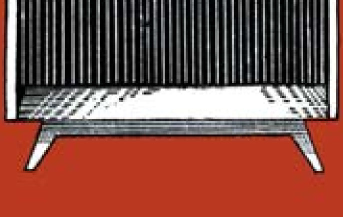
THE GRAMOPHONE HANDBOOK

Percy Wilson, M.A.

Technical Editor of *The Gramophone*



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Here is the most up-to-date and comprehensive handbook on modern developments in High Fidelity Sound Reproduction that is available in any part of the world. The author is the doyen of writers on gramophone subjects, whose name is a household word wherever the art and science of sound reproduction is studied. He has been known for many years as having the knack of translating even the more difficult technical ideas into simple and colourful language that every intelligent person can understand. His reviews and reports as Technical Editor of *The Gramophone* are followed every month with avidity by technicians and general public alike. At the New York Audio Fair last year it was a slogan, 'If Percy Wilson says so, it is so !'

Though even the most expert technician will find much to ponder over in its suggestions for development and future progress, the book is intended mainly for the ordinary man of an inquiring turn of mind, who wants to know something of the ideas behind this modern development of so-called High Fidelity reproduction of sound. So it describes the fundamental principles of reproduction and the equipment that is used to give realistic results. The principles and performance criteria of pickups, amplifiers, loud speakers, and tape recorders are all dealt with in some detail and there are valuable chapters on record wear and care of records, on planning a High Fidelity equipment, on installation and maintenance and on the prospects of stereophonic reproduction. A comprehensive glossary containing explanations of more than 150 of the most common technical terms is included.

With 16 *halftone plates*, 40 *line illustrations and diagrams*

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by

PERCY WILSON, M.A.
Technical Editor of *The Gramophone*

With a Foreword by
CHRISTOPHER STONE

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FOREWORD
by Christopher Stone

On the first Sunday of September during my morning bicycle ride towards Palace Gate and the Kensington Gardens I passed a man obviously of some importance who was leading a very fat old dog, no longer a terrier puppy, on a lead—very gently. At the time I was pondering what on earth I should try to say about this book, which I had left at home bulky in its final galley proofs. I suddenly remembered a recent letter from a distant friend mentioning a podgy old favourite dog 'who must be 80 or more by their rate'.

So I got the clue. I started helping my sister and brother-in-law, Faith and Monty Compton Mackenzie over thirty years ago in running *The Gramophone* and was soon aware of a technical and friendly enthusiast in the Board of Education called Percy Wilson, who contributed his first article for us on Needle Track Alignment in September 1924. He became a steady friend and a steady expert. His parents used to make me a Christmas cake every year and his brother joined our staff; and his sons have fully proved their brilliance in the tracks that their father encouraged them to plan. The years have passed in peace and war and always progress of science and wider circles of sympathy and exchange of ideas and development. Percy Wilson, with psychic intuitions and unceasing energy, is still in the scholarly forefront of electronic and all technical knowledge and discussion to help other enthusiasts in and beyond the sphere of the evergrowing 'gramophone'.

The old dog who blinked at the pages of Needle Track Alignment in September 1924 is glad to feel the gentle lead round his neck and to look up with a glint in his bleary eye at the author of this stalwart Handbook.

PREFACE

'Developments are now taking place at such a pace, particularly in regard to electrical reproduction, that the near future may bring new apparatus as superior to our present instruments as these are to the gramophones and phonographs of yesterday.'

The quotation is from *Modern Gramophones and Electrical Reproducers* which was written by the present author, in collaboration with G. W. Webb, in 1929.

That was three years after the introduction of electrical recording and an even shorter time from the appearance of the first commercial radiogram. The acoustic gramophone with its sound box, tone-arm and horn still held the field and indeed there were many gramophone fans who steadfastly (and loudly) refused even to contemplate that an electrical system of either recording or reproducing could possibly be better than their beloved 'acoustical' methods.

The die-hards are now dead. Acoustic gramophones are museum pieces, and records made by the acoustic process, and indeed even in early electrical recordings, are worthless, save where they have an historical or collectors' value.

Recording and reproducing has now reached a standard of verisimilitude which was almost beyond imagination and certainly beyond calculation before the war.

It is the object of this Handbook to describe the ways in which this standard has been achieved. An attempt has been made to describe the fundamental ideas in non-technical language as far as possible; but to have avoided technicalities altogether would have made the narrative extremely barren.

The expedient has therefore been adopted of segregating the more technical discussions and even of relegating them to appendices to the various chapters. It is hoped that in this way the main text will have assumed an essentially practical character.

There may still be sections, however—for example, in Chapter V—which are too difficult initially for the ordinary reader to assimilate. The reader is strongly advised not to struggle through such sections, but to skim them rapidly and come back later. It will be found that a useful comprehension of the main principles, and of their practical application, can be secured without any facility to perform the various technological calculations which are given for the benefit of the more advanced reader. A thorough grasp of the analogy between electrical and mechanical and acoustic quantities is, however, required before a complete understanding of the recent and forthcoming developments can be achieved; and it will be found worth while to come back again and again to the descriptive sections which deal with these matters (Sects. 5.4, 9.1).

The author's thanks are due, and are gratefully given, to a number of firms who have supplied illustrations, on request, for inclusion in the book; to 'The Gramophone' and 'The Wireless World' for permission to reprint matter which has appeared in the pages of those magazines; to Mr C. E. Watts for preparing a number of photomicrographs and for many stimulating ideas; and especially to Mr S. Kelly and Mr W. A. Chislett who read the manuscript with critical eyes and made many helpful suggestions.

P. W.

Oxford, November, 1956.

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I

HIGH FIDELITY: PAST, PRESENT AND FUTURE

1.1 The Purpose of Listening

Have you ever asked yourself what it is that you really want to hear when you play a gramophone record? It seems a simple enough question, yet there is no simple answer. Indeed there are several different answers, none of them simple.

Let us suppose you have chosen a record of Beethoven's Emperor Concerto. If you are a pianist you may wish to study how Backhaus tackles particular phrases in the music; or how Furtwängler or some other famous conductor brings out the climaxes; or you may just want to familiarize yourself with the pattern of the music so that you may know it all subconsciously, without the need for deliberate thought.

If you are a singer you may have similar objectives in playing records of an opera or, say, one of the Kathleen Ferrier or Elisabeth Schumann records.

On the other hand, you may, as an ordinary music lover, just wish to play a record to recall some memorable experience at a concert or theatre; or because you have found in the past that you gain comfort or enjoyment from playing that particular disc.

Whatever your motive, one thing is clear: you do not wish to listen to an orchestra or to an opera as though it were being performed in your own room. That would be overwhelming. You may perhaps wish to hear precisely the same succession of sounds (but minus your neighbour's sniffles) at precisely the same intensities that you heard on some memorable occasion when you went to the Festival Hall or to Covent Garden. But you can be sure that you never will. Such experiences are unique.

1.2 Illusions of Reality

All you can ever hope to have is an illusion of some kind. And remember: the fellow who sat some rows behind you may want to obtain from the same gramophone record an illusion of what he heard from his seat; and the sounds that reached him there may have been quite different in intensity, and to some degree even in quality and timing, from those that you heard.

The wonder is that it should be possible to provide these different illusions from a single recording. But so it is. Why and how, it is the object of the following pages to explain.

We shall of course spend more time on the 'how' than the 'why'. But we must, at the outset, refer to the nature of sound and the processes of recording and reproducing; and we must make ourselves familiar with the meaning of a number of technical terms. So make a practice of referring to the Glossary.

1.3 High Fidelity

Now there is one phrase which you will repeatedly see in the Press, and particularly in advertisements, which appears to be a technical term but is not. That is the phrase 'high fidelity', contracted sometimes to 'hi-fi'. What it means no one quite knows. It seems to have been coined in the United States some time in the nineteen-thirties to denote a standard of reproduction which the technicians thought to be a close approximation to the ideal. Since then a great deal of research has been undertaken to ascertain more nearly what that ideal is; and though we cannot define it with any degree of precision, we can specify some of its characteristics and we can say with assurance that certain methods will yield a quality of reproduction which everyone will agree to be nearer to it than anything one heard before the war. And by everyone is meant musician, technician and ordinary listener alike. A few years ago, when further advances in the technique of recording and reproducing were proudly announced under the title of 'high fidelity', musical opinion showed itself to be strongly hostile to the new claims: comments were rife about the 'siren-like tone' of the strings and the 'chromium plating' of the treble generally. Many musicians roundly declared that the old 'mellow' quality was much more realistic than the latest hi-fi, besides being more pleasant to listen to.

It is now known that both parties were right. Substantial advances *had* been made both in recording and reproducing, but those advances had the effect of bringing into prominence some defects that had previously been negligible. Now that those defects have been analysed and ways have been devised of avoiding them, it can be claimed that a standard of reproduction is possible from a modern disc record that is far higher than even the most sanguine amongst us dreamed of before the war, and that at an outlay which is not at all unreasonable.

1.4 Types of Recording

Indeed, one can say with assurance that recording and reproducing technique is not far from the limit of what is feasible so long as disc records running at a constant angular speed are used to transmit vibrations to a stylus of finite dimensions.

This naturally brings us straight to the question whether disc records are likely to be superseded within, say, the next ten or twenty years. Already magnetic tape records are available that can give a quality of reproduction which compares favourably with that of the best disc records; and this magnetic system has been developed to give a three-dimensional, stereophonic effect which adds decidedly to the realism of the reproduction (see Sect. 13.7). A system of recording and reproducing by light rays is also in course of development and rumour has it that considerable advances are on the way, especially in the cheapening of production costs.

The great advantage that disc records have at present is economic. They can be pressed from 'stampers' rapidly and cheaply: the whole of the record (both sides) is pressed out at one operation. Tape and film records, on the other hand, have to be copied from a 'master' sequentially, inch by inch. It is true that apparatus can be set up to copy a hundred or a thousand tapes simultaneously from the same original, but the expense of, and also the space required in, copying remains much higher than is the stamping of discs.

1.5 Disc *v.* Tape

There is, however, a compensating advantage which many will regard as altogether outweighing the expense. All recordings nowadays are made first of all on tape and are later transferred to disc. The transfer process is elaborate and at each stage some loss, particularly in the treble register, is inevitable. The 'definition' and 'resolution' of the different instruments are far superior in a reproduction from an original than they are from a pressing, particularly after the stamper has been worn by use for a considerable number of pressings. In transferring to commercial tapes, however, there is no valid reason why any loss should occur except in the first process, which is a transfer from a tape recorded at high speed (30 in. per second) to one at a lower speed (7½ in. per second); nor why any one of the copies should be inferior to any other.

At the moment this advantage in transfer loss is to some extent counterbalanced by the fact that reproduction from disc records running at standard speed can, at best, extend about half an octave higher in the scale than that from tape records running at the standard speed of 7½ in. per second. But this balance may well be altered in the not too distant future by improvements in tape material.

Again, although at the present time tape records cost about twice as much as disc records, there is a counterbalancing factor in that it is possible for an enthusiast to make his own tape records, e.g. from broadcasting. To obtain a quality at all comparable to that of tapes produced professionally, a first-class recorder and a first-class 'frequency modulation tuner' (see Sect. 4.21) will be needed, and these are much more expensive than a good 'pickup' and 'turntable'. On the other hand, tape recorders and F.M. tuners are in their infancy, and it may be argued that developments in the near future may well make existing designs obsolete, whereas present-day pickups and motors are the result of many years of experience.

There is, however, another important factor in favour of the disc that is likely to persist for many years to come. This is the large selection of musical works recorded by famous artists that is available. One can virtually choose one's own programme from disc records: with radio and tape one has to be content with what is provided.

Ultimately, therefore, the question at issue comes back to one of expense. The counsel of perfection is to have a comprehensive system capable of reproducing discs, ordinary tapes and stereophonic tapes, and of recording tapes through microphone or F.M. tuner. As will be seen later, this will involve a duplication of both amplifier and loud-speaker systems, and the expense would be very considerable—say, of the order of £400 to £500 for a 'high fidelity' equipment. The wise man with a limited purse will choose to build up his equipment stage by stage, being careful, so far as possible, not to spend his money on apparatus which he will have to scrap when he comes to the next stage. He will therefore start with a good pickup and turntable, a good amplifier and a reasonably good loud-speaker system that can be improved as time goes on by additions rather than by substitutions.

1.6 What is Hi-Fi?

So we come back to the teasing question with which we started this chapter. What is a 'high-fidelity' system? By the time you have finished reading this book I hope you will be able to give a reasonable answer to that question for yourself, or, at the least, to appreciate the answer which I shall try to build up for you. The most that can be said at this early stage is that a high-fidelity sound-reproducing equipment is one which you can turn on at will to give you a lively and vivid representation of a musical performance which you and your guests, or anyone else knowledgeable in music, will instantly recognize as being both enjoyable and free from discomfort and as having a striking correlation with an original performance of the same work by the same artists.

Though it may not appear so at first sight, that description implies a standard of judgement based on listening experience. When Edison first recorded 'Mary had a little lamb' it was hailed by the folk of his time as portraying the 'intonations, inflections, pauses and quality' with fidelity! More fulsome claims were made when Berliner substituted the 'lateral-cut' disc record for the 'hill-and-dale' cylinder. In 1926 electrical recording altered the whole basis of one's judgement, and by 1933 a standard had become common which made us ashamed of our previous judgements. Yes, one began to wonder how in the world one could have listened with pleasure to the earlier efforts. So a new standard of high fidelity came into being and was described as such. Nowadays one recognizes that standard as being quite inferior. Fortunately we know enough by now of the characteristics of human hearing to be able to assert with confidence that future standards will not be greatly different from those we rely on today. We are indeed rapidly approaching the time when, in the words used by Edward Bellamy in 1888 in his remarkable novel *Looking Backward*, we can devise 'an arrangement for providing everyone with music in their homes, perfect in quality, unlimited in quantity, suited to every mood, and beginning and ceasing at will'.

II

THE NATURE OF SOUND

2.1 Sound Waves

Sound is the sensation produced in the ear by rapid variations in air pressure. These variations may be produced either by the motion to and fro of a material object (e.g. a diaphragm or a reed or the vocal chords) or they may be the result of some other physical process such as an explosion. In either case they are transmitted through space in the form of waves, the air being alternately compressed and rarefied in the path of the wave.

2.2 Qualities of Musical Sound

The ear distinguishes between two types of sound: the one it recognizes as having a more or less pleasing regularity whilst the other is just 'noise'. It is because the ear makes this distinction and recognizes a quality known as 'pitch' in the former type of sound that musical instruments become possible. These, however, would be poor affairs were it not for the fact that the ear also finds differences of quality or 'timbre' between notes which it recognizes as being of the same pitch. Long before the reason for this became known, musicians had found means of entertaining their fellows by grouping notes together and finding different kinds of instruments to produce them. Three ways were used to produce the required vibrations: scraping, blowing and striking. So we have the three groups of instruments in an orchestra: strings, wind and percussion.

It was a momentous discovery when it was found that the pitch of a note produced by each of these types was related to the number of vibrations made per second by the vibrating body, be it a string, a reed or a skin; and that the waves set up in the air had a like number of vibrations per second. From that moment music became a science as well as an art.

2.3 Musical Intervals

Everyone is now familiar with the keyboard of a pianoforte, with its division of the musical scale into *octaves* and into tones and semitones. But think how exciting it must have been when it was first discovered that the *intervals* that musicians had long recognized as fundamental to the musical scale were definitely related to each other in *frequency* of vibration, at whatever part of the scale they occurred and whatever instrument was concerned in their production. Thus raising the pitch of a note by an *octave* meant just doubling the number of vibrations per second. Similarly, a ratio of 3:1 corresponds to the interval known to musicians as the *twelfth*, made up of an octave and a *fifth*. We can, in fact, set out in the form of fractions of whole numbers the frequency relationships of all the musical intervals. Thus:

Octave	2:1
Fifth	3:2
Fourth	4:3
Major Third	5:4
Minor Sixth	8:5
Minor Third	6:5
Major Sixth	5:3
Double Octave	4:1 and so on.

The notes whose frequencies are exact multiples of a given note are called *harmonics*. So the harmonic scale consists of a *fundamental* note, its octave, twelfth double octave and so on.

2.4 Complex Notes

The next momentous discovery in musical science was that almost all musical notes are compounded of simple *tones*, consisting of a fundamental tone (which determines the pitch of the musical note) and a number of its harmonics; and that the timbre or character of the musical note is determined by the relative loudness of the respective harmonics (some of which of course may be so feeble as virtually to be missing altogether). Musicians therefore often refer to the harmonics of a fundamental tone as its *overtones* or *upper partials*.

So the science of musical sounds starts from the basis that each sound has three characteristics: its pitch, corresponding to

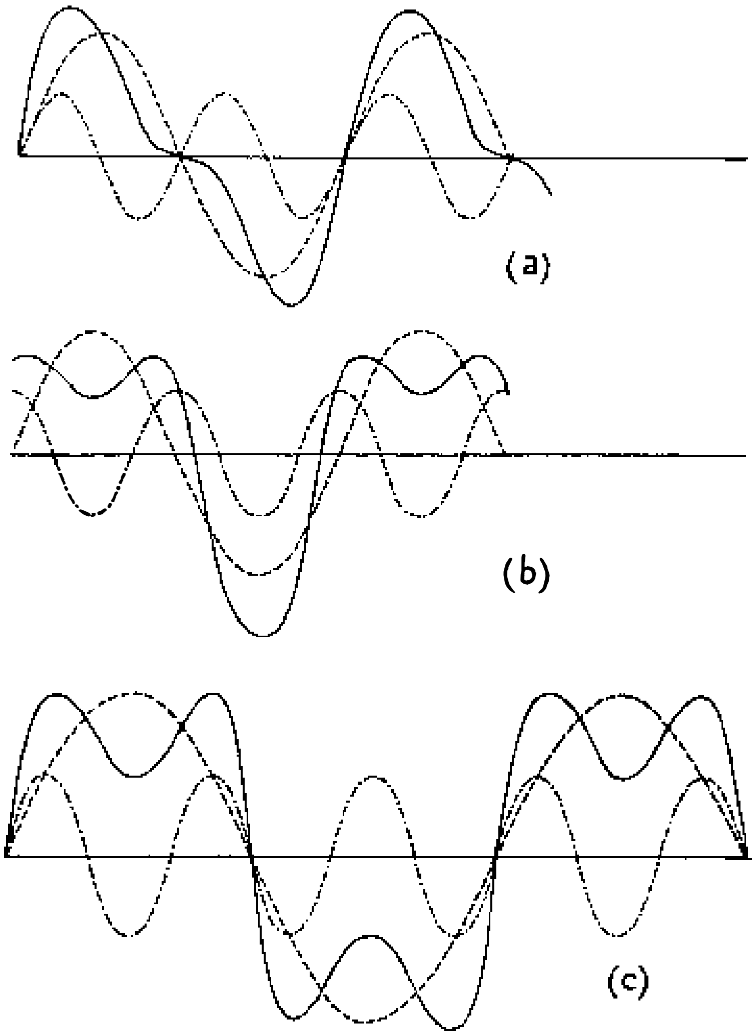


Figure 1

(*a*) Fundamental tone with Second Harmonic of half amplitude.
(*b*) Fundamental tone with Second Harmonic in different phase.
(*c*) Fundamental with Third Harmonic at half amplitude.

the frequency of the fundamental tone; its character, depending on the proportions in which overtones are combined with the fundamental; and its loudness. The latter, of course, depends on the physiological characteristics of the human ear; as does also the fact that sometimes the ear disentangles the tones of which a musical sound is composed and hears them separately, whilst at other times it hears them in groups, as it were, and so as distinct musical notes each compounded of its own fundamental and overtones.

2.5 Pitch Sensitivity

Another peculiarity of the human ear is that when a series of overtones are sounding together, the pitch of the compound note so formed may seem to be that of the fundamental tone which may be so weak as to be inaudible. This is a fortunate circumstance for the reproduction of sound, for had it not been so the inventions of instruments like the telephone and the gramophone would not have been possible: the sounds which the primitive instruments produced would have been totally unrecognizable.

2.6 Audible Range of Frequency

The ear is, in fact, very sensitive to differences of pitch. A change of frequency of 0·3 per cent is perceptible to the normal ear at the middle regions of the scale. Its range of perception extends over about 10 octaves from about 16 vibrations per second (more usually referred to as *cycles per second* or, in contracted form, c/s) to over 16,000 c/s.

