

LEMENT BROWN'S

Intro duc tion

Hi-Fi

to



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Clement Brown's

Introduction
to
HI-FI

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Preface

THIS book has been written by a music-lover who hopes that his contribution to the cause of high quality sound reproduction will encourage others to take an interest in it. The author has concentrated on guidance and information which an association with both musicians and engineers has shown to be of practical value when considering the possibility of good sound in the home. The depth of one's pocket has not been overlooked in describing the desirable features of high fidelity equipment for reproduction from records, tape and radio.

At the present time, strong and sometimes harsh words are being said about stereophonic sound. The amateur will ask : " Does stereo mean a step forward towards more realistic sound reproduction ? " The answer will be plain to everyone who hears a properly conducted demonstration, and the subject is accordingly discussed in this book. It is not assumed, however, that there is any need to buy stereo in whatever form a manufacturer chooses to present it : it is emphasised that this development is really satisfactory only if it supplements the high standards already achieved in single-channel sound.

Grateful thanks are given to E.M.I. Records Ltd., the B.B.C., N.V. Philips' Gloeilampenfabrieken, Holland, and the other concerns who have supplied data and illustrations for inclusion in the book.

CLEMENT BROWN

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INTRODUCING HIGH FIDELITY

THE phrase "high fidelity" or its abbreviation "hi-fi" has been used to describe a wide variety of sound reproduction equipment, ranging from small battery portable radio receivers to professional gramophone equipment costing several hundred pounds. It even seems to have crept into other fields, such as cosmetics! Its correct and original use, however, is to describe the realistic sound reproduction possible with the best equipment currently available, and it is with this that we are concerned in this book. It was not, incidentally, until comparatively recently that the words "high fidelity" came to be extensively used, although, since the earliest days of the gramophone, enthusiasts have talked about the "fidelity" or "faithfulness" of the reproduction made possible by each development in the field of sound reproduction.

Direct comparisons between reproduced and original sound have been organised by several authorities on high fidelity sound, and we have to-day reached the point where, provided that the listening conditions are carefully chosen, it is very difficult to distinguish correctly between the two. It is worth mentioning at the start, however, that we cannot have complete fidelity to the original sound of a large orchestra when we reproduce it in our living-rooms. For one thing, the shape and other characteristics of the living-room affect the sound reproduced in it. Nevertheless, with the best equipment we can, in our living-rooms, enjoy a pleasing impression of the original sound, a natural reproduction with many of the characteristics of the concert performance, but presented in a manner to suit our domestic surroundings.

Different listeners have different requirements. The musician, for example, will make different demands on his equipment to those of the concert-goer who, though a discerning listener, does not himself play an instrument. Another category of listener includes the music-lover who has little opportunity or inclination to attend

concerts. We need not be surprised at the size of this group when we consider the vast repertoire of recordings available for playing at home and the many hours of broadcasting each day. The repertoire of recordings, it may be pointed out, includes many hundreds of unfamiliar works seldom performed in the concert hall. Then, again, there are those whose interest in recorded sound may be mainly in popular music or jazz, and who have come to realise that with ordinary (*i.e.* not high fidelity) equipment they miss a great deal of the original performance,

The world of recording, at its best, offers a number of advantages, such as an adequate rehearsal, performance in first-class acoustic conditions and the ability to make alterations to a recording after it has been made in the studio. With these advantages the recording engineer can produce recordings which will give the most pleasing effect when replayed in domestic conditions.

Most recordings and radio transmissions have always been produced with professional equipments and processes of high standard. Unfortunately, however, the normal commercially produced equipment available for their reproduction has always tended to lag well behind the standards of the recording equipment. Even to-day, the mass-produced radiograms and record players cannot do justice to the high quality of the recordings and programmes available. Instruments of this type undoubtedly do a good job in their own highly competitive field, but it must be remembered that they are built to a price rather than to a standard of reproduction.

With the steadily increasing interest in reproduced music as an entertainment medium and cultural pursuit, however, a section of the radio industry began to devote itself to the production of better quality equipment to realise more fully the potentialities of modern records and radio transmissions. Advances in electronics, and in the techniques of manufacturing the components used in sound reproduction equipment, have brought good quality reproduction equipment within the reach of the enthusiast.

It is next to impossible to obtain good quality reproduction if the component parts of the equipment are produced with an eye to keeping costs to the minimum possible. Generally speaking, the higher the cost, the better the equipment. This does not mean, however, that a standard of reproduction which merits the term "high fidelity" cannot be obtained for a moderate outlay. Much of the cost

of a conventional radiogram is made up of the elaborate cabinet (designed as an eye-catcher rather than as an adjunct to the quality of the reproduced sound) and the automatic record-changer which, as we shall see later, can with benefit be discarded.

How is the complete newcomer to distinguish the best that is available from that which is only average? The best equipment will provide clean, natural reproduction without the absurd accentuations and contrived effects which some manufacturers introduce in their equipment to give an illusion of "quality." High fidelity sound is the easiest for the musically minded to live with and produces the least "listening fatigue."

The presentation of high fidelity equipment is a good guide for the prospective purchaser, providing reliable clues for the inexperienced. First, it should be clearly understood that high fidelity results are not likely to be obtained from a single unit of furniture. Much is sacrificed when the loudspeaker is mounted in the same cabinet as other, equally vital parts, and the novice should remember that a separately housed loudspeaker is a fundamental requirement. This means a minimum of two pieces of furniture. With the wide range of elegant and often inexpensive cabinets now available, however, there should be no difficulty in finding an arrangement to meet individual tastes. Secondly, most of the components of a high fidelity installation—amplifiers, pick-ups, loudspeakers and so on—are sold separately for the enthusiast to incorporate in his own installation.

Another important pointer to quality is the gramophone turntable. High quality equipment hardly ever incorporates an automatic record-changer. It is just possible for a record-changer to have a mechanical performance which suits the requirements of high fidelity reproduction, but it cannot usually compare with the simpler non-automatic turntable. In any case, the serious collector will be concerned mainly with microgroove records and the only satisfactory way to use these is to handle them personally and carefully, playing them one by one. If the record collection includes some 78 r.p.m. discs (and there are many worth playing), a record-changer can be used for these alone.

These are just preliminary comments. In this book, guidance is given on what can be achieved with current equipment. Approach the "hi-fi" label with caution: make sure that it really means

high fidelity. It is advisable to buy from dealers who are specialists in this field and who stock and will demonstrate the best equipment and components. You will find that they are usually enthusiasts, not just salesmen.

Some Basic Terms

It is customary for manufacturers of high fidelity products to give a certain amount of performance data in their publicity literature.

The performance requirements of particular items of equipment are described in subsequent chapters devoted to the various components comprising a high fidelity installation. The following notes, however, together with the glossary at the end of the book, will serve as an introduction to the basic ideas in the sphere of high fidelity sound reproduction.

Terms used in "Acoustics"

Sound.—Sound is the effect on the ear of variations in air pressure. It can travel in various mediums, but we are concerned only with its propagation in air, in which it has a velocity of 1,100 ft. per second (approximately).

The pressure variations are caused by an object vibrating and subjecting the surrounding air to alternate compression and rarefaction. The air particles are thus agitated backwards and forwards in the path of what we call the sound wave.

Musical Notes : Pitch and Timbre.—A musical note consists of a "fundamental" tone with a certain frequency of vibration, accompanied by a series of "harmonics," each of which is a multiple of the fundamental frequency. The frequency is expressed in c/s (cycles per second). Thus a note with a frequency of 100 c/s will have second, third and fourth harmonics at 200 c/s, 300 c/s and 400 c/s ; higher orders than these will also often be present. The amount of sound energy contained in each harmonic varies according to which instrument or other object is producing the sound.

The "timbre" of a note (*i.e.* its character) depends on the proportion of harmonics to fundamental. We recognise one musical instrument from another largely by the harmonic construction of

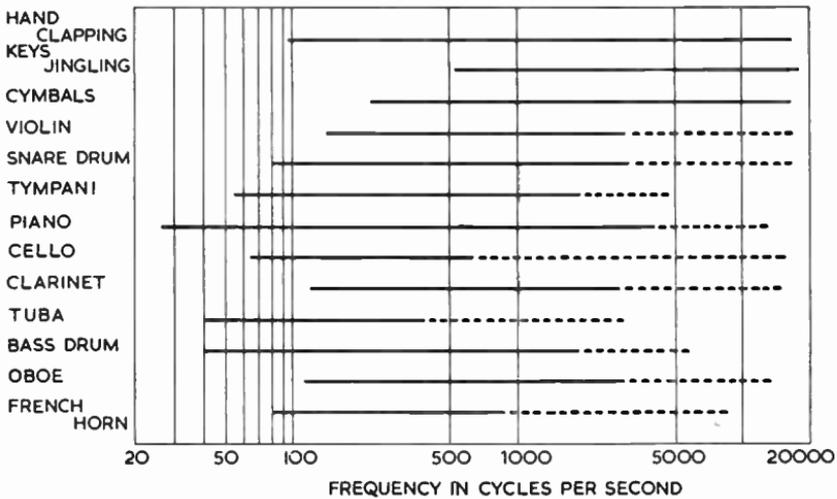


FIG. 1.—FREQUENCY RANGE OF VARIOUS MUSICAL INSTRUMENTS

The solid lines show the range of fundamentals, the broken lines the harmonics.

the sound produced: in one instance, the harmonics comprise a large part of the instrument's output, while in another nearly all the sound energy is in the fundamental tone.

The harmonics are sometimes known as overtones or upper partials.

Audible Frequency Range.—The audible range of frequencies extends from a lower limit of about 20 c/s to an upper limit which depends on the age of the listener and certain physical characteristics of his hearing system. Children may hear components of sounds at 20,000 c/s or higher while elderly people will be limited to 10,000 c/s or lower. This drop in upper frequency limit is a fairly gradual process. Fig. 1 shows the frequency range covered by various instruments, with the harmonics also indicated. Many instruments give some output of harmonics near a young person's upper frequency limit, but it must be remembered that the actual energy output, and therefore the useful information conveyed to the listener, is very small indeed and is present during only a small part of the playing time. At the lower end of the range, there is little at frequencies below 30 c/s which is useful to us, particularly in listening to music.

It is reasonable to conclude that a practical and typical frequency range is 30–16,000 c/s.

Noise.—In general, we describe a sound as “noise” when it has no recognisable musical quality or pitch. Some sounds produced by an orchestra are noise, however, and prominent among these are cymbal crashes, which do not have the harmonic construction referred to earlier. The sounds produced by cymbals and some other percussion instruments are also examples of “transients,” *i.e.* the sound energy reaches a maximum very quickly and dies away comparatively slowly.

Wavelength.—We have noted that a sound wave is produced because the vibration of the sound source produces pressure variations. The distance between points of maximum pressure along the wave is called the “wavelength,” and is determined by dividing the velocity of sound (approximately 1,100 ft. per second) by the frequency. The wavelength of a 15,000 c/s tone is thus less than 1 in. and is about 36 ft. for a frequency of 30 c/s. It will be seen that many rooms cannot accommodate even a half-wavelength of a very low frequency sound ; the significance of this will be referred to later.

Sound Intensity.—We are concerned here with the relative intensities of different sounds and we can measure their ratios by means of a unit called the decibel. This is one-tenth of a Bel, so named after Dr. Alexander Graham Bell, the American inventor of the telephone. The decibel (abbreviated dB) is also much used in electrical measurements. It is found that a ratio of two sound intensities of 2 to 1 is equal to 3 dB ; a ratio of 100 to 1 is equal to 20 dB. Table 1 gives the equivalent in dB of various ratios.

The accepted standard of intensity is a 1,000 c/s tone which is arranged to be just audible to normal ears. This level is said to be the “Threshold of Audibility.” At the other extreme, a sound so loud that it causes pain is said to be at the “Threshold of Pain.” The difference in volume between inaudibility and pain is about 130 dB. The intensity level of a large orchestra reaches 80 dB or more for a fraction of the playing time. A difference in intensity of 1 dB is very small, in fact about the smallest difference that can be

Table 1.—Decibel Equivalent of Power and Voltage Ratios

<i>Power (or Intensity) Ratio</i>	<i>dB</i>	<i>Voltage (or Current) Ratio</i>	<i>dB</i>
1	0	1	0
2	3	2	6
4	6	4	12
8	9	8	18
10	10	10	20
100	20	100	40
10,000	40	10,000	80
1,000,000	60	1,000,000	120

detected by sharp ears. Remember, then, that the decibel is a measure of the ratio between two different sounds and not an absolute unit.

Loudness.—The ear is not equally sensitive at all frequencies. It is most sensitive at middle frequencies, falling in sensitivity above

Table 2.—Intensity Level of Well-known Sounds
(0 dB=0.000204 dynes/sq.cm.)

<i>Intensity Level dB</i>	<i>Typical Sound</i>
130	Threshold of Pain
85	Large orchestra at 20 ft.
80	Noise in underground train
70	Street noise in city
60	Conversation at 4 ft.
50	Noise in restaurant
35	Noise in city flat
30	Suburban street noise
25	Noise in country house
15	Quiet whisper at 4 ft.
0	Threshold of Audibility

and below. The subjective effect "loudness" is thus not the same thing as intensity and a different unit, the Phon, is used to measure it. A table of intensities is given in Table 2 ; the intensity levels are given in dB. The loudness in Phons is the same as the intensity in decibels of an equally loud sound whose frequency is 1,000 c/s.

Scale Distortion.—If the sound intensity is increased in a uniform manner over the whole frequency range, the listener notices an apparent rise in the bass loudness. The opposite happens as the intensity is decreased. This could apply, for example, if the listener was walking away from the sound source. In sound reproduction, the loudness of the bass falls off as the volume control is turned down but the necessary correction can normally be obtained by means of the bass tone control.

It is interesting to note—as something of a side issue—that the pitch of a note seems to decrease as the loudness is reduced. This is particularly noticeable at the low frequency end of the range.

Terms used in Sound Reproduction

Resonance.—Resonances may be mechanical or electrical. All the mechanical parts of the reproducing system (moving parts of the pick-up and loudspeaker, for example) will vibrate, or "resonate," at some frequency depending on their mass and stiffness. In electrical circuits, particularly in the amplifier, resonance can occur at a frequency depending on the values of inductance, capacitance and resistance present. This means that the response to certain frequencies may be greatly increased (or, in some cases, decreased), thus disturbing the accuracy of the overall response. If the response of the amplifier is diagrammatically represented as a line showing the output over the frequency range, the resonance will appear as a pronounced bump at the resonant frequency.

Resonances have a detrimental effect on the reproduction of transient sounds and can, if sufficiently pronounced, spoil sound quality completely. They cannot be completely eliminated, but good design will ensure that they are not troublesome within the frequency range to be reproduced.

Frequency Response.—It is evident from Fig. 1 that there is little point in trying to reproduce frequencies below 30 c/s. More-

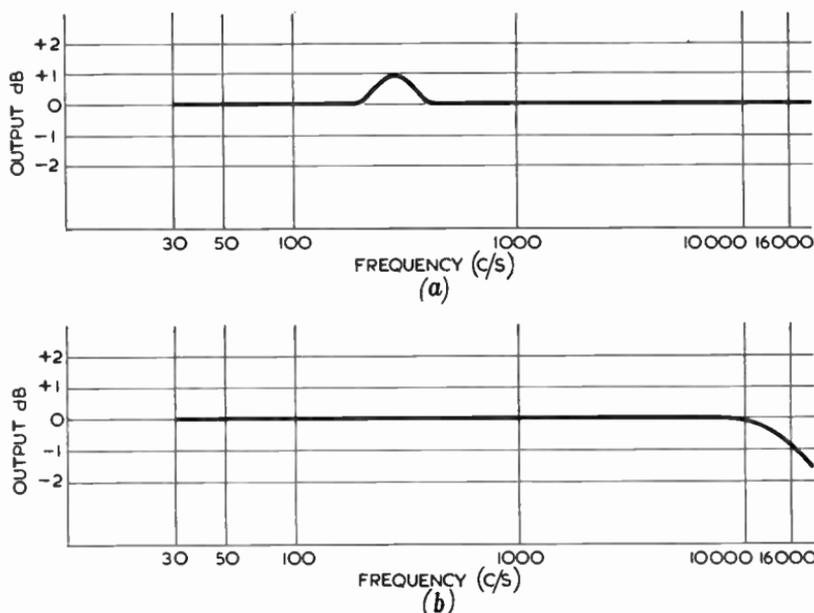


FIG. 2.—TWO ILLUSTRATIONS OF THE STATEMENT: FREQUENCY RESPONSE 30-16,000 c/s \pm 1dB.

Response (a) has a slight peak between 100 and 1,000 c/s; response (b) begins to fall off at 10,000 c/s.

over, such low frequencies are not recorded or transmitted at present and, even if they were, the characteristics of the average living-room would not permit their accurate reproduction.

At the other end of the range, however, there is every good reason to secure reproduction as far as the upper limit of audibility. The frequency response required of reproducing equipment is, therefore, about 30 to 16,000 c/s (see Fig. 2).

Ideally, the response to all frequencies in this range would be uniform. In practice, there are always variations from a flat, or "linear" response and it is the concern of the equipment manufacturer to keep such variations within reasonable bounds. As previously indicated, sudden, peaky variations may indicate the existence of a resonance in the system. Small variations are often only the result of a minor circuit misadjustment, and can usually be easily corrected.

The decibel is used to indicate any departure from a linear

response. A frequency response quoted as $30-16,000 \pm 1$ dB means that variations from linearity do not exceed 1 dB. The response at 1,000 c/s is usually taken as the point from which variations are measured, but 400 c/s is also fairly commonly used. The reader will find that the decibel is a most important term in sound reproduction.

Distortion.—All the equipments contributing to the sound finally reproduced are responsible for some distortion of the original sound. With gramophone records the trouble starts when a small amount is introduced by the recording studio equipment ; a little more is introduced in the processing of the recording, and yet more is contributed by the reproducing equipment. In high fidelity work, the total distortion is likely to range up to three per cent or so, but this is a great deal less than an ordinary radio set or radiogram produces on its own account.

The two main forms of distortion in reproducing equipment are "harmonic" and "intermodulation" distortion. Harmonic distortion is the addition of *unwanted* harmonics to the signal being reproduced. Just as, for example, musical instruments produce harmonics of the fundamental frequency (see "Musical Notes : Pitch and Timbre" earlier in this chapter), so a valve amplifier may generate its own set of harmonics, though with less pleasing results. Measurements of harmonic distortion are made by feeding a pure note, or sine wave, into the equipment being tested, and examining its output. A sine wave is not in itself a musical note, as it has no natural harmonics of its own. The presence of unwanted harmonics in the output of an equipment into which a sine wave is fed may, therefore, be recognised and measured. Suppose that a 60 c/s sine wave is applied to an item of reproducing equipment : the output will consist of the 60 c/s fundamental, together with small amounts of unwanted 120 c/s second harmonic, 180 c/s third harmonic, 240 c/s fourth harmonic and so on up to higher orders.

More noticeable than harmonic distortion is intermodulation distortion. This occurs when one tone "modulates" another which is being reproduced at the same instant. The result is undesirable combinations of the two. For example, if two tones having frequencies of 60 c/s and 8,000 c/s are to be reproduced at the same time, they should both be present at the output without

disturbing each other. If intermodulation occurs, sum and difference tones will be generated: that is, frequencies of 8,060 c/s and 7,940 c/s will also be present. Too large a proportion of this most unwelcome effect can rob the reproduction of sparkle and definition and it is fortunate that only a small amount is generated in the best of modern equipment. Harmonic distortion has also been greatly reduced by modern design techniques, particularly in amplifiers.

Sounds of a transient nature such as those produced by piano, cymbals and drums must be reproduced in a crisp and life-like manner. The question of distortion-free response to transients is closely bound up with that of frequency response. Readers will notice that manufacturers usually claim a much wider frequency response for their products than is necessary for reproduction of the audible range—especially in the case of amplifiers. In practice, a frequency response which does not extend smoothly beyond the limits of audibility may be a sign that resonances are present, together with the distortion which will adversely affect the clean reproduction of transients.

The nuisance effect of the various forms of distortion has been widely studied and there is no doubt that we shall learn still more about it in the future. The measurement of distortion is also a problem at times. This is certainly the case with loudspeakers, and manufacturers seldom quote distortion figures for these; if a few decided to do so, the rest would have to follow suit in order that we could make comparisons. The difficulty with loudspeakers lies in establishing a method of measuring and declaring distortion in a form which has any real practical meaning and which could be used by all concerned.

This is not to say that the enthusiast should not try to get the lowest distortion for his money. Where possible, it is a good idea to listen to the proposed installation in its entirety before purchase. Notice should also be taken of the conclusions reached by authorities, writing in reputable journals. He can benefit from their experience in conducting listening tests.

When considering the total distortion experienced by the ear, we must remember to include also the effect of the listening room. This will be discussed later and the question of the volume level at which we listen will also be linked with distortion.

Noise.—We referred to noise earlier in connection with acoustics ; in that instance it was an apparently unmusical but essential part of the listening experience.

Other types of noise obviously interfere with our listening, for example external noises penetrating to the auditorium of a not very well designed concert-hall. Reproducing equipment can also generate noise. Hum can be introduced in amplifier circuits and connections, and hiss, occupying a band of frequencies, can be generated in valves and components such as resistors : in faulty equipment it may also arise from contacts or joints. Here, of course, is another good reason for the avoidance of resonances : a peak in the frequency response of the system might easily emphasise such noise. Another form of extraneous " noise " can be introduced by valves which are " microphonic " ; that is to say have a tendency to act as microphones to local sounds, producing a distinctive " pinging " effect. Fortunately, this form of noise has been much reduced by the development of special valves for use in the early stages of amplifiers.

A figure for combined hum and noise is usually given in specifications and is normally expressed as a certain level in dB below the rated output power of the system. A level of -80 dB with respect to the rated output is often achieved in good amplifying equipment. In practice, you should not be able to notice any appreciable hum unless you put your ear right up to the loudspeaker with the amplifier volume control at maximum.

A well-known mechanically produced noise is " surface noise " from records. This should be negligible with clean microgroove records and a stylus in good condition. Appreciable surface noise will obviously prevent clear reproduction of quiet passages of music.

Dynamic Range.—This is the range from quietest to loudest sounds—from " pianissimo " to " fortissimo " if you like. The range covered by an orchestra is some 80 dB, the loudest sounds occurring for only a fraction of their playing time.

With reproduced sound, the dynamic range is much limited by the recording or broadcasting medium. Noise level will determine the quietest sounds we hear and thus directly influence dynamic range. At the other end of the range, a limitation—beyond our control—is imposed by the record or transmission, which can contain only a certain level of modulation before distortion occurs. Of course,

the maximum volume level which the listener finds acceptable having regard to domestic circumstances, or, alternatively, the maximum power handling capacities of his equipment, is the final limitation.

Sources of High Quality Sound

There are three sound sources of importance for domestic use : disc records, magnetic tape recordings and radio transmissions.

A high fidelity installation can be used in connection with one or more of these and, bearing in mind that all three can be stereophonic (the last when the B.B.C. offers a regular service), a comprehensive and versatile installation is possible. An all embracing system would permit reproduction of both normal and stereo discs and tapes, normal radio plus the possibility of stereo and the recording of radio programmes and "live" musical performances on tape. A possible extra is television sound. The quality of the sound transmitted with television is good, but it is only recently that one or two special equipments which take advantage of it have been made available to the enthusiast.

Let us briefly examine the potentialities of the sources available. The frequency range offered by the best microgroove records is about 30-15,000 c/s. With care in reproduction, noise should be very slight and the dynamic range impressive. Distortion in the best examples is very small ; but disc reproduction has certain inherent distortions, as we shall see in the next chapter.

The commercially recorded tapes which are available appear to have a frequency range which is slightly inferior to that of disc records, but they make up for this in other ways, especially where distortion is concerned. A frequency response up to 16,000 c/s is possible in the case of skilfully handled recordings made by the amateur under good conditions.

Although the amateur may not wish to get involved in tape recording or reproduction, he should certainly incorporate a radio tuner in his installation in order to take advantage of the B.B.C.'s high quality v.h.f./f.m. transmissions. This is the cheapest of all the sound sources, as far as the amateur is concerned.

The best v.h.f./f.m. broadcasts offer a frequency range of about 40-15,000 c/s and reception is virtually free from background

noise, locally produced electrical interference or disturbance from other stations. Only the *best* broadcasts can be regarded as high fidelity material. These are mainly transmissions which originate in local studios and do not suffer much from distribution through long land-lines.

Listeners in the London area are fortunate in being able to hear, under good conditions, the broadcasts from the B.B.C.'s Maida Vale Studios, transmitted from the v.h.f. station at Wrotham, Kent. A wide frequency range is achieved.

How can the listener be confident that he is being given the right sort of material, even if he knows that his equipment satisfies all recognised technical requirements? Does the music sound convincing, apart from questions of frequency response and so on?

Where radio is concerned, he can be sure that the studio personnel know a great deal about orchestra balance and other factors which influence tonal quality and the artistic merit of the performance. Their work is very important indeed ; after all, the listener has to take what he is offered and it is essential that he is presented with material which has been properly prepared for a domestic environment.

With records (both disc and tape), the situation is different. Some manufacturers, for instance, have consistently introduced reverberation effects, both natural and otherwise, into their recordings, alleging that this gives the best concert-hall impression in the home. Others prefer a drier, less reverberant quality which gives greater definition.

Both musically informed and technically minded enthusiasts can find what they seek ; happy is the manufacturer who meets all requirements in one record ! The amateur, faced with making a choice from the great wealth of recorded music, can obtain guidance from reputable record reviews, the best of which give proper consideration to both artistic and technical matters. As in other fields, the collector can find (after a little experiment) the reviewers who are most in sympathy with his own tastes.

2

RECORDS AND PICK-UPS

UP to about 1950, it was common practice for sound to be recorded directly on to a master disc. The performers would assemble in the studio and, if the first disc produced was unsatisfactory, they would go through their whole performance again. To-day, however, recordings are first made on magnetic tape, usually running at the speed of 15 in. per second. The recording is then played back on the spot to those in charge of the recording session, who can decide straight away whether its quality is satisfactory. If necessary, further "takes"—often of only short passages of music—can be made. The result of the day's work is a large number of lengths of tape, and the master tape is prepared from them by the highly skilled process of editing. The tape can then be stored until it is required.

The next stage is the cutting of a disc, in preparation for the complex procedure of quantity manufacture of the records. A mirror-smooth lacquer disc is used and the cutting is carried out on a special machine designed to ensure, amongst other things, the maximum possible constancy of turntable speed.

The cutter itself is a sapphire or diamond stylus shaped to a high degree of accuracy ; its tip is flat and not spherical like that of the reproducing stylus. Sufficient heat is applied to the cutter (by electrical means) to soften the lacquer at the point where the cutter is touching it. This "hot stylus" process is largely responsible for the extended frequency range of the modern record and also influences the surface noise of the the finished product.

A silver or gold solution is then sprayed on to the lacquer disc, which is subsequently immersed in an electro-plating bath. It emerges coated with a metal shell known as the Master ; this is a "negative," with ridges corresponding to the grooves in the original disc. A second shell is grown from it, known as the Mother : a "positive" with grooves. Finally a number of negatives, the

stampers, are grown from the Mother and these are used in the record presses, one for each side of the record to be made.

The material used for microgroove records is compounded of a vinyl plastic and other ingredients. It is suitably treated and mixed to obtain the correct texture, rolled into a sheet and cut into pieces containing the amount needed for the size of record to be made. The record press is fitted with two stampers, one in the fixed lower portion of the press and one in the hinged upper part. After the record labels have been placed in position on each stamper, a warmed lump of the plastic material is placed on the lower stamper and the press is closed. Heat is applied and, after a short while, the press is opened and the finished record removed.

Each disc is examined and, after having its edge trimmed, it is ready for packing. During manufacture, each operation is the subject of rigorous control and inspection. Samples are taken for laboratory inspection as well as for examination by the factory inspectors. The number of faulty discs which do slip through is a very small proportion indeed of the total.

Recording Characteristics

Meeting the requirement for longer playing time than the 78 r.p.m. record provided involved cutting more grooves to the inch and also rotating the record at a slower speed. The final choice—a compromise—was not an easy one to make. More grooves per inch means that the amplitude (the amount of lateral displacement of groove by cutter) which can be accommodated without physical break-through between adjacent grooves is smaller, and a lower speed of the groove past the stylus affects high frequency response. The number of grooves per inch finally decided upon was 200–300, and two rotational speeds have been adopted: $33\frac{1}{3}$ and 45 r.p.m. Another major difference between 78 r.p.m. records and later types is the groove width. This and other matters are shown in Fig. 1.

Variable groove spacing is common nowadays. During the cutting of the original lacquer disc, the spacing between the grooves is increased either automatically or manually to allow peaks in the music to be accommodated without break-through between grooves, a very close spacing being reverted to during quiet passages. This

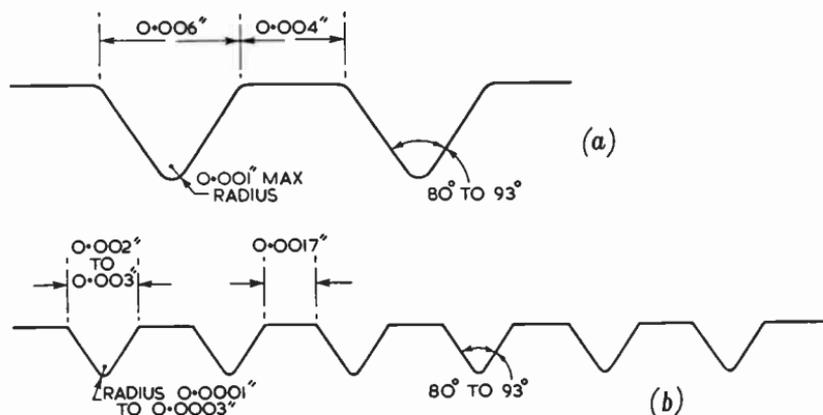


FIG. 1.—GROOVE CONTOURS

(a) Coarse groove (78 r.p.m.), 90–120 grooves per inch. (b) Microgroove, 200–300 grooves per inch.

practice enables a wider dynamic range to be recorded without the loss of playing time that would occur if the wider groove spacing was used throughout the record. The figure of 200–300 grooves per inch is a guide only, therefore, and is decreased considerably when high amplitudes are recorded.

Music contains relatively little energy in the treble compared with that in the bass and middle range, and it is, therefore, possible to increase the recorded level at high frequencies before being faced with the danger of break-through between grooves. This accentuation of the treble is done to improve the ratio of signal to noise, *i.e.* the proportion of recorded sound to unwanted background noise. As far as the recording process is concerned, the unwanted noise is at a constant level at all frequencies. As the sound energy of the recorded signal is low at the higher frequencies, however, this noise becomes a greater problem here. The recorded sound is therefore emphasised at higher frequencies during recording, and during reproduction a corresponding reduction, or, as it is called, “de-emphasis” of the higher frequencies is introduced. In this way, the level of unwanted noise is reduced. This is an additional advantage to that gained from the use of a vinyl plastic, which is much less noisy than the abrasive-dust loaded shellac used for 78 r.p.m. discs.

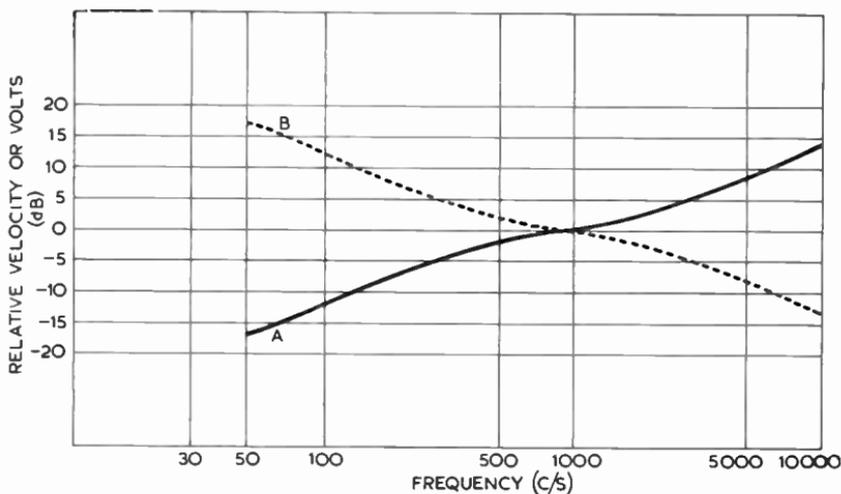


FIG. 2.—MICROGROOVE RECORDING (A) AND PLAYBACK (B) CHARACTERISTICS

These characteristics for 33½ and 45 r.p.m. recordings are laid down by British Standard B.S.1928. Note that the playback curve B, shown with a broken line, is the inverse of the recording curve A.

The low frequencies are attenuated, on the other hand, in view of the energy concentrated in this part of the frequency range.

All this has led to a certain method of proportioning the level of the sound being recorded with respect to frequency: the various levels (that at 1,000 c/s is the reference point), rising with frequency, can be presented graphically. The current recording characteristic is shown in Fig. 2. This has become the standard curve for microgroove records, and is defined in British Standard Specification B.S. 1928. It is the same as the American standard R.I.A.A. curve. (There is another, slightly different recording characteristic for 78 r.p.m. records.)

By passing the incoming signals through fixed tone control networks, determined with great accuracy, they are automatically given the desired recording characteristic. If the record is subsequently played with a high quality pick-up—of which more later—the pick-up's output will correspond to the relative levels indicated in Fig. 2. In other words, the bass will be very thin indeed and the treble will be accentuated. It is usual for a circuit to be incorporated

in the high fidelity amplifier in order to provide a characteristic exactly opposite to that of Fig. 2—a mirror image of it, in fact. This circuit boosts the bass and attenuates the treble, thereby “correcting” or “equalising” the pick-up output so that it is then a nearly straight line, in comparison with the tilted recording curve shown in the illustration. The ideal is an absolutely straight line response, although this cannot be completely achieved because of the effect of resonances.

Due to the lack of agreement amongst recording companies prior to the adoption as standard for long-playing records of the R.I.A.A. curve, a selection of recording characteristics have in the past been used, and each theoretically requires its own equalising facilities in the amplifier. Fortunately, many of the characteristics that have been used are very similar, so that it is not necessary to provide for equalisation of more than three or four characteristics. The present happy situation with new recordings calls for only one circuit for microgroove records and one for coarse-groove, 78 r.p.m. records and even the latter may, with the 78 r.p.m. record itself, soon disappear.

It should be mentioned in passing that not all records provide a straight line response when reproduced with the correct equalisation: circumstances sometimes dictate a different response at both ends of the frequency range. Also, the enthusiast may himself decide that use of the tone controls to provide further alteration of the response is necessary, even though his amplifier is providing the basic equalisation in the usual way.

It is worth the enthusiast noting that, although a recording has obviously originated in the U.S.A., Europe or elsewhere and been made as a tape some time ago, it may still have the standard recording characteristic, provided that the disc was cut in this country within the last few years.

The Stylus

The modern reproducing stylus is almost invariably one of two types: sapphire or diamond. Both are produced to close manufacturing tolerances to ensure a correct fit in the groove (Fig. 3) and, where styli of reputable make are concerned, the tip is given a high polish. Tip dimensions are given beneath Fig. 3.

Although natural sapphire can be used, the synthetic type is found to be more convenient for the large-scale production which is required to-day. Sapphire, natural and synthetic, is aluminium oxide. Ruby has also been used and this, although of different colour to the sapphire, has a similar chemical composition.

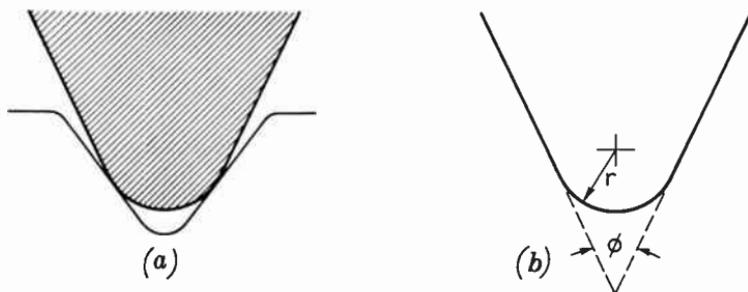


FIG. 3.—(a) CORRECT FIT OF STYLUS TIP IN GROOVE. (b) TIP DIMENSIONS

The included angle of the tip, ϕ , is 40° to 50° . Radius r is 0.0008 to 0.001 in. for microgroove styli, 0.002 to 0.003 in. for coarse groove and 0.0005 to 0.0006 in. for stereo styli.

A common method of manufacture involves, first, heating the aluminium oxide powder. The large piece of the raw material thus produced is then sawn into fragments prior to the final, highly skilled operations of shaping and polishing the spherical tip with diamond dust and grinding wheel.

A diamond stylus starts its life as a fragment of the stone or as a suitably proportioned cylinder drilled from a large diamond. The higher price of the stylus is not due to the cost of the raw material, however, but to the time taken to produce the correct shape and polish. Diamond powder is, of course, the hardest material available for this process.

If the price of a diamond stylus seems at first to be rather high, it should be remembered that this is more than outweighed by its long life and the corresponding protection offered to the records. For example, a diamond stylus could cost £4, against 8s. for a sapphire—ten times as much. The diamond, however, is likely to last more than twenty times as long. The actual life of styli and the effects of wear will be discussed in a separate section.

It is appropriate to give at this stage a reminder that only reliable

brands of stylus should be used ; these will often be the ones which are either marketed or approved by the pick-up manufacturer.

Pick-ups

The pick-up's job is to convert the lateral displacement of the stylus by the groove of the record into electrical signals. The stylus movement must correspond as closely as possible to that of the cutting stylus which cut and modulated the groove in the original lacquer disc.

It is essential that the pick-up should trace the recorded modulations without objectionable distortion and high noise level. The efficiency should be as high as possible and serious record wear should not occur. There are, however, certain limitations inherent in the reproducing process : two outstanding ones involve the shape and size of the stylus and the design of the pick-up arm.

A pick-up should not be too delicate, but it is as well to point out that most advanced types need (and deserve) a certain care and consideration in use. It is impressive to realise that the maintenance demanded by a high quality pick-up is negligible, apart from the all-important matter of stylus replacement. Even this does not happen very often if a diamond is used—and most high class pick-ups are fitted with a diamond stylus as a matter of course.

Before embarking on a description of the various types of pick-up, the principal terms associated with them must be explained. The first is the relationship between the "sensitivity" of a pick-up and its output voltage. Sensitivity is the output for a given input : it is given in millivolts per centimetre per second velocity of the recorded modulation (mV. per cm/sec.) The specification of a pick-up might quote a sensitivity of 4 mV. per cm/sec. Recorded velocity is varying continuously, and to quote an "average output" is far from precise. A typical velocity would be 10 cm/sec., and at this the pick-up instanced above would have an output of 40 mV. Still greater velocities occur on many records—and, of course, many lower ones.

The moving part of a pick-up is held in place by bearings of one form or another. Their functions include the centring of the stylus and the damping of resonances. Lateral movement of the stylus by the groove modulations must obviously meet with a certain stiffness and, once the stylus has been displaced sideways, it must be returned

by the bearings to its central position. "Compliance," the reciprocal of stiffness, is the term used in connection with measurements of this, providing a figure which relates displacement to the force exerted. A typical compliance for a high fidelity pick-up is 5×10^{-6} cm/dyne. High compliance is aimed at, and is achieved in the best of current designs.

In order that a pick-up shall respond to the enormous accelerations imposed by a microgroove record and give a good high frequency performance, it is necessary for its moving part to have an extremely small "mass." The mass reflected at the stylus tip is what matters (that, after all, is what the record is concerned with) and a figure of two or three milligrams is usual in top class pick-ups.

Various resonances can occur in a pick-up, and the two main ones, at a low and a high frequency, do their best to alter the frequency response from the ideal "straight line." These resonances depend for their nature and position in the frequency spectrum on the masses and compliances in the pick-up and record.

The low frequency resonance depends on the compliance of the pick-up's moving part and the effective lateral mass of the complete pick-up (including the arm). The record material is not infinitely stiff, and therefore its compliance will resonate with the effective mass of the moving system, giving a high frequency resonance. Clearly, the compliance of the record material is a constant factor, and it is therefore necessary to make the effective mass acting at the stylus as small as possible so that the high frequency resonance can be made to occur above the audible range.

The magnitude of the resonance, as well as its position in the frequency spectrum, determines its effect on the reproduction. It shows itself as a deviation from the optimum frequency response, and is measured in dB. Damping is always applied in one form or another to control resonance. There is a limit to this, however, because damping absorbs power which is required for other purposes. The answer is to make the masses involved small enough to reduce the need for heavy damping.

There are two main types of pick-up to be considered, magnetic and crystal ones. Many magnetic pick-ups are suitable for high quality installations. Their output voltage is rather low in the majority of cases, but the more comprehensive high fidelity amplifiers provide sufficient amplification to make up for this. In general,

refined performance is achieved at the expense of output voltage. Only a few crystal pick-ups can be considered for high fidelity use. The main advantages of this type of pick-up are cheapness and high output voltage. Higher output means that an amplifier with simpler input circuits can be used. Two or three of the most recent crystal pick-ups are, however, quite suitable for high quality installations where modest outlay is the governing factor in the choice of equipment.

