes of negative carrier shift (DC plate current decreases with modulation) are a distorted modulated signal, improper impedance match between modulator and modulated stage, or between modulated stage and its load, a failing modulated-amplifier tube, poor power-supply regulation, or insufficient RF excitation at the grid of the modulated amplifier. Overmodulation can also produce a DC plate-current decrease.

19. *What will cause upward fluctuation of the antenna current when an amplitude-modulated transmitter is modulated?*—Upward fluctuation in this

instance is normal—it shows that the power output is increasing with modulation and the sideband components are being radiated.

20. *In a modulated Class-C RF amplifier, what is the effect of insufficient excitation?*—The modulation system cannot follow the modulation crests. As a result, insufficient peak power is generated during the modulation crest, causing negative carrier shift (lessened plate-current meter-reading, with modulation) and a decrease in the antenna-current. Under these circumstances, it is difficult to attain normal high-percentage modulation.

21. *How would loss of RF excitation affect a Class-C modulated amplifier when using grid-leak bias only?*—With loss of bias, excessive plate current flows, blowing fuses or operating the circuit breakers and possibly damaging the tubes and associated components of the modulated stage. An improper load would be reflected to the modulator, establishing improper operating conditions that might also damage the modulator tubes and their associated components.

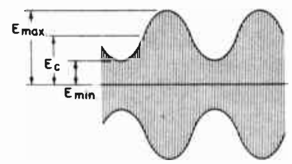
22. *What might cause variations in the average plate current of a Class-B modulator?*—The plate current of a Class-B modulator normally varies during modulation.

23. *What would be the effect of a shorted turn in a Class-B modulation transformer?*—A shorted turn (or turns, depending on how much of the winding is shorted) can cause transformer losses and reduced efficiency. There is the possibility of high current flow in the remaining section and consequent burnout of the winding.

24. *What might cause frequency modulation in an amplitude-modulated radiotelephone transmitter?*—Improper isolation between its modulated sections and the oscillator, or a power-system defect that causes the changing power requirements of the modulator section to affect the supply voltages to the oscillator. Improper tuning can make the oscillator unusually susceptible to even slight changes in loading or supply voltage.

25. *How can the distortion effects caused by Class-C operation of an RF amplifier be minimized?*—By adjusting the load on the stage, the excitation, the grid bias, the supply voltages, and the characteristics of the resonant tank circuit to operate as a team during tuning. Furthermore, neutralization must be exact and parasitic oscillations should not be present. The grid circuit must be designed to place a reasonably constant load on the driving stage, which is the source of the modulated RF envelope that must be amplified by the Class-C linear stage.

26. *If the first speech amplifier of a radiotelephone transmitter were overdriven, but the modulation percentage capabilities of the transmitter were not exceeded, what would be the effect upon the output of the transmitter?*—The crest of the modulating wave would be limited, and a distorted modulation would be transmitted. If only one polarity of the audio waveform is compressed by overdriving the first speech-amplifier stage, carrier shift will also result. Spurious high-frequency components might also be radiated because of the clipped audio wave.



$$\% \text{ MODULATION} = \frac{E_{max.} - E_{min.}}{2E_c} \times 100$$

$$\% \text{ MODULATION (SINUSOIDAL LINEAR)} = \frac{E_{max} - E_c}{E_c} \times 100$$

Fig. 12. RF envelope produced with 50% modulation.

27. *Describe three methods of reducing the RF harmonic emission of a radiotelephone transmitter.*—There are many ways of minimizing the harmonic radiation of a radiotelephone transmitter. The use of pi-network tank circuits and filters between transmitter and antenna system is particularly effective in reducing harmonic content of the RF wave. The antenna system, if designed specifically for the desired operating frequency, will function as a poor radiator at the harmonic frequency. Properly-tuned tank circuits throughout the transmitter, and shielding (such as the use of a Faraday shield between the final tank circuit and the antenna-coupling network) do much to reduce harmonic components.

REVIEW QUESTIONS

1. What is the major advantage of grid modulation?
2. What determines the bandwidth of an amplitude-modulated signal?
3. How is overmodulation prevented in AM transmission?
4. For 100% modulation, what percentage of the total transmitted power is in the sidebands? In plate modulation, what is the source of this sideband power?
5. In what manner does the average plate current of a properly-adjusted modulated amplifier vary with the modulation?
6. Why should negative overmodulation peaks be avoided in particular?
7. In what maner does the antenna current vary with the modulation in an amplitude-modulated system?

Answers to these questions will be included in PHOTOFACT Set No. 573

Lesson 11

Power Sources

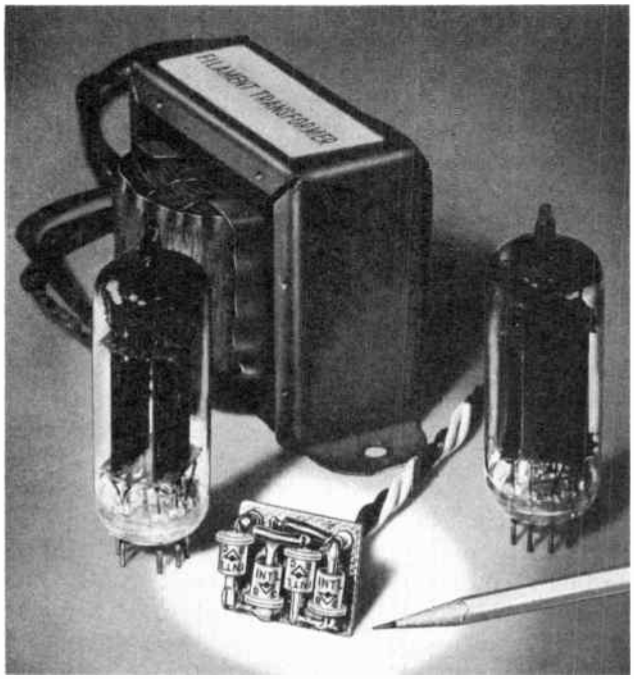


Fig. 1. These silicon power rectifiers do the same job as the tubes and transformer.

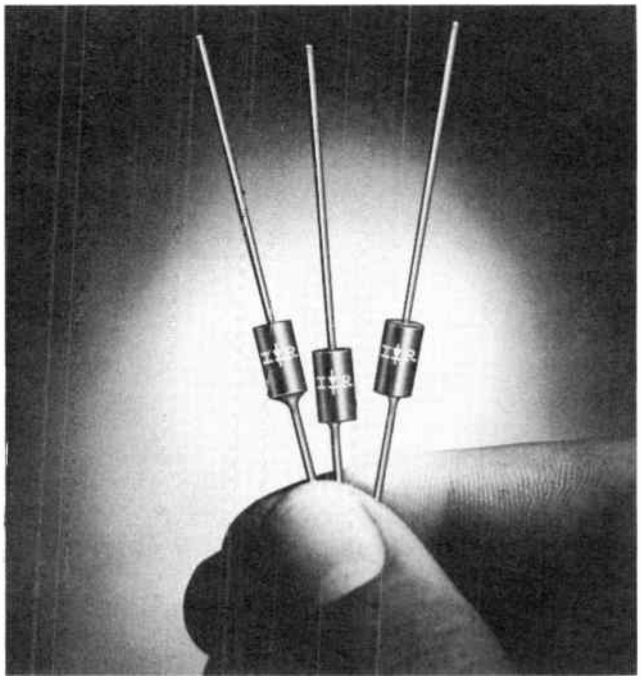


Fig. 2. These silicon rectifiers are rated at 750 ma, 200 to 600 PIV.

In recent years there have been substantial improvements in the power supply facilities of radiocommunications systems. In low-power AC-operated power supplies, germanium and silicon rectifier diodes are replacing vacuum-tube selenium rectifier types. Most new low to medium power units now use silicon diode rectifiers almost exclusively. In fact, there are some radio broadcast transmitters that are powered entirely with silicon power rectifiers instead of vacuum and gas tube types.

Zinc-carbon dry cells and lead-acid storage batteries are still very popular and used widely in communications equipment. Mercury cells are popular in transistorized equipment because of their small size and long life. However, such batteries as the new alkaline-manganese primary battery and the sealed nickel-cadmium rechargeable secondary battery have become increasingly popular.

The solar battery has become an important part of space and other advanced communications systems. Solar cells generally operate in conjunction with rechargeable sealed batteries.

SILICON POWER RECTIFIERS

The principal advantage of silicon power rectifiers is immediately obvious when you look at Fig. 1. The four silicon rectifiers can provide twice as much current at approximately the same voltage as the two dual-rectifier tubes and the transformer. With one-fiftieth of the volume and one one-hundredth of the weight of the comparable tube circuit, the silicon bridge will provide 500 milliamperes of current at 350 volts RMS. Silicon rectifiers are available with peak inverse voltage ratings between 50 and 500 volts. If higher voltages are to be handled, a number of units can be connected in series. For higher current demands, parallel combinations can be used.

Fig. 3. Silicon rectifier mounting designed to replace octal-based vacuum tube.

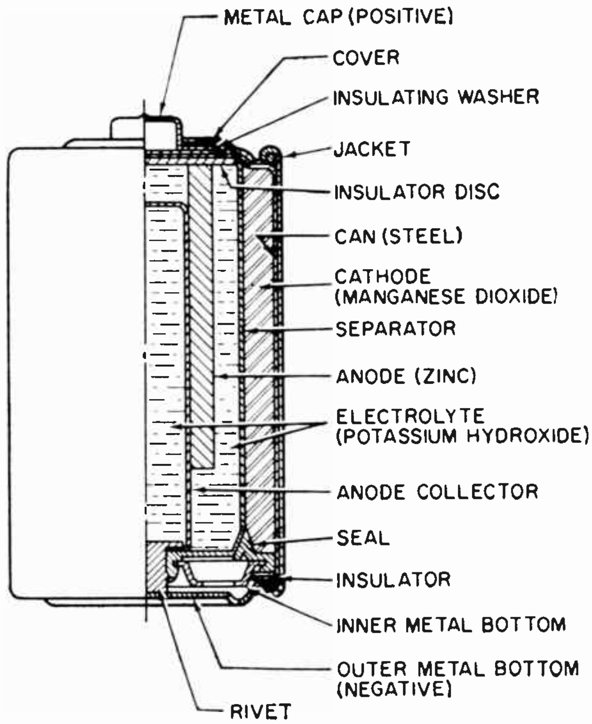


Fig. 4. Design features of a typical alkaline battery cell.

The silicon rectifier, Fig. 2, is basically a P-N semiconductor junction. The N portion of the material serves as the cathode, the P side as the anode. When the anode is positive with respect to the cathode, a large current will flow because of the low resistance of the junction. Voltage of a reverse polarity does not result in a significant current flow because of the high reverse resistance of the junction. Thus, when an AC voltage is applied, as for any rectifier type, a unidirectional current will flow.

The advantages of the silicon rectifier are thus its very low forward resistance, which permits a very high forward current to flow with relation to the junction size, and its high peak inverse voltage. The forward voltage drop is very low which means that only a small amount of power need be dissipated by the junction. Thus, in directly replacing another type of rectifier, there is an improvement in the power supply regulation.

Some silicon power rectifier replacement units, such as the one shown in Fig. 3, have been developed in recent years. It need only be plugged into the vacated vacuum-tube rectifier socket. Direct replacements of this type are available in current ratings from 85 to 600 milliamperes, with peak inverse voltage values between 1500 and 2800 volts.

ALKALINE PRIMARY BATTERY

A popular new dry cell battery is shown in Fig. 4. The alkaline electrolyte is potassium hydroxide, which has a high conductivity and results in low internal resistance of the cell. The cathode is manganese dioxide and the positive anode is zinc. The cathode is of high density, and the zinc anode makes contact with the electrolyte over a large surface area. Thus, the battery is capable of heavy drain and high current operation. It is substantially superior to the regular zinc-carbon dry cell, having a service life as much as ten times greater. For light loads, the alkaline cell has a service life two to three times longer than the conventional dry cell.

Alkaline batteries are available in the various standard dry cell shapes and sizes. Sometimes they are called alkaline energizers.

NICKEL-CADMIUM BATTERY

The nickel-cadmium battery, Fig. 5, is a dry sealed secondary type. It can be manufactured in various shapes and sizes (including standard dry cell dimensions) according to mounting requirements. It is a sealed type and does not require the addition of liquids. Furthermore, long idle periods in either a charged or uncharged state do not adversely affect battery life and operation. Such a battery responds equally well to a light trickle charge or a quick high-current charge.

The electrolyte is potassium hydroxide; the negative electrode, cadmium; and the positive electrode, nickel hydroxide. On discharge, cadmium oxide

Fig. 5. Examples of nickel-cadmium rechargeable batteries.

changes to metallic cadmium. The electrodes are very stable and there is very little internal discharge, which contributes to the long life of this type of battery.

A typical charging circuit for a rechargeable battery is given in Fig. 6. The values for resistors R1 and R3 are selected according to the desired charging current requirements of the particular battery.

SOLAR BATTERY

The solar battery has become increasingly important in this age of space communications. The high efficiency silicon solar batteries now available match, watt for watt, the power available from dry-cell and mercury-cell batteries. Size comparsions are made in Fig. 7.

The complete solar power system consists of solar cells and rechargeable storage batteries. The solar cells supply power in sunlight only. Simultaneously, they can be used to recharge the batteries, usually nickel-cadmium types. In darkness, the rechargeable batteries supply power to the radio circuits.

A switching arrangement can be used to make the power changeover at appropriate times. However, the entire system can be made automatic in its operation. Such is the case with the arrangement of Fig.

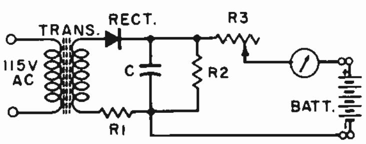


Fig. 6. Battery-charger circuit for nickel-cadmium batteries.

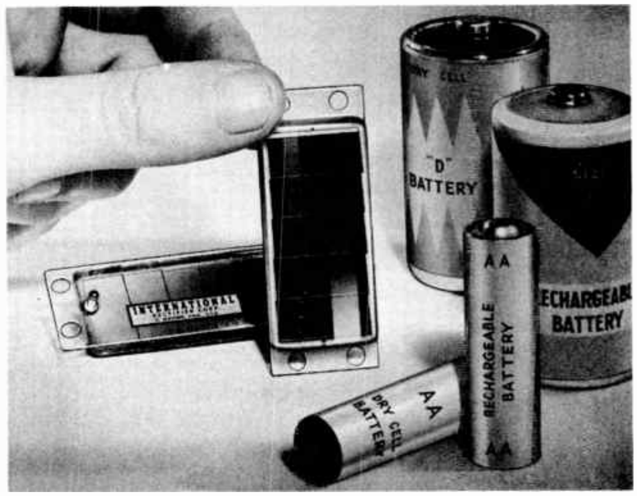


Fig. 7. Silicon solar-cell batteries shown in comparison with standard dry-cell and rechargeable batteries.

8. The silicon diode prevents the batteries from discharging through the solar cells when they are inactive (in darkness).

When the solar cells supply energy, the potential of the solar battery is such that the silicon diode is forward biased. Consequently, there is a low resistance path for the current flow out of the solar cell. However, in terms of the rechargeable battery current flow, it sees a high resistance in the path to the solar cells, because the battery voltage places a reverse bias on the silicon diode. The silicon diode therefore presents a high resistance path insofar as the direction of current flow out of the battery into the solar cells. Thus, the solar cells can be connected permanently in the circuit and need not be switched off when they are not generating power.

TRANSISTOR POWER SUPPLY

In vehicular radio services, the transistor power supply circuit has taken over from conventional mechanical vibrators and dynamotors. Such a transistorized unit has as its advantage low battery drain, longer

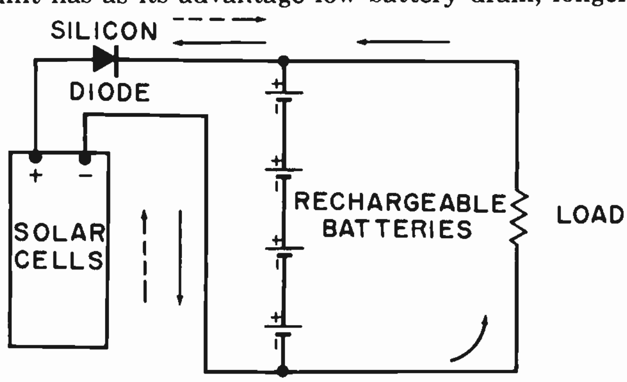


Fig. 8. Solar power supply circuit hook-up.

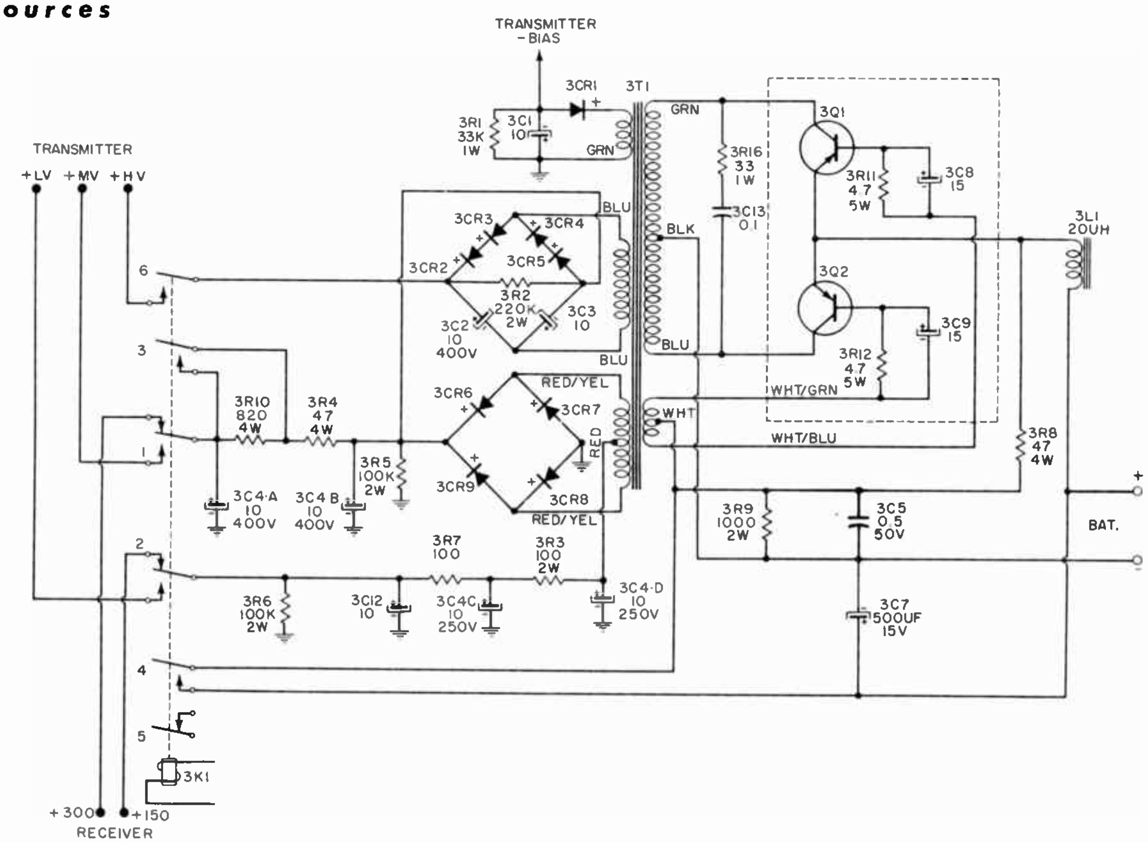


Fig. 9. RCA transistor power supply for vehicular radio set.

life, and a substantially higher order of reliability. A supply used with a typical mobile transmitter-receiver is shown in Fig. 9.

A push-pull transistor oscillator, operating at several hundred cycles, develops the high-current AC variations needed to drive the primary side of the power transformer. The transistor oscillator itself is powered from the storage battery of the vehicle. The operating voltages are derived from three separate secondary windings. Silicon power rectifiers are used in various configurations to convert the high-voltage AC back to DC. At the top is a simple half-wave rectifier which develops the negative bias voltage for the transmitter. The middle DC voltage source is a voltage doubler circuit, while a bridge rectifier is used across the bottom secondary of the transformer.

The oscillations depend on current feedback into the transistor base circuits. This feedback is by way of the winding shown beneath the primary winding of the transformer. The base-emitter bias is such that the two transistors conduct. However, there is an inherent unbalance in the transistors and in the two halves of the primary circuit. Consequently, the transistor currents are somewhat unequal. At the start, therefore, one draws a stronger current.

As the current builds up, a voltage is induced into the feedback winding. Since the ends of the windings are connected to the transistor bases, in push-pull fashion, the voltage on one base will rise at the same time the voltage on the other falls. In fact, a forward voltage is applied to the more heavily conducting transistor and a reverse voltage is applied to the other. Thus, the current through the first transistor continues to increase while the second transistor is driven to cutoff. Eventually, the core of the transformer becomes saturated and, since magnetic flux no longer increases to sustain the voltage across the feedback winding, the magnetic field collapses.

The feedback now reverses polarity. With reverse feedback, the first transistor is driven to cutoff and the second one into conduction. The second transistor current rises until the transformer core becomes saturated. Once again the magnetic flux reaches maximum, collapses and reverses polarity to cause reversal of transistor operation.

Current flow thus "switches" from one transistor to the other, causing an AC current variation in the primary of the power transformer. The characteristics of the saturable core of the transformer determine the frequency of oscillation. As mentioned previously, this is often several hundred cycles, simplifying the design of the power supply rectifier and filter circuits. The strong AC current variations in the primary develop the necessary high voltage secondary potentials needed to develop the DC voltages for operating the receiver and transmitter of the radiocommunications unit. In transmit operation, resistor 3R8 is shorted out to permit a stronger transistor current flow and therefore a higher power capability for use when the transmitter is switched on.

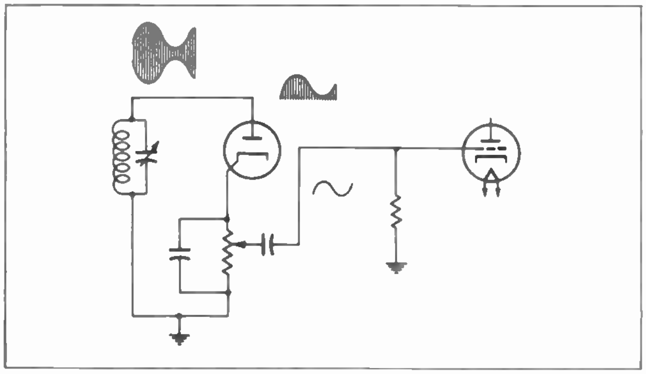


Fig. 10. Diode detector and coupling network to audio amplifier.

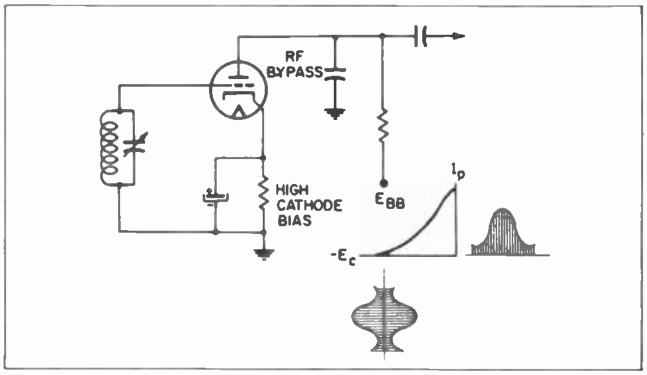


Fig. 11. Basic plate detector circuit.

The series of contacts shown at the left are associated with the transmit-receive switching. When the transmit switch on the microphone is depressed, relay 3K1 is energized and pulls the contacts down. As shown, the contacts are in the receive position. The middle and the bottom rectifier-filter circuit is in operation, providing 300 and 150 volts for receiver operation. On transmit operation, four voltages are made available—a low voltage by way of contact 2, a medium voltage by way of contact 1, a high voltage by way of contact 6, and negative bias for the transmitter by the top secondary. The high voltage is derived by combining the voltages made available by the middle and the lower rectifier sections. DC voltages for the tube filaments and relay coils are taken from the storage battery.

PREPARATION FOR LICENSE EXAMINATION

1. *Draw a simple schematic of a vacuum-tube diode detector, and show a method of coupling it to an audio amplifier.*—See Fig. 10.

2. *Explain the operation of a diode detector.*—A diode detector is a combination rectifier and filter. Its rectifier action permits conduction during one alternation of an applied modulation envelope. A unidirectional current follows the variations of the radio-frequency peaks; hence, the diode current flow is a replica of the modulation present on the incoming radio-frequency envelope. The output network acts as an RF filter, but does not filter out the modulating signal. As a result, the original modulation is recovered at the output of the diode detector.

3. *What is the principal advantage of a diode over a grid-leak triode detector?*—It is capable of handling a strong input signal without distortion, particularly at high modulation levels, and has a simple and uncomplicated circuit.

4. *Describe the operation of a crystal detector.*—A crystal detector functions like the diode detector discussed in question 2. The crystal is composed of some type of crystalline material such as germanium or silicon, having a rectifying characteristic. It will pass current more readily in one direction than the other. One side of the crystal detector is a semiconductor wafer, and the other is a fine wire ("cat whisker") that contacts the wafer.

Older crystals had an adjustable "cat whisker," which was set to the most sensitive detection point that could be found on the crystal. The modern crystal is a carefully machined and shielded permanent device.

5. *Draw a simple schematic of a triode vacuum tube connected for plate or power detection.*—See Fig. 11.

6. *Explain the operation of a power or plate rectification type of vacuum-tube detector.*—A plate or power detector is biased near cutoff; plate current flows only during the positive alternations of the radio-frequency cycles of the applied modulation envelope. As in the diode detector, the instantaneous plate current follows the peak variations of the modulation envelope. Unlike the diode detector, however, the triode circuit amplifies the variations arriving at its grid. An output network filters out the radio-frequency components.

If the applied signal is strong enough to swing over a major portion of the linear part of the transfer characteristic, a good replica of the modulation will be developed in the output. The input level should not be too high or it will swing off the linear portion of the transfer curve. Thus, the plate detector overloads early, in comparison with the diode demodulator, but does deliver a strong output when excited by a signal of suitable level.

7. *What operating conditions define a tube that is being used as a power detector?*—The power detector is biased nearly to cutoff. This can be in the form of fixed or cathode bias.

8. *What are the characteristics of plate detection?*—Refer to questions 6 and 7. The plate detector delivers a strong and essentially undistorted output when driven by a moderate signal, and is seriously overloaded by a strong signal. It presents very light loading to the preceding stage, compared with other types of detectors.

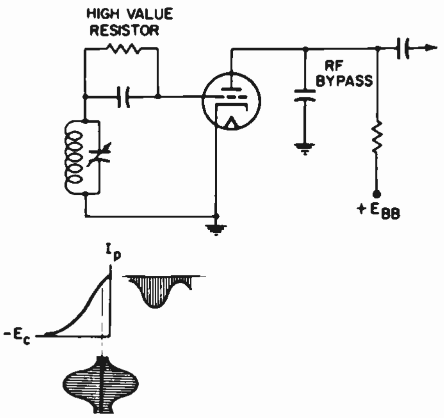


Fig. 12. Basic grid-leak detector circuit.

9. *List and explain the characteristics of a square-law vacuum-tube detector.*—A square-law detector, by operating on the nonlinear portion of its characteristic curve, develops an output that is proportional to the square of the applied voltage. It is used for heterodyning and other specialized applications. However, it would produce a distorted output when excited by a conventional AM envelope.

10. *Draw a simple schematic of a triode vacuum tube connected for grid-leak capacitor detection.*—See Fig. 12.

11. *Explain the operation of a grid-leak detector.*—The grid-to-cathode circuit of a grid-leak detector functions like a diode detector, the grid serving as the plate of the diode operation. (Refer to question 2.) However, an amplified version of the demodulated signal at the grid is developed in the plate output circuit.

The grid-leak detector is biased near saturation by the grid current drawn during the positive crest of the RF cycles of the applied modulation envelope. The negative alternations of the applied modulation envelope swing over the linear portion of the tube transfer characteristic, as shown in Fig. 12. The instantaneous plate current follows the variations of the negative RF peaks, and these variations produce an amplified version of the grid-signal change in the output. The RF cycles are filtered out by the output capacitor.

The grid-leak detector is sensitive and develops a reasonably strong output. Like the plate detector, it must not be overloaded by too strong a signal; otherwise, a reasonably undistorted output cannot be developed.

12. *Is a grid-leak detector more, or less, sensitive than a power detector (plate rectifier)? Why?*—More sensitive. By operating at a low bias (near saturation), it offers maximum amplification to a weak signal. A plate detector operates near cutoff, where the mutual conductance is low and a weak applied signal is not amplified as much as it would be higher on the transfer characteristic.

13. *What effect does the reception of modulated signals have on the plate current of a grid-leak type of detector? On a grid-bias plate detector?*—Increases in the incoming signal amplitude (modulated carrier) cause plate current to decrease for the grid-leak detector, and to increase for the plate detector.

14. *Draw a simple schematic of a regenerative detector.*—See Fig. 13.

15. *How does the resistance in the grid-leak network of a regenerative detector affect its sensitivity?*—In general, the higher the grid-leak resistance, the higher the sensitivity (up to the limit that produces instability or blocking). Several megohms is typical.

16. *What feedback conditions must be satisfied in a regenerative detector in order for it to sustain oscillations?*—Adequate in-phase feedback to overcome grid-circuit losses, as in any other self-excited oscillator. These losses include the loading inserted by the antenna or preceding stage.

17. *What effect might be caused by a shorted grid capacitor in a three-circuit regenerative receiver?*—The grid-leak bias circuit would be shorted out, causing loss of receiver sensitivity.

18. *What might be the cause of low sensitivity in a three-circuit regenerative receiver?*—Improper tuning. To derive peak sensitivity from a regenerative detector, there must be a proper amount of feedback and optimum coupling between the antenna and detector, or between a preceding RF stage and the detector. Improper voltages, a failing tube, or a defective component could cause loss of sensitivity.

19. *Describe the operation of a regenerative receiver.*—The major units of a regenerative receiver are an optional RF amplifier, a grid-leak detector with feedback, an audio amplifier, and a power source. The RF amplifier, audio amplifier, and power source are conventional. The demodulator is a grid-leak detector which functions as discussed in question 11 and shown in Fig. 12, except that a feedback link is provided, usually the tickler coil shown in Fig. 13. The circuit supplies a controlled in-phase feedback to the grid circuit. The incoming modulated signal is detected in the conventional manner

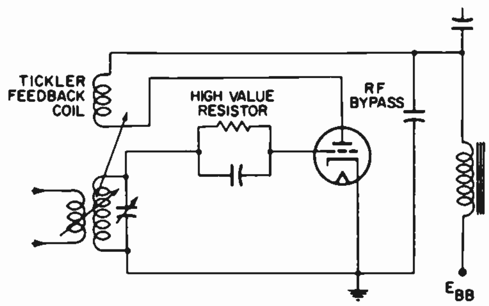


Fig. 13. Basic regenerative detector circuit.

by the grid-leak detector. However, some of the RF output of the grid detector is fed back to the grid circuit in phase, to reinforce the original grid signal. This feedback increases the impedance and the effective Q of the input resonant circuit, so that higher sensitivity and selectivity result.

The amount of feedback can usually be controlled because the sensitivity of a regenerative detector increases up to the point where self-oscillation occurs. Thus, in the reception of a modulated signal, the regeneration control is advanced to this point. It is then turned back slightly until the oscillations cease. In the reception of a CW signal, however, the regeneration control is advanced to the point of oscillation, because oscillations are necessary to recover the interrupted carrier (CW) information.

20. *How is a regenerative receiver adjusted for maximum sensitivity?*—To receive a modulated signal, the regeneration control is advanced to the oscillation point and then backed off very slightly. If the antenna coupling is controllable, it and the regeneration control are regulated simultaneously for the most sensitive operation. The antenna coupling is made as tight as possible so the regeneration control can be advanced almost to the limit of its range before the circuit goes into oscillation. For CW reception, the regeneration control is advanced to the point of oscillation so that heterodyning can occur.

21. *In a regenerative receiver, what circuit conditions are necessary for maximum response to a modulated signal?*—Input coupling and regeneration must be optimized. To do this, the regeneration control should be advanced to the point of oscillation and then backed off slightly. Refer to questions 19 and 20.

22. *What feedback conditions must be satisfied in a regenerative detector for most stable operation of the detector circuit in an oscillating condition?*—Stable operation occurs at an adjustment that is not the same as for maximum sensitivity. If connected directly to the detector, the antenna must be very stable. Stability is better when antenna coupling is somewhat less tight than required for maximum sensitivity. Likewise, the regeneration control can be advanced a bit beyond the point at which the set breaks into oscillation.

The feedback should be of reasonable constant amplitude, and the input coupling should be such that the oscillations and circuit remain stable in operation.

23. *Why is it necessary to use an oscillating detector for reception of an unmodulated carrier?*—The function of the oscillating detector is to set up an audible difference frequency between it and the interrupted incoming carrier. Thus, the interrupted carrier (CW) is reduced to an audible, interrupted tone. The difference frequency between the incoming carrier and the frequency of an oscillating detector represents the audio frequency of the interrupted tone at the output of the regenerative receiver.

In a superheterodyne receiver, the interrupted tone at its output is due to the difference frequency between the IF carrier and the beat-frequency oscillator (BFO), which must be turned on to receive CW signals.

REVIEW QUESTIONS

1. Give the advantages of the nickel-cadmium battery.
2. Why can the dimensions of the silicon rectifier be small with relation to its current carrying ability?
3. In what two ways are solar cells used as power sources?
4. What is meant by the reverse resistance of a junction?
5. What is the specific function of the transistors of a transistor power supply?

Answers to these questions will be included in PHOTOFACT Set No. 573

Lesson 12

Radio Detectors

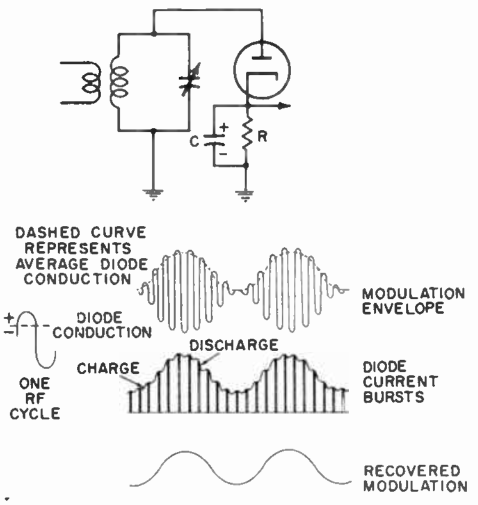


Fig. 1. Basic diode detector circuit, and an analysis of its signal waveforms.

In AM radiocommunications services, the superheterodyne receiver and the simple diode detector are mainstays. In some low-cost hand-held and portable units, limited to a few receiving stages, the superregenerative detector is used because of its high sensitivity and strong output. A new form of AM demodulator called the product detector is used in single-sideband systems.

In FM radiocommunications systems, conventional phase discriminator and gated-beam demodulators are the most popular, although some ratio detectors are used.

DIODE DETECTOR

The diode detector functions as a combination rectifier and filter of AM waves. The first step in the demodulation process, as shown in Fig. 1, involves rectification of the individual cycles. The peak amplitude of the rectified RF current varies in accordance with the AM variations. The RF variations are then filtered out, leaving only the original audio modulation.

The diode detector, which may be either the vacuum-tube or crystal type, has a low forward resistance and a high back resistance. During positive excursions of the RF signal, the plate of the diode is more positive than the cathode. Consequently, current flows through the diode. The DC current path is from cathode to plate, through the tuned-circuit coil and load resistor R, back to the cathode. The magnitude of this current depends on the peak amplitudes of the RF carrier as it varies with modulation.

When the plate is negative with respect to the cathode, the diode displays a very high resistance to any current flow. When connected as shown in Fig. 1, the plate is actually negative with respect to the cathode for more than 180° of each RF cycle. This is a result of diode current through the load resistor, making the cathode positive with respect to ground. Before the diode can conduct, the RF voltage must rise to a level which exceeds that at the cathode. As a result, diode current flows only during a portion of the positive alternation of each RF cycle. Diode current therefore flows in bursts or pulses, as emphasized in waveform B of Fig. 1.

Actually, output filter capacitor C charges to the approximate level of each applied RF peak. The peak level changes over a period of cycles in accordance with the audio modulation being conveyed. The time constant of the output resistor and capacitor is long compared to the period of the RF frequency. Hence, there is only a small discharge between cycles, and the RF variations are filtered out. Since the peak charge placed on the output R-C combination follows the modulation envelope, the average voltage variation across the output corresponds to the original modulation.

SUPERREGENERATIVE DETECTORS

The superregenerative detector has an extremely high sensitivity. For VHF and UHF reception, the design need incorporate only a few stages. Its selectivity is poor, however, and it radiates an interfering signal when coupled to an antenna. To better understand the operation of a superregenerative detector, let us first consider the general operation of two other types—the grid-leak and the regenerative detector.

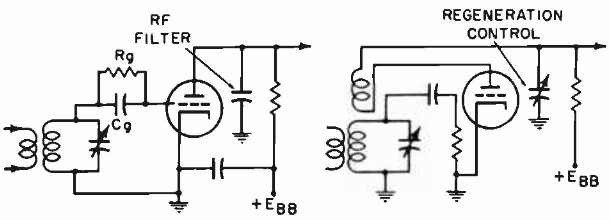


Fig. 2. Fundamental grid-leak and regenerative detector circuits.

A grid-leak detector, as shown in Fig. 2A, is a combination diode detector and amplifier. The control grid and cathode of the tube function as anode and cathode, respectively, of a diode detector. The positive alternation of each RF cycle causes a flow of grid current which develops a negative charge across capacitor Cg. Between cycles this charge remains relatively constant because of the high value of grid resistor Rg (the RgCg time constant is long in comparison to the period of the RF cycle). Changes in carrier amplitude due to audio modulation, on the other hand, occur at a much slower rate. Consequently, the amount of grid current drawn, and the charge on the capacitor, will vary at an audio rate, resulting in a corresponding variation in the grid bias. This, in turn, varies the average plate current and, therefore, an amplified audio voltage variation appears in the plate circuit of the detector. The capacitor in the plate circuit filters out the RF variations.

A grid-leak detector can be made even more sensitive with the use of regenerative feedback as shown in Fig. 2B. In this circuit some of the RF energy in the plate circuit is fed back to the grid with the proper phase to reinforce the original RF grid voltage variations. Feedback causes an accumulative buildup of the grid signal, resulting in a very high output for only a small input. Too much feedback cannot be used, however, because it will cause self-oscillation and the stage will cease to function as a detector. If the feedback is great enough to overcome the grid circuit losses, the stage will perform as an Armstrong oscillator instead of a regenerative detector. The most sensitive point of operation, therefore, is where the stage is just about ready to break into oscillation. Regenerative detectors usually employ a regeneration control which permits the operator to adjust the circuit for optimum efficiency by regulating the amount of feedback.

It should be mentioned that a regenerative detector can be used to receive code (CW or A1 signals) when adjusted for an oscillating condition. By detuning the resonant circuit slightly, above or below the frequency of an incoming code-interrupted carrier, an audible beat note results for each incoming code mark (dot or dash).

One significant fact to note is that in the reception of modulated waves, maximum sensitivity and selectivity is displayed near the oscillation point. The superregenerative detector maintains a high sensitivity by introducing controlled oscillations. Schematically, as shown in Fig. 3, the superregenerative detector need not differ from that of the regenerative detector. The main difference is that grid resistor Rg and grid capacitor Cg have a substantially longer time constant.

The amount of feedback is such that oscillations would normally be sustained, which would make the stage ineffective as a detector were it not for the long grid time constant which cuts off the oscillation (quenches them) in a cyclic manner. It is the flow of grid current that places the cutoff bias on the grid capacitor. The value of Rg must be so large that the bias voltage caused by the Cg discharge current will hold the tube in cutoff for a large portion of each oscillation cycle.

When the capacitor has discharged to the cutoff level, oscillations begin anew. The oscillations, as shown in Fig. 3, build up to the level at which grid current flows. Now the oscillations decline gradually to zero as the charge on the capacitor builds up to a value higher than the cutoff voltage for the tube. The charge on the grid capacitor now leaks off gradually until the tube can conduct once again.

The RgCg time constant must be long enough that the oscillations are interrupted for some time. The actual value of the time constant determines the frequency of interruption. This is called the quench or squegging frequency. This quench frequency is usually on the order of several hundred kilocycles per second.

Demodulation of the incoming modulated wave is accomplished by causing the quenching frequency to vary with the modulation on the incoming carrier. Let us consider the operation of the superregenerative detector when no signal is being received. Initially there is certain to be some input circuit noise, and small as it might be, it will cause a variation in plate current that will start the feedback activity.

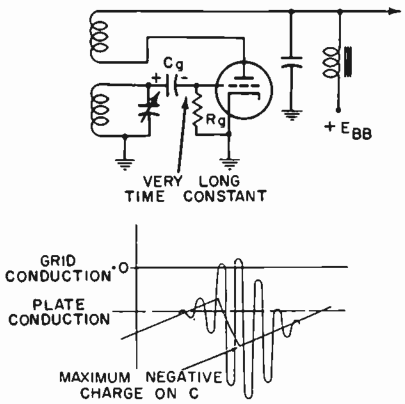


Fig. 3. Basic superregenerative detector, and an analysis of grid and plate currents.

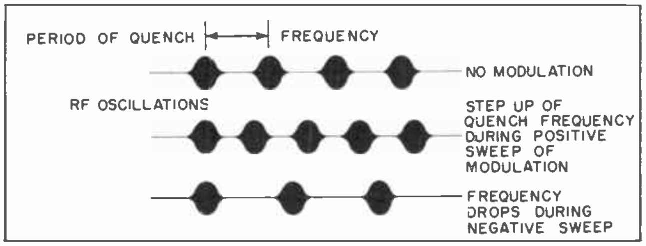


Fig. 4. The period between quench-frequency bursts varies with modulation.