The standard of pitch is arbitrary. In scientific work the agreed standard takes 256 c/s as representing middle C on the pianoforte; in musical practice a standard of 264 c/s used to be common, but nowadays it seems to be more usual to tune to A=440 c/s which is equivalent to C=261·6 c/s or C^3=2,093 c/s. Taking the scientific scale, we have the following sequence of octaves:

C_4	C_3	C_2	C_1	C	C^1	C^2	C^3	C^4	C^5	C^6
16	32	64	128	256	512	1,024	2,048	4,096	8,192	16,384

On this scale the notes on the pianoforte range from $3\frac{1}{4}$ octaves below middle C (27 c/s) to 4 octaves above (4,096 c/s); but it has

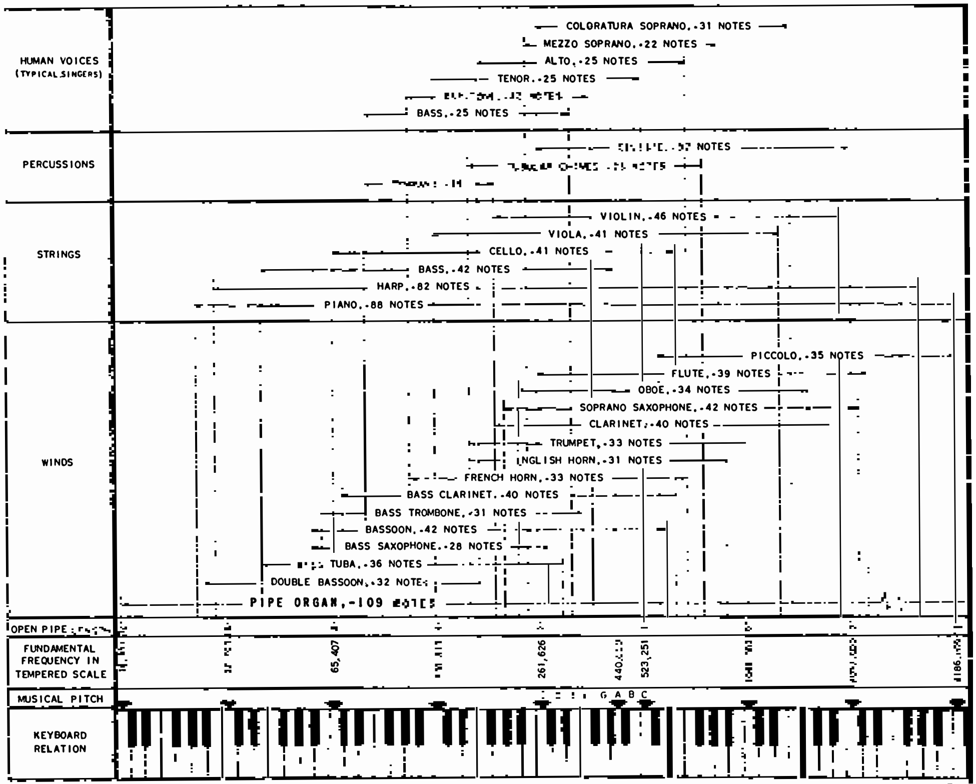


Figure 2

Range of Fundamental Frequencies for different instruments. (*By courtesy of Vox Records*) been found that 95 per cent of musical scores only range between about 40 to 1,600 c/s whilst less than 1 per cent have *fundamental* notes above about 2,000 c/s.

But what about the harmonics? They, of course, extend far beyond that range and with reed instruments, such as the oboe or clarinet, the higher *odd* harmonics (the fifth and the seventh) may be relatively strong. At present, however, there is a certain amount of controversy about the range of frequency that is involved in actual musical performances. Thus Dr F. A. Kuttner, writing in the American magazine *High Fidelity*, claims that though the range of audible frequencies may extend to 16,000 c/s or above, the intensity required to make the higher frequencies audible is much greater than occurs in actual musical practice; and that for musical purposes a range up to 10,000 c/s will 'fulfil the most exacting demands of musicians' super-ears'.

If these were the only considerations involved we might well decide that a frequency range from, say, 30 up to 10,000 c/s is all that is necessary for proper musical delineation. There is, however, another factor that calls for attention. This is an exception to the description given above of the composition of musical notes. There are, in fact, certain sounds used in music, particularly by percussion instruments, which are composed of more than a simple fundamental tone and its harmonics. They are known as *transients* and are characterized by a relatively sudden onset and a slow dying away. Their frequency spectrum contains a whole range of tones which need not be harmonically related to the lowest tone, and can extend well above 10,000 c/s.

2.7 Loudness Sensitivity

The sensitivity of the ear to loudness is much more involved and depends on the pitch as well as on the extent of the variations in air pressure. It is found that there is a certain 'threshold' of intensity below which sounds are not heard at all. Above this threshold a certain percentage increase in intensity is required before a difference in loudness can be appreciated. As the intensity is increased there comes a stage where it produces a tickling or even painful sensation. There is thus a 'threshold of feeling', and between these two lies the audibility area. At very high and very low frequencies these thresholds intersect: the sensations of hearing and feeling become merged, and it is difficult to distinguish between them.

These relationships are shown in Fig. 3, which is due to Dr Harvey Fletcher of the Bell Telephone Laboratories. It will be seen that more than one million times as much energy is required to make a sound audible at 32 c/s as at 1,000 c/s and more than ten million times as much as at 2,000 c/s!

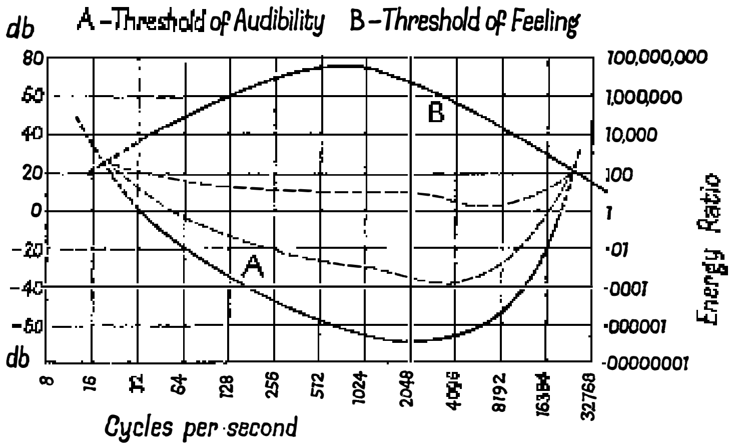


Figure 3
Audibility Curves.

The fact that a certain *percentage* increase in intensity is needed before an increase in loudness can be detected has led to the use of a 'logarithmic' measure which transforms proportions into additive units. It is known as the *decibel*, and its value has been chosen so as to correspond to the smallest increment of loudness that can be detected in the middle range. Thus, if the intensities of two notes differ by three decibels, the second note will have twice the power and therefore sound about twice as loud as the first. For a 6-decibel increase, the second note will be about four times as loud, for a 9-decibel increase, eight times as loud, and so on. The total intensity range of an orchestra is about 90 decibels.

It is important to notice that the decibel (usually contracted to db) relates to the *difference* of intensity-level (or of energy-level) and not to any absolute standard. The zero-level has to be fixed arbitrarily, just as it has in the measurement of temperature. It follows that the unit can be applied to differences of energy-levels in any branch of science or engineering and not merely to sound. It has, in fact, become the standard in electronics and in certain branches of optics as well as in acoustics. Thus, since doubling a voltage in electronics involves a fourfold increase in intensity or energy-level, it is represented by an increase of 6 db.

Since wide variations in intensity are needed before sounds of different pitch become audible, it is to be expected that similar variations will occur between sounds of equal loudness. But equal loudness between notes of different pitch is not easily recognizable. Elaborate experiments were carried out on this at the Bell Telephone Laboratories and led to what are known as the Fletcher-Munson contours of equal loudness. These contours, of course, lie between the thresholds shown in Fig. 3. Two typical ones are indicated. It should be remembered, of course, that these curves can only be taken as guides to average conditions and not as absolute standards.

2.8 Sound Wave Propagation

One or two features of musical sounds as we hear them from, say, an orchestra, should be noticed before we consider the problems relating to reproduction of sound. Since the propagation of sound is by means of air waves, there is a certain sound velocity with which the wave as a whole travels. This varies somewhat with the temperature of the air, but (fortunately for us!) is the same for different frequencies at the same temperature. At a temperature of 70°F. it is about 1,132 ft. per second. The *wave-length* of any musical note (i.e. the distance between successive points of maximum pressure) is this velocity divided by the frequency of the sound. It ranges from about 35 ft. for a frequency of 32 c/s down to 13 in. for a frequency of 1,000 c/s and 1 in. for a frequency of just over 13,000 c/s.

Because of this, the low notes spread out more in space than the high notes; the former, indeed, spread round obstacles of the size normally met with in everyday life, but the latter are more directive.

2.9 Reverberation

Moreover, when we listen to sound in a room or an auditorium we hear not only the sound as directly radiated from the source, but also the various reflections from the walls. On reflection at a surface, part of the sound wave may be absorbed and the amount of absorption varies with the frequency. This combination of reflection and absorption alters the character of the sounds heard by a listener. As much as 90 per cent of the intensity of the sound he hears from an orchestra may be reflected sound. This reflected sound can be heard either as an *echo*, when the interval between the arrival at the listener of the direct and reflected sound is long enough for the latter to be recognizable apart from the direct sound, or as *reverberation*, in which case the ear does not distinguish between the direct and reflected sounds but hears them all together as a single, persistent sound.

Whilst echo is clearly undesirable in any auditorium, a certain amount of reverberation is an advantage. Without the reverberation the music may sound dry and even harsh; with it a certain softness or mellowness is introduced. But too much reverberation will muffle the tone and lead to lack of definition.

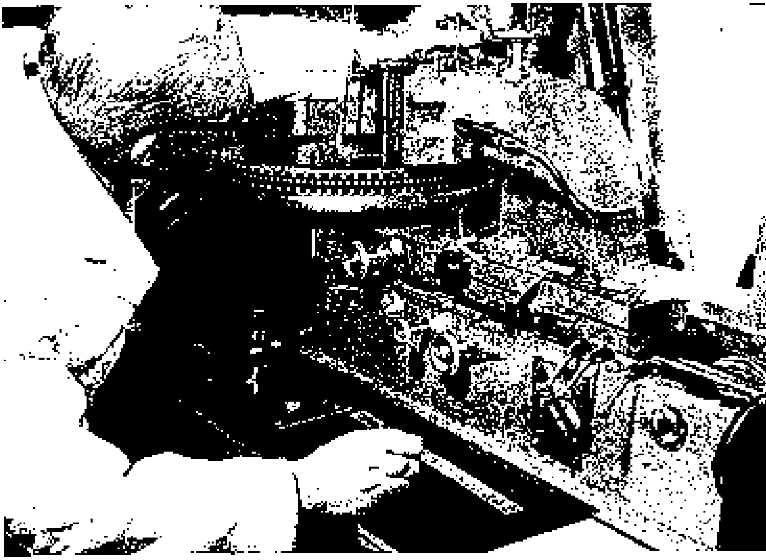
It has therefore become the practice to specify the 'reverberation time' of an auditorium, defined as the time in seconds for a reverberant sound to decay in intensity by 60 db, i.e. in the ratio of one million. This reverberation time will vary of course for different frequencies, so a frequency of 1,000 c/s is usually taken as the standard.

The optimum reverberation time will depend of course on the music, the character of the auditorium, the size of the playing group and to some extent with taste. It will be longest for a church where it may be as much as 3–4 seconds. It will be least for speech or for solo pianoforte, and rather larger for chamber music. If the reverberation time is less than ½ second a speaker will find the hall 'dead'; a large orchestra may require as much as 2 seconds.

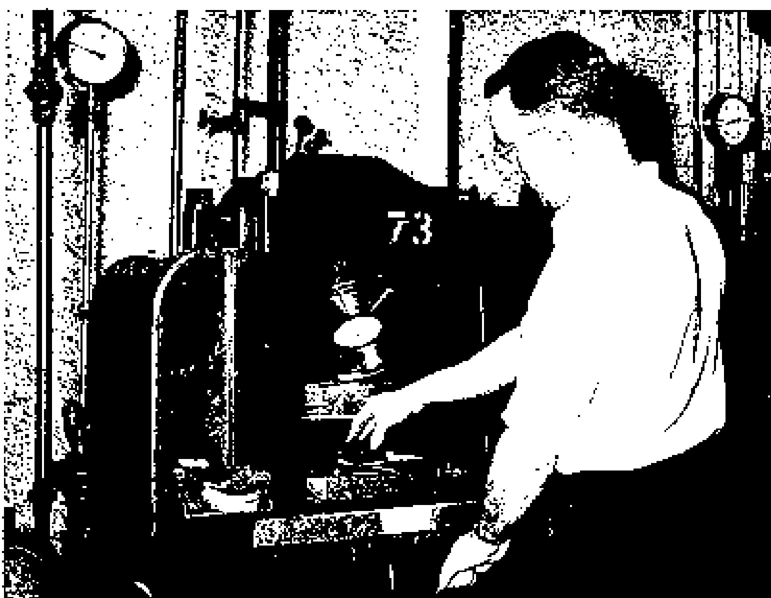
In recent years a great deal of research has been carried out to devise means of adjusting the reverberation times of auditoria by the distribution of absorbent material. One of the tricky problems, for example, has been to design seating material, etc., so that the hall should vary little in reverberation time whether or not an audience is present. The Royal Festival Hall, London, was designed in the light of this research. Its acoustical properties are usually considered to be near perfection, and to be affected but little by the presence of an audience. But it is reported that many artists find it 'difficult', and certainly at the demonstrations of record reproduction conducted there by Mr G. A. Briggs in November 1954 one noticed that the types of music which require the smallest reverberation time sounded better when an audience was present than they did at rehearsals.[1]

Now, having read this difficult chapter you are urged to buy, beg, borrow or otherwise get hold of a copy of the record called 'This is High Fidelity', issued by Vox Productions Ltd under the number DL 130 and to play Side B. This illustrates, in actual sound, all the principles described here, starting with pure tones from 15,000 c/s down to 30 c/s, continuing with pictures on the nature of sound and the qualities of the instruments of the orchestra, and ending with examples of the importance of studio acoustics.

See *The Gramophone*, February 1955, p. 424.

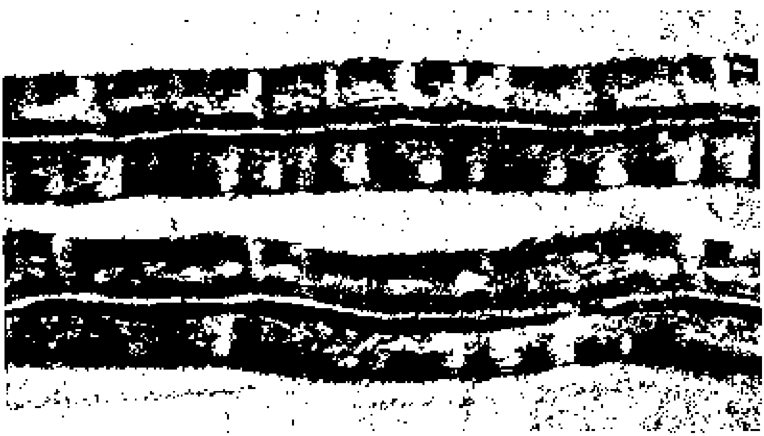


III (*a*) H.M.V. Disc Cutter



III (*b*) Decca Record Press

(*a*)



(*b*)

IV Photomicrographs of Coarse (78 r.p.m.) Groove: (*a*) before and (*b*) after playing with a sapphire stylus

III

RECORDING AND REPRODUCING SOUND

3.1 Recording Processes

Before 1925 the process of recording consisted of the transfer of the 'live' sound through one or more small horns to vibrate the glass diaphragm of a recording instrument. To the diaphragm a sapphire cutter was fixed, either directly or through a leverage system. This cutter gouged out a groove in a disc of wax which was revolving at a constant angular speed on a carriage which moved laterally at a constant speed under the cutting stylus.

The process thus consisted of the conversion of sound vibrations into the mechanical vibrations of a recording diaphragm and stylus and thence to geometrical waves on a disc of wax.

This 'acoustical' system of recording had severe limitations imposed upon it, not only by the fact that only a small number of artists could be grouped round a recording horn and by the very small amount of energy that could be transferred to actuate the cutting stylus, but also by the fact that the system was essentially a *resonant* system.

A word of explanation is needed about the use of the word 'resonant' in this connexion. It is not used in the sense of sonorousness that musicians intend when they refer to a singer's voice as being superbly resonant. It means a preference for some particular frequency of vibration. All vibrating bodies possessing both elasticity and mass have several resonant frequencies at which they will vibrate more readily and powerfully than at any other frequency. No doubt you have heard the story that Caruso could break a wineglass into fragments by singing particular notes. That violent action took place when he happened to strike the notes corresponding to the resonant frequencies of the glass.

Now in recording and reproducing sound the last thing we want is a preference of our apparatus for particular notes. We want it to be *aperiodic*, not resonant. This was not possible with acoustical recording apparatus. But it is possible with the electronic recording systems that have now been developed; or at least it is possible to devise apparatus with no pronounced resonant frequencies within the range which we want to record.

3.2 Electrical Recording

Essentially, the electrical system consists of a microphone which converts sound vibrations into electrical vibrations which can be uniformly amplified in an electronic amplifier. At one time the electrical vibrations were used directly to actuate an electromagnetic recorder which converted the electrical vibrations into mechanical vibrations in a sapphire cutter on the wax recording disc.

In recent years a lacquer coating on a metal disc has taken the place of the wax; and an intermediate stage has been introduced in the recording. The amplified electrical vibrations from the microphone are now used to make a magnetic tape record (see Chapter XIII). This has many advantages, including durability (wax is apt to be fragile!). The tape can be played back immediately (and without damage to the original) and can therefore be criticized, re-recorded if necessary, and even strung together in bits and pieces, technically known as 'editing'. After the tape recording has been passed for quality it can be transferred at leisure to the lacquer disc.

In this case there are thus no fewer than eight distinct stages of transfer. First, the sound vibrations to mechanical vibrations in the microphone and thence to electrical vibrations. Then from electrical vibrations to magnetic vibrations in the tape-recording head, and thence to a magnetic pattern on the tape. Then from this pattern back to magnetic vibrations in the play-back head, and thence to electrical vibrations. Then from electrical vibrations, suitably amplified in the play-back amplifier, to the electromagnetic recorder, where they produce mechanical vibrations in the cutting stylus, and so a geometrical pattern is formed on the disc record.

Whatever the method of recording, the instrument that transforms the vibrations in one medium into vibrations in another is known as a *transducer*. Thus, microphones, magnetic tape heads, electromagnetic recorders are all transducers. So are gramophone pickups and loud-speakers.

In the making of modern disc records there are two electronic amplifiers in the recording system, one between microphone and tape and the other between tape and cutting head. In each of these amplifiers it is possible to include 'equalization' circuits to compensate for faulty characteristics in the microphone, the magnetic tape recorder or in the cutting head. Theoretically it is possible to make large corrections in this way; but it is always preferable in a system of this kind to make each unit conform to prescribed characteristics as nearly as possible.

But what are the prescribed characteristics to be? At first sight this would seem to be an easy question to answer. One would assume that the objective should be to produce in the geometrical wave-form on the recorded disc an exact replica of the wave-form of the air-pressure variations that impinge on a microphone placed in one of the best listening positions in a concert hall. This would imply that the system taken as a whole:

(1) should have a uniform response to frequencies throughout the whole audible scale, i.e. at least from 30 c/s to 16,000 c/s. It should treat all frequencies alike; so that if a tone of intensity 'I' is sung into the microphone, the wave-form of the trace on the record should correspond, on some appropriate measure, to an intensity 'I', whatever the frequency of the tone may have been;
(2) the condition in (1) should hold whatever the value of 'I' within the loudness limits of the music;
(3) no frequencies should appear in the recorded trace other than those that were sung into the microphone.

If these conditions were fulfilled, one would think, and if similar conditions were also fulfilled in the reproducing system, then the reproduced sounds should be a perfect copy of the original sounds that one would have heard at the 'best seat' at which the microphone was placed.

So one would think. But that would be wrong. The reasons are partly physical and partly physiological. Let us look at the latter first.

3.3 How One Listens

When you listen in the best seat you listen with two ears, and the orchestra is spread out in space in front of you. The microphone has one ear and only records the variations of air pressure as they occur at each instant. Moreover, your two ears are at the sides of your head and not in front. If you want to appreciate what sort of difference this makes, just try the experiment of cupping your hands behind your ears the next time you go to a concert. Perhaps most important of all, the listening faculty of your ears is directed by a mind which can focus attention. You can in fact ignore some of the sounds that impinge upon you and concentrate on those you wish to hear: within limits, of course. The microphone has no faculty of concentration. It does not distinguish between direct sounds and reflected sounds. The ear probably does, but how much no one yet knows.