Magnetic pick-ups give an output voltage which is proportional to recorded velocity, and are therefore known as "constant velocity" pick-ups. With their linear ("flat") frequency response, their output when playing a record made in accordance with the R.I.A.A. recording characteristic (see Fig. 2) will follow this curve so that the amplifier to which a magnetic pick-up is connected must incorporate a circuit which by providing a characteristic of opposite slope to that in Fig. 2 (*i.e.* a mirror-image of it), passes on a signal which is sensibly "flat." The four main types of magnetic pick-up are the moving-coil, moving-magnet, moving-armature and variable-reluctance ones.

Let us take the first of these to illustrate the principle of operation of magnetic pick-ups. A diagram showing the construction of one form of this type of pick-up is given in Fig. 5. From the electrical point of view, the main components are a magnet, a coil and a stylus mounted on a cantilever. The coil/stylus/cantilever assembly is so arranged that the side-to-side movement of the stylus in the record groove produces rotational movements of the coil in the gap of the magnet. The changes in the flux of the magnet gap which these movements cause induce small electrical voltages in the coil, and these form the signal that is passed on to the amplifier. The principle of operation of the other forms of magnetic pick-up is the same, the differences between them being in the different forms of construction. There are certain advantages and disadvantages, as we shall see, in these different forms of construction.

Different types of pick-up coil have different electrical impedances, and it is common practice for impedance matching devices to be inserted between the pick-up and the first stage of the amplifier.

The Moving-coil Pick-up.—The first type of moving-coil pick-up was designed by Voigt in the early 1930s, and subsequently

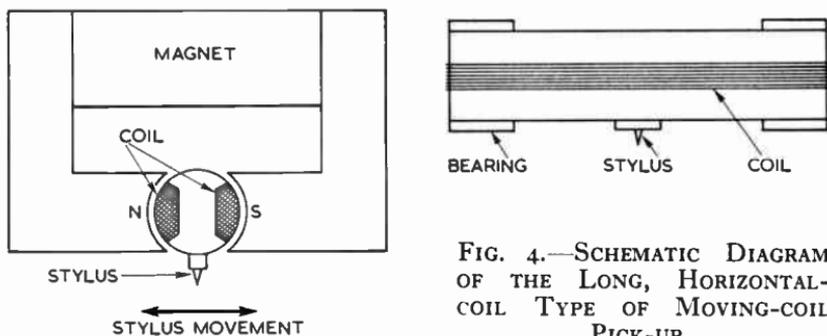


FIG. 4.—SCHEMATIC DIAGRAM OF THE LONG, HORIZONTAL-COIL TYPE OF MOVING-COIL PICK-UP

The left-hand illustration shows the complete assembly viewed from the front. The right-hand illustration shows the stylus/coil assembly viewed from the side.

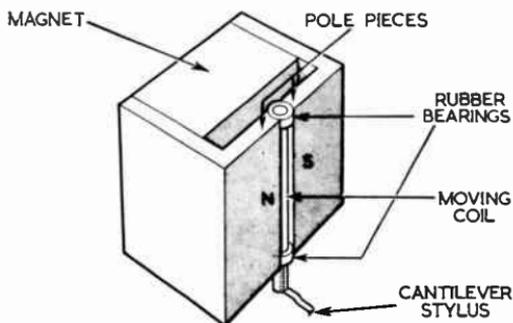


FIG. 5.—SCHEMATIC DIAGRAM OF THE VERTICAL-COIL AND CANTILEVER TYPE OF MOVING-COIL PICK-UP

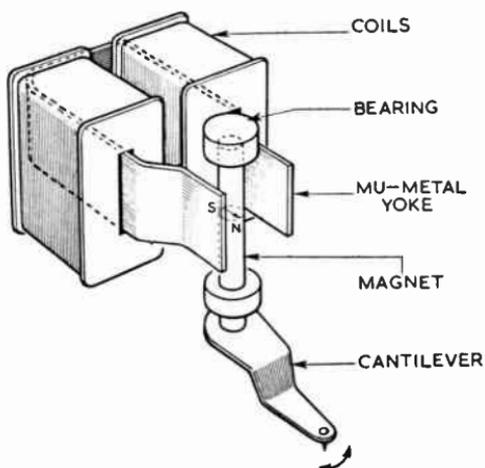


FIG. 6.—THE MOVING-MAGNET PICK-UP

The Ferrodure magnet, approximately 8 mm. long and 0.8 mm. in diameter, is diametrically magnetised.

marketed by several firms. Its moving part is a long, thin coil (see Fig. 4) which has a small moment of inertia and hence a small effective mass. If the pick-up is carefully constructed, the frequency of resonance can be made to occur at a high point where it will not affect reproduction.

The small coil consists of a very few turns of extremely fine wire. It is, therefore, a low impedance device with a small output voltage (a fraction of a millivolt), and a matching transformer, usually supplied by the pick-up manufacturer, must be used to connect it to the amplifier. The output from the secondary of the transformer is likely to be about 3 mV. per cm/sec. Some examples of this type of pick-up have suffered from harmonic distortion and needle chatter.

Another, more recent, form of moving-coil pick-up is shown in Fig. 5. The coil is again long and thin, but in this case it is mounted vertically. Some means of converting the sideways movement of the stylus into rotation of the coil is therefore necessary, and a short "cantilever" is used for this purpose. The cantilever itself has certain advantages which will be apparent when the distortions afflicting record reproduction are discussed. On the other hand, it obviously adds mass to the moving system, although a reduction in the number of coil turns can make up for this. The effective mass is not more than two milligrams in the best examples—as, for example, in the Ortofon pick-up imported into this country.

The high frequency resonance in such pick-ups is seldom lower than about 20 kc/s. In all moving-coil types, the centring of the stylus and the damping are by bushes of rubber or plastics material; the lateral compliance (*i.e.* that affecting the sideways stylus movement) is usually about 5×10^{-6} cm/dyne.

The ribbon pick-up, a rare bird indeed, is essentially a moving-coil type. In this type, a thin "ribbon" of metal takes the place of the coil in the gap of the magnet. Its output is even less than in the examples just described but the frequency response is excellent.

The Moving-magnet Pick-up.—In this pick-up, developed and first marketed by Philips, the coil is fixed and a rod of Ferrodure, magnetised across its diameter, is the moving part. The rod is vertical, as in some moving-coil pick-ups, and a cantilever is once more used. The arrangement is illustrated in Fig. 6.

Since the coil is fixed, there is no objection to its being large. It is accordingly given several thousand turns of wire and provides a fairly high output (about 4 mV. per cm/sec.) without the need for a step-up matching transformer.

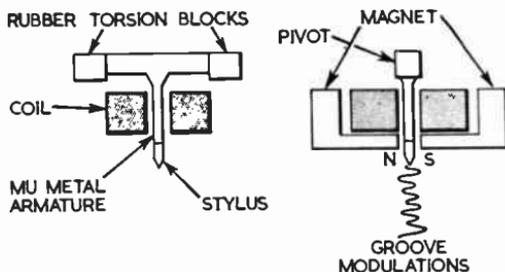
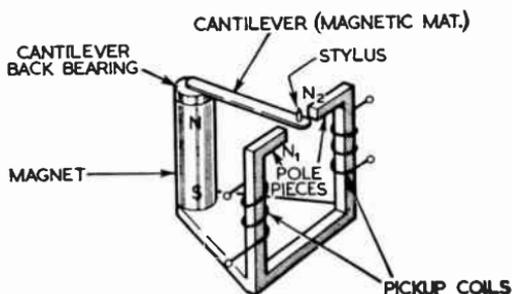


FIG. 7 (left).—SCHEMATIC VIEWS OF A MOVING ARMATURE PICK-UP

The left-hand illustration is a side view, with the magnet removed, the right-hand illustration being a front view. The coil surrounds the armature.

FIG. 8 (right).—SCHEMATIC VIEW OF THE VARIABLE RELUCTANCE PICK-UP



A big advantage is the ease of stylus replacement. The cantilever is cleated to the rod magnet, and this assembly is simply pulled from the pick-up and a new one pushed in. The Ferroxdure magnet is quite cheap and is therefore expendable. The magnets of replacement assemblies will not become demagnetised under normal storage conditions.

Moving Armature Pick-ups.—This type is represented schematically in Fig. 7. The armature has a stylus tip at one end and is pivoted at the other end. A rubber block has often been used as the pivot and this exercises the restraining force necessary to centre the armature. Stiffness in the vertical direction is a disadvantage of this type.

This basic form of construction has been retained in recent

models: in the Connoisseur pick-up, for example, the armature has a very small mass and the pivoting is improved by incorporating a nylon suspension.

Variable Reluctance Pick-ups.—The most popular, and one of the cheapest forms of magnetic pick-up is the variable reluctance type. Basically, the moving armature type previously mentioned is also of this type, but it is generally considered separately. The coils (see Fig. 8) are wound on pole pieces forming part of a magnetic circuit which is completed by a stylus bar. Displacement of the stylus by the groove modulations results in variations in the magnetic flux in the poles. A voltage is therefore induced in the series-wound coils. In this system it is the stylus bar itself which exhibits resonances, and these are controlled by the application of damping material. In most models, the high frequency resonance is above the highest recorded frequency.

Variable reluctance pick-ups are usually presented in the form of a "cartridge" having a common magnet system and two stylus bars, one for microgroove and one for 78 r.p.m. The cartridge is sold as a separate item and, as a result of wide agreement on mounting methods, it can be fitted into most of the arms now available. This type of pick-up has a high impedance and an output of 3 mV. per cm/sec. or more. It is rather susceptible to hum pick-up, and to reduce this it is usual to surround the cartridge with a shield of suitable magnetic screening material.

In this and other types of pick-up, a "live" connection is taken from one side of the coils while a connection from the other side is ultimately taken to the chassis (the "earth" side) of the amplifier.

Crystal Pick-ups.—Certain types of crystal material produce electrical voltages on opposite faces when subjected to mechanical

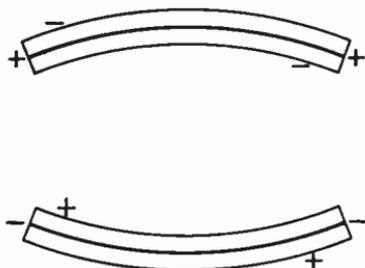


FIG. 9.—CRYSTAL "BIMORPHS" SUBJECTED TO BENDING

When a crystal bimorph is subjected to a bending force by the stylus, voltages are produced, as shown, on opposite faces and at the junction of the conductive faces.

strain. The voltage is proportional to the force applied. Rochelle Salt is the material most used in crystal pick-ups ; it is cheap and fairly easy to use. Two pieces, fixed together to form a "bimorph," is the arrangement normally used in modern pick-ups, and this can be subjected to bending (see Fig. 9) or twisting in order to produce the required voltage.

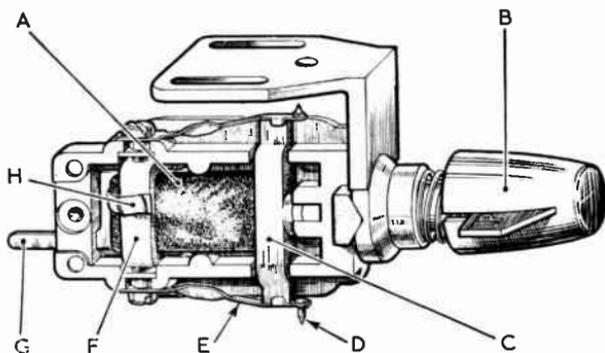


FIG. 10.—CUT-AWAY VIEW OF A CRYSTAL PICK-UP
 A crystal bimorph ; B turnover knob ; C plastic driving member ; D stylus ; E stylus arm ; F plastic clamping block ; G output terminal ; H foil electrode connecting crystal and terminal.

The crystal dissolves at high temperatures and the upper limit for a pick-up is about 45°C . (112°F .) In addition, the frequency characteristic changes with temperature below this limit, and the crystal also suffers from extremes of humidity.

In present-day pick-ups, the crystal is protected from the effects of humidity by what appears to be grease. This is actually a specially prepared material having carefully calculated properties. These, together with the properties of the clamp holding the crystal and the coupler joining it to the stylus, determine the frequency characteristic of the pick-up. By careful design, the signal appearing at the pick-up's output terminals can be approximately equalised—that is, the bass boost and treble cut needed to produce a linear response will be provided in the pick-up itself.

This is a rough and ready equalisation, but it does enable the pick-up to be connected to an amplifier having a "flat" response without the intervention of equalising circuits. Inaccuracies in the

response can then be corrected, when listening, by using the amplifier's tone controls.

In such cases, the amplifier should have a high value of input impedance ($\frac{1}{2}$ Megohm, for example). Sometimes, a simple network of resistors and capacitors can be connected between pick-up and amplifier in order to smooth out the response still further. It should be realised that this is not recording characteristic equalisation; such equalisation is not needed and, indeed, it cannot be achieved with any degree of accuracy. It is possible with recent models, however, to insert a different network which actually turns the response into something like that which would be obtained from a magnetic "constant velocity" pick-up. Connection can then be made to the amplifier input normally reserved for magnetic pick-ups.

The frequency response of crystal pick-ups is usually inferior to that of magnetic types but at least one recent design challenges the average magnetic pick-up. Response to transients is not so good as in magnetic designs. Lateral compliance of the moving system is also less, and the deterioration at high temperatures is a disadvantage when tropical use is required. Sensitivity is anything from about 30-150 mV. per cm/sec.

"Ceramic" pick-ups, using barium titanate bender elements instead of crystals, are suitable for high temperatures and are not humidity conscious. At the time of writing, however, their mechanical properties and response characteristics are not good enough for high fidelity applications.

Limitations of Record Reproduction

The first inherent limitation is due to the difference in shape between the cutting stylus and the reproducing stylus. The cutter does not turn to face the instantaneous direction of the groove and, in consequence, the groove width is constant along a radius of the record. In Fig. 11, the cutter is represented by a triangle (very similar to its actual shape) and a section of the reproducing tip by a circle. It is clear that the groove width is not constant as far as the reproducing tip is concerned, and, in order to trace the modulated groove, the tip must rise as the groove narrows in relation to tip diameter.

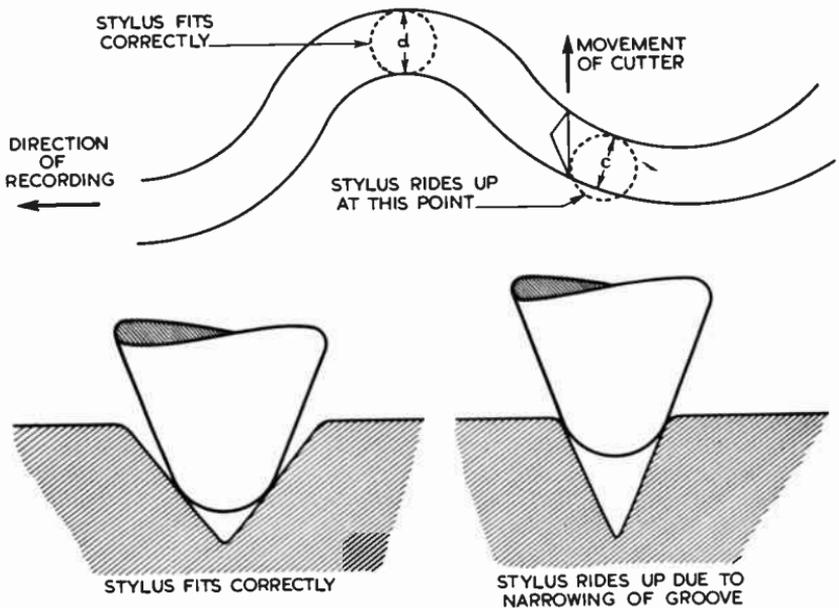


FIG. 11.—ILLUSTRATING THE "PINCH" EFFECT

The stylus tip rises as the groove narrows—width c is smaller than d .

This "pinch effect" vibrates the stylus vertically at twice the fundamental frequency of the modulation, and gives rise to "tracing distortion." It is very important that the construction of the pick-up makes allowance for pinch effect and its moving system must have some vertical compliance, introduced by the coil or armature bearings or by a cantilever. The idea is to obtain sufficient vertical compliance to prevent the stylus riding up out of the groove altogether. At the same time, this compliance must not be accompanied by an output voltage from the pick-up. The only output wanted is that due to lateral stylus movement—output due to pinch effect will be even harmonics (2nd, 4th, etc.) of the wanted frequency. The ability of a pick-up to combat this objectionable tracing distortion is a reflection of its quality. A cantilever stylus, now quite common in modestly priced pick-ups, helps a great deal.

A pick-up with good vertical compliance will also give a minimum of needle chatter. A coil or armature which is very rigidly coupled to the stylus will cause a great deal of noise to be radiated from the

record. This is objectionable because it, too, is composed largely of even harmonics.

Tracing distortion and radiated noise increase as the speed of the groove past the stylus *decreases*, and it is unfortunate that the inner grooves of a record move more slowly than the outer ones. For example, the outer grooves of a 12-inch long-playing record

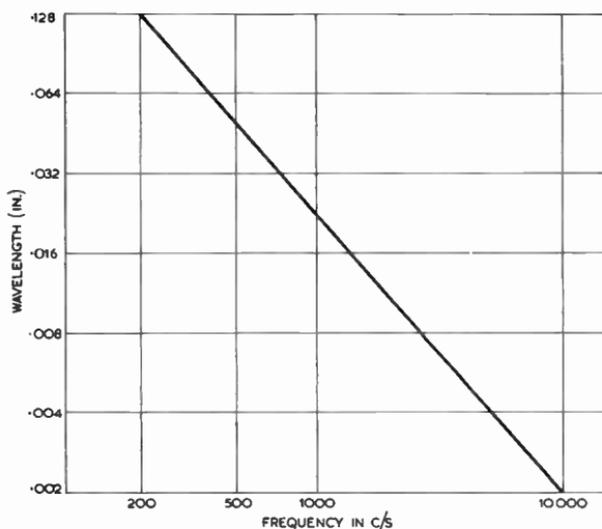


FIG. 12.—RELATIONSHIP BETWEEN RECORDED WAVELENGTH AND FREQUENCY FOR A 12-IN., 33 $\frac{1}{3}$ R.P.M. RECORD

have a velocity of 20 in./sec. while the inner grooves move at less than half that speed. Distortion is therefore worse at the end of the record, and must be kept within bounds by careful record production and pick-up design. Odd harmonics (3rd, 5th, etc.) are generated as well as the even orders just discussed, and the overall distortion increases as the amplitude of the modulations is increased.

Something else happens as the stylus approaches the inner grooves, and again it is an effect inherent in record reproduction. The wavelength of a recorded note becomes smaller in relation to the dimensions of the stylus tip, which fits less readily into the small radius of the modulation. This limits the high frequency response compared with that obtained at the beginning of the record. Fig. 12

shows wavelength plotted against frequency for a 12-inch record at $33\frac{1}{3}$ r.p.m. This effect must not be confused with the wavelength of sound waves, determined by dividing the velocity of sound by the frequency. Here, the wavelength of any note decreases steadily throughout the record, as the velocity of the *record groove* decreases.

It was stated earlier that adequate vertical compliance is important in preventing the stylus from riding up out of the groove. The playing weight of the pick-up must also be considered and this must be sufficient to keep the stylus in proper contact. For any pick-up there is some minimum playing weight, below which there will be an increase in distortion and record wear (even if groove-jumping does not actually occur). An excessive playing weight, on the other hand, accelerates record wear and causes a loss of high frequency response. Indeed, a heavy pick-up, particularly one with even a slightly worn stylus, will remove high frequencies from the record altogether !

The moral, of course, is to use the playing weight recommended by the pick-up manufacturer and to keep an eye on the stylus, which must always be a correct fit in the groove. Playing weights for modern high quality pick-ups are usually between 3 and 6 grams ; still lower figures are possible with a few advanced designs intended for stereophonic records.

It is unfortunate that, even to-day, microgroove records are sometimes encountered which have been cut at excessively high volume levels and exhibit defects in the groove shape. No self-respecting pick-up can be expected to play them. Records which give repeated groove-jumping trouble with the best modern pick-ups should be tried carefully in the best possible conditions (this means a new stylus) and, if nothing can be done with them, the attention of the record manufacturer should be demanded—as forcibly as circumstances require.

Pick-up Arms

In many cases the pick-up head and arm are made by the same manufacturer and are intended to be used together for best results. There are, however, many examples of arms with head “shell” which will accept various cartridges provided that they have the standard fixing bracket with half an inch between fixing centres.

Arms vary a good deal in price according to the standard of construction and the facilities offered. They are nearly all made to the same principle: they are pivoted at one point, and carry the head in an arc across the record.

Records are cut, however, by a head and stylus which move in a straight line across a radius of the record. It would evidently be best if the reproduction pick-up did the same. Attempts have been

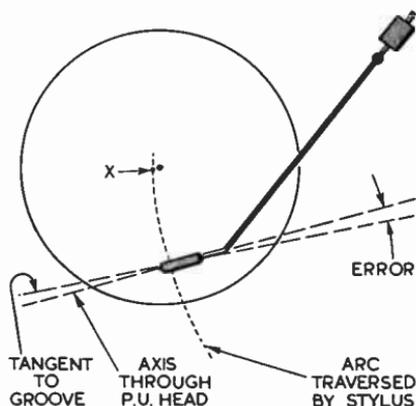


FIG. 13.—TRACKING ERROR

The angle between a tangent to the groove and the axis through the pick-up head is a measure of tracking error.

made to produce radial carriers—indeed, a few have been marketed—but it is very difficult to produce a mechanically sound job at a price which will be acceptable to the non-professional user.

To return, then, to the type of arm in common use. The main problem is to ensure that the axis through the pick-up head is as near as possible a tangent to the groove. The actual relationship, of course, varies as the pick-up traverses the record. The angle which the head axis makes with the tangent to the groove is a measure of the “tracking error” (see Fig. 13). It is reduced to a minimum in practice by (a) putting a bend in the arm (hence the “offset” often referred to), (b) making the arm as long as possible, and (c) allowing the stylus to fall a little in front of the turntable centre, as indicated at *X* in Fig. 13.

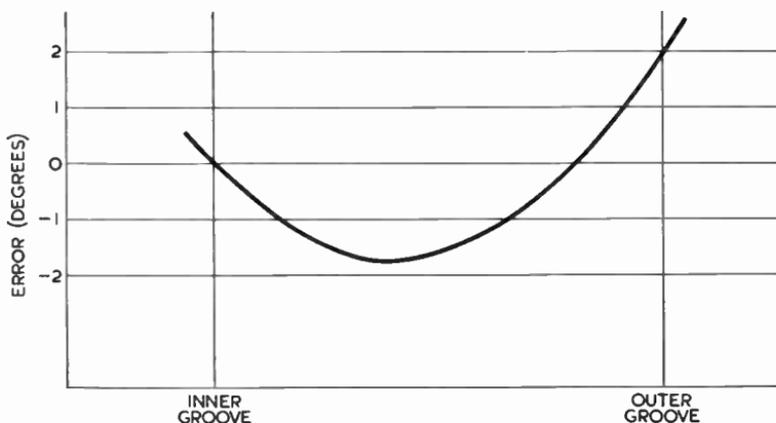


FIG. 14.—VARIATION IN TRACKING ERROR AS A PICK-UP TRAVERSES A 12-IN. DISC

We have already noted that distortions afflicting a pick-up are worse near the centre of the record, where the linear groove speed reaches its minimum. Tracking error causes further distortion, and the error is therefore made to be a maximum at the outside of a 12-in. record.

The variation in tracking error can be represented graphically as shown in Fig. 14. The maximum error of about 2° is seen to be at the outside grooves of the record. It falls to zero as the pick-up moves across the record, rises a little, but is still small at the point where the run-off groove is reached. This curve is a typical one for an arm of conventional design, small enough for convenient use in a normal domestic installation. It would have to be revised for "transcription" type arms intended to accommodate records larger than those of 12 in. diameter, but we are here concerned only with commercially produced discs, of which the largest are at present the 12-in. diameter ones.

Designing arms in such a way that the stylus overhangs the turntable spindle, although effective in minimising tracking error, leads to "side thrust." The friction between stylus and groove tends to pull the pick-up inwards across the record, although the mounting of the pick-up and turntable unit is known to be on an even keel.

There are, of course, other possible causes of side thrust, such as

an inward tilt of the arm pivot and inaccuracies in the pivot bearing. It has been claimed in some quarters that a little friction in the pivot will balance out the inward pull of the arm, but this cannot be properly controlled and is likely to be a more potent cause of record wear (and even groove-jumping) than the side thrust inherent in the arm. A well-designed arm will, in fact, exhibit only a little side thrust and other steps can be taken to counteract it. For example, a very slight tilt of the pick-up *away* from the record can be arranged to give an outward force which just balances the inward pull of the rotating record. This will be discussed again at a later stage.

The force needed to overcome the friction in the pivot bearing and to keep the arm moving across the record may be about half a gram in very good arms ; it should certainly not exceed one gram. Remember, the greater the friction, the greater the playing weight needed to keep the pick-up tracking properly.

Attempts other than the radial carriers already mentioned have been made to reduce tracking error. Arms have been developed which employ a link motion to turn the head slightly as it traverses the record, thus keeping the axis through the head more nearly tangential to the groove. This method is effective, but the more elaborate construction necessitates more bearings and cost tends to be high if friction is to be small. There is less to go wrong in the conventional arm and the tracking error of 2° maximum now achieved is not at all bad.

Tracking error depends not only on design of the arm itself but also on its accurate installation. If it is mounted on a base plate with the turntable as a complete unit, the manufacturer will have looked after this matter. If the arm is purchased separately, as is often the case, the person who fits it to the motor board must follow very carefully the manufacturer's instructions. The main point to watch is the distance from the pick-up's pivot centre to the turntable spindle centre. A small error in this distance will have an appreciable effect on the tracking error. A few arms have adjustable offset to enable the user to find the condition of minimum error for various record sizes ; if the instructions are not followed to the letter, the error is likely to be more than optimum, not less.

Most arms have a height adjustment to make them suitable for use with various makes of turntable. Playing weight adjustment of high fidelity pick-ups is achieved by means of a sliding or rotating

weight behind the pivot, adjustment on cheap arms being normally effected by means of a spring. An adjustment weight is to be preferred on any pick-up provided that the overall mass of the arm is not too great.

As stated earlier, the pick-up's low frequency resonance is produced by the effective mass of the whole pick-up resonating with the compliance of the head's moving system. In good pick-ups, this happens in a perfectly safe region : often between 15 and 20 c/s. The resonance is lowered in frequency by increasing the compliance or increasing the mass. Some enthusiasts like to install a versatile arm and try out various cartridges in it. This is not such a good idea as one might at first suppose. Sooner or later a cartridge will be used the compliance of which brings the resonance within the audible range ; not only this, but the resonance may settle in the 20-25 c/s region, where the "rumble" of many motor units is situated. This, of course, is an illustration of the need to consider the head and arm together as a complete component.

One final word : the pivot bearings of a pick-up should be lubricated only if the manufacturer gives specific instructions on the point. It is possible that the force needed to move the pick-up across the record will be increased considerably if well fitting bearings are lubricated. This is a matter which should be checked most carefully.

The Turntable

Although record changers do a good job in the highly competitive world of the radiogram and record player, they cannot be considered for high fidelity installations. There are many reasons for this, but it will not be of particular value to catalogue them here at length. Outstanding reasons should be noticed, however, for the benefit of the music-lover who has a large collection of 78 r.p.m. records and who feels that a record changer is essential for these.

One point is that the low playing weight advisable for high quality pick-ups is not readily obtainable on record changers. Again, the pick-up arm approaches the stack of records at a rather unconventional angle. A record changer is complex ; there is more to go wrong and a misadjustment could easily damage the pick-up or the records.

The reader should not jump to the conclusion that a record changer generates more background noise than any other type of player. A cheap, badly designed non-automatic player could easily produce just as much noise.



FIG. 15.—THE CONNOISSEUR TYPE B TRANSCRIPTION TURNTABLE

A record changer may be useful, then, where there is a large collection of 78 r.p.m. records to be coped with. It can incorporate a cheap crystal pick-up. Microgroove records, however, should not be played on it. Extended play 45 r.p.m. records have a long enough playing time to be played singly without provoking feelings of frustration, and long-playing records should be handled singly, with the reverence due to a heavily taxed product.

Turntables which are robust and basically simple in construction are to be preferred. A turntable with pick-up arm attached may be purchased for about £10, and this may give adequate service in modest outfits which fall short of the highest fidelity. However, a higher standard is desirable when the installation incorporates a loudspeaker and amplifier which have good low frequency response and which would expose mechanical imperfections. A "transcription" turntable (the name is borrowed from professional recording practice) meets these requirements. They are available as separate

turntable units for use with almost any pick-up and also in the form of combined turntable and pick-up assemblies. The approximate price range is £15 to £30.

Transcription turntables are characterised by heavy, accurately balanced turntables having a large part of the mass concentrated at the rim ; precision ground and lapped bearings are also outstanding features and there is a generally high standard of workmanship and finish. Speed fluctuations ("wow" and "flutter") and mechanically generated noise ("rumble") are of a very low order.

Wow and Flutter.—Wow is a slow pitch fluctuation at the rate of a few times per second. If the turntable is causing it, the fluctuation may be found to correspond to a mechanical irregularity at once or twice per revolution. A record with an oversize centre hole which has been placed off-centre on the turntable can have the same effect, as can eccentricity of the record groove. Flutter is a quicker fluctuation which can be due to inaccuracies in the transmission between motor and turntable. Wow and flutter are particularly noticeable during the reproduction of sustained notes such as those produced by the piano and wind instruments.

The wow or flutter (or both combined) are normally quoted as a percentage variation of a nominal frequency. If the measurement is made by examining the output of a pick-up playing a test disc which contains, for example, a steady 3,000 c/s tone, the pitch fluctuation can be expressed as the percentage variation of the tone. Variation between 2,995 and 3,005 c/s means that there is a fluctuation of ± 0.16 per cent, or an overall fluctuation of 0.32 per cent. There is a good reason for using a frequency of about 3,000 c/s for tests : the listener particularly notices pitch fluctuations at mid-frequencies.

There is not complete accord over the matter of test methods, but work has been done with a view to relating the various test results to the listener's subjective impressions. Figures for wow and flutter could be given in several ways—for example, as peak or r.m.s. values. A combined peak wow and flutter of 0.2 per cent is probably satisfactory, while 0.1 per cent is very good and is achieved with the best transcription turntables.

Rumble.—This is the low frequency noise reproduced by wide range sound systems when there is unbalance in the motor or

inaccuracies in transmission of the drive. A turntable which rumbles may vibrate vertically, horizontally or with both components. Pick-up resonance in the rumble region (20-50 c/s) will emphasise the noise ; crystal pick-ups have often been offenders. The enthusiast who invests in a transcription model and uses it carefully is not likely to be troubled with rumble.

Speed Control.—Some turntables have three or four fixed speeds. The enthusiast checking the speed with the aid of a stroboscope disc may find that the turntable is running a little fast or slow and consequently decide that he has grounds for complaint. A certain amount of variation is, in fact, acceptable. The nominal speeds and agreed tolerances are given in British Standard Specification B.S. 1928, and are as follows :

33 $\frac{1}{3}$ r.p.m. limits :	32.96 to 33.7 r.p.m.
45 r.p.m. limits :	44.44 to 45.45 r.p.m.
78 r.p.m. limits :	76.92 to 78.93 r.p.m.

It is possible for factors outside the control of the maker to influence the speed. For example, an excessive variation in mains supply frequency could cause the speed to fall outside the limits quoted above. The speed of the induction motor normally used to drive the turntable depends largely on this frequency.

Musicians (and some technicians) who possess " absolute pitch " and who are irritated by quite small variations from it, however, demand some means of correcting the speed. This is often provided on transcription turntables. One method uses a magnetic system—an eddy current disc brake—and another varies the gear ratio of the transmission from the motor. Variations of about three per cent above and below the nominal are provided on some turntables ; a wider variation is made possible in one or two instances. A pitch variation of half a semi-tone corresponds to a three per cent change in turntable speed—about 1 r.p.m. for a 33 $\frac{1}{3}$ r.p.m. record.

The enthusiast who does not possess absolute pitch may also find a speed adjustment useful. Records have been encountered which exhibit a gradual pitch variation and almost any listener might notice this and wish to correct it. In addition, some users will wish to play a record and accompany it at the piano. A pitch difference between the two will be most noticeable and speed adjustment will be essential.

Musically knowledgeable listeners may, of course, require an absolute check on pitch. They will hardly need to be told that, if there is no piano in the house, a tuning fork will be useful. Indeed, this simple tool is highly recommended to all users of high quality equipment. An A fork (giving a 440 c/s tone) is very suitable and costs only a matter of shillings.

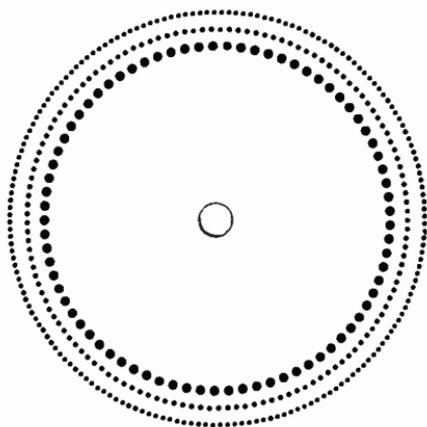


FIG. 16.—STROBOSCOPIC DISC

The other tool needed by the enthusiast is the stroboscope. This is normally in the form of a disc for use on the turntable, as shown in Fig. 16. The appropriate set of black and white marks is viewed with the aid of an electric lamp which is fed from the A.C. mains which is supplying the equipment. The turntable speed is then adjusted until the marks appear to be stationary. Speed checks must be made with the disc on top of a record which is being played; the adjustment will then take into account the slight drop in speed which may occur due to friction between stylus and groove.

It should be noted that the stroboscope is of use only in checking the turntable speed in relation to the mains frequency which happens to apply at a particular moment. If this departs from the standard 50 c/s, a final check on pitch, as distinct from relative speed, is the only solution for the purist. Experience has shown, however, that few record collectors bother with this, showing a touching faith in the integrity and watchfulness of the electricity authorities.

Finally, one or two of the more luxuriously appointed turn-

tables have their own built-in stroboscopes. The Connoisseur transcription unit, for example, incorporates a stroboscopic disc which is viewed in a mirror with the aid of an internal light. The well-known Garrard Model 301 is available with stroboscopic markings on the turntable rim.

Stylus Life and Record Wear

Only a few years ago, an almost everlasting life was claimed for the sapphire stylus. No one would dare to make such a claim to-day, especially when the life of the sapphire has to be compared with that of the genuinely long-lasting diamond. Sapphires have not changed but fortunately the attitude towards them has, due mainly to the efforts of various authorities to convince consumers and dealers of the need for regular replacement.

It seems still quite common, however, for many users of radio-grams and players to forget all about the stylus for several years at a time. The dreadful consequences of using a three-year-old sapphire at a 12 gram playing weight are perhaps a little outside the scope of this book, but readers should study the accompanying pictures most carefully. These show the very serious wear that has occurred in the groove of a long-playing record with a stylus tip which has been used for considerably less than three years (Fig. 17).

We are concerned here with styli used at a playing weight which is typical of high quality pick-ups (*e.g.* 6 grams is a reasonable figure). It should be added that too low a playing weight may well cause as much damage as an excessive figure—the stylus will jump about in the groove. The manufacturer's recommendation should be followed.

The life of a sapphire stylus is in fact quite short and, at the same time, difficult to predict. With every possible care, a sapphire cannot be expected to contribute to high fidelity results for longer than 40 to 50 playing hours. A neglected stylus, apart from the distortion which it introduces, causes permanent damage to the record. A diamond may last as long as 2,000 playing hours and a comparison of prices—for example, 8s. for a sapphire against £4 for a diamond—shows that this is more of a wise investment than a luxury. Of course, replacement of the diamond at the proper time is just as important as it is for the sapphire. Most high quality pick-ups have a diamond for microgroove records as a standard fitting.

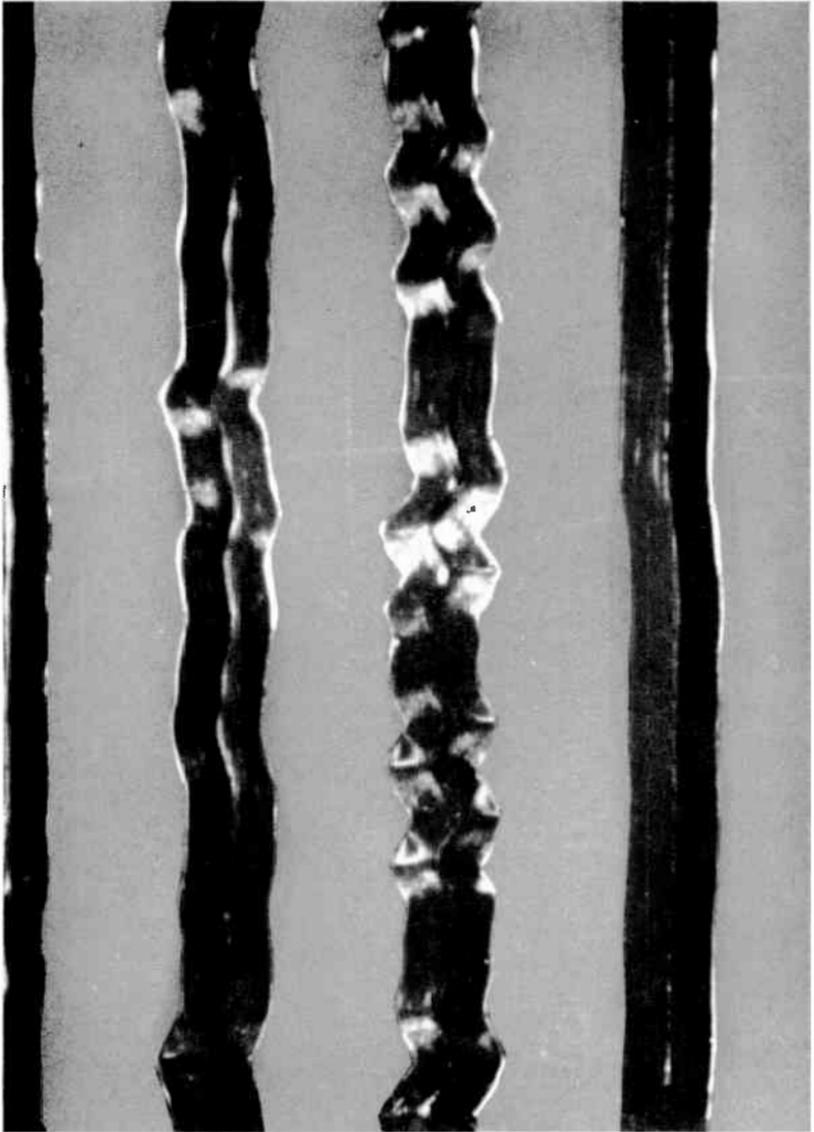


FIG. 17 (a).—PHOTOGRAPH OF UNPLAYED MICROGROOVES
Compare with the photograph, Fig. 17 (b), of the same grooves after being played
under bad conditions.

(Courtesy E.M.I. Records Ltd.)

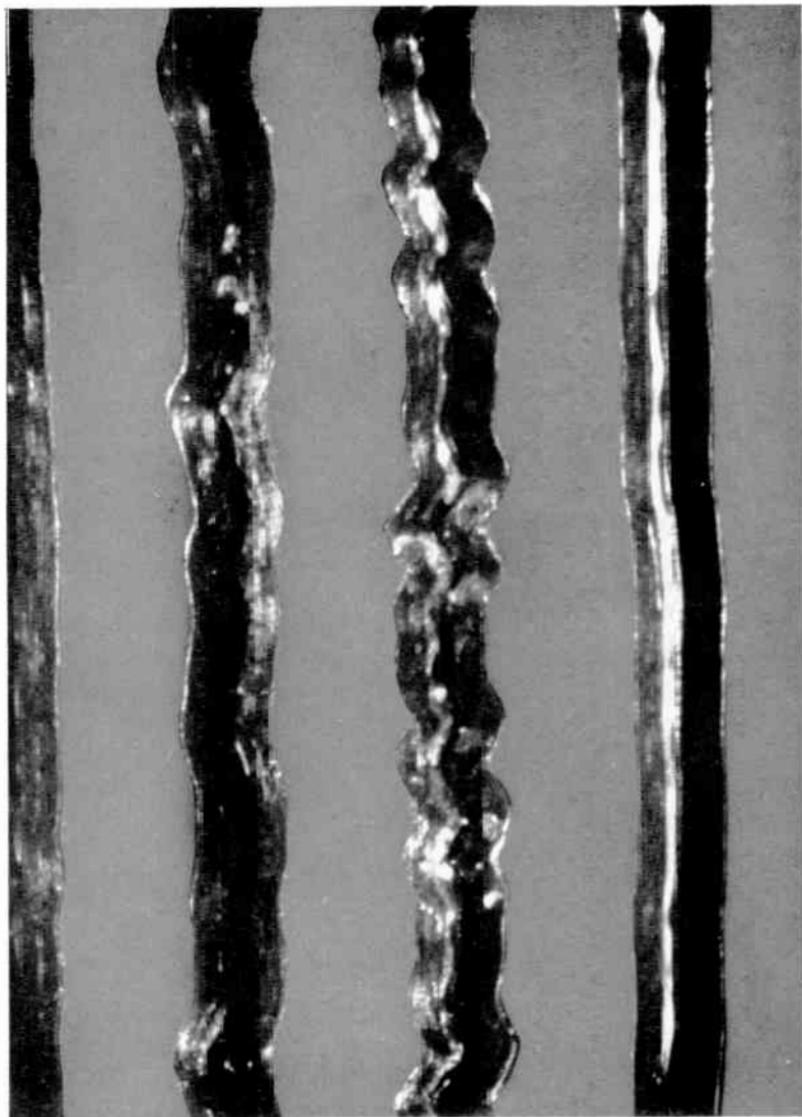


FIG. 17 (b).—THE MICROGROOVES OF FIG. 17 (a) AFTER A FEW PLAYINGS AT EXCESSIVE PLAYING WEIGHT AND WITHOUT ATTENTION TO DUST REMOVAL

(Courtesy E.M.I. Records Ltd.)