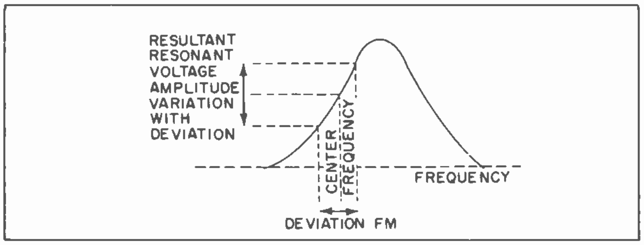


Fig. 5. How slope detection is accomplished with a superregenerative detector.

The feedback will reinforce this initial change and oscillations will build up and have the same frequency as the tuned circuit. They will continue to increase in level until the peaks of oscillation cause grid current flow. The grid current flow, as shown in Fig. 3, will charge the grid capacitor. The increase in the grid bias will cause the oscillations to decline. They will, of course, have died out before the charge on the capacitor diminishes to the conduction level of the tube. Thus, there will be no oscillations until the capacitor has discharged to a level that will permit the tube to conduct. Noise components will then initiate a new cycle of oscillations. The quenched oscillations (on and off oscillation rate) will continue at an essentially constant frequency, as in Fig. 4. It is important to recognize that the superregenerative detector is extremely sensitive, and with no received signal is actually responding to the very weak noises present in the input circuit.

A received signal adds to the bias contributed by the grid circuit, and takes over the initiation of the buildup of oscillations in place of the noise components.

When the incoming signal is modulated, the "timing" of the "oscillation start" will vary in accordance with the modulation. On crests of the modulated wave, the periods of nonconduction will be shorter. Consequently, the squelching frequency will increase as shown in Fig. 4. When the modulation swings into its trough, it will take longer for the tube bias to reach the conduction level, and there will be a wider spacing between oscillating periods.

As the quenching frequency varies with the incoming modulation, there will be a change in average plate current. The more oscillating periods per second, the higher the average plate current. Conversely, fewer oscillating periods will result in lower average plate current. In other words, the average plate current will follow the modulation of the incoming carrier.

An amplified version of this variation will be developed in the plate output circuit of the superregenerating detector. By detuning the plate circuit, the superrengenerative detector can be made sensitive to an FM modulated wave. In this application, it operates like a common FM slope detector. Conversion from FM to AM takes place in the tuned circuit. As shown in Fig. 5, the amplitude of the tuned circuit voltage varies with the frequency change of the incoming FM wave. This change in amplitude represents a corresponding change in the grid bias, causing an average change in plate current, just as in the case of an incoming AM wave. A disadvantage of the superregenerative circuit as an FM detector is that it must be tuned very carefully and must be free of drift so that the incoming center frequency can be ideally positioned on the slope of the resonant circuit response.

PRODUCT DETECTORS

In a single-sideband system, the carrier and one sideband are suppressed; thus, only a single sideband is conveyed between the transmitter and the receiver. To recover the modulation, therefore, a local carrier must be introduced in the receiver.

One obvious method of demodulating a single sideband signal is to use an oscillator that will reinsert a carrier at the IF frequency of the receiver. The inserted carrier and the incoming sideband are then applied to a conventional diode detector. The inserted carrier must have a high order of stability and must be substantially greater in amplitude than the incoming signal. This method of single-sideband demodulation has stability, distortion, and signal-level problems.

A more satisfactory method of demodulating single-sideband signals is to use a product detector such as that in Fig. 6. This circuit uses the heterodyning process to recover the original audio information. The basic principle of operation is the same as for the input mixer of a superheterodyne receiver. In this system, direct conversion is made between the single-sideband and audio frequencies by introducing a local carrier which, in effect, amplitude modulates the single-sideband signal.

Since the output of such mixing is a product of the two signals, such a demodulator is called a product detector. However, it is the difference frequency which is emphasized in the output. The difference frequency is the difference between the inserted carrier and the incoming sideband signal, which is the original audio frequency. Since the heterodyning usually occurs at the IF frequency of the receiver, the sideband and inserted carrier are filtered out in the output of the product detector.

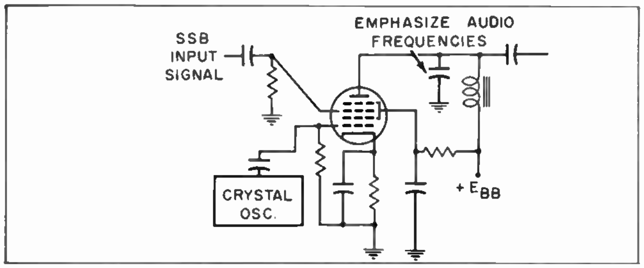


Fig. 6. Simplified product detector circuit.

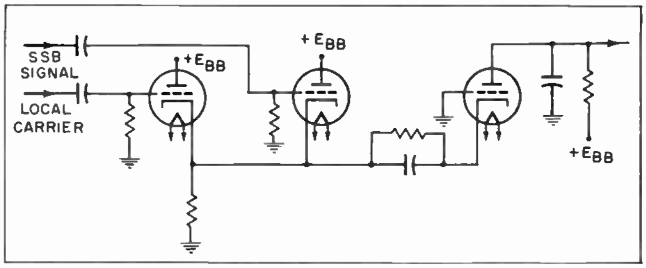


Fig. 7. Fundamental circuit of the Crosby product detector.

As shown in Fig. 6, it is possible to use a crystal oscillator as the local carrier generator. The crystal signal is applied to one of the signal grids of a pentagrid converter, and the single sideband component is applied to the other. The two grids are biased for linear operation; thus, the only audio output that exists results from the heterodyning action between the local carrier oscillation and the incoming sideband signal. If we assume the incoming sideband component is on a frequency of 456 kilocycles and the inserted local carrier is on a frequency of 455 kilocycles, the audio output frequency will be a 1000 cycle tone.

The Crosby triple-triode product detector is shown in Fig. 7. The input triodes are connected as cathode-followers and are driven by the single-sideband signal and the inserted local carrier. These two signals combine in the cathode circuit, which is also common to the cathode of the grounded-grid output stage. The bias on this stage is adjusted with the separate cathode resistor to obtain the most favorable mixing action with a minimum of distortion. The output circuit of the grounded-grid stage emphasizes the audio component and filters out the IF frequency.

PHASE DISCRIMINATOR

The two most common FM demodulators used in radiocommunications equipment are the Foster-Seeley phase discriminator and the gated-beam FM detector. A conventional phase discriminator is shown in Fig. 8. It consists of a double-diode arrangement with a double-tuned input transformer. When an incoming signal is of the same frequency as the tuned input transformer (center frequency of the FM signal) the identical currents drawn by the two diodes produce a net output of zero. When the incoming FM signal deviates from its center frequency, the diodes conduct unequally, in accordance with the direction and magnitude of the deviation. The changing diode currents develop an output which varies in amplitude in accordance with the original audio modulation.

The input transformer is very important to the operation of the discriminator because it develops the two out-of-phase signal components. Signal is coupled into the diode circuit in two ways. There is a direct connection by way of coupling capacitor C1, producing signal voltage E3 across inductor L3. This signal voltage is in phase with the primary voltage Ep developed across the primary winding. The second signal component applied to the diode circuit is developed across the secondary of the tuned input transformer, and is 90° out of phase with the signal in the primary winding. Secondary voltages E1 and E2 are of opposite polarities, as applied to the diode plate sections, and both are in quadrature with the direct-coupled voltage E3—one leading and the other lagging.

The net voltage applied to the top diode, therefore, is the difference between E1 and E3. These two voltages are 90° related and constitute the voltage marked Ed1 on the schematic diagram, and in the vector diagram of Fig. 9A, which shows the vector relationships at resonance. The net voltage across the bottom diode is the vector sum of E2 and E3. E2 you recall is 180° related to E1 as shown in Fig. 9. The resultant voltage applied to the bottom diode is Ed2. Notice that Ed1 and Ed2 are of equal magnitude, resulting in equal diode currents through the resistor-capacitor output network. The top diode current flows up through resistor R2; while the bottom diode current flows down through resistor R3. Since they are equal and opposite, the net voltage output is zero at the resonant frequency.

What causes the change in the output voltage when the signal swings above or below resonance in the input circuit of the discriminator? The key lies in the change in phase of the induced secondary current above and below resonance. Above resonance the secondary circuit becomes inductive, and below resonance it becomes capacitive. Thus, the secondary voltage will lead or lag the primary voltage by more

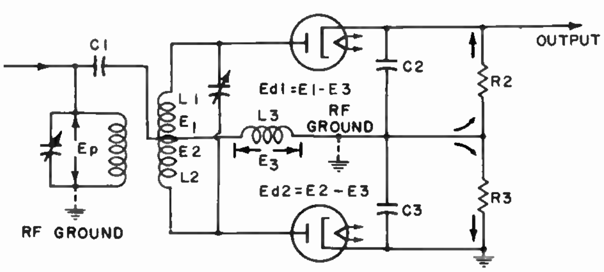


Fig. 8. Conventional phase discriminator circuit.

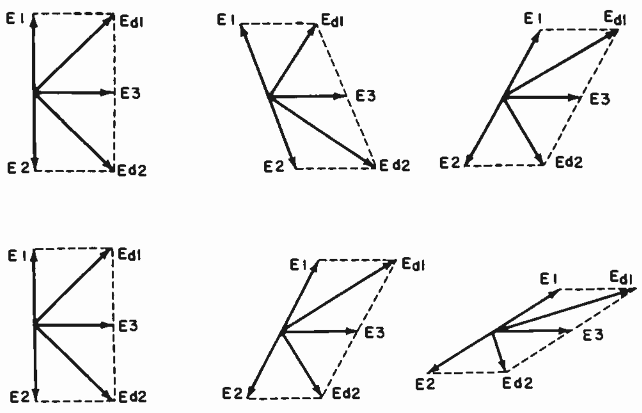


Fig. 9. Vector relationships of the voltages in the discriminator circuit.

or less than 90°, depending on the direction and magnitude of the frequency change.

Inasmuch as voltage E3 is always in phase with primary voltage Ep, the two secondary voltages E1 and E2 will change from their phase relationship with E3 as shown in diagrams B and C of Fig. 9. Below resonance (Fig. 9B), notice that E1 leads E3 by more than 90° while E2 lags E3 by less than 90°. Consequently, the net voltage Ed2 applied to the bottom diode exceeds the net voltage Ed1 applied to the top diode. Thus, the current through resistor R3 exceeds that through resistor R2 and the output voltage waveform swings in a negative direction. An opposite relationship, applied to a frequency deviation on the high frequency side of resonance, will result in voltage E1 leading E3 by less than 90° while E1 will lag E3 by more than 90° (Fig. 9C). Thus, the top diode conducts more heavily and a positive voltage is developed across the output. Capacitors C2 and C3 filter out the RF components, leaving only the audio variations.

As the incoming FM signal deviates first to one side of resonance and then to the other, in accordance with the original negative and positive alternations of the modulating audio wave, the diode output will vary correspondingly to develop the negative and positive amplitude variations of the original modulation.

In your study of frequency modulators, you learned that the amplitude of the modulating wave determines how much the FM carrier deviates from center. In the demodulation process, the difference between the diode currents is determined by the extent of the frequency deviation. This relationship is shown by the second set of vectors in Fig. 9 (D, E, and F). Notice that the more the incoming signal departs from center frequency, the more E1 and E2 depart from their 90° relationship to E3. In this example, representing a deviation above resonance, we find that the Ed1 resultant vector continues to increase while the Ed2 vector decreases (Fig. 9E). Thus, diode 1 current dominates, and as the deviation increases, as in Fig. 9F, Ed1 becomes greater and greater, producing a stronger positive alternation at the discriminator output.

In summary, the FM discriminator responds to the incoming FM wave in three ways. It responds to the *direction* of the frequency change, reproducing either the negative or positive alternation of the original modulation. It also responds to *extent* of the frequency change, producing an output variation that corresponds to the original magnitude of the modulating wave. Further, the FM discriminator responds to the *rate* of change in the frequency deviation. As you learned in your study of FM modulators, the rate at which the frequency deviates depends on the frequency of the modulating wave. In the demodulation process, the frequency of the discriminator output corresponds to the rate at which the incoming signal changes frequency. Thus, it reproduces the original frequency of the modulating wave.

GATED-BEAM FM DETECTOR

This type of detector uses the special constructional features of a gated-beam tube to demodulate an incoming FM signal. In a gated-beam tube, the electron beam is guided from cathode to plate by special shields and apertures. Control electrodes are the signal grid (sometimes called a limiter grid) and the quadrature grid. The plate and an accelerator electrode operate at positive potentials and provide the necessary acceleration for the electron beam.

It is the positive potential of the accelerator electrode (Fig. 10) that attracts the electrons away from the cathode. Whether or not the electrons pass through the accelerator aperture toward the plate depends on the signal-grid voltage. When the signal grid is more than a few volts negative, electrons cannot flow to the plate.

When the signal grid is less negative than necessary to produce cutoff, the electrons continue toward the plate. However, these electrons next encounter the quadrature grid. If the quadrature grid is more than a few volts negative, electron flow to the plate will be cut off. If the quadrature grid voltage is less than the negative cutoff value, the electrons will

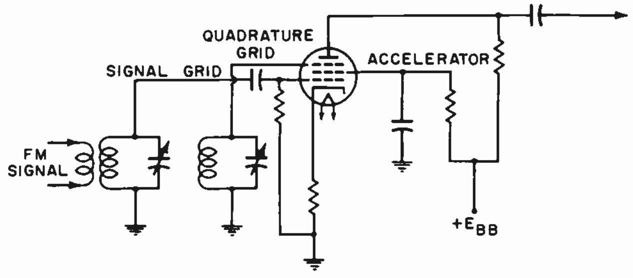


Fig. 10. Basic circuit for a gated-beam detector.

reach the plate. The ability of the signal and quadrature grids to control operation between cutoff and saturation with only small voltage changes provides a means of amplitude limiting the incoming FM signal (just like the separate limiter stages in the IF system of most FM receivers), as well as a means of demodulating the FM signal. Thus, the gated-beam circuit is both a limiter and detector.

In acting as a limiter, the incoming signal varies tube conduction between cutoff and saturation. Amplitude variations and noise components are thus clipped sharply.

The FM demodulation is a function of the quadrature relationship between the voltages developed across the tuned circuits of the signal and quadrature grids. At resonance, the signal voltage developed across the quadrature circuit lags the signal-grid voltage by 90°. This is a result of the space-charge (capacitive) coupling between the two grids.

Above or below the resonant frequency, the quadrature circuit will appear inductive or capacitive. Consequently, the quadrature voltage will lag the voltage at the signal grid by more or less than 90°.

What effect does this shift in phase between quadrature- and signal-grid voltages have on the average plate current? When a center-frequency signal is present at the signal grid, a 90° counterpart is present at the quadrature grid. The signal grid will permit electrons to pass during the positive alternation of the incoming signal. Likewise, the quadrature grid will permit current to pass during the positive alternation of any signal present at its grid. Since the two voltages are 90° related, both grids are positive simultaneously for only about one-fourth the period of the input cycle. Thus, plate current is in the form of short bursts.

When the incoming signal swings higher in frequency, the voltage on the quadrature grid lags the input signal by more than 90°. The new phase relationship decreases the period of tube conduction to less than one-quarter of the input cycle, and the average value of plate current decreases.

Conversely, when the incoming signal swings lower in frequency, the phase difference between grid voltages is less than 90°. The tube then conducts for a longer time during each cycle, and average plate current is more than that which flows at the center frequency.

In summary, the average plate current varies with respect to the incoming FM deviations. Consequently, the gated-beam discriminator develops an output current that corresponds to the modulation on the FM wave. The greater the deviation, the more the quadrature grid voltage will shift in phase away from 90°, and the more the average plate current will change from its resonant value. Thus, the gated-beam tube responds to the magnitude of the original FM modulation. The rate at which the phase angle deviates at the quadrature grid depends on the rate the incoming FM signal deviates about its center frequency. In this manner, the discriminator responds to the frequency of the original modulation.

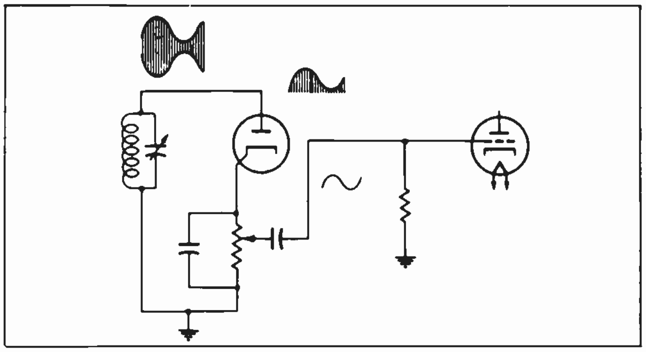


Fig. 11. Diode detector circuit, showing coupling to audio amplifier stage.

PREPARATION FOR LICENSE EXAMINATION

1. *Draw a simple schematic of a vacuum-tube diode detector, and show a method of coupling it to an audio amplifier.*—See Fig. 11.

2. *Explain the operation of a diode detector.*—A diode detector is a combination rectifier and filter. Its rectifier action permits conduction during periods of one polarity alternation of an applied modulation envelope. The magnitude of the unidirectional current increases and decreases with the variations of the RF peaks. Hence, average diode current is representative of the RF carrier modulation. The output network acts as an RF filter, but does not filter out the modulating signal. As a result, the original modulation is recovered at the output of the diode detector.

3. *What is the principal advantage of a diode over a grid-leak triode detector?*—It is capable of handling a strong input signal without distortion, particularly at high modulation levels, and its circuit is simpler and less complicated.

4. *Describe the operation of a crystal detector (rectifier).*—A crystal detector functions like the diode detector discussed in question 2. The crystal is composed of some type of crystalline material, such as germanium or silicon, which has a rectifying characteristic (it will pass current more readily in one direction than the other). One side of the crystal detector is a semiconductor wafer, and the other is a fine wire ("cat whisker") that contacts the wafer.

Older crystals had an adjustable "cat whisker" which was set to the most sensitive detection point that could be found on the crystal. The modern crystal is a carefully machined and permanently shielded device.

5. *Draw a simple schematic of a triode vacuum*

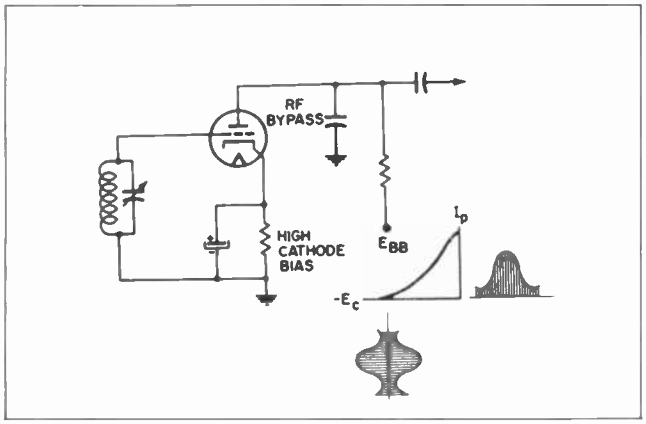


Fig. 12. Basic plate detector circuit.

tube connected for plate or power detection.—See Fig. 12.

6. *Explain the operation of a power or plate rectifier vacuum-tube detector.*—A plate or power detector is biased near cutoff; plate current flows only during positive alternations of the RF cycles of the applied modulation envelope. As in the diode detector, the average plate current follows the audio variations of the modulation envelope. Unlike the diode detector, however, the triode circuit provides amplification.

If the applied signal level is kept within the limits of the linear part of the transfer characteristic, a good replica of the modulation will be developed at the output. If the input level is too high, it will swing off the linear portion of the transfer curve. The plate detector thus overloads more easily than the diode demodulator, but it nevertheless delivers a strong output when excited by a signal of suitable level.

7. *What operating conditions determine that a tube is being used as a power detector?*—The power detector is biased nearly to cutoff. This can be in the form of fixed or cathode bias.

8. *What are the characteristics of plate detection?*—The plate detector delivers a strong and essentially undistorted output when driven by a moderate signal, and is seriously overloaded when the signal becomes excessive. It presents very light loading to the preceding stage, compared with other types of detectors. Refer to questions 6 and 7.

9. *List and explain the characteristics of a square-law vacuum-tube detector.*—A square-law detector, by operating on the non-linear portion of its characteristic curve, develops an output which is proportional to the square of the applied voltage. It is used for heterodyning and other specialized applications. However, it would produce a distorted output if excited by a conventional AM envelope.

10. *Draw a simple schematic of a triode vacuum tube connected for grid-leak detection.*—See Fig. 13.

11. *Explain the operation of a grid-leak detector.*—The grid-cathode circuit of a grid-leak detector functions like a diode detector, the grid serving as the anode. However, an amplified version of the demodulated signal at the grid is developed in the plate circuit.

The grid-leak detector is biased near saturation by the grid current drawn during the positive crest of the RF input cycles. The negative alternations swing down through the linear portion of the tube transfer characteristic, as shown in Fig. 13. The average plate current follows the variations of the negative RF peaks, and these variations produce an amplified version of the grid-signal change in the output. The RF cycles are filtered out in the plate circuit.

The grid-leak detector is sensitive and develops a reasonably strong output. Like the plate detector, it must not be overloaded by too strong a signal; otherwise, a reasonably undistorted output cannot be developed.

12. *Is a grid-leak detector more, or less, sensitive than a power detector? Why?*—More sensitive. By operating at a low bias (near saturation) it offers maximum amplification to a weak signal. A plate detector operates near cutoff, where mutual conductance is low and a weak signal is not amplified as much as it would be higher on the transfer characteristic.

13. *What effect does the reception of modulated signals have on the plate current of a grid-leak detector? On a plate detector?*—The stronger the incoming signal (modulated carrier), the more the plate current will decrease for the grid-leak detector. With the plate detector, plate current will increase.

14. *Draw a simple schematic of a regenerative detector.*—See Fig. 14.

15. *How does the resistance in the grid-leak circuit of a regenerative detector affect the sensitivity of the detector?*—In general, the higher the grid-leak resistance, the higher the sensitivity (up to the limit of instability or blocking). Several megohms is typical.

16. *What feedback conditions must be satisfied in*

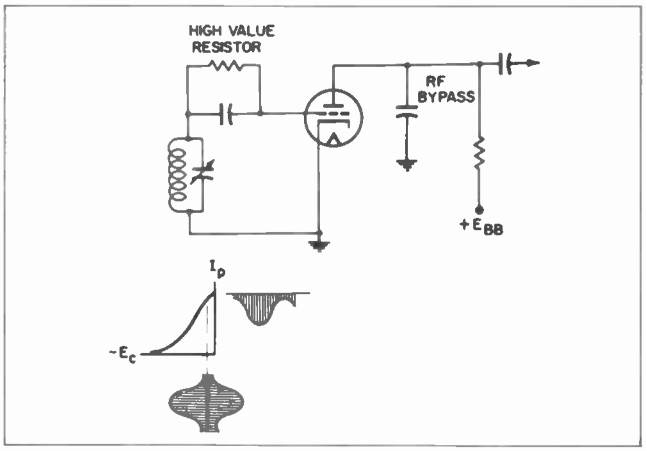


Fig. 13. Basic grid-leak detector circuit.

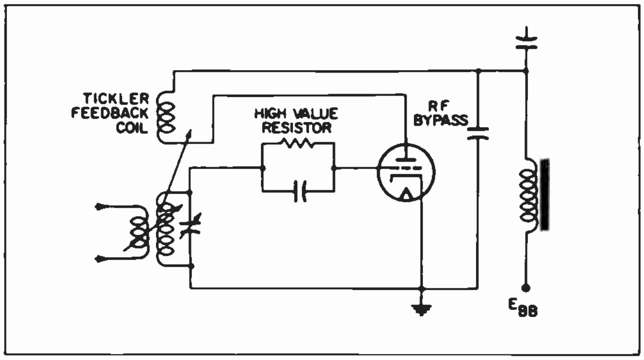


Fig. 14. Regenerative detector.

a regenerative detector in order to obtain sustained oscillations?—Adequate in-phase feedback to overcome grid-circuit losses, as in any other self-excited oscillator. These losses include the loading of the antenna or preceding stage.

17. *What effect might be caused by a shorted grid capacitor in a three-circuit regenerative receiver?*—The grid-leak bias circuit would be shorted out, causing loss of receiver sensitivity.

18. *What might be the cause of low sensitivity in a three-circuit regenerative receiver?*—Improper tuning. To derive peak sensitivity from a regenerative detector, there must be a proper amount of feedback and optimum coupling between the antenna (or preceding stage) and detector. Improper voltages, a failing tube, or a defective component could cause a loss of sensitivity.

19. *Describe the operation of a regenerative receiver.*—The conventional major units of a regenerative receiver are an optional RF amplifier, a grid-leak detector with feedback, an audio amplifier, and a power source. The demodulator is a grid-leak detector that functions like the one discussed in question 11 and shown in Fig. 13, except that a feedback link is provided, usually a tickler-coil arrangement as in Fig. 14. The circuit supplies a controlled in-phase feedback to the grid circuit. The incoming modulated signal is detected in the conventional manner by the grid-leak detector. However, some of the output is fed back to the grid circuit to reinforce the original grid signal. This feedback increases the impedance and the effective Q of the input resonant circuit, so that higher sensitivity and selectivity result.

The amount of feedback can usually be controlled because the sensitivity of a regenerative detector increases up to the point where self-oscillation occurs. Thus, in the reception of a modulated signal, the regeneration control is advanced to this point. It is then retarded slightly until the oscillations cease. In the reception of a CW signal, however, the regeneration control is advanced to the point of oscillation, because oscillations are necessary to recover the interrupted carrier (CW) information.

20. *In a regenerative receiver, what circuit conditions are necessary for maximum response to a modulated signal?*—Input coupling and regeneration must be optimum, which is achieved by advancing the regeneration control to the point of oscillation and then backed off slightly. (Refer to question 19.)

21. *In a regenerative detector, what feedback conditions must be satisfied for most stable operation in an oscillating condition?*—The stable oscillation point is not the same as for maximum sensitivity. If connected directly to the detector, the antenna must be very stable. Stability is better when antenna coupling is somewhat less tight than required for maximum sensitivity. Likewise, the regeneration control should be advanced a bit beyond the point at which the stage breaks into oscillation. The feedback should be of reasonably constant amplitude, and input coupling should be such that the operation remains stable.

22. *Why is it necessary to use an oscillating detector for reception of an unmodulated carrier?*—The function of the oscillating detector is to set up an audible difference frequency between it and the incoming carrier. The difference frequency between the incoming carrier and the frequency of an oscillating detector represents the audio frequency of the interrupted tone at the output of the regenerative receiver.

In a superheterodyne receiver, the interrupted tone is due to the difference frequency between the interrupted IF carrier and the frequency of the beat-frequency oscillator (BFO), which must be turned on to receive CW signals.

REVIEW QUESTIONS

1. What is the phase relationship between the input and output voltages of a double-tuned transformer?
2. During what portion of the radio-frequency cycle does a diode detector conduct?
3. What are the two input signal paths of a phase discriminator?
4. Why can the gated-beam tube be used as a limiter?
5. Briefly describe the function of the quenching oscillation.
6. What two voltages determine the duration of current flow in a gated-beam detector?
7. Why is the output of the phase discriminator zero at the resonant frequency?
8. What are the features of a super-regenerative detector?

Answers to these questions will be included in PHOTOFACT SET No. 573

ANSWER SHEET

For Questions in Lessons 9 through 12

LESSON 9—ANSWERS

1. In a phase-modulated system equalization is used to obtain a frequency-modulated resultant although the angle modulation process is being used. The equalization network displays an attenuation with increased frequency so that equal modulating-signals of differing frequencies produce equal deviations in the FM wave.
2. A reactance tube is capacitive when the current it introduces into the tank circuit of an oscillator leads the tank-circuit voltage.
3. Pre-emphasis causes the high-frequency modulating signals to produce a greater deviation than the lower frequencies, improving the signal-to-noise and signal-to-interference ratios of the FM system. The frequency characteristic must be corrected by the use of a de-emphasis network at the receiver.
4. The higher the modulation index for a given audio frequency, the greater the bandwidth occupied by the signal. The modulation index at the highest modulating frequency determines the bandwidth required by the station.
5. In FM transmission, 100% modulation corresponds to the maximum deviation permitted by the particular FCC station assignment.
6. In a direct frequency modulation process the frequency of the oscillator is changed directly by introducing a varying reactive component into its resonant tank circuit. In a phase modulation process the phase of the center-frequency generated by the oscillator is shifted back and forth with the modulation. Angle modulation of this type results in a frequency deviation of the RF signal. If equalization is used in the phase-modulating process, a true FM wave results. This method of generating an FM wave is called indirect-FM.
7. The G_m of the phase modulator tube is changed by the applied modulating wave. Consequently there is an output variation in amplitude which, when recombined with the center frequency, produces an angle-modulated resultant.
8. Overmodulation in an FM system is prevented by audio clipping. In this process the modulation peaks are clipped by diode (or other) circuits to prevent the modulator from causing deviation greater than the assigned maximum.

LESSON 10—ANSWERS

1. Grid modulation requires much less audio power for a given modulated-RF power output.
2. The bandwidth is determined by the highest modulating frequency.
3. In most AM transmitters overmodulation is prevented by an audio clipper stage. Its operation is the same as that used for FM transmitters.
4. With 100% modulation there is a 50% increase in power output. Consequently, the power in the sidebands is one-third of the total power output at 100% modulation. This additional power is supplied by the modulator in a plate modulated system.
5. When the transmitter is adjusted properly and symmetrical modulation is applied, there will be no change of average plate current in the modulated amplifier.
6. When there are negative overmodulation peaks, the carrier is cut off momentarily, producing a greatly distorted modulation envelope and generating spurious signals on frequencies other than the assigned channel.
7. In an amplitude-modulated system the RF power output of the antenna increases with modulation. Consequently, the antenna current will rise with an increase in the modulation percentage.

LESSON 11—ANSWERS

1. The nickel-cadmium battery is rechargeable. At the same time it is sealed and does not require the addition of any electrolyte. Units can be constructed in various shapes and sizes to meet specific needs. They have a long life and can be stored in either a charged or discharged condition.
2. The silicon rectifier junction has a very low forward resistance. Consequently, there is a minimum forward voltage loss and, for a given rectifier current, a substantially smaller amount of power must be dissipated by the junction in comparison to other types of rectifiers.
3. Solar cells can be used to supply power directly to an electronic unit. They can also be used to charge rechargeable batteries; the batteries, in turn, supply operating power for electronic units.
4. It refers to the resistance to electron flow offered by the junction when a reverse voltage is present across the junction terminals.

(continued)

5. The oscillating transistor circuit serves as a power converter between low voltage DC and high voltage AC. The switching action is comparable to that of a mechanical vibrator.

LESSON 12—ANSWERS

1. At the resonant frequency the input and output voltages are 90° related. Off of the resonant frequency the two voltages are more or less than 90° related.
2. The diode conducts for only a small segment of the positive alternation of the radio-frequency cycle.
3. One path is direct through a coupling capacitor while the second path is by way of mutual coupling between the two windings of a tuned transformer.
4. If the signal swings a small amount negative at both the signal and quadrature grids of a gated-beam tube it is possible to cut-off the plate current flow. An incoming signal can be confined within narrow voltage limits and, therefore, amplitude limiting takes place.
5. The quenching oscillations cause the oscillations of a superregenerative detector to cut on and off. Thus a high sensitivity can be obtained operating in the oscillating range without permitting the oscillations to build up to a level which will cause continuous uninterrupted oscillations.
6. The phase relationship between the signal and quadrature grid voltages determines the time duration of current flow and therefore the average plate current.
7. It is zero because the phase relationship among the radio-frequency signals is such that both diodes receive the same net voltage. They conduct equal but opposite current through the output circuit, producing a net voltage of zero at the resonant frequency.
8. A superregenerative detector has a very high sensitivity developing a strong output from a very weak signal input. It can be used to demodulate AM- or FM-modulated signals. It is rather critical of tuning, has a wide bandwidth, and can radiate an interfering signal.

Lesson 13

Receiving Systems

INTRODUCTION

In the radiocommunication service the superheterodyne receiver is king. It has a high degree of stability, excellent sensitivity, fine selectivity, and lends itself to a practical and effective system of tuning. Occasionally, however, a superregenerative receiver is used in small lightweight equipment operating on the higher-frequency bands, and tuned-radio-frequency receivers are sometimes to be found in low-frequency service. For example, most shipboard installations include a TRF emergency receiver. However, tracking, instability, and feedback present problems which are difficult to overcome in this type of receiver.

The superheterodyne uses a beat-frequency process in its mixer stage. Incoming signal and local-oscillator signal beat together to produce a "difference frequency." When the receiver is tuned, the frequencies of the RF amplifier and oscillator change, so that a constant difference frequency is maintained. The bulk of the signal amplification is done at this fixed intermediate frequency. Since the IF amplifier can be designed to operate at a single frequency (which is lower than the signal frequency), high gain, excellent selectivity, and a high degree of stability can be achieved in circuit design. Adjustable tuned circuits are used in an IF-amplifier system so that each stage may be tuned individually to operate at the intermediate frequency. In normal operation, these tuned circuits need not be readjusted for an indefinite period of time.

Only the incoming-RF and oscillator tuned circuits need be adjusted when the receiver has to be operated at a different frequency. This is much less of a problem than would be encountered with a tuned-radio-frequency type of receiver in which many resonant circuits have to be tuned each time a frequency change is necessary.

An IF amplifier can be designed to display a maximum sensitivity and uniform gain over the desired bandwidth, and its response can be made to drop off very sharply outside of this desired bandpass. Consequently, the likelihood of adjacent-channel interference is much reduced.

The use of the superheterodyne principle is not without problems, one of which is the instability of the local oscillator. Local-oscillator drift causes the frequency of the IF signal to move out of the bandpass of the IF amplifier. Distortion, reduction in signal level, and interference can result from such drift. In radiocommunication services, the operator should not have to interrupt his work in order to retune the receiver; so in many receivers, the local oscillator is crystal-controlled to prevent it from drifting off frequency.

Image frequency pick-up is an ever-present superheterodyne problem. Also, there are spurious signal combinations that can produce IF interference. You are familiar with the image interference problem which exists in the broadcast band. The local oscillator of a broadcast receiver is tuned to the high-frequency side of the signal frequency by an amount equal to the IF frequency. When the intermediate frequency is 455 kc, the local oscillator frequency must vary between 995 kc and 2055 kc as the receiver is tuned between 540 and 1600 kc. It is also possible that signals on the high-frequency side of the local oscillator frequency, if they reach the mixer, can heterodyne with the local oscillator to produce a 455-kc difference frequency. For example, when the broadcast-receiver dial is set to 540 kc, the local-oscillator frequency is 995 kc. If a 1450-kc signal reaches the mixer it can heterodyne with the 955 kc local-oscillator signal and produce an IF signal. This 1450-kc signal is called the *image frequency*. Notice that it is separated from the *desired* signal frequency by twice the IF frequency (540 kc plus 2 x 455 kc = 1450 kc).

As shown in Fig. 1, the image-frequency response of a broadcast receiver with a 455-kc IF extends from 1450 to 2510 kc. Inasmuch as the broadcast band extends only to 1600 kc, the broadcast image-frequency range is said to exist between 1450 kc and 1600 kc. A broadcast receiver, therefore, when it is tuned between 540 kc and 690 kc, can be subject to interference from strong signals on frequencies between 1450 kc and 1600 kc.

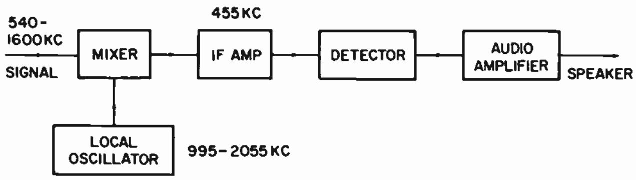


Fig. 1. The basic broadcast superheterodyne.

Image frequency interference is reduced by taking steps to prevent the image signals from reaching the mixer. Small broadcast receivers have only the antenna-mixer resonant circuit to provide selectivity. This simple tuned circuit does not offer too much in the way of image rejection. High-quality broadcast receivers and most communications receivers also include RF amplifiers and/or a group of preselector resonant circuits that provide more selectivity with a resulting improvement in image-frequency rejection. In two-way radio and other advanced communications services, special resonant traps are often included which are tuned to the image signal to prevent it from reaching the mixer.

The problem of image-frequency rejection has a great influence on the selection of an intermediate frequency for a communications receiver. In general, a low IF frequency offers higher gain, more stability, and better selectivity. However, the image response is better with a higher IF frequency because there is a greater separation between the signal frequency and the image frequency. This wide separation makes it easier to design resonant circuits which will reject the image frequency and pass the desired frequency.

Since many of the radiocommunication services operate on frequencies much higher than the broadcast band, the intermediate frequencies used in communications receivers fall between approximately 1.6 mc (1600 kc) and 12 mc. There are some lower-frequency IF amplifiers (less than 500 kc) but these are usually restricted to double- or triple-conversion superheterodyne receivers (which will be discussed later) or those applications in which there is only a limited tuning range. For example, a low-frequency IF amplifier is usually used in Citizens-band radio equipment since it operates in the 27-mc range. With the receiver tuned to the lowest-frequency channel (26.965 mc), the image frequency with a 455-kc IF is 27.875 mc (26.965 plus 2 x 455). It is apparent, therefore, that the image-frequency range is outside the tuning range of the Citizens-band receiver.

If a receiver has to cover a range of frequencies between 40 and 50 mc, it would be extremely difficult to obtain much image rejection using a 455-kc IF, since there would be image frequencies all along the tuning range at 910-kc (0.91-mc) intervals. However, if an IF frequency higher than 5 mc were used, the image-frequencies would again be outside the frequency range of the receiver.

It is also important to realize that the higher the signal frequency, the more difficult it is to obtain the narrow RF response necessary for good image rejection, unless the image frequency is well separated from the desired frequency. For example, if the receiver is tuned to 500 mc and a 455-kc IF frequency were used, the RF selectivity would have to be such that there could be no reception of a signal at 499.09 mc. This is a tough design problem. However, with a frequency separation of 10 mc between signal and image, the proper rejection can be obtained easily.

It is apparent that the design of a superheterodyne communications receiver must be a compromise between good image rejection and the advantages gained by using a low IF frequency. Therefore, one cannot expect any definite standardization of intermediate frequencies used in communications receivers, since the choice of frequency is dictated by the type of service to be rendered, unit size, and cost.

DUAL-CONVERSION SUPERHETERODYNE RECEIVERS

The dual-conversion receiver takes better advantage of the attributes of the heterodyne principle. It uses both a low and a high intermediate frequency. The high IF provides the wide spread between signal and image frequency necessary for good RF-stage image rejection, while the low IF provides the high selectivity which results in good adjacent-channel interference rejection and high receiver sensitivity.

Fig. 2 shows a functional block diagram of a double superheterodyne receiver which is typical of the type used in the HF, VHF, and UHF communication bands. In this particular set the high IF is 10.7 mc and the low IF is 1650 kc.

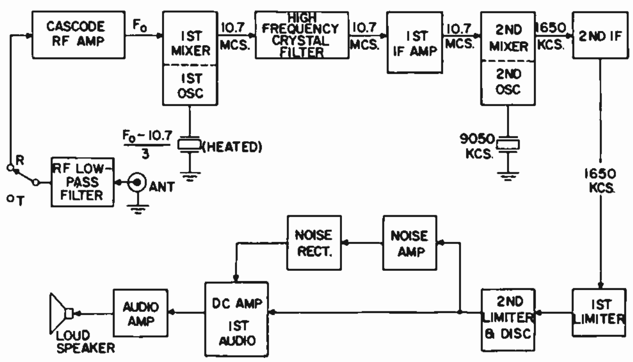


Fig. 2. Functional block diagram of an FM receiver.

In order to obtain good selectivity, most communications receivers include one or more RF amplifiers, preceded by a low-pass filter to reject interference from signals on frequencies above the operating range. Although the receiver in Fig. 2 is adjustable to certain specific frequencies within its range it is not continuously tunable. The receiver frequency depends on the crystal used in the first local oscillator.

Let us assume that the receiver is to be adjusted to receive a signal on 66.7 mc. The first local-oscillator crystal frequency must be selected so that a 10.7-mc difference is obtained. The crystal oscillator cannot be made to operate on the desired local oscillator signal frequency since, to obtain a 10.7 mc difference frequency, the oscillator frequency must be 56 mc (66.7 mc — 10.7 mc). This frequency is beyond the range of a normal, stable crystal. Therefore, if the third harmonic of the crystal is to be employed, the fundamental oscillations can occur at 18.67 mc (56.3), and the oscillator output circuit used to multiply the frequency to the desired 56 mc.

To obtain high selectivity for the receiver, the output of the first mixer can be applied to a crystal filter. The crystal filter is designed to give almost an ideal response, passing the desired signal and very sharply rejecting adjacent channel signals. After high-IF amplification, the signal is passed to the second mixer, another crystal-controlled oscillator, which operates at 9.05 mc to produce a low IF of 1650 kc (1.65 mc). A limiter arrangement follows the low-IF amplifier, after which the signal is fed to gated-beam detector.

As you learned in the study of FM demodulation, the received signal causes a sharp decrease in background noise because of limiting action. When there is no incoming signal, this background noise is amplified and the noise output in the speaker becomes annoying. Most communications receivers include some method of squelching this background noise during no-signal conditions. Additional circuits are sometimes included to reduce noise levels, particularly the noise associated with weak signals. Suitable noise rejection circuits in a receiver can extend its reception range for a considerable distance.

Audio amplifier stages raise the signal level for driving the loudspeaker. Inasmuch as many communications receivers are used in vehicles or in other noisy locations, plenty of audio power must be available.

THE RECEIVER IN THE SYSTEM

Receivers fit into a communications system in three different ways. In one plan (Fig. 3A), the transmitter and receiver are separate: each is a complete self-contained unit. Even separate antennas are used. This plan is most often used in high-powered point-to-point systems or in the base station of a mobile system.