At the other end of the system when you listen to the sounds issuing from a loud-speaker, the value of having two ears is almost lost: you are listening to sounds coming from a restricted space. As will be seen in a later chapter, the effect of *binaural* listening can be simulated, but it needs a special type of recording to achieve any real accuracy.

Now let us look for a moment at the physical difficulties involved. First of all, notice that the problem of direct and reflected sound is doubled. The concert hall has its own reverberation effects and perhaps one would like to repeat these at home. But in reproduction the home conditions impose themselves on top of the 'recorded ambience',[1] and if the room is small may be decisive. Obviously, too, the type of furnishing and the positioning of the loud-speaker may have a vital effect; and all this is outside the control or knowledge of the recording engineer.

Again, the problems relating to volume-level are not easy of solution or even of exact definition. Obviously, the listener to the reproduction does not seek to have the effect of an orchestra or an organ in his living-room. But that does not necessarily mean, as is often assumed, that he wants to listen at a lower volume-level than he would hear in his best seat in the concert hall.

[1] This is Mr Briggs's lovely phrase by which he means, of course, the effect on the record of the studio acoustics.

3.4 Optimum Recording Conditions

At one of the preliminary sessions before Mr G. A. Briggs's second Royal Festival Hall demonstrations, the B.B.C. engineers measured and noted on the score the volume-level reaching a broadcasting microphone during part of the performance when a recording was being made; and then when the record was played at the actual demonstration the reproduction-level at that same spot was adjusted to correspond. Most of us were surprised to find how low that level was. The volume indeed was considerably lower than had previously been thought desirable for reproduction in home conditions. Equally significant was another test that was made: before the level was adjusted to the measured amount it had been set by ear and the difference between the two settings was less than 2 db.

This experiment, then, seemed to demonstrate that we are accustomed to play our records *too loudly* at home—a conclusion, incidentally, which has long been held by most wives about their menfolk.

Two other conclusions from the demonstrations seem likely to be of importance for the future of recording. The first was that for playing in a large hall, records with a comparatively high proportion of surface noise were to be avoided. The second was that those records sounded best that had been recorded in the open air or in a 'dead' studio; this, however, is not necessarily the case for home conditions where a certain recorded ambience can often make for very pleasant listening.

All these considerations make it very difficult to say with any assurance what are the best conditions for recording. The whole business is very much of an art. Much still depends on the skilful adjustment of studio acoustics to suit the type of music, the size of orchestra, etc.; and the placing of particular instruments or singers in relation to flat walls or absorbent materials can be quite important. The use of subsidiary microphones which may be switched or faded in to reinforce the contribution of particular sections to the sounds picked up by a main microphone has become standard practice. At one time it was not uncommon for the bass or high treble to be boosted (or, more rarely, attenuated) at the whim of the recording director who might, or might not, be a musician. But that practice seems to be frowned upon nowadays: much more importance is now attached to having a *precise* knowledge of the frequency characteristic of the recording process. The reason for this is related to what is perhaps the most striking development of the recording art: the success of 'long-playing' records.

3.5 Recording Characteristics

By the time electrical recording was introduced it had become standard practice for records to be either 10 or 12 in. in diameter and for the recording to extend at the rate of 100 grooves to the inch from radii of about 5·8 and 4·8 in. respectively to an inner radius of not less than 2 in. The records were played at a constant angular speed of 78 revolutions per minute (r.p.m.) so that in each revolution (1/78 of a minute) 37 in. of groove would pass under the stylus at the outside and only 12 in. at the inside of the record. Why a standard of 78 r.p.m. was fixed no one seems to know; in the early days speeds used to vary from about 76–82 r.p.m. It was thought, however, that 12 in. per revolution or 13 in. per second was rather too low a speed for adequate reproduction of treble notes; and it had been proposed (as long ago as 1888 and several times in the interim) to devise a means of speeding up the revolutions as the stylus travelled in towards the centre in such a way as to maintain a constant *linear* speed under the stylus of, say, 20 in. per second. This should have improved the quality and increased the playing time. The idea, however, was not pursued very far, notwithstanding the growing pressure of the musical public for longer playing times.

As the present author explained in a special article in *The Gramophone* in December 1926, this demand could only be met in one (or a combination) of four ways:

1. A slower groove speed either by:
   (*a*) a slower angular speed, or
   (*b*) a constant linear speed.
2. More grooves to the inch.
3. Larger disc records or abandonment of the disc for a film or tape-recording process.

1(*a*) meant increased difficulty in recording treble notes, and 2 meant corresponding difficulties at the bass end of the scale.

Let us see how this arises.

It was assumed (largely for reasons connected with the characteristics of acoustic gramophones) that to achieve a uniform frequency response bass notes had to be recorded with greater *amplitude* (i.e. that the groove must have a greater excursion from side to side) than treble notes. The amplitude, in fact, should vary inversely as the frequency. Even with a groove spacing of 100 per inch, and a groove width which had become usual for

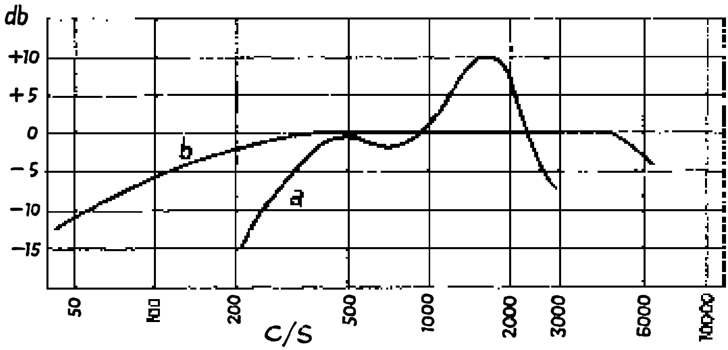


Figure 4

Recording Characteristics.

(*a*) Acoustic Recording.

(*b*) Early Electric Recording.

the use of steel needles, it had been found impossible to record notes below 200 c/s at the amplitudes required for a reasonably loud recording with a response up to 5,000 c/s. The bass response was in practice progressively attenuated below 300 c/s.

So it was concluded that closer groove spacing was undesirable.

The adoption of a slower angular speed would similarly, it was thought, have led to insuperable troubles at the treble end of the scale. The wavelength of a note is inversely proportional to its frequency and so treble notes are more tightly packed along the length of the groove. At 78 r.p.m. only 13 in. of groove pass the stylus per second or under 3/1,000 of an inch (3 mils) in 1/5,000 of a second. So there is not much space (compared with a steel needle with a point diameter of, say, 4 mils and *a fortiori*, a chisel-pointed needle) for the recording of a 5,000-c/s note!

The recording characteristic of the early 'electric' records were therefore standardized on the basis shown in Fig. 4. (The level portion was recorded on a basis that came to be known, for certain technical reasons, as 'the constant velocity' system.) For comparison a typical recording characteristic of an acoustic recording instrument is also shown.

3.6 Long-Playing Records

When the acoustic gramophone began to be superseded by the electrical reproducer these arguments lost their force. Electronic amplification made it possible to record at a lower amplitude level and a closer groove spacing was possible. Whereas the early pickups were cumbersome affairs, new designs began to appear with quite tiny moving parts which called for much less energy from the record to drive them. Even before full advantage was taken of these developments, Decca showed that it was possible to extend the frequency range by as much as an octave in the treble and even to give a pre-emphasis in recording to frequencies above 5,000 c/s. Many years before, the present writer in company with Mr P. A. G. Voigt, Chief Recording Engineer of the Edison Bell Record Company, were almost alone in calling for such pre-emphasis, even though it was apparent that the corresponding attenuation in reproduction through an electronic system might be used to reduce needle scratch; and both had designed light-weight pickups to assist in the scheme. The success of the Decca *f.f.r.r.* (full frequency range recording) system, as it was called, demonstrated the validity of these suggestions in a most spectacular way.

But full development had to wait until after the war, by which time a new record material became available. Previously, shellac with various 'fillers' had been the basis of the record material, and ingenious methods had been invented for crushing and sifting the powder so as to give it a finer granular structure. The new material, 'vinylite', had no appreciable granular structure and was for practical purposes continuous. Much smaller indentations could therefore be moulded into it, so that a smaller groove ('a microgroove') with a stylus of smaller tip diameter became feasible and an extension of the frequency range of recording to as high as 20,000 c/s (at 78 r.p.m.) was achieved in experimental records.

3.7 Pre-emphasis and De-emphasis

After that the path of progress became clear. The objective was to accentuate the treble and attenuate the bass in recording and reverse the process in reproduction so that in the end a level response should be achieved. This almost meant that notes of equal intensities in the original air-pressure variations in front of the microphone would be represented in the record trace by grooves of equal amplitude, whatever their frequencies might be.

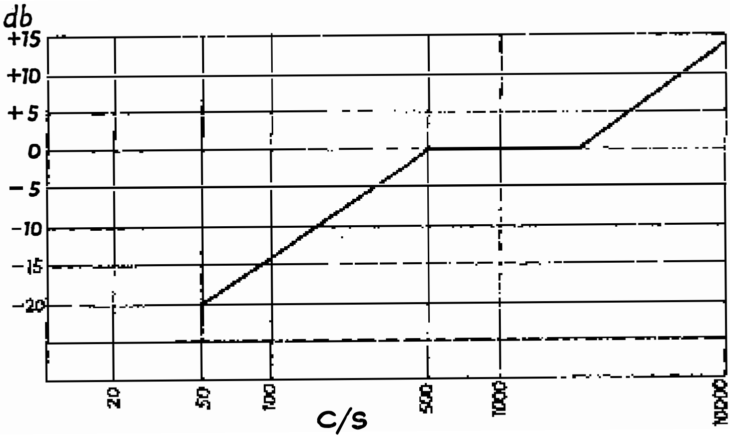


Figure 5

Basis of Standard Recording Characteristic for L.P. Records.

It was found, however, that this theoretical 'constant amplitude' system could not be tolerated in practice by the pickups then available and departures from it were made at both ends of the scale.

Unfortunately, the several recording companies in America, Britain, France, and Germany, favoured different recording characteristics, and it was not until the autumn of 1954 that a standard response was agreed upon.

In an appendix to this chapter details are given of a number of the recording characteristics that were commonly used. It will be seen that much confusion reigned. The American standard now agreed is known as the R.I.A.A. (Record Industry Association of America) and provides for a 13·6 db pre-emphasis at 10 kc/s and a 17 db attenuation at 50 c/s.

For reference, an extract from the specification of standard record characteristics adopted by the British Standards Institution is also set out in the Appendix.

Two technical terms have come to be widely used in connexion with these recording characteristics and should therefore be noted here. These are 'roll-off' and 'turn-over'. *Roll-off* refers to the attenuation necessary in reproduction to compensate for pre-emphasis of treble in recording; thus the roll-off for the original N.A.B. curve was 16 db at 10 kc/s.

Turn-over refers to the frequency at which increase in the bass frequencies should take place (progressively) to compensate for the attenuation in recording.

They are not very happy terms.

With all microgroove recordings a standard record speed of $33\frac{1}{3}$ r.p.m. was at first used because this was the speed that had been adopted some years before by the cinema industry for use with 'talkies'. For a 12-in. record a playing time of up to 25–30 minutes per side was thus achieved in place of the maximum of 5 minutes for the old 78 r.p.m. records. This held the field until 1952 when RCA in America and the E.M.I. group in Great Britain re-introduced 7-in. microgroove records to play at a speed of 45 r.p.m. This speed had originally been used in 1949. The idea behind it was that a *shorter* playing time was needed for single solos, etc., and the 7-in. record could provide for this with an economy of record material and storage space. To preserve quality at the smaller inside radii a higher angular speed was thought desirable. Later on this advantage was abandoned by the introduction of what are known as E.P. (extended play) records which carry the recording to a smaller radius than ever before. They are thus more difficult to reproduce without distortion.

So as to extend the frequency range from microgroove records one American company (Audiophile) have introduced vinylite records made on microgroove principles (and to the standard curve) to play at a speed of 78 r.p.m. A frequency response up to 20 kc/s is claimed for these compared with the normal standard of 15 kc/s for the $33\frac{1}{3}$ r.p.m. records.

It has been noted above that when constant angular speed is used the linear speed at the inside grooves is only about 13 in.

per second compared with about 40 in. per second at the outside groove of a 12-in. record. This causes a progressive attenuation of treble notes in reproduction from the outside to the inside of a record. To compensate for this some recording companies use a progressively increasing treble pre-emphasis as the stylus moves across the record. This is known as *radius correction.*

APPENDIX TO CHAPTER III

A. RECORDING CHARACTERISTICS

1. Pre-Standard

Type	*Turn-over point* *Treble*	*Bass*	*Pre-emphasis at 10 kc/s*	*De-emphasis at 50 c/s*
Old 78's	Flat	300	—	12 db
f.f.r.r.	3,000	400	5 db	12 db
Am. Col.	1,600	500	16 db	14 db
A.E.S.[1]	2,500	400	12 db	18 db
N.A.B.[2]	1,600	500	16 db	16 db
N.A.R.T.B.	1,600	500	12 db	16 db
RCA new	2,500	500	12 db	16 db
old	1,600	600	14 db	24 db
Decca	1,600	500	10–12 db	12·5 db
H.M.V. / Brit. Col.	2,500	500	15 db	14 db
Nixa	1,600 / 2,500	500	16 db	16 db / 18 db
DGG	As for old 78's			

2. 1954 Standard (R.I.A.A.)

The recording standards now agreed both in America and in Great Britain have the characteristics shown in the following table:

[1] For this curve the bass was continuously attenuated below 50 c/s.
[2] For this curve the bass attenuation was the same at 30 c/s as at 50 c/s.

Microgroove (db)	*Frequency (c/s)*	*Coarse groove (db)*
−18·7	30	−15·7
−17·0	50	−14·1
−13·2	100	−10·3
− 8·3	200	− 5·9
− 5·6	300	− 3·6
− 2·7	500	− 1·6
− 0·1	1,000	− 0·1
+ 2·5	2,000	+ 1·3
+ 4·6	3,000	+ 2·7
+ 8·1	5,000	+ 5·4
+13·6	10,000	+10·4
+17·1	15,000	+13·7

The inverse replay characteristics are defined by reference to resistance capacity networks that can be used to provide the required boost in the bass and attenuation in the treble.

B. BRITISH STANDARDS

	Microgroove	*Coarse groove*
1. Minimum top width	0·002 in.	0·006 in.
Maximum bottom radius	0·0003 in.	0·001 in.
Included angle	80°–93°	80°–93°
2. Speed of rotation for 50 c/s supplies	$33\frac{1}{3} \pm 0{\cdot}5\%$ $45{\cdot}11 \pm 0{\cdot}5\%$	$77{\cdot}92 \pm 0{\cdot}5\%$
3. Diameter of inside groove	$4\frac{3}{4}$ in. ($33\frac{1}{3}$) $4\frac{1}{4}$ in. (45)	$3\frac{3}{4}$ (78)
4. Outer diameter of recorded surface	11·5 ±0·02 9·5 ±0·02 6·594±0·02	
5. Diameter of centre hole	Max. 0·2885 in.	Min. 0·2850 in.
6. Maximum eccentricity of centre hole to centre of spiral	0·005 in.	
7. Recording Characteristic	As for American standard (see A.2 above)	
8. Diameter of turntable spindle	Max. 0·282 in.	Min. 0·278 in.
Transcription	Max. 0·284 in.	Min. 0·283 in.

9. Turntable speed: $33\frac{1}{3}$ r.p.m. 32·96 to 33·7 r.p.m.
   45 r.p.m. 44·44 to 45·45 r.p.m.
   78 r.p.m. 76·92 to 78·93 r.p.m.

10. Reproducing stylus radius:

		Standard *in.*	*Transcription* *in.*
Coarse groove	Max.	0·003	0·0025
	Min.	0·002	0·002
Microgroove	Max.	0·001	0·001
	Min.	0·0008	0·0008

Note: There are many old 78 r.p.m. records that require a stylus with a tip radius larger than 0·003 in.

11. Reproducing stylus tip angle: Not less than 40° and not greater than 50°
12. Colour coding   Coarse grooves: green
    Microgrooves: red

IV

REPRODUCING SYSTEMS

4.1 Phonographs and Gramophones

The original reproducing instrument was called a 'phonograph' by Edison, and the name remained in current usage for many years, particularly in America. At first the records were cylindrical but later the disc record was introduced because of the need for duplication. Edison's original patents covered both types. In both, the recorded wave-form was at right angles to the record surface and not from side to side of the groove. It was therefore known as the 'hill-and-dale' cut.

The word 'gramophone' was coined by Berliner in 1887 when he introduced the 'lateral cut' discs we know today. At first it was the proprietary name for The Gramophone Company ('His Master's Voice'). The Columbia Company used the term 'graphophone', but this was discontinued when the two companies amalgamated to form the E.M.I. group (Electrical and Musical Industries).

Nowadays, the word *gramophone* is the standard name for a record reproducer in Great Britain and the word *phonograph* in America. They are combined with the word 'radio' to form the combinations *radio-gramophone* and *radio-phonograph* when the instrument is an electrical reproducer that will play both radio programmes and records. Henceforth in this book we shall use the word gramophone only.

The original gramophones were purely acoustical devices with 'sound-boxes', 'tone arms' and 'horns'. No means of amplification were used: all the energy was extracted from the motor driving the record. The record in fact acted as a sort of 'gating' device. The system is now practically obsolete and we shall say no more about it here, beyond remarking that compared with modern instruments the acoustic gramophone was a remarkably efficient device, in that the sound output energy bore a relatively high ratio to the mechanical input energy. Those who wish to learn more about the system are referred to the author's previous work, *Modern Gramophones and Electrical Reproducers* (Cassell & Co., 1929).

4.2 Sources for Reproduction

Nowadays, four systems of reproduction are in general use:

(1) from radio broadcasting;
(2) from disc records;
(3) from magnetic tape;
(4) from films by light rays.

All four systems make use of electronic amplifiers and loud-speakers, the 'sources' alone being different. It is therefore possible to have a domestic installation using the different sources to feed a common amplifier and loud-speaker system. Installations comprising the first three sources are common; the fourth source has not been usually added, but developments along these lines may be seen before long.

Some remarks about the relative merits of tape and disc records were made in the first chapter and a further discussion of tape systems will be given in a later chapter.

4.21 Frequency Modulation Radio Tuners

We are not in this book primarily concerned with the technicalities of radio as a source, and we shall not describe in any detail the devices involved. Since, however, the amateur may well use radio to make tape recordings for himself of good musical programmes, a few remarks are needed about the two types of tuner that are available. These are known as A.M. (amplitude modulation) tuners and F.M. (frequency modulation) tuners. The former are of the type for long, medium and short waves that have been in use in radio receivers for many years. Unfortunately, owing to competition between nations for wave allocation, the audio frequency range of each broadcasting station has to be drastically limited and as a rule reproduction beyond 5,000 c/s without background noise and interference is not possible. F.M. tuners, on the other hand, receive the B.B.C. programmes on a very short wave-length, or as it is more usually described, a very high carrier frequency (V.H.F.) of between 88 and 95 megacycles (mega=1 million). These transmissions are comparatively new and, like television transmissions, are of limited range. Provided, however, that sufficient signal strength is available (and for this a special aerial may be needed if you live at long distances—say 30–70 miles from the transmitter according to the character of the intervening country) and provided that the transmission is accurately tuned in, the system is such that the programme can be received with virtually no background noise or interference (apart from slight noises from the ignition systems of passing motor-cars). Moreover, a frequency range from 30 c/s to at least 10,000 c/s and sometimes even 15,000 c/s, depending on the nature of the programme, can be obtained from an F.M. transmission. This is adequate for domestic tape recording. The reader should note, however, that copyright questions might arise if he were to use such recordings for more than purely personal and domestic listening. (See Appendix to Chapter XIII.)

4.22 Disc Records

For the playing of disc records, the 'source' is a gramophone pickup and turntable—or, as they are sometimes called, the cartridge and the record player. These have been greatly improved in recent years. Their characteristics and the problems connected with them will be described in separate chapters.

Separate chapters also will be devoted to each of the common elements—the loud-speaker system and the electronic amplifier. Here we will only remark that it is only because of the flexibility and adaptability of electronic amplifiers that we have come to know of the contributions that each part of the frequency spectrum makes to the quality of musical performances; and of the types of distortion that may arise and their cause.