Stylus life is difficult to predict because of the factors which influence it. Side thrust of the pick-up, perhaps due to faulty bearings or installation, will accelerate wear of both stylus and record. A pick-up with a stiff armature system (and probably a correspondingly high playing weight to keep it in the groove) will also hasten wear. The performance of a pick-up in this respect will depend very much on the price paid. If these factors have been taken care of, there still remains the most serious one of all: the presence of dust in the record groove.

The Dust Menace.—Microgroove records exhibit a liking for dust which is attracted to them due to an electrostatic charge which exists on the playing surface. Rubbing the surface with a dry cloth or pad only serves to intensify the charge so that more dust is attracted; it also damages the record and increases surface noise in reproduction.

There are several specially prepared cleaning cloths which possess "anti-static" properties—the Philips Discleaner and the Emitex by E.M.I. are examples. These are treated with a suitable cleaning substance which spreads a molecular film over the record and in the grooves. The film is subsequently disturbed by the stylus, but it links up again with the help of moisture from the atmosphere. After some time, the effect will be seen to have worn off and further treatment is then necessary. Liquid preparations are also available for application with a suitable cloth. When applying, first blow any large dust particles from the record and then apply the cloth with gentle pressure, following the grooves.

Curious-minded record collectors found out a long time ago that well-diluted detergent of the liquid variety has a perfectly good "anti-static" effect. Ethylene glycol (motor car anti-freeze) also appears to be effective. The enthusiast should not experiment, however, unless he has technical knowledge of the material concerned. In particular, the stickiness of some materials will attract more dust and form mud in the grooves. It is far better to use materials of proved suitability, *i.e.* the preparations made for the purpose. It should be noted that, in general, these are intended for microgroove records only.

An ingenious and efficient device known as the "Dust Bug" deserves mention at this point. It consists of a plastic arm carrying a tuft of nylon and a dust collecting pad to which is applied a cleaning

fluid. The whole assembly is mounted next to the turntable and tracks across the record rather like a pick-up, cleaning dust from the grooves and depositing the necessary film of cleaning fluid. This device is the invention of Mr. C. E. Watts, a noted enthusiast, and is available from many record and equipment dealers. The "Parastat" machine is another development due to Mr. Watts; this is for installation in dealers' premises and provides a permanent cure for the dust-attraction problem.

Records should be carefully handled and kept in their covers when not in use. Never touch the playing surfaces but handle records so that the fingertips are on or near the label and the thumb crooked over the edge of the disc. A little practice makes this a foolproof and elegant method and avoids the fingermarks which could pick up dust.

Handling the Pick-up.—The requirements for high quality pick-ups, already outlined, virtually rule out automatic mechanisms which will position the stylus in the run-in groove. The obvious alternative is manual operation, although there is the danger that record or stylus may be damaged due to an unsteady hand. Pick-ups are usually handled by a small lifting hook on the arm and accidents can easily happen.

It is important to mount the pick-up so that it can be manipulated conveniently. One possible method of lifting the pick-up is to exert gentle pressure on the counterweight which overhangs the back end of many pick-ups in order to lift the stylus from the record. This is quick and convenient once one gets used to the idea.

There are manually operated devices on the market which will gently lower the pick-up. Some are cueing devices and provide for selection of particular record grooves. These gadgets are very useful safeguards indeed.

Some pick-up arms are fitted with a stop which prevents the stylus dropping on to the motor board. If this is not the case, it is a wise plan to fix a piece of rubber to the board or base plate in such a position that some part of the arm or the back of the head will contact it in the event of an accident.

Stylus Replacement.—We return now to the subject of replacing the stylus when it has become worn. It is not easy to decide when to do this. Obviously distorted reproduction will provide

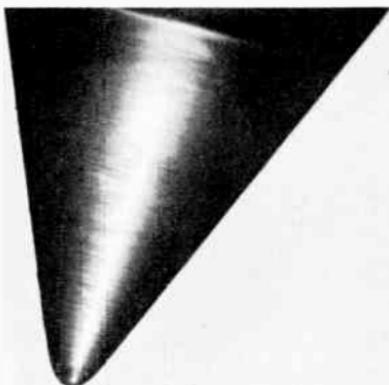


FIG. 18 (a).—NEW MICROGROOVE SAPPHIRE STYLUS
(Courtesy E.M.I. Records Ltd.)



FIG. 18 (b).—EXCESSIVELY WORN STYLUS
Note "flat" worn on the tip.
(Courtesy E.M.I. Records Ltd.)

clear warning when the listener is very familiar with the particular record, but there is still the danger that deterioration may be overlooked and that the tip, assuming chisel-like cutting edges, will cause serious and permanent damage to the record.

Microscope inspection is very useful, and in this way the user can watch for the formation of flat areas each side of the tip (see Fig. 18 (a) and (b)). A stylus has ended its useful life when "flats" of about 0.0005 in. have formed. Perhaps not many record collectors will have access to a professional type microscope and it should therefore be mentioned that Philips Electrical Limited promote a "Needle Clinic" service whereby small microscopes (not professional, but better than nothing at all) are made available to dealers. The dealers are then encouraged to offer a free stylus inspection service. The microscopes are now available to the public. This does seem to be the only attempt made so far to provide the public with a service of this type.

Apart from microscope inspection, the safest procedure is a careful check of hours of use or record sides played. In average conditions, a sapphire should not be used longer than about 50 playing hours. A diamond, which should be used if at all possible, should be limited to about 2,000 hours. We are considering micro-groove records, of course, but the sapphire used for 78 r.p.m. discs should also be limited to 50 hours (unless the records have previously been played with steel or fibre needles). The estimated life is reduced in all cases if conditions have been bad.

With due attention to all the factors which have been mentioned, a record can be in virtually mint condition after many years of regular use. On the other hand, neglect of the stylus or failure to keep records free from dust will cause permanent damage to the grooves. A check can be kept on the stylus by noting in a book the records played every day. Alternatively, small digital counters are available: it is possible to fit one near the pick-up arm so that it indicates "one more nail in the coffin" each time the pick-up is placed on its rest.

Finally, good quality styli will be sold by dealers who are familiar with high fidelity requirements. Money should not be saved on this item—a poorly polished tip is likely to cause surface noise and may accelerate wear. A few makes of pick-up have to be returned to the works for stylus replacement.

3

AMPLIFIERS AND RADIO TUNERS

THE high fidelity amplifiers produced by specialist manufacturers are made in relatively small batches compared with the streamlined production methods which are essential in the manufacture of chassis for competitively priced radiograms and record players. A clear-cut comparison of prices is admittedly rather difficult because the amplifier of a radiogram is not sold separately.

It is clear nevertheless that the consumer often benefits from the specialists' methods and lower overhead costs—very clear indeed when it is considered that a creditable high fidelity system can be assembled for the price of a deluxe radiogram of far inferior performance. The pursuit of high fidelity is very much a matter of shopping wisely and well. It had better be added that a few of the big names in the radio industry do in fact produce some good amplifiers, particularly when there are high fidelity enthusiasts on the staff. However, one suspects that the profits from this side of their activities are not likely to butter many parsnips !

The audio specialist, then, is mainly responsible for the high standards of sound reproduction which have become commercially practical. This is especially true of the amplifier ; a high standard of reliability is achieved and impressive specifications are offered even in moderately priced examples.

Amplifier and Control Unit

The amplifier links the various sound sources—pick-up, radio and so on—to the loudspeaker. Since these inputs deliver very small signal voltages, the amplifier must apply to them a degree of voltage amplification and subsequently produce enough power to drive the loudspeaker. The inputs must be provided with the

correct conditions for efficient working and tone controls must be provided so that the listener can adjust the tonal balance to his liking. A volume control and on/off switch are also required and, at the output end, means of adjustment to suit different loudspeakers.

For convenience, the equipment may be considered in two parts. The first is the "control unit," which contains the tone control and initial voltage amplifying circuits and on which are situated the input sockets. The other is the "power amplifier," the main function of which is to produce the power to drive the loudspeaker but which also includes the main voltage amplifying circuits and the mains supply section.

Until quite recently, it was the usual practice with high fidelity equipment for the control unit and power amplifier to be two separate units. This arrangement is particularly appropriate for large equipments, as the control unit can then be fitted in a conveniently situated cut-out in a cabinet and the bulky power amplifier chassis hidden away in a suitably ventilated position. The control unit is sometimes called the pre-amplifier as it does usually incorporate preliminary amplifying circuits.

The alternative mechanical arrangement is the combined or integrated control unit and amplifier, where everything is arranged on one chassis and a suitable cover provided. This method is used in what are sometimes called "unit" installations. The amplifier and, say, a radio tuner can stand on a bookcase or room-divider, and no special "hi-fi furniture" is required.

For the purpose of explanation, it is simplest to regard the control unit and power amplifier as separate items.

Control Unit Inputs.—A control unit usually subjects the incoming signal to several stages of amplification, preparing it for the circuits of the power amplifier. The various inputs cannot all be treated alike, however, as they will be at various voltage levels. Thus one function of the control unit is to produce the same voltage at the output of the unit whatever the nature of the input. A magnetic pick-up, for example, will call for more amplification, or "gain" as it is called, than a crystal pick-up or radio tuner. The control unit's output is, of course, regulated by the volume control, and the output voltage with the volume control turned to maximum

is (approximately) that which will produce the rated power from the power amplifier.

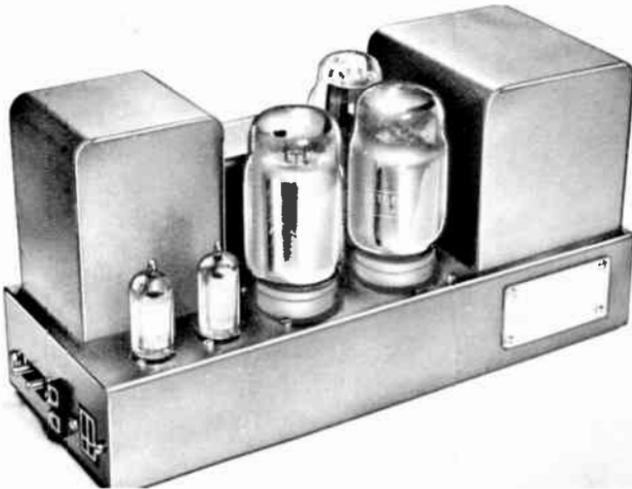


FIG. 1 (a).—ACOUSTICAL QUAD II POWER AMPLIFIER

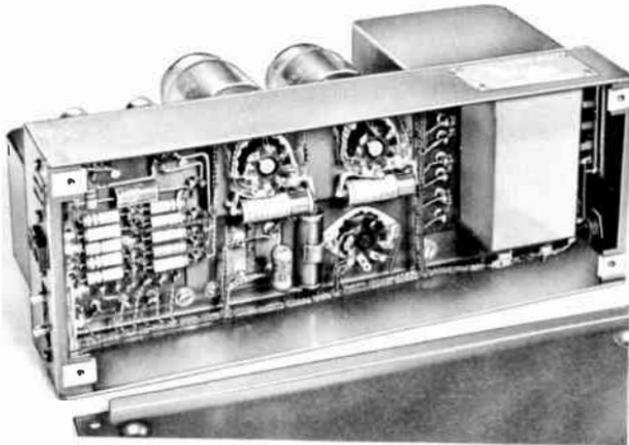


FIG. 1 (b).—UNDER CHASSIS VIEW OF QUAD II AMPLIFIER WITH BASE COVER REMOVED

Note neat positioning of components and arrangement of wiring.

It is necessary to introduce the idea of "sensitivity" here once more. The sensitivity of a control unit input is the voltage to be applied in order to produce the rated output from the amplifier.

The control unit input which will cope with the few millivolts output of a magnetic pick-up is obviously more sensitive than the input intended to accept the 200 mV. or more provided by a radio tuner ; thus a sensitivity of 5 mV. is "higher" than one of 200 mV. To complete the picture, the inputs which have the highest sensitivity are those associated with the circuits having highest gain. It should be clear that a 10 watt amplifier with its control unit could have a low or high gain. A high gain can only be obtained with several valve stages, so the control unit with the most accommodating input arrangements will be the most expensive.

Let us now look more closely at the types of input provided. A magnetic pick-up, as we have seen, may produce 4 mV. for 1 cm/sec. recorded velocity. A fair average figure for recorded velocity is 10 cm/sec. ; the pick-up therefore averages 40 mV. and the input sensitivity should be 40 mV. Of course, some pick-ups give less output than this ; only 8 to 10 mV. in some instances. (In the case of a moving-coil pick-up, the voltage concerned is that present at the secondary terminals of its associated transformer.) Control unit sensitivities as high as 5 mV. are quite common.

A crystal pick-up produces more output—as high as 50 mV. per cm/sec. in some cases. Keeping to the average velocity used just now, a control unit sensitivity of only 500 mV. (0.5 V.) will be adequate. (Remember, the lower the pick-up's output, the higher the sensitivity and gain required.)

Radio tuners—which will be referred to in more detail later—depend not on a velocity but on a broadcast signal. It can safely be assumed that any tuner, given correct working conditions, will produce enough output for any control unit.

Another input provided on the more comprehensive equipments is for dynamic microphone (moving-coil and ribbon types) : the sensitivity is often as high as 3–5 mV.

Tape recording enthusiasts will wish to incorporate tape playback and recording in the installation and the majority of control units have facilities to enable this to be done. A "tape" input for use with a complete tape recorder will be similar in sensitivity to that provided for radio (*e.g.* 200 mV). A few control units have an input with a sensitivity up in the 3 mV. region for direct connection of a tape head.

A control unit could have one of several combinations of these

inputs. For example, if minimum outlay on the installation is the main consideration, the enthusiast will probably have to make do with a crystal pick-up. This will work perfectly well with the less ambitious amplifiers; inputs may be provided for just crystal pick-up and radio. Such points serve to illustrate the importance of planning a new installation carefully. A simple control unit which caters for a crystal pick-up cannot be used with a high quality magnetic type if the owner decides in due course that he can afford one.

Inadequate sensitivity is not the only reason for this. If a magnetic pick-up is connected to the input designed for a crystal one, the resulting sound will be most unpleasant—a great deal of screeching treble and no bass. This is because the pick-up's output corresponds closely to the recording characteristic, as discussed in Chapter 2. Its output must therefore be passed through an electrical correcting network such as is incorporated in all but the simplest control units. This network gives a reproducing characteristic B (see Fig. 2, Chapter 2) which is the inverse of the recording characteristic A. The signal emerges with a virtually "flat" characteristic and is then passed on for further amplification.

The crystal pick-up needs none of this equalisation. An input with a "flat" frequency characteristic is often all that is needed. The most complicated arrangement encountered with crystal pick-up inputs is a simple network to "iron out the bumps" in the pick-up's response. The manufacturer will advise on any refinement of this sort. It is emphasised that the use of such networks has nothing to do with recording characteristics. A crystal pick-up has its own in-built correction (of a very approximate nature) which is determined by design factors.

Another factor to be considered when connecting equipment up to the control unit is "impedance matching." The pick-ups and other items have widely varying impedances and the user, when he discovers the actual impedance values and tries to relate them to the figures given in the amplifier specification, may be thoroughly confused. For the sake of clarity, it is sufficient to say here that the user can forget about the actual impedance of a pick-up and instead concentrate on the "load impedance" with which it should, according to the manufacturer, work most happily. The load quoted as optimum should, of course, be provided by the control unit without

the need for any external adjustments. Although "load impedance" is the expression often used, "load resistance" is also correct; a load for a magnetic pick-up may be a single resistor connected across it.

A typical figure for a magnetic pick-up's load would be 50,000 ohms (50k) or higher; for a crystal pick-up it is usually 100k ohms or more and for a radio tuner about 100k-500k ohms. There is a slight complication where a moving-coil pick-up is concerned: the transformer supplied with it not only steps up the voltage but also matches the moving coil's low impedance to the control unit's higher value. Manufacturers' recommendations should be followed closely; a bad mis-match can cause distortion and lack of output. For example, an incorrectly loaded magnetic pick-up may be responsible for an electrical resonance, the effects of which can be heard in the reproduction.

Amplifier manufacturers have found several ways of providing in the control unit the optimum load for the external items of equipment. An input designed for magnetic pick-ups could have, say, a 68k ohms resistor connected across it internally. This simple load would be suitable for several makes of variable reluctance pick-up. However, more flexible arrangements are normally provided. A continuously variable load can be made available by means of one or more potentiometers. Certain control units are provided with a range of small plug-in units, each one containing the components (resistance and capacitance) which will match one or more makes of pick-up to the input circuits. This is a very good idea as it means that the manufacturer can produce another such device whenever new pick-ups are put on the market so that the control unit remains as flexible as it was when the designer planned its original facilities.

The Controls.—The first of these is the "selector" or "function" switch, to select between pick-up, radio, tape and so on. It is usual for the networks which deal with recording characteristic correction to be associated with this switch. A minimum of one correction network for microgroove and one for 78 r.p.m. should be incorporated. There is no longer much justification for providing corrections other than the internationally agreed ones, discussed in Chapter 2. The switch positions for pick-up will therefore probably be marked LP and 78 (or R.I.A.A. and 78). If the collector has some

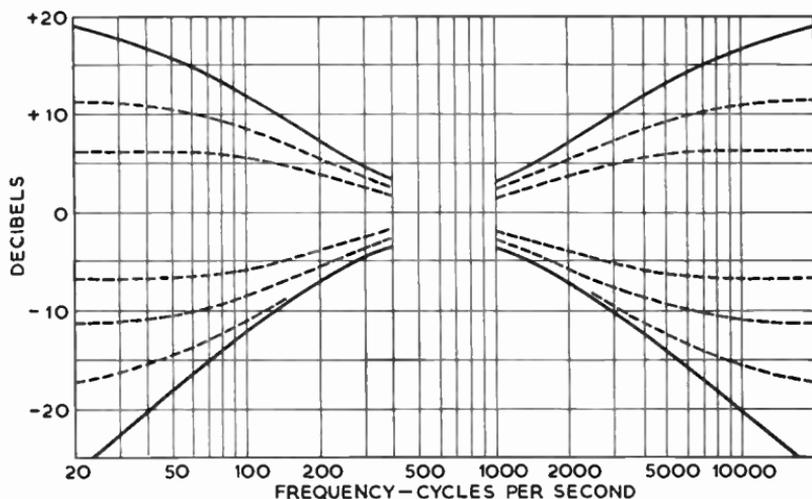


FIG. 2 (a).—FREQUENCY RESPONSE CURVES FOR A PASSIVE TONE CONTROL CIRCUIT

older records, made in the days when new recording characteristics were being foisted on us every month, he can make them sound agreeable with the aid of the tone controls.

Independent bass and treble controls are provided on all high fidelity equipments in order that the listener can obtain the tonal balance he requires. By means of these, shortcomings in a record or broadcast can, to some extent, be corrected, as also can the effect of the acoustics of the listening room. The frequency response of the signal leaving the control unit should be "flat" when the tone controls are at their mid-positions. On either side, there will be a range of boost and cut of 10 dB or more; 10 dB is plenty.

The effect of one common tone control system on response is illustrated in Fig. 2 (a). It will be seen that the range of boost and cut is some 15 dB with respect to the 50 c/s and 10 kc/s regions. It is also clear that when the controls are at or near maximum boost or cut not only are the bass and treble frequencies affected but also frequencies quite near to 1,000 c/s are appreciably affected. An alternative tone control system, preferred by the author, gives the required adjustment at the end of the frequency range without upsetting other regions to any great extent. The effect of this system

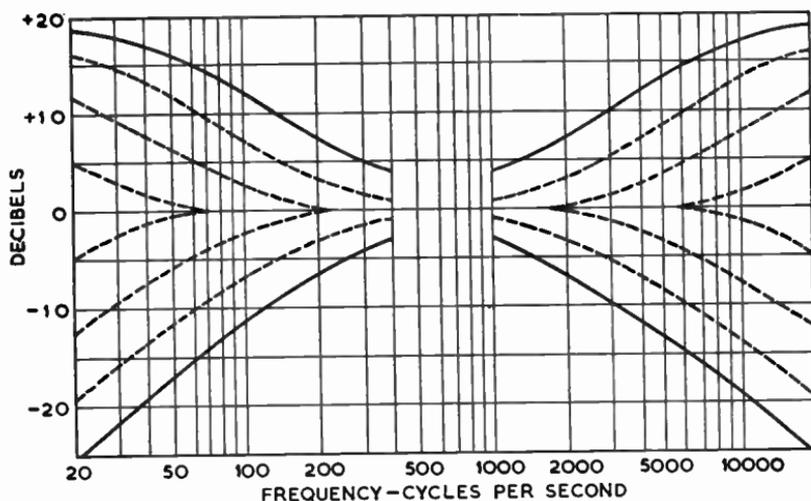


FIG. 2 (b).—FREQUENCY RESPONSE CURVES FOR A NEGATIVE FEEDBACK TONE CONTROL CIRCUIT (BAXANDALL CIRCUIT)

is illustrated in Fig. 2 (b). This type of control—often called the Baxandall system, which is in quite common use, is part of a “negative feedback” system; feedback, the main use of which is to reduce distortion, will be dealt with separately.

The above controls, with the addition of a volume control and mains switch, are all that are provided on many control units. They will, in fact, be sufficient for most requirements, but a number of extra refinements are sometimes added. A variable low-pass filter is useful in reducing scratch from old records or other types of high-pitched noises. The filter usually takes the form of a switch adjustable to several frequencies (5, 8 and 12 kc/s for example) above which the signal is sharply attenuated. A “slope” control is often fitted in association with this switch filter to vary the rate of attenuation at each step. The effect of these controls is shown in Fig. 3. The listener who uses only the best of current programme material will have little use for such a filter system. Enthusiasts new to record-collecting will not be faced with the scratch problem—unless their budgets will stand the strain of records from the Golden Age.

The characteristics of the human ear require that the bass and, to a lesser extent, the treble are boosted when the volume level is

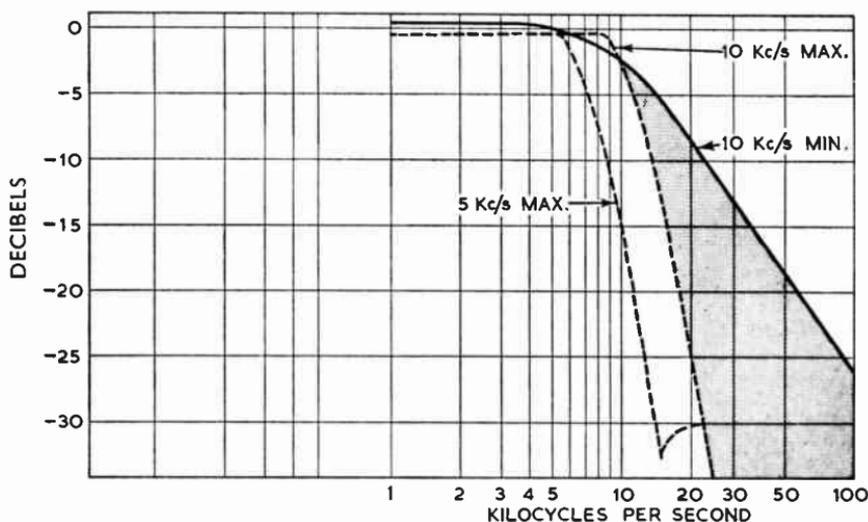


FIG. 3.—FREQUENCY RESPONSE CHARACTERISTICS OF LOW-PASS FILTER AND SLOPE CONTROLS

The broken lines show the affect of switching a low-pass filter to the 5 and 10 kc/s positions. The shaded portion shows the variation of the 10-kc/s cut-off made possible by adjusting the slope control.

low. A separate "loudness" control is therefore provided on some control units to look after this phenomenon. Unfortunately, this leaves out of account too many factors for much reliability to be achieved; for example, the effects on the tonal balance of listening at varying distances are ignored. A more reliable method may one day be devised; meanwhile it seems likely that the bass and treble controls can give all the adjustment that is needed.

Another refinement which has been offered on occasion is the "presence" control, which usually boosts the mid-frequencies a little and is said to make the sound seem "closer." The writer feels that considerations of presence are best left to the recording and broadcasting engineers, who are usually well aware of its merits and limitations and can provide all that is required in the programme material itself. It will be seen that the loudness control effectively depresses the mid-frequencies while the presence control boosts them: perhaps the author may be forgiven for wanting to observe both in action at the same time!

The last refinement to be mentioned is the rumble filter, which

sharply attenuates frequencies below, say, 30 c/s. This is useful if the turntable is not above reproach. Not all equipments have such a filter ; those that have use either an in-built circuit or one which can be switched into operation. Incidentally, the sharpness of attenuation in a filter is given in dB per octave. For a cut-off which is at all sharp, a minimum rate is 12 dB per octave (12 dB/8ve).

Control Unit Output.—An output is often provided for tape recording. Its voltage level (preferably 100 mV. or more) should be independent of the main volume control and will best be adjusted with a separate control—a small pre-set control is useful.

Where the cable which is to link a separate control unit to its power amplifier is short (a few feet) the output may well be at high impedance. On the other hand, several yards of cable would cause serious high frequency losses with a high impedance output. A "cathode-follower" output stage is incorporated in a few elaborate control units. This is a method of using a valve, not to give any amplification, but to produce a low impedance output. If the output is at low impedance, the connecting cable can be quite long. Whether a cathode-follower is used or not, the power amplifier input which accepts the signal from the control unit is at high impedance (*N.B.*, a high impedance can usually be fed quite satisfactorily from a low impedance, but not vice versa).

The Power Amplifier—How Many Watts?—This is a question which cannot be answered precisely or in a way which will give a rule for the potential enthusiast to follow. The power output will depend on the size of the listening room and, most probably, on whether the user lives in a flat or a detached house. It is a matter of taste, too—some listeners like more sound than others.

It must be remembered that the power we are talking about is that delivered to the loudspeaker, which is a rather inefficient device. In a modern living-room, the average acoustic power radiated by the loudspeaker is a small fraction of a watt. If we suppose that the rather large power of 200 mW. is being radiated by a loudspeaker which is ten per cent efficient, then the average amplifier output is 2 watts. Listeners who have sampled modern long-playing records and f.m. radio transmissions will appreciate that the dynamic range can be quite great ; it is therefore essential to have enough power

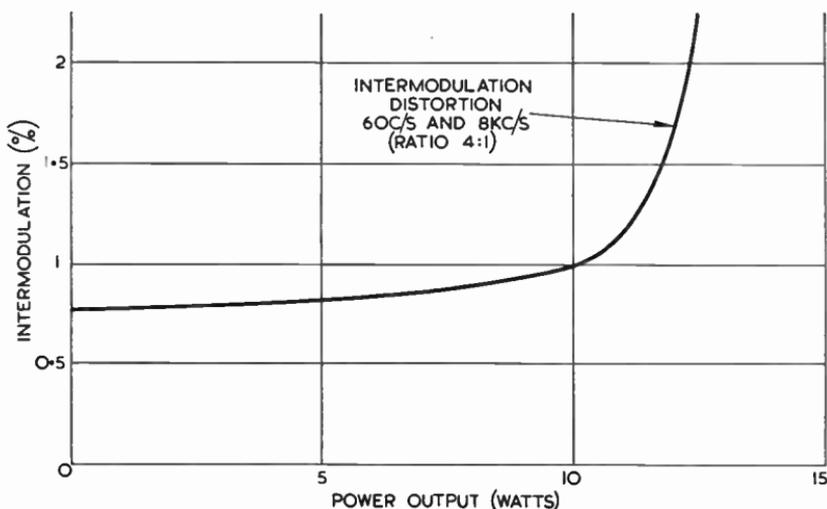


FIG. 4.—INTERMODULATION DISTORTION PLOTTED AGAINST OUTPUT POWER

in reserve to handle without distortion the sudden rise in energy involved in transient sounds. To allow for this, the amplifier rating must be about 10 watts, assuming a loudspeaker of average efficiency.

A visit to a few high fidelity specialist dealers will show that a large proportion of popular amplifiers have maximum outputs in the 10–15 watts region. In many instances, the designers will have taken the trouble to test them with a variety of loudspeakers and will have found that a power of this order is sufficient for average conditions. The author has dared to assume that a modern living-room is 16 ft. by 12 ft. by 9 ft. high.

It is relevant to point out here that the distortion produced by an amplifier does not rise evenly as the output increases. Some published specifications include a curve which relates harmonic distortion or, more usefully, intermodulation distortion, to the output power. Fig. 4 gives a not very flattering picture of what happens. This amplifier can be rated at 10 watts and, at this power, intermodulation is seen to have the satisfactory value of one per cent. Above this power there is a “knee” in the curve, for which the characteristics of the output stage are responsible, and the distortion rises steeply

with increasing power. The main forms of distortion were explained in Chapter 1. Intermodulation is the most audible and unpleasant.

One sometimes reads of amplifiers which have outputs of 50-100 watts or more. Such figures usually originate in the U.S.A. and occasionally Europe, and refer to the peak power, not the r.m.s. power on which specifications are based in this country. This is mentioned in case it is thought that American enthusiasts combine hi-fi with public address. Another point is that the large power rating may correspond to a higher distortion level than a British manufacturer's rating—clearly by increasing the distortion figure the same amplifier could be presented as one of "higher" power. Nevertheless, even when taking these factors into account, Americans do tend to favour large amplifiers.

The Output Stage.—This most important part of the amplifier is largely responsible for the quality of the final result. Nearly all high fidelity amplifiers use two output valves in a "push-pull" output stage. This not only gives the power we require for present-day installations but, by its mode of operation, cancels out even harmonics (2nd., 4th., etc.) generated in the amplifier. Unfortunately, the odd harmonics (3rd., 5th., etc.) generated in the system still have to be dealt with, and these are the more objectionable ones. There is, as we shall see, a method of reducing them considerably.

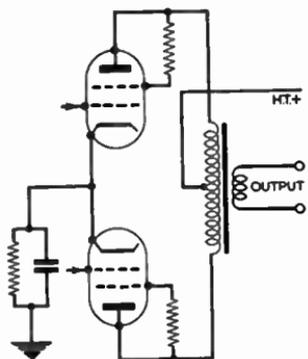


FIG. 5.—SIMPLE PUSH-PULL OUTPUT STAGE WITH TRIODE-CONNECTED TETRAODE VALVES

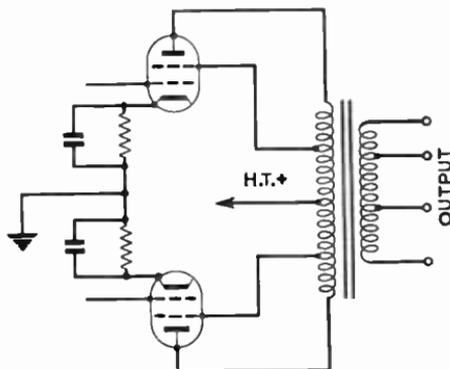


FIG. 6.—BASIC ULTRA-LINEAR PUSH-PULL OUTPUT STAGE

The high impedance of the pair of output valves—several thousand ohms—must be matched to the low impedance of the loudspeaker. The output transformer therefore enters on the scene. The output stage with its transformer is shown in Fig 5. The valves are tetrodes, a type commonly used in modern amplifiers. If

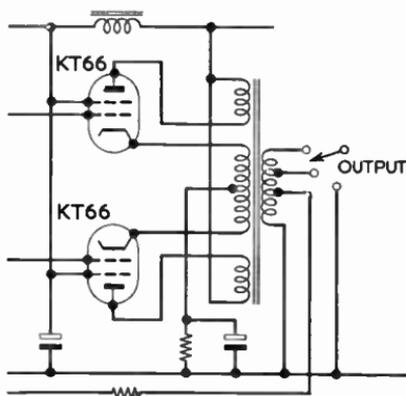
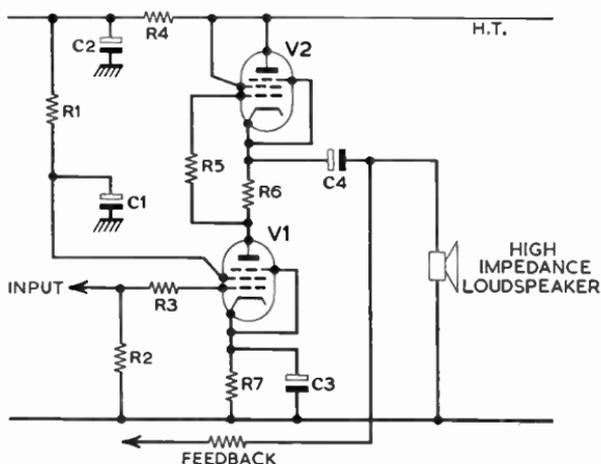


FIG. 7 (left).—OUTPUT STAGE OF THE ACOUSTICAL QUAD II POWER AMPLIFIER

The portion of the output transformer primary winding common to each valve is connected between the two cathodes.

FIG. 8 (right).—PHILIPS TRANSFORMERLESS OUTPUT STAGE



the amplifier is to meet our exacting requirements where distortion and frequency response are concerned, the output transformer must be very carefully designed and constructed. This means a core of generous proportions and large, carefully arranged copper windings ; in a word, the transformer will be expensive. The experience of

home constructors can be instanced: they have sometimes found that the output transformer accounts for as much as one-third of the total cost of the amplifier. Until quite recently, this important item was very large as well as costly, but the specially developed "C" core has altered the situation. This saving in bulk has been matched by reductions in the sizes of valves and other components.

Very few amplifiers now use the simple push-pull stage shown in Fig. 5. A modified version, the "ultra-linear" or distributed-load output stage has been developed and offers certain advantages. The basic arrangement is shown in Fig. 6, from which it will be seen that the screens of the tetrode valves are connected to tappings on the output transformer. Tetrode valves are noted for their efficiency, while triode valves (at one time used in most amplifiers) have other desirable characteristics. The ultra-linear arrangement inherits excellent traits from both types. Among the benefits it gives are greater efficiency and less distortion. A number of manufacturers have developed further variations of this ultra-linear technique, for example the arrangement used in the Acoustical Quad amplifier (see Fig. 7).

While on the subject of the output stage, the reader may well ask whether any attempt has been made to eliminate the costly output transformer. The answer is that this has been tried—and successfully. One system is to match to a low impedance loudspeaker by means of a large number of valves in parallel. This is, however, itself expensive, although it works after a fashion. The more successful method, used in the U.S.A. and on the Continent, involves high impedance loudspeakers. A pair of valves are chosen which will present the lowest possible impedance (in the 800–1,000 ohms region) and the loudspeaker's speech coil is wound to match this—a difficult operation but not insuperably so. This system involves new circuit arrangements, however, which introduce their own complications. One circuit is shown in Fig. 8. Transformerless high fidelity amplifiers of this type are not on the market in this country at the time of writing. They are marketed by Philips on the Continent.

Negative Feedback.—In all modern amplifiers, some of the output voltage (*i.e.* that applied to the loudspeaker) is fed back to the input. This voltage is in "opposite phase" to the signal—that

is, it will tend to cancel the signal. It should be noted that great care is required in designing a feedback "loop," in particular to ensure that the feedback is, in fact, in opposite phase throughout the frequency range. A simplified power amplifier circuit with a feedback loop is shown in Fig. 9. There are several ways of applying negative feedback, and many amplifiers actually have more than one loop. (Note that we are concerned here with voltage feedback rather than current feedback, which is also possible.)

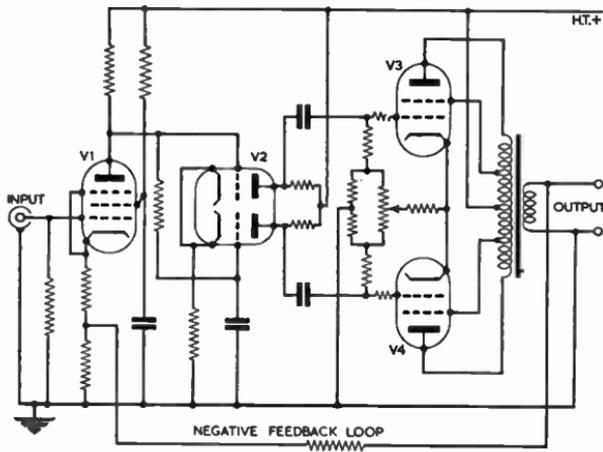


FIG. 9.—CIRCUIT DIAGRAM OF A TYPICAL HIGH FIDELITY POWER AMPLIFIER, INCORPORATING A SINGLE OVERALL NEGATIVE FEEDBACK LOOP

The first result of applying feedback is a reduction in the overall gain of the amplifier. We have already noted that the decibel is used to express ratios; in connection with feedback, it is usual to express the ratio of the original output voltage without feedback to the final output voltage after feedback has been applied. That is, when we talk about so many dB of feedback in an amplifier, we are referring to the reduction in gain due to the feedback. It is common practice in modern amplifiers for at least 20 dB of feedback to be applied, and the amount is often considerably more.

Careful application of the most suitable degree of feedback offers a number of benefits. It reduces distortion and noise;

frequency response and the reproduction of transient signals are improved ; and the output resistance of the amplifier is reduced—the significance of this will be dealt with when loudspeaker matching is discussed.

Negative feedback is not the cure for every ill ; the amplifier must be of good design in the first place. The output transformer is again the item which calls for the most attention. If it is inadequate we may get “ phase shifting ” so that the feedback, instead of remaining negative, tends to go positive—possibly only over part of the frequency range. The result may be oscillation, audible or inaudible but detrimental to the reproduction in either case.

Since the feedback causes a reduction in overall gain, further amplification must be provided to make good the loss. In a typical amplifier, this would be provided by the first valve (see the circuit in Fig. 9). Apart from this first valve and those used in the output stage, at least one more valve, possibly a triode or double triode, is required in an amplifier to produce the equal and opposite voltages which drive the push-pull power valves of the output stage.

It should be added that the advantages of negative feedback are also exploited in the control unit, where it can be associated with the tone controls and initial amplifying circuits.

Loudspeaker Matching.—It is often assumed that very precise matching of the loudspeaker impedance to that of the amplifier is essential. Admittedly, connecting a 3-ohm speaker to an amplifier which has an output impedance of 15 ohms is likely to cause loss of output and some distortion. On the other hand, connecting a 15-ohm loudspeaker to an amplifier with an output impedance of 3 ohms is not nearly so bad. The possibility of a severe mis-match is avoided in many amplifiers by the fact that two or more output tapplings are provided to give a suitable output for most of the high quality loudspeakers available. It is as well to remember also that the 15-ohm impedance quoted for a loudspeaker may well apply at only one or two particular frequencies ; elsewhere it may be a good deal higher or lower.

However, what really puts paid to the traditional ideas about matching is the fact that the loudspeaker, 15 ohms or otherwise, is actually connected to a source which has a resistance of a fraction of an ohm. This is almost a short-circuit as far as the loudspeaker is

concerned, and the reason for arranging things this way is to damp out the tendency of the loudspeaker cone to vibrate at a resonant frequency. For example, after receiving a sudden, powerful signal of a transient nature, the cone vibrations would die away gradually unless heavily damped.

This leads us to what is usually called the "damping factor" of the amplifier: the ratio of the load impedance to the amplifier's internal resistance. If the nominal impedance is 15 ohms and the source resistance $\frac{1}{2}$ ohm, the damping factor is 30. (This degree of damping is provided by many amplifiers.) Some amplifiers have a control for varying the damping factor, the idea being to ensure the right amount of damping for every loudspeaker system. The enthusiast is not likely to find this very useful unless he has measuring instruments with which to check the result.

The conclusion is that an appreciable damping factor (between 20 and 30, say) is an essential feature in a high fidelity amplifier. It is made possible by the skilful use of feedback. The loudspeaker system itself contributes to the damping because of the way it is housed—this contribution is, in fact, considerable in high quality systems.

Performance Figures.—Frequency response of the amplifier and its control unit must extend smoothly throughout and beyond the audible range. Deviation from a "flat" response are given in decibels, *e.g.* ± 0.5 dB from 20–20,000 c/s. This example is a typical and satisfactory one, but we are more sure of satisfaction if further figures show that the response falls away smoothly outside of the audible range, *e.g.* ± 1 dB from 5–50,000 c/s. If the deviations from linearity are not quoted and cannot be ascertained on enquiry, the amplifier should be regarded with considerable suspicion. Amplifiers of reputable make (perhaps excepting the cheapest) often have a better extended response than that just quoted.

It is useful to know the intermodulation distortion and, if it is not quoted, the prospective purchaser should enquire about it. A figure of one per cent at the rated output is satisfactory. Harmonic distortion (the *total* harmonic content) is still quoted more often than intermodulation. A figure of 0.1 per cent at 1,000 c/s and rated output is satisfactory; smaller amounts are often quoted.