The most common plan for mobile and low-powered base stations is shown in Fig. 3B. In this arrangement the receiver and transmitter are separate, but the power supply and the antenna are common. Transmit-receive switching takes care of the change-over of the antenna and power-supply facilities. Often the transmitter, receiver and power supply are

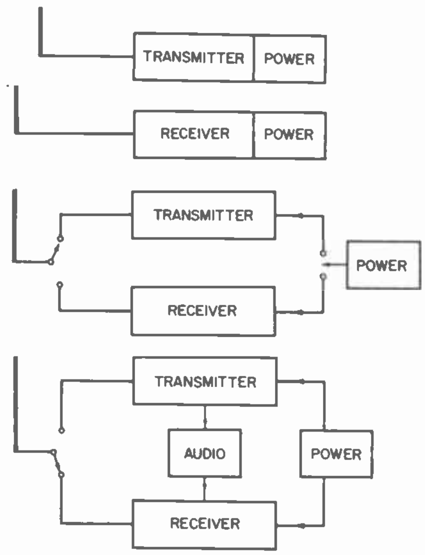


Fig. 3. Basic receiver and transmitter arrangements.

built into a single package which is called the transmitter-receiver unit.

Smaller-sized, lower-power, and/or lower-cost units, similar to the one shown in Fig. 3C, are called *transceivers.* Not only are the power supply and antenna system common, but certain other circuits are used by both the transmitter and receiver. In most of these the audio section doubles as both a speech amplifier-modulator and an audio amplifier-audio output section. Transceivers are available for both AM and FM use, although usually they are associated with AM systems. Citizens-band radio units and small-boat radiotelephone transceivers are typical of AM types.

TYPICAL COMMUNICATION RECEIVER

A schematic diagram for the receiving section of an *Aerotron* mobile FM transceiver is shown in Fig. 4. From the specifications, given in Fig. 5, notice its high order of frequency stability. As mentioned previously, this is very important because many communications receivers are not tunable, and since they are operated by non-technical personnel, they must hold firmly to the desired signal frequency.

Sensitivity ratings of less than 1 μv are typical for receivers of this type. The sensitivity of this particular receiver is given as 0.6 microvolt for 20 db quieting which means that 0.6 microvolts of signal input will cause the receiver noise output to be 20 db less than with no signal.

As is customary in voice-communication systems, the audio bandwidth is quite narrow—extending from 300 cps to 2500 cps. The selectivity of the receiver is quite narrow—the 6 db-down points are usually only 7.5 kc apart. The bandpass is flat within ½ db over a 6-kc bandwidth; however, note that the response is down 100 db just 16 kc on either side of

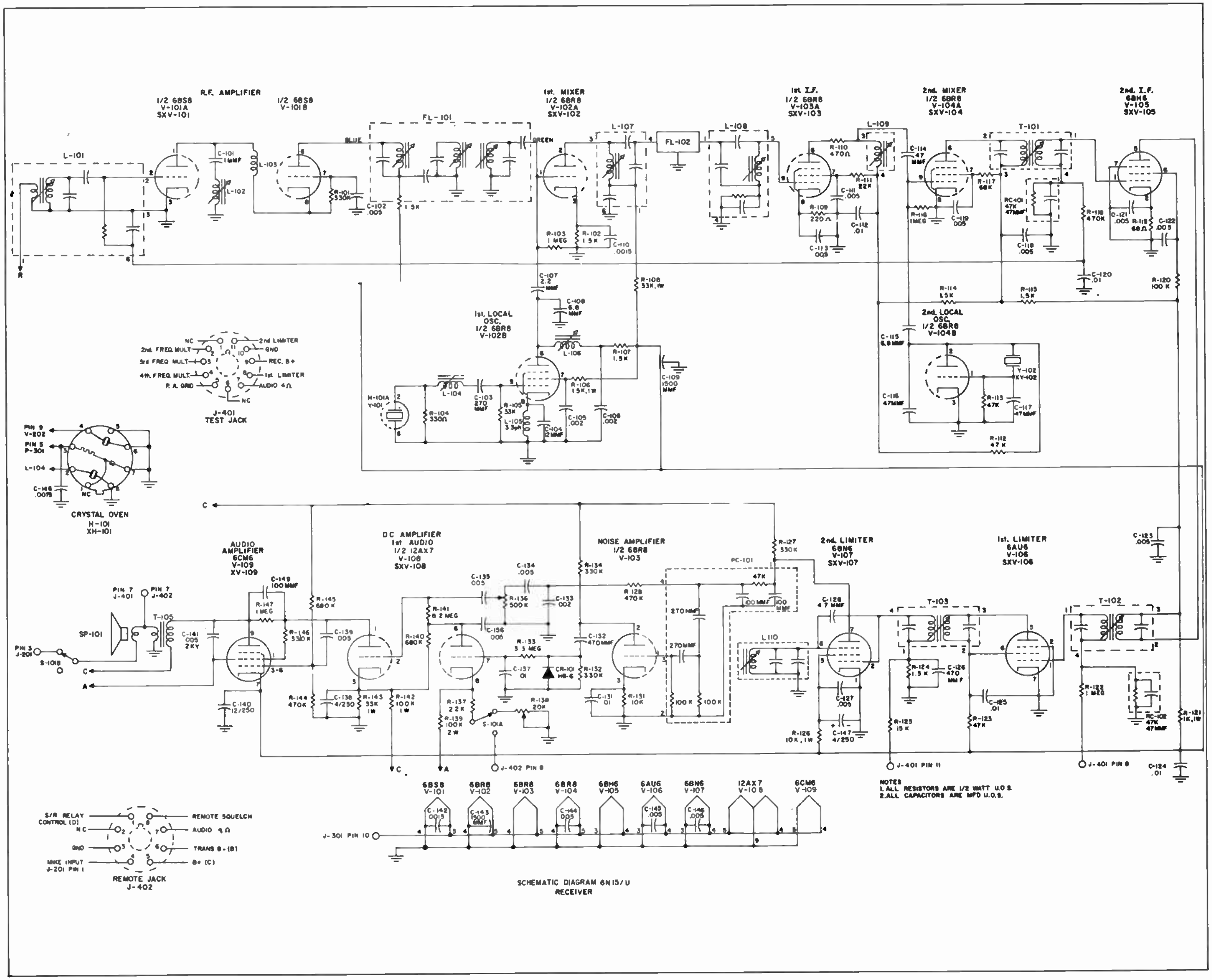


Fig. 4. Aerotron FM communications receiver.

Frequency Stability:	0.0005% over −40 to +75°C
Sensitivity:	0.6 microvolt or less for 20 db quieting
Selectivity:	± 7.5 kc at 6 db down
	± 16 kc at 100 db down
Modulation Acceptance:	± ½ db throughout band-pass range of ± 6 kc
Overall System Audio Response:	± 2 db from 300 to 2500 cycles
Audio Output:	1.5 watts with less than 10% distortion
Audio Level:	Less than 1 db variation in audio output from 0.6 microvolt to 0.1 volts RF input
Squelch:	Fully noise compensated; front panel adjustable

Fig. 5. Specifications of receiver.

the center frequency. This will give you a good idea of the selectivity that is incorporated into a modern communications receiver.

The audio output of 1.5 watts has less than 10% distortion. Furthermore, there is no more than 1 db of variation in this output for signal levels from 0.6 μv to 100 mv. Thus, there will be an essentially constant audio output despite wide input-signal variations—a condition which is quite prevalent in mobile-radio services. As a result, it is not necessary for the operator to continually change the audio volume control when reception is switched among various stations.

As can be seen in Fig. 4, the RF amplifier is cascode-connected. Most servicemen are familiar with the use of the cascode amplifier in television tuners. It is used in high-frequency communications receivers because of the same favorable operating features: namely, low noise content, favorable impedance relations, and high stability. Transformer L101 provides a match between the low-impedance antenna system and the input to the cascode amplifier. AVC is applied to grid 2 to prevent overloading when strong signals are received.

A series-resonant circuit consisting of C101 and L102 is connected from the plate of the first section of the cascode to ground. This image-rejection circuit is made resonant to the image frequency (signal frequency plus twice the IF frequency). This simple technique is very effective for a fixed-tuned receiver, however, image-frequency rejection becomes more difficult when a receiver must tune over a band of frequencies.

A three-section resonant network links the output of the cascode amplifier to the grid of the triode mixer. The selectivity of a tuning circuit at high frequencies is usually poor when a single resonant circuit is used. A group of resonant circuits in cascade improves selectivity making it possible to obtain faster drop-off response immediately outside of the desired bandpass. Cascade resonant circuits are quite common in communications receivers. In fact, some IF circuits may use as many as ten sections.

In your study of piezo-electric crystals you learned that they display characteristics similar to resonant circuits, therefore, crystals connected in various configurations can be used to obtain almost ideal selectivity curves. Many communications receivers use these "crystal filters" as the major component in determining the selectivity of the receiver. Such a crystal filter (FL-102) is connected between the output of the first mixer and the input of the high-IF amplifier.

The local-oscillator signal is coupled to the mixer through capacitor C107. A pentode crystal oscillator is used with the grid-cathode circuit components chosen for efficient overtone operation. Inductor L104 and the capacitance of the tube function as an impedance-matching network because a crystal has a low impedance in series-mode overtone operation. A high impedance thus exists from grid to ground at the crystal's third harmonic; the plate circuit of the oscillator is also tuned to the third harmonic of the crystal frequency. Small changes in oscillator frequency can be made by the L104 adjustment, allowing the crystal to be set precisely on frequency.

The crystal filter is hermetically sealed and contains six elements. The networks L107 and L108 are impedance matching devices; L107 matches the first mixer to the crystal filter and L108 provides a match between the filter and the first IF stage.

The first IF amplifier employs a single-tuned resonant circuit in its output. Resistor R110 provides some loading of the resonant circuit to obtain better bandpass and tuning stability. The output of the first IF amplifier is capacitively coupled through C114 to the grid of the second mixer.

The second mixer receives its local oscillator signal from a crystal oscillator operating on the 9.05-mc fundamental mode of the crystal. The 1.65-mc output of the second mixer is coupled through a double-tuned IF transformer to the grid of the second IF stage. After amplification, the IF signal is coupled via another double-tuned transformer to the first limiter.

The limiter operates at very-low plate and screen-grid potentials because of the voltage drop introduced by resistor R123. Receiver gain ahead of this stage is so high as to produce a small negative voltage across RC-102 from thermal receiver noise alone. This voltage may be measured at pin #8 on test jack J401 and is an excellent indication of overall receiver gain. If the voltage measured at this point is below −0.3 volts (with no signal input), the gain of the preceding stages is marginal, indicating that tube replacement or receiver realignment may be necessary.

It is apparent that the average communication receiver is highly sensitive; therefore, provisions should be made to allow limiting of even very weak signals. The limiter tube will limit signals of less than 1 μv measured at the antenna terminal.

A gated-beam tube is used as the demodulator and second limiter. Operation of this circuit is described in Lesson 12. The demodulator output is coupled to two circuits. PC-101 contains components which function as a bandpass network which couples noise components to the control-grid of the noise amplifier. The demodulator output is also passed through a de-emphasis network, composed of resistor R128 and capacitor C133, and coupled by C134 to the audio gain potentiometer R136. The signal from this control is conveyed via capacitor C135 to the triode audio amplifier, and thence to a pentode audio-output stage.

Noise amplifier tube V103 operates with a constant gain. Its noise output is rectified by crystal diode CR101 and filtered by resistor R133 and capacitor C137 developing −9 volts DC at the grid of the DC-amplifier tube. The grid-to-cathode voltage of this tube is determined by this −9 volts and the positive voltage present at the cathode as a result of voltage divider R139 and R137 and squelch control R138.

The DC-amplifier plate-current flow through resistors R140 and R142 determines the DC voltage that is present between cathode and grid of the first audio stage. This voltage is enough to cut off the first audio amplifier stage when no signal is being received, thereby muting the receiver and preventing receiver noise from reaching the loudspeaker. The noise signal rectified in the output of the noise amplifier develops about +9 volts at the grid of the DC amplifier.

When a signal is received, the noise level drops because of limiter action and the noise-rejection characteristics of FM demodulation. Consequently, very little (if any) noise reaches the grid of the noise amplifier, therefore the +9 volts is no longer present at the grid of the DC amplifier. This removes the cut-off bias from the grid of the first audio amplifier, permitting the stage to operate in a normal manner. The audio signal is amplified and applied to the audio output stage and loudspeaker.

The first audio amplifier tube is often called the squelch or gated tube because it is controlled by the presence of noise at the output of the sound detector. When no signal is being received the noise components are strong, and the receiver is muted. Upon receiving a signal, the noise components are reduced, the squelch tube bias becomes normal, and the audio system operates.

PREPARING FOR THE LICENSE EXAMINATION

1. *Why are high-reactance headphones generally more satisfactory than low-reactance types, for use with radio receivers?*—High-reactance headphones allow a receiver to be operated into a higher impedance load. They can be coupled directly to the plate circuit of a tube, presenting less load and permitting a greater audio signal to be developed.

2. *Why should polarity be observed in connecting magnetic headphones directly in the plate circuit of a vacuum tube?*—To insure that the fields of the electromagnet and permanent magnet are aiding. This precaution need not be observed for crystal headsets.

3. *If low-impedance headphones (on the order of 75 ohms) are to be connected to the output of a vacuum-tube amplifier, how can this be done to permit most satisfactory operation?*—A transformer should be used to match the high-impedance output of the stage to the low impedance of the headset.

4. *What type of radiotelephone receiver, using vacuum tubes, does not require an oscillator?*—A tuned-radio-frequency (TRF) receiver.

5. *Draw a diagram of a tuned-radio-frequency receiver*—See Fig. 6.

6. *What is the principal advantage of the tetrode over the triode in a radio receiver?*—The tetrode does not require neutralization; also, tetrode stages usually have higher gain.

7. *What type of radio receivers are subject to image interference?*—Superheterodyne receivers.

8. *What types of radio receivers contain IF transformers?*—Superheterodyne receivers. These are the transformers that transfer the IF signal between IF amplifiers.

9. *Draw a block diagram of a typical superheterodyne receiver using a 455-kc IF and capable of receiving AM signals. Indicate the frequencies in the various stages when the receiver is tuned to 2450 kc. What is the frequency of a station that might cause image interference to the receiver when tuned to 2450 kc?* The image frequency would be 2450 kc plus two times the IF in kilocycles. In the example of Fig. 7, with an IF of 455 kc, the image frequency would be 3360 kc ($2450 + 2 \times 455$).

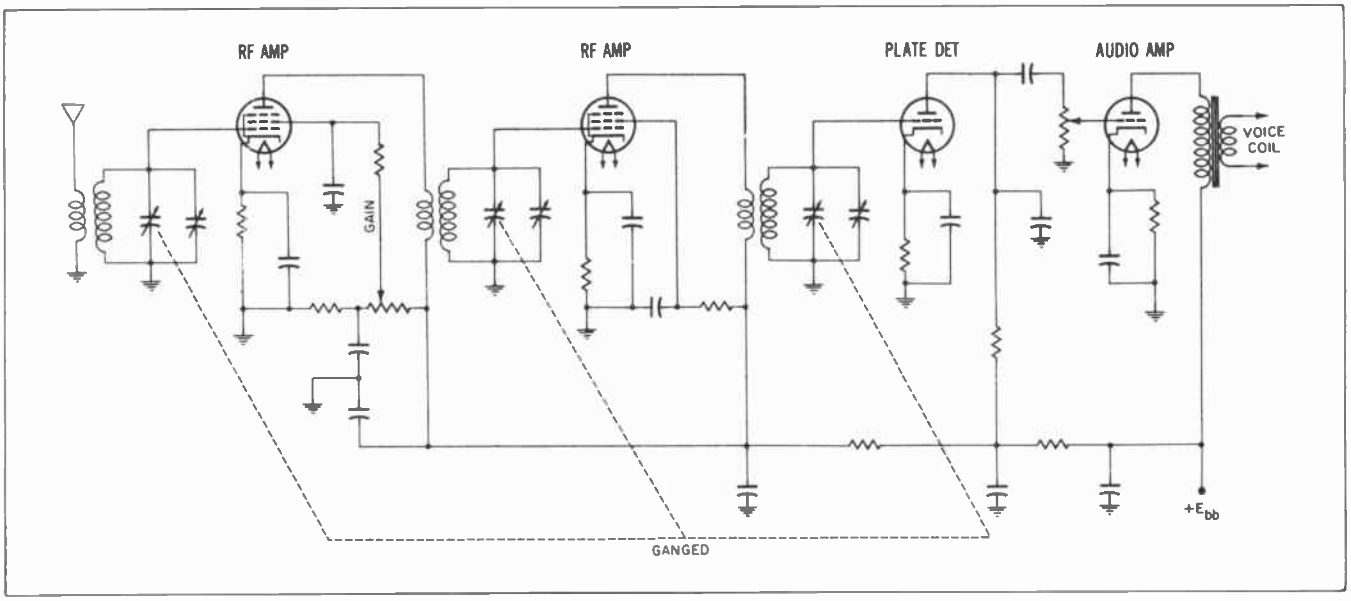


Fig. 6. Tuned RF receiver.

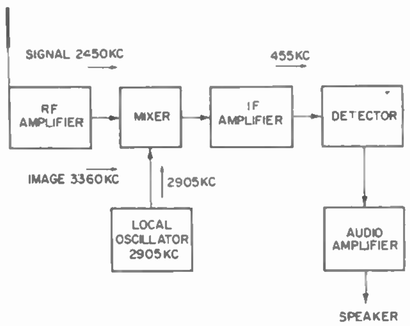


Fig. 7. Functional block diagram of a superheterodyne receiver.

10. *Explain the purpose and operation of the first detector in a superheterodyne receiver.* It is a mixer consisting of a nonlinear stage that mixes the incoming signal with the local-oscillator signal. The result is a difference frequency in the output corresponding to the frequency of the IF amplifier in the receiver. To keep the signal-frequency, local-oscillator, and sum-frequency components from appearing in the IF amplifiers, they are eliminated by the output circuit, which is tuned to emphasize the difference frequency only.

As the receiver is tuned over a given frequency range, the local-oscillator frequency follows the frequency of the input circuit, to insure that the first detector produces only the intermediate frequency.

11. *Explain the relationship between the signal, oscillator, and image frequencies in a superheterodyne receiver.* In a superheterodyne receiver, it is possible for a signal other than the desired one to mix with the local-oscillator signal and produce an IF difference frequency. In the example of Fig. 7, the desired input frequency is 2450 kc. If the local-oscillator frequency is set to 2905 kc, a difference frequency of 455 kc will appear in the output. A strong signal on 3360 kc may reach the grid of the mixer. If the signal beats with the local-oscillator signal, a difference frequency of 455 kc (3360 minus 2905) is again produced. Hence, it is possible for an image-frequency signal to interfere with the desired signal.

Image-frequency interference is reduced by using highly-selective input circuits, RF stages between the antenna and mixer, and double or triple conversion.

12. *If a superheterodyne receiver is tuned to 1000 kc and its local oscillator is operating at 1300 kc, what incoming signal frequency could cause image reception?* 1600 kc. The receiver IF is 1300 kc minus 1000 kc, or 300 kc. The image frequency is 1000 kc plus two times 300 kc, or 1600 kc.

13. *What are the advantages of adding a tuned RF amplifier stage ahead of the first detector (converter) stage of a superheterodyne receiver?*—Better image-frequency rejection and selectivity, higher signal-to-noise and signal-to-interference ratios, and reduced local-oscillator radiation.

14. *What is the purpose of operating a second oscillator near the intermediate frequency of the receiver?*—To permit reception of a CW or any other unmodulated carrier. Such an oscillator is called a beat-frequency oscillator (BFO).

15. *What is the purpose of shielding in a multistage radio receiver?*—To prevent oscillation. When several high-gain amplifiers are used, even a very small percentage of the output signal, if fed back to the sensitive input stages, will set up oscillations which make the receiver unstable or inoperative. Good shielding prevents radiation and minimizes

hum and noise pickup. Undesired magnetic and electric coupling are also minimized by proper shielding.

16. *What is AVC and how is it accomplished in a radio receiver?*—Automatic volume control (AVC) permits the receiver to display maximum sensitivity to a weak signal, while lowering its sensitivity to a strong signal. AVC action prevents a moderate or strong incoming signal from overloading the receiver and distorting the output, or causing the receiver to become inoperative because of blocking. It also improves the signal-to-noise ratio.

AVC action is accomplished by taking a DC control voltage from the diode detector or a special AVC diode stage. The diode current is applied to a resistor-capacitor combination which has a long time-constant; the negative side of the capacitor supplies bias to one or more IF or RF stages. When a strong signal is received, a high negative voltage appears on the AVC capacitor and line, reducing the receiver gain and preventing the strong incoming signals from overloading the other stages. When the incoming signel is weak, there is little or no DC voltage on the AVC capacitor. Consequently, the receiver gain and sensitivity remain at their maximum.

17. *What is meant by double detection in a receiver?*—A superheterodyne is sometimes referred to as a double-detector receiver. The first detector is the mixer, which converts the incoming signal to the intermediate frequency. The second detector demodulates the IF envelope to recover the original modulation.

18. *Compare the selectivity and sensitivity of tuned-radio-frequency, superregenerative, and superheterodyne receivers.*—The superheterodyne receiver has high selectivity and sensitivity, but is the most elaborate of the three.

The superregenerative receiver has a very high sensitivity, considering the few stages used, but its selectivity is poorest.

A tuned-radio frequency receiver can be made to have a good sensitivity, and its selectivity depends on the number of RF stages employed. It is often employed for emergency use (where low power-drain is important) because stability, selectivity, and sensitivity can be obtained with only a few stages. It does not radiate unwanted signals because it has no oscillating stage.

19. *Draw a block diagram of an FM superheterodyne receiver and compare operation with an AM set.*—The RF, mixer, local oscillator, and IF-amplifier systems are quite similar to their counterparts in an AM superheterodyne receiver. In a wide-band FM receiver, the bandwidths of the RF and IF stages are broader than those in a conventional AM superheterodyne. The audio-amplifiers are similar except that a deemphasis network is required, the frequency response is broader, and the distortion is less.

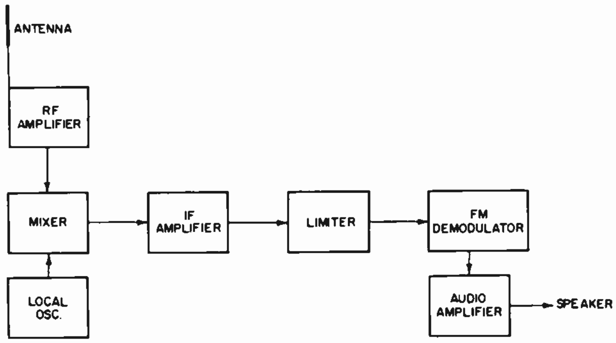


Fig. 8. Block diagram of an FM receiver.

The receiver of a narrow-band FM communications system has a limited bandwidth, and more emphasis is placed on stability. Often, the FM communications receiver is fixed-tuned by using crystals in the local-oscillator circuit. The audio-frequency response is quite narrow because communications channels are concerned only with voice frequencies.

An FM receiver, shown in Fig. 8, uses a limiter and an FM demodulator. The limiter stage is usually a saturated IF amplifier that removes any amplitude variations from the incoming FM signal. The FM demodulator is usually a conventional discriminator, or a ratio detector. Sometimes a gated-beam detector is used to remove the information from the FM signal. Some FM demodulators have limiting characteristics—while demodulating the FM signal, they also suppress amplitude variations. With such a demodulator, a limiter stage is not normally needed. The major difference, then, between the FM and AM receiver is in the use of limiters and FM demodulators.

LESSON 13

REVIEW QUESTIONS

1. What is an image frequency?
2. Give the advantages of a double superheterodyne receiver.
3. In what two applications are piezoelectric crystals used in a receiver?
4. Name three methods of reducing image response.
5. Why is a simple superheterodyne with a low IF frequency satisfactory for Citizens band reception?
6. Why are RF and IF selectivity important characteristics of a communications receiver?
7. Describe the basic principle of operation of the squelch circuit of an FM communications receiver.
8. In what terms is the sensitivity of a communications receiver rated?

Answers to these questions will be included in PHOTOFACT Set No. 577

Lesson 14

Two-Way Radio Circuit Descriptions (FM)

INTRODUCTION

Frequency-modulated systems are dominant among the land vehicle and other two-way radio services that come under the general heading of public-safety, industrial, and land transportation. The most notable exception is the Citizens band radio service which uses amplitude modulation. AM is also prevalent in the small-boat marine and the aviation radio services. Again there are exceptions, particularly when planes or boats are tied in with land vehicle systems.

There are any number of two-way radio schemes and arrangements. The most popular plan uses a base station and a series of mobile units. The base station is usually installed in or near the place of business, perhaps convenient to the dispatcher's office of a large organization. Usually the base station transmitter and receiver are near the operating control center of the system.

In some cases, the transmitter-receiver unit is installed in suitable housing at the top of a nearby ridge or at the top level of a tall building, and operated by remote control from the control center. A variety of combinations are given in Fig. 1. In other installations only the transmitter is located at the high location, while the receiver is convenient to the dispatcher at the control center.

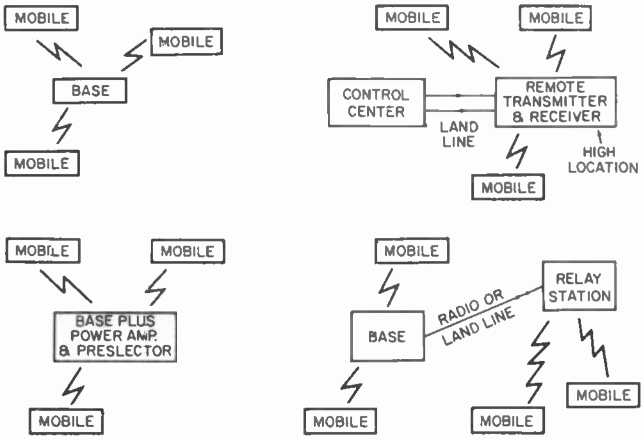


Fig. 1. Mobile base station plans.

In many two-way radio systems the base station and each mobile station are identical, with the exception that the mobile power supply operates off the vehicle's battery while the base station equipment is powered from 110 volts AC. In some schemes, the base station and mobile equipment is added to the base-station transmitter. In this plan the base station power output is greater than the power output of the mobile units, so that stronger signals are delivered to the mobile receivers and they can move into more difficult reception areas.

At times, an additional preselector-amplifier is placed ahead of the regular receiver of the base station. The added sensitivity and selectivity can be of help in receiving longer range signals from the mobile units. A relay station can be used to transmit stronger signals behind ridges or into difficult reception areas at the extremes of the system range. At the relay station, a receiver picks up the signal transmitted from the control center. The demodulated signal is then used to modulate a transmitter which sends out a stronger signal into the difficult area. The relay transmitter can operate at a lower, the same, or a greater power output than the control-center transmitter—as determined by the area to be covered.

Vehicular installations are of two basic types. The transmitter-receiver and power supply can be mounted as a single unit, usually in the trunk, and the remote control box is mounted beneath the dashboard (as shown in Fig. 2). This control box houses the necessary operating controls plus suitable connectors for attachment of the microphone and loudspeaker. In practically all two-way radios, the transmit-receive switch is part of the microphone. Depressing this switch places the transmitter on the air; when the switch is released the radio returns to the receive position.

A close-up of a control box as well as the microphone and switch are shown in Fig. 3. Notice that there are only three operating controls on the control box. These are the ON-OFF-STANDBY switch, VOLUME control, and SQUELCH control. The squelch control

Fig. 2. Two-way radio control box and speaker.
(Courtesy Motorola, Inc.)

is adjusted for a quiet background when no signal is being received, and should not be advanced too far because it can have an adverse influence on the sensitivity of the receiver to a weak signal. It should be adjusted just to the point at which background noise ceases to be annoying.

A second common installation plan mounts the entire two-way radio set as a single unit beneath the dashboard. As shown in Fig. 4, the control facilities are then a part of the transmitter-receiver and power supply unit. In some cases the speaker is built into the same cabinet; in others, it plugs into the unit but can be mounted wherever convenient. Receive and transmit lights can be seen in Fig. 4. Two toggle switches which permit the choice of one of two frequencies, in both the receive and the transmit positions, are located on the extreme left and right sides of the control unit.

COMMERCIAL MOBILE STATIONS

The transmitter schematic for the RCA two-way radio set pictured in Fig. 4 is given in Fig. 5. As shown at the top left of the schematic diagram, two oscillator circuits are provided for two-frequency

Fig. 3. Close-up of control box, microphone and transmit switch.
(Courtesy General Electric Co.)

Fig. 4. Single-unit two-way radio.
(Courtesy Radio Corp. of America)

operation. If a crystal oven is included, the operating frequency can be maintained within a tighter tolerance as indicated under frequency stability in the specifications chart. The crystal oscillator circuit is a modified Pierce-type with screen grid, control grid, and cathode operating as a Pierce triode oscillator with its oscillations electron-coupled to the plate circuit..

The crystal frequency falls between 2 and 3 megacycles according to the assigned carrier frequency. A small trimmer capacitor 2C2 permits a precise adjustment of the operating frequency of the crystal oscillator. The phase modulator is excited by the RF signal from the untuned plate circuit of the oscillator. The phase modulator is identical to the type discussed in Lesson 9, providing a maximum phase swing of approximately 90°. A radio-frequency signal is supplied to both the grid (by way of capacitor 2C5) and the plate (by way of capacitor 2C6) of the modulator. The audio signal arrives from the second audio stage by way of a low pass filter (inductor 2L12 and capacitor 2C41), which attenuates audio frequencies above 3000 cycles. This filter also removes any spurious high frequency components generated in the clipping process.

The audio signal is supplied to the control grid of the first audio stage through a pre-emphasis network consisting of 2C48 and 2R35. When a carbon microphone is used, the DC voltage drop developed across 2R36, which is part of a voltage divider network connected to the supply voltage line, provides microphone bias. Jumper A is removed when the microphone does not need bias.

The output of the audio amplifier is applied to the series-connected audio limiter. This circuit is similar to the limiters covered in Lessons 9 and 10. The resistance of the limiter circuit, and capacitor 2C45, provide the integration needed to round off and

Fig. 6. Aerotron 100-watt base station.

terminal of the low-power transmitter-receiver. The contacts of the changeover relay K601 switch the antenna to the input of the receiver when the relay is not energized. When the relay is energized with the operation of the microphone switch, the relay contacts apply the RF excitation to the grid circuit of the power amplifier. The second set of relay contacts link the output of the power amplifier to the antenna.

A dual tetrode is used in the push-pull power amplifier; no neutralization is necessary. Inductor L601 and split capacitor C603 serve as the grid tuned circuit; the split-capacitor arrangement permits the rotor plates to be grounded even though they are a part of a balanced resonant circuit. The grounded rotor is advantageous because the hand capacity associated with the tuning shaft will have a minimum influence on the resonant frequency of the grid circuit. A combination of grid leak and external bias is used. Switch S601 is a tune-operate control which lowers the screen voltage during the initial transmitter tuning steps.

The resonant plate circuit is composed of inductor L604 and capacitor C605 with a parasitic resistor connected between the rotor and ground. Resistors R604 and R605 are also parasitic suppressors; they reduce the tendency for an amplifier to self-oscillate at very high frequencies. These resistors are usually mounted very near the tube electrodes and insert a loading resistance on any possible combination of external components that may tend to resonate with the tube capacities.

Inductor L605 is a low-impedance secondary winding that provides proper transformation between the output of the power amplifier and the antenna. Capacitor C607 is used to tune the antenna system by tuning out any reactive components that may reflect an improper load to the transmitter or cause a mismatch between the transmitter and antenna.

The plate voltage is decoupled by capacitor C606 and radio-frequency choke L603. An R-C decoupling network is also used in the screen grid circuit of the transmitter.

TRANSISTORIZED EXCITER

The GE transmitter shown in Fig. 8 uses a transistorized RF exciter, the oscillator of which is shown in

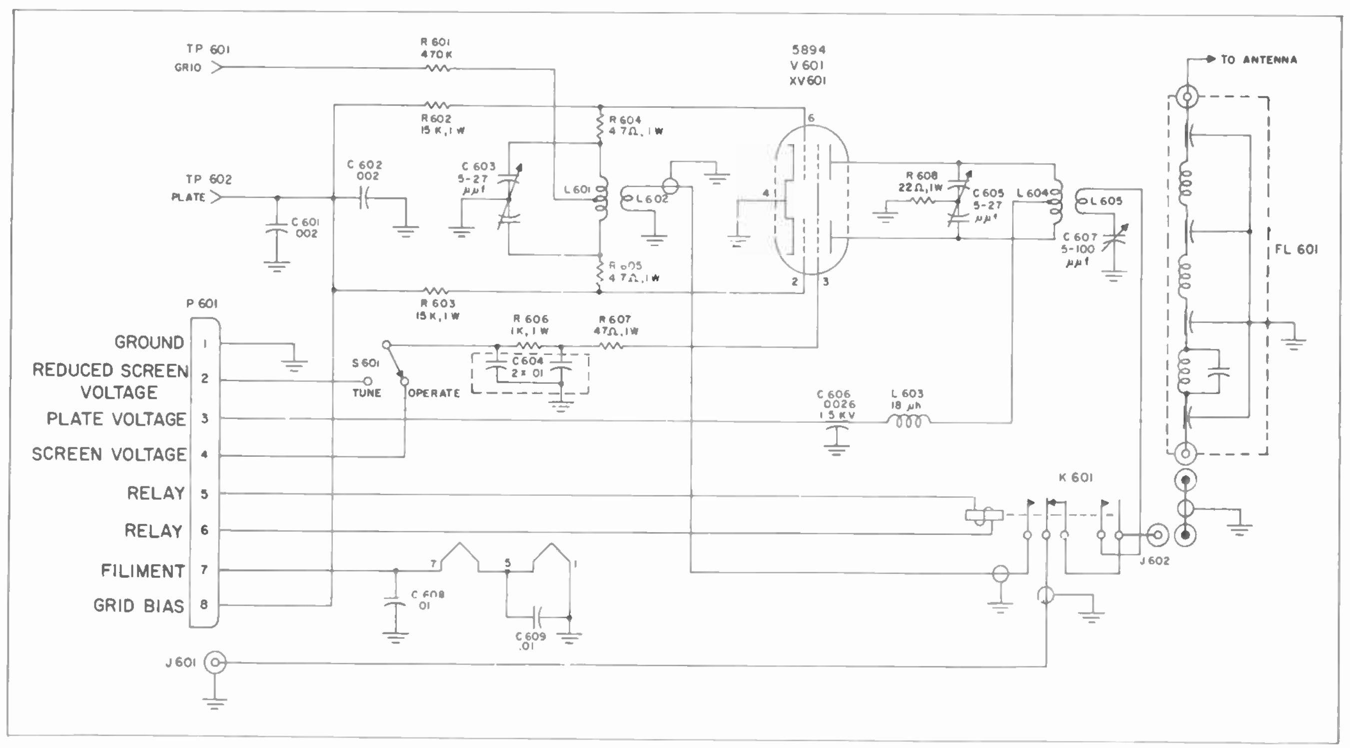


Fig. 7. Base station power amplifier.

smooth the audio-signal peaks after they have been clipped.

Notice that the second audio stage has a quiet-channel input—a low-pitched audio tone used to modulate the transmitter. This tone unsquelches the receiver for the desired station. In the absence of the tone, all receivers are squelched and interference from other stations is eliminated. When a two-way radio system does not possess quiet-channel capabilities, it is possible for interfering signals to enter the receiver and unsquelch the audio circuit. The use of the quiet-channel technique requires the presence of an audio tone of a specific frequency before the receiver will unsquelch. Furthermore, with the use of different tones, several groups of stations can be operated on the same radio channel and one group will not hear communications between stations of another group. In this arrangement, the frequency of the audio tone determines which particular station or group of stations is selected.

The phase-modulator output is supplied to the control grid of the first tripler 2V2B through capacitor 2C9. The tripler multiplies the center frequency of the modulated signal by three. As you learned, most multiplier stages operate in a Class-C fashion with a resonant plate circuit tuned to the desired harmonic. The resonant plate circuits are completed by jumpers connected among terminals 1, 2, 3, and 4 according to the desired operating frequency.

The RF drive to the tripler stage is indicated by the voltage drop measured across grid resistor 2R8. This voltage drop is determined by the tripler grid current—which, as you learned in your study of Class-C amplifiers, depends on the level of the RF excitation applied to the grid. It is this grid current that develops the Class-C grid bias for the stage.

Coupling between the tripler-plate tuned circuit and the grid tuned circuit of the next stage is through 2C13. The individual tuned circuits are mounted in shields; therefore, there is no mutual coupling. Proper shielding of resonant circuits is also important in obtaining stability and minimum radiation of spurious signals. In transmitter design it is important that only the final output frequency of the transmitter be conveyed to the antenna. Various crystal and multiplier frequencies should not reach the output stage, and therefore must not be radiated by the various tuned circuits used in the transmitter.

According to the final output frequency, the next RF stage is used as either a doubler or a tripler. In other respects this circuit is similar to that of the previous tripler. RF drive can be indicated by measuring the DC voltage drop across 2R12.

The next stage of the transmitter is a doubler. The doubler stage (and the final PA as well) use a combination of grid-leak and external fixed bias derived from a negative source in the power supply. A mutually-coupled, double-tuned resonant transformer conveys the RF excitation from the output of the doubler 2V4 to the grid circuit of the power amplifier 2V5. Capacitor 2C39 and inductor 2L11 form the tuned plate circuit of this stage, while capacitor 2C35 provides neutralization and inductor 2L9 and resistor 2R23 suppress spurious oscillations in the output.

If switch 2S1 is open, the final power amplifier can be operated at reduced power for tuning purposes. In tuning the power amplifier, it is helpful to be able to measure plate current by connecting an appropriate meter across resistor 2R39 in the plate-voltage supply.

The power-amplifier output is coupled to the antenna by way of the mutually-coupled coils 2L11 and 2L12, and the harmonic-suppression filter 2FL1. The variable capacitor 2C39 is used for plate tuning, while capacitor 2C40 is used to tune the antenna circuit. Inasmuch as the transmitter is designed to supply signal to a low-impedance antenna system, the mutually-coupled arrangement provides a transformation from the high-impedance output of the power amplifier to the low impedance of the antenna system.

Network 2FL1 is a low-pass filter which provides a 70 db attenuation to frequencies above the carrier. This network prevents the antenna system from radiating carrier-frequency harmonics which can cause interference in other frequency bands.

Relay 2K1 is activated by the transmit-receive switch of the set. When the relay is energized by holding down the transmit-receive switch of the microphone, the relay contacts switch the antenna from the receiver to the transmitter. When the transmit switch is released, the antenna is switched back to the receiver input.

BASE-STATION POWER AMPLIFIER

Long-range communications and/or poor propagation conditions often dictate the use of a higher-powered base station transmitter. Many systems use mobile-type equipment at the base station or use a base station transmitter with the same power output as the mobile units. When the system is to be expanded for operation into more difficult receiving areas, or the range of the system must be extended, it is helpful to be able to add certain equipment to the base station in order to increase the power output.

An Aerotron unit is shown in Fig. 6. The cabinet houses the additional RF power amplifier and includes facilities for the initial Aerotron 20-watt station. The 20-watt unit, in this case, acts as the FM exciter for the 100-watt power amplifier. The schematic diagram of the power amplifier is given in Fig. 7.

Connector J601, shown at the bottom left of the schematic, links the power amplifier to the antenna

Two-Way Radio Circuit Descriptions (FM)

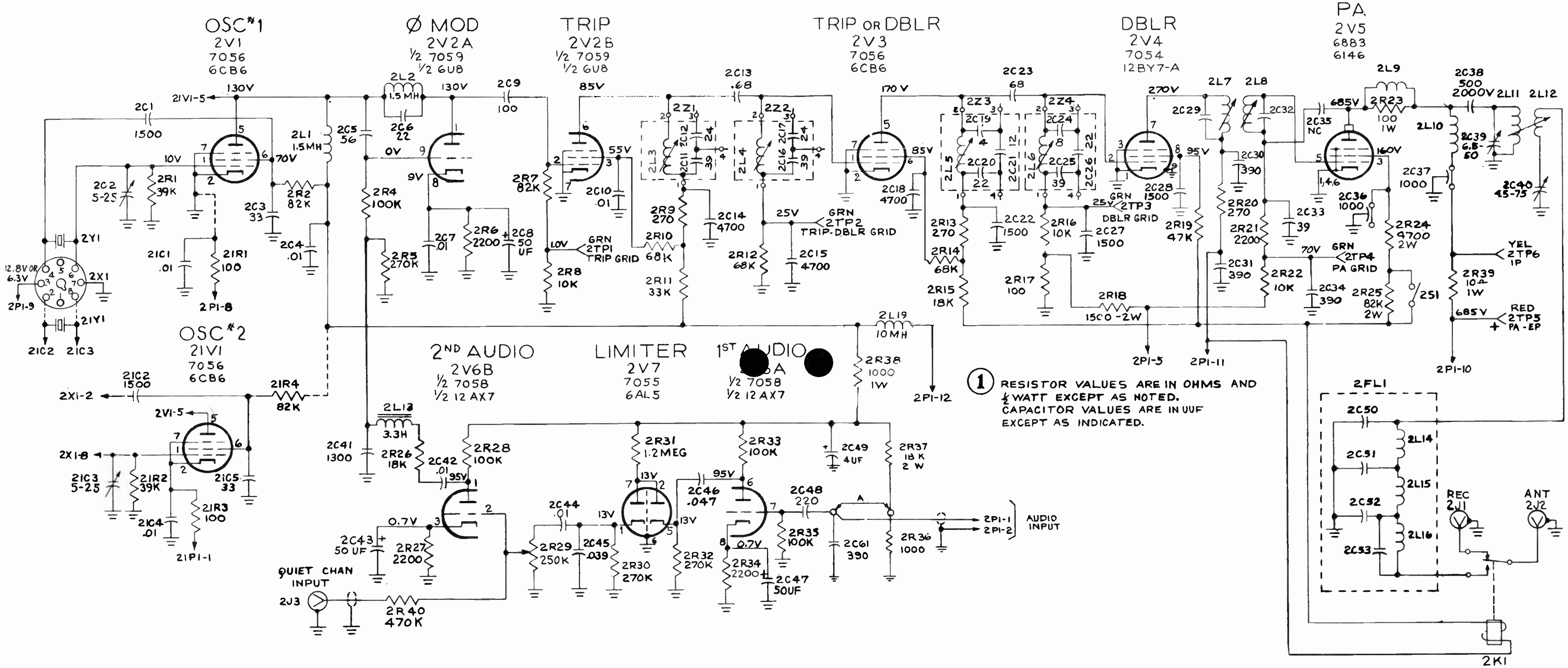


Fig. 5. Transmitter of RCA two-way radio.