For example, it is easy to design electrical wave-filters which will cut off the transmission of electrical power below a given frequency or above a certain frequency, or outside the range between a lower limit and an upper limit. By inserting these into our amplifier we can limit the frequency response of our reproducing system as we wish and so learn to recognize what effect the various limitations have on the quality.

Again, by deliberately inserting components to give resonant peaks at various frequencies we can similarly learn what effects these have on the quality.

It is in this way that a demonstration such as that given on Side A of the Vox record (DL 130) mentioned at the end of Chapter II can be built up. There we are shown aurally what various limitations in frequency range really mean, what peaks at various places sound like, and how different kinds of distortion affect the quality.

It is by similar means that the characteristics of the sounds produced by various types of musical instrument have been determined, e.g. what are the relative strengths of the overtones in notes produced by, say, violins and oboes, and how the volume-level affects these. Musical analysis has therefore become something of an exact science!

4.3 How Each Octave Affects Quality

We remarked in Chapter II that the musical range consists of 10 octaves from 16 c/s to 16,000 c/s but that the contribution of the extremes to musical quality is not very great. In the modern high-fidelity systems we can, in fact, record and reproduce the 9 octaves above 32 c/s. Ordinary home radio with which most people are familiar can only deal with about 5 octaves from about 120 c/s to 5,000 c/s, and many even fall short of that.

Let us look at this frequency spectrum and note what contribution each octave makes to our listening.

The *lowest octave* from 16 to 32 c/s is felt rather than heard. Musical scores contain very few notes in this region; and these notes are not at present recorded but sometimes, particularly with the organ, a *difference tone* may be produced by two notes sounding together in the next octave. This gives the effect of a swelling beat note in this lowest range. By omitting this range altogether very little is lost.

The *second octave* from 32 to 64 c/s is much more important, though unfortunately it cannot be reproduced with any precision in small rooms since the wave-lengths involved are comparable to the room dimensions and what are known as *standing waves*, echoing back and forth in the room, are easily set up in these conditions (32 c/s has a wave-length of 35 ft.; for 64 c/s the length is 17½ ft.; but it is the half and quarter wave-lengths that are particularly important).

Some of the fundamental notes of bass instruments are in this region (e.g. organ, piano, double bassoon, tuba, double bass and harp). These notes generally give the sensation of rhythm and power to the music.

Third Octave 64 to 128 c/s

It is in this range, however, that most bass notes are to be found. These, too, give body to the music. Over-emphasis results in boominess. It is not uncommon for the loud-speaker cabinets of the radiogram type to have resonances in this region. It is here, too, that mains hum usually makes its appearance as the octave, 100 c/s, of the mains frequency.

Fourth Octave 128 to 256 c/s

This contains the fundamental tones of voices and of 'cello, viola (part), clarinet, horns and trumpet (part). These add what one may describe as richness to the quality.

Here, too, exaggeration gives rise to a peculiar boominess.

Fifth Octave 256 to 512 c/s

In this octave we are proceeding from the region of power to that of intelligibility. We are entering the range of the oboe, the flute and the violin. We leave the fundamental notes of basses and baritones and meet with those of sopranos.

A peak in this region gives a most peculiar 'roof of the mouth' quality.

Sixth and Seventh Octaves 512 to 2,048 c/s

Most of the intelligibility of music and speech is to be found here. It is often known as the telephone region because a limitation of response to it gives the reproduction just that hard quality. It is, of course, the range that is most easily reproduced.

Over-emphasis in the sixth octave gives a hollow quality, not unlike that of a megaphone. Peaks in the middle of the seventh octave lead to a tinny quality like that of the early gramophones.

It is a general experience that loudness in this region tends to produce 'listener fatigue'. It is often an advantage, therefore, and particularly with older recordings, to be able to attenuate it.

Eighth Octave 2,048 to 4,096 c/s

This was the range added by the pre-war electrical records and reproducers to our listening. It is of particular importance in giving brilliance and articulation to the reproduction. The characteristics of the fricative and labial consonants lie here. So also, unfortunately, do the most objectionable qualities of needle scratch (the coarse, 'sandpaper' quality).

A rising response at the upper end adds what is known as 'presence' to the reproduction; a falling response gives dullness.

Sharp peaks give a distinctly nasal quality. At one time they were not uncommon, due to a cavity resonance in the condenser-type microphone that was used for recording. Faulty cutting heads have also been responsible for similar unpleasant effects.

Ninth Octave 4,096 to 8,192 c/s

This is the octave responsible for most of the distinctive quality of musical instruments. It contains the most important overtones. Accurate sibilance is characteristic of good, but not over-accentuated, response in this region. It is important, too, for 'presence'. Peaks in this octave give rise to stridencies.

Tenth Octave 8,192 to 16,000 c/s

Important overtones, particularly of reeds and tympani, cymbals, etc., are to be found in this octave which is responsible for the lively, sparkling character of music. Good, smooth response here is also important for accurate reproduction of transients.

Peakiness in this octave (which is not uncommon) may cause 'comb and paper' tone in the strings or an over-all siren-like quality. Over-accentuation generally gives rise to what has been called the 'chromium plating' of some so-called 'hi-fi' systems.

4.4 Effect of Peaks

Two points of general importance should be particularly noticed in regard to the foregoing description. The first is the difference between over-accentuation by a rising response in a certain band and peakiness. The former may be due to comparatively harmless causes such as incorrect equalization of a recording characteristic. Almost always it can be corrected in the amplifier once it has been identified. Peakiness is a more vicious thing and can only be dealt with by finding and removing the offending element in the system. It is due to sharp resonances, whether in the pickup, the carrying arm, the amplifier or the loud-speaker. It may be responsible for distressing forms of distortion. It will not only over-emphasize the fundamentals of notes occurring at that frequency, it will also strongly reinforce the overtones of notes whose fundamentals may be well below the region and for that reason the characteristic timbres of the instruments producing those overtones may well be changed or exaggerated, and this may be a serious matter.

4.5 Musical Balance

The second point is that a reproduction which contains high note components without lows, or lows without highs always leads to a certain discomfort. If the response at one end of the frequency spectrum is restricted, that at the other should be limited to balance it. If the response at one end is extended then that at the other should be extended too. A good empirical rule is that the response should be balanced above and below a frequency of 800 c/s. There is no virtue in that particular figure: it just happens that way. Another form of the rule, which is sometimes more convenient, is that the upper and lower frequencies multiplied together should give a product of 640,000.

Thus $400 \times 1{,}600 = 200 \times 3{,}200 = 100 \times 6{,}400$
$= 50 \times 12{,}800 = 640{,}000.$

Thus, if for some reason it becomes necessary to attenuate the bass below 100 c/s, then the treble above 6,400 c/s should likewise be attenuated to preserve a balance.

Remember, however, that this is just an empirical rule devised to take account of a psychological observation. It does not appear to have any theoretical explanation at present in the science of acoustics and must not, certainly not, be regarded as a law of the Medes and Persians.

4.6 How Distortion Affects the Ear

Another curious fact should be noticed at this point. Although restriction of frequency range is in itself a form of distortion, it is found that if other forms of distortion are present it is preferable to have a restricted range rather than full range. The ear is more distressed by these other forms of distortion than it is by restricted range. It seems to be a general rule that the ear does not miss what it does not hear nearly so much as it resents what it does hear if that appears to it to be unnatural. Thus it will seem to add a weak fundamental tone and to recognize a complex note as of that pitch, even when that fundamental is absent in the original. But it will not tolerate nasality or piercing top notes. One of the sure tests of positive distortion (i.e. something added as distinct from something missing) is *listener fatigue.* Some twenty years ago one of the advertising slogans for the newly introduced radiogramophones was: 'Listen to the bass!' Yes, the bumps of tympani round about 100 c/s (whose power is mainly found in that region) were made to sound quite impressive by means of cabinet resonances. But listening to those thumps became intolerable after a comparatively short time. So it is, too, with a loud-speaker that gives an exaggerated 'comb and paper' quality to the strings: after one has got over the initial satisfaction of being able to distinguish it easily from the pure tone of the flutes, one's ears soon begin to tire.

4.7 Types of Distortion

So peaks in the frequency response are a more objectionable form of distortion than limitation of range. Unfortunately, too, their causes may also give rise to other forms of distortion which are, perhaps, even more insidious. We shall be warning against many of these causes when we come to describe the various elements of a reproducing system. At the moment it is our object to notice the more potent forms of distortion and how to recognize them.

Harmonic distortion is most often caused by resonances in the mechanically vibrating elements such as the pickup and loud-speaker, but it can be the result of faults in other parts of the apparatus (e.g. valves). It occurs when an original tone is reproduced with an addition of a series of harmonics—octave, twelfth, double octave, and so on. The even harmonics (octave, double octave, etc.) may add a certain fullness to the quality; but the odd harmonics usually tend to a less pleasant or more reedy form.

Intermodulation distortion is perhaps the most vicious of all, and can occur at all parts of the scale. It arises when tones interfere with each other instead of being reproduced clearly and separately. In those circumstances a series of beat notes is produced in the form of tones whose frequencies are the sum and difference of the interfering tones. The effect on the ear is a lack of clarity, particularly in instrumental ensembles, a general mushiness or, it may be, a fluttering of high notes sounding above a forceful bass. The causes may be in any part of the apparatus. They are usually related to what is known as a 'non-linearity'.

As explained earlier, the output intensity I_0 should be exactly proportional to the input intensity I_1 for all values of the latter and independent of the frequency; or what comes to the same thing, the amplitude of the output wave A_0 should be proportional to the amplitude of the input A_1. If this condition is not fulfilled for each part of the apparatus there is a non-linearity, and intermodulation distortion will ensue. Other names for this kind of distortion are therefore *non-linear distortion* and *amplitude distortion.*

There are several other forms of distortion that have been identified in recent years. One is known as *phase distortion.* This occurs if two tones which were exactly together in the original music are reproduced with a slight interval. This can happen in different degrees in amplifiers and control units; but perhaps the most striking illustration occurs in loud-speakers where the sound-waves issuing from the back of the loud-speaker are completely out of phase with those from the front (when the front is pushing the back is sucking). Where the two trains of waves meet there may be either reinforcement or partial cancellation of air-pressure according to the distance the waves have travelled. Similarly, if two speakers are connected to the same amplifier but one has its connexions reversed, one would be moving backward at the instant when the other was moving forward and there would thus be a tendency for the two sound-waves to cancel out.

It is not easy to isolate this kind of distortion from other kinds: it makes the tone muddy instead of crisp and clean.

Another common form of distortion is known as *transient distortion* and occurs when sudden changes, such as are caused by the impact of a piano hammer or a cymbal crash, are not instantaneously reproduced. Theoretically, this requires a long range of frequency response far beyond the audible limits, and without resonance, so that there is no tendency for the unit to 'ring'. A good transient response, for example, is essential for a clean and crisp reproduction of the final passage in Tschaikovsky's '1812' Overture, where the bells and the drums and percussion generally are banging away as hard as they can go. Another example is a record that is obtainable of breaking glass.

Perhaps the best test of all, however, to a critical listener is the quality of the pianoforte tone. If the reproduction sounds crisp and clean and yet has a 'singing' quality, without 'pings', and can be listened to without fatigue, and if it is such that a musician can recognize the make of piano, then the reproducing system is almost certain to be a good one.

The last type of distortion to which we shall refer is *volume distortion.* It occurs when the reproduced sound is appreciably louder, or in some circumstances softer, than one is accustomed to hear in the original. This is partly because loudness alters the harmonic content of notes from the same instrument and partly because the ear reacts differently to notes of different loudness. Excessive volume is much worse than reduced volume. In natural conditions one is accustomed to hearing the same sorts of sound at different volume-levels—e.g. by listening to a concert from different seats, or at a distance in the open air, or from an adjoining room. There are thus many natural volume-levels below that which one would hear close to the source. But there is no natural volume-level greater than this, so that the voice of a speaker or singer reproduced at a level louder than one is accustomed to hear in one's living-room may sound unpleasantly thickened and distorted.

Women seem to be more disturbed by over-loud volume-levels than most men. Loud treble notes in particular seem to hurt their ears. Perhaps that is why there are more 'hi-fi' enthusiasts amongst men than amongst women.

V

PICKUPS AND STYLI

5.1 Types of Pickup

The first stage in the conversion of the pattern inscribed on a disc record into electrical oscillations is the tracing of the groove by the *stylus* in a gramophone pickup.

The second stage is the production of electrical oscillations from the motion of the stylus.

At least three distinct problems are involved in this:

(1) the record must be kept revolving at a constant angular speed, about a centre which must exactly correspond to the centre of the original recording;
(2) the stylus must follow the groove accurately so that its transverse motion corresponds to that of the cutter that made the original lacquer record;
(3) the motion imparted to the stylus must produce an electrical voltage at the output terminals of the pickup which oscillates in exact correspondence with the motion.

It is convenient to consider the third question, the design of a pickup, first since the answer to it will also affect the second.

There are three types of pickup in general use: the variable reluctance or moving iron pickup; the moving coil type; and the crystal pickup. There are also ribbon pickups and ceramic pickups but these are specialized forms of the moving coil and crystal types, respectively.

5.2 Piezo-Electric Pickups

The crystal and ceramic pickups operate by virtue of the fact that when thin slabs cut from crystals of certain substances are put under strain, tiny electrical voltages are set up on opposite faces. If, therefore, the stylus that traces the groove is attached in some way to a slab of crystal, an oscillating electrical voltage will be created, following the mechanical vibrations of the stylus.

5.21 Rochelle Salt Crystal Pickups

Rochelle salt is the most sensitive substance yet found suitable to give this 'piezo-electric' effect as it is called; it produces a relatively large voltage for a given deformation. A stylus cannot, however, be directly attached to a slab of the crystal for use as a pickup since the stiffness of the slab is such that there would be undesirable reactions between stylus and groove; moreover, the crystal itself is very brittle. So some kind of mechanical transmission device has to be inserted between the two. In the original laboratory designs this device was no more than a length of beryllium wire (beryllium being chosen because of its lightness) which was cemented at one end to the slab of crystal which was held in a horizontal plane between two plates of flexible plastic with bakelite sheet outside. The wire at the other end was bent over at right angles to the plane and at its tip a sapphire stylus was cemented.

This was an excellent device but was not (in 1933) considered suitable for commercial production. So in its place a more massive and robust leverage system was substituted, so arranged that a steel gramophone needle could be inserted into one arm of the lever and held by a long needle screw; at the other end was a fork which gripped the slab of crystal between two rubber faces. The system worked well enough up to a point and gave high-voltage output—more than ten times as large as the most sensitive magnetic pickups, and in those days a high output from the pickup (as well as cheapness) was demanded by manufacturers. But the system was too fragile and led to endless trouble: the rubber buffers perished and moisture invaded the cartridges; crystals cracked because of the stiff methods of support, and as Rochelle salt is hygroscopic the moisture wrought havoc inside.

These serious faults, however, were gradually overcome by Cosmocord in Great Britain and the latest designs are completely free from them. It is curious that these designs bear a striking resemblance to the first laboratory system described above. The slab of crystal is now mounted inside a cartridge which is filled with a special flexible gel. To one edge a 'cantilever' may be attached and brought out through the gel to a sapphire stylus at the other end. In other designs the cantilever is pivoted at one end outside the casing and the other end drives the crystal through the intermediary of a plastic pad immediately behind the stylus. Diagrams of these two types are shown in Fig. 6.

The voltage output of both these types has been substantially reduced compared with that of earlier types, but it is much more uniform throughout the frequency range and the reaction of the stylus on the record is much less. We shall revert to this question

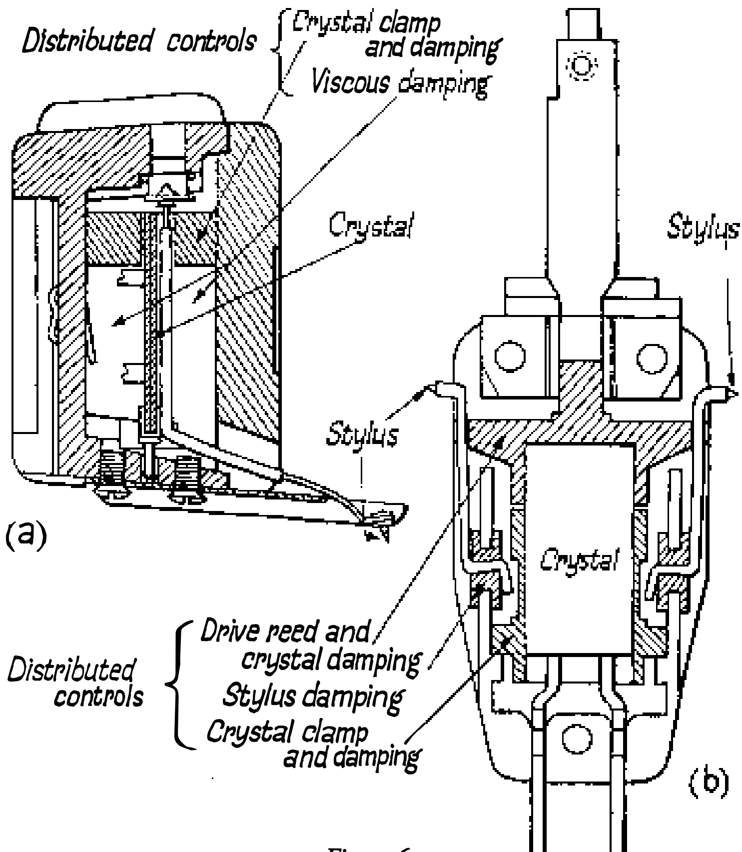


Figure 6

(*a*) Sectional view of ACOS HGP39 Pickup.
(*b*) Sectional view of turnover type crystal P.U. cartridge.

of reaction later since it is an important consideration that applies to all types of pickup.

5.22 Effect of Loading

The frequency response of a crystal pickup depends to a large extent on the nature of the gel in which the crystal is immersed. In free air the response would be proportional to the acceleration of the stylus. If the crystal were rigidly clamped, or if it were compliantly clamped without any resistance loading, the response would be proportional to the displacement of the stylus. In the latter case it would therefore produce a level frequency response in the voltage output if used with a 'constant amplitude' recording (see Sect. 3.7). When used with a 'constant velocity' recording (in which the amplitude of the record groove is inversely proportional to the frequency) the output voltage would vary in the same way: it would in fact fall at the rate of 6 db (i.e. be halved) per octave. The loading provided by the gel, however, may alter all this, according to whether it is purely viscous or has a certain amount of spring associated with it. At first sight it might be thought that it should be possible to choose a gel with properties to match any specified characteristic. In practice, however, such matching cannot be fully realized for a complex characteristic such as is now used for L.P. records; and in any case different characteristics would be required for 78 r.p.m. records and L.P. records. Probably, therefore, for crystal pickups as well as for other types, the best course is to provide separate 'equalizing circuits' for pickup characteristics and for recording characteristics.

5.23 Ceramic Pickups

Ceramic pickups have similar characteristics to crystal pickups but are based on an artificial 'ceramic' built up from barium titanate to have piezo-electric properties. This ceramic is not hygroscopic, is not so fragile as Rochelle salt and its piezo-electric property does not vary with temperature in the same way. Though it is much less sensitive it is more suitable for use in the tropics and in humid climates—provided, of course, that the gel and other parts of the pickup cartridge are suitably chosen. Rochelle salt should not be used at temperatures above about 45°C. or 110°F.

5.3 Types of Electromagnetic Pickups

The possible types of electromagnetic pickup are numerous. The essential feature of all, however, is that the mechanical motion of the stylus should create a corresponding change of magnetic flux through a coil. For this reason all pickups of this type are 'velocity controlled', and not 'amplitude controlled' like the crystal pickup. It follows that the effect of a recording characteristic such as that shown in Fig. 4(*b*) would be a decrease of output at 6 db per octave below 300 c/s and a constant output at frequencies above it up to 5,000 c/s after which there is a falling off at 6 db per octave. In other words the output should follow the recording curve as shown.

The change of magnetic flux through a coil may be brought about either by making the coil move in a magnetic field or by arranging for a magnetic 'armature' to vary the flux through a fixed coil. In the former case we have a 'moving coil' pickup or, if there is effectively only one turn in the coil, a 'ribbon' pickup. In the latter case we have a 'moving iron' or 'variable reluctance' pickup.

5.31 Moving Iron Pickups

Originally, when steel needles were used as the styli with 78 r.p.m. records and a relatively high-voltage output from a pickup was expected, the moving iron type held the field. To increase the efficiency (as a 'transducer') of an electromagnetic pickup one must increase either the rate of change of flux or the number of turns on the coil through which the flux passes. In a moving iron pickup the limit is determined by the flux that the armature can carry and that in its turn is limited by the size and therefore the permissible mass of the armature.