The newcomer to high fidelity, looking at the specifications

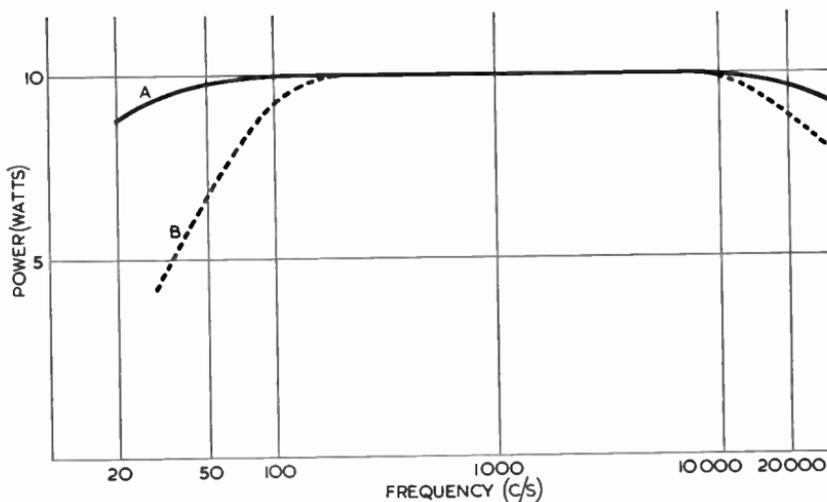


FIG. 10. AMPLIFIER POWER RESPONSE

Curve A shows output reasonably maintained ; in curve B it falls off in the bass and treble.

published by manufacturers, may come to the conclusion that wide frequency response and negligible distortion of the order mentioned above are easily achieved and that there is no need for caution on his part. However, the various figures quoted independently and without qualification do not necessarily tell the whole story.

To begin with, the frequency response may not apply at the full rated output power if the specification does not say so. A typical "power response" is illustrated in Fig. 10. If the power delivered is reasonably near the rated figure *throughout* the audible range, as shown in Curve A, all is well. Curve B shows that full power is not available in the bass or (less seriously) in the treble. Now distortion is closely linked with power delivery. A big proportion of the musical energy is concentrated in the bass and, if the amplifier is being driven by large low frequency signals—as will be

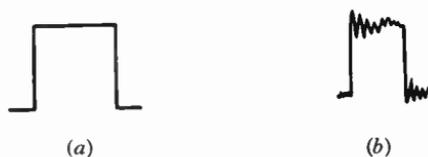


FIG. 11.—SQUARE WAVE TEST

(a) Shows a square wave as applied to the amplifier input. (b) Shows the wave at the output, with severe distortion, evidence that transient response will suffer.

the case unless they are filtered off—an inadequate power response will result in serious distortion. Satisfaction in these respects usually depends very much on the price paid.

Tests for harmonic distortion are made by feeding a pure sine wave input to the amplifier under test and then analysing the output to determine the amount of harmonics which have been added to the signal during its progress through the amplifier. Intermodulation is measured by feeding in a combination of two sine waves and measuring the spurious products of the two signals at the output. Another important test is made with a square wave (see Fig. 11). This is particularly useful in checking transient response. If some feature of the amplifier circuit is inadequate, the amplifier will not respond to the sudden pulse-like square wave (Fig. 11 (a)) but produce a distorted wave as shown in Fig. 11 (b).

Although the enthusiast cannot relate these tests to the music reproduction for which he requires the amplifier, the publication of the results, now quite general, enables him to compare performance specifications in a number of vital respects and to see that he is getting his money's worth.

Hum and noise levels should also be quoted, and are very small indeed in present-day amplifiers. The listener can take it that the noise level is satisfactory if to detect it he has to put his head almost inside the loudspeaker! A combined hum and noise level of 70 dB below full output for the amplifier with its control unit is quite acceptable.

Stereophonic Amplifiers.—Stereophonic sound will be dealt with in a later chapter, but it is convenient to point out here that the two amplifying channels required for stereophonic reproduction should have all the essentials discussed above. It is convenient to arrange the two channels on one chassis. There is no justification in stereophonic amplifiers for sacrificing the high standards of performance and construction that have become almost commonplace in monophonic audio equipment. Some manufacturers, in fact, have, in producing stereophonic amplifiers, simply produced "double" versions of their previous designs.

Printed Circuits.—Printed circuits and the miniature components that are being developed to go with them are of great

interest to the manufacturer of portable radio receivers and other products which can benefit from considerable reduction in size. The technique has been applied to high fidelity equipment in comparatively few instances, but it is likely to be used more often as greater miniaturisation of components becomes possible.

The amateur will wonder whether there is some particular virtue in printed circuits where quality of reproduction is concerned. The answer is that there is none ; there is simply no reason why he should specially seek out printed circuits when purchasing high fidelity equipment. There is no reason to avoid them, either—what matters is the best performance for the price, whatever the technique used.

Radio Tuners

The enthusiast can sample the delights of the high quality v.h.f./f.m. transmissions at quite small cost if he adds a radio tuner to his high fidelity installation. Before considering what form this

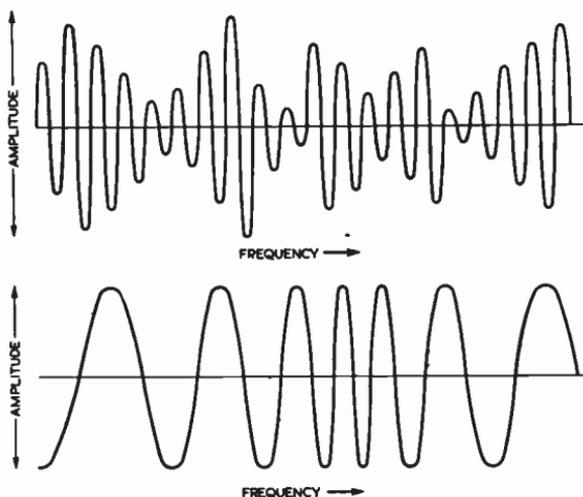


FIG. 12.—DIAGRAMMATIC REPRESENTATION OF A.M. (ABOVE) AND F.M. (BELOW)

item takes, a comparison of the two types of transmission—amplitude modulated (a.m.) and frequency modulated (f.m.)—now in use should be made.

A.M. and F.M.—Most listeners to medium-wave broadcasts are irritated by whistles, whirrings and various other noises caused by interference from stations adjacent to the one they are listening



FIG. 13 (a).—ACOUSTICAL QUAD F.M. TUNER

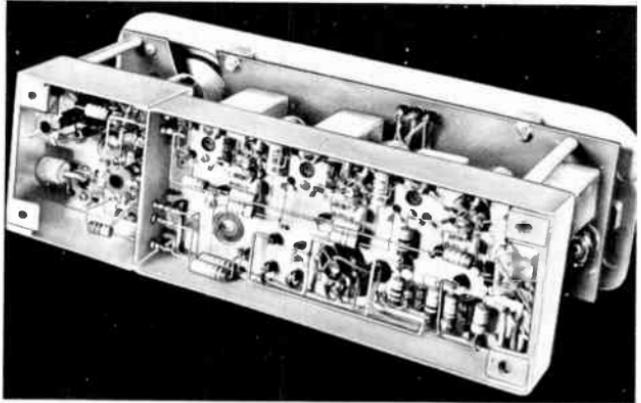


FIG. 13 (b).—REAR VIEW OF THE QUAD F.M. TUNER, WITH COVER REMOVED TO SHOW CONSTRUCTION

to. This is particularly noticeable after sunset. They may also suffer from the equally distressing electrical interference caused by electrical equipment in use in the vicinity. The G.P.O. can often assist in reducing the latter. The former, however, is due to the

fact that too many stations are trying to broadcast in the same frequency band. The chaotic conditions in the medium-wave band are caused by quite powerful stations struggling to make themselves heard above their neighbours in this grossly overcrowded band. It should also be pointed out that the operators of some foreign stations are not so particular as the B.B.C. about keeping to their allotted frequencies.

In order to make a normal medium-wave (or long-wave) receiver at all usable in these conditions, one requirement is to limit the pass-band of the circuits, *i.e.* to make sure that the transmissions of the required station are received and those of adjacent stations rejected. The ways and means do not concern us ; the result, a restricted frequency response, concerns us very much. This disadvantage of restricted frequency response, together with the high noise level, rules out the possibility of using amplitude modulated medium-wave broadcasts for high fidelity purposes except in the very few favourable locations (close to the broadcasting stations) where the full bandwidth can be received without interference : this usually calls for a " t.r.f. " receiver as opposed to the conventional superhet. Indeed, we are reaching the position where medium-wave broadcasts can offer little enjoyment even to less demanding listeners.

The poor quality of medium-wave reception led the B.B.C. to investigate ways of providing a better service. Transmitting on a higher frequency (*i.e.* shorter wavelength) is a much better proposition, and the " very high frequency " band (30–300 Mc/s) was chosen.

It is only possible to receive in a small service area close to the transmitter when broadcasting at v.h.f. An extensive network of stations is, therefore, necessary to give proper coverage of the population, but interference from other distant stations is virtually impossible.

V.H.F. would give good frequency response if the familiar amplitude modulated system was used, but only a combination of v.h.f. with frequency modulation (f.m.) gives the required rejection of noise, *e.g.* electrical interference. The fundamental difference between a.m. and f.m. concerns the way in which the broadcasting station " carrier wave " is made to convey information. With a.m. the carrier wave varies in amplitude (*i.e.* intensity) in proportion to the audio signal which modulates it. With f.m. the carrier varies in frequency according to the audio signal, and the extent of the variation determines the audio amplitude. These two systems are shown

Table 1.—B.B.C. V.H.F. Stations

<i>Stations</i>	<i>Frequencies (Mc/s)</i>		
	<i>Light</i>	<i>Third/ Network Three</i>	<i>Home</i>
Wrotham	89.1	91.3	93.5
Pontop Pike	88.5	90.7	92.9
Wenvoe	89.95	96.8	94.3 (Welsh) 92.125 (West)
Divis	90.1	92.3	94.5
Meldrum	88.7	90.9	93.1
North Hessary Tor	88.1	90.3	92.5
Sutton Coldfield	88.3	90.5	92.7
Norwich	89.7	91.9	94.1
Blaen-plwyf	88.7	90.9	93.1
Holme Moss	89.3	91.5	93.7
Rowridge	88.5	90.7	92.9
Kirk o' Shotts	89.9	92.1	94.3
Sandale	88.1	90.3	92.5 (North) 94.7 (Scottish)
Llandona (Anglesey)	89.6	91.8	94.0
Llangollen (N. Wales)	88.9	91.1	93.3
Rosemarkie	89.6	91.8	94.0
Isle of Man (Douglas)	88.4	90.6	92.8
Orkney	89.3	91.5	93.7
Wick	90.1	92.3	94.5
Peterborough	90.1	92.3	94.5

(by courtesy of B.B.C.)

pictorially in Fig. 12. Electrical interference noise is similar in form to a.m. broadcasts, so that by using f.m. broadcasting and incorporating a "limiter" in f.m. receivers to prevent a.m. signals being reproduced, interference of this type is greatly reduced.

Table 1 lists the B.B.C.'s f.m. stations and their frequencies. The section of the v.h.f. band which they occupy is known as Band II, covering 87.5–100 Mc/s (megacycles per second). The rest of

the v.h.f. band is used by television, business radio and other professional and amateur communication services.

Several factors contribute to the superior sound quality obtained from f.m. broadcasts. The bandwidth can be widened to allow a frequency response of approximately 40–15,000 c/s ; dynamic range, although not all that we could wish, is much wider than in a.m. broadcasting ; and the reduction in noise of all types is quite spectacular.

It must be emphasised that the benefits of this f.m. system are realised only when conditions of transmission and reception are really good. For example, broadcasts from distant studios depend on long Post Office lines to bring the sound signals to the transmitting station, and these may often severely limit the frequency range. Many gramophone records are broadcast and, at the present time, these include a high proportion of 78 r.p.m. discs. Nevertheless, as pointed out in Chapter 1, a broadcast of local origin is usually of very high quality, with wide response and minimum noise level. At the receiving end, a good receiver must be helped by a good aerial if the rejection of local noise is to be complete.

There is, unfortunately, one form of distortion—known as “multipath distortion”—to which, in some localities, v.h.f./f.m. signals are subject. This distortion is caused by the ease with which v.h.f. radio signals are reflected from large objects, buildings, etc. Where both reflected and direct signals are received simultaneously, this may result in an unpleasant breaking up of the higher frequencies, termed the “tissue paper” effect. A more efficient or more directional aerial will usually overcome this problem.

Tuners.—As the name suggests, a tuner incorporates the radio frequency tuning circuits. It receives the radio transmissions and provides an audio output which is ready to be fed into the installation's amplifier. In other words, it is a radio receiver minus the output stage and loudspeaker. The presentation is very similar to that used in amplifiers : a tuner can be obtained in chassis form for installation in your own cabinet, or with a cover if it is to stand by itself on a shelf. Prices are from roughly £15 upwards.

Many different forms of tuners are available. If the listener is interested only in the B.B.C. transmissions, a model which tunes over the f.m. band will be sufficient. Even the trouble of tuning can be

avoided in some models, in which the three B.B.C. frequencies appropriate to the listener's area are selected by a switch. For listeners who enjoy a "world tour," there are tuners with f.m., medium- and long-wave bands ; short-wave bands (a.m.) are added in a few instances.

Since considerable distortion can be introduced when either an a.m. or an f.m. signal is not correctly tuned in, it is worth making sure that the model chosen can be tuned easily and accurately to the

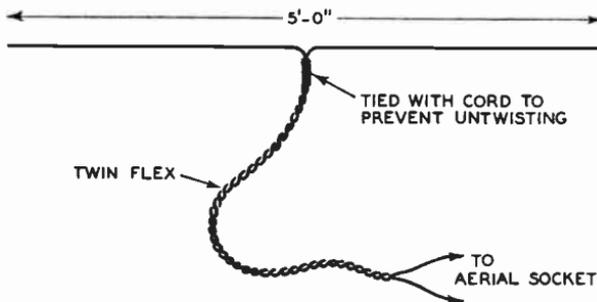


FIG. 14.—CONSTRUCTIONAL DETAILS OF A SIMPLE INDOOR DIPOLE AERIAL SUITABLE FOR USE IN AREAS WHERE SIGNAL STRENGTH IS GOOD

desired stations and will then hold them without distortion caused by tuning drift. A good tuning indicator is helpful here. Some tuners include "automatic frequency correction" (a.f.c.) to counteract errors of tuning and the effect of frequency drift.

Connecting a tuner to the rest of the installation is very simple. The aerial is plugged into the tuner, using cable as specified by the manufacturer. The audio output is taken to the socket provided on virtually every amplifier for this purpose, using screened (coaxial) cable. Many tuners take their power supply from the high fidelity amplifier, but there are plenty of mains-powered tuners for installations where the amplifier cannot supply the h.t. and l.t. supplies required by the tuner. This point should be checked carefully before a tuner is purchased.

It is essential that the aerial is adequate. Where the signal strength is high—up to about 10 miles from the transmitter—a home-made dipole may be sufficient. This can be prepared as

indicated in Fig. 14. It should be mounted horizontally and rotated for maximum signal. Indoor aerials should be as high as possible. Outdoor aerials can be obtained in various degrees of complexity to suit different signal strengths. Combined f.m. and television aerials are also available.

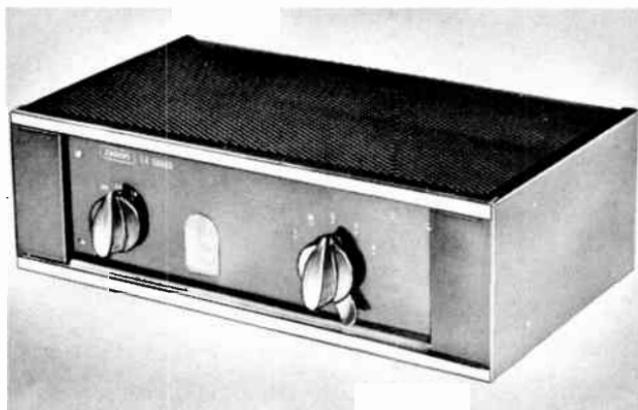


FIG. 15.—THE JASON JTV SHELF-MOUNTING TUNER UNIT FOR F.M. RADIO AND TELEVISION SOUND

Television Sound.—Many viewers and listeners have long suspected that television sound could yield better quality sound than the emasculated noise emitted by the average television receiver. It will, in fact, permit a wide frequency response, but the television sound channel is a.m. and very susceptible to locally produced noise, such as car ignition. To overcome this, television receivers incorporate suppression circuits which may also restrict frequency range.

Nevertheless, a wide demand for something better, suitable for use where interfering noise is not excessive, has been met, and there are a few tuners which will receive the television sound as well as the f.m. band. With one of these, the listener can gratefully turn down the volume on his television set and enjoy yet another application of high fidelity principles—a bit less than the “highest fi” this time but very acceptable just the same.

4

LOUDSPEAKERS

IN embarking on a discussion of loudspeakers, it would be as well to commence by issuing a reminder that this is the item we actually hear and to back this up by saying that shortcomings in the design or installation of this item can do more to rule out convincing, natural-sounding sound reproduction than most other defects in the reproducing chain. It should also be pointed out from the start that loudspeakers, like listeners, all have different ideas about the way in which music should be reproduced !

There are many traps for the unwary. The ability to draw profitable conclusions from tests on loudspeakers depends on experience in listening to both the original and the reproduced sound : relating the wiggles on a chart with the audible result calls for the right mixture of art and science. This may partly account for the fact that many loudspeaker manufacturers do not publish very extensive data about their products. The most useful specification is that devoted mainly to those points which can be used for comparison purposes. A great deal of attention is given in loudspeaker advertisements to describing the design of the cabinet or enclosure ; details of this are very important and useful.

Let us start by considering the construction and behaviour of the moving-coil loudspeaker. With the exception of a few electrostatic loudspeakers, which we shall deal with separately later, and one or two rather specialised types, all current loudspeakers are of this type.

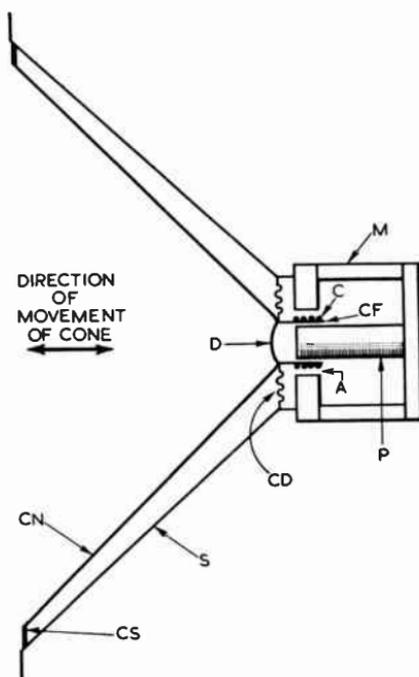
Moving-Coil Loudspeakers

A cross-section of a typical moving-coil loudspeaker is shown in Fig. 1. The output from the amplifier is fed to the coil (C), which is held suspended in the gap (A) of a powerful magnet (M). The coil is wound round a former (CF), and kept from fouling the

faces of the magnet by the centring device (CD). To one end of the coil/coil-former assembly is attached the diaphragm, or cone (CN). This is held at its outer edge by the flexible cone surround (CS) which is connected to the loudspeaker chassis (S). The output currents fed to the coil produce a magnetic field in the coil at right-angles to the magnetic field of the surrounding magnet. The

FIG. 1.—CROSS-SECTION THROUGH
A MOVING-COIL LOUDSPEAKER

- | | |
|----|------------------|
| M | magnet |
| P | pole-piece |
| C | coil |
| A | air-gap |
| D | dome or dust-cap |
| CD | centring device |
| CF | coil former |
| CN | cone |
| CS | cone surround |
| S | chassis |



attraction and repulsion between these two fields moves the coil to and fro in the magnet gap, thereby driving the cone back and forth, as indicated by the arrow, to produce the sound waves.

Several special requirements in this arrangement must be satisfied. For example, a powerful, and therefore expensive, magnet is necessary if a high degree of efficiency and good damping is to be achieved; also the cone surround must be very carefully designed if it is not to interfere too much with the movement of the cone; and the cone must be made as rigid as possible to withstand the stresses which its movement imposes upon it.

Probably everyone would prefer to use a single drive unit to

reproduce the entire audio frequency range in a pleasing manner. This would be simplest, and cheapest. There are difficulties here, however, as the requirements of a cone to reproduce bass frequencies and one to reproduce treble frequencies conflict. The outstanding requirement of a cone for good bass reproduction is that it should be large and robust, so that it will move back and forth in the manner of a piston. On the other hand, a light cone of small diameter is required for efficient reproduction of the higher frequencies.

A drive unit of the type shown on Fig. 1, and of 10-15 in. diameter, will provide good bass. It will also produce some treble. At high frequencies, however, the coil is virtually the only part moving, and the sound energy is radiated mainly from the apex of the cone. Ways of strengthening this high frequency output are by making the coil of very low weight, *e.g.* by winding it with aluminium wire, and/or by fixing a small cone, stiff and light, to the apex of the main cone to handle the frequency range above a certain point. The cone in the majority of moving-coil loudspeakers is made from moulded paper pulp. In the twin cone type of loudspeaker, just mentioned, the high frequency cone is made similarly but is given greater rigidity.

A simple loudspeaker can therefore be successful in reproducing a wide frequency range and there are a number of single and twin cone models which offer remarkable value for money and enjoy wide popularity. The width of response is not the only thing to be considered, however, and prominent among the other factors is sound diffusion. The low frequencies are always widely diffused in the listening room but, as frequency increases, the sound becomes noticeably directional. Few things are more likely to detract from realistic results than a treble output which is too evidently "beamed" at the listener. In single and twin cone speakers, diffusion of high frequencies can be widened by the method of housing the unit and its position, but it is true to say that the quest for non-directional diffusion accounts to a great extent for the trend towards more complex systems. Multi-speaker systems, each unit of which handles a particular part of the range, are naturally more expensive but the cost is often justified by more convincing results. We shall return to the subject of multi-speaker systems later in this chapter.

Resonances.—A loudspeaker by its natural method of operation

exhibits a number of resonances which can be considered for the moment without reference to the method of mounting or housing. The taming of these resonances with a view to meeting high fidelity requirements costs time and money, but is of great importance.

Every loudspeaker has a fundamental resonance. This is mainly determined by the mass of the cone and the stiffness of its movement. Since accurate reproduction cannot be achieved below the frequency of this resonance, it must be kept as low as possible—it has successfully been kept below 30 c/s in some designs. The fundamental resonance is kept as low as possible by paying careful attention to the stiffness of the cone suspension. The centring device, which positions the coil in the magnet gap, also plays a part in determining the frequency of this fundamental resonance.

Apart from the fundamental resonance, there are others which can “colour” the reproduction considerably. Cone surround resonances, in particular, can have most objectionable effects. Nowadays, instead of using the cone material itself for the surround, as in the loudspeakers used for radio receivers (some enthusiasts call these “cooking speakers”!), a material with suitable damping properties is used. Materials such as flannel and, more recently, plastic foam, absorb energy at the cone edge instead of reflecting it back along the cone. The improvement in smoothness of response is considerable, and the reduced surround stiffness also lowers the fundamental resonant frequency. An alternative is to treat a corrugated paper surround with a plastic material but, whatever the method, assembly time and costs are increased. Such improvements are limited to high fidelity loudspeakers and they do, in fact, represent a very big advance in this field.

Lack of stiffness in the movement of the cone, although desirable for several reasons, could lead to excessive movement of the coil out of the magnet gap unless the coil movement is carefully controlled. Air loading introduced by the enclosure in which the loudspeaker is mounted limits the movement to some extent: the movement of a loudspeaker mounted on a flat baffle would be greater than that of the same loudspeaker fitted in a closed box. If the coil is the same length as the magnet gap, as shown in Fig. 2 (a), a large part of the coil could leave the magnetic field, producing harmonic distortion because of the variation in magnetic flux cut by the coil. In (b), the coil is made shorter than the gap so that it cannot leave the

magnetic field so soon ; the same applies in (c), where the coil is longer than the gap. These last two methods are used (within certain limits) in modern loudspeakers.

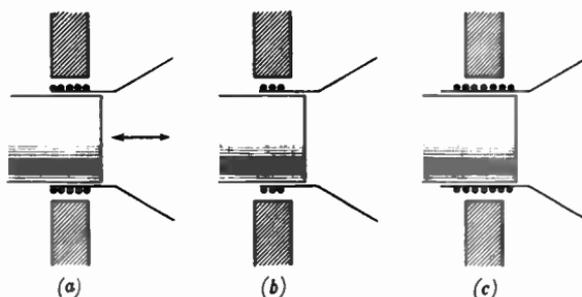


FIG. 2.—MEASURES TAKEN TO PREVENT THE COIL LEAVING THE MAGNETIC FIELD

The Magnet.—Magnets come in various shapes and weights and with different names. These are of no consequence to the amateur ; what matters to him is the cost and the amount of magnetic flux he gets for his money. A first class 12-in. loudspeaker which is to provide either wide-range or bass reproduction may well have a total flux of nearly 200,000 Maxwells, the flux density in the gap, which depends on the construction of the magnet system, being—a typical value—17,000 gauss (or 17,000 lines or 1.7 webers per square metre, if you like).

The total flux is a good guide to the value offered and is a sound basis for comparison purposes. One must remember that a good magnet has to be paid for and the figures mentioned above would belong to a single or twin cone loudspeaker in the £15 class. Impressive transient response, efficiency and power handling capabilities are benefits resulting from a powerful magnet. A sense of proportion is vital, however, since a loudspeaker with the best value in magnet specifications may still not possess certain other features which suit the enthusiast best for his particular application.

One final and essential comment : if a specification quotes only flux density in gauss (or lines), ask the manufacturer for the total flux in Maxwells. This is the figure which enables comparisons to be made.

Impedance.—As indicated in Chapter 3, things are not at all what they seem when we come to consider the impedance of the loudspeaker's coil and, particularly, the way in which this is matched to the amplifier. We must now examine the nature of this impedance more closely.

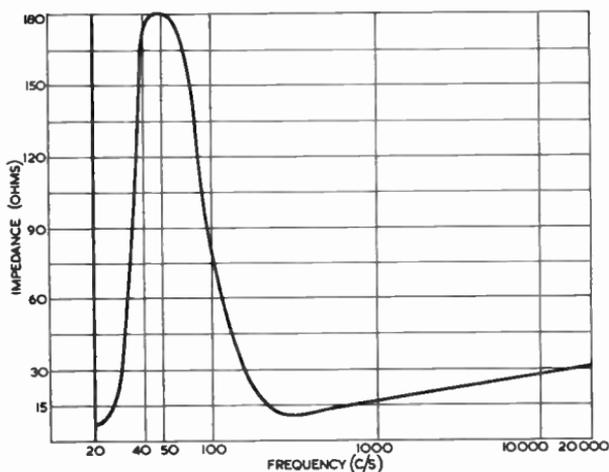


FIG. 3.—IMPEDANCE CURVE OF A MOVING-COIL LOUDSPEAKER MOUNTED ON A BAFFLE

A coil has both resistance and inductance ; the result is that the impedance, and therefore the current through the coil, varies with frequency. It is necessary to use some nominal value of impedance for reference purposes and the value of 400 c/s is normally taken. The most common impedance in high fidelity work is 15 ohms, but 3-, 7- and 10-ohm loudspeakers are also encountered.

This leads us to the loudspeaker's "impedance curve," the first of several measurements which will be mentioned in this chapter and certainly one of the most important. A typical impedance curve is shown in Fig. 3, and it can be seen that there is a big rise in impedance at the frequency of fundamental resonance. The height of this peak depends very much on the enclosure in which the loudspeaker is mounted and this serves to emphasise the fact that overall performance cannot be discussed without bringing in the design of the enclosure. The impedance curve also shows a rise in impedance

with increased frequency ; the enclosure has little effect in this instance and modification to the loudspeaker itself is the only way of reducing this. An aluminium coil is an advantage here, as the way in which aluminium coils are constructed means that they normally have less inductance than the more usual copper ones and will therefore allow more current to flow at high frequencies. A copper ring fitted on the magnet pole-piece, so that it is right in the field in which the coil moves, will also reduce inductance. Another method, used very occasionally, is to make the magnet so powerful that the pole-piece is saturated (*i.e.* it can accept no more flux) ; this gives the same final result and, of course, the large magnet system is advantageous in other respects.

Frequency Response.—Frequency response measurements are useful to the manufacturer when he is designing and producing his loudspeakers. The results of these measurements are, however, of negligible value to the amateur, who will find that careful listening and an examination of the other attributes mentioned in this chapter are more reliable pointers to quality. It is difficult to find a high fidelity loudspeaker nowadays which does not have the entire audio range claimed for it—occasionally with an indication of the linearity of response but usually without this.

Risking the accusation of surliness, the author prefers to leave this subject. To venture farther would take us on to thin ice (and deep water).

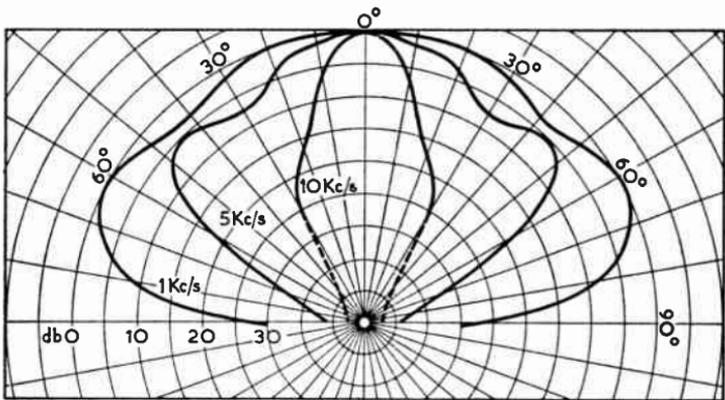


FIG. 4.—POLAR RESPONSE PATTERNS OF A TYPICAL LOUDSPEAKER AT VARIOUS FREQUENCIES

Polar Response.—This refers to the diffusion of the sound. As already indicated, low frequencies are not directional but “beaming” effects become more noticeable as frequency is increased. Fig. 4 shows the extent to which the sound radiation may become directional as frequency rises. The size and shape of the loudspeaker cone influences this and an understanding of what is involved has been largely responsible for the use of high frequency drive units (“tweeters”) of small diameter. These strengthen the output in the treble but, even more important, one or more tweeters can easily be arranged to widen the apparent source of sound and thus minimise directional effects.

Efficiency.—This was earlier related to amplifier output power. It is important to realise that there is simply no point in sacrificing efficiency by saving a pound or two on the loudspeaker; the loss in acoustic output will have to be made up by using more amplifier power. This means either a bigger and more expensive amplifier or the risky alternative of running a smaller amplifier near its rated output most of the time. It is fair to add that the amplifier should in any case be rated a bit higher than the loudspeaker. This provides the best working conditions for both items.

Efficiency depends a great deal on the magnet system of the loudspeaker. A big magnet is a “Good Thing” where power handling capacity and distortion-free response to transient signals are concerned. The amateur about to choose a new loudspeaker should take the opportunity to compare the various makes which employ the type of enclosure in which he is interested. At a reasonably high volume level, unaltered throughout the test, and with a selection of musical material, differences in efficiency and power handling will soon become apparent.

Enclosures

When thoughts are turned to the possibility of cutting the cost of high fidelity, the item which most often receives the amateur's attention is the loudspeaker enclosure. The non-technical enthusiast who cannot face the headaches and possible frustrations of amplifier construction will often undertake a simple woodworking job.

It is necessary to issue a warning which is all too seldom given :

the performance of the loudspeaker, especially the bass response, depends very largely on the enclosure, and it is vitally important that a loudspeaker is housed in a suitable cabinet. To put any loudspeaker, for example, in any old "bass reflex" cabinet is the sheerest folly. A bass reflex enclosure may well need tuning for optimum performance, and the amateur rarely has the measuring instruments for this. All is usually well if the enclosure was designed by the manufacturer of the drive unit with which it is to be used. In most other instances it is safer to buy either the complete system or a separate enclosure intended specifically for the drive unit concerned. There are some enclosures available in kit form which help to reduce costs.

The need for an enclosure is largely due to the fact that if nothing is done to separate acoustically the outputs from front and back of the cone, they will cancel out at low frequencies.

The Baffle.—The simplest way of separating the output from the front and back of the cone is to mount the loudspeaker on a flat baffle. Cancellation still occurs, but at a frequency which depends on the shortest dimension of the baffle, which should be half the wavelength of the lowest note to be produced.

In theory, a 50 c/s note would require a baffle dimension of about 11 ft. The wavelengths at various frequencies are shown in

Table 1.—Wavelengths of Sound

<i>Frequency</i> (c/s)	<i>Wavelength</i> (feet)	<i>Frequency</i> (kc/s)	<i>Wavelength</i> (inches)
30	36	1	13.0
40	28	2	6.5
50	22.4	3	4.5
60	18	4	3.2
80	14	5	2.7
100	11.2	8	1.6
200	5.6	10	1.3
300	3.4	12	1.1
500	2.2	15	0.9
800	1.4	20	0.65

Table 1. In practice, the size can be reduced for a given result since the baffle area is effectively increased by the floor on which it is standing. Baffle-mounting can be taken to its logical conclusion by using a wall of the room. The results are very good indeed and this is a cheap solution of particular interest to anyone having a house built or altered.

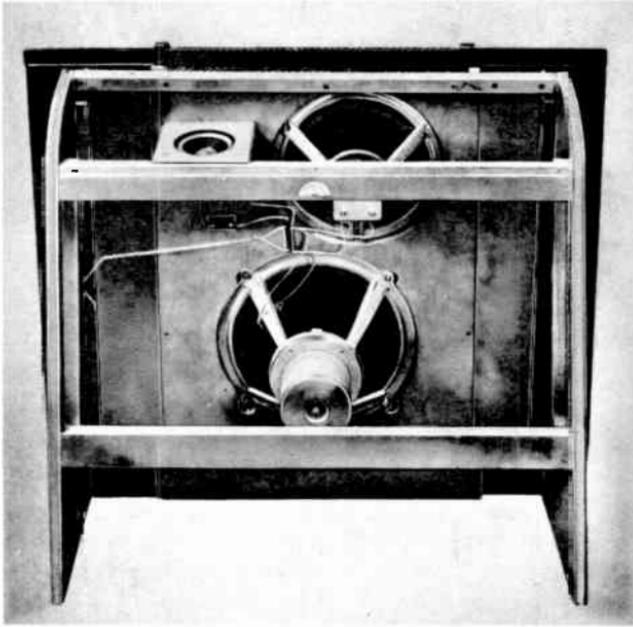


FIG. 5.—REAR VIEW OF THE WHARFEDALE SFB/3 BAFFLE LOUDSPEAKER, SHOWING 12-IN. AND 10-IN. UNITS AND UPWARD-FACING 3-IN. TWEETER

If this was all that could be said for the baffle, it would clearly hold little interest for the majority of people. Fortunately, the many recent improvements in loudspeaker design enable baffles to be considered once more. Good magnetic damping of the cone movement (that big magnet system again!) and the low fundamental resonance made possible by free cone suspension (the flannel or plastic foam surround mentioned earlier) prevent the distortion which would otherwise occur due to the poor acoustic load provided by a baffle of practical size. Further, mounting two speakers close

together and connecting them in parallel is found to give more and cleaner bass ; a further small degree of bass lift can then be introduced at the amplifier, according to taste. Prominent among the advocates of baffles are Wharfedale, who have done a great deal to hasten this come-back of an old favourite.

It should be noted that a loudspeaker should not be mounted in the dead centre of a baffle. The response is improved by mounting it slightly off-centre.

Closed Cabinets.—Apart from mounting a loudspeaker in a wall, an obvious way of preventing cancellation of sound from front and back of the cone is to use a completely air-tight cabinet. In a cabinet of practical size, the springiness of the enclosed air will raise the loudspeaker's resonance and, if this reaches too high a frequency, both music and speech will be "coloured" and made to sound unnatural. However, a specially designed drive unit can have a resonant frequency which is initially so low that the subsequent rise due to the enclosure is acceptable. Quite a small enclosure can be used in this way. An up-to-date example was developed by Goodmans.

Vented Enclosures.—If a vent is cut in a wall of the enclosure, the performance of the loudspeaker changes considerably. The enclosure now becomes a resonating system due to the behaviour of the air near the vent ; it is in fact a Helmholtz resonator, so named after a physicist who conducted extensive research into the properties of sound. The frequency of this resonance depends on the volume of air in the enclosure and the dimensions of the vent.

This is the underlying principle of the " reflex " enclosures which are in common use. The vent may be a single aperture or several and the cabinet proportions can be adapted to particular requirements. The resonant frequency has to be matched to that of the drive unit, and in this way the optimum acoustic loading is applied to the cone—a definite requirement in producing clean bass performance. A poorly adjusted enclosure, on the other hand, will result in boominess and distortion : hence the warning given earlier. In a correctly designed system, there is some output from the vent at the resonant frequency as well as from the cone.

It should be added that the fundamental resonance of a loud-

speaker drops a little in frequency as the cone and suspension age. This obviously means that the tuning of a "reflex" enclosure cannot remain exact over a long period. The best solution is to design the enclosure for a "compromise frequency" which is a little lower than that of the new loudspeaker's resonance.

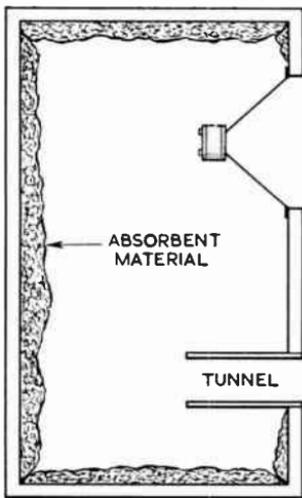


FIG. 6.—CROSS-SECTIONAL VIEW OF A VENTED ENCLOSURE WITH AN INTERNAL TUNNEL

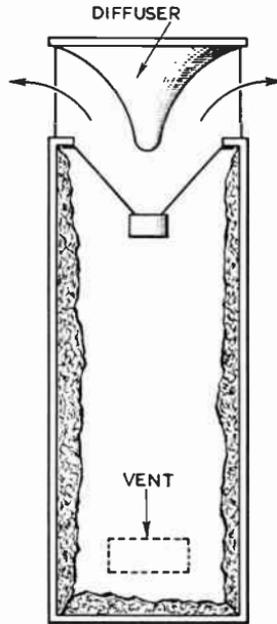


FIG. 7.—CROSS-SECTIONAL VIEW OF A COLUMN ENCLOSURE

The drive unit faces upwards into a diffuser.

The lower the loudspeaker resonance, the bigger must be the vented enclosure. Ways have, however, been found of reducing the size without sacrificing too much in performance. The volume can be reduced if the mass of air around the vent is increased. The most straightforward way of doing this is to extend the vent into the enclosure by means of a tunnel, as shown in Fig. 6.

Another method is to cover the vent partly or entirely with a material which adds resistive loading to the speaker (a fairly dense

cloth material imposes friction on the air movement). An alternative method is to divide the vent aperture into small holes or slits.

These treatments alter the resonant behaviour of the enclosure and improve the impedance curve of the loudspeaker. Resistive (or "friction") loading has been adopted by several manufacturers, including Goodmans and Wharfedale.

Columns.—These have become quite popular on account of the small amount of floor space required: the slim proportions are illustrated in Fig. 7. Mounting a suitable diffuser above the loudspeaker gives a completely non-directional distribution of sound. The enclosure is in some ways like a "reflex" type and some bass radiation is obtained from a suitably positioned vent. However, its proportions make it behave as a tuned pipe, and the resonances which are produced by this mode of operation have to be controlled by careful internal damping and solid cabinet construction. Column speakers employing 8 in. drive units are available from a number of manufacturers.

Horns.—A horn (see Fig. 8) provides the most efficient means of coupling a speaker cone to the surrounding air. Unfortunately, however, the length of the horn and the size of its mouth must be very large indeed if deep bass is to be reproduced. The straight horn depicted in Fig. 8 can, therefore, be used only for high frequency speakers, where the shorter wavelengths permit a horn of handy dimensions. (A moving-coil drive unit with a small diaphragm instead of a cone is often used in a horn of this type.)

A horn can be "folded" with little loss of efficiency, and the whole structure can then be contained in a cabinet of reasonable size. A wide-range drive unit cannot be used at the throat of the horn, however, as the high notes would be absorbed on their way around the folds, so that a separate high note speaker would be needed to make up for the loss. An exception was the Voigt Corner Horn. This was shortened sufficiently to avoid the need for a fold in its length, and the fall-off in bass which would naturally follow was compensated by a resonant enclosure in the bottom of the horn. The horn path was shaped so as to give good high frequency distribution and the drive unit gave a strong treble output.