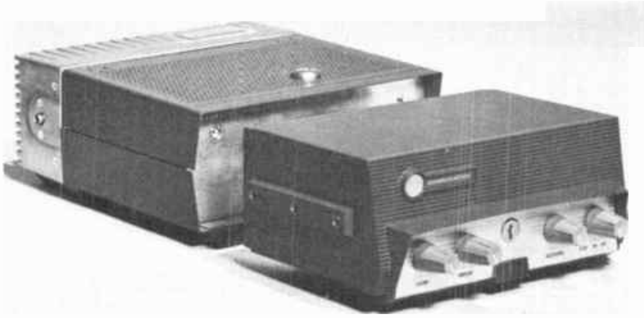


Fig. 8. General Electric transistorized mobile station.

Fig. 9. The feedback ratio of the Colpitts-type circuit is established by capacitors C4 and C5, and the collector circuit is tuned to twice the oscillator frequency. A buffer stage isolates the oscillator from a delay-line modulator, which is followed by a doubler stage.

Notice the similarity between transistor RF circuits and those of vacuum tubes. For example, the base and collector tuned circuits are comparable to the plate and grid tuned circuits of a vacuum-tube RF amplifier. Transistors, however, have low-impedance inputs and outputs; consequently, the base and collector elements are connected to the resonant circuits at low-impedance taps on the coils, making it possible to obtain high-Q resonant circuits by avoiding severe loading from the low impedances of the transistors.

The phase modulator in the GE transmitter is unique. A delay line is, in effect, an artificial transmission line. As you know, it takes a specific amount of time for an RF signal to travel along a transmission line, according to the characteristics of that line. Likewise, it takes a specific interval of time for an RF signal to travel down and back the electrical length of a delay line. If the delay time of the line can be made to vary with the audio information, the phase of the RF signal will be varied according to the delay characteristics of the line. This is, in effect, phase modulation. The actual delay characteristic of a line can be altered by a DC bias placed across the line. If the bias on the line is made to vary at an audio rate, the characteristics of the line will change in a corresponding manner, and the RF signal on the line will be phase-modulated.

The output of the last transistorized multiplier stage is coupled by a low impedance coupling link to

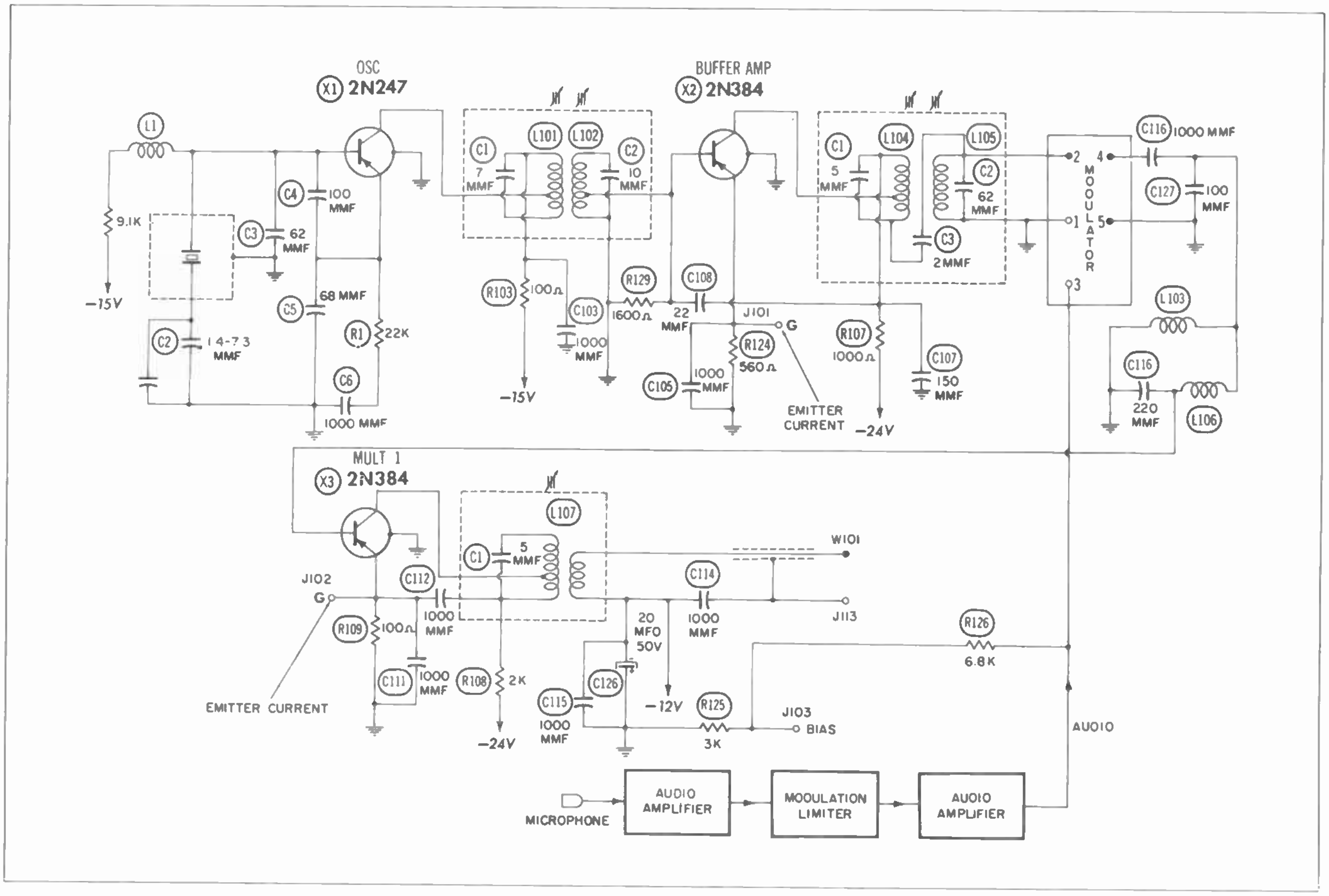


Fig. 9. Schematic of the station in Fig. 8.

the first vacuum-tube stage of the transmitter. Succeeding vacuum-tube stages build up the power level of the FM signal.

In your study of Class-C vacuum tube stages you learned that the grid current rises as the RF excitation is increased by tuning the associated tank circuit to resonance. In a similar manner, the base current increases when the RF excitation to a transistor stage is increased. Since this current also flows in the emitter circuit, resonance can be indicated by an increase in emitter current when the base tank circuit is tuned to resonance.

When the collector tank circuit of a transistorized class-C amplifier is tuned to resonance, there is a reduction in the collector current, just as the plate current in the vacuum-tube Class-C stage decreases when the plate tank circuit is tuned to resonance. Since the transistor collector current also flows in the emitter circuit, there will be a dip in emitter current when the collector tank circuit is tuned to resonance. If the Q of the collector tank circuit is lowered by the introduction of a load, there will be an increase in collector current, causing a rise in the emitter current meter reading.

Transistor stages are usually monitored by measuring their emitter currents. In the schematic diagram of Fig. 9, metering points are present at J101 and J102 in the emitter circuits of the buffer amplifier and multiplier.

REVIEW QUESTIONS

1. What is function of the audio clipper in an FM transmitter?
2. Give the uses for a relay transmitter, a supplemental power amplifier, and a receiver preselector.
3. What are the applications for low-pass audio filters and integrators in transmitters?
4. What is meant by instantaneous deviation control (IDC)?
5. Describe the principle of quiet-channel operation.
6. Why is a low-pass filter usually used in the RF power output stage of a transmitter?
7. What three adjustments are usually associated with the RF power-output system of a transmitter?
8. How is a transistor Class-C amplifier usually metered?

Answers to these questions will be included in Photofact Set No. 577

Lesson 15

Two-Way Radio Circuit Descriptions (AM)

INTRODUCTION

Amplitude modulation is widely used in communications. In low-power equipment, AM lends itself to simple circuitry and the construction of compact equipment. Its narrow bandpass is a particular advantage in low-frequency operation. If the highest-frequency audio component is limited to 3000 cycles, the total required bandwidth is only 6 kc. In FM transmission, a bandwidth of at least 20 kc is allocated for a frequency deviation of only ±5 kc.

AM is used extensively in the 2-3 mc spectrum for small-boat radio allocations. In keeping with the type of modulation widely used in IF and HF aviation, navigation and landing systems, AM is used even in the VHF aviation band. Amplitude modulation is also used in Citizens-band equipment.

For point-to-point, long distance, and relay systems certain more-specialized forms of amplitude modulation have become increasingly popular. Single-sideband transmission (SSB) has grown encouragingly in recent years. This narrow-band method of transmission has been particularly effective in overcoming much interference in long-range communications.

SMALL-BOAT RADIO

The small-boat radio unit shown in Fig. 1 has a 20-watt transmitter that can be operated on any one of five channels between 2 and 5 mc. Only nine tubes are used, five of them a part of the receiver. Five controls are needed to operate this marine transmitter-receiver—the RECEIVE-TRANSMIT switch on the microphone, and the SQUELCH, OFF-STANDBY switch, VOLUME, and CHANNEL SELECTOR front-panel controls. The unit incorporates a vibrator power supply which is operated from the boat's battery.

The oscillator section is crystal controlled, and separate crystal circuits are provided for each of the five channels. In the receive mode, the crystal frequency will be 455 kc either above or below the signal frequency, depending on the image-frequency problems of the particular frequency allocation.

In the receiver, a conventional double-tuned IF amplifier is used, supplying signal to a diode detector. The diode detector develops an AVC voltage which is applied to the grid of the IF amplifier and the signal grid of the converter. The detected signal is fed to the audio amplifier and output section through a noise-limiter diode.

Noise-limiter action adjusts automatically to the received signal level. If noise peaks exceed the carrier-modulation level, the noise diode cuts off and prevents noise components from reaching the grid of the first audio stage. As you have learned in your study of receiver circuits, such a limiter circuit reduces noise but does not eliminate it. Thus it is still important to provide noise suppressors throughout the electrical system of the boat, just as in the case of a car-radio installation.

A conventional squelch circuit, using a pentode tube controlled by AVC bias, cuts off the audio driver during the absence of incoming signal. Hence, the loudspeaker is silent when no signal is received.

In the transmitter section, a triode crystal oscillator is used in a Pierce circuit. A selector switch chooses the crystal for the desired operating frequency. Although the Pierce oscillator has an untuned output, it supplies almost one watt, the output needed to drive the modulated power amplifier.

It is interesting to note the six individual operations that are performed when the frequency selector switch is set to a new frequency. In the receiver, two sections switch in the proper crystal circuit for the local oscillator. In the transmitter, the frequency-selector switch chooses the transmitting crystal, the capacitor to resonate the power-amplifier tank circuit, the matching tap on the tank coil, and the antenna loading tap.

The modulator section consists of a single voltage amplifier, transformer-coupled to a Class AB_2 push-pull power amplifier. The modulation transformer matches the impedance of the modulator stage to the input impedance of the modulated Class-C RF amplifier. Overmodulation is prevented by the saturable core of the modulation transformer and a negative-peak clipper diode which limits the negative audio peaks which might cause modulation in excess of 100%.

The microphone used with the transmitter is a high-output carbon type, which is capacitively coupled to the grid of the speech amplifier. The DC voltage needed for the carbon microphone is obtained across a resistor in the cathode circuit of the modulator. When the TRANSMIT switch is depressed, it causes a relay to be energized, transferring the power supply voltage and the antenna from the receiver to the transmitter. When the switch is released, both the antenna and the DC power are again connected to the receiver.

Fig. 1. Marco small-boat radiotelephone.

TRANSISTORIZED MARINE RADIOTELEPHONE

The marine radio shown in Figs. 2 and 3 uses a vacuum-tube RF section in the transmitter, but a transistorized receiver, speech amplifier-modulator, and power supply. The power input to the final RF amplifier is 65 watts. The unit uses three vacuum tubes and ten transistors and provides a choice of five marine channels. The receiver is also tunable over the AM broadcast band.

The three vacuum-tube stages which comprise the transmitter RF section are shown at the top left in Fig. 3. A pentode crystal oscillator is used to supply excitation to the two parallel-connected tubes of the Class-C power amplifier stage. The voltage drop measured across grid resistor R7 is determined by the amount of grid current and thus indicates the RF drive to the power-amplifier stage.

Parasitic-suppression resistors are used in the control-grid and plate circuits. Inductor L4 is an RF load choke, while capacitor C9 blocks the DC plate voltage from the pi-network tank circuit. Modulation is introduced at the junction of RF choke L4 and capacitor C8, and at the screen grids of the PA section. Plate current can be calculated by measuring the voltage across 10-ohm resistor R11.

The resonant frequency of the power-amplifier tank circuit is determined mainly by the tap on tank coil L5. This tap is pre-set at the time of installation, according to the frequency of operation. The match between antenna and power amplifier is determined largely by adjustable antenna-loading capacitors C11 through C15. As in the previously-described transmitter, a tapped loading coil is used to tune the antenna system.

In transmit operation, the microphone signal is applied to the emitter circuit of the first audio amplifier, shown at the bottom right of the schematic diagram, Fig. 3. A transformer-coupled audio power stage follows, the output of which is coupled through trans-

Fig. 2. Kaar Marine radiotelephone.

formers T10 and T7 to the modulator. The secondary of modulation transformer T8 is connected in series with the B+ voltage to the modulated Class-C amplifier. A modulation limiter CR3 prevents negative overmodulation peaks while a low-pass pi-filter network attenuates frequency components above 3000 cps.

Power and Control

The power-supply circuits of the Kaar Marine Radiotelephone are quite unique. A 12-volt battery is used to power all the receiver transistors, including the first AF and audio-output transistors, which are used in both the receiver and the transmitter sections. When switch S3 is closed, the battery voltage is filtered by resistor R53 and capacitors C36 and C65 and applied to the A+ and A— lines. Voltage regulation is accomplished by zener-diode D1.

Notice that the positive side of the battery connects to the *filtered* A+ line through silicon diode CR9 which provides reverse-polarity protection. If the battery is connected to the unit with the proper polarity, this diode has a very low resistance and does not impede the current flow from the battery. As you know, transistors and other components can be damaged when connected to a power source with improper polarity. The function of the protective diode is to prevent this from happening. When the diode is back-biased it has a very high resistance that prevents the application of power to the transistor stages. Lamp DS2 will also light to indicate when the battery has been connected incorrectly.

The transmitter-filament circuits are energized when the switch S4 (lower left) is actuated. The transmitter only goes on the air when the microphone keying switch is closed. This switch closes the contacts of relay K2 applying power to the modulator transistors, and the power-oscillator.

When the transmitter power supply operates, relay K1 is also energized. The contacts of relay K1 then switch a number of receiver circuits to the transmit condition, and the cathodes of the transmitter tubes are grounded, placing them in operation. The antenna is changed from the receiver to the transmitter. The audio output stage is connected to the input of the modulator and the microphone signal is switched into circuit of the first audio amplifier.

Receiver

The receiver section consists of a transistorized mixer, IF amplifier, and detector-AVC combination. The receiver local oscillator, also transistorized, is shown at the right center, in Fig. 3.

When a communication is to be received, the channel-selector switch connects the proper mixer-tuning capacitor according to the chosen frequency. The same switch chooses the proper crystal so the local oscillator will produce a 455-kc IF.

For the reception of broadcast signals, the mixer circuit and the local oscillator must be made tunable. In this case, the mixer tuned-circuit consists of transformer T2 and capacitors C16 and C17. In the local-oscillator circuit, the broadcast setting connects transformer T13 and capacitors C58 and C59 to form the resonant circuit. C16 and C58 are ganged together and form the tuning capacitor. Local-oscillator injection for all bands is via the secondary winding of transformer T12 and capacitor C52.

Two resonant circuits and a low-impedance secondary are used to couple the mixer output to the base of the IF amplifier. A similar IF coil couples the IF amplifier to the detector. The audio output from the detector's emitter circuit is coupled to the volume control through capacitor C34.

A noise-limiter diode CR2 is associated with the detector output. The collector-current flow for the detector stage is a function of the receiver carrier level; when noise components exceed this level the noise diode CR2 opens and blocks their transfer to the volume control. CR2 can be disabled by switch S2.

AGC is also developed by the DC component of current flow. The AGC current is applied through RF choke L7 to the emitter of the mixer transistor. C32 and C64 function as AVC filters.

A SINGLE-SIDEBAND (SSB) SYSTEM

In a single-sideband system the carrier is first generated in a normal manner. However, during the modulation process the carrier is removed, leaving only the upper and lower sidebands. After the modulator stage, one of the two sidebands is removed; the sideband that remains is then amplified and transmitted.

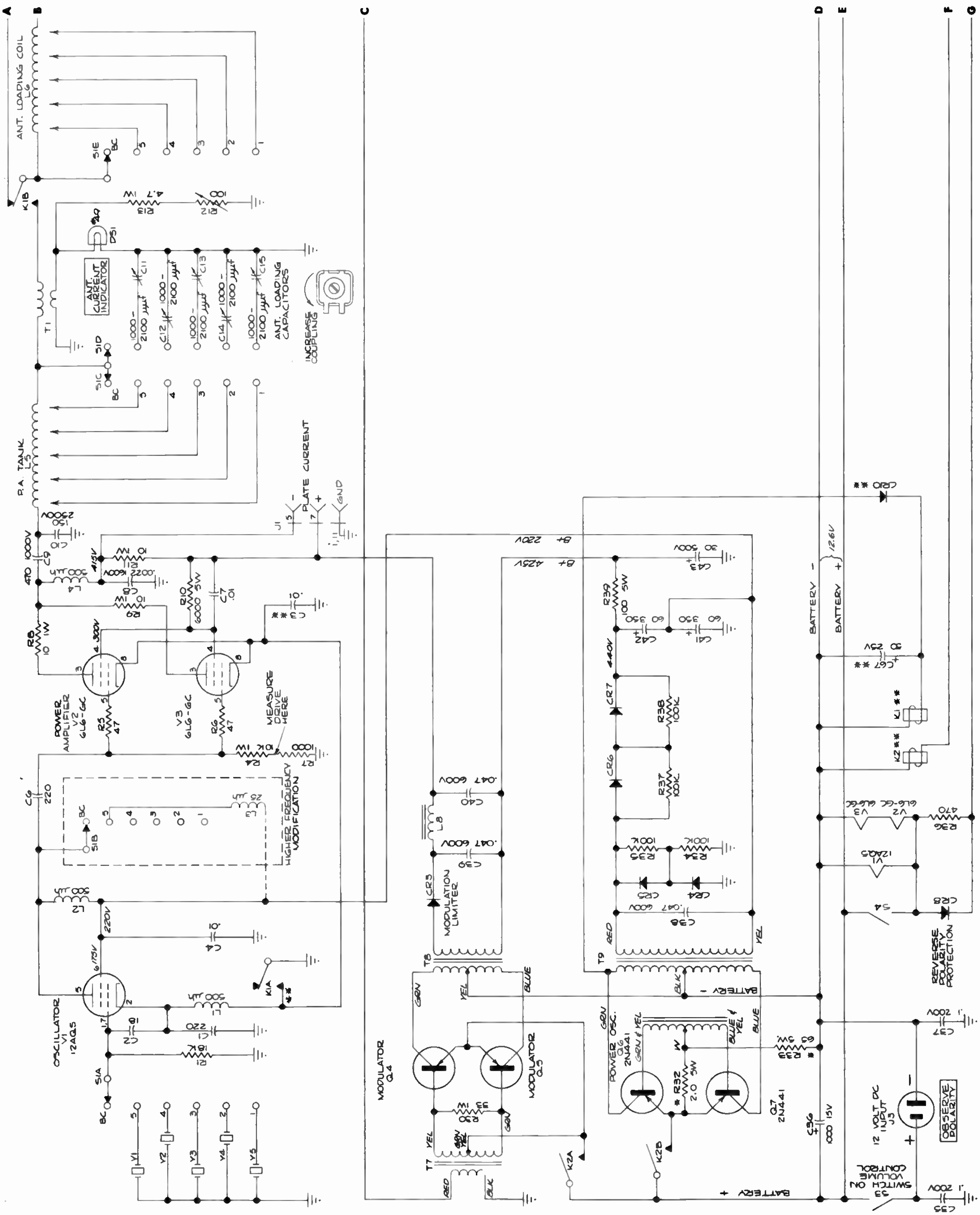
Inasmuch as the SSB signal is actually formed at a low signal level in the transmitter, the RF amplifiers that follow need only amplify that signal. Thus the power can be concentrated into the amplification of this one signal component, while in a conventional double-sideband system the power must be distributed among the carrier and two sidebands. Therefore, for a specific single-sideband output power, the SSB transmitter is more efficient and can be more compact compared to a conventional AM transmitter with a comparable communications capability.

A functional block diagram of a Collins SSB transceiver is given in Fig. 4. In the transceiver arrangement a number of stages are used for both the receive and transmit operations. The solid and dashed lines show respectively the transmit and the receive signal paths. The transceiver uses twenty tubes and five crystal diodes. The unit operates within the frequency band between 1.6 and 15 mc, at a power output of 100 watts. The receiver sensitivity is 0.5 microvolts.

Transmit Operation

One of the supplemental advantages of a single-sideband system is that a practical and low-cost voice-operated transmitter (VOX) can be designed. In this type of circuit, the transmitter goes on the air whenever the operator speaks into the microphone. When he is not speaking, the unit automatically returns to its receive function.

The first stage of the transmitter, shown at the top left of the diagram, is the speech amplifier. Its responsibility is to increase the level of the microphone signal. Its output is sent to a cathode follower and then to the balanced modulator. The audio signal is also applied to a series of VOX stages including an amplifier, rectifier, and relay control. In these circuits, the amplified microphone signal is rectified to form a DC control voltage that operates a series of send-receive relays. Whenever the microphone is used, this circuit goes into operation instantaneously and puts the transmitter on the air. The function of the anti-trip rectifier is to prevent the loudspeaker output, when receiving, from placing the transmitter on the air.


ANT. LOADING COIL L6
ANT. CURRENT INDICATOR
ANT. LOADING CAPACITORS
INCREASE COUPLING
P.A. TANK L5
PLATE CURRENT
POWER AMPLIFIER V2 6L6-GC
V3 6L6-GC
MEASURE DRIVE HERE
HIGHER FREQUENCY MODIFICATION
OSCILLATOR V1 12AQ5
MODULATION LIMITER
MODULATOR Q4
MODULATOR Q5
POWER OSC. Q6 2N441
Q7 2N441
BATTERY
REVERSE POLARITY PROTECTION
12 VOLT DC INPUT J3
OBSERVE POLARITY
S3 SWITCH ON VOLUME CONTROL

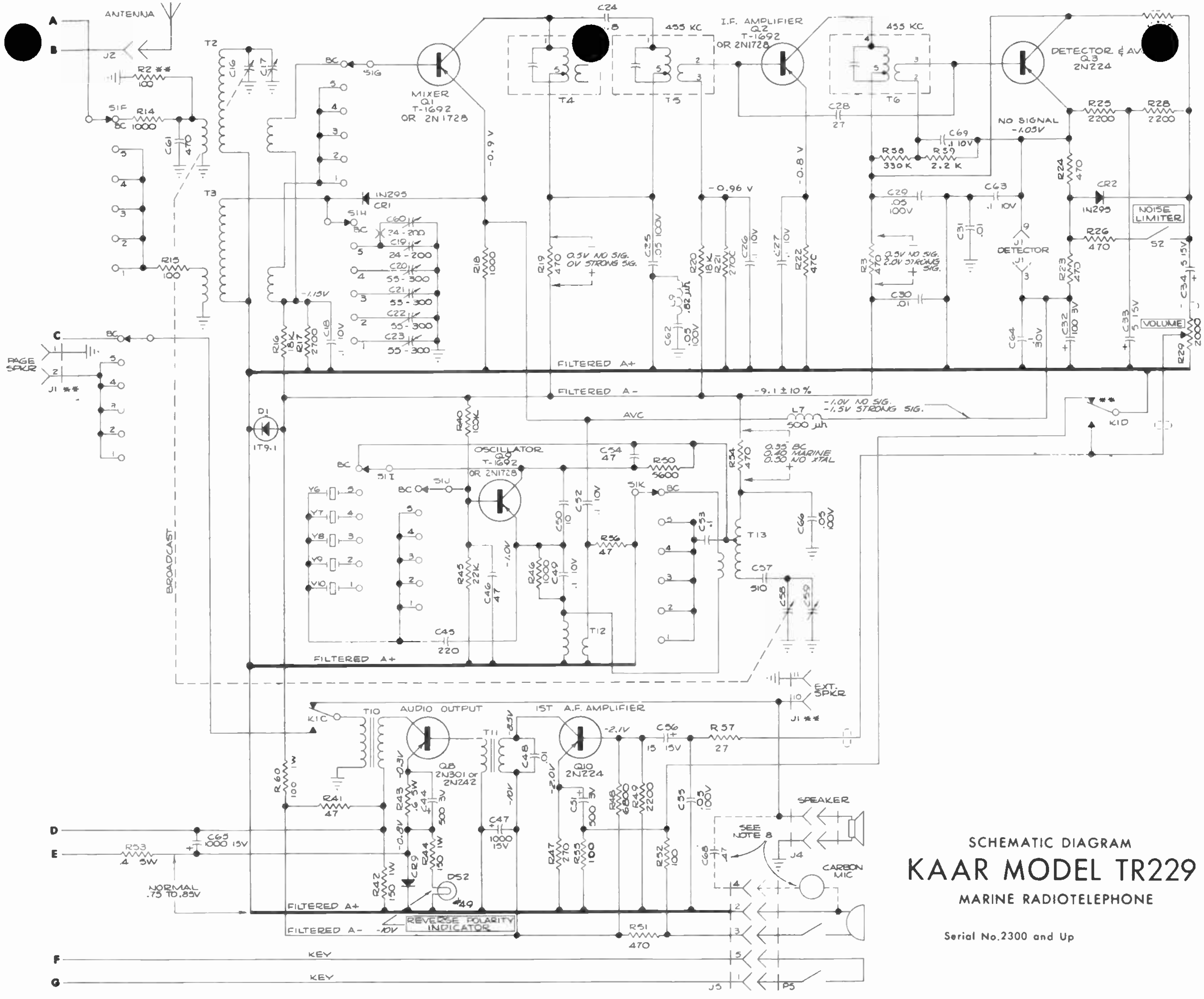


Fig. 3. Schematic of Kaar Marine Unit.

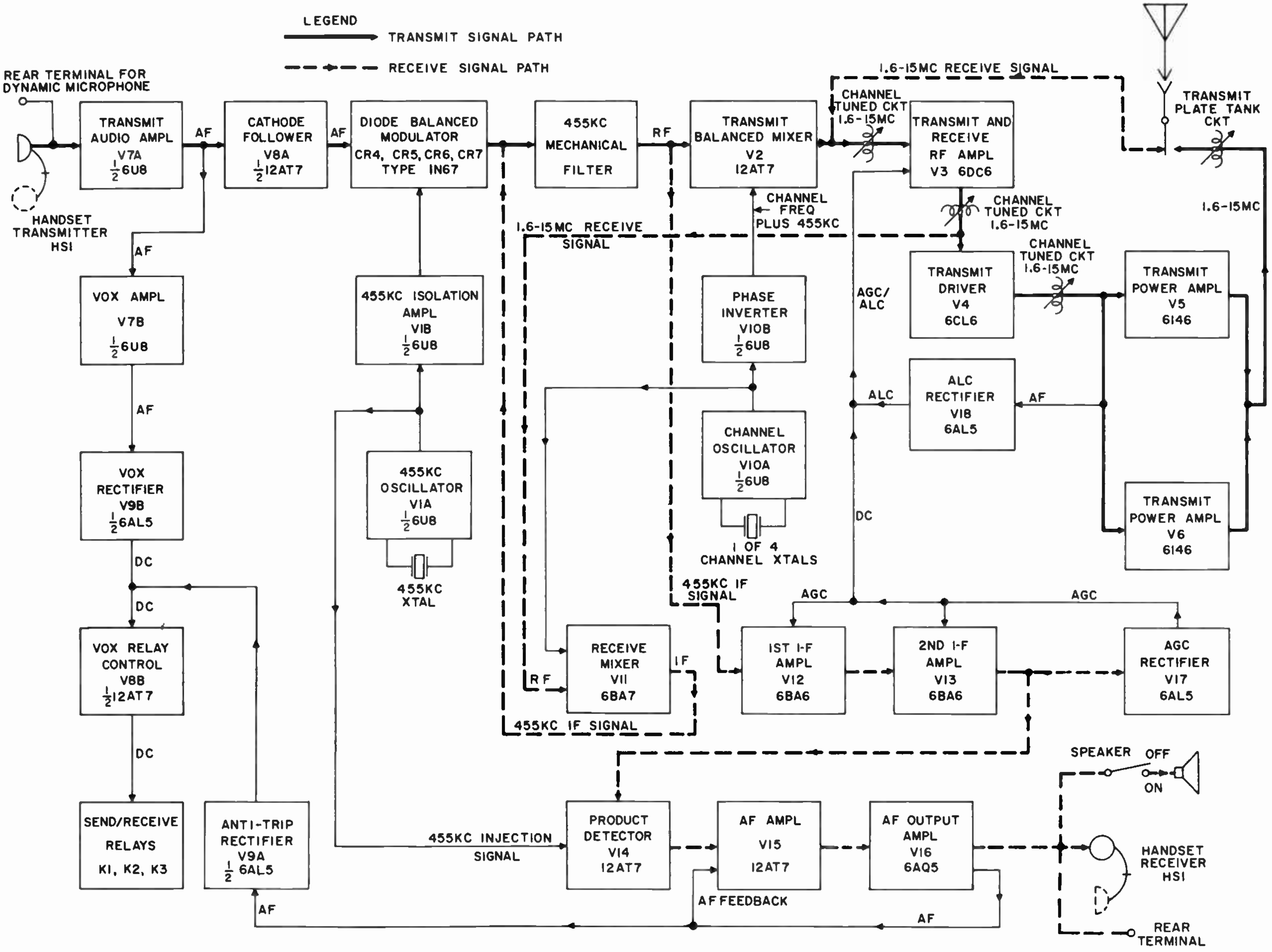


Fig. 4. Functional plan of Collins SSB system.

As shown at the center of the block diagram, the carrier oscillator operates at 455 kc. This low-frequency signal is coupled to a balanced-modulator diode through a 455-kc isolation amplifier. The balanced modulator generates two AM sidebands, upper and lower, and at the same time removes the carrier.

A typical balanced modulator is shown in Fig. 5. In a four-diode balanced modulator, the diodes are connected in a bridge circuit. These diodes should be matched so that they have the same forward resistance. The audio is applied at two opposite corners of the bridge; the carrier voltage is impressed at the remaining two corners. Modulated output is taken from the same two terminals at which the audio signal was applied. However, a suitable filter prevents the low-frequency audio components from being developed in the output circuit which couples the RF sidebands to the next stage of the transmitter.

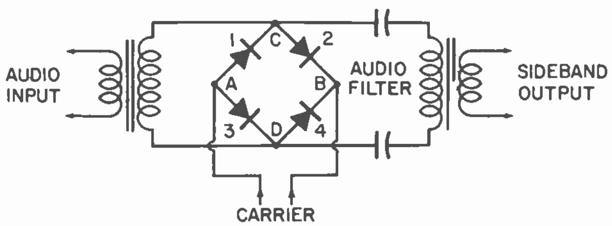


Fig. 5. The basic balanced modulator.

When no audio signal is applied to the modulator, the bridge is balanced; although the carrier signal is present, the signal currents in both legs of the bridge are the same. Consequently, there is no RF voltage drop across terminals C and D. In other words, the carrier-frequency signal does not reach the output of the modulator.

The presence of an audio signal unbalances the bridge; when the audio biases the bridge in the positive direction (a positive alternation), diodes 2 and 3 are biased in the forward direction while diodes 1 and 4 are biased with reverse polarity. As the biased diodes are affected by the carrier signal in the now unbalanced bridge, sideband frequencies develop in the output. The magnitude of the sideband components follow the amplitude changes in the audio signal.

On the opposite alternation of the audio signal, diodes 1 and 4 are biased in the forward direction while the reverse bias is now applied to diodes 2 and 3. Again sideband components are formed, which now correspond to the *negative* sweep of the audio signal, and these components appear as the output. As a result, a modulation envelope is developed; the carrier is absent and the envelope shape depends upon the addition and subtraction of the two sidebands.

The double-sideband, suppressed-carrier signal is now fed into a sideband filter. In the diagram of Fig. 4 this is called a 455-kc mechanical filter. Its function is to remove one of the sidebands. In the circuit of Fig. 4, the upper sideband is removed while the lower sideband is passed on to the mixer. An example will clarify the task of the filter. Let us say that a 2000-cps audio signal is being used to modulate the transmitter. The two sidebands at the output of the balanced modulator will be at frequencies of 457 kc and 453 kc. The sideband filter will pass the 453-kc signal to its output, but it will reject the 457-kc component. Only low frequency sidebands will be passed to the next stage. The filter will pass those frequency components between 454.7 kc and 452 kc, corresponding to an audio frequency range of 300 to 3000 cps. It is apparent that although the filter is called a 455-kc filter, it actually passes only a band of frequencies on the low-frequency side of 455 kc. The filter is designed with as much rejection to the carrier frequency (455 kc) and to the upper sideband frequencies as possible.

The function of the balanced mixer is to raise the frequency of the SSB signal to the actual transmitting frequency of the station. The mixer is a heterodyne-type, similar to the mixer in a superheterodyne receiver. In this case, however, the injection frequency is much higher than the sideband signals. This makes the difference frequency at the output of the balanced mixer substantially higher in frequency than the incoming signal from the 455-kc filter.

The injection signal is supplied by the channel oscillator. Its output is fed to the balanced mixer through a phase inverter. The phase inverter and balanced mixer prevent the injection-frequency component from reaching the output, in much the same manner as the carrier frequency component was blocked from the output of the diode balanced modulator.

Let us determine the sideband-frequency spectrum at the balanced mixer output when a 6-mc crystal frequency is used. The output frequency will be the difference between the channel-oscillator frequency and the sideband signal. As mentioned earlier, this sideband has frequencies ranging between 454.7 and 452 kc. If the channel oscillator frequency is 6 mc, the difference-frequencies at the output of the balanced mixer will be in the range of 5.5453 mc (6 — 0.4547) to 5.548 mc (6 — 0.452). The frequency relationships throughout the transmitter and receiver are given in the chart of Fig. 6.

The SSB signal is now increased in power level by the RF amplifiers prior to being applied to the power-amplifier stage. In a single-sideband transmitter, the RF power amplifiers which follow the modulator must operate in a linear fashion so as not to distort the modulation envelope. Consequently, the power-amplifier stages of the SSB transmitter are operated either Class A or Class B, instead of Class C.

TRANSMIT

Original Audio	30-3000 cycles
Carrier Frequency	455 kc
Balanced Modulator Output	454.7-452 kc 455.3-458 kc
Sideband Filter Output	454.7-452 kc
Crystal Frequency	6 mc
Balanced Mixed Output	5.543-5.548 mc

RECEIVE

Sideband Received	5.543-5.548 mc
Local Oscillator	6 mc
Receive Mixer Output	454.7-452 kc
Sideband Filter Output	454.7-452 kc
Injection Signal	455 kc
Product Detector Output	30-3000 cycles

Fig. 6. Frequency components in the SSB system.

Receive Operation

The receiver signal path follows the dashed line in Fig. 4. An incoming signal is first applied to the receiver RF amplifier—notice that this low-level signal amplifier is used for both the transmit and receive functions of the transceiver. The output of the RF amplifier is mixed (in the receiver mixer) with a local-oscillator signal that is derived from the same oscillator that supplies injection signal for the transmit mixer.

In the receive mixer, the incoming SSB signal (sideband frequencies between 5.5453 mc and 6.548 mc) is combined with the channel-oscillator signal. The output of the mixer selects the difference frequencies (the frequencies between 454.7 kc and 452 kc) and applies them to the 455-kc mechanical filter. The bandpass of this filter is the same as the frequency range of the IF signal.

Following the filter, the received signal is passed through two IF amplifiers and then to the product detector (operation of the product detector was described in Lesson 13). The carrier-injection signal for the product detector is derived from the 455-kc oscillator. As you will recall, this oscillator was also used in the transmit operation. The difference components at the output of the product detector fall in the 300 to 3000-cps audio range. A two-stage audio amplifier follows, raising the audio to a level suitable for speaker operation.

REVIEW QUESTIONS

1. How can coarse and fine frequency adjustments of a resonant line be provided?
2. What is the reason for an audio clipper in an AM transmitter?
3. What is the purpose of the balanced modulator in an SSB transmitter?
4. Why is a sideband filter needed?
5. What is the purpose of a tapped antenna-loading coil?
6. How can a transmitter resonant circuit be pre-set for operation on a particular frequency?
7. Give the basic principles of the VOR aviation homing system.
8. Why are circuit breakers, relays, thermal delay circuits, and other automatic switching devices needed in high-powered transmitters?

Answers to these questions will be included in PHOTOFACT Set No. 577

Lesson 16

Test Equipment

REQUIRED TEST EQUIPMENT

Two or three pieces of test equipment are needed to check out a transmitter, to make sure it complies with FCC technical regulations. One such instrument is an accurate frequency meter, used to determine if the transmitter is set exactly on the assigned frequency. The same meter is generally used for checking the frequency stability of the transmitter. Once a transmitter is set on its assigned frequency, its frequency drift may be no more than that permitted by FCC regulations. Generally, this requirement is in terms of a percentage of the assigned frequency.

Modulation meters are required for checking the percentage of modulation, to make certain it is no greater than that permitted by FCC regulations. In an FM system, 100% modulation represents a frequency deviation of 5 kc for some installations, and for other services, a maximum deviation of 15 kc. Again, the modulation meter not only is useful in making certain that 100% modulation is not exceeded, but also permits the technician to adjust the transmitter for adequate deviation.

Coverage and reliability are improved if the transmitter is made to deviate to its maximum limit on modulation peaks. Most transmitters include special circuits which prevent instantaneous modulation peaks in excess of 100%.

For AM communications systems, the amplitude modulation must not exceed 100%. A test setup can be arranged to measure the actual amplitude-modulation percentage. Here again, the modulation level should be adjusted as high as possible (average above 70%) for the greatest coverage and reliability. At the same time, modulation peaks must not exceed 100%. In AM transmitters, too, special circuits are usually incorporated to prevent modulation peaks from overmodulating the transmitter.

An accurate RF power-output meter is helpful in deriving the best performance from each transmitter. Most communications transmitters are FCC-approved and do not require an accurate power measurement. If the transmitter is operated according to its accompanying instructions, it can be assumed to be operating at the rated power output.

Whether this type of transmitter, or one that requires power-output measurements, is employed, a power indicator is useful—if for no other reason than making certain the transmitter is matched to the antenna system. When the two are matched, the antenna radiates almost the total power the transmitter is capable of delivering.

Simpler test equipment such as RF output indicators, absorption wavemeters, grid-dip oscillators, and others are useful in transmitter tune-up and receiver adjustments, and in the localization of trouble in the two-way radio system.

An accurate signal generator is particularly important in receiver alignment. Many of these receivers have an extraordinary sensitivity, down to less than 1 uv. This sensitivity is possible only if the receiver circuits have been critically aligned. Keep in mind that most of these receivers are fixed-tuned—the user has no way of tuning in the signal if it is absent or mushy.

Some standard pieces of electronic test equipment such as a VOM, VTVM, capacitor checker, oscilloscope, and other component testers are helpful, too.

THE ABSORPTION WAVEMETER

The basic RF indicator and frequency meter is the absorption wavemeter shown in Figs. 1 and 2. It is hardly more than a calibrated resonant circuit which,

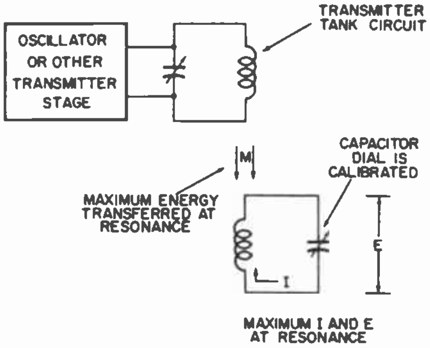


Fig. 1. Principle of the absorption wavemeter.

when coupled near the source of RF energy, can withdraw some of the energy. This meter will absorb maximum energy when tuned to the same resonant frequency as the source.

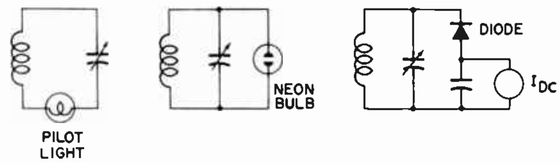


Fig. 2. Indicators for absorption wavemeters.

Some form of RF indicator such as a lamp, neon bulb, or crystal-and-DC-meter combination can be used to indicate the relative strength of the energy absorbed by the resonant circuit of the wavemeter. When the wavemeter is tuned to the frequency of the RF source, the indicator will read maximum; but if tuned to either side of the resonant frequency, the meter reading or lamp brilliancy will decrease.