5.32 Moving Coil Pickups

In the moving coil type the permissible mass and therefore size of coil limits the design not only because it controls the number of turns but also because it limits the area through which the magnetic flux passes. The only chances of extending these limits is to improve magnet strength per unit area (and this has been done in modern designs) and to devise better arrangements for concentrating or directing the flux (and current designs are sadly deficient in this respect).

5.33 Frequency Response

However, now that public opinion has become content to pay more for electric amplifiers so as to have a greater degree of amplification available, it has become feasible to design both moving iron and moving coil pickups with smaller moving parts and this has made an extension of the frequency response possible. Whereas before 1939 a frequency response up to 8,000 c/s was only achieved in the most advanced designs and with precision workmanship, the range can now be extended at least to 16,000 c/s without undue difficulty. In a few designs a response up to 20,000 c/s has been achieved. In all cases, however, this success has had to be paid for by a reduced output voltage.

5.4 Mechanical Vibration

The features that have been mentioned about the progress that has been made in design of pickups illustrate some quite general principles that apply to all mechanically vibrating devices. Always there are three fundamental characteristics that determine the response of the system. These are the mass and the stiffness of the moving parts and the frictional resistance to motion of the material in which they are working.

In the case of steady motion the mass does not matter; it is only when there is a change of motion that it comes into play. Thus, if you are pushing a roller across a lawn, the mass of the roller does not affect the motion once that has become steady; it does affect it when you are getting up speed or when you are slowing down, and it would be the deciding factor if you were to try to move the roller to and fro very quickly, i.e. when you give it a vibratory motion.

In both cases the friction between the roller and the ground plays an important part. Indeed if there were no friction you would just get 'wheel spin'; the roller would not turn at all, but would slide along the ground. Similarly the resistance of the air has some effect on the motion; if the motion were in a denser and more viscous material it would have an even greater effect.

But what about stiffness? To see how this affects motion it is better to think of its opposite (or in terms of measurement, its reciprocal) which is called *compliance*. A piece of indiarubber has little stiffness but considerable compliance; a steel spring has greater stiffness and less compliance. The vibrations that can be set up in the balance wheel of a watch depend on the spring compliance just as much as on the wheel mass.

5.41 Resonance and Damping

Similarly, in electrical circuits there are three corresponding properties which determine the passage of an electric current.[1] These are known as *inductance* corresponding to mass, *capacitance* corresponding to stiffness (or more correctly to its compliance), and *resistance* corresponding to friction or viscosity: and they affect the electrical current in precisely the same way as their counterparts did the mechanical motion. The watch spring will vibrate most easily at its 'resonant' frequency (as did Caruso's wineglass) and this frequency is determined by the mass and the compliance and practically not at all by the resistance of the air. Similarly, in an electrical circuit that contains inductance and capacitance and resistance the resonant frequency is determined principally by the inductance and capacitance. The amplitude of the vibration at the resonant frequency is determined by the resistance; at other frequencies all three are concerned. Mass and inductance on the one hand, and compliance and capacitance on the other have what is known as *reactance* and these combine with the resistance to give what is known as the *impedance* of the circuit to the vibratory motion. The reactance of a mass increases whilst that of a compliance decreases as the frequency of motion is increased; and with any body such as a spring which has both mass and compliance the reactance of the one tends to counteract that of the other. When the two reactances are equal the spring vibrates at its natural frequency (its resonance) and there is no restraint on the possible motion other than the resistance of the medium. That is why Caruso's wineglasses broke into fragments when his voice happened to hit their resonances. They would not have done so if they had been in a more viscous material which would have offered greater resistance to the vibrations.

[1] Throughout this book, what is known as the 'old' analogy between mechanical and electrical quantities (as suggested by Lord Rayleigh and developed by Prof. Kennelly) is used. It is simpler to visualize, though in some respects less useful for calculation, than the more recondite analogy suggested in 1933 by F. A. Firestone.

This property of viscosity and other forms of resistance to restrain excessive vibration is called *damping*.

Now since all vibrating systems have both mass and compliance, or a series of masses and compliances, they all have a series of resonant frequencies. If the lowest of these is above the range of vibrations with which we are concerned, well and good; but that is an exceptional case. Usually we have several resonances in the range and then the damping becomes a crucial factor. But remember, damping has to be overcome: it absorbs energy and therefore when the damping is heavy more driving force is necessary to produce the motion (when friction is greater, you have to push harder!). So it is an advantage in most of the applications with which we are here concerned to have a system which requires little damping and this means that the mass should be small, and the compliance between moving parts small, and between them and any fixed part large.

5.42 Mechanical/Electrical Analogies

This analogy between vibratory motion and electrical circuit theory has been one of the most fruitful ideas that has been introduced into the science of acoustics. For every mechanical problem there is an electrical circuit problem and the solution of the one leads to the solution of the other. So it is with pickups. By setting down the electrical analogue of, say, the crystal pickup design shown in Fig. 6(*a*) it becomes easy for a competent engineer to work out in detail the main features of the frequency response and then to choose the values of mass and compliance of the various parts that will be required to give a desired frequency response. Whether those particular values can be secured by the use of known materials is, of course, another matter altogether. To trace in detail what these effects are is beyond the scope of this book. Interested readers are referred to a particularly informative paper by S. Kelly on pp. 91–9 of the 'Journal of the British Sound Recording Association' for January 1954. One or two of the conclusions should, however, be noted here.

5.5 Pickups as Mechanical Vibrators

The mechanical system of a pickup taken as a whole appears to have a mass, a compliance and a resistance, viewed from the stylus tip. The record material also has a compliance, and the arm which carries the pickup across the record has an effective lateral mass. The main resonant peaks in the frequency response are determined by the combinations of these masses and compliances.

5.51 Lateral Mass and Compliance

Thus the low-frequency resonance is determined by the total armature system compliance and the effective lateral mass; the record compliance will resonate with the effective armature mass referred to the stylus and give a high-frequency resonance. The compliance of vinyl (L.P.) records is lower than that of shellac (standard 78 r.p.m.) so that, other things being equal, the H.F. resonance for L.P. records will be lower in the scale than that for standard 78 r.p.m. records.

If a cantilever is inserted between the stylus tip and the main moving system (armature or moving coil or crystal) two additional resonances are introduced, because the cantilever has both mass and compliance and these combine with the other masses and compliances to produce multiple resonances. Thus in one practical design Mr Kelly traced resonances at 15 kc/s, 6 kc/s, 2,500 c/s, 700 c/s and 40 c/s.

5.52 Vertical Forces

Another interesting conclusion that emerged from Mr Kelly's analysis was that if the vertical force pressing the stylus down on to the record is less than the horizontal force due to the motion of the record groove, the stylus will tend to ride up one or other of the walls of the groove. Assuming that the stylus rides evenly in a groove which has 90° included angle between faces, and that there is no static side pressure (e.g. due to stiff bearings) the minimum weight in grams required to keep the stylus in the groove is equal to the maximum displacement in centimetres divided by 981 times the stylus compliance. This consideration enables the maximum impedance at the stylus to be calculated for adequate groove tracing.

Another important conclusion related to the compliance of the system in the direction at right angles to the surface of the record; but before we can appreciate this we must consider the question of the stylus a little more carefully.

5.6 Groove Shapes

Until about 1925 no attempt seems to have been made to standardize the shape of the record groove even in the same recording studio. Each recording engineer had his own pet ideas about the shape of cutting tool, the pressure, the consistency of the wax and so on that produced the best results. After the advent of electrical recording, however, a study began to be made of all the problems involved, including the way in which the various materials behaved in the making of the record. By 1935 it had been decided that a V-shaped groove with an included angle of 80°–85° and a bottom radius of 0·002 to 0·003 in. was the most satisfactory. The number of grooves to the inch varied from about 90 for very heavy recordings to 120 for lighter music and the width of the groove across the top was about 0·004 in.

5.61 Pre-war Contours

Up to then, of course, all sorts of different sizes and shapes had been in use. Thus in 1928 Columbia had a much sharper and

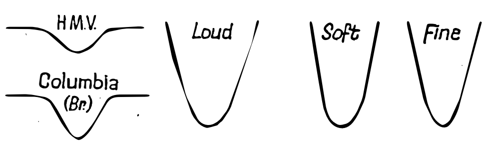


Figure 7

Pre-war Groove and Steel needle Contours (× 53 approx.).

deeper groove than H.M.V. and the bottom radius was smaller. Fig. 7 shows the contours, magnified 53 times, of sections of records made at this time.

The differences, perhaps, were not of such importance in those days as they are now, for then either steel or triangular fibre or thorn needles were used as the styli to track in the groove and the idea was that the needle should be worn so as to fit the groove during the first few revolutions. It was also supposed that the contour of the needle should be such that its tip would ride in the bottom of the groove.

The contours, on the same scale of magnification, of a *loud*, *soft* and *fine* needle are also given in Fig. 7.

5.62 Microgroove Standards

With the advent of microgroove records and lightweight pickups, standardization of groove section became a virtual necessity (Fig. 8). It is also agreed that the reproducing stylus should have a spherical tip whose radius is slightly larger than the radius of the bottom of the groove. The stylus therefore rides on the walls of the groove and about half or one-third of the way up as shown in Fig. 9(*a*). Standard dimensions are given in Appendix B

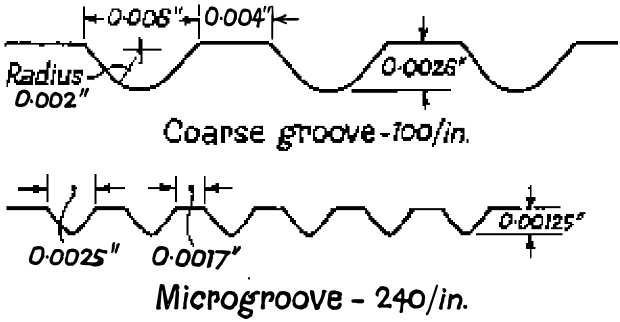


Figure 8

Modern Groove Contours.

to Chapter III. The number of recorded grooves per inch is between 90 and 120 for standard (78 r.p.m.) records and between 200 and 300 for microgroove records.

5.7 Styli

With the adoption of these standards, the 'one record only' steel needle has been discarded, and hard styli have come into general use. The wearing in of steel needles produces 'flats' larger than many of the tiny indentations of the high notes and playing with such a needle would cause rapid record wear. Thorns and fibres can continue to be used at any rate with standard records (or coarse-groove records, as they had better be called) provided it is realized that their relatively compliant point, other things being equal, will lead to an attenuation of high note response, and that in any event particular care is needed to shape the points accurately. A response up to 14 kc/s, however, can certainly be achieved with a thorn stylus.

The most common styli these days are fabricated sapphires though highly polished diamonds are coming more and more into popular favour, because their life (i.e. before deleterious flats begin to show) may be fifty times as long. These are now made to a tip radius of 0·002 in. for coarse grooves and 0·001 in. for microgrooves, though latterly styli with a tip radius of 0·0005 in. are coming into use in America. On the current philosophy, however, these should only be used with records whose grooves have a smaller bottom radius than microgrooves. It has been

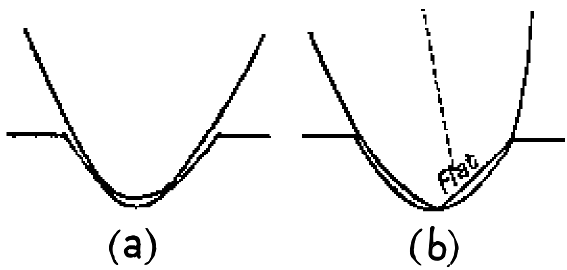


Figure 9

New and worn styli in groove. In (*b*) there is also tracking error.

suggested that a compromise can be effected by tilting the stylus at an angle, much in the same way that steel needles had to be used with a tilt of about 60° to the record. This, however, would only serve to accentuate the *pinch effect* as we shall explain in the next section.

The same problem arises, of course, when we try to use modern styli of 0·002 radius with pre-war coarse-groove records. Everyone who tries to do so will at once notice a disturbing increase of surface noise. For such records, in fact, a stylus of radius 0·003 in., and in some cases 0·004 in., is more suitable; or a thorn needle used with greater downward pressure and a needle angle of 60° to 70°. To get some idea of the effect hold a pencil with its point in vertical contact with a piece of paper and then proceed to draw it across the paper. You will get a series of jerks particularly if you have a light pressure. The jerks are reduced if you trail the pencil at an angle.

5.71 Pinch Effect

The cutting tool which inscribed the original lacquer disc from which records are derived has a flat cutting face which always moves in the same plane radial to the record. The groove is therefore of the same width *radially* and the width at right angles to its own curve varies from place to place. This can readily be seen from the diagram in Fig. 10 where the circle represents the horizontal section of the stylus and the triangle that of the cutting tool. A waist is formed in the groove between the crests of each wave-form because the cutting face is maintained radially (e.g. up and down the page in the figure).

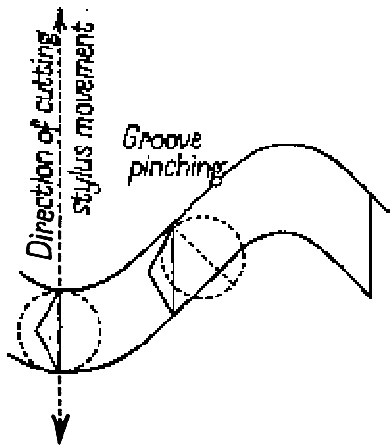
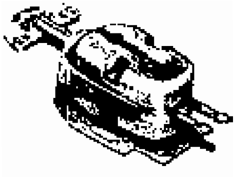


Figure 10
Pinch Effect. Since cutting stylus does not twist to face groove direction waists are formed in groove. To accommodate its diameter to these, reproducing stylus must rise and tracing is not accurate.

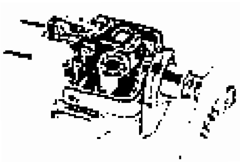
The reproducing stylus, on the other hand, by following the groove, maintains itself with its points of contact always across the groove at right angles to the instantaneous direction of the groove. To do this the stylus has to lift itself in the groove so that the section at the surface of the record is a circle of varying diameter. The effect of this is twofold.

5.72 Tracing Distortion

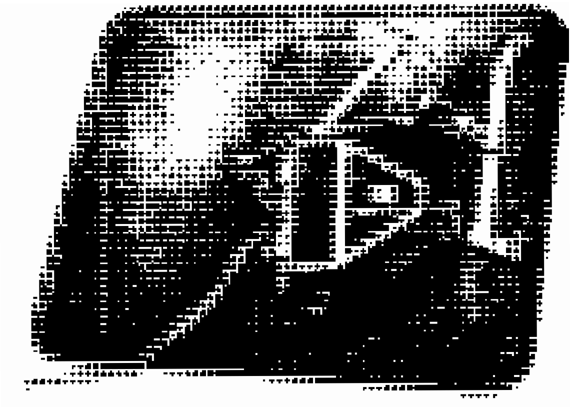
First, geometrically, the points of contact of the reproducing stylus are only identical with those of the recorder at the crests of the waves (or when there is no modulation). This *must* mean that the reproducing stylus cannot follow exactly the same curve as the recording stylus: there must be some 'tracing distortion' and this distortion will be greatest when the modulation has the greatest curvature, which is at the inner grooves of the record and when high and low notes are sounding together at a large intensity.



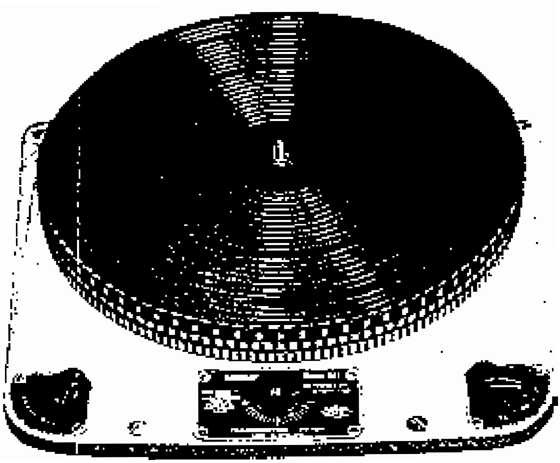
(*a*) Tannoy Variluctance Cartridge



(*b*) Goldring 500

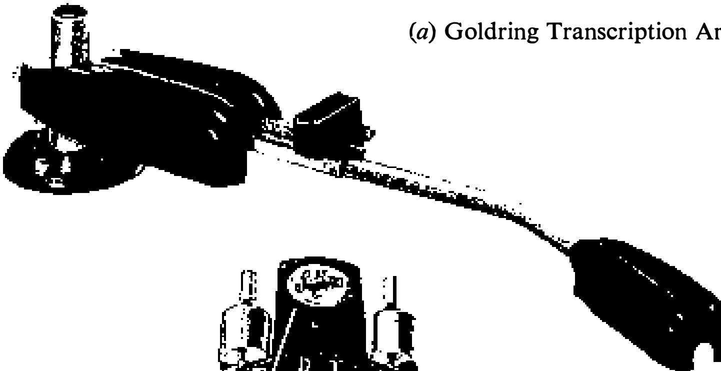


(*c*) View beneath the Goldring-Lenco Transcription Turntable

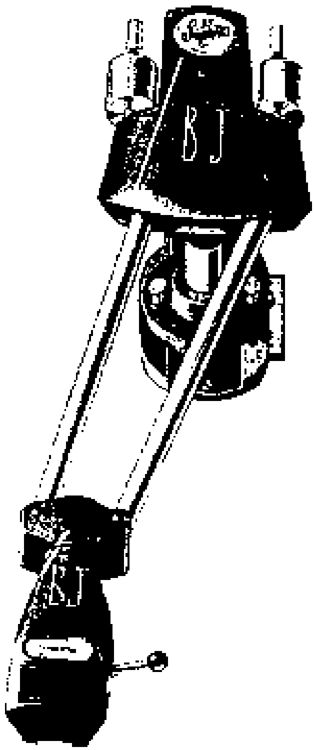


(*d*) Garrard 301 Transcription Turntable

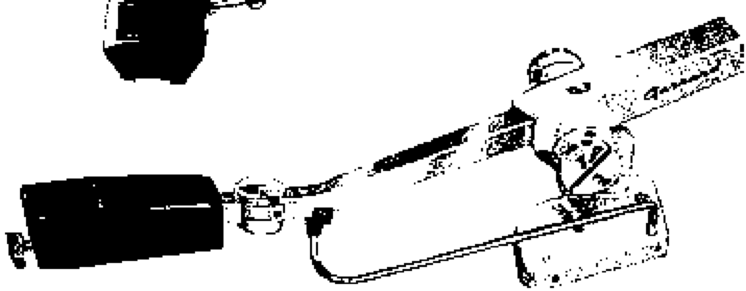
V PICKUPS AND TURNTABLES



(*a*) Goldring Transcription Arm



(*b*) B.J. Super 90 Arm



(*c*) Garrard PA 10 Transcription P.V. Arm

VI PICKUP ARMS

5.73 Groove Contact

The second effect is dynamical. As the stylus moves up and down to accommodate its contact diameter to the groove, oscillating stresses are set up. If these are not exactly taken up by the pickup the stylus will ride up out of contact with the groove wall, at least on one side. Also, if the vertical force keeping the stylus in contact with the record is too small, the tendency will be for the stylus to be thrown out of the groove. With a large playing weight (necessitated by a stiff armature system), on the other hand, the tendency will be for the stylus to break through the wall of the groove in much the same way as a river wears down its banks. This effect is shown in Plate VII (*d*) which is a photomicrograph of the groove formed by a plucked bass viol. The record has been played only five times with one of the best moving coil pickups available and in the optimum playing conditions that have yet been devised. Yet the wear on the 'banks of the groove' is well in evidence.

5.74 Needle Chatter

Again, if the moving parts of the pickup have insufficient vertical compliance the pickup head will tend to vibrate as a whole and an appreciable radiation of acoustical energy will take place from the disc at double the modulation frequency. Hence what is known as 'needle chatter'. If on the other hand the pickup has an appreciable vertical response so that this needle chatter is absorbed, second harmonic distortion will be produced in the electrical output. So one wants the absorption to be by means other than conversion into pickup response!