A wide-range drive unit can also be used if the back of the cone

instead of the front is loaded with the horn. This is rather a far cry from the original idea of a horn but the various arrangements which can be devised all enable pleasing results to be obtained in a cabinet

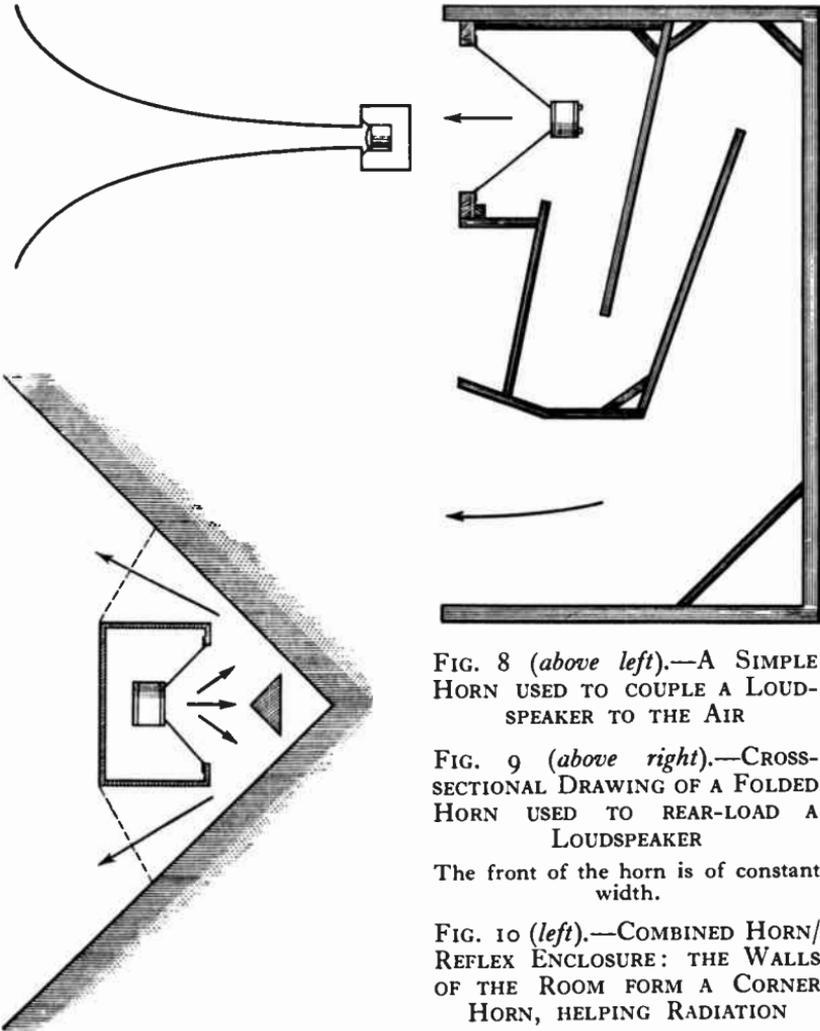


FIG. 8 (above left).—A SIMPLE HORN USED TO COUPLE A LOUDSPEAKER TO THE AIR

FIG. 9 (above right).—CROSS-SECTIONAL DRAWING OF A FOLDED HORN USED TO REAR-LOAD A LOUDSPEAKER

The front of the horn is of constant width.

FIG. 10 (left).—COMBINED HORN/REFLEX ENCLOSURE: THE WALLS OF THE ROOM FORM A CORNER HORN, HELPING RADIATION

of small dimensions. A representative method of partitioning the space in a rectangular cabinet is illustrated in Fig. 9. Treble radiation is direct from the front of the cone, bass radiation being

via the back of the cone and the folded horn. This method is used in the Lowther "Acousta."

Many other commercially available enclosures are based on the horn principle. Some corner designs use the walls of the room to complete the path of the horn. A corner speaker by Burne-Jones Ltd. provides a "reflex" loading for the drive unit and also uses the room corner as shown in Fig. 10. Treble output and diffusion are improved by separate drive units mounted at the top of the enclosure.

Periphonic Loading.—The "Periphonic" system is used by G.E.C. in large and small loudspeakers. Two drive units are housed in an air-tight enclosure, arranged one behind the other and connected so that their cone movements are out of phase. The conventional moulded paper cone would not stand the pressure set up by this "push-pull" operation and G.E.C. employ drive units with metal cones. This system is claimed to improve low frequency performance by substantially reducing the generation of second harmonics. Output above 1,500 c/s is handled by separate high frequency radiators.

Damping.—Damping materials are supplied to the internal surfaces of most enclosures, particularly vented types, to absorb reflections. Such reflected energy can set up "standing waves," the formation of which depends on the distance between opposite surfaces of the enclosure. Damping materials such as felt or glass wool are attached to the surfaces in most instances; they are even more effective if spaced off a little. The reflected energy can be dealt with more successfully if the enclosure has no parallel surfaces. However, a cabinet of irregular shape is not likely to be acceptable from the point of view of appearance; the nearest approach is an enclosure of triangular section for use in a corner.

It is sometimes found that, where the enclosure houses a wide-range loudspeaker, too much damping material tends to take some of the sparkle out of the sound. It is very much a matter of taste, and the effect obviously depends on the characteristics of the loudspeaker itself at middle and high frequencies.

Construction Material.—Although many enclosures depend on controlled resonant behaviour for their successful operation,

resonances of the walls of the cabinet must in general be avoided. This can be done by making them of heavy, rigid timber or an equally dense substitute. This is expensive, but there can be no compromise if the very best bass response is required. In the case of baffles, and panels intended for use across a corner of the room, the construction may employ two plywood sheets with dry sand in the space between them. The sand effectively absorbs the vibrations and the result is an inert panel which adds nothing of its own to the loudspeaker's output. Enthusiasts who are having a house built or a room modified would be well advised to construct an enclosure from bricks or concrete blocks—the results surpass those from any wooden cabinet. The enclosure could be in a corner or made in the form of a "buttress" on a dividing wall; the final finish could match the decor of the room.

Multi-Speaker Systems.—The frequency spectrum may be divided between two or more loudspeakers, each of which can then be designed to have the most desirable characteristics for its particular range. A bass reproducer might handle frequencies up to, say, 1,000 c/s, and a treble unit can take the response from that point up to the limit of audibility. The electrical division between the two is looked after by a crossover filter. A third speaker to handle the mid-range can be introduced if required.

Such arrangements overcome the problem of the conflicting requirements of high and low note radiation at the expense of simplicity. It can be claimed that distortion is reduced. A major advantage lies in the fact that the treble speaker, which is invariably small, can be positioned so as to avoid beaming the high frequency energy. This is facilitated by its modest baffle requirements (made possible by the short wavelengths being reproduced).

An alternative "multi-speaker" system is the "coaxial" speaker, which combines two loudspeakers in a single unit. It is specially suitable for listeners who prefer sounds of all frequencies to come from approximately the same point. In this type, sometimes known by the name "dual concentric," the high note drive unit is housed in the magnet system of the bass speaker and the horn which couples it to the air is situated in the centre of the main cone. A loudspeaker of this type can be used in a vented enclosure or any other design intended for direct radiation of the sound. The directional

properties are fixed by the arrangement adopted. A comparison of various types of loudspeaker will quickly show whether this or a less directional arrangement is preferred.

Tweeters.—This name is affectionately applied to loudspeakers which handle only high frequencies. There have been various ingenious designs aimed at producing a smooth, extended treble

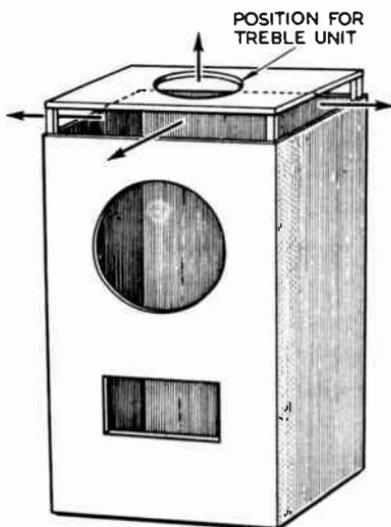


FIG. 11.—A SIMPLE TWO-SPEAKER SYSTEM

The treble unit is mounted on an upward-facing baffle.

response. Prominent among these is the horn-loaded Ionophone, with which the author was at one time associated (perhaps this accounts for its non-appearance on the British market !). This unique device has no moving parts ; instead, a radio frequency discharge is set up inside a quartz tube and the oscillator producing this is modulated by the audio signal. Of the tweeters which *are* in general use, the ribbon type is outstanding. In principle this is basically a moving-coil device, but instead of a coil of several turns of wire there is a single strip, or ribbon, of very thin foil. This is suspended between the poles of a powerful magnet and coupled to the outside air with a small horn. The large magnet is expensive, but is justified

by the superior results. One of the few examples to be marketed is the Kelly Mk 11. Small horn-loaded diaphragm loudspeakers are used in some two- and three-way systems of the direct radiator type (*i.e.* all units facing the listener). Goodmans advocate these and incorporate them in several multi-speaker systems.

Apart from the above types, conventional moving-coil tweeters of about 2 in. to 8 in. diameter are widely used. The coils are usually wound with aluminium wire, for reasons already indicated. The smaller ones must be protected from low frequency signals, which would cause large cone movements and consequent damage (this applies also to ribbon and small horn-loaded units). It is one of the functions of the crossover filter to do this. Of course, this is all taken care of in complete loudspeaker systems. A section is included at the end of this chapter for those who wish to add a second loudspeaker to an existing one.

Conclusion.—A typical simple two-speaker system is shown in Fig. 11. This is not intended to represent an actual design although many systems are very similar. It will be seen that the tweeter faces upwards so that the walls can be used to help distribute the treble. In a corner position, there is wide enough diffusion to make the source of sound appear quite large and the bass is helped as well.

There are probably more non-directional systems on the market than any other type. Prices range from about £15 to £100.

Electrostatic Loudspeakers

The last type of loudspeaker to be mentioned is one that, as far as the present situation is concerned, needs no enclosure at all. Work undertaken many years ago quickly led to electrostatic devices which would handle a part of the frequency range, but it is only comparatively recently that a compact electrostatic loudspeaker which works over virtually the entire audio spectrum has been developed. Only one wide-range model is commercially available at the time of writing.

Briefly, a simple electrostatic speaker consists of a flexible diaphragm mounted very close to a rigid plate. A varying voltage applied to these two parts, which are the basic essentials of a capacitor, causes corresponding movements of the diaphragm towards the plate. It is found that, to reduce distortion, it is necessary first to

apply a fixed d.c. polarising voltage to attract the diaphragm towards the plate by a certain amount. The a.c. signal voltages from the amplifier now vary the diaphragm's permanent attraction. A perforated fixed plate is also essential, otherwise air trapped behind it would limit the movement of the diaphragm. The arrangement is shown in Fig. 13.

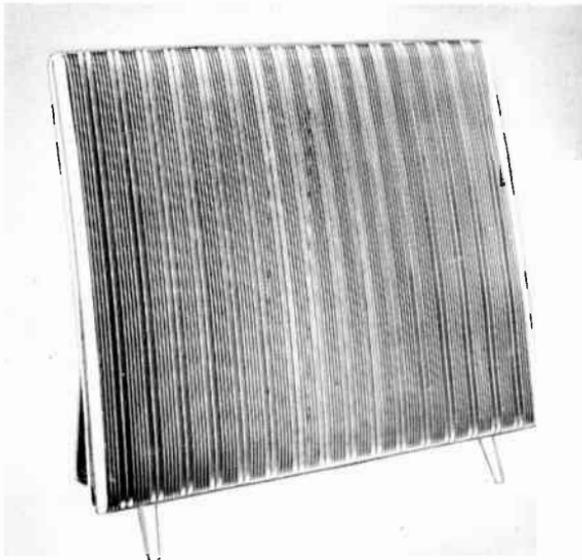


FIG. 12.—THE QUAD ELECTROSTATIC LOUDSPEAKER

This simple type is mentioned mainly in order to contrast it with the later development, the "push-pull" electrostatic. Simple tweeters do enjoy some popularity, of course, and their surprising cheapness enables many firms to use them in so-called hi-fi reproducers and the more cheerful type of record player. In general, their characteristics rule out their inclusion in genuine high fidelity installations.

Early push-pull models, largely experimental, still gave an output which was rich in harmonics but further development in post-war years led to a considerably improved version. The diaphragm of this type (see Fig. 14) is positioned between two perforated plates by means of insulating spacers.

As shown in the diagram, the polarising voltage is applied via a resistor R of high value. The object of this is to prevent variation in the charge even during the time taken for the large movements involved in low frequency reproduction. The resistance multiplied by the loudspeaker's capacitance gives a certain time constant, which must be long for the lowest frequency to be reproduced. It

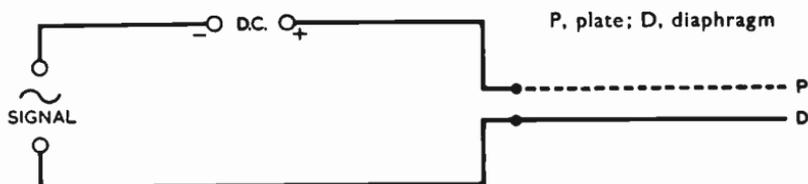


FIG. 13.—ELEMENTS OF A SIMPLE ELECTROSTATIC LOUDSPEAKER

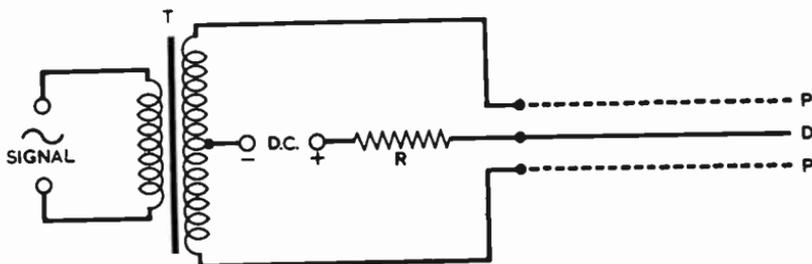


FIG. 14.—ELEMENTS OF A PUSH-PULL ELECTROSTATIC LOUDSPEAKER

is also important that the charge shall not distribute itself unevenly over the diaphragm such as to cause a disproportionately strong attraction at any point. A constant charge per unit is required and therefore the diaphragm's conductive coating is given a very high resistance, to prevent the charge moving about on the surface.

The outstanding design requirement, then, is an electrostatic force which is proportional to the signal voltage. With this requirement satisfied, we have a loudspeaker in which large diaphragm movements can take place with very little distortion. A linear relationship between input and output is obviously a requirement for a good moving-coil speaker too, but, whether this ideal can be achieved or not, the fact remains that the cone and coil have considerable weight.

This brings us directly to the way in which the modern electrostatic loudspeaker scores over the long-established moving-coil type. The lightness of the diaphragm ensures instant movement on application of a sudden signal and equally prompt cessation of movement when the signal is removed. The result is a very good transient response. A cone, on the other hand, does not move in one

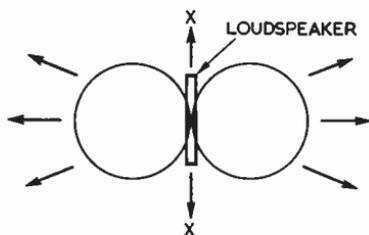


FIG. 15 (a).—SOUND RADIATION OF A DOUBLET

There is no radiation in the plane of the loudspeaker (*i.e.* direction "x.").

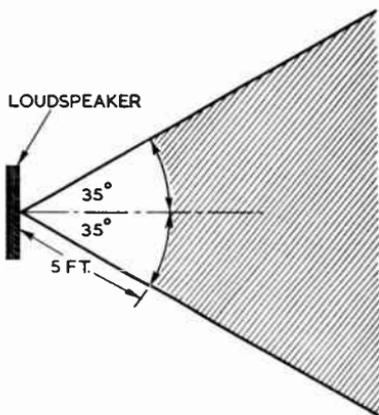


FIG. 15 (b).—OPTIMUM LISTENING AREA

Based on the Acoustical Quad electrostatic loudspeaker.

piece under all circumstances ; there is some deformation, depending on the nature of the signal. It is thus especially at a disadvantage when faced with a transient signal. The electrostatic loudspeaker also exhibits fewer resonances and a smoother frequency response.

There is obviously a practical limit for the dimensions of any loudspeaker—domestic considerations alone impose this—but it has been found possible to obtain adequate bass from a free-standing electrostatic loudspeaker which radiates from its entire surface, without acoustic loading. The diaphragm is big enough and can make sufficiently large excursions to push enough air. Acoustic loading by means of an enclosure would give a further extension of bass response, but a loudspeaker of practical size which avoids the resonant behaviour which enclosures introduce is obviously an extremely attractive proposition.

The only wide-range electrostatic loudspeaker currently available is the Acoustical QUAD. This model measures approximately $34\frac{1}{2}$ in. wide \times 31 in. high \times $10\frac{1}{2}$ in. deep at the base. The overall thickness of the plate and diaphragm assembly is about $2\frac{1}{2}$ in.

A free-standing sound source of this type, radiating from front and rear, is known as a "doublet." The recent development of the baffle loudspeaker using moving-coil drive units, mentioned earlier, is also of this type. A theoretical polar response is shown in Fig. 15. There is no output from the sides of the speaker and none above or below. The effect of this distribution will be realised when room acoustics are discussed. Results are very different from those produced by a multi-speaker moving-coil system, where the higher frequencies and much of the middle range are projected in various directions to achieve a certain diffusion.

Differences in diffusion coupled with low distortion and absence of resonances have led many listeners to express doubts about the sound quality. Expressions such as "cold" and "lifeless" (how inappropriate!) have illustrated how very *different* a doublet loudspeaker sounds to them.

A further point about the sound distribution brings to mind the multi-speaker system once more. In that type, the conflicting requirements of good high and low note efficiency and diffusion are what lead to the use of separate cones. The electrostatic loudspeaker is treated in similar fashion, the diaphragm being divided into several sections, each handling a certain frequency band. Suitable high note diffusion is further helped by making the diaphragm convex in one plane.

Wall mounting of the electrostatic loudspeaker, using the wall as a baffle, may well become popular in due course. A doublet cannot be mounted *against* a wall, however, nor can it be used in any position which traps air behind it.

The Acoustical QUAD has an in-built transformer which matches the high impedance capacitative load to a conventional amplifier. A dividing network for the sections of diaphragm is incorporated. For good technical reasons, the loudspeaker will not work equally well with all amplifiers: instability is likely in some cases. The makers of the loudspeaker and many audio specialists in the trade can give advice on this matter to prospective purchasers.

A polarising voltage of several kilovolts is called for because of

the wide diaphragm-plate spacing necessary in the loudspeaker's bass section. An E.H.T. unit, ready for connection to an a.c. supply, is fitted in the bottom of the loudspeaker: the power consumed is negligible.

Multi-Speaker Systems

Adding a second loudspeaker to an existing one, to extend the treble response or to modify the diffusion of the treble and middle range, is a fairly simple matter, and quite non-technical enthusiasts often undertake interesting and fruitful experiments in this way. As indicated earlier, crossover filters or "networks" must be used in this case to separate the loudspeakers electrically so that each can handle the part of the spectrum (and the power involved) for which it is most suitable.

Before considering an electrical division of the loudspeakers, however, we should see what can be achieved by connecting two wide-range loudspeakers together without this separation.

Two in Parallel.—Connecting two loudspeakers in parallel has the effect of reducing the peak in the impedance curve at resonance (see Fig. 3) and makes for a generally improved bass response. This, therefore, will be a very useful and economical move if an improvement in treble performance can be arranged at the same time.

Let us assume that the existing speaker is a 12 in. or 10 in. unit and that the bass response has been found adequate. If its treble response falls smoothly away, a second loudspeaker of similar size and power handling capabilities which has the required treble performance can be added in parallel. This new unit may be anything from 8 in. to 12 in., but obviously not a small tweeter.

The two loudspeakers could be mounted on a baffle, in which case they should be situated as close together as possible. They could be placed in the same cabinet if this arrangement is more suitable. It is important that they should be in parallel—loudspeakers should never be connected in series as this means that each of them has the other's resistance between it and the amplifier, to the detriment of the latter's damping effect. It is also necessary for them to be in phase—that is, the cones must move in and out

together. This can be checked by listening: if there is a serious lack of bass, the speakers are out of phase and the connections to one of them must be reversed.

If two speakers are in parallel, the effective impedance will be halved. If 15-ohm models are used, the amplifier should be adjusted for the nearest impedance to $7\frac{1}{2}$ ohms. A nominal impedance between 6 and 9 ohms provides a reasonable match.

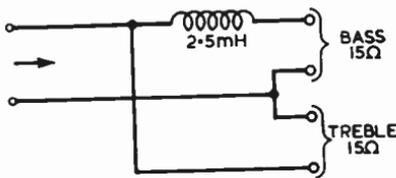


FIG. 16.—SIMPLE FILTER TO LIMIT HIGH FREQUENCY INPUT TO EXISTING LOUDSPEAKER

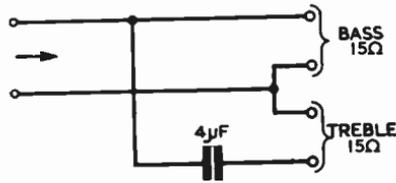


FIG. 17.—USE OF CAPACITOR TO ADD TREBLE UNIT TO EXISTING LOUDSPEAKER

Simple Filter.—If the existing loudspeaker has a treble response which is objectionable, adding a second unit which has a pleasing response will make little overall difference. Matters can be improved by preventing high frequencies—above 1,000 c/s, say—from reaching the first speaker. An inductance in series with it, as shown in Fig. 16, will achieve this. The effective impedance is no longer halved: the combination should be connected to the amplifier's 15 ohm output.

Adding a Tweeter.—A small moving-coil unit or a horn-loaded tweeter can be added in parallel with practically any loudspeaker system in order to reinforce the treble. Low frequencies must be filtered out or the tweeter will be damaged. There are several self-contained and housed tweeters on the market which incorporate a filter capacitor and are ready for connection.

If the drive unit is purchased by itself, it must be connected via a capacitor as shown in Fig. 17. If both main loudspeaker and tweeter have an impedance of 15 ohms, the amplifier output should be the same and the tweeter will handle frequencies above about 3,000 c/s. Some small moving-coil units, particularly those with aluminium wire coils, may have a non-standard impedance a little

below 15 ohms but the arrangement described need not be altered for these. Common tweeter sizes are 2, 3 and 4 in. diameter.

The tweeter may be mounted on a small baffle (6 in. square is more than adequate) and arranged on the main enclosure facing upwards or tilted forwards. The position is not important provided that it is not lifted from the main cabinet altogether. Phasing is of no consequence.

It should be remembered that the original loudspeaker will in this arrangement still be handling the whole frequency range, and the tweeter will add its contribution to the upper register.

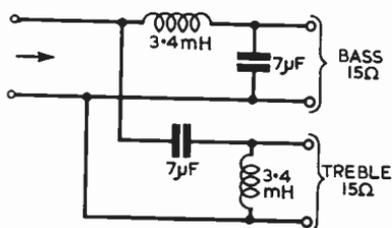


FIG. 18.—HALF-SECTION CROSSOVER FILTER FOR SEPARATE BASS AND TREBLE UNITS

Complete Filter.—An arrangement which confines the bass to one loudspeaker and the rest of the range to another gives very fine results, assuming that each unit is specially suited to its particular job. The bass loudspeaker can be in a vented enclosure and the second loudspeaker—a high quality 8 in. unit, for example—can be mounted on a baffle as big as the top of the enclosure (see Fig. 11).

The 1,000 c/s crossover filter shown in Fig. 18 could be used. This circuit gives a fairly steep attenuation of response each side of the crossover frequency. It is known as a “half-section” filter and the rate of attenuation is 12 dB/Octave.

With regard to phasing, the connections to one loudspeaker should be reversed to ascertain whether sound quality is affected. If a slight difference is detected, the listener should settle for the connection which sounds right (*i.e.* the smoothest-sounding response). A more objective method of checking phasing is to connect a 1.5 volt torch battery across each loudspeaker in turn, noting which way the

cone moves. The loudspeaker terminals can then be marked + or — and this “polarity” observed when circuit connections are made. This treatment must be reserved for the larger loudspeakers ; never connect a battery across a small tweeter of any description.

Components.—Complete crossover filters are made by several loudspeaker manufacturers, including Wharfedale and Goodmans. Suitable air-cored inductors and high quality capacitors are sold by many dealers. Values shown in the diagrams are approximate and a 10 per cent tolerance is reasonable. Paper or metallised-paper capacitors with a working voltage of 50 v. or more will be satisfactory. The air-cored inductors are simply coils of copper wire, of sufficiently large gauge to ensure that the losses they introduce into the circuit are very small. Even these losses can be reduced by winding the coils on magnetic cores : this enables the same inductance to be achieved with fewer turns of wire. Mullard Ltd. advocate the use of cores of the moulded ferrous oxide variety, and market suitable types under the Ferroxcube trade name : they will supply coil-winding data. These cores, together with the most up-to-date capacitors, enable quite small crossover filters to be assembled. Perhaps it should be emphasised that other types of magnetic core are not suitable.

More elaborate circuits exist for specific applications, and loudspeaker manufacturers can often provide details. It should be noted that two loudspeakers whose impedances are very different cannot be used together in conjunction with a crossover filter. On the other hand, a high frequency loudspeaker (of the small moving-coil variety) can have a slightly lower nominal impedance than its companion. The nominal value will apply at mid-frequencies, but the actual value is likely to be higher than this in its working range.

It is possible to effect an economy in the circuit shown in Fig. 18 by raising the crossover frequency to 2,000 c/s. The frequency having been doubled, the inductance and capacitance values will be halved. However, the 1,000 c/s crossover gives the best results. Of course, if the frequency is lowered to 500 c/s, the component values must be doubled.

LISTENING ROOM ACOUSTICS

A BRIEF discussion of the room's principal effects on sound reproduction is essential at this stage. For most enthusiasts, the listening room is the living-room and opportunities to influence the distribution of the loudspeaker's output are strictly limited. However, opportunities do sometimes arise—depending on domestic circumstances—and it is important in any event to realise that the rather odd characteristics of the room take their toll before we have our chance to assess the quality of reproduction.

It will be appreciated that a sound wave can travel only a certain distance before its energy is dissipated. If the wave strikes a wall, some of the energy is absorbed, generating heat, and some carries on through the wall and is heard on the other side. Another part, often considerable, is reflected. We are concerned here with the reflections in the listening room and the ways in which we can absorb some of them.

Reverberation and Absorption

Too much reverberation, due to reflections from the surfaces in the room, leads to generally "muddled" results. The "reverberation time" is the time taken for the sound energy to fall to one millionth of its original value. This is a decay of 60 dB.

The various materials used for walls, ceilings and floors absorb different amounts of energy throughout the audio range. For example, absorption could be such that reverberation was the same at high and middle frequencies but increased below this. A characteristic of that sort might well be found agreeable; it depends to some extent on the taste of the listener.

Many other factors have to be considered, however, and the process of measuring a reverberation time and determining whether it is the most suitable for the particular application is very complex

and difficult. The expert is helped by musical experience and an appreciation of people's reactions and tastes ; he is able to reach some sort of conclusion based on his knowledge of the way in which materials are used in the construction of a house. One difficult factor concerns the tendency of large areas of, say, floor or ceiling to resonate and therefore absorb surprisingly large amounts of energy at particular frequencies.

The most suitable reverberation time depends on the size of the room and for most living-rooms, a figure of about half a second has often been found very satisfactory. This refers to middle frequencies ; it can be contrasted with the corresponding figure of 1.5 sec. for the auditorium of the Royal Festival Hall. As it happens, the comparison cannot be made without qualification : the half-second for a living-room is based on the assumption that *only* reproduced music is catered for. Players in, say, an amateur string quartet using the same room might not find the acoustics to their liking. Further, the single-channel sound with which we are all familiar is the basis of much of the work carried out so far : we shall have to wait until we have had sufficient experience with stereophonic sound to know to what extent present thought has to be modified.

The normal furnishings of a room, and the listeners themselves, also absorb sound energy in varying degrees and over various parts of the audible frequency range. The often quoted half-second reverberation time might be automatically achieved at mid-frequencies by a quite fortuitous combination of soft furnishings and decorative surfaces. This must apply to a large number of living-rooms, and this favourable amount of absorption may also be operative at higher frequencies. On the other hand, the modern trend in furnishing seems to be away from those materials which absorb sound over the widest frequency range. Where large surfaces are concerned, glass is one of the worst acoustically ; large windows are obviously desirable just the same. In some instances, structural resonances can give rise to effects which the listener finds troublesome but which he is unable to identify.

Clearly, some people will be fortunate enough to have practically ideal listening rooms where reverberation is concerned. Others, less fortunate, can make a limited number of improvements, but the extent of these will depend on whether technical requirements are compatible with the family's ideas about room decor. Different

flooring materials offer definite possibilities: thick carpeting is certainly the best and foam rubber underlay, though more expensive than hair felt, gives the finishing touch to both acoustics and comfort. Cork tile and rubber floors are probably next on the list but some extra thick rugs are required. Solid floors (*e.g.* concrete or composition) are much better than wood boards on joists.

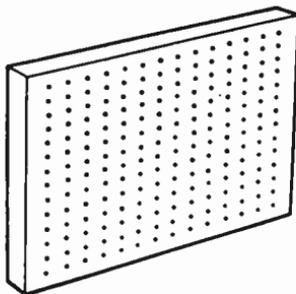


FIG. 1.—PERFORATED
ACOUSTIC TILE

If the enthusiast has floors of this type as well as generous soft furnishings, yet feels that he would be happier with more absorption in the high and middle frequency range, he can use the special acoustic materials which are sometimes employed in offices, etc. Acoustic tiles of the type shown in Fig. 1 come in several thicknesses and in 1 and 2 ft. square sizes. Other types, of similar construction but with plain or slightly decorative surfaces, are also available. Such materials can be fixed to limited areas of ceiling or wall; it is easy to overdo this, however, and the advice of an expert should be sought. It is, of course, a more straightforward matter to modify a separate music room than to treat a living-room.

Low frequencies are little affected by the application of the well-known acoustic tiles. Improvements involve special wall panelling acting as a series of resonators and absorbing energy in a fairly limited range. This treatment can look very pleasing and might be considered for a separate music room in a new house. There is, in fact, a good deal that can be done when a house is being built or when structural alterations are made to an existing house. In this connection, further requirements for the perfectionist will be mentioned in the next section.

Room Resonances

We are concerned in this section not with resonances of materials but with those due to the dimensions of the room. There are resonant vibrations of the air in every room and these occur at frequencies at which a dimension is one-half wavelength. For example, if a room is 16 ft. long, there is a resonance at 35 c/s. There are others at harmonics of this frequency—at the second harmonic (70 c/s) and third harmonic (105 c/s)—and many more associated with the width, height and diagonal dimensions. What are known as “standing waves” occur at the resonant frequencies, giving rise to increases in pressure at certain points.

This is not mentioned in order to point to some quick remedy. Indeed, there is no way in which a fundamental change can be made. However, most of the pressure points fall in the bass region which we are trying to reproduce, and it is often found that an unfortunate choice of position for the loudspeaker or our favourite chair rules out all hope for natural results. Moving the chair will take the listener away from a pressure maximum; this might overcome a certain boominess which had been blamed on the loudspeaker. Moving the loudspeaker itself will cause different resonances to be excited more strongly and the result may be preferable to the original arrangement. A “ringing” or “barking” effect is sometimes noticed in rooms where the walls are not very solid (usually in new houses!). This is due to a combination of air and structural resonances and little can be done about it short of major alterations.

It has been pointed out by several authorities that air resonances should be distributed as widely and evenly as possible. Quite obviously they cannot be eliminated. This distribution is at its best when the room has certain proportions, and the ratio of 1 : 1.6 : 2.5 for height, width and length has been suggested by J. Volkman, an investigator in this field. This would suit a fairly large room and, to take an example at random, the dimensions could be 9 ft. high, 14 ft. 6 in. wide and 22 ft. 6 in. long. An alternative ratio of 1 : 1.25 : 1.6 has been suggested for a small room. Whatever its proportions, a room will be improved acoustically by irregular projections and broken surfaces.

Position of Loudspeaker

Most people seem to prefer a corner position for the loudspeaker on the grounds of convenience, and many loudspeakers are made with this in mind. A corner position helps bass performance but it does not follow that room resonances are activated in the most acceptable way. Even so, the corner position may be the most favoured just the same because, as mentioned before, high frequency

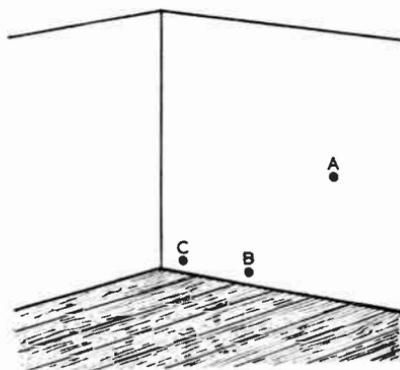


FIG. 2.—LOUDSPEAKER POSITIONS IN WALL
Position A gives half the bass radiation of position B, and only a quarter as much as position C.

diffusion can be enhanced by this arrangement where so many current designs are concerned. The best course is to experiment with the loudspeaker position, having due regard to the design and purpose of the cabinet, also trying as many seating positions as the room layout will permit.

Mounting the loudspeaker in a wall was mentioned in Chapter 4. Again, the proximity of the loudspeaker to a corner will influence bass response. Referring to Fig. 2, a loudspeaker mounted at position B will radiate twice as much power as one fitted in the middle of the wall, *i.e.* at A. Mounted in the corner, at C, the radiated power will be four times as much as at A.

It should be added that a corner position for an enclosure does not give quite the same thing. The position (see Fig. 3) is obviously somewhere between B and C in Fig. 2 so far as bass output is concerned.

If the loudspeaker is mounted in a wall, the hole made to receive it should have chamfered edges on both sides. Otherwise, there is bound to be a short "pipe" on one or both sides of the loudspeaker and resonances, which would affect performance, might result.

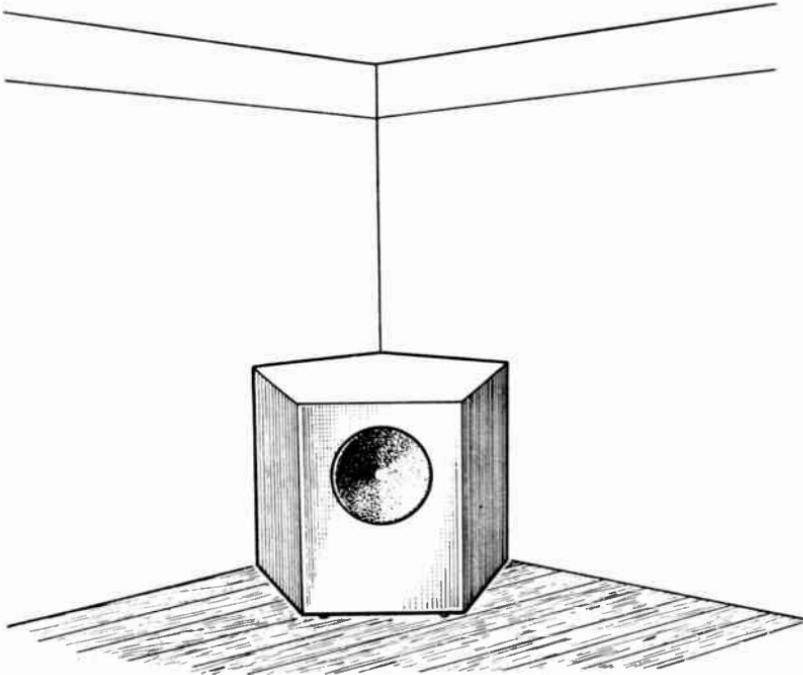


FIG. 3.—CORNER POSITION FOR LOUDSPEAKER ENCLOSURE

The output of a "doublet" such as the electrostatic loudspeaker has been commented on in the previous chapter. Since it only radiates sound "fore and aft" it will only excite room resonances in those directions. Also, the listener hears directly radiated sound and not the diffused sound which, in most other loudspeaker systems, is necessary for pleasant results.

In addition to offering the advantages noted at the end of Chapter 4, two loudspeakers in parallel (in separate positions in the room) enable air resonances to be excited in a more complex and often more pleasing way. This is partly responsible for the natural

results of stereophony and we shall, in effect, complete our discussion of this topic in the next chapter.

Low Frequency Limit

Contrary to popular opinion, the lowest note which we can comfortably reproduce in a room is not finally determined by the equipment. The room has the last word (a very audible one at times) and the lowest frequency is the one the half wavelength of which corresponds to the room's longest dimension (note that this will be a diagonal measurement in the case of a corner mounted loudspeaker). The bass response falls off below this frequency.

This does not mean that the enthusiast who uses a small room can lower his sights too far: too many sacrifices in amplifier and loudspeaker specification lead to distortion in that bass which is appropriate to the room. But it does mean that a loudspeaker which can accurately reproduce 30 c/s is wasted in a room measuring 12 ft. by 10 ft. It is better to settle for a smaller loudspeaker with good performance down to 50 c/s. The money saved here is best lavished on the pick-up. Many people who misguidedly buy a big loudspeaker for a tiny flat spend most of their time boosting the bass at the amplifier. The result is distortion and the most unpleasant excitation of room resonances. It contributes in no small measure to what is often called "listening fatigue."

These remarks do not contradict what was said earlier about the effect of loudspeaker position on bass radiation. Obviously, all the factors mentioned should be carefully weighed in the balance before a choice of loudspeaker is made.

Conclusion

Some listeners will be better served than others where the listening room is concerned. Really serious shortcomings exist in some instances and no fundamental changes can be made in the normal course of events. The enthusiast can, however, mitigate the worst effects by sensible choice of loudspeaker and some experiment with its position in the room. If a corner position is the most convenient, a little experiment with seating arrangements may be rewarding. First-class results are obtainable in spite of many

difficulties. The advent of stereo will help matters ; it is interesting to note that the two loudspeakers which are necessary in a stereo installation give superior results whichever type of record is being played.

An existing room can be improved, particularly where absorption of the higher frequencies is concerned, at a time when major alterations or redecoration are planned. Considerably more can be done when a house is being designed and built ; close attention should then be paid to the construction and proportions of the room. The various improvements can be definite features of the room and can enhance its appearance. Needless to say, a music room can be acceptable for other purposes—it would be restful as a study, for example. It is also worth bearing in mind that most improvements to acoustics also improve thermal insulation.

6

STEREOPHONIC SOUND

THE arrival of stereophonic sound as a commercial proposition opens the door to higher fidelity than that which has been possible so far. It also makes possible the exploitation of oddities and superficial excitements. These may impress by their novelty, but the music-lover, after hearing the moving tributes to British Railways and the interminable counter-marching of the stereo troops favoured by many demonstrators, is likely to ask whether anything of musical value is in fact offered.

Those who persist in their search for better sound should not take long to realise that stereo is of great importance to them provided that it is not allowed to replace what has already been proved of value. An installation which adds stereo to accepted high fidelity standards will always give the most outstanding results. We shall therefore proceed with that thought in mind.

Calling It Names

As with many new developments, the terminology to be applied to the two types of sound reproduction has caused some misunderstandings and arguments. The familiar gramophone has been unfairly called "monaural" (and even "steam hi-fi"!) while the new development was blessed from the start with a convenient and glamorous abbreviation.

The redoubtable Harry F. Olson of R.C.A. in America has given a neat summing-up. He applies "monaural" and "binaural" to what may be called closed circuits (see Fig. 1 (a) and (b)). Monaural, in his definition, comprises a system with one microphone in the studio (or a system of microphones) connected to a pair of headphones for the listener as in Fig. 1 (a). The binaural system, as shown in Fig. 1 (b), involves two microphones (or sets of microphones) and a pair of headphones of which the two

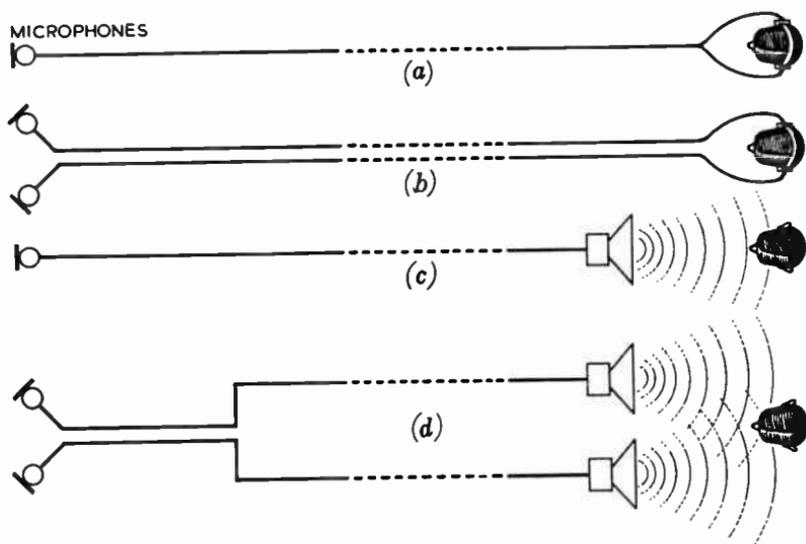


FIG. 1.—SYSTEMS WITH ONE AND TWO TRANSDUCING CHANNELS
 (a) Monaural, (b) binaural, (c) monophonic, (d) stereophonic.

earpieces are connected to one microphone, or set of microphones, each.

The word "monophonic" (offering the abbreviation "mono") is applied to a system, as shown in Fig. 1 (c), which uses loudspeakers with one recording channel. A system involving two separate recording channels, combined on a disc or tape in such a manner that they can be separated at the reproducing end and fed to separate loudspeakers, no matter how many, merits the name "stereophonic." Incidentally, it seems that musicians occasionally use the word "monophonic" in a different sense, but it is best not to quibble now that we have found such a promising terminology.

It should be clear that the numbers of microphones and loudspeakers do not determine the matter: a monaural or monophonic system could use twenty microphones (in order to get a well-balanced sound), and a stereophonic system could have two or more loudspeakers in each channel (for reasons given in Chapter 4). The number of transducing channels—which bring the sound from studio to listener—is what counts. Two channels are not the limit; they are merely the minimum.

Headphones do not concern us here and we can therefore forget all about monaural and binaural. All reproduced sound will be mono or stereo for the remainder of this book.

Reasons for Stereo

Most observers who are interested in the world of the gramophone will want to understand the justification for all the money and ingenuity that has been spent on this development. In pointing to the justification, some fault must be found with the mono sound reproduction which we have enjoyed for so long and which has reached such a high standard in recent years. Some brief comments on our hearing mechanism will help to lead up to a comparison of stereo with mono.