If the resonant frequency of the wavemeter tank circuit is known from the dial setting, the frequency of the RF energy can be determined. Usually the capacitor dial of the wavemeter is calibrated in frequency. Therefore, the setting of the pointer on the calibrated scale, when the capacitor is tuned for maximum RF indication, shows the frequency of the RF signal being measured. In other absorption wavemeters, the dial is calibrated from 0 to 100 and the exact resonant frequency of the tank circuit is determined from a chart.

Wavemeters are usually equipped with replaceable coils so they can be made to operate on different frequency bands, with a separate dial scale or calibration chart for each band.

To provide minimum loading and additional convenience, some absorption wavemeters include a low-impedance pickup coil. The main meter coil remains part of the wavemeter proper and is not coupled to the RF energy being measured. The small pickup loop is coupled to the source of energy and transfers the small amount needed into the absorption-wavemeter circuit (Fig. 3).

The absorption wavemeter is important in making approximate frequency measurements while a transmitter is being tuned. It also serves as a good indicator of the strength of the RF energy. When set at a fixed position from the energy source, the influence of tuning on the output can be noticed immediately.

Most absorption wavemeters also include a phone jack into which a pair of headsets can be plugged, and any modulation on the RF signal heard. Hence, when the absorption wavemeter is used to check out RF amplifiers that convey a modulated RF signal, the quality of that modulation can be tested, using the detector circuit that is part of many absorption wavemeters. (For proper demodulation of an FM signal, some form of FM detector would have to be associated with the wavemeter.)

The wavemeter principle can also be used as a sensitive RF output indicator. In fact, it is no problem to attach a small antenna to a wavemeter, as shown in Fig. 4, to make it even more sensitive to the output of a transmitter.

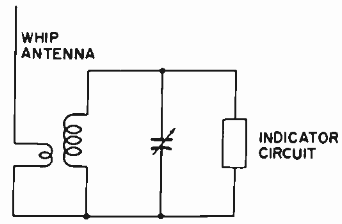


Fig. 4. Use of wavemeter principle in an RF indicator.

If the wavemeter is tuned to the transmitter operating frequency and placed somewhere in its immediate vicinity, a strong RF indication can be obtained. It is in effect a field-strength meter. With the meter positioned a fixed distance from a transmitter, various tuning adjustments can be made to maximize the RF output. In fact the wavemeter, if placed in the field of the transmitter antenna, permits a rather good indication of the tuning of the antenna system and the effectiveness of energy transfer from transmitter to antenna.

TUNING METER

A nonresonant RF indicator is shown in Fig. 5. This is a very popular instrument for field checking the power output and tuning of communications trans-

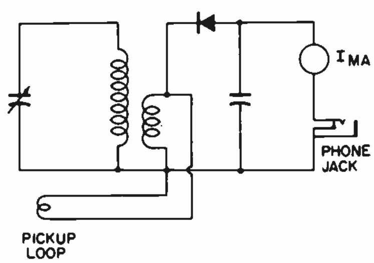


Fig. 3. Absorption wavemeter with pickup loop and phone jack.

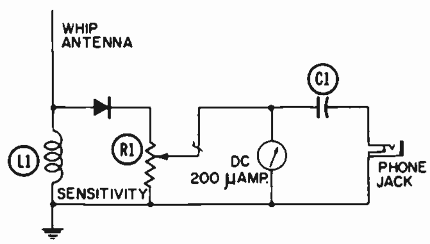


Fig. 5. Typical RF field indicator.

mitters. In consists of a crystal diode and a sensitive DC meter. The indicator is a simple rectifier-and-filter circuit. Capacitor C1 and potentiometer R1 function as a filter to smooth out the unidirectional detector pulses. Thus, the steady current flow through the DC meter is a function of the signal strength at the input. To improve the sensitivity of the device, particularly when HF and VHF signals are being checked, a short antenna can be attached. Sensitivity can be adjusted with potentiometer R1. The amount of resistance inserted into the circuit influences the amplitude of the current flowing through the DC meter.

A tuning meter of this type, when placed near the transmitter or its antenna, will indicate the relative power output of the transmitter, and the effect of any transmitter adjustment on the power output can then be noted.

It must be stressed that this type of RF meter, being untuned, is sensitive to an extremely wide frequency range. For this reason, it cannot be used to check the transmitter frequency.

GRID-DIP OSCILLATOR

The grid-dip oscillator is a useful test instrument for checking transmitter circuits. Most grid-dip oscillators can also be used as absorption wavemeters.

The grid-dipper contains a frequency-calibrated oscillator. The Millen grid-dip oscillator in Fig. 6 uses a Colpitts circuit that operates over a frequency range between 1.7 and 300 mc. Seven plug-in coils are employed to cover overlapping frequency ranges between these two extremes. A sensitive DC meter

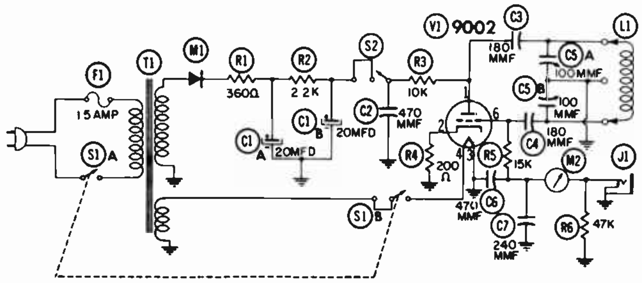
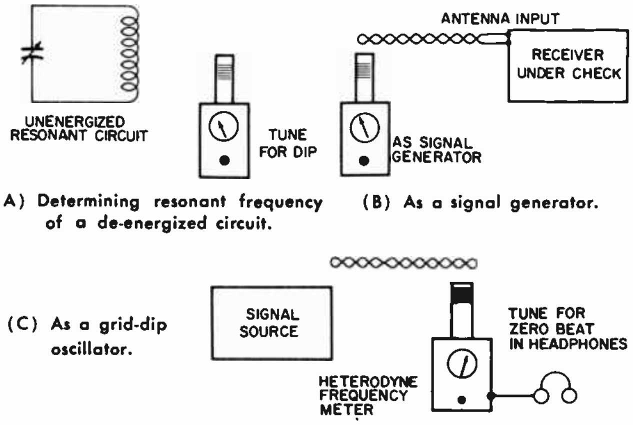


Fig. 6. Circuit of the Millen grid-dip oscillator.

M2 is positioned in the oscillator grid circuit for measurement of the current there. The variable capacitor of the grid-dip oscillator is accurately calibrated and is used, in conjunction with an accompanying chart, to set the oscillator to a specific frequency.

As a grid-dip oscillator, the test unit can be used to determine the resonant frequency of a de-energized tuned circuit. When a resonant circuit is brought close to the oscillating tank circuit, the tuned circuit under measurement absorbs some of the energy from the oscillator tank circuit. (Refer to Fig. 7.) Inasmuch as energy is removed from the tank circuit of the grid-dip oscillator, the oscillator feedback into the grid circuit decreases. As a result, the grid-current meter reading drops, or "dips."



(A) Determining resonant frequency of a de-energized circuit.

(B) As a signal generator.

(C) As a grid-dip oscillator.

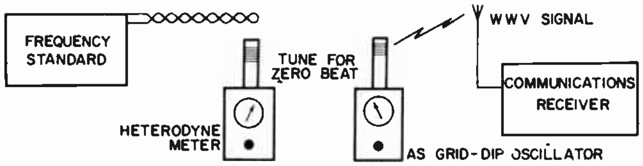
Fig. 7. Using the grid-dip meter.

When the grid-dip oscillator is set on the exact frequency of the resonant circuit under measurement, the meter will dip to its minimum value. This setting indicates that the grid-dip oscillator is generating a signal of the same frequency as the resonant tuned circuit under check.

A grid-dip oscillator can be utilized as a signal generator, as shown in Fig. 7. Therefore, it can be used in signal-tracing a communication receiver, and if the dial can be calibrated very accurately, for alignment work to a limited extent.

The grid-dip oscillator can also be employed as an oscillating detector, similar in action to a heterodyne frequency meter. In this application, as shown in Fig. 7, the grid-dip oscillator is brought near the source of RF energy. A pair of headphones, inserted into its phone jack, will pick up a beat note when the frequency of the grid-dip oscillator is brought near the signal-source frequency. If this note is zero-beat, the grid-dip oscillator is set to the same frequency as the source of the signal. In this application the grid-dip oscillator has been used for determining the frequency of an unknown signal source.

The oscillating-detector principle of the grid-dip meter can in itself be used to calibrate the meter accurately, as shown in Fig. 8. In this check, it is coupled near a crystal-controlled frequency stand-



(A) By using a frequency standard.

(B) By using a communications receiver.

Fig. 8. Calibrating a grid-dip meter.

ard. Whenever the grid-dip oscillator is tuned to the crystal frequency or one of its harmonics, a beat note will be heard. At the beat-note position, the grid-dip calibration should be checked. Some grid-dip oscillators provide a calibration control so the oscillator can be reset if it has drifted.

Still another method of checking the calibration of a grid-dip oscillator is to tune a communications receiver to WWV frequency (2.5, 5, 10, 15, 20, and 25 mc), as in Fig. 8. The grid-dip oscillator is then tuned to the same frequency. When a zero beat is heard at the receiver output, the grid-dip oscillator has been set to the same frequency as the incoming WWV signal. The dial calibration can be checked at this point.

When the oscillator tube is turned off, the grid-dip oscillator becomes an absorption wavemeter because, with no plate potential supplied to it, the tube functions as a diode and the meter becomes part of the diode load circuit. When coupled near and tuned to the frequency of an RF energy source, the meter will indicate any current increase. The operation is similar to that discussed for absorption wavemeters.

POWER OUTPUT

Power output can be measured by attaching a dummy load to the transmitter output. The dummy load should have the same impedance as the antenna system into which the transmitter normally works.

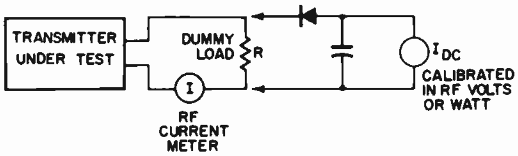


Fig. 9. RF power-output measurement.

An RF ammeter (Fig. 9) can be inserted into the dummy-load circuit. Power output will be:

$$P = I^2R$$

A calibrated RF voltmeter can also be used to measure the RF voltage across the dummy load. In this case the RF power output is:

$$P = E^2/R$$

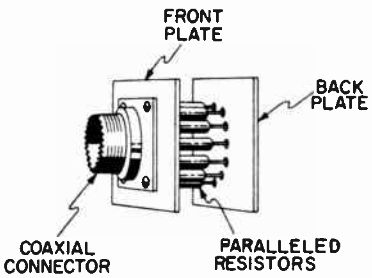


Fig. 10. Home-constructed dummy load.

An RF voltmeter is generally a crystal diode rectifier and a sensitive DC meter calibrated to measure RF voltage. The technician can build up a matched dummy load by using parallel resistors, coaxial fittings, and a mount, as shown in Fig. 10. The 50-ohm dummy shown can be plugged into the antenna-output fitting of the transmitter. Resistors should have sufficient ratings to dissipate the output power of the transmitter.

COMMERCIAL RF POWER METERS

A problem in making RF power measurements is that circuit operating conditions change when the test instruments are inserted across the transmitter output or into the transmission-line path between the transmitter and antenna system. Commercial instruments, referred to as insertion-type RF wattmeters, provide the answer to this problem.

Fig. 11. An RF wattmeter.

Fig. 12. Gertsch Model FM-6 frequency meter.

A typical insertion-type wattmeter is the one made by Bird Electronic Corporation and shown in Figs. 11 and 12. This unit is designed specifically for line insertion between a 50-ohm transmitter output and a 50-ohm antenna system. As shown in Fig. 12, it is inserted between the transmitter output and the coaxial transmission line going to the antenna system. Various plug-in termination elements are made available. By insertion of the proper element, six wattage ranges can be measured—0-10, 0-25, 0-50, 0-100, 0-250, and 0-500.

The instrument responds to the direction of wave travel and is capable of measuring the power in the forward wave traveling between transmitter and antenna, as well as the power contained in the reflected wave traveling back toward the transmitter because of a mismatch in the antenna system. It is apparent that the RF wattmeter is helpful not only in making power measurements, but also in adjusting the transmission line and antenna system for a minimum standing-wave ratio to insure the most efficient transfer of power from transmitter to antenna.

In using an RF power meter of this type, it is very important to insert a plug-in element of the proper size and in the proper direction. For example, the reflected power of a closely matched system is much lower than the direct power. To make an accurate measurement of the reflected power therefore requires the use of a low-power plug-in element. Moreover, if this element is inserted in the improper direction, the strong direct power will be supplied to it, and the crystal and meter could be damaged.

FREQUENCY AND FREQUENCY-DRIFT MEASUREMENT

The FCC requires that each transmitter operate on its assigned frequency or frequencies. Futhermore, any drift from that assigned frequency must be maintained within strict tolerances. In most two-way radio services, the permissible percentage of drift is only 0.0005% at frequencies over 50 mc.

The frequency meter must be of the highest quality, and its tolerances should be even stricter than those of the transmitter if exacting frequency measurements are to be made. A drift tolerance of 0.0001 per cent permits more accurate setting and measurement of transmitter frequency than a less accurate one.

An example of a signal generator with an accuracy of 0.00001% (one part in a million, PPM) is the Gertsch model in Figs. 12 and 13. It is both a very accurate signal source and a precision frequency meter. In the communications services between 20 and 1000 mc, it can be used to measure a transmitter frequency exactly (well within FCC tolerances), to set a transmitter on a specific frequency, and to precisely align a sensitive fixed-tuned communications receiver.

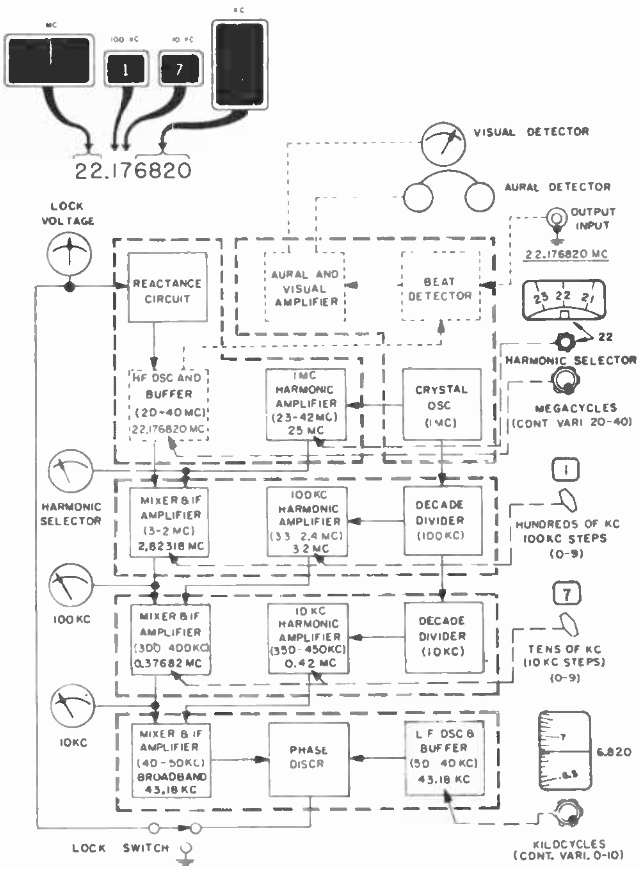


Fig. 13. Block diagram of Gertsch frequency meter.

The functional block diagram of a VHF signal generator and frequency meter is shown in Fig. 15. The two blocks at the top right function as a heterodyne frequency meter. The signal to be measured is applied to the beat detector, along with a signal of known frequency from the high-frequency oscillator and buffer of the generator. The resultant zero beat between the incoming signal and the fundamental or harmonic output of the internal oscillator is amplified and used to present a visual or aural indication. Headphones or a meter can be used to establish an exact zero beat, and the dial reading indicates the unknown frequency.

The dial of the high-frequency oscillator used in the heterodyne frequency-meter section is calibrated in 1-mc increments between 20 and 40 mc, as indicated on the scale at the top left-hand corner of the instrument. To obtain a reading accuracy of one part per one million, there must be an elaborate means of interpolating between these 1-mc points.

A 1-mc crystal oscillator with an accuracy of better than one part in 100 million is used as a base frequency in making this interpolation. The 23rd to 42nd harmonics of this crystal oscillator are beat against the output of the high-frequency oscillator and buffer, and a harmonic is selected that beats the output down to an IF range between 2 and 3 mc.

Let us follow the example shown in the block diagram. The incoming signal frequency is 22.176820 mc. Of course, this is not known when the signal is first applied. However, a zero beat was obtained when the high-frequency oscillator and buffer was tuned somewhere between 22 and 23 mc, as shown in the read-out blocks at the top left of the block diagram in Fig. 13.

The proper harmonic of the 1-mc crystal is determined by choosing the next lower one to the reading on the megacycle dial. (Notice the number 22 directly below the main scale of the megacycle dial.)

After the signal is beat down into the 2-3-mc range (25-22.176820 = 2.823180), a 100-kc oscillator is utilized as a base frequency. One of its harmonics is now employed to beat the 2-3-mc component down to the 300-400-kc range. This is accomplished by positioning the set switch of the 100-kc divider for a maximum reading on the 100-kc meter. In the example the 100-kc harmonic on 3-2 mc, when beat against the 2.82318-mc output of the first mixer and IF amplifier, produces a difference frequency of 0.37682 mc. The 100-kc maximum was obtained with the hundreds-of-kilocycles dial set to position 1.

A similar arrangement is used to beat the difference frequency down still lower. In this instance, a 10-kc generator acts as the base frequency, and its harmonic beats the signal down to the 40- to 50-kc range. It was necessary here to use the 7 position to obtain maximum output on the 10-kc meter.

In the final step, a continuously variable low-frequency oscillator operating between 40 and 50 kc is used. The two components are actually compared in a phase discriminator, which then supplies a correction voltage through a reactance-tube circuit to the high-frequency oscillator. The oscillator dial is moved very carefully until the lock-voltage meter is centered. This makes certain the two frequency components are on the exact frequency and in phase. The low-frequency oscillator dial is now varied slightly until a zero beat is obtained, and the dial setting is noted. The incoming signal frequency is the total of the dial and decade reading, as shown at the top left of the block diagram.

The accuracy with which a frequency measurement can be made is apparent when we consider that the very accurate 1-mc crystal also insures the accuracy of the 100- and 10-kc decade dividers. The lock-in arrangement assures proper setting of the low-frequency oscillator.

The frequency drift can be determined by noticing the maximum departure of the incoming signal frequency from the assigned frequency over a period of time. At no time should the transmitter frequency change more than the percentage specified by the FCC.

The Lampkin micrometer frequency meter shown in Figs. 14 and 15, in conjunction with an appropriate chart, gives a direct reading in percentage of frequency drift (often referred to as percentage deviation). It should not be confused with the desired and normal frequency deviation of an FM transmitter. The meter reading indicates the percentage of separation between the actual and assigned frequency of the transmitter.

Fig. 14. Lampkin micrometer frequency meter.

The micrometer frequency meter is a small and economical signal generator and heterodyne frequency meter consisting of a carefully calibrated variable-frequency (ratio-coupled) oscillator that operates between 2.33-2.67 mc. Harmonics of this oscillator permit frequency measurements of up to several hundred megacycles. A diode harmonic generator is useful in obtaining strong harmonics up in the very-high-frequency range. An accessory unit permits measurements up into the UHF communications spectrum.

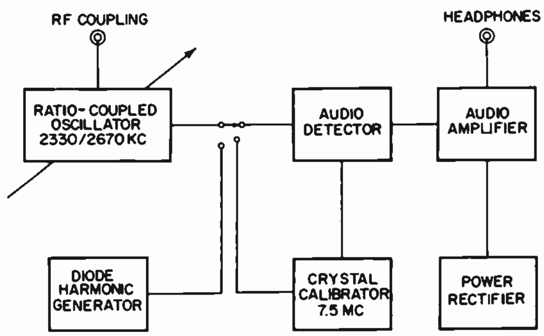


Fig. 15. Functional plan of Lampkin frequency meter.

The heterodyne section consists of an audio detector and amplifier. A crystal calibrator is used; the calibration occurs at 7.5 mc, the third-harmonic output (2.5 mc) of the variable-frequency oscillator. The frequency meter can also be checked with the WWV standard-frequency signals. In fact, the accuracy of the instrument is dependent on how well the variable-frequency oscillator can be calibrated. Again, it is a matter of just how well the known frequency is known.

In calibrating the signal generator on the WWV transmission, the calibrated dial of the micrometer frequency meter is set to the exact frequency of the WWV transmission. The two signal components are then picked up on a communications receiver tuned to this frequency. The calibrating trimmer of the frequency meter is varied until an exact zero beat is obtained with the main dial of the frequency meter set to the WWV wavelength.

The accuracy of the basic micrometer frequency meter of this type falls between 0.0025-0.005%. Its accuracy is satisfactory for communications frequencies below 50 mc. As mentioned previously, the frequency tolerance established by the FCC for frequencies above 50 mc is now 0.0005%. As a result, an accessory crystal calibrator is required with the basic micrometer frequency meter in order to obtain a frequency accuracy of 0.0001% above 50 mc.

FM DEVIATION MEASUREMENT

It is necessary that the frequency deviation of an FM communications transmitter be measured to insure compliance with FCC maximum deviation limits and to provide strong and usable FM signals at each communications receiver. The FM deviation is measured on an FM modulation meter. The Lampkin unit, shown in Figs. 16 and 17, and the deviation meter section of the Motorola frequency and deviation meter in Fig. 18, are basically high-quality FM receivers. They can be adjusted precisely, and the demodulated output can be measured exactly in a calibrated vacuum-tube voltmeter circuit.

Fig. 16. Lampkin Model 205A FM modulation meter.

A versatile switching arrangement permits the 205A to be used for a number of adjustments. In the TUNE MAXIMUM position the meter reads the DC component of the limiter-tube grid current. The receiver section of the deviation meter can now be tuned for maximum incoming signal, and the local oscillator set to the heterodyning frequency required.

The TUNE ZERO position connects the discriminator output to the input of the VTVM tube. This position, by indicating the proper center-frequency tuning, permits the discriminator to be set exactly.

These two adjustments are made with no modulation applied to the transmitter under test. The selector switch can be connected to the MODULATION test position. Now the DC component at the output of the peak rectifier and filter is supplied to the VTVM. Normal voice modulation or tone can be applied to the FM transmitter, and the meter will read its peak deviation. Both the positive and the negative peaks can be measured by setting a polarity switch associated with the discriminator output.

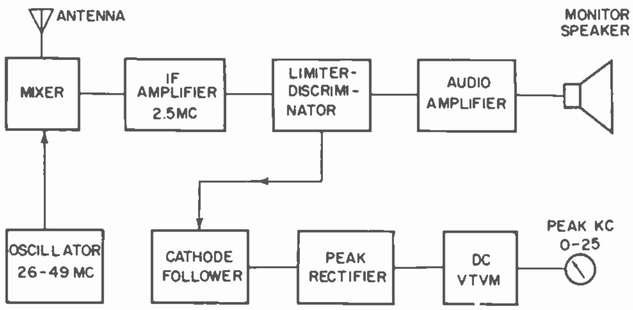


Fig. 17. Functional plan of Lampkin modulation meter.

The FM modulation meter permits the communications technician to set the modulation of the transmitter at a level that will provide a high percentage of modulation, yet not cause a greater deviation than permitted by the FCC.

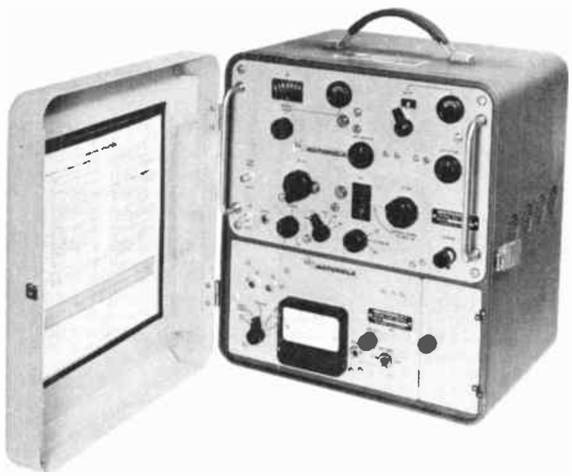


Fig. 18. Motorola Model T1099A frequency and deviation meter.

As mentioned previously, most communications transmitters include special speech-clipping circuits that reduce the amplitude of the voice peaks. The adjustment of these circuits can also be observed on the modulation monitor. Speech peaks should be clipped as much as possible, up to the point where the quality of the audio reproduction is adversely affected. The proper setting of the modulation level and peak clipping provides a high average modulation percentage without over-modulation peaks.

The principle of operation of the Motorola peak modulation deviation meter in Fig. 18 is the same. It has two maximum deviation ranges, 0-15 and 0-7.5 kc, and in conjunction with an appropriate frequency meter which supplies the local-oscillator signal for the mixer, is usable over a center-frequency range between 20 and 1000 mc. The frequency-meter portion of the instrument is similar to the Gertsch generator described previously. The Motorola deviation meter is an all-semiconductor unit, using crystal diodes and transistors throughout.

AM MODULATION CHECK

An oscilloscope is useful in checking not only the percentage of modulation, but its fidelity as well. If the modulation process introduces any distortion, it will be evident on the oscilloscope screen. One example is improper adjustment of the limiter and modulator, which can clip the voice frequencies severely.

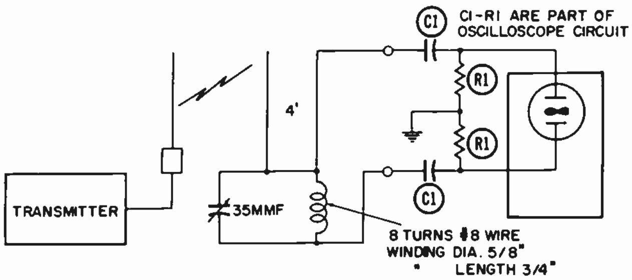


Fig. 19. Simple modulation-envelope check method.

Fig. 19 shows one method of using an oscilloscope to check amplitude modulation. A small portion of the modulated RF energy is removed from the plate tank circuit or antenna system and supplied to the vertical-deflection plates of the oscilloscope. (Because of the high frequency of the energy, the entire vertical-deflection system is not used, only the plates.) If required, a link coupling and an additional resonant tank circuit can be used to supply more RF voltage. In this tuned arrangement the pickup loop need not be coupled as close to the RF source as before.

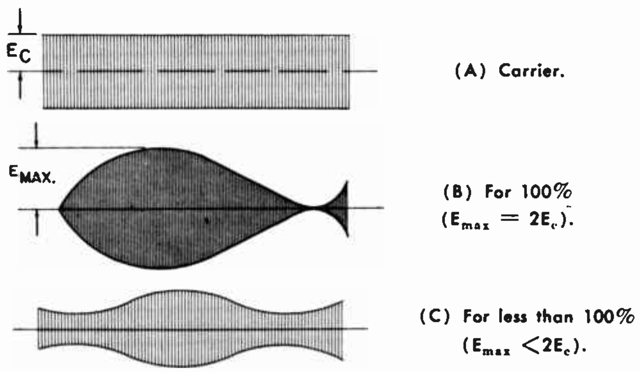


Fig. 20. Envelope check of modulation.

In making a modulation-percentage measurement, the carrier is sine-wave modulated. If the fidelity of the modulation is to be checked as well, make certain a pure, good-quality sine wave is used.

The modulation envelope is displayed on the oscilloscope screen, as shown in Fig. 20. In measuring the percentage of modulation, the carrier is first displayed without modulation, and its vertical height is adjusted between appropriate divisions on the oscilloscope screen. Now the modulation is added and the increase in pattern height noted. 100% modulation is indicated when the trough of the modulation envelope goes to zero and the crest rises to twice the amplitude of the unmodulated carrier.

A lower percentage of modulation can be measured and the actual percentage calculated from the following formula:

$$\%\ \text{modulation} = \frac{E_{max} - E_c}{E_c} \times 100$$

By selecting the proper resonant circuit, the arrangement in Fig. 19 can be used for almost all AM communications transmitters. Degree of modulation, distortion, and modulation-limiter activities can also be observed on the reproduced envelope as adjustments are made.

QUESTIONS

1. Give three uses for an absorption wavemeter.
2. In addition to its use as an absorption wavemeter, what additional facilities are provided by a grid-dip meter?
3. Describe the basic principle of the reflectometer.
4. Why is exceptionally accurate equipment needed to measure the absolute frequency and the frequency drift of many types of communications transmitters?
5. What are the limitations of a simple tuning meter?
6. How is RF power measured?
7. Of what significance is the measurement of reflected power on the transmission line of an antenna system?
8. Give the operating principles of a modulation monitor.

Answers to these questions will be included in PHOTOFACT Set No. 577

ANSWER SHEET

For Questions in Lessons 13 through 16

LESSON 13 — ANSWERS

1. A signal frequency that is separated from the signal frequency to which the receiver is tuned by twice the IF frequency.
2. High sensitivity and selectivity and better image-frequency rejection.
3. To crystal-control the transmitter frequency and to crystal-control the receiver local oscillator frequency.
4. Good RF selectivity, use of a high IF frequency, and a double superheterodyne arrangement.
5. Because of the narrow bandwidth over which the Citizens-band receiver is tunable and the good selectivity that can be designed into the RF stage.
6. The RF selectivity determines the image frequency rejection while the IF selectivity establishes the adjacent channel rejection of the receiver.
7. The squelch circuit of an FM communication receiver uses the noise output of the FM demodulator to establish a cutoff bias on one of the audio stages, muting the receiver. When a signal is picked up, the limiter action of the receiver reduces the noise output of the discriminator. The absence of noise signal in the squelch circuit causes the squelch system to return normal bias to the audio amplifier stage.
8. The sensitivity is rated in microvolts per a certain db quieting. It represents the minimum signal that will cause the background noise level to be reduced so many db below the incoming signal level.

LESSON 14 — ANSWERS

1. It clips audio peaks so that the transmitter will not be overmodulated. and the deviation of the transmitter will not exceed the FCC limits.
2. A relay transmitter amplifies and retransmits an incoming signal to send a stronger signal into a difficult or more remote receiving area. A supplemental power amplifier is added between the regular transmitter output and the antenna system in order to give an additional boost in the power level of the transmitted signal. A receiver-preselector is placed ahead of the normal receiver to boost weak incoming signals.
3. The low-pass filters prevent the radiation of spurious high-frequency components that result from voice-frequency clipping. They also attenuate audio frequency components above a specific high-frequency limit (usually 3000 cycles) and provide a phase-to-frequency correction for the phase-modulated FM transmitter.
4. The instantaneous deviation control sets the level of the modulating signal to obtain good but not excessive deviation of the FM signal.
5. In quiet-channel operation, a special tone signal is transmitted to the receiver to activate its circuits. Since other signals on the same frequency will not operate the receiver, the receiver remains quiet unless the desired signal with its special tone is received.
6. To minimize the radiation of RF harmonics.
7. The plate circuit tuning, the load coupling, and the antenna tuning.
8. By measuring the emitter current.

LESSON 15 — ANSWERS

1. Coarse frequency change can be accomplished with a shorting bar that can be moved along the line, while the fine frequency adjustment is usually a small adjustable capacitor that can be placed across the resonant line.
2. The audio clipper removes voice peaks so that the transmitter will not be overmodulated. Overmodulation of an AM transmitter causes the generation of spurious signal components and contributes distortion to the desired signal.
3. The balanced modulator removes the carrier but permits the two sidebands to pass on to the next stage.
4. A sideband filter removes the undesired sideband and passes along the sideband that is to be transmitted.
5. The tapped antenna loading coil permits the antenna to be tuned and matched to the output of the transmitter.
6. With the use of pre-set adjustable capacitors or coils that can be switched into the resonant circuit according to the frequency of operation.
7. In the VOR homing system a phase comparison is made between two arriving signals (one coming in on a subcarrier). This phase difference is a function of the angle of arrival of the signal at the receiver with relation to the geographic position of the VOR station.

(continued)

8. Automatic switching facilities and safety devices are used to permit transmitter operation without the possibility of damage to the high-power and costly components of a high-power transmitter by a faulty component.

LESSON 16 — ANSWERS

1. To measure relative output, check for spurious and harmonic signal components, aid in neutralization, and in tuning to a desired harmonic frequency.
2. The grid-dip meter can be used to check the frequency of resonant circuits without any energy being supplied to that resonant circuit except by the grid-dip meter itself.
3. The reflectometer by proper positioning of its pick-up probes is able to separately measure the forward and reflected power on a transmission line, and by so doing, allows the amount of energy to a load as well as the amount reflected from the load to be determined.
4. Because of the very close tolerances of FCC-assigned frequencies.
5. It is non-resonant, and therefore, gives no indication of the frequency of the RF energy it picks up.
6. RF power can be determined by measuring the energy supplied to a matched dummy load. If the impedance of the antenna system is known, the power can be determined using a power law calculation after measurement of either the RF current or RF voltage. Power can also be measured with a suitably calibrated RF detector and DC metering circuit.
7. It determines how efficiently a transmitter is matched to an antenna system. With a perfect match there should be no reflected power.
8. A modulation monitor measures the percentage of modulation of an AM or FM transmitted signal. It does so by using the magnitude of the carrier of an AM signal as a reference level. The change in the resultant wave with modulation is then indicated on a suitably calibrated meter. In the case of FM modulation the incoming center frequency is used as a reference and the calibrated modulation meter responds to an incoming change in frequency.

Lesson 17

Basic Transmitter-Tuning Procedure

INTRODUCTION

Various types of test instruments used for transmitter tuning and maintenance were covered in Lesson 16. Included in the discussion were a tuning meter, an absorption wavemeter, a grid-dip oscillator, an RF power meter, a frequency meter, and a modulation meter. Standard test instruments such as the VOM, VTVM, and oscilloscope also find application in two-way radio servicing. Various test facilities are often included in a single test unit. Suitable connectors and test leads permit convenient test-instrument insertion into key points of specific transmitter models.

Many transmitters have built-in metering facilities. Either a single meter can be switched into individual circuits for current and voltage measurements, or specific meters are connected permanently into key transmitter circuits. Low-power transmitters, even though they do not have an output meter, often include some kind of output indicator such as a neon bulb, to give some indication of transmitter output.

Four factors of special concern in tuning a transmitter are operating frequency, frequency drift, power output, and modulation level. Other factors such as operating efficiency, minimum radiation of spurious signals, stability, reliability, and other operational conditions also should be considered.

CLASS-C AMPLIFIER TUNING

Control-grid current and plate (or cathode) current readings can tell much about the operation and tuning of a Class-C amplifier. The grid current can be used to indicate much about the tuning of the grid circuit, the development of grid-leak bias, and the level of excitation made available from the preceding stage. The plate-current reading tells much about the tuning of the output circuit, and the effectiveness of the stage in delivering power to the next stage, or the antenna system if it is a final amplifier.

Current meters of suitable value can be inserted directly into the control-grid and plate circuits as shown in Fig. 1. Usually the meters are protected by RF chokes and/or capacitors, because RF energy must be blocked from the meter movements to prevent damage. The meters are DC types and measure the average or DC component of grid, plate, or cathode current.

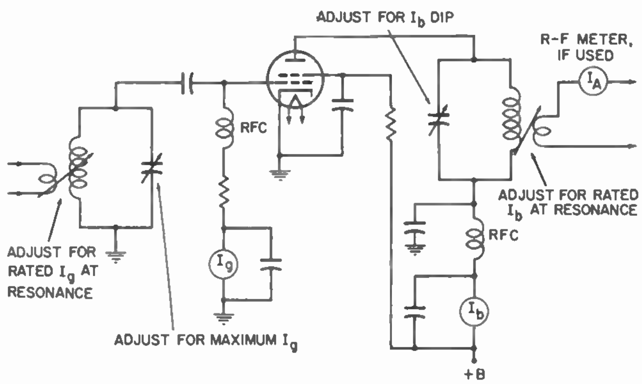


Fig. 1. A metered Class-C amplifier.

Another common method of metering communication transmitters is shown in Fig. 2. In the metering circuit used in the plate, the low-value resistor acts as a meter shunt. Consequently, a basic meter movement, if suitably calibrated, can be used to measure low, medium, and high currents by proper selection of the value of the shunt resistor. Such a plan is particularly adaptable to meter-switching ar-

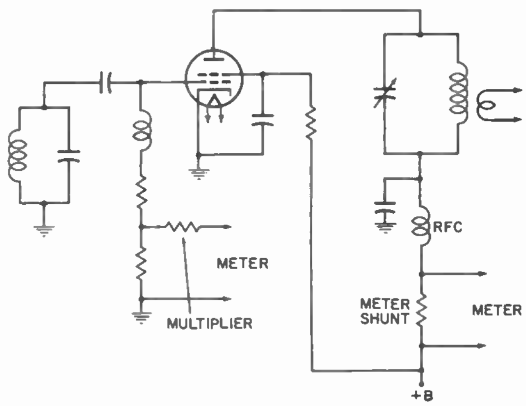


Fig. 2. Alternate metering plan.

rangements which use a single meter to measure currents in various circuits throughout the transmitter.

A similar arrangement is used in the grid circuit. In this example, a basic low-voltage voltmeter can be used. The value of the shunting resistor, as well as the value of the series multiplier resistor, is selected to calibrate the basic meter movement with relation to the normal current range in the circuit to be measured. This plan can also be used in meter-switching arrangements.

Input Tuning

The first adjustments to be made in a Class-C amplifier involve the excitation from the preceding stage and the tuning of the resonant grid circuit. Grid-circuit tuning must be done with the tube filament operating. The reason for this is obvious; there will be no flow of grid current unless the cathode is emitting electrons. The grid circuits of low-powered stages are usually tuned with the plate voltage applied; however, to prevent excessive plate-current flow, the initial grid-circuit tuning of a high-powered amplifier is usually performed with the plate and screen voltages turned off.

The tuned circuit associated with the input must be brought into resonance, and at the same time, the excitation supplied from the preceding stage must be set to the normal value. When the grid tuned circuit of Fig. 1 is tuned to resonance, a maximum RF voltage appears between grid and cathode. Consequently, there will be a maximum grid-current flow. Thus in using a meter to tune the grid circuit, the control is varied until the grid-current meter reads maximum. In the adjustment of many Class-C amplifiers, particularly low-powered stages, this is the only grid circuit adjustment required. In higher-powered amplifiers, however, it is sometimes necessary to adjust the grid current to a specific value after the grid tank has been resonated. The power output of the preceding stage, and hence the input to the stage being tuned, might be controlled by varying the degree of coupling between stages, or by regulating its screen or plate voltage. In practice, the output control of the preceding stage would be adjusted until a specified amount of grid current flows when the grid tuned circuit is peaked at resonance. Sometimes the grid tank must be retuned after the input level is adjusted.

Output Circuit

In a low-powered Class-C stage the next step is to "dip" the plate current. When the plate tank is tuned through resonance, its impedance rises to a maximum value. Consequently, the plate current drops or dips to a minimum value. Thus, the proper plate-current resonance tuning is indicated by minimum reading (sometimes called maximum dip) of either a plate or cathode meter.

It should be mentioned that an absorption wavemeter or other form of RF indicator can also be used in resonating a tank circuit. Whenever a tank circuit is brought into resonance its impedance, as mentioned previously, becomes maximum, and therefore, the RF voltage across the resonant circuit rises to a maximum. Thus, a wavemeter or some other form of RF indicator will indicate a maximum reading when the tank circuit is peaked at resonance.

In order to prevent the stage from drawing excessive current during the tuning-up process, higher-powered Class-C amplifiers are often tuned initially with a reduced value of plate and/or screen voltage applied, and less than normal load connected to the output. (Some load is usually preferred to prevent the tank-circuit voltage from building up to an excessively high value that can cause arcing and possible breakdown of insulating materials.)

In the tuning of a high-power stage, the plate tank is first tuned to resonance as indicated by a maximum dip in the plate-current meter reading. It is then possible to increase the loading on the power amplifier until the recommended value of plate current is drawn; as the load is increased, the plate-current reading will rise. Loading reflects resistance into the tank circuit and lowers its impedance and Q; therefore, a higher plate-current flow results.

In adjusting the tuning and loading, there is usually some interaction. Consequently, both adjustments must be jockeyed back and forth until the proper plate current is drawn when the tuned circuit is at exact resonance. This process is called "rocking."

NEUTRALIZATION

Triode Class-C amplifiers usually require neutralization. Even certain multi-grid tubes, depending upon the frequency of operation, require neutralization. Normally, some form of adjustable degenerative feedback is used to cancel out the tendency toward self-oscillation. However, the neutralization of multi-grid tubes is often non-critical, and non-adjustable neutralization schemes can therefore be used. Several typical neutralization methods were described in Lesson 5.

Those amplifiers that require it are usually neutralized with the plate supply voltage turned off. Even though the plate voltage is off, some of the RF energy present in the grid circuit will leak into the plate circuit when a stage is not neutralized. As shown in Fig. 3, a wavemeter or some other type of RF indicator can be used to indicate the presence of this energy in the plate circuit. In fact, one of the objectives of the neutralization procedure is to make the necessary adjustments which will remove any trace of RF energy in the plate circuit.

In an un-neutralized amplifier, when the plate tank is tuned through resonance (even though no plate power is applied), there is leakage of RF energy from the grid circuit to the plate circuit. At plate resonance, therefore, there will be a maximum amount of energy withdrawn from the grid tuned circuit. As a result there will be a dip in the grid-current meter reading. The greater the need for neutralization, the more energy the plate circuit will withdraw from the grid circuit when the plate circuit is tuned through resonance. It is apparent, therefore, that the grid current meter can be used advantageously in the neutralization procedure. *When a stage is completely neutralized, it is possible to tune the plate tank circuit through resonance without causing a dip in the grid-current meter reading.*

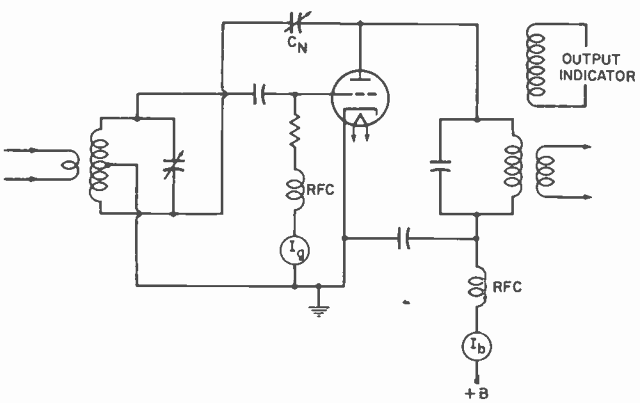


Fig. 3. Triode Class-C amplifiers must be neutralized.