5.75 Vertical Compliance: Cantilever and Other Types

Two ways so far have been devised for doing this. The first is the use of a cantilever between stylus and the transducer element (whether crystal or moving coil or whatnot). The absorption here is greatly improved if the cantilever is made or built up of a self-damping material such as whale-bone, or if some form of resistive damping can be applied externally, e.g. by plastic pads. The latter, however, is apt to be very tricky, since it is only too easy to have the absorption unbalanced for left and right transverse motions and such unbalance will inevitably introduce non-linear (or intermodulation) distortion; an unbalance can, and almost certainly will, develop in course of use even though there was an exact balance when the cantilever and its damping elements were first assembled. A simpler, if less effective, system is to paint the back of the cantilever with a solution of soft plastic so as to simulate a self-damping system. Brush strokes which end always just behind the point where the stylus is fixed are the most effective since in that case a blob of the damping material is left at the most sensitive spot.

The second method that has been devised is to have the stylus mounted on an element which is capable of limited and preferably damped motion in a vertical direction. Two forms have been proposed for this purpose. In one, the stylus is at the end of a tiny needle shank which can move to a limited extent in a sheath, being controlled by a nylon thread. In another form, devised by the author, the stylus is mounted on a plate which is backed by a plastic located in a slot in the pickup casing. (Fig. 13).

5.76 Ellipsoidal Styli

There is nothing in any of these forms of design, however, that will minimize the *tracing distortion* inherent in the geometrical problem to which reference has been made. One proposal that has been suggested to meet the problem, though only partially, is to use an ellipsoidal stylus with its *major* axis across the groove. In this case, as can readily be seen from Fig. 10, the shifting of the contact points to and fro along the length of the groove is much less than with a spherical tip though the contact points are not themselves identical with those of the recording cutter. The one objection to this form is that the stylus becomes more fragile and wear is more rapid; and after wear at the ends of the major axis has taken place the flats form a less obtuse angle than in the spherical case and a more potent cutting edge is formed to produce record wear.

It will also be seen from Fig. 10 that if the surface section of the stylus is an ellipse with its *minor* axis across the groove, as was always the case with a steel needle played at an angle to the record surface, both the geometrical and the dynamical results of pinch effect are bound to be increased.

5.77 Limitations on Design

From the foregoing discussion it will be appreciated that tracing error and all its concomitants are an inevitable result of trying to use an indented groove to control the motion of a stylus which is of comparable dimensions to the indentations in the groove and is not completely free, dynamically. By this system the most we can ever hope to do is to find ways and means of keeping the distortion and other deleterious effects to a minimum. Most of them would not arise if we could devise an imponderable, microscopic tool to do the tracing: a ray of light, for example, or a stream of electrons such as is used in a television tube. That is not a fantastic demand; something approaching it indeed has been suggested—for light ray reproduction—and may yet prove to have commercial prospects one day.

For the present, however, we must think in terms of styli and other ponderable devices. For these our discussion enables us to set down a few principles for reduction of ill effects. For example:

(1) The impedance of the pickup as seen from the record should be a minimum both laterally and vertically. To keep down the resistance component means having as little damping as possible; hence the masses involved must be small. The reactance component in that case will be mostly due to the compliances in the system and these must be as small as possible, when they are between moving parts, and as large as possible between moving and fixed parts of the system.

(2) The shape of the stylus must suit the shape of the groove so that the points of contact are about half-way up the walls.

(3) The material of the stylus and the method of mounting must not be such as to induce the formation of flats.

(4) The vertical pressure between stylus and groove must be adequate to maintain contact and must therefore be greater than the maximum horizontal force exerted on the stylus by the record groove. But it should not be much greater.

(5) The effective shape of the stylus tip in the groove should be spherical or ellipsoidal with the major axis across the groove. If, however, the departure from spherical shape is considerable, more frequent change of stylus will be necessary.

(6) The way in which the pickup is carried across the record, and the possibility of side pressure between stylus and groove being created by such means, must not be neglected. These will be considered in our next chapter.

One or two other points about the design of pickups remain to be noticed. It will be recalled that the frequency response will be controlled by the masses and compliances of the system. Fortunately the optimum conditions for this are the same as those noted at (1) above. Now these masses and compliances are determined not only by the material of which the various parts are made, but also by their size and shape and, unfortunately, reducing a mass of a moving part may at the same time increase its compliance. This consideration, for example, puts limits to the design of a cantilever; methods of increasing stiffness without increasing mass (such as using a channel type of section, or twisting a wire) are useful desiderata.

It is not always appreciated that methods of fixing a stylus to an armature or a cantilever may make a world of difference to the response; and that the use of a diamond stylus in place of a sapphire may reduce the range by as much as half an octave. This arises partly because the dimensions of the mounting for a diamond have usually been greater (about $\times 2{\cdot}5$) than that for a sapphire and therefore a stylus of given tip radius (or minimum strength) has had a greater mass in the case of a diamond; and partly because the methods so far devised of cementing the diamond to the mounting give a larger compliance between the two than in the case of the sapphire. Improved mountings for diamond styli are, however, now becoming available.

5.8 Current Designs: 1. Crystal Pickups

Let us now look at some current designs and see how these principles have been applied. So far as crystal and ceramic pickups are concerned the designs shown in Fig. 6 have proved so satisfactory that no substantial change can be looked for. Improved methods may be devised for fixing the stylus to the cantilever, so as to reduce mass and compliance, and for mounting the cantilever itself, so as to facilitate stylus changing; and it may be that more useful types of gel will be discovered. But those are only matters of factory development. The principles described enable a response to at least 17 kc/s to be achieved with the highest resonance at 20 kc/s, and that with less than 2% intermodulation distortion, and with lateral and vertical compliances at the stylus sufficient to enable any record to be negotiated.

The design in Fig. 6(*b*) differs from that in Fig. 6(*a*) in one important respect. In the former the drive to the crystal is transmitted through a plastic pad which also acts as a damping element at the most effective point in the whole system, i.e. just behind the stylus; moreover, a similar cantilever and pad can be mounted at the other side of the cartridge so that two different styli can be used with the same crystal, one for coarse-groove records and one for microgrooves. These 'turnover cartridges' have become very popular. But, of course, the gel cannot be used to give different equalization characteristics for the two types of record, and the two cantilever systems, though balanced, are not entirely independent. Moreover, two different styli are not really sufficient for playing all types of record. At least three and preferably four should be provided for, viz.: 0·001 in. (1 mil) for microgroove records, 2 mils for post-1950 coarse grooves, 3 mils for records made between 1925 and 1950 (except Columbia between 1925 and 1933 for which 2 mils may be better) and 4 mils for earlier records. These dates are only general guides for the pre-1950 records: the best size for any particular record should be chosen by trial. So for anyone who has a valuable collection of pre-war discs the 'clip-on' type of cartridge shown in Fig. 6(*a*) is preferable.

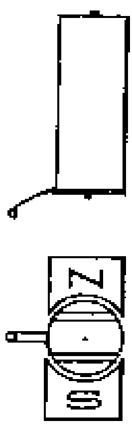


Figure 11
Modern Moving Coil Pickup. With long coil (after Voigt) and cantilever.

5.82 Moving Coil Pickups

The moving coil type of pickup with a long narrow coil was originally designed by Mr Voigt and has held the field against all comers. Its moment of inertia about the axis of rotation and therefore its effective mass at the stylus is very low. Most designs up to the present, however, have had magnetic systems of low efficiency. (The magnets have wasted the greater part of their sweetness on the desert air.) We may therefore expect to see improvements in this respect.

In current examples the voltage output is no more than about 3 millivolts. Fortunately the electrical impedance of the coil is very low so a comparatively high ratio transformer can be used

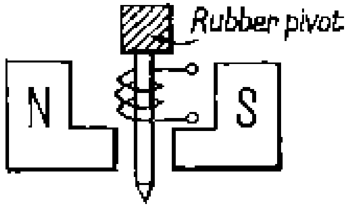


Figure 12
Decca Pickup.

to step up the voltage to about 50 millivolts at the input to the amplifier.

One improvement on the design has made an appearance commercially. In this the coil barrel is made to rotate about a vertical axis and the stylus is attached through the intermediary of a cantilever to the end of the barrel and not to the middle. This improved type is shown in Fig. 11. The design has improved the tracing at the inner record grooves; but it is not so easy to extend the high note peak to a point above 20 kc/s as it is in the original design.

5.83 Moving Iron or Variable Reluctance Pickups

Great changes have taken place in the design of moving iron, or variable reluctance pickups, as they are now called.

The most popular pre-war designs followed the original Kellogg pickup fairly closely probably because the arguments in its favour were so cogently given by Kellogg in his 1927 paper.[1] Magnetically speaking, those arguments were sound. Certain types, however, that were rejected by Kellogg on those grounds

[1] A.I.E.E. October 1927.

have been shown to be dynamically superior; this was first demonstrated in the H.M.V. No. 12 and No. 15 pickups, which themselves are now virtually superseded by another design rejected by Kellogg but successfully developed by Schwarz in the Decca pickup. An outline of this is shown in Fig. 12. This has been one of the most successful designs of the post-war years; but considerable changes now appear to be required if the high-note resonance is to be carried beyond 14 kc/s. One such change is to be found in the recent Connoisseur Super-Lightweight pickup which uses the sheath and nylon thread device previously mentioned.

Another similar design that has established a dominant place in America is the G.E.C. variable reluctance pickup. Several variations of this design are extant in America. According to the American 'Consumers' Union' tests the most successful seems to have been the 'Recordon' which is known in Great Britain as the 'Goldring 500'. Here a tiny cantilever of magnetic material is used to vary the reluctance of the magnetic gap between two pole pieces on each of which a coil of wire is disposed. By having the coils on the pole pieces instead of round the armature the mass of the latter can be substantially reduced without loss of winding space for the coils. In the Goldring design the cantilever is only held in a plastic block at the end remote from the pole pieces. There are no constraints at the stylus end which is between the magnetic poles. A certain amount of damping can, however, be applied by painting the cantilever with soft plastic as mentioned earlier.

5.9 Negative Compliance (Magnetic)

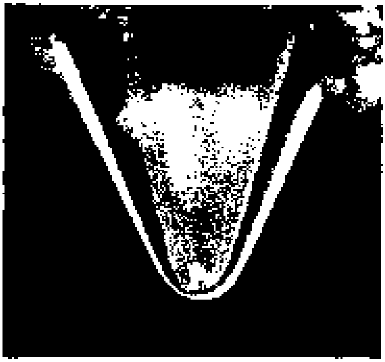
One of the disadvantages of this kind of design (and indeed of most moving iron pickups) is that when the armature is displaced from its mid-position between the two poles there is an unbalanced magnetic force in operation tending to pull the armature farther over towards the nearer pole piece. It has in fact all the characteristics of a *negative* spring or compliance. Coupled with this is the fact that the change of flux in the gap follows a non-linear law for any but very small displacements. If non-linear distortion is to be avoided, therefore, the gap must be comparatively large and the cantilever carefully centred. If the gap is large enough, as it is in the Goldring, it is usually considered that there is no need to correct the negative compliance by a positive one (a spring of some kind). But the penalty for this omission is a reduced voltage output. Other designs of this type, such as the Tannoy, have therefore attempted to improve on this situation by adding resilient pads to press against the cantilever when it is displaced. These can serve the double purpose of providing the positive compliance and also a certain resistive damping at the most sensitive point. It is unwise, however, to place such pads between the cantilever and the pole pieces, since in practice it is virtually impossible that way to get an exact balance on each side and an unbalance dynamically is just as bad in producing non-linear distortion as an unbalance magnetically. A better way is to put a single pad of soft plastic between the back of the stylus mounting on the cantilever and the case of the cartridge; in that way, which is the one used by Tannoy, it is possible by cunning design to obtain a nearly symmetrical system of positive compliance and resistive damping as well. Moreover, the damping is effective also for vertical displacements of the stylus and the proportion between the lateral and vertical damping can be suitably chosen by the shape and mounting of the damping pad. When this system is used it is safe to have smaller magnetic gaps, and therefore a greater voltage output (subject of course to the magnetic saturation point of the cantilever material), provided always that care is taken in use to keep the cantilever and its pad in its original central position.

5.91 Hysteresis Effects

There has been one criticism levelled against the variable reluctance pickup as compared with the moving coil type. This is that when the flux is changing in a magnetic material such as a cantilever or other type of armature, there is a certain *hysteresis* (or lagging of effect behind the cause) which may introduce another form of non-linear distortion. What is not often realized is that *all* mechanisms which have damping systems that absorb energy exhibit hysteresis effects of a not dissimilar kind.

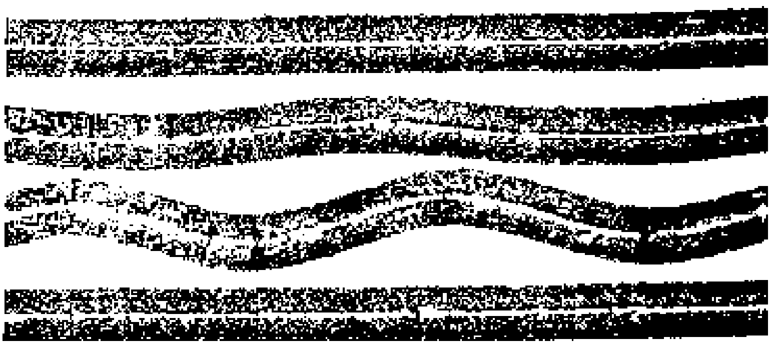
5.92 Self-balancing Magnetic Circuits

In principle, however, it would be better if the magnetic non-linearity were corrected magnetically and not by mechanical

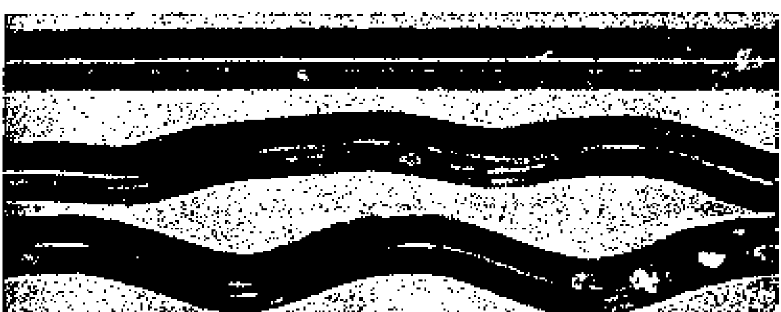


(*a*) New Sapphire Stylus

(*b*) Sapphire Stylus worn until shoulders have formed

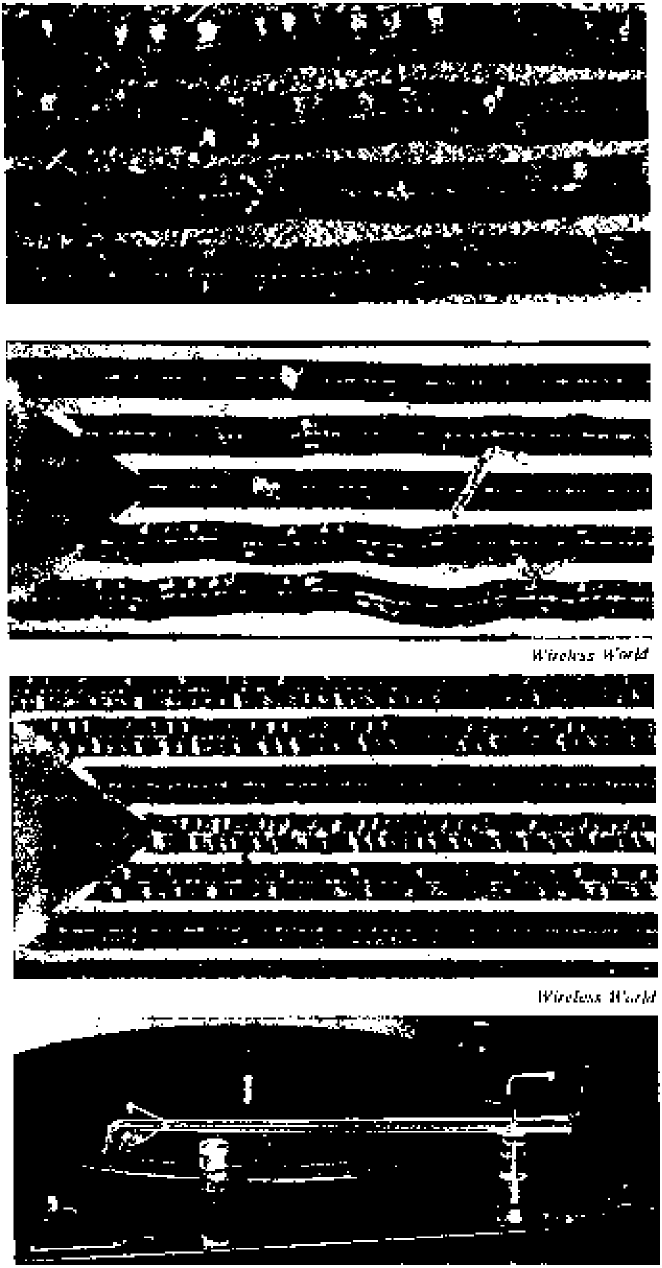


(*c*) L.P. Pressing showing how groove wall 'rubs up' with worn styli



(*d*) Recording of plucked Bass Viol after five playings with moving coil pickup

VII WEAR ON STYLI AND GROOVES



(*a*)
(*b*)
(*c*)
(*d*)

Wireless World

VIII The Dust Problem: (*a*) L.P. Pressing, unplayed, that has been on display in a dealer's window; (*b*) L.P. Pressing before and (*c*) after cleaning with the Dust-Bug; (*d*) the Dust-Bug means. Several ways of doing this have been patented by the author. One of the most effective of these is shown diagrammatically in Fig. 13. Here the coils are disposed about two like poles N and N[1] and the armature in the form of a star-shaped, flat stamping of magnetic material is disposed between them at the end of a rod of plastic. The stylus is cemented to the face of the armature. Two other poles of S and S[1] of the magnet system are

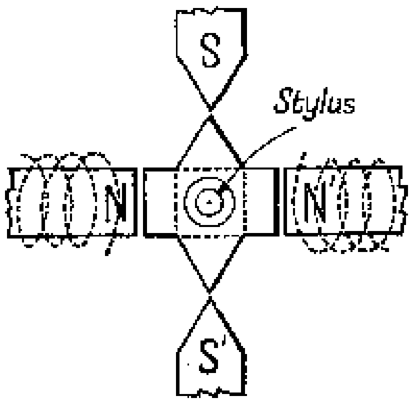


Figure 13
Magnetically Balanced Variable Reluctance Pickup.

opposite two points of the star and at right angles to N and N[1]. As the armature is displaced towards N and away from N[1] both the gaps at S and S[1] are opened and a magnetic restoring force is created there to counteract the over-balancing pull of the pole N. The respective gaps can therefore be so adjusted if desired as to give a positive restoring force instead of a negative compliance; and it is better to err a little on this side. On the other hand, the magnetic efficiency of the system is large and consistent by virtue of the fact that it is a function of the difference between the flux passing from N to S and S[1] and that passing from N[1] to S and S[1], the total flux remaining constant.

The method of mounting the star armature can of course provide damping for both transverse and vertical modes of vibration.

VI

CARRYING ARMS AND TURNTABLES

6.1 Motion Across the Record

The pickup is carried across the record on some sort of carriage or pivoted arm. The properties of this arm must therefore be studied from two aspects, geometrical and mechanical. For the first we examine the geometrical requirements so that the pickup may be carried across in the proper direction; in the second we inquire what effects the mechanical structure may have on the pickup response and upon record wear.

Now when the record is made the recording matrix rotates at a constant speed and at the same time the turntable moves at a constant speed under the recording stylus. If no mechanical vibrations were being impressed on the stylus it would cut a groove in the matrix in the form of a spiral—what mathematicians call an Archimedean spiral, after the Greek philosopher who investigated its properties. This spiral may therefore be called the mean line of the groove, since the effect of the vibrations of the stylus is to cut a sinuous curve with the spiral as centre line, or in other words to impress modulations on the spiral.

The recording stylus in its vibrations to and fro across the mean line is always moving radially, i.e. towards or away from the axis about which the matrix is rotating. Its motion across (or relative to) the matrix is likewise in a radial straight line.

For exact correspondence between the conditions of recording and reproducing we should therefore arrange that the reproducing stylus in its path across the record should move in a radial straight line, and that the axis about which it vibrates should always be at right angles to this straight line. This axis should therefore be tangential to the mean line of the groove at each point.

6.11 Radial Carriers

The simplest way of arranging for the stylus to travel across the record in a radial straight line is to mount the pickup on some sort of carriage which will either float across, e.g. on baths of mercury (see Patent 177,215 of 1922), or be guided across on a rail. Both methods are feasible and we will consider suitable devices in a later section; but they have not hitherto been considered commercially attractive.