The whole complex hearing process is not yet understood in every detail but there is a good deal about which investigators can feel certain. The location of sounds in the horizontal plane by our ears and nervous system is in itself most complicated. When the sound source is to one side of us, the ears experience differences in sound intensity because the head effectively masks the ear which is furthest from the source. Another factor is the difference in time of arrival at each ear of the sound. The process which applies at low frequencies is not the same as that for high frequencies. Head movements are involved when we wish to determine the location of a sound source in the vertical plane. In estimating distance, the brain relies largely on memory of similar experiences. All these processes take place very rapidly and automatically, and hold good to a large extent for people whose hearing is less than perfect.

These considerations of sound location may be expressed in another way: we are able to "sort out" one sound from another. The laymen who is not particularly concerned about the why and wherefore will be quite aware that he is able to push unwanted noises into the background while he concentrates on a particular sound. This faculty, and all that makes it possible, is used in the concert hall as well as in everyday activities.

We can now suggest the basic limitation of any system which attempts to convey information via a single recording or transmitting sound-channel: our ears and brain cannot exercise their usual powers and they have to accept the mass of sound just as it comes,

We cannot distinguish the relative positions of sound sources in a monophonic system.

Any possessor of a tape recorder can have a partial illustration of what is lacking in mono recording. When he is about to record with the microphone, he may go to great lengths to ensure that all is quiet. However, the indiscriminating single microphone will not concentrate as its owner did, and he may well be surprised at the amount of background noise when the recording is played back.

Recording companies have displayed a great deal of cunning in their attempts to overcome the disadvantage of a single channel. In broadcasting, the great care taken over problems of balance enables us to hear most of the inner orchestral parts in even a complex work, where the original sound may be far from transparent in texture. Recording engineers have ingeniously added reverberation to aid the illusion of concert hall acoustics, and this can be pleasing although it does nothing to lessen the congestion in loud passages of music which is characteristic of mono sound.

A convincing representation of studio or concert hall acoustics is probably the most valuable feature of stereo. The listener has the impression that the orchestra is spread out between the two loudspeakers—and even beyond them. Localisation of particular instruments becomes possible and an illusion of distance, associated with reverberation, adds to the overall effect. Stereo does not go so far as to permit localisation in the vertical plane, but this is much less important and the horizontal spread of sound does give the impression that another dimension has been added (although this is *not* 3-D !).

The serious music-lover is likely to regard stereo's more obvious effects as being of secondary importance. After all, the positions of the players in an orchestra are of no great concern to him unless he is preoccupied with orchestral technique. Unfortunately, some recordings have emphasised the orchestral layout to the extent that the listener feels that he is sharing the rostrum with the conductor. This is probably the last thing the listener wants ; a favourite seat in the Grand Tier is a much better vantage point.

What is wanted from stereo is the warmth and naturalness of tone, the definition and the sense of music's own surroundings which mono reproduction is unable to provide. It is pleasant to be able to report that many stereo recordings give us these advantages

and that even greater realism can be expected. A natural separation of instruments is wanted, of course, and this is what gives definition and convincing tone. This does not alter the fact, however, that undue exaggeration detracts from the value of stereo. The various benefits are not restricted to orchestral music: chamber music sounds more convincing and even a solo instrument's tone is enhanced.

Although a powerful suggestion of "visual images" will not help those interested in orchestral music, the opera enthusiast has more to gain. In mono reproduction, movements are converted into variations in loudness; the enthusiast's imagination has had to make up for a lot in this respect. In stereo, the singers' movements across the stage are easily followed. The natural separation of sounds which is a feature of stereo ensures that simultaneous activities on the stage can be mentally identified and sorted out. Outdoor events sound quite spectacular, for similar reasons.

Stereo Records

Although stereo disc records appeared on the market suddenly—some believe precipitously—behind their development is a formidable history of investigation and research. The fundamental limitations of mono sound had been examined in laboratories all over the world. Experimental work was stimulated by the investigations into the mechanism of hearing undertaken by those who were themselves not concerned with sound reproduction. Indeed, work on the directional nature of hearing was going on when sound reproduction was in its earliest stage: Lord Rayleigh made notable contributions in this field before the end of the nineteenth century. Some experimental stereo discs were cut in the early 1930s.

Practical demonstrations of stereo on magnetic tape eventually became possible and application of multi-channel techniques to film was also successful. A well-known result of American contributions to stereo was Walt Disney's film "Fantasia," which was shown in the U.S.A. with a multi-channel sound track. Two-channel stereo was made available in this country in 1955, when E.M.I. marketed their "Stereosonic" magnetic tape records together with suitable reproducing equipment. Other tape records were introduced by Saga Films Ltd. in 1958.

Although three or more channels can give spectacular results in the cinema, two channels are generally considered the maximum economically possible for domestic use. The enthusiast with much time and money to spend on his amusements could perhaps enjoy himself with four channels and these can, in fact, be accommodated on magnetic tape. However, at present, despite the steady progress of tape, the disc seems to be the only form for a stereo recording which will have a wide appeal, and two channels are evidently the limit here.

The Stereo Groove.—We have already noted that the groove of a mono record, when modulated, is displaced laterally, and that the pick-up stylus is vibrated from side to side in tracing the groove. A certain amount of vertical stylus movement is also desirable, but the ideal mono pick-up would not produce any output from this.

With stereo, the situation is very different. The complex-cut groove moves the stylus laterally, vertically and in directions between these two extremes. The stylus must therefore have freedom to move in all directions, and the pick-up is designed to resolve these complex modulations into two signal voltages which have the correct relationship between them.

The late A. D. Blumlein, working with E.M.I., made possible the stereo disc which we now use; the results of his investigations, which he initiated in 1929, are contained in British Patent No. 394,325. Blumlein showed that two channels could be accommodated in one groove by combining lateral and vertical modulations, the lateral modulations providing the set of signals for one channel, and the vertical modulations the set of signals for the other. He also showed that each groove wall could be modulated at 45° to the vertical—the system which has since been decided on for general use in cutting stereo discs. It was demonstrated that these two systems were fundamentally similar; in fact, examining the geometry of the groove, it is found that the present “45/45” system is the vertical/lateral system displaced through 45° .

The behaviour of the groove in the 45/45 system can be explained as follows. The groove before modulation is similar to that in a mono record. Referring to Fig. 2 (a), when the right-hand channel is modulated, the width and depth of the groove alter and the stylus is pushed in the direction indicated—that is, at 45° to the vertical.

In Fig. 2 (b), the left-hand channel is modulated and the stylus is pushed across in the other direction, again at 45° to the vertical. The right-hand channel (the right-hand wall of the groove) is nearest the edge of the record and the left-hand channel is nearest the centre.

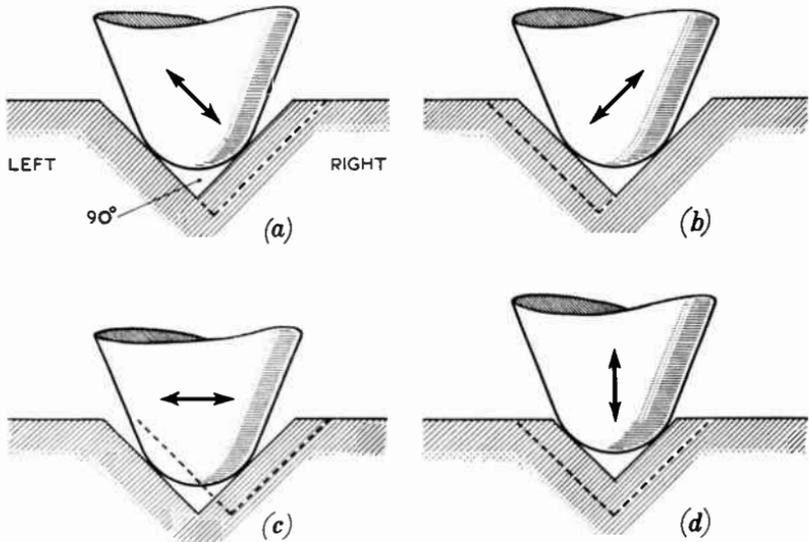


FIG. 2.—MOVEMENT OF STYLUS IN A COMPLEX-CUT GROOVE
 (a) Right-hand channel modulated, (b) left-hand channel modulated, (c) both channels modulated equally and in phase, (d) both channels modulated equally and in opposite phase.

Moving on to illustration 2 (c), when both channels are equally modulated in phase (*i.e.* in step with each other), the width and depth of the groove remain constant and the stylus is pushed sideways as it would be in a mono groove. When both channels are equally modulated in opposite phase (out of step), groove width and depth vary and the stylus is pushed in a vertical direction.

A very good idea of the appearance of stereo grooves is given by Fig. 3. These are not real grooves: they are models carved out of perspex and are part of a larger model built in the Philips Laboratories in Eindhoven, Holland. Groove (a) corresponds to Fig. 2 (c) and it can be seen that the groove is being modulated laterally. In groove (b), only the right-hand channel is modulated, while in groove

(c) the left-hand channel carries a low frequency signal and the right-hand channel a high frequency signal. Groove (c) is a fair illustration of what happens when music is recorded; the stylus movement is a complex combination of slanting, vertical and lateral movements.

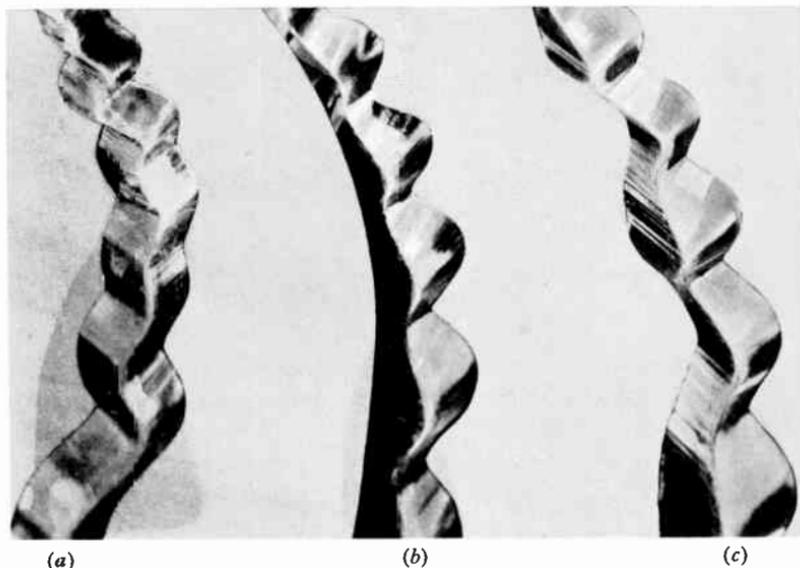


FIG. 3.—MODEL OF STEREO GROOVES

(a) Groove walls modulated equally and in phase, (b) right-hand groove wall modulated, (c) dissimilar modulation of groove walls.

(Courtesy N. V. Philips' Gloeilampenfabrieken, Holland.)

The stereo disc looks very similar to the mono microgroove disc and is, of course, made of the same material. Although there is wide agreement on a number of its features, it will be particularly satisfactory when a British Standard for it is issued.

Compatibility.—A stereo disc can only be played with a pick-up which is intended for the purpose. A mono pick-up will not have sufficient vertical compliance to cope with the groove's vertical movements, and a stereo disc will therefore be ruined by playing it with the wrong pick-up.

On the other hand, a stereo pick-up will play any microgroove record. There is a lot to be said for retaining an existing pick-up

for mono records (if it is a good one). However, newcomers to record collecting will probably wish to use one pick-up for all microgroove records and one of their first requirements will, therefore, be a good stereo pick-up.

A separate pick-up (or one side of a turnover cartridge) is, of course, still a requirement for 78 r.p.m. records.

The Stylus

A gradual reduction in pick-up playing weight has been a feature of the gramophone's development. Associated with this is a reduction in the size of the stylus tip and the result, provided that care is exercised in other ways, is less record wear. The introduction of stereo discs was the signal for a further advance and a tip radius of a half of one thousandth of an inch (0.0005 in. or a "half-thou.") was agreed between most of the organisations concerned in the matter as suitable. It is also important to note that a reduced tip size for a given groove dimension gives less tracing distortion.

The reader may occasionally see the micron, a Continental unit, used in connection with stylus sizes. A micron is a thousandth of a millimetre and a little arithmetic will show that one thou. equals approximately 25 microns. The half-thou. stereo tip radius may conveniently be called 12 microns.

If the tip radius is reduced, the playing weight must also be reduced if record wear is to be kept at a minimum. High fidelity pick-ups for mono records have reached the stage where a 6 to 7 gram playing weight is common. If the record wear is not to be worse when the half-thou. stereo tip is used, the playing weight must be reduced to a maximum of 4 grams. This presents a number of problems to the pick-up designer, but several pick-ups which will track successfully within the 4-gram limit have appeared. We can look forward to more of such pick-ups and to an eventual reduction in playing weight to about 1 gram.

Most manufacturers of the cheaper stereo pick-ups—most crystal models—have fitted 0.7 thou. tips so as to obtain the higher playing weight required with automatic record changers. The enthusiast is not likely to want a record changer for his stereo records, but he should still be cautious when buying a stereo pick-up: only a half-thou. tip will give the required results from the records.

A sapphire stylus is still less of a good proposition for stereo than it is for mono. The prospective purchaser is not likely to meet any difficulty, however, as the high fidelity specialist manufacturers have forestalled any misunderstandings by fitting only diamond styli to their pick-ups.

As stated earlier, a stereo pick-up will also play mono micro-groove records. The fact that a half-thou. stylus is used is an advantage where tracing distortion is concerned. The small radius at the bottom of the groove of a modern long-playing record makes possible this useful versatility.

Finally, a proper check on the amount of use the stylus receives is even more important with stereo than with mono reproduction. A half-thou. diamond will last 1,500 hours or more, depending on conditions of use. At playing weights of 4 grams or less, the design and installation of the pick-up arm is of extreme importance. Friction in bearings, leading to side pressure, will cause wear on one wall of the groove and possible groove-jumping. Attention to dust removal will be rewarded by long record life and low noise level. As with mono records, a proprietary brand of record cleaner is needed for proper cleanliness ; a cloth dampened with water is not adequate.

Stereo Pick-ups

A stereo pick-up has to resolve the complex movements of the stylus into two electrical signals which are ready for amplification. Ideally, the separation between the signals would be very great but, in practice, this is not possible in either the record or the pick-up. Separation becomes increasingly difficult as the extreme high and low frequencies are approached. Interaction between the two channels is known as "crosstalk" and a figure for "crosstalk rejection" is generally quoted, a typical figure being 20 dB at 1,000 c/s. A test record is used to measure this, so that the quoted figure is the total for pick-up and record together. The method of measuring the crosstalk rejection is to play a stereo disc on which one channel only has been recorded. The output from the pick-up should then consist of a set of signals at one set of pick-up terminals, and nothing at the other set. The strength of signal at the terminals where no signal should be present is the amount of crosstalk, and

the amount by which this is lower than on the other terminals is the crosstalk rejection. It is possible, by using an optical method, to measure the crosstalk for the record alone.

A pick-up which has good separation between channels, which will track the record properly with a half-thou. stylus and 4 grams pressure and which will exhibit the smooth response typical of good mono pick-ups is not easy to design and produce, nor is it likely to be cheap. At the time of writing, the pick-ups which can meet

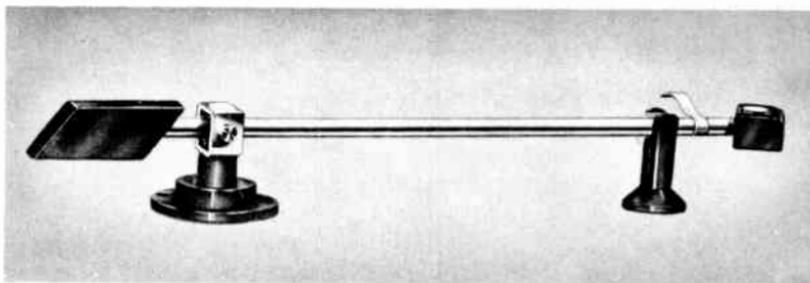


FIG. 4.—THE DECCA FFSS STEREO PICK-UP

reasonable high fidelity requirements are, with the exception of one miniature ceramic type (Connoisseur), all magnetic types, and can be numbered on the fingers of one hand.

As in mono pick-ups, the compliance of the head's moving system must be high if the pick-up is to track correctly at a small playing weight, and with stereo pick-ups this compliance is required vertically as well as laterally. In addition, considerations of tracking and response require a reduction in the mass of the armature system. The result is that stereo pick-ups have a very low sensitivity. The very successful Decca FFSS pick-up, for example, has a sensitivity of 1.4 mV. per cm/sec. on each channel. Reference to Chapter 2 will show that this is much lower than that for a mono pick-up of the magnetic type. The output bears the same relationship to the recording characteristic as in the case of mono pick-ups. It should be noted that the load resistance for a pick-up, mentioned in Chapter 2, must be applied to both channels of stereo models.

The Decca pick-up just referred to is supplied as a complete head and arm assembly and, as a result of care in construction and

assembly, a playing weight of 3 grams has been achieved. However, the majority of the new stereo pick-ups are in cartridge form and it is important to emphasise that these must be used in arms which will function correctly at low playing weights.

FIG. 5 (*right*).—THE PRINCIPLE OF THE GOLDRING MODEL 700 "BALANCED ARMATURE" STEREOPHONIC PICK-UP

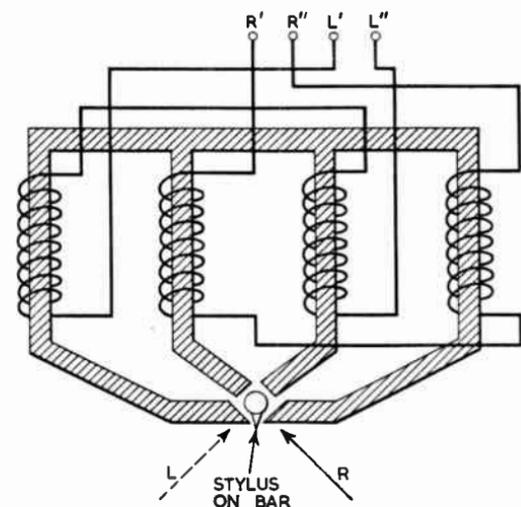
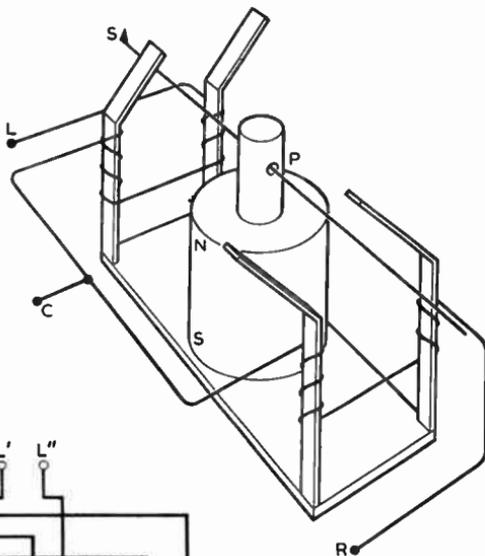


FIG. 6 (*left*).—THE PRINCIPLE OF THE TANNOY "VARI-TWIN" MAGNETIC STEREOPHONIC PICK-UP

The principles of two types of stereo cartridge are shown in Figs. 5 and 6. The Goldring model 700 is very much like a pair of the variable reluctance pick-ups shown in Fig. 8, Chapter 2. As indicated in Fig. 5, the stylus S is mounted on a stylus bar extending between two pairs of poles and pivoted at P; hence the

name "balanced armature" used by this manufacturer. The bar is positioned so that it can complete two pairs of magnetic circuits, and the disposition of the poles is such that the "left" channel modulation varies the flux in the front part of the assembly (nearest the stylus) and the "right" channel modulation the flux to the rear part. Two pairs of coils are so interconnected that left channel, right channel and common connections can be made as shown.

There are four magnetic circuits in the Tannoy "Vari-Twin" cartridge, and the stylus bar is pivoted at one end. As shown in Fig. 6, the basic essentials are two pairs of magnetic paths 90° apart and at 45° to the horizontal; this is the same arrangement that exists in the record groove, where the groove walls are nominally 90° apart and modulations are at 45° to the record surface. Thus the arrangement of magnetic and electrical circuits is such that modulation of the left and right channels results in outputs from terminals L', L" and R', R" respectively. The actual movement of the stylus is complex, of course, and the "left" and "right" information is produced in varying proportions at these terminals.

A complete head and arm assembly has also been introduced by E.M.I., and has been very well received. The stylus mass is less than 1 milligram, the playing weight $2\frac{1}{2}$ grams, and the lateral compliance 7×10^{-6} cm/dyne. The arm is supported by a critically-damped unipivot.

The connecting lead for a stereo pick-up will often consist of two inner conductors and an outer screen. Two separate pairs of leads may be better in some instances from the point of view of hum pick up, and this arrangement will sometimes be specified.

Stereo Amplifiers

Apart from the fact that two channels of amplification are necessary, each separate from input to output stage in the electrical sense, the stereo amplifier is not fundamentally different from its mono counterpart. One or two new controls are added for the sake of convenience. Manufacturers have found it possible, with some ingenuity and a few economies, to produce new amplifiers without doubling size or price. A small sacrifice in output power can result in very acceptable savings in the cost of output stages and the power supply section, and this economy is widely practised. It seems

unlikely, however, that a reduction of more than 20 per cent in output power is justified—assuming each channel to be equivalent to a mono amplifier.

Another economy which is practised is to provide only enough gain for use with a crystal pick-up, which has quite a high output even in its stereo version. This is an acceptable compromise where cost, above all else, is the deciding factor in planning a new installation.

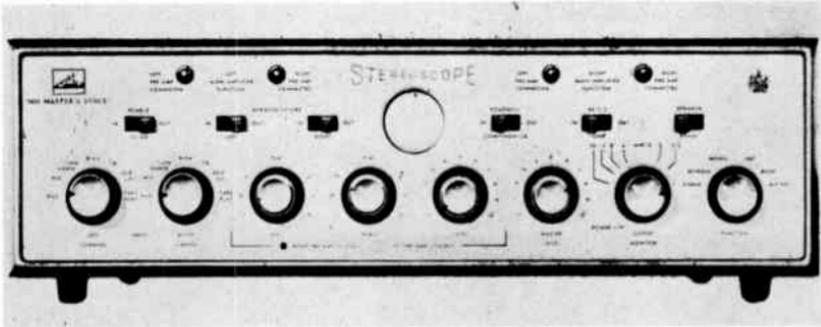


FIG. 7.—“HIS MASTER’S VOICE” MODEL 555 “STEREOSCOPE”
INTEGRATED STEREO AMPLIFIER

The output from each channel is 10 watts. A cathode-ray tube is incorporated for balancing and loudspeaker phasing purposes.

(The Gramophone Company Ltd.)

At the present time, however, a magnetic pick-up is essential (with the exception previously noted) if the most obvious, fundamental high fidelity requirements are to be satisfied, and these, as we have noted, have a very small output, so that the amplifier must provide more gain and will cost more. Performance is, as always, linked with price and it is for the enthusiast to choose. Stereo amplifiers which sacrifice nothing in gain and very little in output power appear to have a minimum price of roughly £35.

The compact combined amplifier and control unit, for shelf or table use, is possibly more popular than ever in the stereo field. The alternative, also widely used in mono reproduction, is to have the control unit mounted in a cabinet and connected to a separate power amplifier chassis.

Controls.—Many stereo amplifiers incorporate a “balance” control. This is used to centre the sound image if unbalance at

some stage has caused lateral shifting. Unbalance could arise in the pick-up, amplifier, loudspeakers or because of room acoustics. The balance control simply adjusts the gain of one channel relative to the other. Balancing is, of course, carried out while sound is being reproduced. It will not do, however, to assume that some particular solo musician in the recording is intended to be central and to base the balance on him: the best balancing signal is that provided specifically for the purpose on the demonstration records issued by the major recording companies. Unfortunately, most demonstration records seem to be of the 12 in. variety; there is an outstanding need for a handy 7 in., 45 r.p.m. disc containing a balance signal and a few demonstration items.

In a few equipments, the need for a balancing control is eliminated by the use of double concentric volume controls. The control knobs can be turned as one if overall volume adjustment is desired: if balancing is necessary each can be turned independently. Tone controls are usually ganged, so that turning the single "bass" or "treble" knob will give an adjustment which is the same for each channel. In a few instances, however, these are also of the double concentric type, and this has the advantage that it is possible with them to correct, at least partly, inequalities—in the two loudspeakers, for example—in response.

Other controls peculiar to stereo are reversing and stereo/mono switches. The first of these is often provided so that the connections to the two channels can be reversed: this is more convenient than correcting errors in connections elsewhere in the installation. The facility for selecting stereo or mono is always provided in one form or another: the two channels can then be paralleled while mono records are played so that the total output is available for mono reproduction. The two channels can usually be left independent at all times if that is preferred.

Loudspeakers for Stereo

If a loudspeaker sounds extremely good on mono, it is very likely that a pair of the same type will give equally acceptable stereo sound. There is no reason to believe that high quality requirements undergo some change in the case of stereo reproduction, so that the pointers towards quality given in Chapter 4 still apply. All the



FIG. 8.—STEREO INSTALLATION USING TWO COLUMN LOUSPEAKERS
(*Expert Gramophones Ltd.*)

same, good loudspeakers tend to be big, and two of these may well be an embarrassment in many rooms. The problem lies in finding sufficient floor (or shelf) space for them, and it is necessary for many people to compromise by using one very good loudspeaker with another which is rather less good.

As mentioned earlier, there is not complete and general agreement in the theories that have been put forward in connection with hearing and the localisation of sounds. One result of this is a tendency for different companies to use different techniques in the studio, involving several possible microphone arrangements. Some are better than others; the worst examples have produced a "hole-in-the-middle" effect, where sounds tend to divide between the two loudspeakers instead of producing an even "acoustic scene" between them. Fortunately, there are few such recordings. However, loudspeakers which beam the middle and high frequencies at the listener are also inclined to produce this effect: one's attention is drawn to each of the two sources, and the illusion of a spread of sound may well be destroyed.

The omni-directional loudspeakers which give the widely diffused

output so pleasing in mono reproduction are, it appears, the most satisfactory for stereo. Most manufacturers seem to think so and are proceeding along those lines. One design which is proving very popular is the column loudspeaker (see Fig. 7, Chapter 4), occupying as little as one square foot of floor space. There are numerous multi-speaker systems of reasonable size in which undue directional effects are avoided.

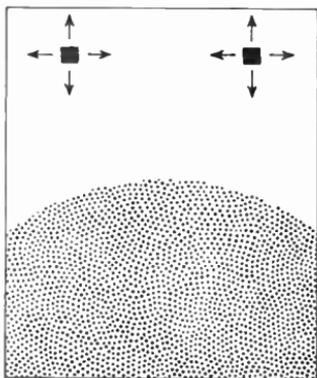


FIG. 9.—APPROXIMATE STEREO LISTENING AREA (SHOWN SHADED) WHEN OMNI-DIRECTIONAL LOUDSPEAKERS ARE USED

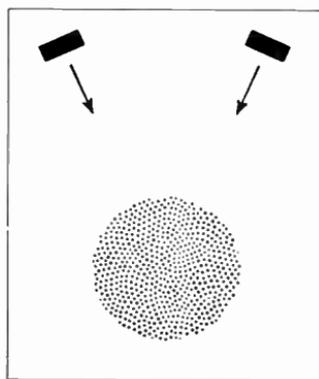


FIG. 10.—APPROXIMATE STEREO LISTENING AREA (SHOWN SHADED) WHEN VERY DIRECTIONAL LOUDSPEAKERS ARE USED

Some listeners will be obliged to use shelf-mounting loudspeakers because of space considerations. Most of those at present available give a rather directional output so that, provided they have a strong high frequency response, best results are likely to be obtained with the loudspeakers facing upwards.

If strong directional effects are avoided, the useful listening area in the room will be roughly as shown shaded in Fig. 9. The listeners should be as far from the loudspeakers as possible, and certainly not less than the distance which separates the loudspeakers. With directional loudspeakers, the listening area will be smaller, as indicated in Fig. 10, but it will be possible in some rooms to enlarge the area by facing the loudspeakers forward instead of turning them inwards. An alternative, if domestic arrangements permit, is to turn the loudspeakers towards the wall. Hard and fast rules are not

possible, however. A little experiment will show what gives the most convincing sound picture.

With many types of loudspeaker, it is necessary to ensure that the two outputs are in phase ; if they are not, the stereo illusion may be lost. A simple test can be carried out by playing a mono record of instrumental or vocal music (with both amplifier channels operating). If the listener stands at the usual distance from the loudspeakers and in a central position, the sound should seem to come from midway between them. If the sound divides itself between the loudspeakers, the effect of reversing the connections to one of them should be tried.

In mono reproduction, two loudspeakers in parallel and in phase activate room resonances in a more complex and normally more pleasing way. This applies even if the loudspeakers are dissimilar, provided that they are both wide-range types, and it also holds good for stereo. Some experiment with positioning is usually necessary in order to obtain the smoothest bass performance ; in particular, the bass re-inforcement given by a corner position may result in boominess with some types of enclosure.

Once suitable positions have been found, there will be ample evidence that two good loudspeakers are justified and that anything else is a compromise. The more obvious stereo effects—indeed, the most spectacular ones—are confined to the upper frequencies, but the overall improvement in tonal quality made possible by stereo recording is displayed throughout the audible range.

Conversion from Mono

The owner of high quality equipment need not dispose of it in order to “go stereo.” There is a lot to be said for adding a second channel to an existing installation. This has its inconvenient points, particularly where housing the new amplifier is concerned. On the other hand, lowering standards in order to obtain a compact new stereo outfit may lead to early disappointment.

If the existing pick-up is a very good one, the counsel of perfection is to keep it and use a separate stereo model. Two pick-up arms can be arranged one each side of the turntable in many installations. The next best thing is to dispose of the mono pick-up and use a stereo one to play all microgroove records ; this should compare in

quality with its predecessor, otherwise the sacrifice of quality will be noticed in spite of the excitements of stereo.

A good turntable is an outstanding requirement, particularly if one or both of the loudspeakers has a good bass response. A stereo pick-up responds readily to vibrations in vertical as well as lateral directions, and will therefore expose more rumble than a mono pick-up of comparable performance.

If an existing amplifier is to be retained, another having similar input arrangement and performance characteristics can be added. An exact match is not essential, but obviously a mongrel 5-watt chassis should not be in the same kennel as a pedigree 15-watt type. Two good amplifiers of different powers could be used, however, to drive a large and a small loudspeaker. Acceptable stereo for minimum outlay can in this way be provided, but there is need for great care in trying out such a combination. Too many dissimilarities between channels will result in a badly distorted and one-sided stereo image.

When separate amplifiers are used, balancing has to be carried out with the respective volume controls unless an extra balance control can be connected between the two equipments (a few manufacturers do make provision for this). The two separate sets of tone controls often prove to be a blessing in disguise as they can, within limits, equalise the response characteristics of the channels.

Gradual conversion to stereo is possible in several ways. A good approach is to purchase a stereo control unit for use, at first, with one separate power amplifier; the second amplifier chassis can be added at any time. A complete twin-channel amplifier of the shelf-mounting variety can be used with channels paralleled to drive one loudspeaker. The second loudspeaker and the stereo pick-up can be added at a later date.

Where the loudspeaker is concerned, it has already been indicated that similar models will give best results. If it is necessary to use a second speaker which takes up less floor (or shelf) space, this should have a degree of high note diffusion which compares with the existing one.

An alternative method used by several manufacturers employs the existing loudspeaker to reproduce the bass, derived from both channels and combined in a special filter unit. Separate and comparatively inexpensive loudspeakers are employed to handle the

middle and high frequencies—and, of course, the bulk of the stereo information. In one system marketed by Goodmans, the separate loudspeakers each use 6-in. drive units facing upwards with a diffusing cone to give an omni-directional output. The main basic arrangement is shown in Fig. 11 (a), where the existing loudspeaker receives only low frequencies, via the filter, and the “bowl” units

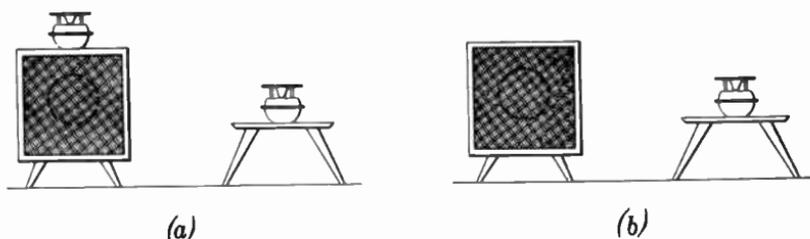


FIG. 11.—GOODMANS' "STEREOPHONIC BOWL" LOUDSPEAKERS USED WITH AN EXISTING LOUDSPEAKER

(a) Two bowls with common bass reproducer; (b) one bowl with a wide-range loudspeaker.

deal with everything above about 300 c/s. Neither bowl need stand on the bass loudspeaker: the main consideration is to place them so that the maximum listening area is obtained. An alternative arrangement is shown in Fig. 11 (b): this employs the existing loudspeaker to reproduce the whole range of one channel and the bass from the other, a single bowl being used to deal with the second channel's higher register only.

Stereo on Tape

Disc records are not the only medium for stereo. Tape records and equipment offer sound reproduction of very high quality, and this medium is preferred by many enthusiasts. It is particularly suitable for stereo work. The pros and cons will be discussed in the next chapter.

TAPE AND HIGH FIDELITY

MAGNETIC recording on tape has much to commend it to the amateur. Tape is a versatile medium and manufacturers are doing their utmost to make it an economical one. The development of magnetic recording tapes and mechanisms owes much to the work carried out in Germany during the Second World War (while the Allies developed wire recording). Since then, recording enthusiasts have been able to choose from an ever-increasing range of portable machines, each an armoury of gadgets and facilities. One is impressed by the value for money offered in this very competitive field.

The recording enthusiast's activities are, as often as not, non-musical in nature. High fidelity results are seldom the prime requirement ; indeed, the nature of the sound sources and the conditions under which they have to be recorded preclude any possibility of top quality results unless enormous sums of money are spent on equipment.

The amateur whose main interest is music will find that tape recording and reproducing facilities can be incorporated in the home music system in a quite straightforward way. Mono and stereo tape records are available and home recordings can be made from f.m. radio. Where circumstances permit, "live" musical performances can be recorded with a microphone. In view of the versatility of this medium, it is hardly surprising that some enthusiasts make tape the centre piece of the high fidelity installation ; they accord the disc record a begrudged second place—and sometimes leave it out altogether.

Tape versus Disc

An outstanding advantage of tape recording is the low level of distortion that can be achieved. We have already noted that there is some deterioration in quality as a disc is played through, there

being greater distortion near the centre of a record than at the outer parts: the distortion in a tape recording, on the other hand, is (or should be) constant throughout the playing time, and the actual amount is very small if care is taken over the recording process.



FIG. 1.—FERROGRAPH TAPE RECORDER IN A HEAL CABINET
(Heal & Son, Ltd.)

The frequency response of a tape recording depends largely on the speed of the tape past the recording head, and this in turn determines the cost of the recording. Commercial tape records and the better home recordings are recorded at the $7\frac{1}{2}$ in. per second speed, at which a wide response is obtainable. At this speed, the cost is at least as much as that of disc records. The improvements in tape and equipment which are constantly being made should, however, eventually enable good results to be achieved at the next lowest speed ($3\frac{3}{4}$ i.p.s.), and this will halve the cost.

The dynamic range of a tape recording depends on the way in which the recording was made and the programme source used. It can be wider than that achieved in disc recording. Where dynamic range and certain types of distortion are concerned, the situation is at its most favourable with the best commercial tape records. These, like discs, are copies of the recording companies' master tapes but they suffer less from the intrusion of complicated equipment in the copying process ; there is nothing in the business of producing tape records which has the inherent hazards of disc cutting and pressing. The "background noises" associated with tape and disc (hiss, etc.) are comparable. It should be possible for discs to have the advantage here, provided they are carefully treated.

Tape equipment which can compare in quality with the best gramophone equipment tends to be rather expensive—but not disproportionately so. The operation of the equipment is considered by many to be irritatingly complicated : there is the trouble of tape threading and the waiting while a reel is rewound (we shall see in a later chapter that efforts are being made to overcome this problem). Tape's attractive versatility, on the other hand, is reckoned by the initiated to make up for a host of apparent inconveniences.

If tape is used only for reproduction—and this is the cheapest way of using the equipment—a big disadvantage becomes apparent. Tape records, excellent though they are, at present offer a comparatively small selection of music. The answer, of course, is to do your own recording (*e.g.* from f.m. radio) to make up for this.

Lastly, it should be pointed out that recordings made on tape can be erased and the tape later used for a new recording, and the process can be carried on almost indefinitely. This may be contrasted with the depressing business of selling an unwanted disc (the unfortunate owner of a "poorly reviewed" disc may find difficulty in giving it away !). Although tape is not indestructible, it can be handled much more freely than a disc. Moreover, it can be chopped into lengths, "edited" and generally treated in a ruthless manner without its properties being impaired.

If the layman who reads this has obtained the impression that tape has many advantages, he will be on the right lines. He will also be correct if he concludes that tape is a little more expensive and complicated, at the present time, than disc. It is for him to decide whether simplicity or versatility meet his requirements, having

regard to domestic circumstances and the time which can be allocated to the pursuit of high fidelity sound.

The Tape

The tape consists of many millions of ferrous oxide particles applied in a thin, even layer to a plastic base. It is $\frac{1}{4}$ in. wide and, in its standard version, is about 0.002 in. thick. A thinner, "long playing" version is available, and the thickness is 0.0014 in. or less; a still thinner "double play" tape has also been introduced.

Common spool sizes are 3 in., 5 in. and 7 in. It is possible to use larger diameter spools, such as $8\frac{1}{4}$ in., on some recorders. The recording times for various spool sizes are given in Table 1. It will be seen that the current type of long playing tape increases the playing time by fifty per cent.

Table 1.—Recording Times (per Track) for Various Speeds and Tape Lengths

Spool diameter (in.)	Type of Tape	Approximate tape length (ft.)	Recording Time (minutes)		
			$7\frac{1}{2}$ i.p.s.	$3\frac{3}{4}$ i.p.s.	$1\frac{7}{8}$ i.p.s.
3	Standard	200	5	10	20
5	Standard	600	15	30	60
7	Standard	1,200	30	60	120
3	Long play	300	8	15	30
5	Long play	900	23	45	90
7	Long play	1,800	45	90	180
7	Double play	2,400	60	120	240

In many domestic machines, half the width of the tape is recorded at a time. When one half has been recorded, the tape direction is reversed or the spools are interchanged, and the other half is then recorded. This method is known as "half-track" or "twin-track" recording; the times given in Table 1 apply to full-track recording

and will be doubled for twin-track. The internationally agreed method of using the tracks is as follows: looking at the tape on its glossy, non-magnetic side when it is resting in the recorder, the top track is recorded with the tape moving from left to right. The disposition of the tracks on the $\frac{1}{4}$ -in. wide tape is shown in Fig. 2. Bearing in mind the economy made possible by twin-track recording,

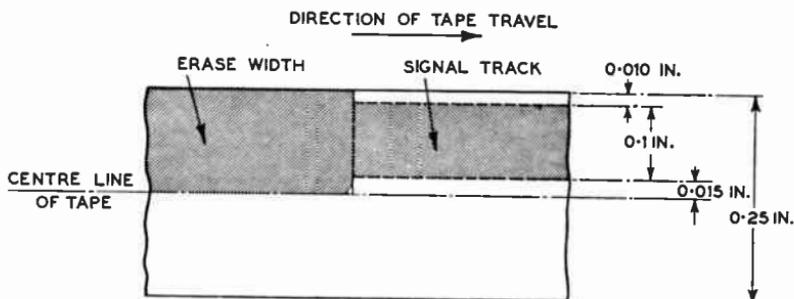


FIG. 2.—ARRANGEMENT AND DIMENSIONS FOR TWIN-TRACK RECORDING ON $\frac{1}{4}$ -IN. TAPE

the amateur can work out the cost of tape recording in relation to the lengths of musical works he wishes to record. Typical prices for 7-in. spools of tape are 35s. for the standard variety and 50s. for long playing.

P.V.C. (Polyvinylchloride) is a widely used base material and it is mechanically reliable. Alternative materials are used for some brands of the thinner, long playing tape. Mechanical considerations, including tape dimensions, are dealt with in British Standard Specification B.S.1568: 1960.

The Heads

The tape is made to store information by passing it in front of, and in contact with, the recording head, a schematic diagram of which is seen in Fig. 3. An audio frequency signal applied to the coil causes a corresponding variation of magnetic field across a thin gap in the core, and this produces a permanent alteration in the pattern of the magnetic particles on the tape. If the tape is subsequently pulled past the same head or a similar one, a small signal

voltage is induced in the coil, and this can be passed on to a suitable amplifier for reproduction.

One magnetic head can be used for both recording and playback and this arrangement is used for the sake of economy in many domestic recorders. However, many machines for high quality applications have separate heads which are designed for their specific

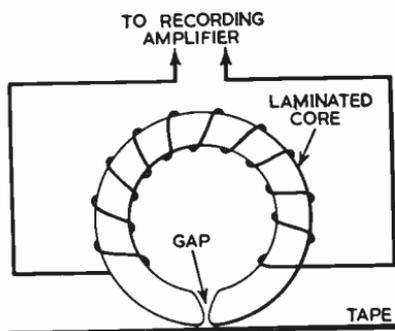


FIG. 3.—SCHEMATIC DIAGRAM OF A TAPE HEAD

tasks. Where this is done, the actual recording on the tape can be monitored by the playback head whilst the recording is in progress, provided that the recorder incorporates two amplifier channels.