As mentioned previously, neutralization reduces the tendency of a Class-C amplifier to self-oscillate. When a Class-C amplifier self oscillates, it generates a spurious and unstable signal and interferes with the amplification of the desired signal. In the neutralization process, the controls are adjusted to stop the transfer of energy between grid and plate circuits. In so doing, the stage is set so that, when plate power is applied, there will also be no leakage of energy from plate circuit to grid circuit (a necessary condition for producing self-oscillation). Thus, by adjusting the stage so that it does not convey energy from grid to plate circuit with no plate power applied, we also guarantee that there will be no transfer of energy from plate to grid when the power is turned on.

The actual recommended neutralization procedure varies. In most cases the neutralization capacitor is first set to its minimum value. The plate supply voltage is off, but the filaments are in operation and normal excitation is applied to the grid. The plate tank circuit is then tuned through resonance. At resonance, there should be a dip in the grid current and the RF indicator will read maximum. The neutralization capacitor is then advanced slightly. Once again the plate tank circuit is tuned through resonance and the extent of the grid-meter dip and/or the strength of the RF energy noted.

If there is still an indication of RF energy transfer to the plate tank circuit, the neutralization capacitor is advanced a bit more. Step by step the neutralization capacitor is advanced until a point is reached at which there is no grid-current dip when the plate tank circuit is tuned through resonance. Once the neutralization capacitor is advanced beyond the point of a proper setting, there will again be an increase in the amount of energy transferred between the grid and plate circuits. In a critical circuit, there is only one definite setting of the neutralization capacitor that will prevent the transfer of energy or, in other words, completely neutralize the stage.

On occasion, complete neutralization cannot be attained. When this happens, one must be especially careful in neutralizing the amplifier to make certain that the very minimum of energy is transferred. In this case, although complete neutralization is not possible, the feedback is reduced to such a low level that oscillations cannot be sustained. However, this is not the ideal condition and occasionally other problems arise, particularly when the RF is modulated.

TUNING THE RF EXCITER

The three basic functions of the RF exciter section of a transmitter are to (1) generate a stable RF sine wave, (2) multiply the oscillator frequency to obtain the assigned carrier frequency of the transmitter, and (3) increase the power of the RF excitation to the level needed to drive the power amplifier.

Most transmitters use a highly stable crystal-controlled electron-coupled oscillator. Small adustable inductors or capacitors (shown in Fig. 4) are used to change the crystal characteristics slightly to provide a very fine adjustment of the oscillating frequency. One of the types of frequency meters discussed in Lesson 16 can be used to set the oscillator on some precise frequency. This is accomplished in one of two basic ways. The frequency meter can be used to measure the actual frequency of the oscillator, and the oscillator can then be adjusted to a definite subharmonic of the assigned carrier frequency of the transmitter. The more common method is to use a frequency meter to measure the actual transmitter frequency. The oscillator frequency can then be adjusted with the trimmer capacitor or the variable inductor until the transmitted carrier is on its assigned value.

In communications equipment, many crystal oscillators have an untuned output. Consequently, there is no oscillator-tuning adjustment except the one that sets the oscillator to an exact frequency. In some other transmitters, the oscillator is also used as a doubler. In this case, there is a tuned plate circuit which is made resonant at twice the actual oscillator frequency.

The oscillator-plate tank circuit could be tuned to the second harmonic with the aid of a plate-current meter; the tank circuit would be tuned for a dip in the plate-current reading. However, in actual communications equipment, facilities are not usually included for metering the crystal oscillator circuit. Inasmuch as the degree of coupling between the crystal oscillator and the next Class-C stage is fixed by design, it is possible to tune the crystal-oscillator output circuit by observing the grid-current meter reading of the next stage. When the tank circuit is tuned to resonance, there will be maximum output, and therefore a maximum grid-current meter reading at the next stage.

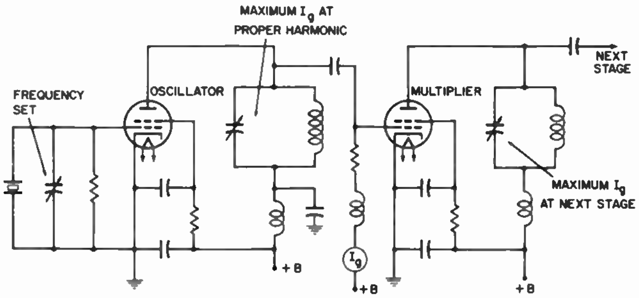


Fig. 4. Oscillator-multiplier adjustments.

In most communications transmitters, a series of stages are needed to obtain the total transmitter-frequency multiplication required. Doubler and tripler stages are common, and a quadrupler multiplier is occasionally used. Multiplier stages are tuned in the same manner as a regular Class-C amplifier; the tuned-grid circuit is adjusted for maximum grid current, and the plate-tuned circuit for minimum plate current. Often, metering facilities are provided only for the grid circuits. In these units, the plate-tuned circuit is resonated by adjusting it for maximum grid-current indication in the next stage.

The tuning of a multiplier stage has one serious problem: The plate tank circuit must be tuned to the *proper harmonic* of the signal supplied to the grid. If, by design, the tuned plate circuit has a narrow frequency range, it is usually not possible to tune to other than the correct harmonic. Even so, some means should be used to make certain that the tank circuit is tuned to the correct frequency, because a circuit defect might cause it to tune to an incorrect harmonic. Some tuned circuits associated with multiplier stages have adequate range to tune through more than one harmonic. A suitable RF indicator should be used to ascertain that the resonant circuit is tuned to the correct harmonic. An absorption wavemeter is an ideal RF indicator to check the frequency in a multiplier. The wavemeter need only be placed in the vicinity of the tuned circuit under tests. For example, if a certain multiplier stage has a 7-mc input signal and is to be used as a tripler, the wavemeter would read a maximum at 21 megacycles when the plate tank circuit is tuned to the third harmonic. If a stronger output is obtained at 28 or 14, it indicates that the tank circuit is not tuned to the proper harmonic.

A grid-dip meter can also be used to check the resonant frequency of a tank circuit. It gives a positive indication of the harmonic to which a tank circuit is tuned, even though no power is supplied to the RF exciter. As you know the grid-dip generates its own oscillations and gives a definite reading whenever its frequency is made the same as that of the resonant circuit to which it has been coupled.

POWER AMPLIFIER AND ANTENNA TUNING

Four major adjustments are usually associated with the tuning of the final power amplifier and antenna. These are the grid circuit, tuned plate circuit, antenna coupling, and antenna resonant tuning. The tuning controls and circuits of Figs. 5 and 6 are typical. Sometimes an additional coupling control is used to control the magnitude of the RF excitation to the power amplifier. However the coupling from the preceding stage is usually fixed at some optimum amount.

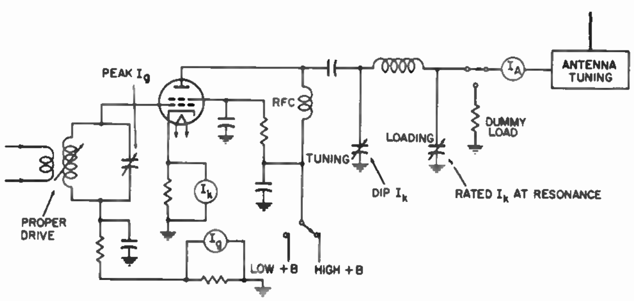


Fig. 5. Power amplifier tuning.

As in any Class-C amplifier, the input circuit is tuned to resonance as indicated by maximum grid current. If there is an excitation-coupling control it is now adjusted until a specific amount of grid current is drawn with the tuned grid circuit set at resonance. Often, the input circuit is tuned before any power is applied to the screen and plate of the power amplifier. Some other power amplifiers are tuned initially with a low value of screen voltage and/or plate voltage.

Most power amplifiers cannot be tuned unless some load is placed on the transmitter output. This can be in the form of an antenna or a resistive (dummy) load. There are various types of resistive loads available that are calibrated to measure power output. Such dummy loads are particularly useful in tuning a transmitter for peak performance without radiating any signal.

With light antenna loading present, the plate is tuned to resonance as indicated by maximum plate-current (or cathode-current) dip. It is then possible to resonate the antenna. The antenna tuning is varied until maximum plate current is drawn when the plate tank circuit is tuned to exact resonance. Very often this process involves considerable rocking between the two controls because the antenna initially reflects some reactance into the tuned circuit, and therefore is able to change the resonant frequency of the tuned plate circuit; hence, the plate tuned circuit must be returned to resonance each time the antenna is tuned. Once the antenna is brought into resonance and is reflecting a resistive load to the plate tuned circuit, it will be possible to vary the coupling (loading) between the plate tuned circuit and the antenna without causing any shift in the resonant frequency of the tuned circuit.

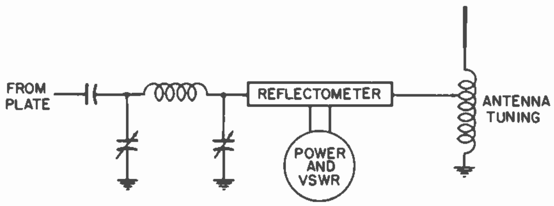


Fig. 6. Use of the reflectometer.

A power-output meter or antenna-current meter is particularly helpful in bringing the antenna system into resonance. When such a meter is used, it is necessary only to tune the antenna circuit until the output reading is maximum. Plate tuning can then be readjusted for resonance. Alternately adjust the two controls until a maximum output is obtained with the plate tank tuned to exact resonance.

After the antenna is brought into resonance, the coupling between the power amplifier and the antenna can be adjusted until the plate current is of the specified value.

Finally, full power can be applied to the amplifier, and various controls can be touched up slightly for optimum setting.

When a transmission line is used to link the output of the transmitter with the antenna, a reflectometer or power-output meter that reads direct and reflected power can be of advantage. As indicated in Fig. 6, such output indicators are calibrated to read forward and reflected power as well as the standing-wave ratio on the transmission line. By subtracting the reflected power reading from the forward power reading, the actual power delivered to the antenna can be determined. The power radiated by the antenna is the real criterion of how well the transmitter has been tuned.

The standing-wave measurement checks out the match between the transmission line and the antenna. If the antenna system is tunable, it is possible to adjust the system until a minimum standing-wave ratio is obtained.

TUNING A TRANSISTORIZED CLASS-C AMPLIFIER

Transistorized Class-C amplifiers are usually tuned with the aid of a current meter inserted in the emitter circuit. Usually, the drive to a transistor stage is measured by metering the base current. The circuit of Fig. 7 shows a typical Class-C transistor amplifier and associated adjustments. When the tuned input circuit is resonant at the frequency of the RF excitation, maximum signal voltage is present between base and emitter. Consequently, there is a maximum flow of base current. Inasmuch as the base current also flows through the emitter circuit, the emitter meter indicates the level of the excitation to the stage. The input resonant circuit is thus tuned for maximum emitter current. If necessary, the level of the RF excitation can be regulated so that a specific amount of emitter current flows.

When the collector tank circuit is tuned through resonance, it displays a maximum impedance. Consequently, a dip is seen in collector current. Inasmuch as collector current also flows in the emitter circuit, the emitter-current reading will dip when the collector tank circuit is adjusted for resonance.

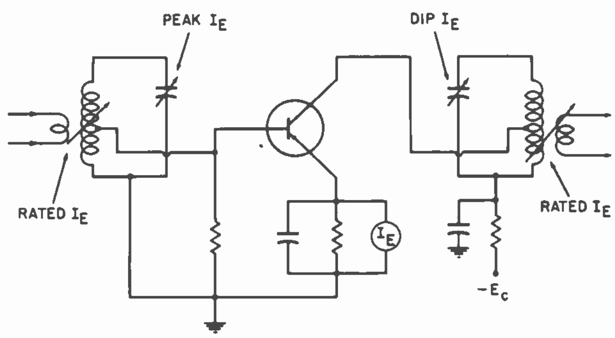


Fig. 7. Tuning Class-C transistor amplifier.

With the antenna loosely coupled to the collector tank circuit, the antenna can be tuned to resonance as indicated by a maximum emitter-current reading (at resonance the antenna will draw maximum power out of the tank circuit). The coupling between the collector and antenna tuned circuits can then be adjusted for the most effective transfer of power with the proper value of emitter current. As the load on the Class-C stage is increased, the effective Q of the collector tank circuit decreases and there is an increase in collector current.

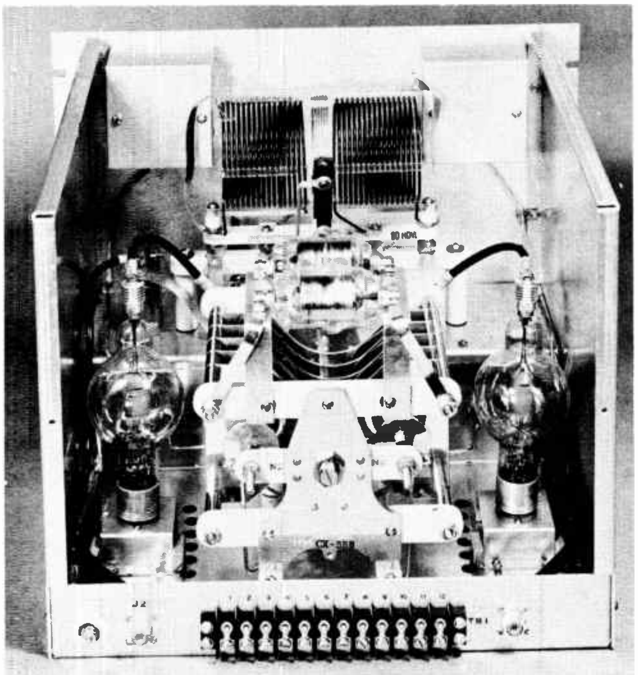


Fig. 8. Final power amplifier of Gates 500-watt transmitter.

TUNING A HIGH-POWER AMPLIFIER

The power amplifier of a Gates 500-watt communications transmitter is shown in Figs. 8 and 9. This is a 2-22 mc transmitter for use by police, aviation, marine, etc., stations. A push-pull neutralized triode circuit with tuned grid and plate circuits is used. Criss-cross neutralization between the plate of one tube and the grid of the other is employed. Unlike a single-ended stage, the correct out-of-phase neutralizing signal can be obtained for each grid without the use of a tapped inductor. The two neutralizing capacitors N2 are shown just below the center of the photograph. Grid, plate, and antenna output currents are metered. The antenna coupling network is shown in Fig. 10.

The recommended procedure for neutralizing and tuning this stage is:

1. Proper excitation is applied to the input of the final stage (plate power has not been applied), and grid capacitor C17 is tuned for maximum grid current.

2. In order to neutralize the stage, some form of RF-output indicator is loosely coupled to the plate inductor L7 (the neutralizing capacitors are set to maximum capacity), and plate capacitor C23 is adjusted for maximum RF indication.

3. Adjust the neutralizing capacitors simultaneously for minimum RF indication. As the capacitors are adjusted beyond this position, the RF output indication will increase. Return to the position of zero or minimum RF indication.

4. Tune capacitor C23 through its range while observing the output indicator and grid-current meter. If the meter dips as C23 is tuned, thorough neutrali-

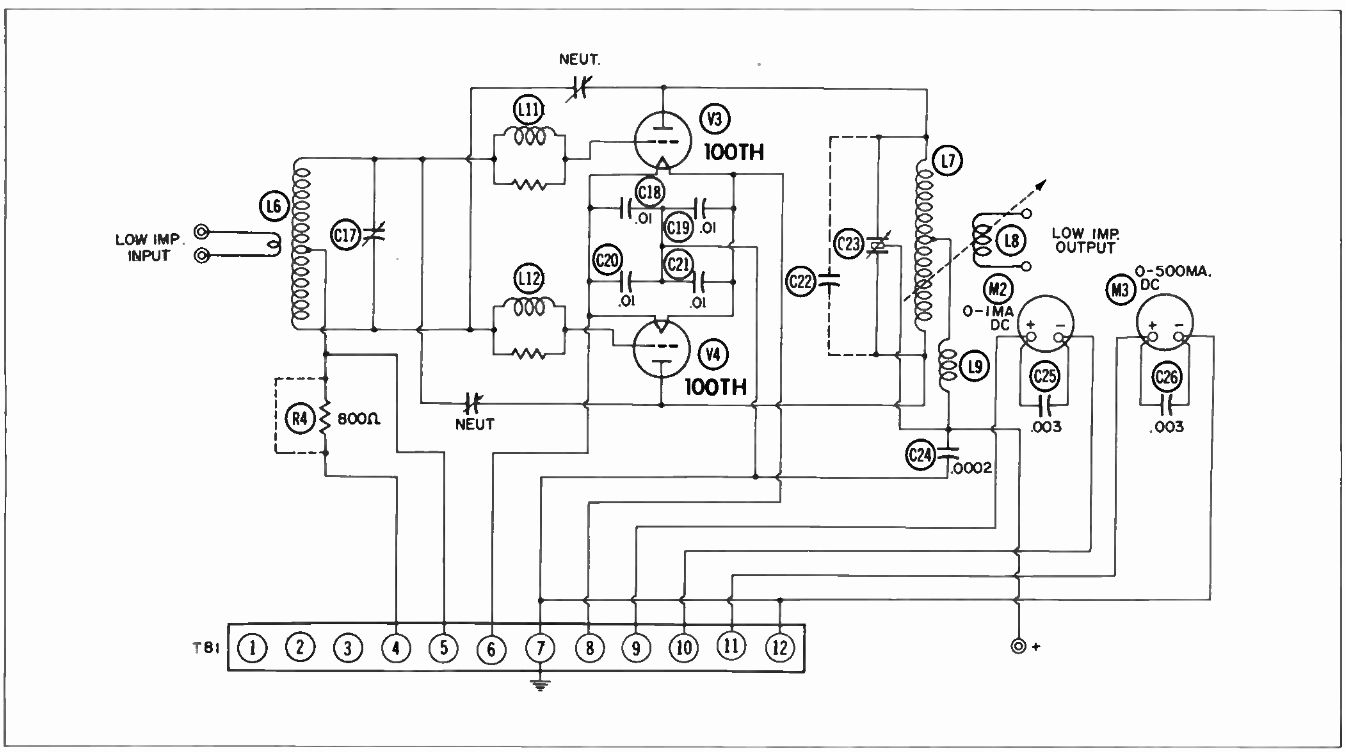


Fig. 9. Schematic of Gates power amplifier.

zation has not been attained. Retouch the neutralizing adjustments for zero or minimum effect on the grid-current meter when the circuit is at resonance.

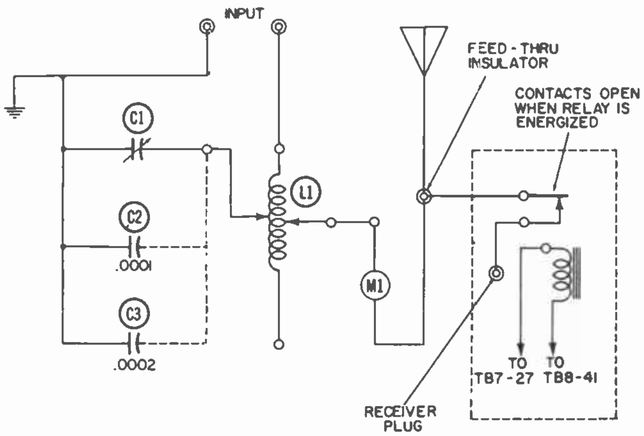


Fig. 10. Antenna coupling network for Gates transmitter.

5. Some load can now be coupled to the stage, and power applied. In the Gates transmitter, power can first be switched to one tube and then to both, to make sure excessive plate current is not drawn. Capacitor C23 is now carefully tuned for a plate-current dip.

6. The antenna-coupling circuit is next adjusted to resonate the antenna and reflect a matched load to the transmitter. The main function of the right tap on L1 (Fig. 10) is to bring the antenna into resonance. Capacitor C1 and the other tap on L1 largely determine the reflection of the correct load to the transmitter. If the resonant setting of C23 does not change much from its unloaded setting, and if the rated plate current is drawn at the same time the RF antenna current is maximum, the antenna system is at resonance and is loading the transmitter properly.

PREPARATION FOR LICENSE EXAMINATION

1. *Describe the construction and characteristics of a D'Arsonval meter.*—The D'Arsonval meter is a current-indicating device that uses a permanent magnet and a moving coil, as shown in Fig. 11. The current to be measured is sent through a coil of fine wire and two spiral springs. The magnetic field set up around the coil reacts with the permanent-magnet field, and this reaction sets up a torque that moves the coil clockwise until the spiral spring exerts an equal and opposite force. A pointer attached to the moving coil moves across a calibrated scale to indicate the actual current value. Upon removal of the current, the spiral springs return the coil and pointer to zero. A higher applied current develops a greater torque, causing the pointer to move farther along the scale.

The D'Arsonval movement can be made very sensitive. When a suitable series resistor is added, it can be calibrated to measure volts, or with a suitable

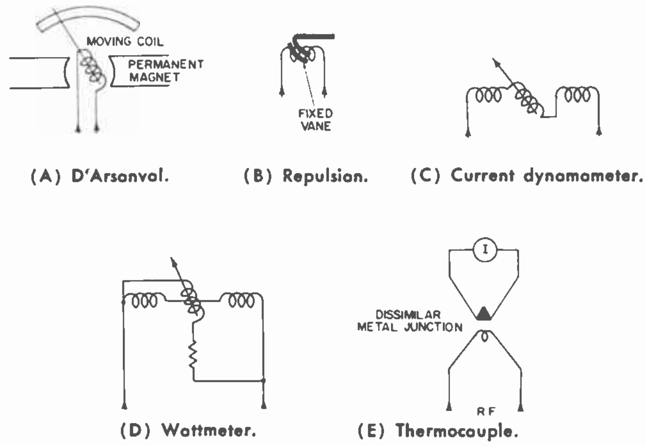


Fig. 11. Basic meter movements.

source of voltage and a network of switched resistors, can be made to measure resistance. Although basically a DC meter, it can also be used to measure AC currents and voltages with a suitable rectifier.

2. *Describe the construction and characteristics of a repulsion ammeter.*—The repulsion ammeter, often referred to as a moving-vane type, consists of a fixed and a movable iron vane inserted in the field of a magnet coil. (Refer to Fig. 11B.) When a current is introduced into the field coil, the resultant electromagnetic field magnetizes both vanes. The two repel each other and the movable vane, being mounted on a pivot, moves a pointer across a calibrated scale. The repulsion ammeter can measure DC or low-frequency AC current. The latter can be applied directly—no rectifier is needed.

3. *Describe the construction and characteristics of a dynamometer.*—The dynamometer movement, as shown in Fig. 11C, consists of a movable coil, a pointer and associated scale, and two fixed coils. To measure current, the movable and fixed coils are connected in series. The torque produced by the magnetic reaction between the fields of the movable and fixed coils causes the movable coil to move the pointer across the calibrated scale. The dynamometer, like the repulsion movement, can be used to measure DC or low-frequency AC current.

4. *Describe the construction and characteristics of a wattmeter; a thermocouple meter.*—The wattmeter (Fig. 11D) employs a dynamometer-type movement. However, the two fixed coils are connected in series across the line. The movable coil is connected in series with a resistor across the line, and acts as a voltage-measuring device because the current through the series coil is a function of the applied voltage. The fixed coils, having a very low

resistance, respond to the current flow in the line. The deflection of the pointer is therefore a function of voltage and current, or power. The response, or torque, is also a function of the phase relationship between current and voltage. Consequently, the meter responds to the true power, compensating automatically for the load power factor.

The thermocouple movement, shown in Fig. 11E, is used mainly for the measurement of RF current, although it responds to both DC and low-frequency AC currents. It consists of a thermocouple and a sensitive permanent-magnet movement. The current flow in the heater winding heats up the dissimilar metals of the thermocouple, causing a potential difference to be developed across the thermocouple. Current then flows through the sensitive DC meter because of this potential difference. Being heat-operated, the unit will respond to the rms value of the current to be measured.

5. *What is the relationship between the effective value and the heating value of RF current?*—They are the same. This is why the thermocouple meter is said to respond to the effective value of RF current.

6. *A frequency meter having an over-all error proportional to frequency is accurate to 10 cycles when set at 600 kilocycles. What is its error in cycles when set at 1110 kilocycles?*—The percentage error at 600 kc is:

$$\% \text{ Error} = \frac{10 \times 100}{600{,}000} = .001\tfrac{2}{3}\%$$

At 1110 kc:

$$\text{Frequency} = .001\tfrac{2}{3} \times 1110 \text{ kc} \times 1000 = 18.5 \text{ cycles}$$

7. *A heterodyne frequency meter with a calibrated range of 1000 to 5000 kilocycles is used to measure the second harmonic of a transmitter operating on approximately 500 kilocycles. The meter reads 1008 kilocycles. What is the actual frequency of the transmitter output?*—

$$\frac{1008 \text{ kc}}{2} = 504 \text{ kc}$$

8. *Discuss Lecher wires, their properties and use.*—A Lecher-wire arrangement is commonly used to measure frequencies in the VHF and UHF ranges. The Lecher wire is a resonant circuit composed of a section of open-wire transmission line mounted on some type of form. In association with a suitable indicator, as shown in Fig. 12, it is able to function as an absorption wavemeter when loosely coupled to a source of high-frequency energy by way of a pickup loop or capacitive-coupling arrangement.

A shorting bar, when slid along the line, is able to tune the line and set up a strong standing wave. Minimum and maximum positions of the standing wave are located with the indicator. By measuring the separation between adjacent minimum or maximum positions, the wavelength of the signal to be measured can be ascertained. This reading can then be converted to frequency by calculation.

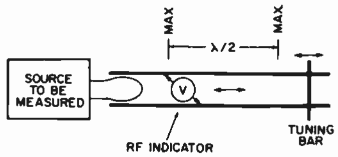


Fig. 12. Lecher-wire wavemeter.

9. *A ship radiotelephone transmitter is operating on 2738 kilocycles. At a certain distance from the transmitter, the 2738-kilocycle signal has a measured field strength of 147 millivolts per meter. The second-harmonic field at the same point is 405 microvolts per meter. To the nearest whole unit in decibels, how much has the harmonic emission been attenuated below the 2738-kilocycle fundamental?*—

$$\text{db} = 20 \log \frac{E_1}{E_2} = 20 \log \frac{147}{0.405}$$

$$= 20 \log 363 = 51 \text{ db}$$

QUESTIONS

1. What happens to the emitter current in a transistorized Class-C amplifier when the collector tank circuit is tuned through resonance?
2. What happens to the grid current in a Class-C amplifier when the excitation is increased?
3. What happens to the cathode current when the load on an RF power amplifier is decreased?
4. What happens to the amplifier plate-current reading when the antenna system is brought into resonance?
5. How can you use a grid-current meter to determine if a triode Class-C stage is neutralized?
6. What method can be used to tune a multiplier stage to the proper harmonic?
7. What type of meter is used to measure grid and plate current? What type of meter is used to measure antenna current?
8. Give the steps you would follow to tune a Class-C power amplifier.

Answers to these questions will be included in PHOTOFACT Set No. 581.

Lesson 18

Citizens Band Installation and Adjustment

The basic functions of Citizens-band radio equipment differ very little from model to model (the block diagram of Fig. 1 is of a typical CB unit). The units are basically transceivers with the antenna, power supply, and audio section used for both transmit and receive functions. The receiver is usually a superheterodyne and generally uses an RF amplifier and one or two stages of IF amplification.

The receiver can be either tunable over the entire Citizens band or of the crystal-controlled type. Some units permit both tunable operation and a choice of several crystal-controlled frequencies. The usual Citizens band unit contains an AM detector and a two-stage audio amplifier. Noise limiter and squelch circuits are commonly included.

The transmitter consists of two, or sometimes three, RF stages. It is crystal-controlled, and the operator can select any one of the several operating frequencies (channels). In the transmit position, the audio stages serve as the microphone speech amplifier and modulator.

A panel-mounted switch or, more often, a relay circuit accomplishes transmit-receive changeover. The switching usually involves the antenna, microphone, loudspeaker, and the audio-output circuit. In RECEIVE position, the antenna is connected to the receiver input, and the loudspeaker is connected to the output of the audio system. In TRANSMIT, the antenna is transferred to the output of the transmitter, the microphone is connected to the audio amplifier, and the audio-amplifier output is applied to the transmitter as modulation.

For base station operation, the power supply is AC-operated from the 115-volt line. For vehicular installations, the unit operates from a vehicle battery using either a vibrator or transistor-type power supply circuit. All-transistor models are operated from self-contained batteries, usually a dry cell, a

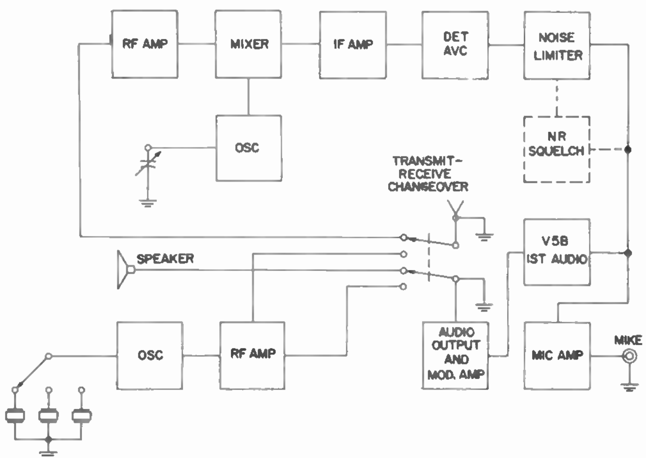


Fig. 1. Functional-block diagram of a Citizens band radio.

Fig. 2. International Crystal Citizens band units.

mercury cell, or a rechargeable nickel-cadmium battery, however some units have provision for operating from the vehicle battery.

Two typical Citizens-band units, manufactured by The International Crystal Manufacturing Company, are pictured in Fig. 2. The Model 10 is a small compact unit which has only four operating controls. Its receiver is a tunable type and can be set to any desired Class-D Citizens-band channel by using the control at the left. Notice the dial is calibrated in terms of the channel number. The transmitter can be set for any one of three crystal-controlled frequencies by using the selector switch at the right. The two other controls are SOUND VOLUME and the RECEIVE-TRANSMIT switch.

The other unit is a more elaborate model. Its receiver is tunable but this unit permits a choice between two crystal-controlled receiver frequencies. It also includes a squelch circuit. When suitable crystals are installed the transmitter can be operated on any of three Citizens-band channels. The transmit-receive changeover is relay-controlled, and is actuated by the microphone handswitch.

ALL-TRANSISTOR CB UNITS

It is apparent that Citizens-band units are much less elaborate than the commercial two-way radio gear considered in previous lessons. Likewise the transistorized CB units are simpler than their commercial counterparts. All-transistor CB units have transmitter power-input levels from less than 100 milliwatts to the FCC maximum of 5 watts. When the transmitter power input does not exceed 100 milliwatts, and the antenna is no longer than five feet, station license is not necessary for communication with similar units. However, if these units are used as a part of a regular CB system, they must be licensed. All units having an input power in excess of 100 milliwatts must be licensed.

Fig. 3. Osborne all-transistor 5-watt CB unit.

The Osborne all-transistor CB unit in Fig. 3 operates with 5 watts input, delivering better than 3 RF watts into the antenna system. Except for its small size and light weight (one-fourth that of an average vacuum-tube CB unit), the Osborne Citizens-band unit has specifications similar to its vacuum-tube counterpart. It has facilities for four crystal-controlled frequencies.

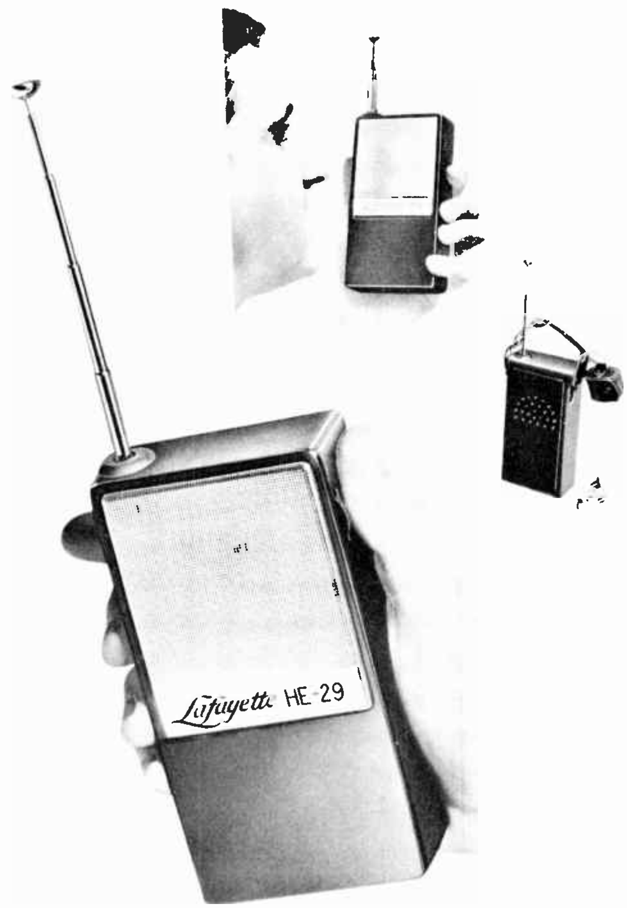


Fig. 4. Lafayette 100-milliwatt hand-held unit.

The Lafayette unit shown in Fig. 4 is typical of the low-power hand-held units. Its input power is 100 mw. In such a unit the speaker also serves as a microphone. The push-to-talk switch is located on the side of the case.

A Webcor transistorized CB transceiver is shown schematically in Fig. 5. All functions are handled by nine transistors and two diodes. The transmitter has an input power of 100 mw and the receiver boasts a sensitivity of 1uv for a 10 db signal-to-noise ratio.

In receive position, the incoming signal is applied to the base circuit of the converter via a tuned circuit. A crystal oscillator provides an injection voltage for the converter through capacitor C17. Two IF-ampli-

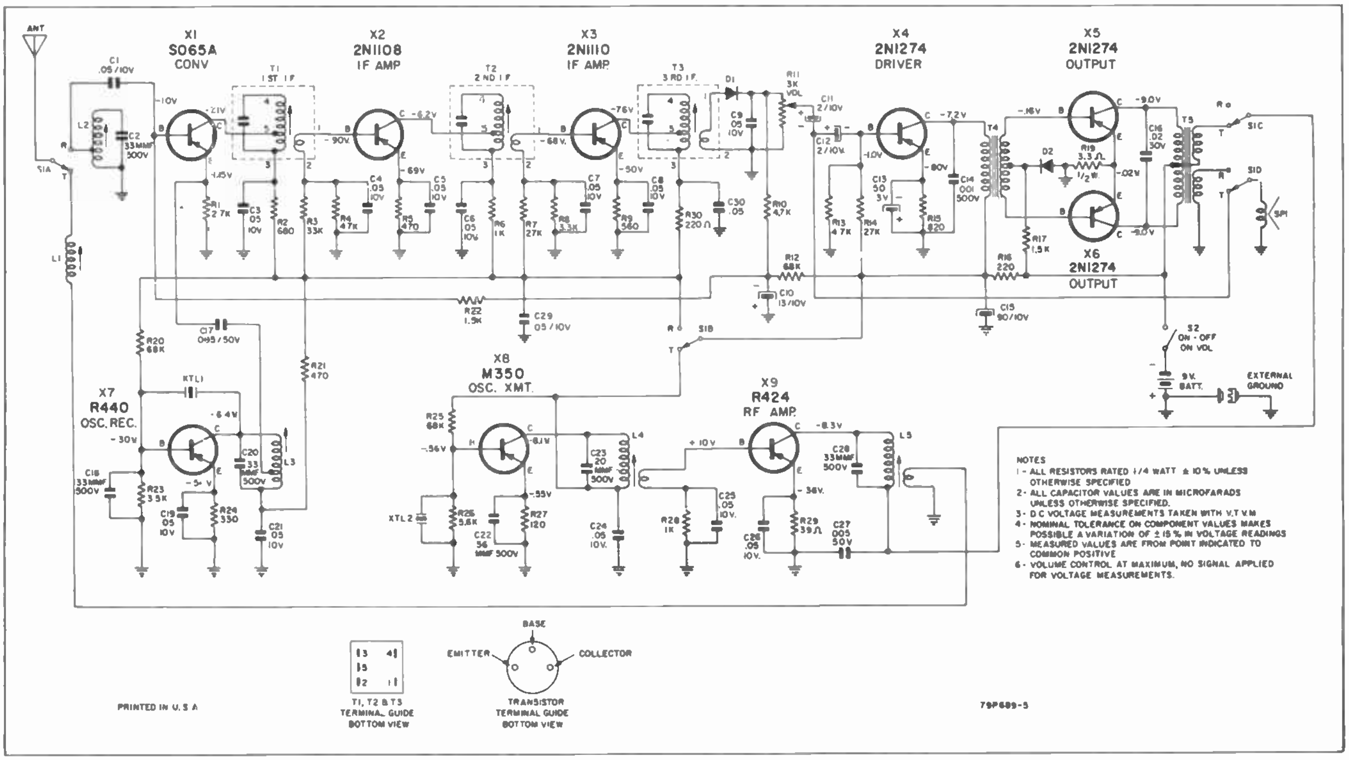


Fig. 5. Webcor hand-held all-transistor CB unit.

fier stages follow. A crystal detector circuit is used, developing the audio signal across the volume control potentiometer R11. A transformer-coupled audio amplifier and push-pull output stage follow. Positive AVC voltage is supplied to counteract the base bias of the converter to prevent over-load with the reception of a strong signal.

The RF section of the transmitter is a two-stage affair consisting of a crystal oscillator and a Class-C amplifier. Notice that the audio output transformer T5 has two secondary windings. The voice-frequency variations across the top winding are used to collector-modulate the transmitter RF amplifier. In the transmit condition, the loudspeaker is used as a microphone and supplies a signal for the base of the audio-amplifier driver. In the receive function, the bottom secondary of the output transformer supplies audio power to the loudspeaker voice coil.

Section S1A of the transmit-receive switch changes the antenna from the receiver input to the transmitter output. Section S1B switches the battery voltage between the transmitter and some stages of the receiver section.

INSTALLATION

Several major steps are involved in the installation of a CB unit. An antenna must be selected and installed. The transceiver itself must be mounted and a transmission line routed from it to the antenna. The transmitter must be tested to make certain it complies with FCC rules and technical standards. Most CB units are so designed that transmitter operation does comply; the major responsibility of the installer is to make certain that optimum transmitter performance is obtained. The receiver operation must also be checked and appropriate steps taken to minimize noise and interference pick-up.

The three most common Citizen-band antennas are the quarter-wave ground-plane, the quarter-wave coaxial, and the quarter-wave whip, as shown in Fig. 6. The first two are used almost exclusively for base stations, while the latter are popular for vehicle installations.

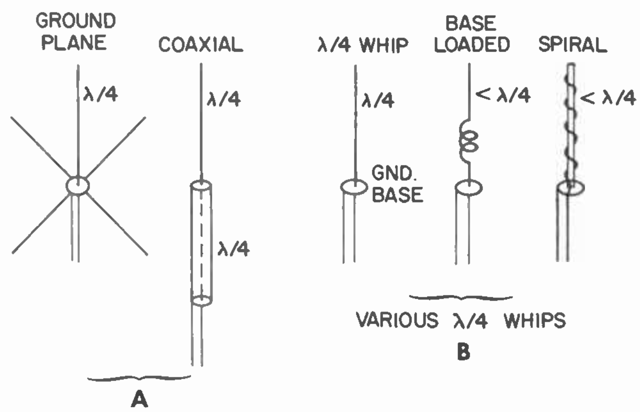


Fig. 6. The five basic CB antennas.

Occasionally, more elaborate base-station antennas are used to deliver stronger signals to difficult receiving areas. If communications are only between base stations, it is possible to use higher-gain beamed antennas with parasitic elements; these include Yagi types.

The length of a full quarter-wave mobile whip antenna is about 108 inches. A somewhat shorter physical length is permissible when spiral-type construction is used as shown in Fig. 6B. For short-range communications, very short base-loaded whip antennas are available.

If communication is to be established over a significant range, the base-station antenna should be mounted high and clear. Keep in mind, however, that the FCC limits the antenna height to no more than 20 feet above an existing structure. Furthermore, if the antenna is mounted on an existing mast or tower the antenna may not extend above the top of any radiating element of the antenna which was already mounted on the tower.

Transmission Line

The two most common types of coaxial transmission line used in Citizens-band installations are RG-58/U and RG-8/U. RG-58/U is used more frequently because it is less costly and easier to handle. However, its loss at 27 mc is 2 db per 100 feet compared to a 1 db loss in RG-8/U. This loss is unimportant for many installations. For example, in a vehicular installation the length of line is seldom more than 20 feet. However, for base station installations where the antenna may be 50 or more feet away from the CB unit, the lower-loss lines are preferable, for it is important to radiate every bit of available power.

The most common type of coaxial hardware used in Citizens-band equipment is the PL-259 or UHF-type connector and receptacle, although standard phono plugs or auto-radio plugs and sockets are used in some equipment. Recommended procedures for attaching RG-8/U and RG-58/U cables to a PL-259 connector are shown in Fig. 7. Since the RG-58/U coaxial cable is of small diameter, a UG-175/U adapter is used for attaching this cable to the PL-259 connector.