6.12 Swivelling Arms

The more usual system is an arm carrying the pickup in a circular arc across the record, but various types of linkage (e.g. a Peaucellier's cell) have been proposed (Patents 6050 of 1905, 27608 of 1906, 24371 and 26158 and 422638 of 1910, 116163 of 1917), and latterly one system has achieved commercial success.

6.13 Effect of Curved Track

Let us then inquire, first of all, what the effects will be of the curved track across the record. They will be threefold:

(1) As the stylus moves in towards the centre it will move slowly away from the initial radius in the direction in which the groove is passing under it. The speed of the groove relative to the stylus will therefore slowly diminish, and cause a slow flattening of pitch (such as there would be if the turntable slowed up). This flattening, however, amounts to only 1 in 400,000 between consecutive grooves of a 78 r.p.m. record and is quite inappreciable.

(2) The friction of the groove upon the stylus will exert a pressure tending to move the stylus and arm inwards. This is an important effect both in its reaction on the pickup and in causing record wear and will therefore be considered in some detail later, under the heading of *side pressure*.

(3) The axis in the pickup about which the stylus vibrates is not always tangential to the record groove, with the result that in its oscillations about its mean position the stylus cannot move radially in the direction in which the sinuosities (the modulation) on the groove were recorded. This impairs the reproduction and causes severe intermodulation distortion of a percentage amount approximately proportional

to the angle of tangential error. Moreover, if the error is considerable the stylus will be skewed across the groove and will ride on the top of one wall with its point resting against the other wall (Fig. (9*b*))—a dangerous position for causing record wear.

6.2 Geometrical Considerations

The geometry and mechanics involved were investigated by the author in articles published in *The Gramophone* in September and October 1924. Two formulae were derived which enabled the tracking error to be reduced to less than 2° at every point of a 12-in. record. An improved form of the formulae was suggested a few years later by Mr F. C. G. Davey, and were elaborated by the present author in *The Gramophone*, April 1930. These formulae do *not* correspond with those derived later in America by B. Bauer (*Electronics*, March 1945). As the complete analysis has not hitherto been published it is given in an appendix to this chapter.

The simplest arrangement (geometrically) is that of a straight arm with the pickup mounted at one end in such a way that the axis about which the stylus rocks points directly to the other end of the arm where the horizontal and vertical pivots are; and in which the arm is so mounted that the stylus just reaches to the middle of the turntable spindle when the arm is moved to the centre. There are in fact some carrying arms of this type even today.

6.21 Tracking Error

The tracking error is the angle which the rocking axis of the stylus (which in this case is the line of the arm) makes with the tangent to the mean line of the groove at each point where the circular arc followed by the stylus cuts it. The tracking error will change from a large value at the outside groove to a smaller value at the inside groove; if the length of the arm between pivot and stylus is 8 in., the errors at different radii will be as shown in the following table:

radius	6 in.	5 in.	4 in.	3 in.	2 in.
error	22°	$18\frac{1}{4}$°	$14\frac{1}{2}$°	$10\frac{3}{4}$°	$7\frac{1}{4}$°

These values are plotted on a graph in Fig. 14(*a*). Now if, somehow, we could arrange the geometry so as to shift the zero line of the graph to the dotted line, we should get a range of smaller values for the tracking error, some in one direction (positive) and some the other way (negative).

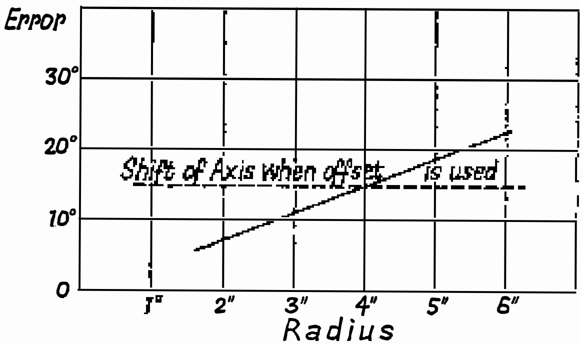


Figure 14(a)
Curve of Tracking Error.

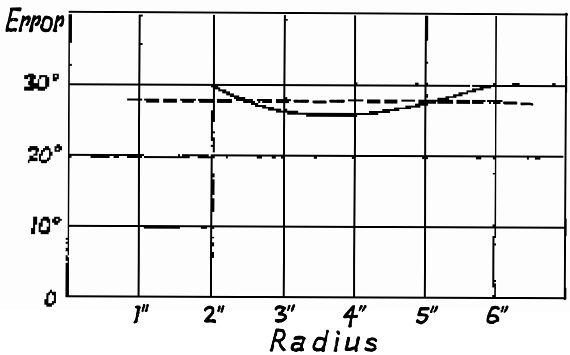


Figure 14(b)
Curve of Tracking Error showing effect of overlap.

6.22 Offset

This in fact can be done by mounting the pickup on the arm so that the rocking axis points to the right of the back pivot. Thus if the angle through which we twist the pickup were $14\frac{1}{2}°$ we should get the following table of errors:

radius	6 in.	5 in.	4 in.	3 in.	2 in.
error	$+7\frac{1}{2}°$	$+3\frac{3}{4}°$	0°	$-3\frac{1}{4}°$	$-7\frac{1}{4}°$

The angle through which we have twisted the pickup is called the '*divergence*' or '*offset-angle*'. Now suppose we could arrange the geometry so as to tilt the curve of error to the position shown in Fig. 14(*b*). We might then introduce an offset so as to shift the zero axis to the position shown dotted and we should have a remarkably small range of tracking error across the record, with two zero points within the range.

6.23 Overlap

Well, we can do this by mounting the arm in such a way that, when brought to the centre, the stylus will *overlap* the spindle by a critical amount. For an 8-in. arm the distance between centres should be 7·2 in., giving an overlap of 0·8 in. and the divergence should be 28°. This gives the following range of tracking error:

radius	6 in.	5 in.	4 in.	3·46 in.	3 in.	2·5 in.	2 in.
error	+2°	0°	−1¾°	−2°	−1¾°	0°	+2°

The error is no more than 2° at all points across the record!

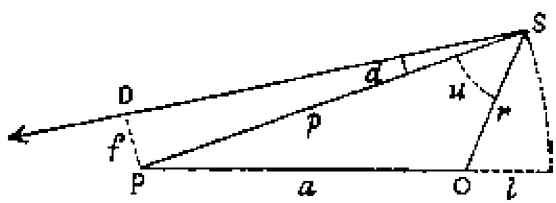


Figure 15
Diagram of overlap and offset.

Now let us look at Fig. 15, which shows the geometrical arrangement which gives this remarkable result. Here P represents the back pivot, O the record centre, S the stylus and SD the direction of the rocking axis of the stylus. Let us denote the distances OP by *a* and PS by *p*, and the offset angle PSD by *d*. Suppose, too, we drop a perpendicular PD from P to the line SD and call this distance *f*, the *linear offset*.

6.24 Optimum Values

Then if the inner radius is 2 in. and the outer one 6 in. the formulae derived in the appendix give the following values:

$$\text{overlap} = p - a \text{ (where } a^2 = p^2 - 12\text{)}$$

and linear offset, $f = 3{\cdot}73$ in.

The linear offset is always the same (nearly $3\frac{3}{4}$ in.) whatever the length of arm or distance between centres! It can also be shown that a point of zero error always occurs at a radius of 2·4 in. (the other being at about 5·2 in.). This is a very fortunate result since the average position for the inner recorded groove on 10-in. and 12-in. microgroove records is just about at that radius. For 78 r.p.m. coarse-groove records the minimum recorded radius is $1\frac{7}{8}$ in. and the average about $2\frac{1}{4}$ in.

If we were to take $r_0 = 6$ and $r_1 = 1$ in the formulae worked out in the appendix we should have:

$$\text{overlap} = p - a \text{ (where } p^2 - a^2 = 6\text{)}$$
$$\text{linear offset} = 3 \text{ in.}$$

and the zero error in the range would occur at 2 in. radius. The maximum errors, however, at radii of 2·5 in. and 6 in. would be about double those given by the previous arrangement, and this means that *on the average* there would be tracking error to cause intermodulation distortion at the inner grooves of 10-in. and 12-in. records. Some designers, however, consider that this disadvantage is overborne by the advantage of having a smaller overlap (for an 8-in. arm it works out to be 0·4 in. instead of 0·8 in.) and a smaller tracking error at the inner grooves of 7-in. (and especially E.P.—extended play) records.

You pay your money and you take your choice!

The optimum values of *a* and *d* in the two cases are given in the following table.

p	*a*		*p–a*		*d*		*Max. error*	
8	7·2	7·6	0·8	0·4	28°	22°	2°	4°
9	8·3	8·7	0·7	0·3	$24\frac{1}{2}$°	$19\frac{1}{2}$°	2°	$3\frac{1}{2}$°
10	9·4	9·7	0·6	0·3	22°	$17\frac{1}{2}$°	$1\frac{1}{2}$°	3°
11	10·4	10·8	0·6	0·2	20°	16°	$1\frac{1}{2}$°	$2\frac{1}{2}$°
12	11·5	11·8	0·5	0·2	18°	$14\frac{1}{2}$°	$1\frac{1}{4}$°	2°

6.25 Other Effects

Two further points should be noticed about the arrangement we have just described.

(1) The change of error as the stylus tracks across the record is double the maximum error, and is thus also at a minimum as compared with other arrangements. Any flats worn on the stylus are thus not spread so much round the circumference of the stylus.

(2) The process of making the stylus overlap the turntable spindle (i.e. making a less than p) has the effect of increasing the tracking error, but of making it more uniform across the record so that it can be corrected by a constant angle of divergence d. This has the effect of increasing the side pressure between stylus and groove; fortunately, the fact that the tracking error is made more uniform enables us to counterbalance the side-pressure completely by a dynamic system of levelling. This is described in Section 12.13.

6.26 Alignment Protractor

For measuring tracking errors (or errors in alignment as they have often been called) the author devised a special 'alignment protractor'. The design was published in *The Gramophone* in May 1925 and is reproduced in Fig. 16.

6.3 Mechanical Considerations

The forces which act upon the stylus when a record is being played may conveniently be grouped under six heads:

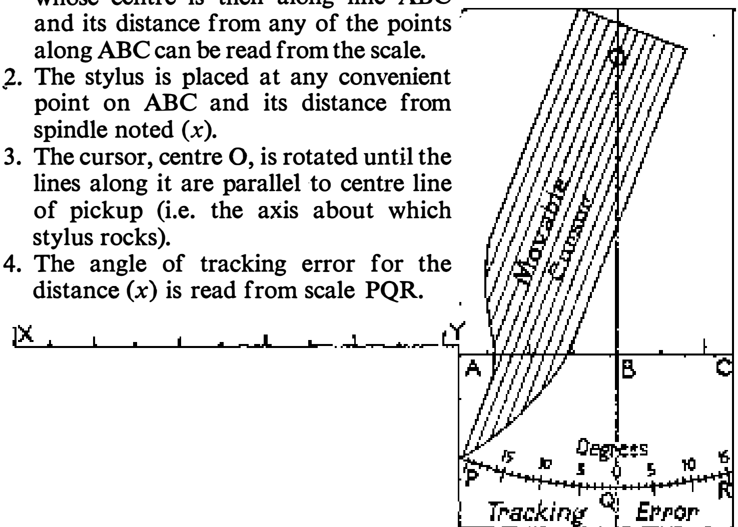
(1) The friction between the record and the stylus.
(2) The frictional forces of the arm bearings.
(3) Side pressure of the groove on the stylus.
(4) The force due to faulty centring of the record or to a warped record.
(5) Gravity and the reaction to gravity at the stylus tip.
(6) The forces due to the recording.

6.31 Side Pressure

The force due to friction is on the average tangential to the mean line of the groove. It is balanced partly by stress in the carrying arm (which refuses to be elongated) and partly by side pressure between stylus and groove. As already noted, this side pressure increases the more the stylus is made to overlap the spindle and at the critical setting for best alignment it is practically constant at all points across the record. (It varies as the tangent of the angle which is the sum of the divergence and the tracking error.)

Figure 16

1. The edge XY is placed against spindle whose centre is then along line ABC and its distance from any of the points along ABC can be read from the scale.
2. The stylus is placed at any convenient point on ABC and its distance from spindle noted (x).
3. The cursor, centre O, is rotated until the lines along it are parallel to centre line of pickup (i.e. the axis about which stylus rocks).
4. The angle of tracking error for the distance (x) is read from scale PQR.



6.32 Static Forces

Now there are three other common causes of side pressure: stiff bearings of the arm, a tilt in the vertical bearing so that the arm has a tendency to swing one way or the other, and a turntable that is not level, so that the stylus has to move uphill or downhill, as it were. Stiff bearings give an irregular side pressure, so it is highly important to make them free. The side pressure due to gravity (by the tilting either of the vertical bearing or of the turntable) may be in either direction. We can consequently use this property to neutralize the side pressure either inwards or outwards. The method of doing this is described in Section 12.13.

6.33 Warped Records

The effects of a warped record or one in which the central hole does not closely fit the spindle of the turntable (or has not been drilled so as *exactly* to correspond with the centre of the recording) are very pernicious. Both can cause undesirable stresses between record and stylus and intermodulation distortion may become severe.

Particular care should therefore be taken in storage of records to keep them flat, and a special note has been included on this in the next chapter. (Sect. 7.9.)

6.34 Swingers

So far as incorrectly centred records are concerned there is little that the ordinary user can do, except to avoid these 'swingers' like the plague: they can easily be detected in playing by a slight tendency of the pickup to swing in and out during each revolution of the turntable. Of course, if the turntable spindle is undersized every record may be turned into a swinger; in such cases, placing a size 0 plastic capsule (obtainable from a chemist) over the spindle often effects a cure.

The effect of a swinger, from its geometry and apart from its untoward reaction on stylus and pickup, is to introduce a wobble of pitch which also flattens at a very slow rate and the wobble itself produces intermodulation in the form of pronounced sum and difference tones.

Naturally, the effects both of warped records and swingers are increased if the effective mass of the carrying arm when viewed from the stylus is considerable. There is thus a practical advantage in having not too massive an arm.

6.35 Effect of Inertia

But it will be recalled that in our analysis of the frequency response of pickups we found that the low-frequency response of pickups depended upon a resonance which was determined by the mass of the arm and the resultant compliance of the pickup looking in at the stylus. It is the aim of the pickup designer to put this as low as possible and preferably outside the recorded range. This can be done either by increasing the compliance or increasing the mass. In practice, with the values of compliance given by the best pickups (rather greater than 5×10^{-6} cm/dyne), an effective mass of 30 grm. for the arm brings the resonance below 20 c/s. Incidentally, the region 20–25 c/s is dangerous for this resonance because many gramophone motors have a 'rumble' there. But of this more anon.

6.4 Linkage Systems

One pivoted linkage system that has proved successful commercially is known as the BJ arm and is shown in Plate VI. In this a pedestal of trapezoidal shape can rock up and down upon horizontal pivots at the ends of a diameter of a vertical pillar which is fixed in position on the motor-board. On this pedestal two arms are pivoted, one towards the back and one nearer the turntable, so as to rotate about vertical axes. The arms are of unequal length and are also pivoted at their other ends to a pickup holder. The distance between the back pivots is different from that between those on the pickup holder. The effect of this linkage is to twist the pickup head as it proceeds across the record and by suitable choice of pivoting points and length of arms it is possible to correct the tracking error across the record so that the residual amount comes to less than 1°.

Counterbalance weights can be attached to the back pedestal in order to adjust the playing weight, and since the pedestal does not move across the record with the tracking of the pickup, the side pressure between stylus and record (e.g. as caused by a 'swinger' or by faulty levelling) is not affected by the use of counterweights. On the other hand, there is a variation of playing weight as the pickup moves across the record owing to the fact that the distance between pickup and horizontal pivots changes during the transit, whilst that between pivots and counterweights remains constant.

In all such devices there is one disadvantage which, in the absence of fine workmanship, might prove serious: a multiplication of bearings. If only one of these should be stiff, substantial side pressure could be set up; on the other hand, undue looseness would cause the tracking correction to be indeterminate, and might produce a variable and perhaps intermittent side pressure which would be equally objectionable.

6.5 Radial Tracking Carriages

With a linearly tracking carriage it is rather difficult to have so small a mass as 30 grm. which is easily realizable for a pivoted carrying arm. But that is not the reason why such carriages have not been produced commercially. A much more important consideration is the cost of production. In most of the types that have been tried an expensive form of precision workmanship has been found necessary.

In one such device that was marketed in 1929 under the name of 'Raytrak', there were three parts: (i) a standard of polished aluminium fitted on a base plate to be screwed to the motor board; (ii) an aluminium frame carrying a plated circular guide rod; and (iii) a travelling carriage fitted with V-grooved wheels and an adjustable clip to take the pickup. The carriage, of course, was arranged so that the stylus in the playing position travelled across the record radially. By itself, however, this was not sufficient to ensure perfect tangential tracking; a further requirement for this is that the rocking axis of the stylus (and armature) should be at right angles to the radial tracking line. Accurate alignment therefore depended on the way in which the pickup was fixed to the carriage and the residual error from this might well be more than 2°, unless special care is taken.

In a carrier of this type there are two likely sources of trouble. If the stylus is not exactly symmetrical with the guide wheels the record friction will have a turning moment which may cause the wheels to jam on the guide rod, thus producing excessive side pressure if not a definite tendency to lock. The second source of trouble is of an opposite kind. If the construction is so free that locking in the manner just described does not take place, there is a possibility of side-to-side play in the carriage as a whole; and this may not only defeat the object of the design for tangential tracking but cause in itself a rattle in the reproduction due to a form of non-linear distortion. In both cases the main sources of trouble are the wheel bearings.

These difficulties are no doubt responsible for the requirement that has hitherto been found a *sine qua non*: precision workmanship. There is, however, a modification of the design which the present author has found to give trouble-free results without any special precision in the making of the parts. This is to substitute a V-shaped channel for the guide rod and a similar V-shaped channel for the carriage with two fairly large (say $\frac{1}{4}$-in. or over) ball bearings between the two. The carriage channel is fixed inside a tube which also extends round the guide channel as shown in Fig. 17, the clearance between the tube and the underside of the latter being very small. The pickup is attached to an arm which is fixed at right angles to the tube. At the other side of the tube a bracket may be fixed with counterweights attached to adjust the playing weight. A scale to measure the position of the stylus across the record and a leverage system acting on the tube so as to have a mechanical system of lowering and lifting the stylus are simple refinements. Subject to careful initial setting so as to ensure tangentiality, the device has been found to work quite smoothly and to give rise neither to side-play nor side-pressure through jamming.

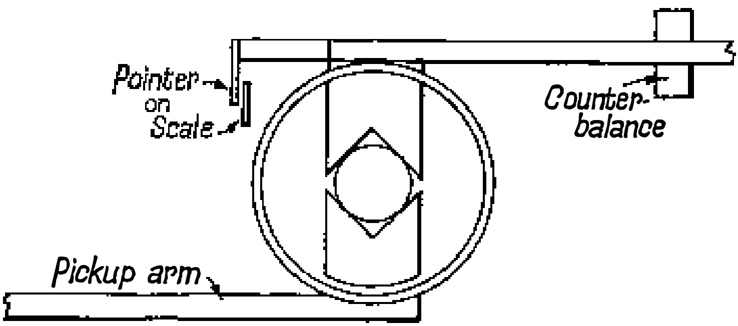


Figure 17

Sectional Diagram of Radial Tracking Carriage sliding on two balls.

6.6 Raising and Lowering the Pickup

The last paragraph introduces the reader to two matters which, so far, have not been satisfactorily dealt with in commercial carrying arms: lifting and lowering and 'cueing' (or selecting a particular passage on a record). Lowering the pickup on to the outer edge of a record, where 'run-in' grooves are usually provided nowadays, is not too difficult; but lifting it off by hand in the middle of a recording, or even at the end, is fraught with considerable risk of damage. The matter is much easier if there is an overhang of the arm behind the horizontal bearings which control the up and down motion (such as is sometimes provided, for example, for the purpose of a counterweight). For then one can mount the arm at the *front* of the cabinet with the pickup on the left and the pedestal (and bearings) on the right. To lift the pickup off the record one simply presses down on the overhang with the right hand and catches hold of the pickup, when clear of the record, with the left. This is a much better system than the more usual one of having the pedestal of the arm situated at the back right-hand corner of the motor board.