The dimensions of the gap in the head are very small, and a playback gap width of 0.0002 in. is quite common. Head performance depends on a variety of factors including the gap dimensions, the polish and general quality of the gap surface and the losses which occur in the laminations from which the core is made. The friction of tape against head causes gradual wear and an uneven gap, and this will lead to a deterioration in the performance. The gap must always be exactly at right angles to the direction of tape motion, as even a slight inaccuracy will cause a reduction in response at high frequencies.

Mechanical Considerations

The tape must be pulled evenly across the gap in the head at one of the standard speeds. These speeds are $7\frac{1}{2}$ i.p.s. and $3\frac{3}{4}$ i.p.s., for domestic purposes. A higher speed of 15 i.p.s. is occasionally used

professionally, but adequate performance should be obtained at $7\frac{1}{2}$ i.p.s. A slower speed of $1\frac{7}{8}$ i.p.s. is provided on some machines and this is suitable for speech recording.

Movement of the tape is taken care of by what is usually called the "tape transport" mechanism. An important requirement for high fidelity work is low wow and flutter (see Chapter 1): the absolute maximum at the $7\frac{1}{2}$ i.p.s. speed should be 0.2 per cent.

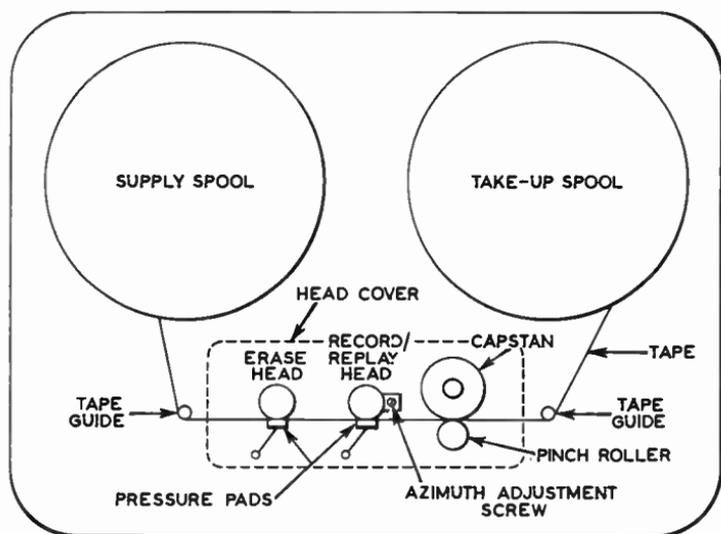


FIG. 4.—LAYOUT OF A TYPICAL TAPE DECK, SHOWING THE MAIN COMPONENTS

It is impossible to achieve such a figure if the tape is driven by the spools on which it is wound. These, therefore, are left merely to wind and rewind the tape which is actually driven by a separate part of the mechanism. The arrangement used is for the tape to be driven by a capstan spindle, against which it is pressed by a rubber wheel or roller. The capstan itself is driven via a flywheel, to obtain constancy of speed.

In professional and some expensive non-professional machines, the contact between tape and head and also the correct tension on the tape are achieved without any further help. In most domestic machines, however, the tape is kept in contact with the head by means of a pressure pad.

Winding and rewinding of the tape is carried out at high speed and, during this operation, pressure pad and roller are released. The motive power for the various operations can be provided by one, two or three motors, according to the ideas of the manufacturer. There is certainly no reason to prefer one method to another ; a high standard of construction and assembly, obviously not attained cheaply, is what matters.

It should be mentioned here that a new reel of tape has an incredibly neat appearance due to the fact that it has been tightly wound on a special machine. It will never look the same again once it has been put into service, but this does not matter provided it is always reasonably neat. Very loose spooling, allowing adjacent turns of tape to move about, will indicate a fault in the recorder—one that, however, can be corrected easily in the normal course of events. The simplified layout of a tape “ deck ” is shown in Fig. 4.

Bias and Erasing

A high frequency “ bias ” signal is always added to the audio signal during recording. This affects the ability of the magnetic particles on the tape to form the required pattern. The bias is normally at a frequency of 50 kc/s or higher, and is produced by a suitable oscillator circuit. Ideally, the bias signal would be adjusted to suit the properties of different brands of tape, but this is not considered worthwhile in domestic equipment.

A high frequency current is also passed through an additional “ erase ” head. This takes place while recording is in progress ; any programme on the tape is thus erased before the relevant section can reach the record head. Since it would be only too easy for a wanted recording to be erased, most machines have some sort of locking device which serves to remind the user that he is about to record and hence erase the existing programme.

It is important that the correct level of bias signal is applied, and it is, therefore, common for semi-professional recorders to incorporate a pre-set control to adjust this.

Frequency Characteristics

The output from a magnetic head is only a millivolt or so and the signal is not uniform at all frequencies. As with the magnetic

gramophone pick-up, careful correction of the frequency response is necessary. Recommendations concerning this characteristic were made by the C.C.I.R. in 1953 and incorporated in British Standard Specification B.S.1568 of 1960. The characteristic is defined for speeds of $7\frac{1}{2}$ i.p.s. and higher.

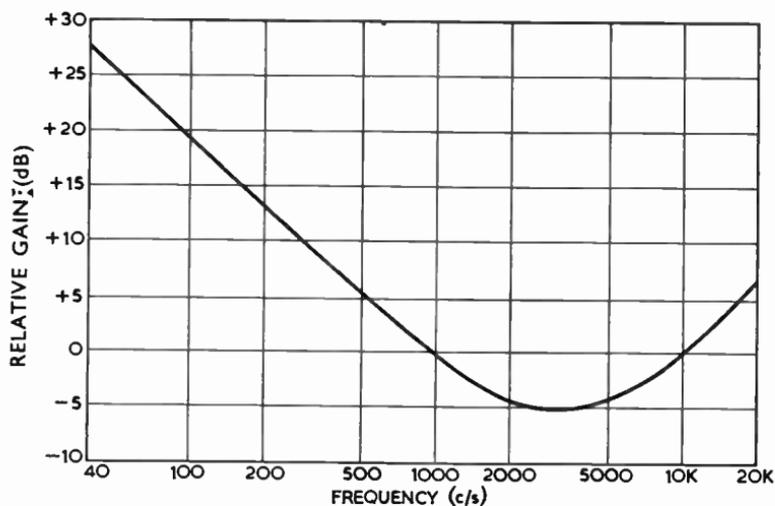


FIG. 5.—TYPICAL TAPE PLAYBACK AMPLIFIER RESPONSE CURVE FOR PLAYBACK AT $7\frac{1}{2}$ I.P.S. SPEED

In practice, the system adopted is for high frequency correction, necessary to compensate for losses in tape and equipment, to be made in the recording amplifier. Low frequency correction then is made in the playback amplifier. The resultant playback response curve for the $7\frac{1}{2}$ i.p.s. speed is shown in Fig. 5. When these corrections have been applied, the signal passed on for reproduction has a substantially level response, the actual width of the response depending on the quality of the heads and associated circuits. As always, a smooth response is as important as a wide one.

It should now be clear that, if only playback facilities are required, circuits to provide bass boost are necessary. If, as is usually the case, full recording facilities are required, a recording amplifier which compensates high frequency losses must also be used. This will incorporate the bias and erase circuits.

High Fidelity Installation

The most usual way of incorporating tape facilities in a high fidelity installation is to buy a tape deck—that is, the mechanical part of a tape recorder—and to use it with a separate complete recording and playback amplifier. The recording/playback amplifier is required to provide the necessary voltage amplification and frequency correction, after which the signal is passed on to the installation's high fidelity amplifier. With the addition of tape facilities, full advantage can be taken of the various possible sound sources, *e.g.* f.m. radio and microphone. A frequency response of about 40–15,000 c/s, level within ± 3 dB, should be obtainable using tape, with a noise level of -50 dB at full output. Dynamic range and distortion depend on the programme material, *i.e.* whether recording from an f.m. broadcast, from the microphone, etc.: they should both (at best) be superior to what can be achieved with gramophone reproduction.

For those who require only playback of commercial tape records an extremely convenient arrangement is possible. Certain high fidelity control units have a special input for tape head, with appropriately high gain and the C.C.I.R. correction of response. The head can thus be connected direct to this input and only the tape deck, without intervening circuits, is required.

Some enthusiasts prefer to use a complete, portable tape recorder. They can use it for various activities such as recording dictation, outdoor sounds and so on, and also connect it to the high fidelity installation when required. Fortunately, a number of the better portables are designed with this in view and have a high impedance output for connection to the "Tape" input on the high fidelity amplifier. Needless to say, the mechanical and electrical requirements are the same as for the separate deck and amplifier.

Tape Records

As indicated earlier, tape records are available both in mono and stereo versions. At the time of writing, they are marketed by E.M.I. on the "H.M.V." and "Columbia" labels and by Saga Films Ltd.

Mono tape records are normally made to the twin track standards mentioned earlier. Stereo tapes are also twin track, of course, but

in this case the two tracks contain the two sets of signals (one set for each channel) and are played simultaneously. Track dimensions and frequency characteristics are the same as for mono recordings. The tape records available so far are for reproduction at $7\frac{1}{2}$ i.p.s., and the largest spool size used is 7 in. diameter.

For stereo tapes, a "stacked" head is used: this is a double head in which the two sections are assembled vertically in line. The two head coils are each connected to a playback amplifier which gives the C.C.I.R. correction and these in turn are taken to the two amplifier and loudspeaker channels.

A few machines cater for stereo playback in addition to full mono and stereo recording facilities. As must be expected, these are quite expensive.

Home Recording

If the tape equipment has been added to a high fidelity installation which includes an f.m. tuner, recordings of the f.m. broadcasts can be made, and it is possible to achieve very high quality results in this way. Many control units have an output socket providing an output of 100 mV. or more especially intended for recording. This output is independent of the amplifier's volume control. To record, the f.m. tuner is connected to the control unit, and the output from this special output socket on the control unit is directly connected to the tape amplifier. The radio programme can be monitored on the installation's loudspeaker while recording is in progress or, alternatively, it may be possible to use headphones or a small loudspeaker for monitoring.

During recording, it is essential to keep a careful check of the "recording level," and an indicator such as a magic-eye or a meter is always provided on the tape equipment for this purpose. Overloading the tape equipment with an excessive signal will cause unpleasant distortion. On the other hand, under-recording will mean that the signal-to-noise ratio will deteriorate and it will no longer be possible to take advantage of the wide dynamic range which the best f.m. transmissions provide.

A microphone is supplied with some types of equipment. This is normally an inexpensive crystal or moving-coil model, suitable for recording speech only. More ambitious microphones are available,

however, and these will be of interest to the amateur who wishes to record his own music practice or the contributions of his friends. Recordings of really high quality are not easily achieved in average domestic surroundings but some enthusiasts have found that perseverance brings its rewards.

Microphones.—Two main types are used. The first is the pressure-operated type, in which the diaphragm is exposed to sound waves on one side only. Many moving-coil microphones are pressure

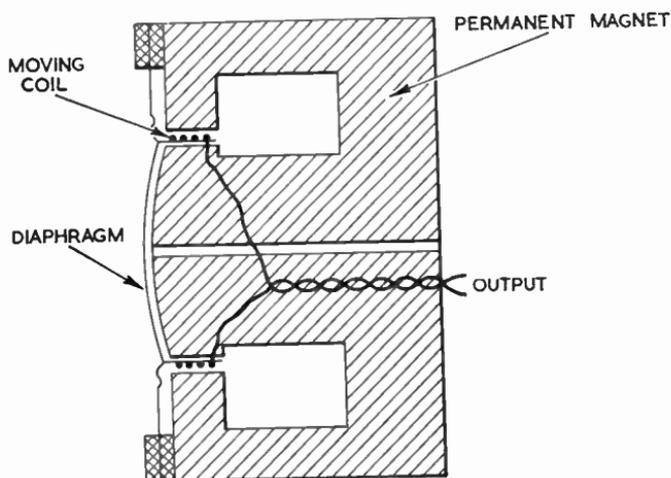


FIG. 6 (a).—CROSS-SECTIONAL VIEW OF A MOVING-COIL MICROPHONE

operated. The other main type is open on both sides, the diaphragm responding to the velocity of the air particles moving in the sound wave. Several makes of ribbon microphone come under this heading. Simplified drawings of a pressure-operated moving-coil microphone and of a velocity-operated ribbon microphone are given in Fig. 6. The moving-coil type is essentially the same as a moving-coil loudspeaker which we considered earlier (see Chapter 4), whilst the ribbon type is basically a smaller version of a ribbon "tweeter."

The above types of microphone are low impedance devices and have to be matched to the high impedance input of the recording amplifier. It is usual to build an impedance-matching transformer

into the microphone housing and, in this case, the connecting cable must be limited—to about 20 ft. in many instances—if serious loss of high frequencies is to be avoided. If a longer cable is necessary, the output must be taken from the microphone at low impedance, and the transformer will then have to be inserted at the input to the

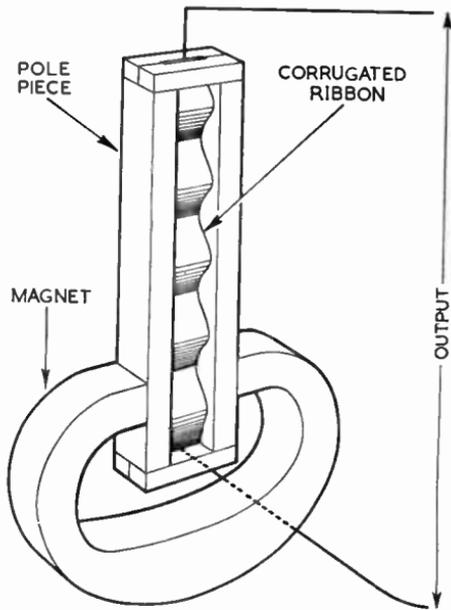


FIG. 6 (b).—PRINCIPLE OF THE RIBBON MICROPHONE

amplifier. High quality microphones require careful handling. In particular, the user should not blow into a ribbon microphone to check that it is working.

Microphones with frequency responses to suit particular applications are available in wide variety. At least as important as the frequency response, however, is the question of directional properties (polar response). A pressure-operated microphone is omni-directional, *i.e.* it is equally sensitive to sounds in all directions, at low frequencies, as shown in Fig. 7 (a). As frequency is increased, however, the wavelength approaches the size of the diaphragm, and the microphone becomes increasingly uni-directional, *i.e.* it is only sensitive to sounds received from directly in front. A velocity-

operated microphone is bi-directional, see response characteristic shown in Fig. 7 (c). In some microphones, the pressure and velocity characteristics are combined to produce a heart-shaped polar response (see Fig. 7 (b)), the name "cardioid" being applied to this type of response.

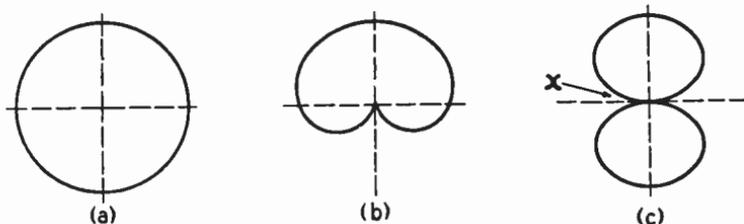


FIG. 7.—MICROPHONE POLAR RESPONSE DIAGRAMS

(a) Omni-directional. All-round sensitivity at lower frequencies but directional at higher frequencies. (b) Uni-directional (cardioid). Very directional with low sensitivity in all directions except the front. (c) Bi-directional. Minimum sensitivity at sides (*i.e.* at *x*).

The bi-directional ribbon type is very suitable for high fidelity indoor recording. It tends to emphasise the bass when close to the sound source and care must be taken to avoid boominess in the recording. This type is available from about £8 upwards.

The amateur can overcome background noise and reverberation problems to a certain extent by the use of a microphone with marked uni-directional characteristics. By careful positioning, he can arrange for the minimum reflected sound to be picked up and for the noise source to be at the rear of the microphone. Unfortunately, a first class cardioid type is quite expensive. A bi-directional microphone is also useful in this connection, as noise arriving from the side (at *X* in Fig. 7 (c)) will be minimised.

Copyright

The recording of sound broadcasts is now a major activity of the enthusiast. Under the terms of the Copyright Act 1956, which came into force in June 1957, the broadcasting authorities' rights will be infringed if sound (or television sound) broadcasts are recorded without permission for any purpose other than private use. This exception does not extend to copyright which may exist in the music or other work which is being broadcast: such

copyright material may not be recorded without the licence or permission of the owner of the copyright. The law also applies to clubs and societies, who must seek permission to reproduce copyright material.

A record manufacturer acquires a copyright in his records as such and these may not be re-recorded for any purpose without the licence or permission of the manufacturer. It is important to realise that the copyright is in the record itself and is separate and distinct from the music or other material which is reproduced by it. This means that a person wishing to copy a gramophone record on to tape, or to copy a tape record, must obtain the licence or permission of both the record manufacturer and the owner of the copyright in the recorded material. Anyone who wishes to consider this further or to obtain more information can write to the Mechanical Copyright Protection Society Ltd., at Elgar House, 380 Streatham High Road, London, S.W.16.

Storing Tapes

A recording has an almost unlimited life if used with care and stored away from extremes of temperature and humidity. It must be kept away from the magnetic fields associated with loudspeakers, transformers, etc. The amateur may wonder why it is safe to use a tape recorder at all, since this contains components which depend on magnetic fields. However, the tape is never close enough to these for ill effects to occur. High fidelity components such as large transformers may, on the other hand, have a big enough leakage field to cause partial erasure if the tape is brought too close. It is often convenient to keep tapes and discs in the same cabinet.

The possibility of magnetic "printing" from one turn of tape to the next must also be considered. This could happen while the tapes are left unplayed in storage. No trouble is likely to be experienced if tapes are played regularly. If the recordings are stored for long periods, they should be re-spooled on the recorder every month or so. This can be done quickly on fast wind and rewind.

Four Tracks

Recent developments have shown that it is now possible to record four tracks on normal $\frac{1}{4}$ -in. tape, instead of two. It will be

seen from Fig. 8 that there are several possible recording arrangements depending on how many heads are used. Tracks 1 and 3 could be recorded in one direction, followed by tape reversal and recording of tracks 2 and 4 in the other direction. Recording time

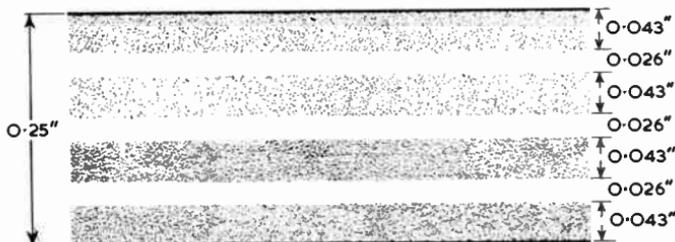


FIG. 8.—ARRANGEMENT OF FOUR TRACKS ON A $\frac{1}{4}$ -IN. TAPE

on stereo could be doubled compared with the more common arrangement while, for mono recording, full-track and half-track working are possible.

A few four-track machines are being made available and these offer both mono and stereo facilities. Others are likely to follow.

Editing

It is of great value to be able to remove unwanted portions of a recording and, conversely, to introduce new lengths of tape. Passages of music or speech can be cut out; irritating noises can be eliminated and broken tapes repaired. The cutting and splicing of tapes was a professional activity not so long ago, but it is now quite commonplace amongst amateurs—indeed, many tape enthusiasts consider they are not being true to their calling if they do not introduce at least one joint into a reel.

Confidence is gained with a little experience and the amateur, using the simplest of tools, can make joints which do not cause any noise as they pass the tape head. A tape is not weakened by the presence of dozens of joints, provided that these have been correctly made.

If a tape has snapped or has to be joined after the removal of an unwanted passage, the procedure is as follows. First assemble the few tools required. These are an editing block (there are several

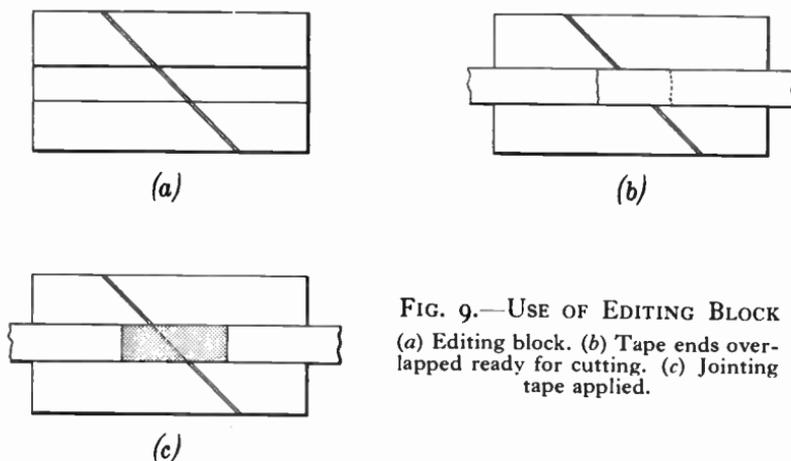


FIG. 9.—USE OF EDITING BLOCK
 (a) Editing block. (b) Tape ends overlapped ready for cutting. (c) Jointing tape applied.

makes available), this, as shown in Fig. 9 (a), being essentially a block with a channel to accept the tape and a central slot cut at an angle of 45° ; a razor blade, which must not be magnetised (check by seeing that it will not pick up even a small magnetic object); and a reel of the special jointing tape sold by most manufacturers of magnetic tape. Proper jointing tape is essential; there is no satisfactory substitute.

Ensure that the two ends of tape are clean. Lay the tape in the block with the glossy side uppermost and with the ends overlapping slightly, as shown in Fig. 9 (b). Cut through the overlap with the razor blade, using the 45° slot as a guide. Finally, butt the two ends together and place about one inch of jointing tape across the break, pressing down firmly, as shown in Fig. 9 (c). A worthwhile refinement is to apply a very little french chalk to the joint in order to remove any stickiness.

Editing is of most use to those who undertake ambitious recordings, collecting material from various sources and mixing in "sound effects." It is useful to the high fidelity enthusiast, however, when he wishes to join together or rearrange items which may have been on separate tapes. Coloured leader tape is available and lengths of this can be spliced in to identify sections of a recording. This tape can be written on with a ball-point pen.

Although editing is simple when the recording is full track, it is necessary with twin-track machines to ensure that only one track

of the tape has been recorded (or that the second track contains something dispensable).

A position indicator, or cueing device, is provided on most recorders, to assist the user to select the part of a recording he requires. This usually takes the form of a digital counter or a "clock" type dial. Such an indicator will give an approximate indication of the section which is to be cut. After this, it is still necessary to find the precise point by careful monitoring. Editing is quite straightforward on the more expensive tape decks: removal of the head cover is simple and often no pressure pad is used for tape to head contact. It is a simple matter to mark the tape with a yellow wax pencil at the point where a cut is to be made. The tape is less accessible in many domestic machines but patience and ingenuity can overcome most of the disadvantages.

Accessories

Two accessories deserve mention. The Ferrograph "De-Fluxer" is designed for demagnetising tape heads—residual magnetism in a recording head tends to increase the level of background hiss on the tape. This device is also useful for erasing short passages of unwanted recording.

The other accessory, available from several makers, is the "bulk eraser." This is an electromagnetic device on which a full spool can be placed, enabling the entire contents of a tape to be erased in a matter of seconds. A bulk eraser is useful for those who do not wish to spend the time taken in "cleaning" the tape by running it through the recorder.

Extra-Musical Possibilities

Some notes on musical activities which owe their inspiration and existence to tape recording will provide an appropriate conclusion to this chapter.

Programmes of sound, created, manipulated and reproduced by electronic means appear to have a wide field of application. The whole purpose of these works is to eliminate performers and, indeed, all obvious human agencies, from the public performance: only loudspeakers and tape equipment are used.

Musique concrète, with mainly French protagonists although with a number of supporters in other countries, uses various sources of sound, partly natural and partly artificial. Such sounds may include, for example, a baby crying, a motor car being started, a tap dripping. Traditional musical instruments as well as specially designed instruments of a technical nature could be involved. The raw materials are subjected to various treatments: the simplest, such as adjustments of pitch, timbre, reverberation and the like, are all straightforward with modern electronic aids. The final product can be obtained by much editing, but it is better to mix the outputs from numerous tapes and to combine them on another (that is, a process of montage).

Another type of work is called simply "electronic music" and employs only electronic sources of sound. Henk Badings, the Dutch composer, is a leading figure in this field and it is significant that he is both an engineer and a musician. He composed the radiophonic opera "Orestes" (which has been broadcast by the B.B.C.) and the electronic ballet music "Cain and Abel."

Electronic music, then, is completely "original" and the microphone does not enter into its creation. Audio sources such as an electronic oscillator can produce glissandi and make possible unconventional musical intervals, as well as ordinary ones like octaves and fifths. The form of electronic oscillator known as the multivibrator produces sounds consisting of a fundamental tone plus all its harmonics up to the audible limit. "White noise," often used to test loudspeakers, is another source; this consists of sound energy evenly distributed over the audio spectrum. The various sections of a composition can be prepared by engineers under the composer's direction and finally combined on one tape.

A few of the examples so far produced have shown that these compositions can be satisfying as an aural experience if they are products of genuine artistic talent and technical ability. They are of even greater value as accompaniments to films and ballet, where there can be a particularly happy merging of visual and aural fantasy. However, there is obviously great scope for the charlatan. Those so far concerned with these compositions have evidently been set on breaking with tradition, and have felt a strong need for innovation, yet new conventions are probably going to be necessary if this field is to develop; traditional music has had its troubles due to lack of

form. In this connection, it is interesting to learn that electronic music is amenable to "musical" notation and that full scores have been evolved.

What has all this to do with High Fidelity? Quite a lot when one considers that many enthusiasts have at least some of the basic materials and tools already in their possession. There is plenty of evidence that amateurs are making tentative experiments in this field. An obvious danger exists that their efforts may quickly degenerate into a series of pointless noises; it should be assumed, perhaps, that this will be due to lack of facilities rather than lack of feeling for the medium. There is clearly a great deal that can be done with an inexpensive audio oscillator, amplifier tone controls and filters, home-made sound sources and a vivid imagination. Reversal of sounds by reversing sections of tape is an elementary but essential operation. Another essential is a full-track tape recorder with separate record and playback heads. "Buy before you try" is probably the best approach in this instance: records of *musique concrète* have been issued by Ducretet-Thomson (on disc, not tape!).

CHOOSING YOUR EQUIPMENT

THE newcomer will probably select equipment by comparing published specifications and by taking every opportunity to listen to various products. He will be concerned, too, with the equipment's appearance and the way in which it can be accommodated.

A summary will be useful at this stage, mainly in order to emphasise points over which misunderstandings sometimes occur. It is particularly important that the prospective purchaser should keep in mind the possibility of future expansion. If the installation is likely to grow, the items chosen initially should have the facilities which will permit extra equipment to be added later with the minimum of trouble.

Pick-Ups and Turntables

Magnetic pick-ups are the most suitable for high fidelity installations. The output voltage is very small: a sensitivity of 3 mV. per cm/sec. would be typical for a mono pick-up and this would mean an average output of roughly 30 mV. The output from a stereo pick-up is considerably less than this at the present time; the sensitivity quoted for a stereo model applies to each channel.

The output from any magnetic pick-up must be "equalised" or "corrected" in the input circuits of the amplifier since the frequency response characteristic approximates to the recording characteristic. This fact, and the low output voltage, obviously influence the choice of an amplifier. Smooth frequency response from 30-16,000 c/s is the aim.

Several crystal pick-ups are available which will suit the more modest installation. The output voltage may average up to 0.5 volt. Most crystal pick-ups have their own in-built correction for the recording characteristic and can be used with a simpler amplifier.

The final choice of a pick-up will, of course, depend on the money available. It is a mistake to try to save on this item, particularly if record playing is to be the main feature of the installation. Whatever the type of pick-up, a diamond stylus should be used and will prove to be more economical in the long run. A careful check should be kept on the amount of use the stylus receives ; both stylus and records must be handled with care and the ill effects of dust should never be underestimated.

The pick-up arm should have a weight for counterbalance, not a spring device. (A satisfactory combination of the two is used occasionally.) Tracking error is low in good pick-up arms : an absolute maximum of 2° , applying to the outside grooves of the record, should be possible but a lower figure is desirable. It is absolutely essential that the vertical and horizontal bearings should not introduce enough friction to cause appreciable side-thrust when the pick-up is in use.

A turntable of the transcription type is highly desirable. A heavy turntable (anything from 5 to 8 lbs. in weight) is an outstanding feature of transcription units : it is usually made of non-magnetic material such as cast aluminium. Turntable weight alone is not a cure for all possible ills with gramophone units and the entire mechanism should exhibit a high mechanical standard. When choosing a turntable, the important thing to remember is that it must be up to the standard of the rest of the equipment. The "rumble" generated by an inadequate turntable will be exposed by a good loudspeaker ; on the other hand, it might not be noticed if the installation has a limited bass response. This is one of the many reasons why the prospective purchaser should first listen to a complete set of equipment of the type which he can afford.

Amplifier and Control Unit

The input arrangements should be sufficiently versatile to cover present and future requirements. The minimum number of inputs normally catered for are pick-up, radio tuner and tape recorder inputs.

The pick-up input is the one needing the most careful consideration as some control units (the simpler ones) cater only for crystal

pick-ups. The input resistance will be anything up to 1 Megohm in this case and the sensitivity in the approximate range 50–200 mV. This is the input voltage which will result in full output power from the amplifier. Remember : the lower this voltage, the higher the sensitivity.

For magnetic pick-ups, a sensitivity of 10 mV. will meet most requirements, although many amplifiers are even more generous in this respect. Stereo amplifiers are the most sensitive and a figure of 5 mV. is typical.

The selector switch connects into circuit an electrical network to apply correction for the recording characteristic. This is essential for all magnetic pick-ups. Correction for at least two recording characteristics should be provided.

The load resistance required by a magnetic pick-up is usually in the 50–100k ohms region. Check that the control unit has a convenient means of adjusting this resistance ; the adjustment may be made at the rear of the unit or by means of a plug-in device.

The input for a radio tuner or complete tape recorder has a sensitivity of about 100 mV. at 100k ohms or higher. A few amplifiers have an input for direct connection of a tape playback head ; sensitivity is then high (3–5 mV.). An output is often provided for recording purposes : this is for connection to a complete tape recorder or the recording amplifier used with a deck.

Controls were dealt with in Chapter 3. Selector switch, volume (with mains switch), bass and treble are the minimum for mono equipment. The same applies to stereo, but a balance control in one form or another is required.

A claim concerning frequency response in a specification is of use only if qualified by an indication of its smoothness. This is indicated in dB. The figures given in Chapter 3 are a good guide. Harmonic distortion as low as 0.2 per cent for control unit and amplifier combined is often claimed. Where the amplifier is concerned, power, response and distortion are closely linked. In particular, the rated power should be delivered to the loudspeaker over the whole frequency range being reproduced. The distortion should also be small over this range. A figure for intermodulation distortion is more useful than a figure for harmonics : 1 per cent is very good.

Radio Tuners

The f.m. tuner may have a tuning dial or station selection may be by means of a switch. The audio output voltage is likely to be in the region of 100 mV., and this is adequate for use with any amplifier. In an earlier chapter, we mentioned that among the most desirable features to look for in an f.m. tuner are ease of tuning and freedom from having to retune constantly because of frequency drift. This suggests that an effective automatic frequency control system is of considerable benefit.

The tuner's power supply needs careful consideration. Many tuners draw their power supplies (both h.t. and l.t.) from the amplifier (via the control unit) and in this case it is necessary to confirm that enough is available from the amplifier. If the power cannot be supplied in this way, a mains-powered tuner must be used.

Tuners offered for high fidelity systems are normally sensitive enough to perform reasonably well even in the "fringe" area of a particular transmitter. However, a properly designed aerial of a type appropriate to the local conditions is essential if the level of background noise is to be minimised. Close to the transmitter, a good indoor aerial will probably be adequate. Noise-free reception, one of the main advantages of f.m., cannot be guaranteed if only a length of wire is used.

Loudspeakers

A good guide to the quality of a moving-coil loudspeaker is the size of its magnet. In general, the larger the total magnetic flux, the better (and costlier) the loudspeaker. A low resonant frequency is desirable for bass loudspeakers, or wide-range units which are to handle bass: a resonance at 35 c/s is typical of good 12 in. drive units.

For modest installations, a single drive unit, 8 in. to 12 in. diameter and covering virtually the entire audible range should prove satisfactory. This can be used in a vented or horn enclosure, in a column or on a baffle. A reasonably smooth performance in the 50-15,000 c/s range can be obtained with many such arrangements.

It is often possible to arrange for the unit first purchased to become at a later date the bass unit of a two- or three-speaker system.

Some moderately-priced multi-speaker systems are available and these offer a widely diffused sound output. Two of these are very suitable for stereo. The same principle is used in some quite expensive loudspeakers (in the £60-£100 range). A single drive unit is used in some expensive loudspeakers, a few large horn-loaded types giving superlative results.

A pair of column loudspeakers for stereo take up very little floor space. Pleasing but less-than-perfect stereo can be obtained in several ways: dissimilar loudspeakers can be used provided that one of them is able to give good bass; alternatively, there are arrangements which enable two inexpensive high-note loudspeakers to be added to an existing bass reproducer.

The effects which the room has on sound quality should always be kept in mind: some effects can be modified. Some experiment with the relative position of loudspeakers and seating arrangements is often rewarding. A large and very efficient loudspeaker with an extended bass performance is an extravagance in a small room. Final selection of a loudspeaker can only be made after a careful listening test using various types of music.

Tape Recorders

Tape can be incorporated in two main ways. A deck with its associated recording amplifier, rather than a completely self-contained recorder, usually offers the best performance for a given outlay. If portability is considered important, one of the larger portable machines will be satisfactory—provided it is really intended to be linked with high fidelity equipment.

Whatever form the recorder takes, a high standard of mechanical construction is vital. The most useful speeds are $7\frac{1}{2}$ and $3\frac{3}{4}$ i.p.s. Wow and flutter should total not more than 0.2 per cent at $7\frac{1}{2}$ i.p.s. and preferably less. The figure for $3\frac{3}{4}$ i.p.s. is likely to be a little higher, but 0.3 per cent or more is well and truly audible on some types of music.

A frequency response of 40-15,000 c/s ± 3 dB is not too much to ask where the higher speed is concerned. A hum and noise level

at least 50 dB below full output is to be expected from a deck with amplifier, and the same figure should be quoted for the better portable machines.

Twin-track recording offers an advantage where playing time is concerned but full-track recording is necessary if much editing of tapes is intended. Separate recording and playback heads are a decided advantage.

Two tracks are used for stereo work and a stereo machine will usually offer twin-track recording facilities for mono. Stereo recording is possible on the most expensive equipments. Four-track machines, offering a further increase in playing time, are likely to arrive in increasing numbers.

Economics

There is a wide price range for most items of equipment. It is best to keep to one standard, according to the money available, and not mix expensive and cheap items together. Of course, this approach must be modified if a certain piece of equipment is to be only a temporary measure. Again, a very comprehensive amplifier could be part of an otherwise modest outfit if its facilities were put to good use at a later date. However, consistency in the selection of equipment is normally of the utmost importance, and a dealer specialising in high quality products will give good advice in this connection.

A few typical "shopping lists" may be of interest. Equipment which can be shelf-mounted or housed in existing furniture is very popular because the money is spent only on items which contribute to the audible result. There must be some "lowest high fidelity" standard and this can probably be obtained for about £50-£60 at the present time. The following list is a reasonable one and allows for a ready-made loudspeaker of good quality. A further pound or two could be saved by buying a loudspeaker enclosure in kit form.

Turntable with crystal pick-up	.	.	.	£20
Combined amplifier-control unit	.	.	.	£20
Loudspeaker system	.	.	.	£15
				<hr/>
Total	.			£55

A much more ambitious system, including f.m. radio, could be as follows :

Transcription turntable	£20
Magnetic pick-up	£15
Combined amplifier-control unit	£25
F.M. tuner	£15
Loudspeaker system	£30
	<hr/>
Total	£105

A stereo record reproducer, complete in cabinets and suitable for the medium to large-sized room, might work out as follows :

Turntable and stereo pick-up	£35
Stereo amplifier	£35
Equipment cabinet	£15
Pair of column speakers.	£40
	<hr/>
Total	£125

An installation based on tape recording may cost about £100. Stereo facilities would add a good deal to this, and an f.m. tuner would add £15-20.

Tape deck with amplifier	£45
Amplifier-control unit	£25
Loudspeaker system	£30
	<hr/>
Total	£100

These prices would include purchase tax where applicable. Round figures are quoted and they are intended only as a rough guide. There are many ways of assembling a creditable installation for appreciably less than £100. It is also possible to spend at least £300 and to get magnificent value for money in doing so.

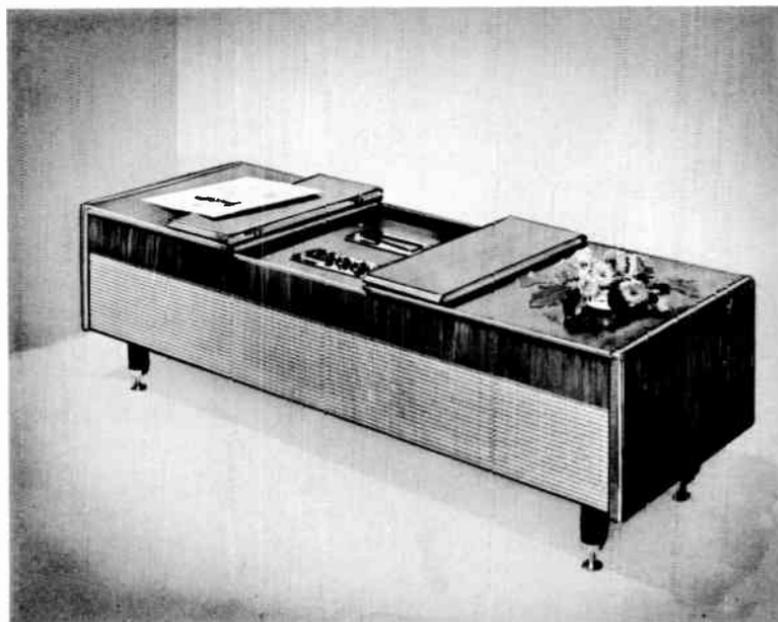


FIG. 1.—G-PLAN CABINET FITTED WITH PYE EQUIPMENT
Space is also provided in this cabinet for a turntable and a tape deck.

Styling

For the majority, "buying high fidelity" has usually involved choosing items of equipment on the basis of technical merit and afterwards assembling them in some suitable way. A turntable and one or more chassis can always be fitted into a cabinet by dealer or customer, whilst equipment comprising separate "units" can stand on a shelf or room divider. Until recently, the usual trouble with either method was that the customer finished up with a number of control panels having nothing in common in the visual sense: the worst excesses of Continental ornamentation were often installed side by side with sober British stove enamelling. The situation was usually made worse by an addition to the outfit some time after the original purchase.

Even to-day, one often comes across ingenious and technically advanced pieces of equipment which have been produced by devoted

enthusiasts but which, judging by appearance, will sell only to others still more devoted. Although there will always be examples of bad design, there have been rapid improvements in the last year or two. Not every firm can afford a design consultant, but there is



FIG. 2.—A NEAT GRAMOPHONE INSTALLATION
The front can be lowered to give access to the amplifier.

evidence that more imagination has been displayed by technical designers. It is now possible to buy two or three items of equipment from one manufacturer with a good chance that the control panels will have similar proportions and finish.

There is a limit to this, of course: a pick-up or turntable is not always part of a range of products which includes, say, a tape deck. Nevertheless, a record reproducing installation or a tape recording

system can now have visual appeal, and several manufacturers have helped matters by making up complete installations in suitable cabinets. Designs which conceal the essentially technical nature of the equipment are not necessarily the most satisfying.

The enthusiast who wishes to give priority to the question of furniture now has a wide choice. There are imaginatively designed cabinets of all shapes and finishes. These may be movable or fixed, console or "lowboy": some cabinets can be used as coffee tables. In certain instances the cabinets cater for a particular make of audio equipment, but most cabinets are easily adapted to take almost any chassis or turntable. Some good-looking imported furniture is available, particularly that of Scandinavian origin. If little money is available for cabinets, an appreciable saving is possible with the kits of parts which are marketed by a few British firms.

Demonstrations

Exhibitions are for the display of goods and demonstrations naturally follow where certain commodities, including audio, are concerned. Real appraisal of audio performance is usually out of the question, however, on such occasions, even if the demonstration rooms are of domestic proportions. The presence of numerous enthusiasts, the high noise level and the havoc wrought by dust in record grooves are among the factors which may prevent a useful conclusion being reached. Listening to stereo is particularly difficult and many people have left exhibitions without having appreciated the difference between stereo and mono. All the same, it is interesting to see nearly every available item of equipment under one roof and the prospective purchaser will welcome the opportunity of comparing features and prices.

A visit to an exhibition may well be a prelude to the more cool and collected appraisal of equipment in a dealer's showroom. Many dealers have excellent rooms in which such matters as reverberation and structural resonance have received attention. There are usually facilities for comparisons between various types and makes of equipment, and various combinations of items by different makers.