Many CB antennas are equipped with a PL-259 socket. Others, particularly those for vehicular mounting , use standard lug terminals. In the latter case, soldered ring-lugs should be attached to the antenna end of the transmission cable. The inner conductor fastens to the terminal at the center of the antenna-mounting base; the outer conductor connects to the ground terminal.

VEHICULAR INSTALLATION

In general, the full quarter-wave whip antenna is preferred. However, its nine-foot length presents mounting and obstruction problems. Usually such an antenna must be mounted on the bumper or far down on the quarter-panel or side of a truck. A tie-down clip is used to hold the antenna tip near roof level when the vehicle is in areas where it is likely to encounter obstructions.

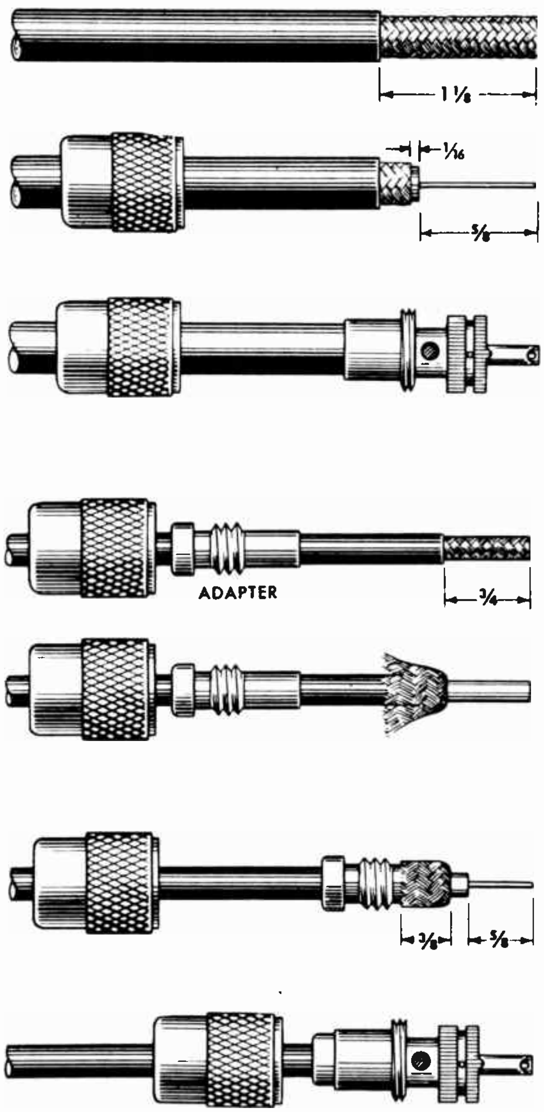


Fig. 7. Attachment of connectors to RG-8/U and RG-58/U cable. (Courtesy RCA)

Short antennas such as the base-loaded and helical (spiral) types can be mounted on the roof, cowl, or other high locations. These types are less efficient than a full-length model, however, they can often be mounted in higher and better locations making up for some of the ill effects of less efficiency.

Most Citizens-band units are used by the vehicle driver and, therefore, are mounted beneath the center of the dashboard or in some other convenient location. Although power for the CB unit can be obtained by connection of wires directly to the battery, it is advisable to connect it to the accessory side of the ignition switch. In this way the unit can only be operated when the ignition switch is on. When the ignition key is removed, it is impossible for unauthorized persons to use the unit. Remember, the FCC says that safeguarding the equipment from such tampering is the user's responsibility.

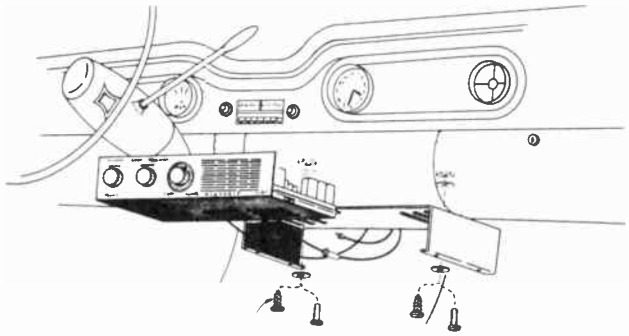


Fig. 8. Typical dashboard installation.

As shown in Fig. 8, the CB unit is usually mounted snug against the bottom of the dash. In fact, most units are equipped with hanger-type mounting brackets. It is necessary to drill several holes for the mounting screws, but be certain not to drill through electrical wires.

After the unit is mounted, the power connection can be made to the accessory terminal of the ignition switch. The power rating of the accessory line is adequate for the usual CB installation. The ground for the CB unit is obtained through its case when it is properly attached. A good ground can be insured by connecting a lead from some convenient ground lug on the unit to a good auto ground-point such as the metal firewall or frame.

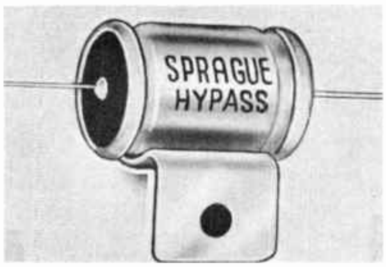


Fig. 9. Coaxial feed-through capacitor.

A coaxial feed-through capacitor for noise filtering can be connected in the power lead to cut down noises that may arrive at the receiver via the battery lines. Such a three-terminal capacitor is shown in Fig. 9. The outer shell is fastened down tightly to the vehicle ground or to the case of the CB unit. One lead connects to the DC input of the unit; the other, to the line from the ignition-switch terminal.

The coaxial transmission line can now be run between the antenna and the CB unit. In a bumper-whip mounting, a special clamp firmly holds the antenna mount. The antenna proper is threaded onto the top of this mounting. Usually the transmission line is brought through the trunk, fed beneath the rear seat, and brought to the front area beneath the floor mat.

A body-mount base is usually installed by drilling four holes—a large hole of 1½-inch diameter for the antenna base connections and three smaller ones for mounting bolts. The transmission line must be threaded along the car frame to the engine compartment. It is then fed into the dash area through some convenient hole in the firewall. If desired, the antenna lead from a bumper-mount can be routed in this manner instead of through the trunk.

When using the short whip antennas for cowl or windshield-corner mounting, a simple mounting assembly can be used. Usually it is the same as that employed for a car radio antenna. Before the antenna is tightened down, the coaxial line is connected to the antenna and fed through the mounting holes into the engine compartment. It is then routed to the CB unit through a convenient hole in the firewall.

Mounting a roof-top whip is often the most difficult assignment. Usually, working space and a location for mounting the antenna can be uncovered by removing the dome light of the car. Most often a ⅝ inch hole is needed for the antenna installation although one should start by using a smaller hole as a guide. It is necessary to snake a pull-wire between the upholstery and car body from the dome area to beneath the dash. The coaxial line can be pulled along the same path.

NOISE REJECTION

A special problem of vehicular radio installations, whether they be in the Citizens band or any of the other two-way radio services, is the suppression of electrical noise. The higher the noise level, the stronger the incoming signal must be, if reliable communications are to be attained. It is of little advantage to have a receiver with a 1-uv sensitivity if the noise level is several microvolts. Unfortunately there are several strong RF noise sources associated with the ignition and electrical systems of a car, boat, or aircraft.

The same basic steps apply to reducing noise in practically all two-way vehicle installations. Consequently, the information given in this Citizens-band lesson also applies equally well to other radio installations.

The vehicle's spark plugs are, in their way, small spark-gap transmitters. More sparking occurs in the distributor. Also, electrical contacts open and close in the voltage regulator causing interference. The extensive wiring in a car can function as an efficient radiator of this RF interference. There are several points at which static electric charges can collect and alternately discharge to create RF interference. Only by proper shielding and filtering can interference from these many sources of noise be reduced to a level

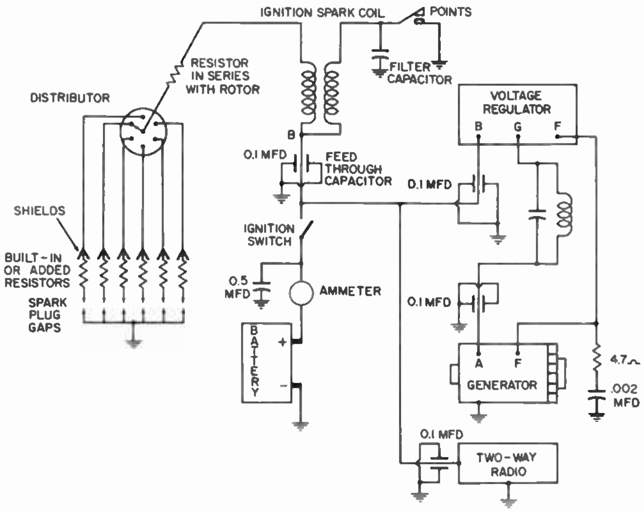


Fig. 10. Noise suppression in vehicle electrical system.

at which a sensitive communications receiver can function. The ignition system of a car, boat, or airplane generates strong noise components. However, the reduction of interference from the ignition system can often be solved with less trouble than interference caused by certain other vehicular disturbances. The generator, regulator, and ignition system are shown schematically in Fig. 10.

A major step in reducing ignition interference is to insert resistance in series with the spark-source. Such resistance does not affect the operation of a properly-adjusted engine. Spark plugs are available (Autolite) with built-in suppression resistors. It is also possible to buy suppression resistors that connect between the top of the spark plug and the ignition wire, also shields are available which can be placed over the plugs to minimize the radiation of RF energy. Resistance ignition cable is also available for use as spark-plug wires. This cable has a resistance of approximately 400 ohms per foot.

The distributor points open and close the battery supply in the primary circuit of the ignition coil. The abrupt collapse of the magnetic field about the coil (when the points open) generates pulses ranging from 10,000 to 20,000 volts across the secondary. These high-voltage pulses and the distributor rotor cause the spark plug gaps to arc in a definite sequence, or firing order, enabling combustion to take place.

A source of contact sparking exists at the rotor of the distributor. Interference from this source can be reduced by inserting a resistance between the secondary side of the ignition coil and the rotor contact. Resistor values between 5K and 10K are generally used. The maximum total resistance used between the ignition coil and each plug-gap should not exceed 15K.

In many installations the suppression of ignition-system noise lowers the RF noise level in the receiver to at least a tolerable level. Of course, the use of good-quality parts in the ignition system and the proper adjustment of spark-gap spacings and distributor points also reduces the amount of interference generated. However, if the ultimate in performance is desired, or if an obstinate case arises, it is important to

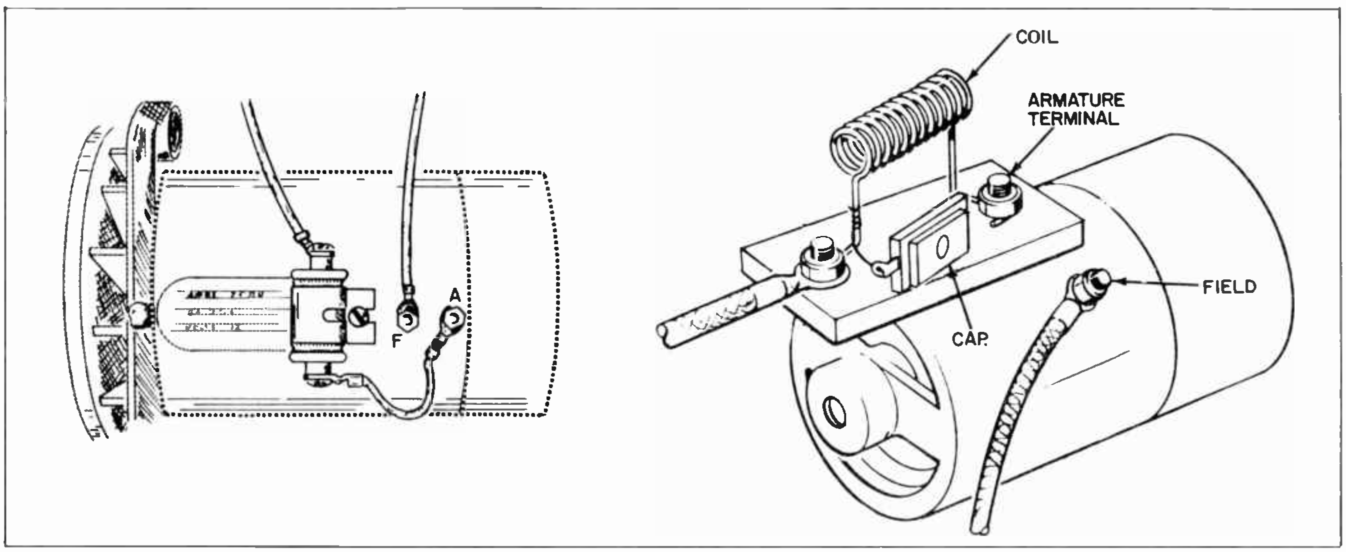


Fig. 11. Noise suppression at the generator.

remember there are other possibilities for noise suppression. RF interference can be reduced in the battery line by inserting a feed-through capacitor at the battery terminal of the ignition coil. The ground lug of the feed-through capacitor is connected to the metal band which supports the ignition coil. One terminal of the capacitor is connected to the battery terminal of the ignition coil (as near the coil as possible); the other capacitor terminal connects to the lead from the ignition switch.

VOLTAGE-REGULATOR AND GENERATOR INTERFERENCE

Ignition noise makes a popping sound that is especially noticeable when the engine is running slowly. Generator noise usually causes a whine, and its pitch varies with the engine speed. To reduce this latter type of interference, a coaxial capacitor should be connected in series with the armature lead of the generator. The capacitor case should be grounded to the generator frame as shown in Fig. 11A. One terminal of the capacitor goes to the armature terminal; the other connects to the lead that runs to the voltage-regulator.

A further reduction in generator noise can be obtained by using a resonant trap. Sparking interference from the generator radiates a wide band of frequencies. However, we are most concerned with noise impulses that occur at the operating frequency of the CB equipment. A parallel-resonant trap circuit connected in series with the armature terminal of the generator, as shown in Figs. 10 and 11B, will display a maximum impedance to CB frequencies. Consequently, these frequencies will be blocked from the electrical system of the vehicle. The parallel resonant trap is tuned with the receiver operating. It is adjusted for minimum generator noise in the set.

Once the generator noise is reduced to a satisfactory level, it is quite possible that voltage-regulator hash will become noticeable. This produces an erratic popping noise that varies only slightly in frequency with engine-speed. A filter has already been placed in the armature line between the voltage regulator and the generator, and an additional coaxial capacitor can be connected near the battery terminal of the voltage regulator.

MISCELLANEOUS FACTORS

Completely-shielded ignition systems are available. These include shielded regulator, shielded ignition coil, and shielded distributor cap. Shielded wires are provided to interconnect the generator and voltage-regulator circuits as well as the coil and spark plugs. Noise suppression kits can also be purchased. They include spark plug suppressors, a distributor suppressor, a voltage-regulator suppressor, and the necessary coaxial capacitors, cables, and other hardware.

In a troublesome noise-reduction problem there are a number of other remedies that can be tried. Filter capacitors may be placed between various battery leads and ground, such as those connecting to the ammeter, gasoline gauge, oil-signal device, ignition switch, etc. Such lines might be of a resonant length and may radiate RF noise very strongly. Headlight and taillight leads and any accessory wiring running from the engine compartment must be suspected in a troublesome case. Some cases may involve the temperature sender, gas-tank float sender, heater blower motor, or electric wiper motor.

Bonding metallic surfaces can also prove helpful. A flexible braid, ½ inch to 1 inch in width, is used to bond the engine to the firewall and frame. Other bonding can be used to form a good electrical path between hood and cowl, or between exhaust system and hanger clamps. All bonded surfaces should be cleaned thoroughly so the braid makes good electrical contact.

Tire static and wheel noise can be reduced in the usual way with static powder and hub springs to connect wheel and axle electrically.

CB RADIO ADJUSTMENT

The receiver of the CB unit is usually checked rather extensively during the installation and noise-suppression procedure. If the receiver is a tunable type, quite a few signals can be received in most localities simply by tuning the receiver through the band. The operation of any squelch or noise-limiting circuits should be checked. It is also important to spend an adequate amount of time teaching the customer how to operate the unit.

In an isolated location, it may be necessary to use another station of the same system for checking-out a particular installation. An accurate test-signal generator can be used for adjustment purposes, if one is available.

When the receiver is crystal-controlled, obviously the reception can be checked only on the channels provided. Most CB units come equipped for Channel 9 operation, which has become a universally-accepted calling frequency. In most locations, it should be possible to pick up some signal on this channel. If not, receiving tests must be made with companion units of the system. A variety of signal sources and test units for Citizens-band adjustment and maintenance are available. Several test-signal sources, as well as tuning and absorption meters, were covered in Lesson 16.

Factors of primary importance in the transmitter are frequency, power input, and modulation level. The technician is also interested in deriving the most output that is possible without exceeding the 5-watt input limit.

Any one of the twenty-two CB channels may be used. However, the frequency must be held within

0.005% of the assigned frequency for each particular channel. Most CB units are supplied with the transmit and receive crystals already inserted for one or more channels. These crystals have been selected and factory-tested to be sure they are within the FCC frequency tolerance.

Crystals for different channels can be ordered by specifying the exact model of CB unit in which the crystals are to be used. Distributed capacities and other characteristics vary from model to model and manufacturer to manufacturer. Thus, any crystal selected must go with the model in order that the unit operate within the FCC frequency tolerance. Don't interchange crystals among different models and makes unless you have a frequency-meter which can measure well within the FCC tolerance. Even then, such measurements and adjustments must be made only by the holder of a second-class radiotelephone or higher-grade FCC license. A commercial license is also required if any modifications or adjustments are made that can possibly cause the DC power input to the final RF stage to rise above the assigned limit.

By FCC rule, the input power to those circuits of a transmitter which contribute RF energy to the antenna system must be measured with a DC voltmeter and milliammeter of suitable accuracy. The product of the DC voltage and the DC current shall not exceed 5 watts. If this input fluctuates with modulation, the power at the *maximum* voice peak shall not exceed 5 watts. Home-constructed units should be checked by a radiotelephone license holder of second-class grade or higher before they are put "on the air." All of this emphasizes the fact that any person interested in doing Citizens-band servicing should take immediate steps to obtain at least a second-class radiotelephone license.

Off-the-air power input and output measurements can be made by non-licensed persons if a dummy load is substituted for the antenna. A #47 bulb, fastened in a plug as shown in Fig. 12, can be used as a dummy load. Dummy loads that connect into a regular PL-259 socket are available on the market. Test sets that make an absolute mesurement of power output while they serve as a dummy load are also available.

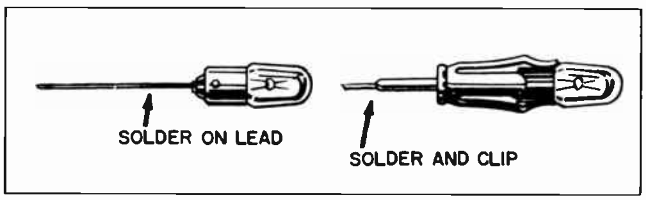


Fig. 12. A #47 bulb as a dummy load.

Some CB units include a convenient test-jack for inserting a DC milliammeter to measure final-amplifier plate currents. If you know the supply voltage to the final amplifier, the power input can be calculated using the power formula (P=EI).

After an installation is made and the receiver is checked, a dummy load can be substituted for the antenna if an on-the-air transmitter check is to be avoided. Many CB units include some form of RF indicator. When the unit is transmitting, the indicator will show that RF energy is being delivered to the dummy load or antenna system. Normally the indicator light (or meter) will fluctuate when you speak into the microphone. This indicates that the RF carrier is being modulated. The antenna can now be reconnected and an on-the-air check made with some other unit of the system.

REVIEW QUESTIONS

1. What form of modulation is used in CB transmitters? What methods are used to prevent overmodulation?
2. What are the power limitations on a CB station?
3. What is the CB frequency tolerance?
4. What steps should be taken to reduce ignition noise?
5. How can generator whine be reduced?
6. How are CB transmitter power output and modulation checked?
7. How do you order crystals for CB equipment?
8. What are the functions of the transmit-receiver changeover switching in a CB unit?

Answers to these questions will be included in PHOTOFACT Set No. 581.

Lesson 19

Two-Way Radio Installation and Adjustment

The usual two-way radio installation for mobile, industrial, or public safety radio service is seldom much more elaborate than a top grade Citizens band installation. Compact single-unit equipment is now available for these services. Space problems are often solved through the use of a multiple unit, such as the Comco model shown in Figs. 1 and 2. In this unit only the small control box and microphone need be mounted near the operator. The main transmitter-receiver unit can be located at a position where it will take up a minimum amount of useful space. The control box is usually mounted beneath the dashboard, and a microphone bracket is positioned at a point convenient to the hand of the operator. A power cable must be installed between the control box and the ignition switch or battery. A power and control cable is also needed to connect the control box with the transmitter-receiver unit which can be mounted in the trunk, engine compartment, at the rear of the driver's seat or at some other appropriate location.

Fig. 1. Comco two-way radio units.

Inasmuch as several bands are used for the services mentioned above, the particular antenna installation depends on the frequency of operation. For operation in the 25-50 megacycle band the antenna installation, except for the antenna length, is quite similar to a Citizens band installation. Since the 27-mc Citizens band is located at the low frequency end of this spectrum, the average mobile antenna is usually somewhat shorter than that of a CB unit.

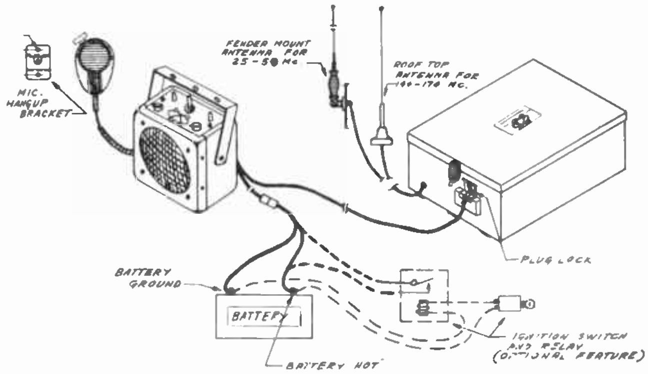


Fig. 2. Basic interconnections of mobile two-way radio components.

If the assigned frequency lies in the VHF or UHF bands, a considerably shorter antenna may be used, and the car roof provides the best antenna mounting. Usually this is an efficient type of installation, because of the higher location of the antenna and the effectiveness of the large-area metallic car top as a ground plane for the antenna system. Rear deck and cowl mountings are also used, but less frequently.

As in the case of a Citizens band installation, coaxial and ground-plane antennas are the most common for base station use in the 25-50 megacycle band. Similar antenna types are available for use in the VHF and UHF bands; however, in these bands a higher gain is practical because high-frequency multiple-element collinear types are no longer than a standard quarter-wave type on the 25-50 megacycle band. The two most common coaxial cable types used are RG-8/U and RG-58/U.

Since rather long-distance communication is often required, the base station antenna is sometimes mounted on a high mast or tower. Many of these installations are similar to the types made for long-range television reception; tower heights in excess of

70 feet are used at times. In some installations the transmitter-antenna site is on the top of a hill, ridge or tall building. Antenna installations must comply with FCC regulations.

FM BUSINESS COMMUNICATOR

In this section the installation and adjustment of a typical FM two-way radio unit designed for use in the business-radio service will be considered. The Gonset G151 (Fig. 3) provides a 36 watt FM signal

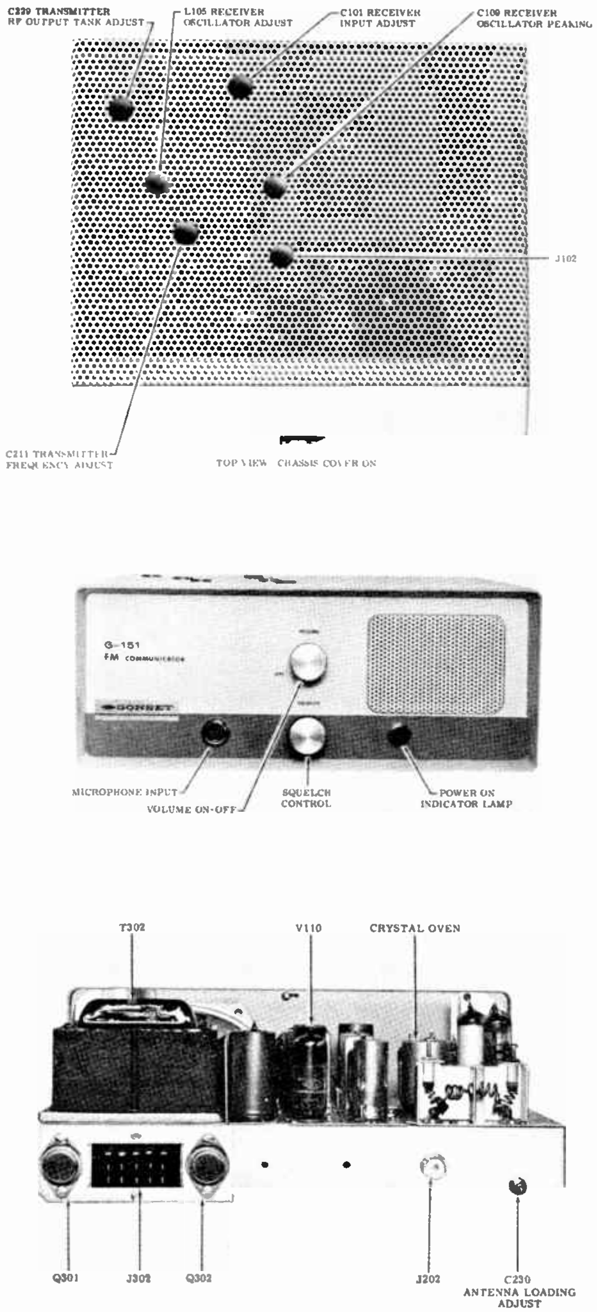


Fig. 3. Gonset FM business radio communicator.

(±5 kc deviation) on any assigned frequency between 151 and 174 mc. The unit is crystal controlled in both transmit and receive positions. By changing power cables, the unit can be operated from either a 117 volt AC or a 12 volt DC power source. Thus, similar units can be used at the base station and mobile stations. The transmitter frequency stability is 0.0005%. Receiver sensitivity is 0.8 microvolt for 20 db quieting.

Pre-installation Check

Prior to the installation of a two-way radio unit it is wise to check its condition and performance. Go through the unit to make certain the tubes are securely in place and that the proper crystals have been installed. The appropriate power cable can now be connected to the unit.

When checking the operation of the Gonset model, first set the volume control to mid-range. Then, while the unit is warming up, connect an FM signal generator to the antenna terminal, and set it to the receive frequency. Use a 5-microvolt FM signal with a minimum of 3 kc deviation at 1000 cycles. A 1000-cycle tone should now be heard through the speaker with the squelch control set at any position.

For checking out the transmitter section, a 50-ohm wattmeter, capable of dissipating a minimum of 40-50 watts, should be connected to the antenna terminal. Depress the microphone press-to-talk switch. The wattmeter should indicate a minimum reading of 36 watts. The transmitter frequency should now be checked to make certain it complies with FCC specifications.

A modulation meter should now be used to determine the deviation characteristic of the transmitter output. Remove the microphone from the microphone input jack and substitute a 1000-cps, 1-volt rms signal. With the transmitter turned on, adjust the deviation potentiometer for a maximum frequency swing of 4.7 kc.

The preceding checks on the transmitter must be made by or under the direct supervision of individuals holding a radiotelephone first or second-class license. If the unit does not perform properly, it is necessary to make additional adjustments and possibly alignment. Alignment and maintenance of the FM communicator will be covered in the final lesson of the course.

Netting

It is necessary to set all the units of an integrated communication system to the correct frequency. Improper netting is a prime cause of poor system performance. All units should be netted precisely prior to installation. After installation has been made the netting should again be checked and fine adjustments made if necessary.

If the system has not been operated previously, it is necessary to select one unit to operate as the base station. Check the transmitter output frequency of this unit and set it in accordance with FCC specifications. Also, check the receiver section to make certain that a received unmodulated signal within FCC specifications will give a zero voltage reading at test point J102-5 (discriminator DC output).

Next, turn on the transmitter associated with one of the mobile units to be netted with the base station, but do not modulate it. Adjust the mobile unit transmitter frequency trimmer control for a zero-voltage reading as indicated by a VTVM connected to test point J102-5 of the base station receiver. Re-verify that the transmitter thus adjusted is within FCC specifications.

To net the mobile unit receiver, turn on the transmitter of the base station. Now adjust the mobile unit receiver local oscillator slug for a zero voltage reading indicated by a VTVM connected to test point J102-5 of the mobile receiver. The above controls are readily accessible at the top of the unit as shown in Fig. 3.

If a unit is to be added to an already established system it should be netted with the base station. The procedure is the same. The transmitter is turned on without modulation and its frequency trimmer control is adjusted for a zero voltage reading measured at the base station receiver. The base station transmitter is now turned on without modulation. The receiver local oscillator slug is set for a zero voltage reading at its discriminator output.

Installation

The Gonset unit can be mounted directly under the dashboard or slant-mounted against the firewall as shown in Fig. 4. Prior to the connection of power to the unit the vehicle voltage regulator should be checked for proper operation. Measure the battery line voltage with engine started but operating below the generator pull-in speed. If the reading is less than 12 volts, check the battery connection and, if necessary, recharge or replace the battery. The engine should now be stepped-up so that the generator is operating at full output. The voltage measured at battery terminals should not exceed 14.5 volts. Let the engine idle and turn on the headlights for a few minutes. Again run up the engine speed to full output. Note the voltage before and after switching the lights off. The reading should stay substantially constant at no more than 14.5 volts. If this voltage is not stable between 14 and about 14.5 volts, the regulator should be adjusted or replaced.

In connecting the power to the unit make certain that proper battery polarity is observed. Always double-check polarity and also make certain the unit is properly grounded to the car frame. Transistors can be ruined if reverse-polarity power is applied to the unit.

For the best over-all performance and range, it is suggested that a vertical quarter-wave antenna be installed at the approximate center of the vehicle top. On some vehicles the interior dome light can be removed temporarily to provide convenient access for drilling the mounting holes and fishing the antenna cable. After the antenna is fastened, a wire must be routed beneath the headliner fabric to a corner post and, through the post to a point behind the dashboard. The antenna transmission line can now be attached to the wire and gently pulled through to the antenna. On convertibles or other vehicles where a rooftop antenna installation is impractical, the antenna may be mounted on the rear deck or trunk lid.

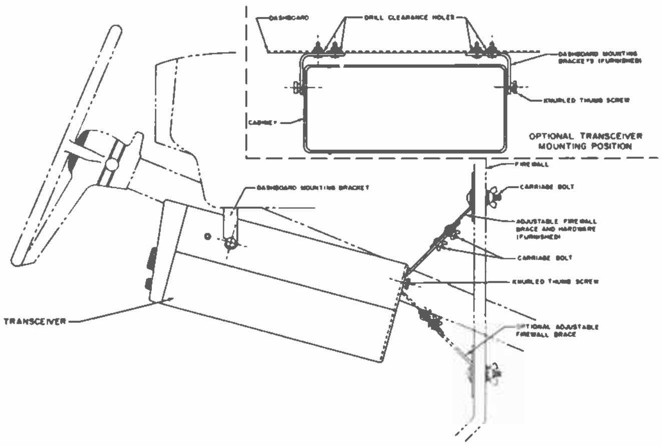


Fig. 4. Mounting the communicator.

Post-Installation Check

The FCC requires that pre-operational checks be made after the initial installation. The frequency and deviation must be within the tolerance set forth in the technical standards. These operational checks must be made by a properly licensed person.

Connect an in-line RF power meter (reflectometer, if available), capable of dissipating 40 watts or more, between the unit and antenna. After a suitable warm-up period, start the engine of the vehicle and accelerate until the generator indicator does not show discharge when the transmitter is operated. The antenna loading control and the transmitter RF output tank circuit are now adjusted for maximum power indication on the meter. If the meter can also read the standing-wave ratio (VSWR) the antenna can be adjusted until there is a minimum standing-wave ratio. Recheck the transmitter frequency and the modulation to make certain the operation of the unit still is within FCC specifications.

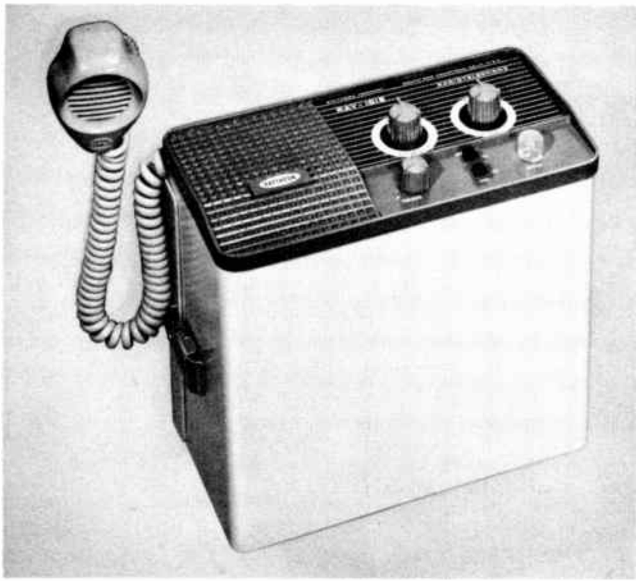
The receiver can be monitored by measuring the AGC voltage present at test point J102-1 with a DC

VTVM. The receiver input tuned circuit is then adjusted for maximum noise output. If there is considerable noise present, it is wise to make additional checks throughout the ignition and wiring circuits of the vehicle. In particular, defective components such as distributor points and rotor, bad plugs, and faulty terminals should be replaced. Noise suppression techniques were covered in Lesson 18. The use of FM modulation is, of course, of great benefit in itself in the suppression of noise.

SMALL-BOAT INSTALLATIONS

The installation of a small-boat radiotelephone does not differ too much from that of a two-way radio installation in a land vehicle. The frequency of operation, however, is much lower, and therefore, the antenna is much shorter. The antenna is highly base-loaded. In fact, a separate loading adjustment is usually provided for each channel. It is also more difficult to obtain a good ground. Since AM modulation is used, noise suppression can at times be troublesome.

A typical Raytheon small-boat radio and suggested mounting position are shown in Fig. 5. Canvas or ventilated plastic covers should be used to protect the unit from water spray.



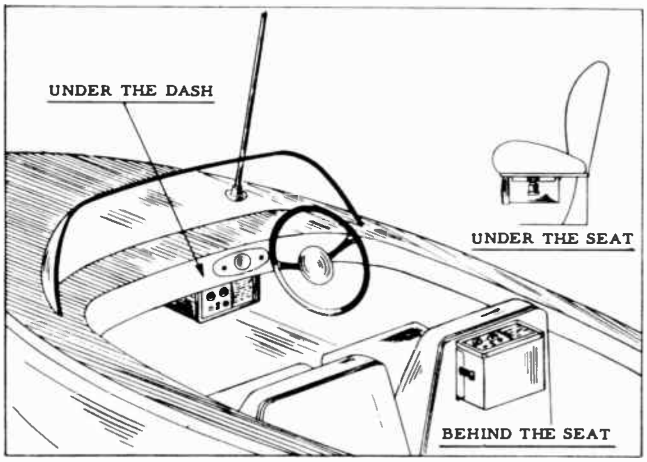


Fig. 5. Raytheon small-boat radio and typical mounting position.

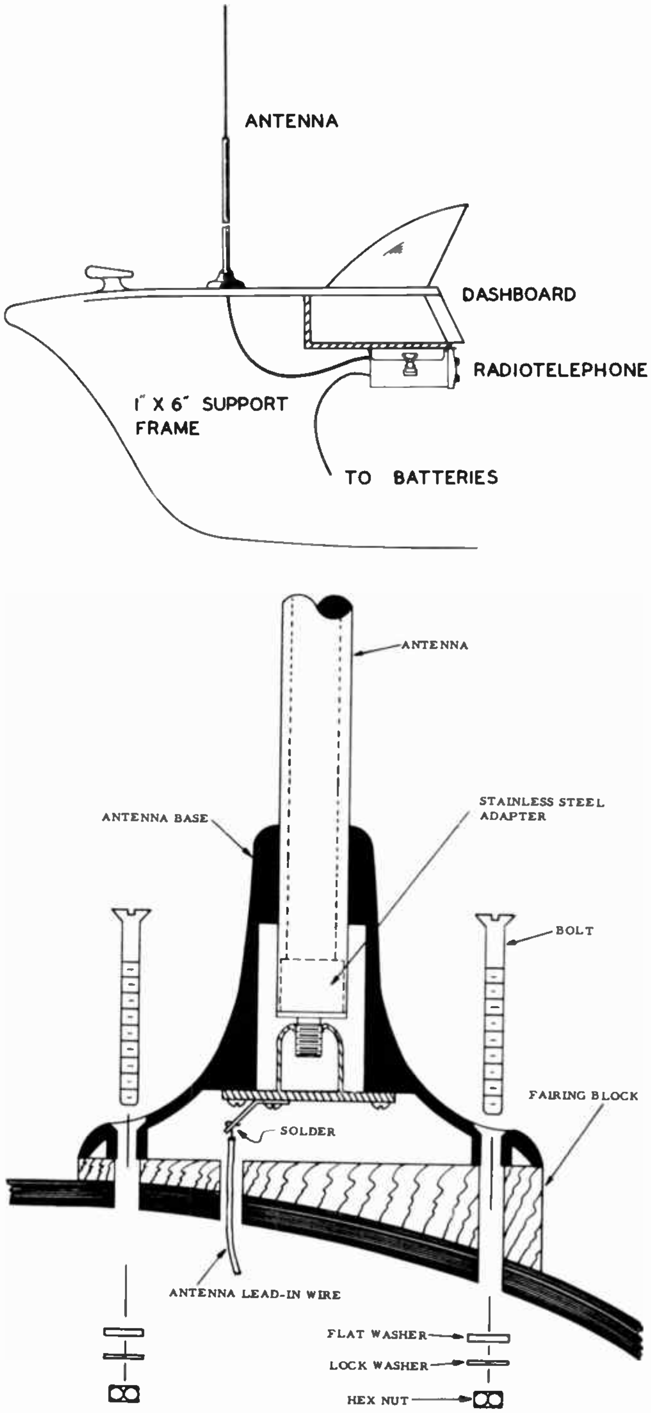


Fig. 6. Small-boat antenna installation.

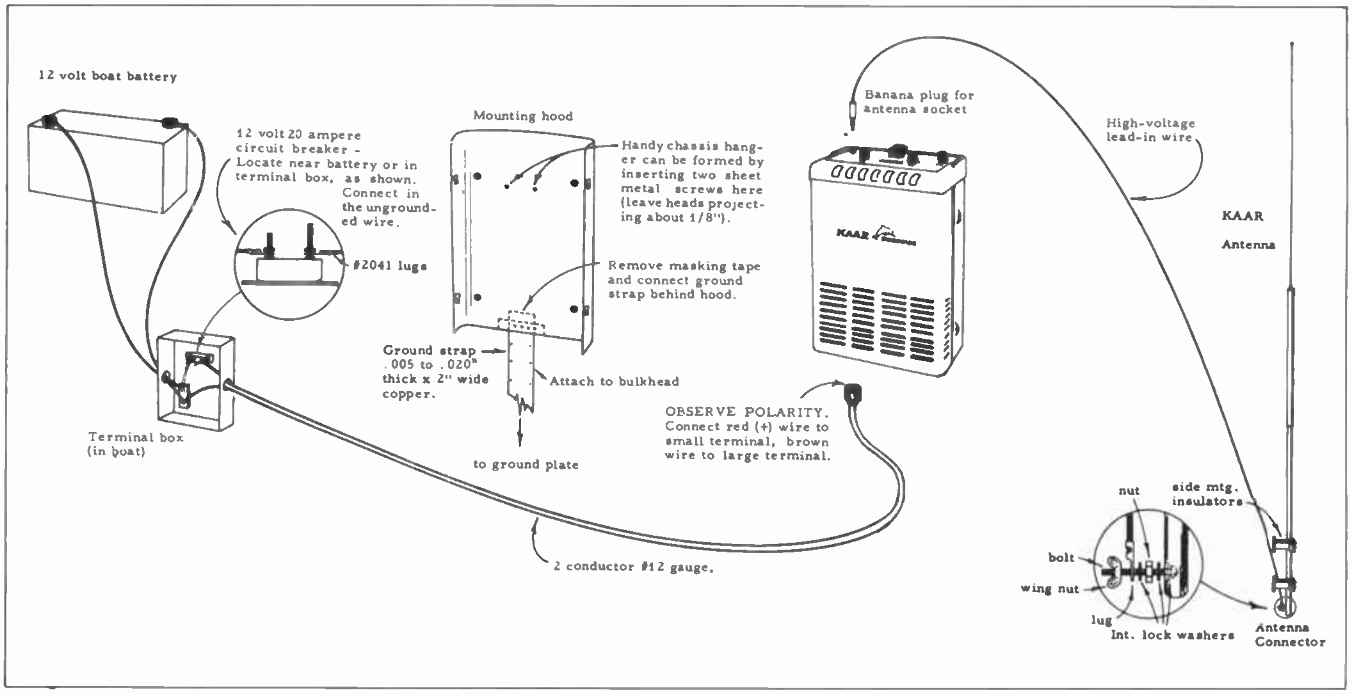


Fig. 7. Installation instructions for Kaar marine radiotelephone.

A typical antenna mounting arrangement is shown in Fig. 6. Notice the fairing block which conforms to the shape of the boat at the mounting position and holds the antenna vertical.

Installation instructions for a Kaar marine radiotelephone are given in Fig. 7. As in the case of a vehicular installation it is important to observe battery polarity. An overload breaker is a wise accessory. The power cable should be as short as practical. Cable clamps and screws can be used to hold the cable in place.

The insulated lead that runs between the radiotelephone and the antenna should be routed away from metallic surfaces and sources of noise; spark plug wire (not resistance type) is often used for this lead.