In making an appraisal of an equipment, various types of music should be played at several different volume levels, and "gimmicks" should be avoided. It is a good plan to take some familiar records



FIG. 3.—“HIS MASTER’S VOICE” MODEL 582 CABINET, FITTED WITH H.M.V. STEREO AMPLIFIER AND PICK-UP. A MATCHING RADIO TUNER UNIT AND A CONNOISSEUR TRANSCRIPTION UNIT ARE INCORPORATED. THE INSTALLATION IS COMPLETED BY MATCHED EXTERNAL LOUDSPEAKERS
(The Gramophone Company Ltd.)

along (but only if they are in new condition !) and to ask for them to be played on equipment which is in the appropriate price range.

The amateur’s success in making a listening test depends on his experience of listening to music ; a hundred listeners will have a hundred different ways of gaining their illusion of reality. Good tonal balance and definition distinguish high fidelity from humbler sound reproduction. A general “sparkle” and clean reproduction of transient sounds such as those produced by percussion instruments should be listened for ; excessive intermodulation distortion will take the liveliness out of the reproduction. The attention should be focused for a while on particular instruments and voices ; note that the timbre is natural. In all these things, smoothness of response is more important than the actual frequency range.

In a good concert hall, the bass provides a solid foundation for

the orchestral tone and is not lumpy or emphasised ; it should be clean and unobtrusive in the demonstration room. A long room is likely to favour bass reproduction.

Many listeners seem to have rather odd notions about the sound made by the bass drum. This instrument does not boom—its output in the 40–50 c/s region breathes its way across the concert hall. A fairly expensive loudspeaker can simulate this very well, a less expensive one may put up a good showing, while on a cheap loudspeaker the instrument can still be recognised although only harmonics are being reproduced.

Some organs produce a 16 c/s note (from a 32-ft. pipe) but such low notes cannot be recorded, much less reproduced. The organ also produces some very high frequencies. It is not entirely fair, therefore, to judge equipment on one's knowledge of what an organ can do. The piano stands a better chance of proper presentation : the bottom A has a fundamental frequency of 27.5 c/s. The harpsichord produces harmonics up to and beyond the audible limit—reproduction with really good equipment is a revelation.

When listening to stereo on stereo/mono equipment, it is best to arrange for a switchover to mono at some suitable time so that comparison of the two can be made. It must be a genuine comparison, with the two channels paralleled for mono reproduction. It will be useful in most instances to incorporate a change from stereo to mono pick-ups when the comparison is made. The comparison should prove that tonal quality and definition are enhanced by stereo. Closing the eyes should help mental appreciation of the spread of sound between the loudspeakers. Unusual noises and "gimmicks" are more than ever a nuisance here. Ideas about the scale of the particular noise become confused : it is clear that the "image of an express train" is taking several seconds to pass between the two speakers and it is disconcerting to realise later that a 60 m.p.h. express is actually travelling at 30 yards per second !

Some dealers will arrange for equipment to be tried out in the customer's home for a time on approval. This is by far the best way of reaching a final conclusion ; the equipment performs under practical conditions and the customer learns what it will be like to live with.

INSTALLING YOUR EQUIPMENT

IF the equipment is complete in cabinets, the dealer will look after matters concerned with its installation. The customer will presumably have selected at least a provisional position for the one or two loudspeakers (bearing in mind our comments on loudspeaker position in Chapter 5) and the equipment cabinet will most likely be near a wall, or, if it is on castors, near a favourite chair. It is best to sit as far from the loudspeakers as the layout of the room will permit.

A large proportion of the high fidelity equipment sold is in the form of "units": the amplifier (with integral controls) and tuner is housed in ventilated cases and similar in appearance if made by one manufacturer. These two units can stand side by side on a bookcase or shelf. The turntable and pick-up could be mounted on some sort of plinth or base, but they will collect dust this way and a box with a lid is better. As we have seen previously, care is required in the selection of a suitable position for loudspeakers. They should not be attached to or stood on the cabinet housing the pick-up.

Tape equipment offers more of a problem because of its extra size and weight. It can stand on an adequate shelf or be hidden away in a cupboard; otherwise, it is more satisfactory to use a cabinet. A portable machine can be stored anywhere, of course, and connections made via plugs and sockets when it is associated with the installation's amplifier.

Connections

The outfit sketched in Fig. 1, comprising amplifier, tuner and turntable with pick-up can serve as a useful example. The principal connections to be made would be as follows:

The mains cables (3) are taken to a common supply point; an earth connection can be made if there is provision for it on both equipment and wall socket. Both these cables and the loudspeaker

lead (*L*) may be in twisted flex, but a heavier grade of rubber or plastic covered cable is often preferred as it helps to prevent tangling and knotting. The loudspeaker lead should be kept as far as possible from the mains-lead and amplifier power supply components, to avoid the possibility of hum pick up in the lead, and some benefit in this connection may be obtained by using twisted lead.

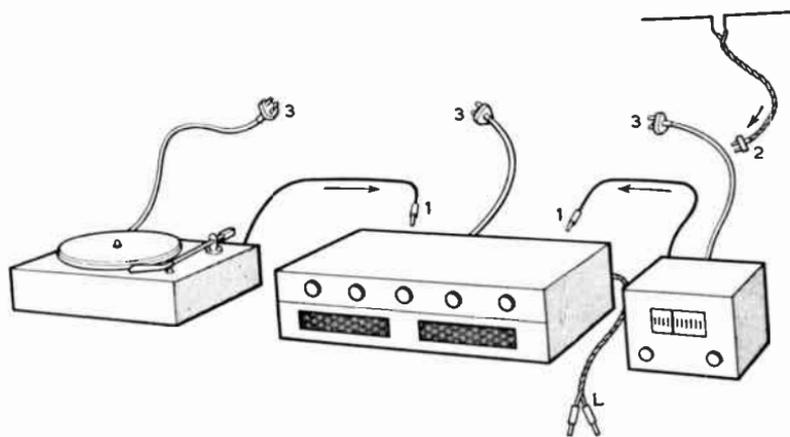


FIG. 1.—PRINCIPAL CONNECTIONS FOR AN INSTALLATION COMPRISING A TURNTABLE WITH PICK-UP, AN AMPLIFIER, AND AN F.M. RADIO TUNER

A pick-up bought separately will have a length of thin screened wire which runs through the arm to the head. When the arm has been installed, the wire should be terminated under the baseboard. The matching transformer for a moving-coil pick-up will usually be connected at this point (see comments in Chapter 2); its final position should be found by moving and turning it around to find the position where hum pick up is at a minimum. The connection to the amplifier input is preferably made with coaxial cable terminating in a screened single-pin plug (1) (the screen is usually the metal outer casing of the plug) which is normally supplied with the amplifier. It is important to ensure that the cable and plug screens (the cable screen is the metal braiding in the cable) are efficiently bonded together. In the case of stereo, an arrangement used in several instances is to extend the pick-up lead by means of two separate coaxial cables; these are taken to input sockets marked "Left" and "Right."

A similar cable and plug is necessary for the tuner's connection

to the amplifier. If the tuner is to draw its power from the amplifier, a 4-way cable and plug is usually required for this: a pair of wires for l.t., one wire for h.t.+ and one earth wire which connects together the amplifier and tuner chassis. It may also be necessary to connect the metal turntable unit chassis to the amplifier chassis, to reduce hum.

The aerial lead for the tuner is often "twin feeder" or flex and the termination will therefore be a miniature 2-pin plug (2). Coaxial cable with appropriate plug is the alternative.

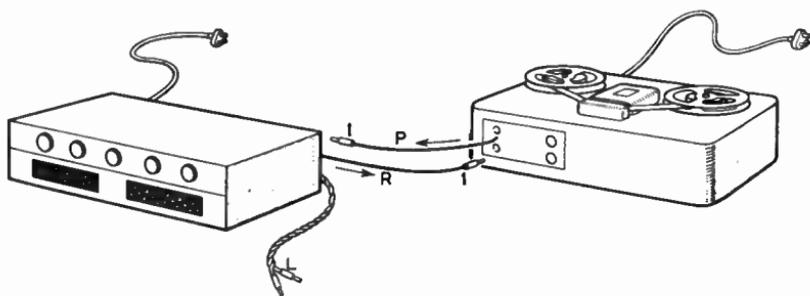


FIG. 2.—CONNECTIONS FOR AN AMPLIFIER AND TAPE RECORDER

The connections for an amplifier and a tape deck with its recording amplifier are shown in Fig. 2. Two important connections have to be made: one for recording (*R*) and one for playback (*P*). Coaxial cable and single pin plugs (or jack plugs) are used and again the cable must be as short as possible to avoid loss of high frequencies. Where the output is known to be at low impedance due, for example, to the use of a cathode follower arrangement, the cable can be quite long.

It is absolutely essential that all "earth" connections involving screens of cables and plugs should be carefully attended to—otherwise, the high signal-to-noise ratio achieved under test conditions by the manufacturer will not be realised in practice.

A recommended Code of Practice for interconnections has been issued by the *Audio Manufacturers' Group*.

Pick-Up and Turntable

These two items will sometimes be purchased as an assembly, in which case the arm will be correctly located with respect to the

turntable. If they are separate, the pick-up must be installed exactly according to the manufacturer's instructions if tracking error is to be minimised.

The first job is to mount the turntable on a suitable baseboard. An aperture has to be cut in the board, and the turntable's baseplate screwed down. Mounting springs are often supplied but these can

FIG. 3 (*right*).—LOCATING THE PICK-UP

Distance D between turntable and pedestal centres *must* be accurately measured.

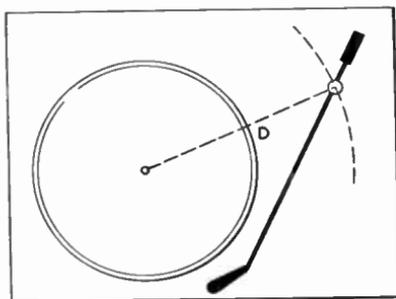


FIG. 4 (*below*).—ADJUSTING THE PICK-UP

The stylus *must* be perpendicular.



be dispensed with—a springy mounting is usually more trouble than it is worth, especially if vibrations from the loudspeaker cannot reach the pick-up.

The all-important measurement is indicated by the dotted line D in Fig. 3. The pedestal of the pick-up can be mounted anywhere on an arc as shown, provided that distance D is that specified by the manufacturer. It is important to realise that this is the distance between the turntable and pedestal *centres*. It will usually be in the 8–9 in. region. A protractor or template is often supplied by the pick-up manufacturer as a guide for fitting. The pick-up may also be mounted on the opposite side of the turntable, facing the other way. Whatever the arrangement, it is essential that the arm can be handled conveniently and that the head does not pick up hum from the motor or elsewhere.

Arms are normally provided with a height adjustment. This should be used to ensure that the stylus is perpendicular to the record surface. This will mean that axes through arm and head must be parallel to the record unless there is some instruction to the contrary (see Fig. 4).

Levelling the Turntable.—Lightweight pick-ups and the advent of stereo discs have increased the importance of ensuring that the base holding the turntable and pick-up is level. Even if the bearings of the pick-up arm are free from excessive frictions, a cabinet or baseboard which is not level can cause side pressure in the pick-up and increased record wear. Many enthusiasts take the trouble to

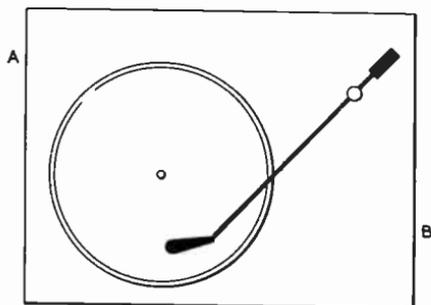


FIG. 5.—DYNAMIC LEVELLING
Adjust height A relative to B.

check levelling with a spirit level but a worthwhile additional precaution is the “dynamic levelling” advocated by Mr. Percy Wilson, Technical Editor of *The Gramophone*. This is a process which takes into account the side pressure under operating conditions. In spite of its advantages, it seems to be a precaution taken only rarely. The method is as follows :

First check with a spirit level that the turntable and pick-up assembly are level. Next it is necessary to find a smooth disc of about 12 in. diameter which can be placed on the turntable. A flat disc of plastics material is suitable but it is vital that this is flat, polished and free from any scratches or other marks.

With the disc in place, start the turntable at its slowest speed and place the pick-up gently on the surface of the disc. If the pick-up has been correctly installed, it will swing inwards or (less probably) outwards across the disc. This should happen when the pick-up is put down in various places on the disc. The baseboard or plate should then be tilted slightly, as indicated in Fig. 5, until the pick-up stays still while the turntable is rotating.

The amount of tilt needed is very small and a small piece of suitable material to act as packing can be used to keep the board in the correct position. A check should be made periodically to ascertain that the adjustment has not been disturbed.

It will be evident that dynamic levelling can be achieved most conveniently where the installation is a fixed one. With a movable equipment, *e.g.* one mounted on castors, adjust to ensure that dynamic levelling is correct when a spirit level indicates correct static levelling. The most useful spirit level is the circular type with a central bubble.

Pick-up Playing Weight.—A calibration on a pick-up arm of playing weight is quite rare so that some device for measuring it is useful. A simple spring balance is suitable. There are also specially made gadgets on the market: the type using a pivoted lever and sliding weight is probably the best. On some arms, the weight is fixed by the manufacturer for a particular head; in any event, the playing weight used must always be that specified by the manufacturer.

The usefulness of a penny is acknowledged everywhere. In audio, even a halfpenny may be handy in an emergency if one remembers that it weighs nearly 6 grams.

Hints and Tips

Frequency Test Records.—Test records containing bands of pure tones or a “gliding tone” are available from several record companies. These are intended for testing pick-ups and for other purposes but the amateur will learn nothing whatever from their use unless he has a valve voltmeter with which to make measurements of the output. If such a record is purchased for some reason, it should never be used with the amplifier volume control turned up: the loudspeaker may be damaged by this. The temptation to turn the volume up is irresistible to many people as even the best response to a 40 c/s tone is not very noticeable unless a great deal of power is driving the loudspeaker—and therein lies the danger.

Two Warnings.—It is a mistake to flick the stylus with a finger

to check that the equipment is working, as the pick-up could be damaged by doing this. Any dust which has accumulated on the stylus should be removed with a small brush.

Equipment should not be switched off at a common point if the turntable is rotating. The rubber wheel driving the turntable is released from its operating position by switching off the motor itself. If the motor is not switched off before the rest of the equipment, the rubber driving wheel will remain in contact with the turntable and will become distorted. A distorted driving wheel is the main cause of rumble. Always switch the turntable off first, then the rest of the equipment.

Ventilation.—If a separate control unit and amplifier are installed in a cabinet, it is usual to put the heavy main amplifier chassis at the bottom. Amplifiers generate considerable heat, which, if not dispersed, will cause deterioration of some components. The power output valves of the main amplifier generate most of the heat and it is fairly easy to arrange for this to be dispersed. An aluminium screen can be arranged, if necessary, to reflect the heat from these valves towards the back of the cabinet, where there should be ample openings to provide good air circulation. This position for the power amplifier also provides good separation between the transformers and such points susceptible to hum pick up as input circuits and tape heads.

Shelf-mounted equipment will be in some kind of ventilated boxes and the main precaution is to leave a space between and behind each item.

Loudspeaker Position.—Apart from considerations of acoustics already dealt with (see Chapters 4, 5 and 8) it is also important to note that it is occasionally possible for “acoustic feedback” to occur between the loudspeaker and the pick-up, causing low-pitched noises. Moving the loudspeaker may help and a possible preventive measure is a resilient mounting (*e.g.* foam rubber) for the loudspeaker or equipment cabinets. This is one situation which may, in spite of what we said earlier, necessitate a spring mounting for the board holding the turntable and pick-up.

Loose or springy floorboards can be troublesome, and further experiment with loudspeaker positioning may be necessary to avoid

them. It is best, however, to correct such defects in floors, as heavy footsteps may cause the pick-up to jump.

Record Storage.—The best way to store records is to keep them upright and in fairly small groups, each containing records of one size. They should be prevented from leaning over. If the storage compartment is not full, put a sheet of plywood next to the records and fill the remaining space with packing. Extra covers, such as the polythene bags sold for the purpose, are useful dust excluders. If horizontal storage is the only possibility, not more than about eight records should be in any one pile. It is convenient to keep discs and tapes in one place—some cabinets have compartments for each.

Conclusion

Emphasis of two particular points—the listener's hearing abilities and the quality of the recording—will make a fitting conclusion to our deliberations, which have so far been mainly concerned with the quality of equipment.

The audible frequency range decreases with age and, realising this, many people of advanced years declare that high quality sound is no longer of use to them. Restricted frequency is not a very serious limitation, however—certainly not a final one. Elderly enthusiasts whose useful hearing response may extend to only 8 kc/s are usually able to appreciate other benefits of high fidelity such as low distortion, good transient response, good sound distribution and the improvement in tonal quality which stereo can give.

Recording quality is still surprisingly variable, but the amateur should find a good record review of assistance when new records are being chosen. Many reviewers comment on both the artistic and the technical merits of a recording. Many matters concerned with reverberation and balance are, however, acceptable or not to the listener according to personal taste, and it is essential to listen to a record to know about them. Broadcast reviews are a useful supplement: one can obtain a very good idea of a record's merits via f.m. radio.

Modern facilities of assembling recordings in instalments, *i.e.* joining lengths of tape together, and obtaining a near perfect result

lead to the possibility that the listener will become conditioned to streamlined productions which he would seldom hear in the concert hall. There is, unfortunately, a race of hi-fi bores who lack the sense of proportion which they might have gained by attending occasional concerts. At best, the gramophone and tape recorder allow the listener a leisurely study of music which he can and should listen to in its natural surroundings. To this is added the opportunity of hearing music which, were it not for the gramophone, would go unperformed.

It must be admitted that high fidelity in the home is often agreeable and worthwhile when playing a quite secondary role. An advertisement in a shop window read: "Wanted—woman for housework in A flat," evidence, no doubt, that even household chores are best performed with an accompaniment in hi-fi. But music is a serious matter to a great many people and they are likely to find that the combination of first-hand musical experience with high fidelity at home is the most rewarding.

HI-FI IN THE FUTURE

ALTHOUGH one may feel fairly certain about the significance of present trends, it is difficult to forecast their final outcome. Some prophecies come true very quickly : others, which seem so obvious and desirable, do not come true at all !

Disc versus Tape

An important issue seems to be disc versus tape. The disc has been with us a long time ; everyone can handle it easily and an enormous repertoire of disc recordings is available. Pick-ups have had a long and distinguished career, culminating in some very refined magnetic types for mono records. But the rush to produce new models in order to meet the stereo disc's precipitate arrival involved a backward step in pick-up design, in spite of all the ingenuity that was displayed.

The lost ground is being made up, however, and pick-up performance can be further improved in the future. A steady reduction in playing weight is an outstanding trend. At least one manufacturer is promising a pick-up which will track the record securely at only 1 gram pressure. This imposes stresses which are small enough to avoid the plastic deformation of the groove which occurs with all existing pick-ups. One result of this development should be a spectacular increase in record life. Perhaps, under these conditions, the sapphire will once more be a worthwhile stylus material. It has even been suggested in some quarters that certain plastics materials (such as P.T.F.E.) could one day be considered for the stylus. A high degree of polish would certainly be possible.

However, some enthusiasts are wondering whether disc reproduction *has* a future, particularly where performance of the highest quality is concerned. The difficulty of handling pick-ups at very low weights, the inevitable fragility of armature and stylus assembly

in magnetic types, and the vulnerability of records ; will not these factors make us lose our patience with the whole affair ? Those who do not admit such things are disadvantages cannot deny the illogical nature of disc reproduction. Three important illogicalities have already been instanced in this book : the groove is cut with a sharp-edged stylus tip and played with a smooth spherical one ; the speed of the groove past the stylus is not the same at any two points ; the record is played with an arm which, though convenient to manufacture and (so far) to use, follows a different path to that taken by the cutting head.

Tape does not have these disadvantages but, as already pointed out, it has a few of its own. High cost has been a definite drawback ; a limited recorded repertoire has been another (for the record-collector, not the hobbyist). Perhaps tape will be more widely used if the cassette or "magazine" developed by R.C.A. in America is made generally available. This device is a plastics housing containing about 600 ft. of standard $\frac{1}{4}$ in. tape recorded on four tracks. The playing time can be longer than for a disc (the speed is $3\frac{3}{4}$ i.p.s., resulting in big economies in tape for both mono and stereo) ; and the layman's objection to threading tape on to spools is overcome with the cassette. A tape deck which employs a magazine-type housing has been introduced by Garrard.

In some recent portable tape recorders, particularly those of Continental origin, great stress is laid on extended high frequency response and startling claims are made for the $3\frac{3}{4}$ i.p.s. speed. The amateur should always be careful to remember that a smooth response is every bit as important as an extended one. It is essential to realise that, at any stage of development, high frequency response is limited by the design of tape heads and other parts. Too much emphasis of high frequencies to overcome limitations in the system at the $3\frac{3}{4}$ i.p.s. speed can only increase noise level and distortion. Also, the lower the tape speed, the more difficult a consistent mechanical performance becomes. Such engineering problems are generally resolved in time, and $3\frac{3}{4}$ i.p.s. will probably be the standard speed for domestic use in due course.

Lower Speed Records

With the many talking points provided by recent developments in high fidelity sound, it is hardly surprising that the topic of $16\frac{2}{3}$

r.p.m. discs has not received so much attention as it once did. There was at one time a certain amount of misrepresentation of this subject in the popular press. Nearly every manufacturer of popular types of record player changer went through a remarkable phase of following his neighbour's example and adding this fourth speed to their machines. Unfortunately for them, however, wow and flutter present enormous problems at $16\frac{2}{3}$ r.p.m., and music recordings made at this speed sound quite intolerable when played on most moderately-priced turntables. They would probably pass muster on some transcription turntables, but hardly any firm making transcription units has bothered to add the fourth speed.

Recordings of speech only made at $16\frac{2}{3}$ r.p.m., using ordinary microgrooves, have appeared on occasions and these, in spite of quite large pitch fluctuations, sound acceptable. Recordings of music at $16\frac{2}{3}$ r.p.m. using a still finer groove (a "picogroove"), necessitating a smaller stylus tip than that now used for stereo discs, were also developed and received some publicity in the U.S.A. These could not be played on existing record changers because the decrease in stylus and groove dimensions call for a playing weight of about 2 grams. In any event, it seems that the increase in playing time was more than offset by an all-round deterioration in sound quality: tracing distortion and high frequency response limitations are major difficulties. Whatever blessings the future may hold, therefore, it is to be hoped that $16\frac{2}{3}$ r.p.m. music discs are not among them.

Returning to existing types of record, perhaps it is not too ungracious to suggest that we deserve a still higher standard of recording. The best of current issues are very pleasing but there are too many which are second rate, with pitch changes, audible tape joins, excessive volume levels and other bad faults. There is no reason why we should accept such low standards in relatively expensive recordings. The more alert record reviewers, fortunately, notice these faults and point them out.

Size of Equipment

Until recently, there seemed little need to look for ways of reducing the size of high fidelity equipment but now, with the increasing number of components which can be involved, especially with stereo, there is more justification in giving consideration to

space saving. The combination of printed circuits, transistors and other small parts makes possible a different concept of equipment design. For example, a "horizontal" layout of the amplifier chassis need no longer be the only approach. New ideas in amplifier design will in any case follow the more widespread use of electrostatic loudspeakers, which could conveniently be wall mounted in pairs for stereo (one each side of the television screen?). This would be a really sensible move—floorspace is at a premium in many homes.

Stereo Broadcasts

The B.B.C.'s experiments with stereo broadcasts via two transmitters have proved instructing and entertaining for many listeners. However, such a system would be very uneconomical for normal use—both for the broadcasting authorities and for the listener who would need two tuners. New stereo systems which allow both channels to be radiated from a single transmitter are being developed in the United States and in the United Kingdom. In America such transmissions are generally made by what is known as "f.m. multiplexing." One British development—the Percival f.m. system—is being developed by E.M.I. in co-operation with the B.B.C. So far as the enthusiast is concerned, only one special tuner or adaptor will be needed. The really important thing is that the system is a "compatible" one, meaning in this instance that the signals in the two channels are combined to give a single f.m. signal for reception by those not equipped for stereo. Thus there is no question of upheaval at the receiving end: the transmissions give stereo for listeners who are equipped to receive it and mono for everyone else.

Another British stereo system, developed by G. D. Browne of the Mullard Research Laboratories, depends upon what is called technically "time multiplexing with pulse amplitude modulation." It is claimed that this system could be easily applied to existing f.m. transmitting and receiving equipment; it would then allow two independent channels to be radiated from a single f.m. transmitter and picked-up on a single f.m. tuner unit. Briefly, the system is to radiate each channel in turn for very short periods, automatic electronic switching of the transmitter and receiver from one channel to the other at the rate of about 30,000 times per second being used. The listener's ear cannot detect this switching, so that each channel is

heard as though it were being radiated continuously. It is claimed that audio information between 30 c/s and 15 kc/s can be reproduced faithfully on each channel. At the receiving end, only a relatively simple "decoder" unit need be added to a single f.m. tuner unit, provided that a dual-channel stereo audio system is already available. Like the Percival system, the signals can be heard as mono on a receiver not fitted with a decoder unit.

At the time of writing it is not known which, if either, system will be adopted by the B.B.C.

Conclusion

And so we still look forward to perfection, and often tend to feel, after some brilliant new development has been placed before us, that "the ultimate" is at last being approached. Whether we shall all agree about it when it comes remains to be seen. Overlooking technical details and considering such factors as convenience of use, physical size and manufacturing cost, it is clear that not one of the several types of equipment used by the enthusiast has yet reached the limit of development. Ingenious schemes are afoot, however, and the commercial fruits of many fertile imaginations will be seen in the years to come.

Meanwhile, the newcomer is urged to make his choice circumspectly but without undue delay. Indeed, the sheer multiplicity of good products already available makes delay dangerous: too protracted a diet of comparative demonstrations invites early atrophy of the hearing faculties. There are thrilling and truly musical experiences to be had from the best of current offerings.

Glossary

A.C. Alternating current. Current which changes its direction of flow in a regular fashion.

Acoustic Feedback. Transfer of sound vibrations from the loudspeaker to some other point in the system.

A.F. Audio frequency. The term is applied to a vibration detectable by the ear but may also be used to describe electrical vibrations.

A.F.C. Automatic frequency control. System incorporated in some radio tuners to ensure the tuner remains "tuned in" to the station being received.

A.M. Amplitude Modulation. Method of radio broadcasting in which the amplitude (strength) of the carrier wave is modulated (varied) by the audio frequencies to be broadcast.

Amplifier. Electronic equipment which increases the amplitude of electrical vibrations. This may be a voltage amplifier which increases the voltage of the signal (*e.g.* in a control unit) or a power amplifier which, after preliminary voltage amplification, produces the power to drive the loudspeaker.

Amplitude. Peak value of a vibration or impulse.

Amplitude Distortion. Also known as non-linear distortion. Occurs when the output of the system is not a true facsimile (at different amplitude) of the input. Includes harmonic and intermodulation distortion.

Anode. The electrode (of a valve) which collects electrons.

Aperiodic. Applied to electrical circuit or mechanical system which is so damped that free oscillation or resonance cannot occur.

Armature. Moving part in, for example, a magnetic pick-up. The stylus is affixed to the armature.

Attenuation. Reduction in amplitude of a signal.

Attenuation Distortion. Lack of constancy between input and output at different frequencies. See frequency distortion.

Azimuth Adjustment. In tape recorders, the adjustment of a magnetic head so that the head gap is at right angles to the direction of travel of the tape.

Baffle. Screen or board to which a loudspeaker can be fitted. Increases the distance between front and back of the loudspeaker ; makes low frequency performance possible to a degree which depends on the dimensions of the baffle.

Bass Reflex Enclosure. See Reflex enclosure.

Bias. The impression of a high frequency magnetic field on the audio frequency field in magnetic recording. Also used to describe the addition of a steady voltage to a signal voltage in the circuits of an amplifier.

Binaural. Term used to describe listening with headphones to signals which are being carried by two transducing channels.

B.S. British Standard Specification. A specification issued by the British Standards Institution.

Cantilever. Link between stylus tip and armature in a pick-up. May convert lateral movement of stylus into rotational movement of armature, as in moving-coil and moving-magnet pick-ups.

Capacitor. The preferred name for what is often called a condenser. Essentially it consists of two plates with insulating material (the dielectric) between them. Allows a.c. to pass, according to value of capacitance and frequency of the a.c. Will not allow d.c. to pass.

Cartridge. The basic essentials of a pick-up, mounted on a bracket to fit into a pick-up arm. The cartridge may be for microgroove records only or it may be a "turnover" type for all types of record. The name "head" is normally applied to a pick-up in a housing which fits a particular arm.

Cathode. The electrode (of a valve) which emits electrons.

Cathode Follower. A valve circuit in which the load is in the cathode circuit of the valve. The arrangement gives a low output impedance and is used when the output lead is to be very long.

C.C.I.R. Comité Consultatif International des Radiocommunications. An advisory body whose recommendations on various technical matters (*e.g.* aspects of tape recording) are widely followed by manufacturers.

Chassis. The metal base on which electronic circuits are built. Sometimes applied to the frame of a loudspeaker.

Choke. See Inductor.

Column Enclosure. Loudspeaker enclosure whose height is great compared with its cross-section area. Its behaviour may usually be compared with that of an organ pipe.

Compliance. The opposite of stiffness.

Condenser. See Capacitor.

Cone. The name commonly applied to the diaphragm of a loudspeaker. Materials used include moulded paper, aluminium, cambric and plastics.

Control Unit. The section of the amplifier which incorporates the input circuits, volume control and tone controls. It is usually a preamplifier as well, *i.e.* its circuits provide some voltage amplification.

Crossover Filter. An electrical filter circuit which separates the amplifier's output into low and high frequency bands in order to drive the separate units of a multi-speaker system. Other names are "separator" and "crossover network."

Cross-talk. Unwanted signal in one channel of a stereo system caused by a signal in the other channel.

Crystal. See Piezo-electric.

c/s. Cycle per second. The number of vibrations of a note per second is expressed in c/s.

Current. The flow of electricity in a circuit. Measured in amperes (A) or milliamperes (mA).

Damping. In audio work, this is the control of vibrations which would otherwise cause distortion. Damping is applied in pick-ups, loudspeakers and other components.

Damping Factor. Ratio of loudspeaker impedance to the output impedance of the amplifier.

D.C. Direct current. Current which flows in one direction.

Decibel. Unit used to express the relationship between two intensities, powers, voltages or currents. The abbreviation is dB.

De-emphasis. Restoration of normal frequency response or tonal balance after pre-emphasis has been applied.

Difference Tone. A tone generated as a result of interaction between two other tones. Its frequency is the difference between the two tones.

Dipole. A form of aerial, usually about a half-wavelength long for the frequency concerned. Used for f.m. and television reception.

Distortion. Unwanted alteration of the signal to be reproduced. Distortion may be an attenuation of the signal or, more seriously, the introduction of unwanted frequencies.

Doublet. Type of loudspeaker with equal radiation of power front and back.

Dynamic Pick-up. Magnetic pick-up. (The term "dynamic" is also applied to microphones and loudspeakers.)

Dynamic Range. Difference in dB between quietest and loudest sounds. The term "dynamics" is used by musicians but, in the present context, the range concerned is that which the recording and reproducing system accommodates.

Editing. Combining sections of one or more tape recordings in the desired sequence.

Efficiency. Ratio of output power to input power. Percentage efficiency is this ratio multiplied by a hundred.

Enclosure. The cabinet or other mounting which prevents cancellation of the outputs from front and back of a loudspeaker. The bass response of a moving-coil speaker depends on the nature of the enclosure.

Equalisation. Equalisation, or correction, is the restoration of correct tonal balance to a disc or tape record.

Erasure. The removal of a recording from a tape, either with the erase head on a tape recorder or with some other device which generates an alternating magnetic field.

Feedback. The return of voltage from the output to the input of an amplifier. Negative voltage feedback reduces overall amplification but gives general improvement in quality. Positive feedback normally causes oscillation but, in certain circumstances, both negative and positive feedback may be used together to give improved performance.

Filter. A circuit which attenuates a certain band of frequencies. A low-pass filter allows signals below a certain frequency to pass through while a high-pass filter allows signals above a certain frequency to pass.

Flutter. A rapid variation of speed of a turntable or tape machine. The subjective effect is a corresponding pitch fluctuation.

F.M. Frequency modulation. The method of broadcasting in which the frequency of the carrier wave is modulated in accordance with the amplitude of the audio signal.

Frequency. Rate of vibration.

Frequency Distortion. Inequalities in sensitivity of an equipment at different frequencies.

Frequency Range. The range of frequencies which an equipment will reproduce without frequency distortion.

Fundamental Frequency. The frequency of the tone which is the basis of a musical note. The note consists of the fundamental frequency, which determines pitch, together with a related series of harmonics.

Gain. The degree of amplification achieved by an amplifier (or by a single valve).

Grid. Valve electrode which influences passage of electrons from cathode to anode.

Harmonic. Component of a musical note having a frequency which is usually a multiple of the fundamental frequency. Sometimes known as an overtone or upper partial. For the benefit of musicians, it is worth adding that the name harmonic is often given to an actual note produced

by an instrument. On a stringed instrument, this can be the note produced by lightly stopping the open string at half its length or in some other position.

Harmonic Distortion. A form of non-linear distortion (or amplitude distortion). The production of spurious harmonics of the original tone which was applied to the input of the system.

Hertz. Continental name for one cycle per second.

H.F. High frequency. The treble end of the audio frequency range.

Horn. A type of enclosure which couples a loudspeaker (at the throat of the horn) to the surrounding air (at the mouth).

H.T. High tension. Normally describes the voltage which is applied to the anode circuits of valves.

Impedance. Opposition to a.c. in a circuit ; measured in ohms. Impedance may be introduced by resistance and/or inductance and/or capacitance.

Inductor. Essentially a coil of wire with either a magnetic material or air as a core. The name choke is sometimes used. Inductance is measured in Henrys (H) or millihenrys (mH).

Intermodulation Distortion. A form of non-linear or amplitude distortion. The production of unwanted tones from the inter-action between two wanted tones. The unwanted products are called sum and difference tones.

i.p.s. Inches per second. Speed of the tape past the heads.

Labyrinth. Type of loudspeaker enclosure.

Level Indicator. Device which indicates recording level (volume) in a tape recorder and provides a check on possible over- or under-recording. The indicator may be a meter or an electronic tube such as a "magic eye."

L.F. Low frequency. The bass end of the audio frequency range.

Load. The component across which the output voltage is developed or which dissipates the power. The loudspeaker forms the load of an amplifier and is itself loaded by its enclosure.

- L.T.** Low tension. Normally describes the voltage which is applied to the heater in a valve.
- Loudness.** Audible intensity of a note. Loudness depends on the frequency as well as the intensity of a note.
- Loudspeaker.** A device which converts electrical power into sound energy. The word "loudspeaker" or "speaker" may describe the drive unit itself as well as the complete system in an enclosure.
- Microphone.** A device which converts sound energy into electrical voltages.
- Microphony.** Variations in the output from a valve produced by vibrations of its electrodes. May be provoked by vibration from a loudspeaker which shares the cabinet with the amplifier. This should not apply to high fidelity equipment.
- Modulation.** The audio frequency variations cut in the record groove. Also describes the impression of one frequency on another.
- Monaural.** Term used to describe listening with headphones to signals which are being carried by one transducing channel.
- Monophonic.** Term used to describe listening with one or more loudspeakers to signals which are being carried by one transducing channel.
- N.F.B., Negative Feedback.** See Feedback.
- Non-Linear Distortion.** See Harmonic and Intermodulation Distortion.
- Octave.** The range of pitch corresponding to a frequency ratio of 1 : 2.
- Ohm.** The unit of resistance or impedance.
- Oscillation.** Generation of alternating quantities in a circuit or vibrations in a mechanical system.
- Oscillator.** Measuring instrument incorporating oscillating circuits and producing tones of various frequencies. Also circuit producing oscillations.
- Peak.** Maximum value of an alternating voltage, current or other quantity. Also used to describe a sudden rise in frequency response such as that caused by a resonance.

Pentode. A five-electrode valve.

Phase. Two alternating quantities having the same frequency are in phase when their instantaneous peak values are in step. Two sound sources are in phase when they are both compressing the air at the same time.

Phase Distortion. Changes in the phase relationship of the components of a complex signal passing through an amplifying chain.

Phon. Unit of loudness, similar to the decibel but taking the sensitivity of the hearing system into account.

Pick-up. A device which converts the vibrations of the stylus in the groove into electrical signals.

Piezo-electric. The property of certain crystals (*e.g.* Rochelle salt) to produce electrical voltages when subjected to strains such as bending and twisting.

Pitch. The subjective effect of a tone's property which determines for the listener the position of the tone in the musical scale.

Playing Weight. Downward pressure of the pick-up on the record. Normally quoted in grams. (Note: 1 oz. is equal to 28.35 grams.)

Positive Feedback. See Feedback.

Potentiometer. A variable resistor, used for volume and tone controls.

Power Response. Frequency response plotted against output power.

Pre-amplifier. Preliminary amplifying stages to raise the voltage of signals from such items as pick-ups and tape heads. See Control Unit.

Pre-emphasis. Emphasis of particular bands of frequencies during recording or f.m. radio transmission.

Push-pull Output. Output stage using two valves (or a double valve) which are driven by voltages equal in magnitude but opposite in phase. The arrangement helps to minimise distortion while providing the required output power.

Reflex Enclosure. Vented type of loudspeaker cabinet.

Resistance. Opposition to flow of current in a circuit.

Resistor. A component which has the property of resistance.

Resonance. Audible vibration at a particular frequency.

Reverberation. Re-echoing in a room of a sound. "Reverberation time" is the time which is required for a sound in a room to die away completely.

R.F. Radio Frequency. Applies to radio transmissions and to those parts of a receiver which amplify or otherwise treat radio signals.

R.I.A.A. Radio Industries Association of America. R.I.A.A. describes a certain recording characteristic for disc records which is the same as that recommended in a British Standard Specification.

Ringling. Spurious series of oscillations.

R.M.S. Equal to the peak value of an alternating current or voltage divided by the square root of two. Since this r.m.s. value is equivalent to that of a direct current or voltage having the same heating effect, it provides a convenient standard for measuring a.c.

Rumble. Low frequency noise heard in the reproduction ; caused by the turntable motor or associated parts.

Rumble Filter. A high-pass filter incorporated in the control unit to cut out rumble.

Screen. A metal can or box or braiding designed to limit the influence of a magnetic or electric field. Also the name given to one of the electrodes in tetrode or pentode valves.

Sensitivity. In amplifying circuits, the input voltage which produces full output. In pick-ups, a measure of the output produced for a certain velocity of the recorded modulation.

Signal. Electrical voltage conveying information.

Signal-to-noise Ratio. Difference between a wanted signal and the noise accompanying it. Expressed in dB.

Slope. Rate or sharpness of attenuation of frequency response.

Stereophonic. Term used to describe listening with two or more loudspeakers to signals which are being carried by two transducing channels.

Stylus (cutting). Sharp-edged cutting tool used to cut the groove in the lacquer disc which initiates the process of disc record production.

Stylus (reproducing). Conical fragment of diamond or sapphire with spherical tip, used to trace the record groove. The plural of stylus is styli.

Stylus Bar. Small metal piece bearing the stylus tip in some pick-ups. In a magnetic pick-up, the stylus bar may be the armature.

Sum Tone. A tone generated as a result of interaction between two other tones. Its frequency is the sum of the two tones.

Tetrode. A four-electrode valve.

Tracing Distortion. A distortion peculiar to disc reproduction, caused by difference in *shape* between cutting and reproducing styli.

Tracking Error. Difference between the *path* travelled by the cutting and reproducing styli.

Transcription Unit. Term applied to gramophone motor and turntable assembly of broadcast studio quality.

Transducer. Device for transforming sound into electrical signals, or vice versa. Examples: pick-ups, microphones, loudspeakers.

Transient. A signal whose maximum value is reached very rapidly.

Transient Distortion. Inability of equipment to respond to transients.

Transistor. Miniature electronic device which can do work of a valve in certain circumstances. Operation is by movement of electrons, or "holes," in a particle of semi-conducting material such as germanium crystal; in comparison, electrons in a valve move through a vacuum. Advantages of transistors include small size, robustness and long life. A transistor has no heating filament and functions without delay when voltage is applied; the absence of a "heater" means that the power supply can be simpler and cheaper.

Triode. A three-electrode valve.

Tuner Unit. Essentially a radio receiver without an output stage, for feeding to a separate amplifier.

Tweeter. A high frequency loudspeaker.

Twin-Track. Applied to tape recordings when half the width of magnetic tape is recorded in one direction of its travel and the other half in the other direction. Also called half-track.

Ultra-linear Output. Particular form of push-pull output stage. See Chapter 3.

Vented Enclosure. Loudspeaker enclosure having one or more vents from which sound is radiated so as to augment the response over a certain part of the low frequency range. Includes "reflex" enclosures and derived types.

V.H.F. Very High Frequency, radio frequencies between 30 and 300 Mc/s.

Voltage. Electric potential causing flow of current in a circuit.

Watt. Unit of electrical power.

Wavelength. Distance between successive peaks or troughs (maximum or minimum values) in a sound or radio wave.

White Noise. Noise whose energy is evenly distributed over a wide frequency range. Sometimes used to test loudspeakers.

Woofers. A loudspeaker designed to reproduce low frequencies.

Wow. A slow speed variation in a turntable or tape recorder. The subjective effect is a corresponding pitch fluctuation.

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