The best performance can be obtained only if an adequate ground system is incorporated. The grounding problem of a metal hull boat is not difficult. The radiotelephone chassis need only be connected electrically to the hull by as short a length of ground strap as possible.

A proper ground system must be installed if the hull is constructed of wood or fiberglass. The FCC recommends a metallic area of 12 square feet be attached to the bottom of the hull. This ground plate can be of brass, copper, or heavy copper foil. All electrical grounds from engine block, battery, radiotelephone, etc. should be grounded to this plate using straps (short as possible).

Some small-boat engines have metallic enclosures and shields; be certain these are grounded. Metallic shields placed around the engine reduce RF noises radiated from the engine and electrical system. Spark plug popping, generator whine, and distributor or

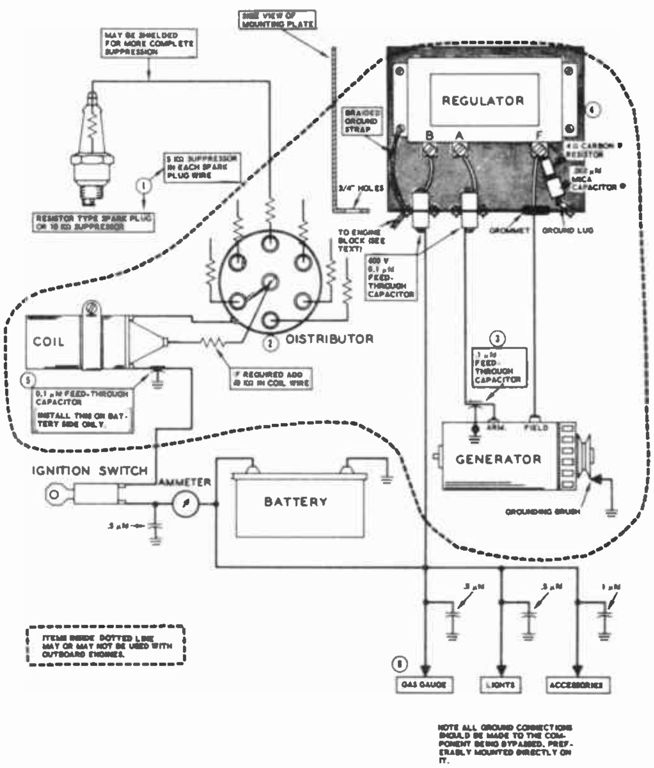


Fig. 8. Noise suppression techniques for a small-boat radio installation. (Courtesy Heath Co.)

regulator noises can interfere with small-boat reception. Land vehicle and small-boat suppression techniques are the same. These are summarized in the suggestions given in Fig. 8.

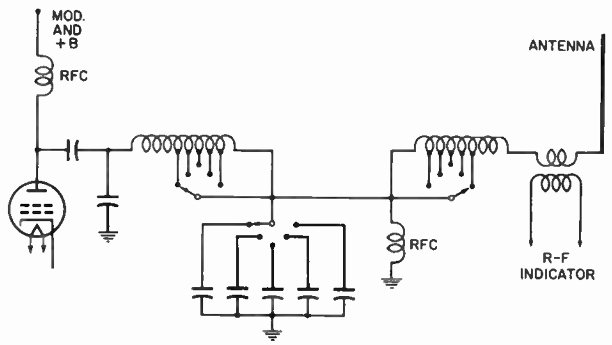


Fig. 9. Typical RF output system of a small-boat radio.

The diagram of Fig. 9 is typical of most marine radiotelephones. A pi-network tank circuit is used to obtain an appropriate match between the output and the low-impedance antenna system. The very short length of the antenna means that a very large loading coil is necessary.

Five loading capacitors are used—one for each of the five channels of the transmitter. There are also five taps on the final tank coil and on the antenna loading coil. Usually a closed-circuit jack is provided so that a current meter can be inserted into either the plate circuit or cathode circuit of the output tube for tuning purposes. The circuit of Fig. 9 also shows an output meter which can be used to give a relative indication of power output.

In tuning up such a transmitter, the taps are positioned along the tank and antenna coils according to the frequency of operation desired. The higher the frequency of operation, the smaller the amount of inductance required.

In a typical tune-up procedure, each of the antenna-coupling capacitors would be set near maximum. Starting at the high frequency end, the taps are positioned along the plate tank and antenna coil from high frequency end to low frequency end. These taps are usually color coded. Most manufacturers include a chart with their instruction manual to help you position each tap according to the frequency of operation.

If tap position information is not available, the correct position is determined experimentally. With the transmitter turned on, the tank coil tap is grasped by the lead only and run up and down the tank coil until a position is found at which the plate or cathode current dips. Usually this position is found for the highest frequency of operation and other taps are then located successively until the lowest frequency tap has been placed in position. A similar procedure is used to position the taps on the antenna coil. In this case each tap position is located when maximum output is shown on the output indicator.

Once the tap positions have been located, the individual loading capacitors permit a fine adjustment on each channel. The plate current is dipped on each of the channels. Usually it is preferable that this occur at some specific value of plate current. If the plate current dip reading on any one of the channels is substantially off, the associated taps on plate coil and antenna coil can be moved slightly. The coupling capacitor is then varied to dip position again and the new current noted. By switching back and forth, it is usually possible to bring the minimum plate current to somewhere near the correct value.

REMOTE CONTROL INSTALLATIONS

There is a variety of remote-control systems used in the two-way radio services. Many vehicle installations are of the remote control type with a control box mounted beneath the dashboard (convenient to the operator) while the transmitter-receiver is mounted in the trunk or at some other location. The functional plan shown in Fig. 10 is typical.

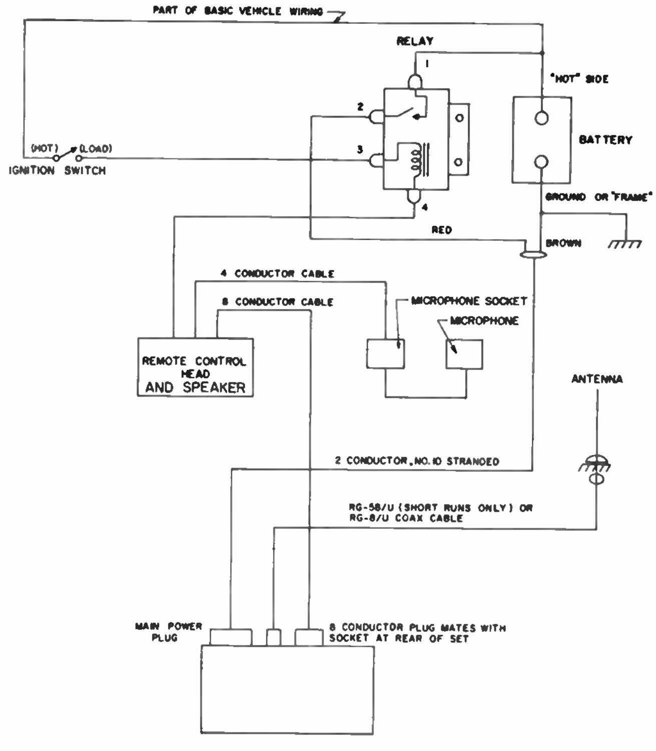


Fig. 10. Aerotron remote-control installation plan.

The vehicle battery is shown at the top right and is linked to the car ignition system as well as the power relay of the two-way radio installation. Battery current will flow through the relay coil only when the ignition switch of the vehicle is turned on.

When the relay is energized, contacts 1 and 2 of the relay close and power is applied to the transmitter-receiver power plug.

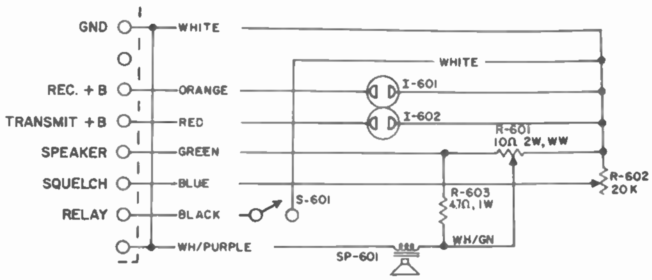


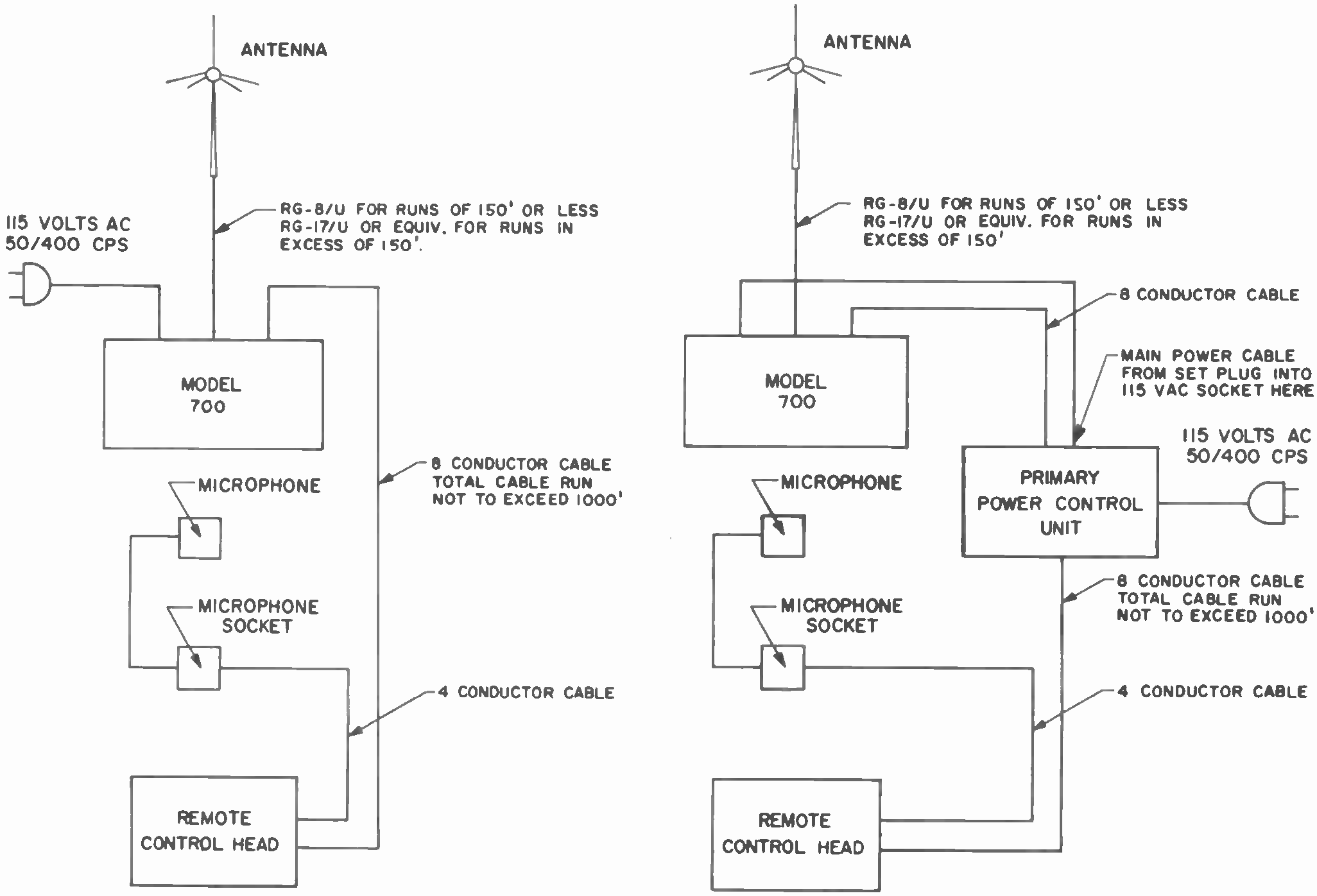
Fig. 11. Aerotron remote-control head.

Remote control heads vary from manufacturer to manufacturer. Some include a built-in speaker and a microphone socket. In other types, the speaker and/or microphone socket are separate and must be linked by cable to the remote control head.

A coaxial cable is connected between the transmitter-receiver and the antenna. If the antenna is mounted at the rear of the vehicle, only a short length of cable is needed.

A multi-conductor cable links the remote control head with the transmitter-receiver. The Aerotron remote control head schematic shown in Fig. 11 is typical of this type. When switch S601 is closed, the battery circuit to the relay coil is completed. Power is then supplied to the transmitter-receiver. The pilot lamp I601 indicates when the receiver is turned on. The microphone switch places the transmitter on the air; at this time, indicator lamp I602 comes on. Potentiometer R601 is the volume control which governs the amount of current flowing in the voice coil of the speaker. Resistor R602 is the squelch control.

Two common base-station remote-control plans are shown in Fig. 12. These arrangements permit the transmitter-receiver to be positioned at a favorable location with respect to the antenna system; at the same time, minimizing the amount of clutter received by a crowded dispatch point. In a typical installation, the transmitter-receiver and remote control head can be separated as much as 1000 feet. The only difference between the two arrangements is that primary power can be controlled from the remote location in the second plan (Fig. 12B). In the first plan (Fig.



(A) Without remote-controlled power.

(B) With remote-controlled power.

Fig. 12. Telephone-line system for remote control operation.

12A) the main power must be turned on and off at the transmitter-receiver location.

In those installations where the transmitter site is on top of a hill or a considerable distance away from control center, the remote control operation is maintained over telephone lines. Both DC current for relay control, and audio-frequency signals are sent over the same telephone pair (see Fig. 13).

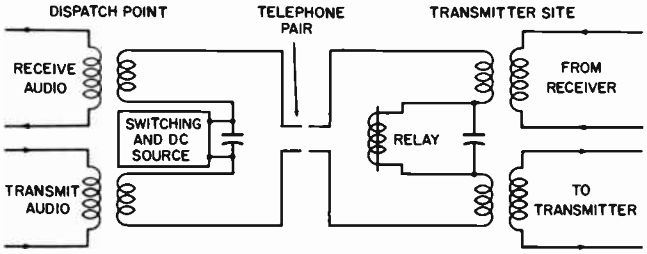


Fig. 13. Basic remote control method.

During transmission, the amplified microphone signal is sent over the line to the modulator section of the transmitter. During reception, the output of the receiver at the remote location is sent over the line to the audio amplifier-loudspeaker system at the remote control point. The function of the relay contacts at the remote point are the same as that of a transmit-receive relay associated with units previously covered, with the exception that the relay coil is energized over the telephone path. When the system is turned to the TRANSMIT position at the remote control point, DC current flows through the telephone line and energizes the relay. When the relay is energized the contacts close and place the transmitter on the air.

More elaborate remote control systems are available that can control more than one receiver and/or transmitter, switch main power, and send back trouble signals to the remote control point. For high-power transmitters, remote metering facilities can also be included.

REVIEW QUESTIONS

1. The FCC is particularly concerned with what three operating parameters of a two-way radio transmitter?
2. At what times is it necessary to make transmitter measurements, in compliance with FCC regulations?
3. What circuits are switched in the transmit-receive changeover operation of the Gonset unit shown in Fig. 5?
4. Why is the proper installation of the antenna particularly important in a small-boat installation?
5. What is the preferred mounting position for a mobile VHF or UHF antenna?
6. What is the frequency tolerance the business radio service in the 150 megacycle band?
7. How can a single telephone pair be used to establish a simple remote control system?
8. How can the meter shown in Fig. 7 be used to measure the standing wave ratio of a two-way radio transmission-line system?

Answers to these questions will be included in PHOTOFACT Set No. 581.

Lesson 20

Two-Way Radio Maintenance and Troubleshooting

INTRODUCTION

Two-way radio maintenance involves three basic procedures—preventive maintenance and performance checks, alignment and tune-up, and trouble localization. A sensible preventive maintenance schedule is the key factor in maintaining a high order of reliable performance. By law, transmitter output, frequency, and modulation must be checked every six months. That is a good time to consider the receiver performance as well. Actually, it is wise to check the equipment monthly, or at least a few times during each compulsory six-month period. Vehicular installations are subject to considerable vibration and need to be checked frequently. Do not permit deteriorating connections and rising interference levels to hamper important communications.

Records should be kept on each unit. Output level plus frequency, current, and voltage readings should be recorded on forms made up for this purpose. When readings begin to change from the normal it is a certain indication that maintenance is necessary. It may be that only a tune-up is required or, a tube is going bad. In other cases it may lead you to a defective part which, if found, may prevent a complete breakdown several weeks later.

The test equipment required for two-way radio maintenance was covered in considerable detail in previous lessons. Of course the test equipment itself must be kept in peak operating condition. In particular, those instruments used to make the required FCC measurements should be religiously maintained.

TUNE-UP AND ALIGNMENT

As in most electronic equipment, improper tuning and adjustment can cause faulty operation. The characteristics of circuits and components change over a period of time. Changes in supply voltage can influence the tuning of both receiver and transmitter. Environmental changes such as temperature or humidity often alter operating conditions. When tubes or other components are replaced, their characteristics often differ from those originally used in the circuit. The severe jolting that a mobile unit encounters can cause operating conditions to change suddenly or perhaps over a period of time. These many conditions, no matter how painstakingly the designer attempts to avoid their influence, require that units be tuned-up and aligned on occasion if peak performance is to be retained.

In this section we will consider in detail the alignment of the FM communicator which was discussed in Lesson 19. From the schematic diagram in Fig. 1, you will notice that the communicator is divided into three major sections—transmitter, receiver, and power supply sub-chassis. Alignment slugs and key test points are marked. You may wish to locate some of these points as you review the circuit description given in Lesson 19. In general, it is a much less confusing arrangement of components than you may have encountered in servicing television receivers. The convenient test points and sockets, which are a part of most two-way radio equipment, are a definite help both for alignment and for localization of faults.

Don't align until you are reasonably certain that it is necessary. The need for alignment is usually indicated by a gradual deterioration of performance in the transmitter or receiver. Perhaps the full transmitter output cannot be obtained or the modulation level seems low. Maybe the receiver has trouble picking up weak signals or, there is a high background-noise level. Perhaps the speech is a bit distorted as though the receiver is not tuned correctly. Of course, other factors can produce the same apparent troubles and these possible conditions should be checked before a decision is made to align the unit.

Standard tests, made each six months to insure optimum operational capabilities, often disclose gradual deterioration of performance as a result of misalignment, incorrect adjustment, tube aging, or component failure. Prior to removal for bench service, however, a visual check of the installation should be made. Check the condition of tubes, cabling, antenna connection, microphone hook-up, and power circuits. If these are all normal and it is still not possible to tune the unit for peak performance, you must determine if the problem is a bad part or a need for general tune-up and alignment.

First you should check key power-supply voltages. In particular, make certain that the power supply is providing full voltage under load. The possible cause of a low voltage reading could go back as far as the voltage regulator or battery of the vehicle.

Gonset recommends the following test equipment to be used in maintenance work on their FM communicator:

1. A stable VHF signal generator with provision for several crystal-controlled outputs. Preferably, the generator output should be fundamental on all ranges, to prevent spurious responses within the equipment.
2. A calibrated attenuator or pad that can be used to reduce the generator output to exactly 0.25 uv or less for making receiver-sensitivity measurements.
3. A modulation monitor and frequency meter. The accuracy of the frequency meter should be at least 0.0002% or better (1 or 2 parts-per-million).
4. An in-line RF wattmeter that can be used to check transmitter output and antenna-system efficiency.
5. A DC VTVM.
6. An AC voltmeter, calibrated in db.

ALIGNMENT PROCEDURES

A thirty-minute warmup period for both test equipment and two-way set should be permitted before alignment begins. Check the power-supply voltage to the receiver at pin 3 of test socket J102, using a DC VTVM; the voltage reading should be 210 volts. The test socket J102 can be seen at the very center of the photo in Lesson 19. Notice from the schematic diagram (Fig. 1) that the supply voltage arrives at this point from the contacts of the transmit-receiver relay. Thus the unit must be in the receive condition to permit a voltage measurement at this spot.

Before starting the alignment procedure, turn the volume control clockwise until some noise is heard in the speaker. The squelch control should be set fully counter-clockwise.

1. Connect the VTVM to pin 1 of J102. At this point the meter will read the limiter grid current. Use the 3- or 5-volt scale of the meter. Connect the signal generator, through a 0.01-mfd isolation capacitor, to pin 2 of the second mixer tube V104A. Apply an unmodulated 455-kc signal to this grid.
2. Adjust IF transformers T107, T106, T105, T104, and T103, in that order, for a maximum reading on the meter. Maintain the input signal level so a reading of not more than 3 volts is obtained on the VTVM.
3. Connect the VTVM to pin 5 of J102. Notice that at this position the meter reads the DC output of the discriminator. Adjust the top core of T108 (secondary of discriminator transformer) until the output voltage reading is zero volts DC. Adjust the bottom core of T108 for equal positive and negative peaks when the signal generated is varied above and below 455 kc by equal amounts. Readjust the top core for a reading of zero volts with the signal generator at exactly 455 kc. The bottom core of transformer T108 tunes the primary of the discriminator transformer.
4. Connect the signal generator to pin 9 of the first mixer tube V102A through a 0.01-mfd isolation capacitor. Apply a 10.7-mc signal to this control grid. Be certain the signal generator is set precisely to 10.7 mc. This can be assured by checking the discriminator output at pin 5 of test jack J102, varying the signal-generator frequency until exactly zero volts is obtained. This setting then corresponds exactly to 10.7 mc since the discriminator has been previously set to exactly 455 kc and a stable crystal oscillator is used to form the second IF.
5. Reconnect the VTVM to pin 1 of socket J102. Set the meter on the 3- or 5-volt scale. Adjust transformers T102 and T101 for maximum meter reading. Keep the signal generator output low enough that the meter reading is less than 3 volts.
6. Connect a generator, with a frequency range between 150 and 175 mc, to the antenna receptacle J202. Set this generator to the exact channel frequency. This can be done by either zero-beating with an accurate heterodyne frequency meter or by checking for discriminator-zero. Adjust L105, L106, and C109 for a maximum meter reading. These adjustments insure proper oscillator frequency and injection voltage.
7. Adjust capacitors C106, C104, and C109 for maximum meter reading. Keep lowering the signal generator output so the meter indication is no more than 3 volts maximum.
8. The receiver can now be "netted" by adjusting inductor L105 in accordance with the procedure suggested in Lesson 19.

Transmitter Alignment

Transmitter alignment and tuneup also requires the use of a VTVM inserted into the appropriate pins of transmitter test socket J203. With the transmitter turned on, (keyed), its supply voltage can be checked by inserting the meter into pin 5 of J203. A normal DC reading is 325 volts. This voltage arrives at the transmitter circuit by way of the transmit-receive relay contacts. In the transmit position, the relay is energized and the contacts closed, applying the DC voltage to the transmitter circuits.

1. Connect the VTVM to pin 1 of the doubler stage, tube V204. The voltage measured at the grid

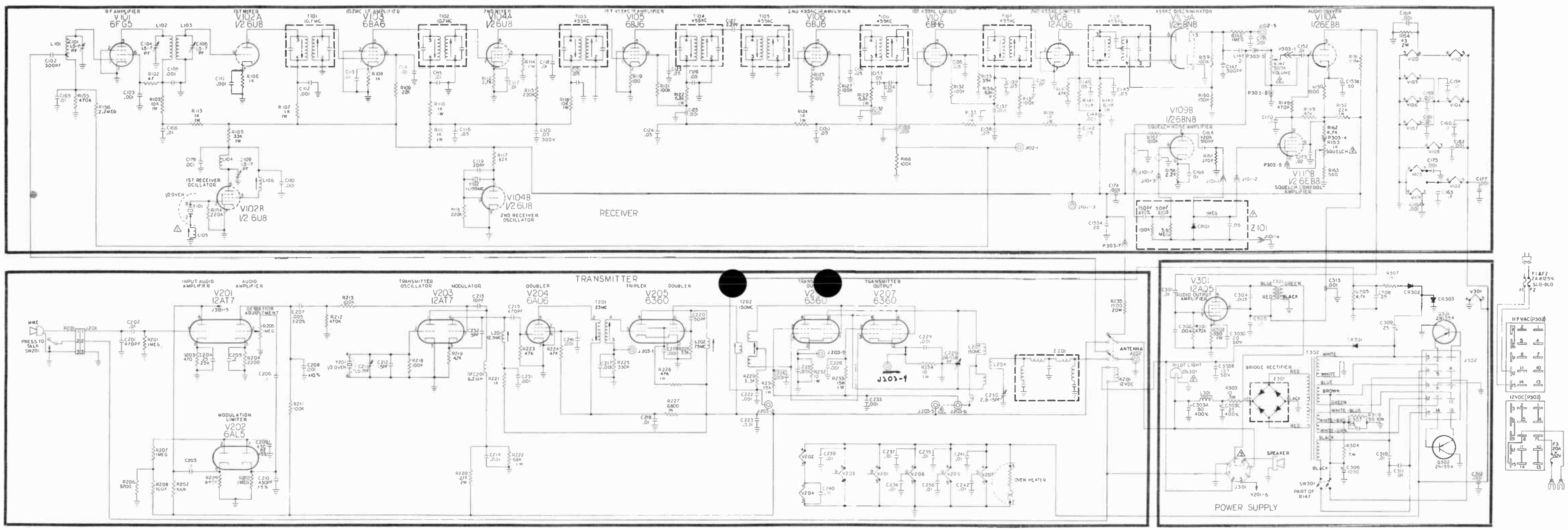


Fig. 1. Schematic diagram of Gon[illegible]M communicator.

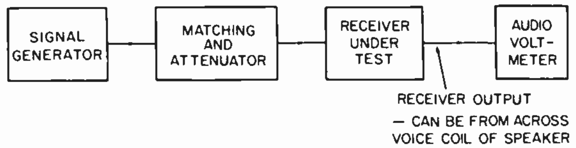


Fig. 2. Receiver sensitivity check.

RECEIVER ALIGNMENT OSCILLATOR

The need for an accurate and stable signal source at 10.7 mc for receiver IF alignment can be met with an inexpensive transistorized oscillator which can be constructed in a very short time from readily-available parts. A non-critical circuit, suggested by Aerotron, is given in Fig. 3.

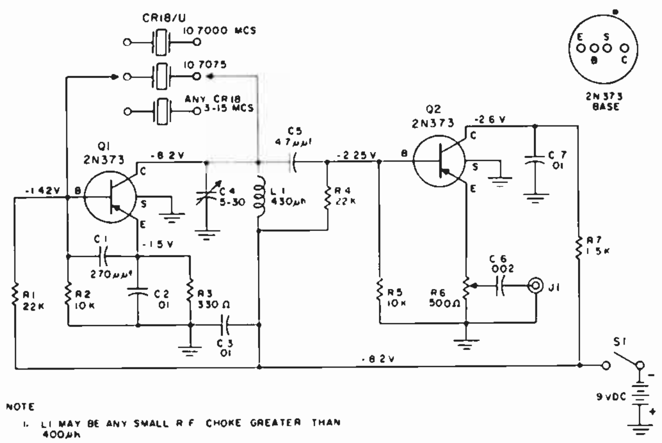


Fig. 3. Receiver alignment test oscillator.

The test oscillator should be constructed on a small metal chassis, keeping all leads as short and direct as possible although actual lead length and placement of parts is not critical if ordinary receiver-construction practices are followed. The battery may be a small transistor-radio type. It should be mounted on the chassis and the entire oscillator unit enclosed in a metal box in order to prevent undesired radiation. The output jack, J-1, should be of either a coaxial or shielded phono-type. All fixed resistors are ½-watt composition and the fixed capacitors are disc-ceramic types. The output-level control, R6, should be of a composition type rather than a wire-wound control.

A single trimmer, C4, has been provided to adjust the exact frequency of the crystals used. If greater precision is desired, individual trimmers of 5-30 mmf may be used from the collector side of each of the crystals to ground, instead of the single trimmer shown. The crystals should also be mounted inside the metal box and can be soldered directly across the selector switch, if desired.

The test oscillator should be carefully checked against a suitable frequency standard and the trimmer (or trimmers) adjusted for a *maximum* error of less than .002% on any of the crystal frequencies used for alignment work. Frequency adjustment may be conveniently done with a communications receiver which includes a crystal calibrator and provision for receiving WWV on 5, 10 or 15 mc. The 100-kc crystal calibrator should first be checked against WWV. The receiver can then be set to exactly 21.4 mc, using the calibrator and BFO to produce a zero beat at this frequency. The test oscillator should be set at the 10.7-mc switch position and placed near the antenna lead of the receiver. The trimmer may then be adjusted to accurately set the test oscillator on 10.700 mc.

It is suggested that crystals be initially installed for 10.7000, 10.7075 and 10.6925 mc. The first frequency will be used for IF alignment and receiver "netting" adjustments. The additional frequencies can be used for proper adjustment of filters, IF transformers and FM detector and, for checking selectivity. If desired, crystals may also be installed for 1650 kc, 455 kc or any other frequency, as long as all crystals are of the fundamental-frequency type.

PREVENTIVE MAINTENANCE

Preventive maintenance is a key servicing factor for reliable peak-performance operation. Such steps provide good insurance that most troubles will not occur when the two-way radio unit is most needed. Important things to include on your preventive maintenance schedule are:

1. Check the power source often. Battery connections should be kept in good condition. Make certain the mountings are secure. Take measurements of battery strength, electrolyte level, and output voltage. Keep watch on the operation of the voltage regulator. Watch out for cable wear.

2. Check antenna and ground connections. Inspect for any physical damage to the antenna and make certain good contact is maintained between the inner contacts of coaxial plugs and antenna elements.

3. Be certain that tubes are seated securely. Check transmitter and receiver tuning. Make a measurement of transmitter frequency and deviation. Check receiver sensitivity.

4. Make routine internal inspections of equipment, looking for signs of overheating or parts deterioration. Keep an eye out for loose coil connections. If the equipment is subjected to environmental extremes such as dust, wind and rain it is wise to establish a preventive maintenance schedule that includes checking of all plugs, connectors, tubes, and fasteners for proper cleanliness, seating, and tightness of fit. Loose foreign objects can be removed from the inside of the cabinet with a soft dry brush

is related to the amount of drive signal supplied by the crystal oscillator.

2. Key the transmitter and verify its frequency of operation with a frequency meter. Adjust L201 for maximum voltage indication.

3. Connect the VTVM to pin 1 of the test socket J203 to read tripler-grid excitation. Tune interstage transformer T201 for maximum voltage reading.

4. Connect the meter to pin 2 of test socket J203 (drive to output stage). Tune L202 for maximum reading.

5. Screw the primary slug of transformer T202 completely out of coil. Turn the secondary slug until it just begins to enter the coil. Key the transmitter and tune the secondary coil for maximum voltage. This reading should be about —25 volts. Slowly turn the primary slug into the primary coil at the rate of 2 turns at a time, retuning the secondary coil each time. Continue this procedure until approximately —50 volts of drive is being developed. In this tuning process, both the resonant tuning and the drive are adjusted alternately until the transformer is tuned to resonance at the same time it delivers the optimum drive to the final power amplifier.

6. The cathode current of the output stage can be measured by inserting the meter at pin 3 or 4 of J203. The plate tank capacitor C229 can now be tuned for minimum cathode current. Capacitors C229 and the antenna tuning capacitor C230 are adjusted alternately for maximum reading on the output-power meter. This should be approximately 36 watts.

7. The antenna can now be connected to the transmitter output. If available, a reflectometer-type power and SWR meter can be connected into the line. Capacitors C229 and C230 can now be retouched for maximum output with minimum standing-wave ratio.

Modulation Adjustment

In preparing for modulation checks it has been assumed that the transmitter has been adjusted for maximum power output on the correct frequency. A 1-volt 1000-cps audio signal must be supplied to the front-panel microphone jack J201. An FM deviation meter, with whatever attenuator or impedance-matching device is required, is connected to the transmitter output J202.

1. Adjust the DEVIATION LIMIT control R205 for 4.8 kc deviation.

2. Check both the positive and negative deviations for deviation percentage. If the modulation is non-symmetrical by more than ½ kc, slightly readjust L201 (modulator plate-circuit tuning) for a linear deviation.

3. If L201 did require readjustment, it will be necessary to recheck the crystal frequency because L201 can cause a slight alteration of crystal frequency. Readjust C211 if necessary.

4. Reduce the audio-generator output to 70 mv. At this input signal level, the deviation should begin to decrease.

5. As a final check, reset the audio level of 1 volt and vary the audio-generator frequency between 200 and 20,000 cps. The deviation should not exceed 5 kc at any frequency.

6. The receiver and transmitter should now be "netted" in accordance with the procedure described in lesson 19.

RECEIVER SENSITIVITY MEASUREMENT

A signal generator and audio voltmeter are used to measure receiver sensitivity in the typical arrangement shown in Fig. 2. Signal generator and receiver should be permitted to warm up at least ½ hour or more. The signal generator is connected through an attenuator pad and/or matching device to the receiver input. The audio voltmeter is connected to the output of the receiver.

It is very important that the signal generator be set precisely to the receive frequency for this measurement. A DC VTVM can be connected to the discriminator output and the signal generator frequency set very carefully for a zero output. The receiver squelch should be turned off.

1. Reduce the signal generator output to zero. Advance the volume control until the output meter reads some reference voltage—say, 10 volts. This 10-volt reading is the reference output-noise level.

2. Increase the signal generator output until the meter reading drops to 1 volt (which represents a 20-db decrease in the output).

3. Read the RF signal voltage applied to the receiver input. This amount of signal (in microvolts) represents the receiver sensitivity for 20-db quieting.

As you know, the noise output of an FM receiver decreases with an increase in the applied signal because of limiting action. This test procedure determines the applied signal level needed to reduce the noise output of the receiver by 20 db.

4. At times, the sensitivity specification of a receiver is given in some other value of quieting such as 6 or 10 db. It should be understood that 10-db quieting at a prescribed signal level is not as good as 20-db quieting at the same signal level. In the former case, the noise output of the receiver has only decreased by 10 db when the signal generator output has been increased to a specified level.

Of course, you can measure the sensitivity of the receiver in terms of 10-db quieting by setting the signal generator output to the level at which the receiver noise output has fallen only to 10 db.

or with a clean, dry air blower. Relay contacts and their operation reliability should be watched.

TROUBLESHOOTING

The same logical steps you would employ in tracing down a defect in a television receiver can be used in locating faults in a two-way radio system. Just as you mentally divide a television receiver into a group of functional sections, a two-way radio system should be segregated into separate units and sections.

A generalized chart for localizing trouble in two-way radio gear follows:

POWER SUPPLY

Inoperative on DC or AC .... (a) Defective fuse or fuses.
(b) Defective switch.
(c) Defective transformer.

Operates OK on AC, blows fuses on DC

1. Vibrator sets .... (a) Defective vibrator.
(b) Defective power cable or plug.

2. Transistor Power .... (a) Defective transistor.
(b) Reversed battery polarity.
(c) Transistor shorted to heat sink (defective insulating washer).

Low B+ voltage operating on DC .... (a) Low battery voltage.
(b) Defective vibrator or transistor.

Low B+ from any power source.................... (a) Shorted tube or shorted B+ bypass capacitor.
(b) Defective rectifier.
(c) Defective filter capacitor.
(d) Defective power transformer.

Once the power supply has been checked, operate the set with a dummy load and check the transmitter as follows:

TRANSMITTER

Inoperative; no RF output .... (a) Defective tube.
(b) Defective relay.
(c) Defective crystal.

Operative, but low RF output .... (a) Defective tube.
(b) Transmitter out of alignment.
(c) Low B+; see "Power Supply" checks.

Output OK, modulation deviation low .... (a) Defective tube in audio system.
(b) Defective microphone.
(c) Automatic deviation control improperly adjusted.

Modulation distorted .... (a) Defective tube in audio system.
(b) Check receiver first; if present on more than one receiver, the transmitter is probably at fault.
(c) Check modulation deviation and reset if necessary.
(d) Check transmitter frequency; reset if out of tolerance.

Output and modulation OK,
frequency out of tolerance .... (a) Defective oscillator tube.
(b) Defective crystal.

After both power supply and transmitter have been checked, connect the set to an antenna and check the receiver as follows:

RECEIVER

Inoperative, no audio .... (a) Defective tube.
(b) Check supply voltages.
(c) "Signal trace" to find faulty stage.
(d) Check relay contacts.

Inoperative but loud hiss at maximum volume and minimum squelch positions .... (a) Defective tube in input stages.
(b) Defective crystal.

Squelch inoperative .... (a) Defective squelch system tube.
(b) Check limiter operation.
(c) If tubes check OK, refer to "Low Sensitivity," below.

Receiver operative but low sensitivity .... (a) Defective tube in RF or IF system.
(b) Defective antenna.
(c) Check limiter voltage. If less than normal, check receiver alignment.

Receiver operative but audio distorted .... (a) Defective tube.
(b) Check discriminator action with signal *known to be on frequency* and having *proper modulation deviation.*
(c) Receiver out of alignment or defective crystal.

Operative, sensitivity normal but excessive ignition noise .... (a) Defective tube.
(b) Check discriminator circuit.
(c) Check limiter action.
(d) Check vehicle for excessive ignition noise.

REVIEW QUESTIONS

1. Give the procedure for making a receiver-sensitivity measurement.
2. How is the proper setting for inductor L202 in the plate circuit of the tripler (Fig. 2) determined?
3. How are the controls associated with first receiver oscillator set correctly?
4. Why is it not necessary to tune the second receiver oscillator?
5. How is the proper drive to the transmitter output stage set?
6. What steps must be taken in the adjustment of the modulation of the FM communicator?
7. What is the function of each set of tape associated with the output system coil of the transmitter shown in Fig. 7?
8. Does 6 db quieting with an applied one microvolt signal represent a higher or lower sensitivity than a 10 db quieting with an applied one microvolt signal?

Answers to these questions will be included in PHOTOFACT Set No. 581

ANSWER SHEET

For Questions in Lessons 17 through 20

LESSON 17 — ANSWERS

1. The emitter current goes through a resonant dip.
2. The grid current rises.
3. The cathode current decreases.
4. The plate current rises.
5. The plate voltage of the stage must be turned off but the grid drive should be on. If the stage is neutralized there will be no dip in the grid current reading as the plate tank is tuned through resonance.
6. There will be a dip in the plate current when the plate tank circuit is tuned through harmonic resonant frequencies. That the tank circuit is tuned to the proper harmonic can be ascertained by using an absorption wavemeter or a grid-dip meter.
7. DC meters which read the average DC component of grid and plate current are used. An RF meter must be used to measure the antenna current.
8. Peak the input resonant circuit for maximum grid current. Adjust the excitation until the required amount of grid current flows when the tuned grid circuit is at resonance. With some loading connected to the output, tune the plate resonant tank circuit for a maximum dip in plate or cathode current. Bring the antenna circuit into resonance by tuning for a maximum plate current at resonant setting. If an antenna current meter, RF voltmeter, or field strength meter is used, the antenna can be tuned for a maximum reading. Adjust the coupling between the plate tank circuit and the antenna system until the required amount of plate (or cathode) current is drawn.

LESSON 18 — ANSWERS

1. Amplitude modulation. Audio peak clippers, saturated transformer cores, and negative overmodulation diodes can be used to prevent overmodulation.
2. On the Class-D Citizens band, the power input limitation to the final RF stage is 5 watts. Unlicensed CB units with an input not to exceed 100 milliwatts may be used to communicate with like units.
3. The frequency tolerance is 0.005% for Class-D operation.
4. Proper equipment adjustment, suppression resistors, feed-through capacitors and proper shielding.
5. Feed-through capacitors, resonance traps, and proper shielding.
6. By measurement of the power delivered to the dummy load. Test instruments are available which read the modulation percentage, at the same time serving as a dummy load and power meter. A reflectometer can also be used to measure both the forward and reflected power to determine exactly how much power is delivered to the antenna.
7. Crystals are ordered according to the desired channel frequency for the transmitter. Selection of receiver crystals is based on the channel frequency, the IF frequency of the receiver, and whether the local oscillator tunes above or below the signal frequency. Crystals are purchased according to the model number of the CB unit so that it will operate within the FCC tolerance.
8. The changeover switch performs the switching that changes the antenna and power circuits between transmitter and receiver. The output of the audio section must also be switched between loudspeaker and the modulating signal input to the transmitter.

LESSON 19 — ANSWERS

1. Power input, frequency, and modulation.
2. Upon installation, whenever changes are made that can influence the three major operating parameters, and at least every six months.
3. Supply voltage and antenna.
4. Because the antenna is very short with relation to the operating wavelength. The antenna system is also important because of the difficulty of obtaining a good ground.
5. The center of the roof, because the large metal roof can serve as a ground plane. It is also usually the highest mounting position available on a vehicle.
6. 0.0005%.
7. The voice frequency as well as a DC control current can be transmitted on the same line. The DC current is used to operate a relay which, in turn, performs the transmit-receive switching.
8. The meter when inserted between the transmitter output and the transmission line (the meter itself must give the same impedance as the transmission line), will give an accurate measure of the standing-wave ratio.

(continued)

LESSON 20 — ANSWERS

1. The receiver is first adjusted with no applied signal and with its gain high enough to read the specific amount of output noise. An unmodulated signal of the desired frequency is then applied to its input. The signal level is increased until the noise output of the receiver has fallen 20 db or some other specified value. The input-signal level that produced this reduction represents the signal sensitivity of the receiver in terms of the specified amount of db quieting.
2. By adjusting the controls until the grid current is peaked at the final stage. If necessary, an absorption wave meter or grid-dip oscillator can be used to make certain the output is tuned to the proper harmonic of the incoming signal.
3. With an applied signal of the proper frequency, the controls are adjusted for peak grid-current flow at the limiter.
4. Regardless of the signal frequency, the high IF frequency is constant.
5. By adjusting the degree of coupling between the windings of the coupling transformer.
6. The modulation meter is attached to the transmitter output. The deviation control R205 is set for a specific level of deviation when a signal of appropriate frequency and amplitude is applied to the microphone input.
7. The three sets of taps permit an optimum inductance for the plate tank circuit, the degree of coupling between the transmitter output and antenna system, and antenna tuning for each operating frequency.
8. A lower sensitivity, because for a given level of signal the noise output has only been reduced 6 db instead of 10 db.