Mechanical lowering and lifting devices are, however, available in the form of a lever projecting across the record underneath the carrying arm. This lever can be raised or lowered by a knob, which may also be used to control the on-off switch and brake for the turntable. Such a device has been used for many years, for example, in the instruments supplied to the blind for use with talking books. An elaboration is also available in which the lever is calibrated so as to act as a groove selecting (cueing) device. One cannot help but feel, however, that for a swinging carrying arm a more satisfactory way of achieving the object would be to have some sort of electromagnetic clutch. Several inventions of this kind were patented before the Second World War, but have not been developed. This is all the more surprising in view of the popularity of record changing mechanisms.

6.7 Automatic Record Changers

Automatic record changers have been improved beyond all recognition in recent years. Twenty years ago the only types available were bulky and clumsy affairs. Modern designs are comparatively light and positive and are much more reliable in action. They place the stylus in the run-in groove of either a 12-, 10- or 7-in. record, the exact position being controlled by an ingenious trip lever and cam which is operated by the record as it falls to the turntable from its position at the top of the spindle. Moreover, the carrying arm is under no mechanical constraints as it moves across the record; and the stylus is placed on the record and removed from it far more gently than it would be if controlled by the somewhat clumsy hand of an ordinary human being. Some of the latest models even choose the proper stylus for the particular type of record.

There are, of course, a number of disadvantages compared with the manually operated record player. Of these the principal one is that to keep the market price within reasonable bounds it is not possible to have the same high degree of precision workmanship as is usually aimed at for the 'transcription turntable'. This means that there must be a lower standard both in respect of constancy of speed and in respect of vibrationless running. Considering the problems involved, accentuated as they have been in the past few years by the provision of the 3-speed (78, 45 and $33\frac{1}{3}$ r.p.m.) change, the standard achieved in some cases is remarkably high.

Practically all modern designs provide for the dropping of the records one by one from the magazine clip at the top of the spindle to the turntable. The second record is therefore played on top of the first, the third on top of the first two and so on. Since as many as ten or a dozen records may be involved the stylus angle of the last may be appreciably different from that of the first; this does not matter so much nowadays when the sapphire is approximately vertical as it did in the old days when a steel needle was played at an angle in the region of 60°. What does matter more is the possibility of slip between record surfaces which can cause quite a distressing variation of pitch—to such an extent, indeed, that some folk have gone to the trouble of sticking thin plastic or rubber mats on top of the record labels. There is an encouragement to slip sometimes in the fact that in record changers the spindle itself does not rotate with the turntable: if the centre hole of the record is undersized, or (what is more usual) if the record label is stuck on so as to overlap the centre hole, the friction with the stationary spindle will tend to retard the record. The remedy, of course, is to examine the labels of every new record very carefully, and cut it away with a razor blade round the centre hole, where necessary. Do not rashly enlarge the centre hole itself. That way you will almost certainly produce a swinger. A circular, surface-milling tool with a centre spindle of exactly the right size to fit in the record hole (0·285 in.) would be a useful accessory for trimming record labels.

6.8 Transcription Turntables

For the highest standard of reproduction what has come to be known as a 'transcription turntable' is advised. There are several first-class examples on the market, in which the turntable is massive, particularly along its outer rim, so as to give it considerable angular inertia ('flywheel effect'), and has been precision-turned at right angles to a hardened and highly polished spindle. The spindle spins in a long cylindrical bearing (with microscopic clearance), the thrust being taken by a single steel ball at the bottom. The workmanship is so precise and the turntable itself is so accurately balanced, that when it is set spinning not the slightest up and down motion can be detected in the rim and the spin will continue for several minutes without seeming to slow up. The turntable is usually made from non-magnetic material (so that there is no tendency to distort the flux in a magnetic pickup—a substantial matter in these days of short styli) and is driven along an internal rim by a rubber 'idler wheel' which is itself driven by a 3-speed 'cone drive' from the electric motor. If this rubber wheel is not accurate both in smoothness of circular circumference and in the centring of its axis of rotation, vibration may be set up in the drive, giving rise to a low-frequency oscillation in the pickup which may be distressingly audible as 'rumble'. For this reason arrangements are usually made for the retraction of the rubber wheel from the drive when the motor is switched off; if it is left in contact in a stationary position for any length of time distinct flats may be formed on it.

6.91 Rumble

Rumble may also be caused by inequality of drive in the electric motor itself, or even by resonance in the springs which keep the idler wheel in contact. If the turntable is massive, the vibration so caused (usually between 20 and 25 c/s, though in a few motors it may be as high as 60 c/s, and these should be avoided at all costs) will not be transmitted directly to the stylus through the record. It is more often transmitted along the motor plate (sometimes called the unit plate) to the base of the pickup arm and along the arm to the cartridge. It is sometimes therefore an advantage to mount the pickup arm on rubber buffers and not directly to the motor plate. A successful scheme is shown in Fig. 18. Arms made of a thin plastic shell, however, may be such grave offenders by virtue of their self-resonance that they are best avoided altogether.

Another trick to stop the transmission of rumble is to screw a block of heavy metal (e.g. one built up of lead sheets) between the motor and the pickup base: there will be at least one position where the vibrations of rumble frequency are reflected. A slot in the motor plate (rightly positioned!) should have a similar effect.

It is worth a good deal of trouble to avoid rumble and fortunately modern motors show a great improvement in this respect on their predecessors. At one time it was thought that the best plan was to have motors giving plenty of power so as to ensure constancy of speed under the varying load of the pickup on the

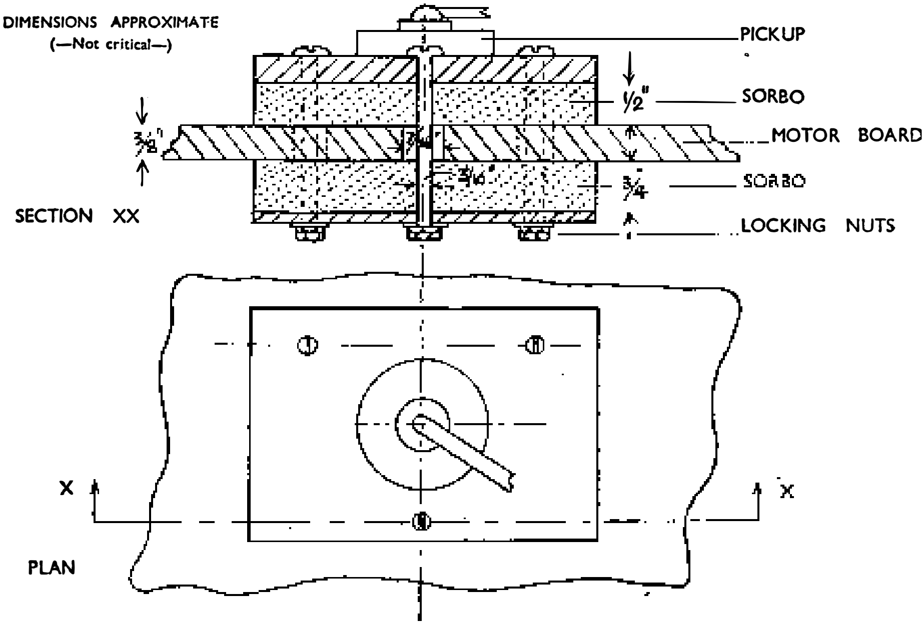


Figure 18
Anti-Rumble Mounting.

record. Such motors almost invariably are offenders in the matter of rumble and certainly many of them run very hot.

6.92 Flutter and Wow

Nowadays, the theory has changed. Small-powered 4-pole motors (even as low as 12–15 watts) are used to drive heavy turntables through precision-ground mechanisms in which friction is at a minimum. 'Flutter' (short-term variation of speed) and 'wow' (speed fluctuation per revolution) are now virtually non-existent and 'rumble' cannot be detected, especially when a high-speed motor is used with precision bearings and a particularly accurate cone drive (1 in 10,000, say) is used. In such a case a well-designed carrying arm can be rigidly mounted on the motor plate without trouble.

6.93 External Vibration

If the record player is being used in a room where plenty of external vibration may be set up (e.g. through the effect of passing traffic on flimsy or resonant floors) the motor plate may be mounted with advantage on springs to a motor board surround. One of the author's correspondents has gone so far as to have a gimbal mounting—fore and aft and port and starboard—as a barrier to external vibration.

6.94 Speed Control

Governor controlled motors have now almost disappeared in favour of the mains-controlled, synchronous or squirrel-cage type. The former have been found to be particularly susceptible to 'wow' and 'flutter' at the low turntable speeds. Unfortunately, this meant abandonment of variable speed control (other than the 'stepped' speed control in the driving cone). A partial control has been restored in some cases by incorporating a device for varying 'eddy current' loss in the driving motor, but the range is only about plus or minus $2\frac{1}{2}$ per cent.

Another scheme that has been tried to solve the problem has been the substitution of a long conical mandrel for the 3-speed cones. This drives a large rubber wheel which can be moved along its surface by a lever, and this wheel then transmits the drive to the under-face of the turntable at different diameters. (Plate V(*c*).)

The reasons why fine control of turntable speed is desired by a number of users is worth noticing. Musicians and particularly those who have the faculty of 'absolute pitch' (i.e. of recognizing the pitch of a note by its exact position in the scale and not merely relatively) tell us that the quality of a musical composition may be marred if the pitch departs from the standard laid down by as much as half a semitone. Now sharpening or flattening a note by a semitone requires an increase or decrease of turntable speed by 6 per cent (i.e. $4\frac{1}{2}$ r.p.m. for a 78-r.p.m. record and 2 r.p.m. for a $33\frac{1}{3}$-r.p.m. record). Such a difference can be caused either by oversized or undersized driving mechanisms or even by a change in the frequency of the A.C. current mains supply owing to varying load at different times of the day. Moreover, some of the early 'vintage' records were actually made to be played at a speed of 82 r.p.m. and there were many that required a speed of 80 r.p.m.

6.95 Stroboscopes

For those who have not the faculty of absolute pitch how is a departure from the true standard to be detected? At times when

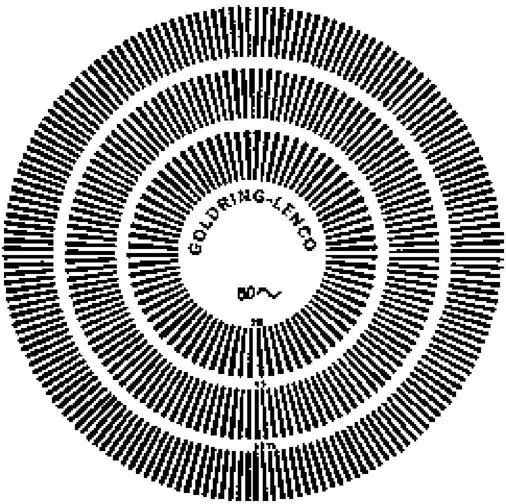


Figure 19

Stroboscope for Turntable speed check.

the frequency of the A.C. electric supply can be relied upon the answer is the use of a stroboscopic disc. On this there are alternate black and white sectors, the number differing according to the speed we wish to test. Its use is based on the fact that an electric light (A.C.) flashes at twice the frequency of the mains supply. So if the frequency is f per second there are $2f$ flashes per second. Now if we arrange the number n of black spokes on the disc so that when the turntable is making r revolutions per minute one spoke moves exactly to the position of the next spoke in the interval between flashes, the spokes will appear to be stationary. To find the number of black spokes required for any speed (per record), therefore, we divide twice the frequency of the electric supply by the number of revolutions per second.

So,
$$n=2f\div\frac{r}{60}=\frac{120f}{r}.$$

In this country the frequency of the mains supply is 50 c/s, so that $120f=6{,}000$. In America the standard frequency is 60 c/s, but some supplies have a frequency of only 25 c/s.

Stroboscopic discs are on the market for speeds of $33\frac{1}{3}$, 45 and 78 r.p.m. One such is illustrated in Fig. 19. Discs may also be obtained for 80 r.p.m.

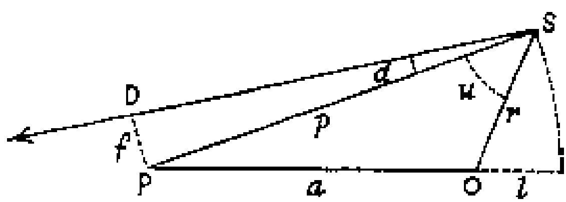
If you turn back to the picture of the recording machine (Plate III (*a*)) you will see that stroboscopic sectors have been painted on the rim of the recording turntable.

Stroboscopes are valuable even when the frequency of the mains supply has altered, for they will show whether there is some mechanical fault in the *mechanism* which governs turntable speed; for any such errors will affect both the electrical control of the motor and the flashing of the electric light in the same way, and the stroboscope will only indicate the relative speed of the turntable to the frequency of the supply. If the latter is 3 per cent low so will be the turntable speed and therefore the pitch of the music reproduced. This latter can therefore only be checked by reference to some standard of pitch.

APPENDIX TO CHAPTER VI

TRACK ALIGNMENT—TRACKING ERRORS

The arrangement of swinging arm and pickup is geometrically equivalent to the diagram below.



Here O represents the record centre, P the back bearing of the arm, S the stylus, SD the direction of the axis about which the stylus and armature rocks. PD is perpendicular to SD.

d=offset angle or divergence.

f=linear offset=$p \sin d$.

l=overlap=$p-a$.

w=complement of u.

Tracking error $x=90°-d-u$

$=w-d.$

x is only zero when $w=d$.

$$\sin w=\cos u=\frac{p^2-a^2+r^2}{2pr}. \qquad \ldots (1)$$

There are two and only two values of r which can give the same 'w'. Let these be m and n.

Then
$$\frac{m^2+p^2-a^2}{2mp}=\frac{n^2+p^2-a^2}{2np},$$

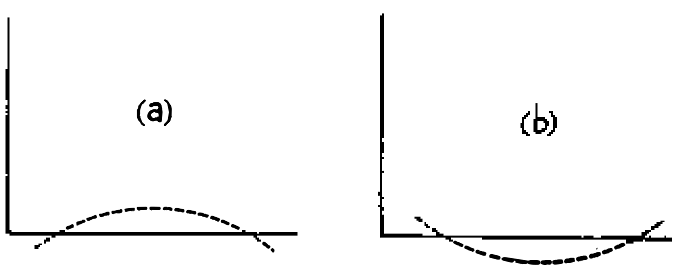
from which
$$p^2=a^2+mn. \qquad \ldots (2)$$

Let us choose f so that the error is zero for these two points.

Then
$$w=d,$$

and
$$f=p \sin w=\frac{m^2+p^2-a^2}{2m}=\frac{m+n}{2}. \qquad \ldots (3)$$

We now have two zero errors in the range and the curve of error is therefore either as in (a) or as in (b) below.



We now want to determine m and n so that the greatest errors are as small as possible. The three points which may be responsible for the greatest error are the two extremes and some point between m and n. To know where the latter is we find the maximum value attained by w.

$$\sin w = \frac{r^2+mn}{2rp} = \frac{r}{2p} + \frac{mn}{2rp}.$$

$$\frac{d \sin w}{dr} = \frac{1}{2p} - \frac{mn}{2r^2 p}.$$

This is zero when $r^2 = mn$ and then $\sin w = \frac{\sqrt{mn}}{p}.$ The two other extreme values are at r_0 and r_1. We get the best range when all these are equal and the middle one is of opposite sign.

$$\frac{r_0^2+mn}{2pr_0} = \frac{r_1^2+mn}{2pr_1},$$

whence $$r_1 r_0 = mn, \qquad \dots (4)$$

$$\sin(d+x_0) = \sin w_0 = \frac{r_0^2 + r_1 r_0}{2pr_0} = \frac{r_0+r_1}{2p},$$

$$\sin(d-x_0) = \frac{\sqrt{mn}}{p} = \frac{\sqrt{r_1 r_0}}{p}.$$

Adding, $$2 \sin d \cos x_0 = \frac{r_1+r_0}{2p} + \frac{\sqrt{r_1 r_0}}{p}$$

$$= \frac{1}{2p}(\sqrt{r_1}+\sqrt{r_0})^2.$$

Since x_0 is small $$\cos x_0 \longrightarrow 1.$$

So $$f = \frac{m+n}{2} = \frac{(\sqrt{r_1}+\sqrt{r_0})^2}{4}. \qquad \dots (5)$$

Hence the two conditions for minimum error are

$$p^2 - a^2 = r_1 r_0,$$

$$f = \frac{(\sqrt{r_1}+\sqrt{r_0})^2}{4}.$$

By extending this analysis it is possible to calculate the best overlap for a given linear offset even where this has not the optimum value derived above.

TABLE OF BEST OVERLAPS

(All dimensions in inches)

OFFSET	*Arm length from back centre to stylus*								
	8	8½	9	9½	10	10½	11	11½	12
2	0	0	0	0	0	0	0	0	0
2¼	0·09	0·09	0·08	0·08	0·08	0·07	0·07	0·06	0·06
2½	0·19	0·18	0·17	0·16	0·15	0·14	0·14	0·13	0·12
2¾	0·29	0·27	0·26	0·24	0·23	0·22	0·21	0·20	0·19
3	0·40	0·37	0·35	0·33	0·31	0·30	0·28	0·27	0·26
3¼	0·52	0·48	0·45	0·43	0·41	0·39	0·37	0·35	0·34
3½	0·65	0·61	0·57	0·54	0·51	0·49	0·46	0·44	0·42
3¾	0·79	0·74	0·69	0·65	0·62	0·59	0·56	0·53	0·51

VII

RECORD WEAR, SURFACE NOISE AND CARE OF RECORDS

7.1 Types of Wear

Record wear is of two kinds: frictional and reactive. The first occurs as the direct result of the rubbing of the stylus on the record groove and the typical sign of it is an increase of surface noise, particularly at the outside groove of a record where the linear speed is greatest. The second occurs as the result of the force reaction between stylus and groove and the typical sign of it is the appearance of 'grey lines' when the record is viewed at an angle.

7.2 Frictional Wear

In the old days, the theory of record playing was that the steel needle should be ground to a better fit by the frictional contact with the groove, and special fillers of abrasive matter were added with this object in view to the shellac and other gums used for record material; common fillers were rottenstone, slate powder and carbon black as well as tougheners such as cotton flock. The texture of the record material was therefore relatively coarse.

This technique has been abandoned in recent years, as indeed has the whole theory of grinding the stylus to fit the groove. Nowadays, flats worn on the stylus are regarded as a menace; and record material is made as finely grained as possible. The 'shellac' material used for coarse-groove (78 r.p.m.) discs has a coarser granular structure than the 'vinyl' or 'geon' used for long-playing discs, but is much finer than was the case twenty or thirty years ago.

7.21 Effect of Playing Weight

The result has been a considerable improvement in surface noise and in frictional wear. Both of these of course depend directly upon the stylus force, or playing weight, required to keep the stylus in contact with the groove. The coming into use of light-weight pickups with smaller moving parts and greater lateral compliance has completely transformed the situation. In the book *Modern Gramophones*, written by the present author in 1929, a normal playing weight of 5 to 5½ oz. was specified. Nowadays, the more usual playing weight is 7 to 10 grm. (or ¼ to ⅓ oz.) and progress is being made in the design of pickups to make a playing weight of under 2 grm. a practical possibility.

With these improvements, as well as those in record material, frictional wear both of record and of stylus has been drastically reduced. The effect has been cumulative. As soon as playing weight could be reduced and record material and groove cross-section were made more uniform, the use of hard styli such as sapphires and diamonds became feasible; and these in their turn have enabled further improvements to be made in the design of pickups, and the 'life' of styli (i.e. before deleterious flats have become worn on to them) has been considerably increased.

7.22 Life of Styli

What that useful life is cannot of course be stated with any precision: it depends so much on conditions of use. The following factors are all important:

(1) type of pickup and particularly its lateral and vertical compliances at the stylus;
(2) type of carrying arm and particularly its alignment and avoidance of self-resonance at critical frequencies (such as rumble frequency);
(3) freedom from side pressure whether from bearings or methods of mounting pickup, arm or turntable;
(4) cleanliness of record. Atmospheric dust is a potent enemy.

A careful user who keeps his records clean and uses a pickup which will track at, say, 5 to 7 grm. playing weight, might expect a life of about 50 hours from a sapphire stylus; but at the moment the author puts the safety figure at no more than 25 hours.

There is as yet no simple way of deciding, from external indications, that the time has come to change a stylus. If the user has facilities for examining it under a microscope or powerful magnifying glass he will of course reject a stylus as soon as a flat of 0·0005 in. width has developed for L.P. records or 0·001 in. width for coarse-groove records. Perhaps, however, the surest guide is the amount of distortion that becomes noticeable at the inner grooves of a record with which the user is quite familiar. The counsel of perfection is to keep a spare stylus assembly handy, and change as soon as deterioration of quality begins to show itself.

The reasonable life of a diamond is forty or fifty times as much as that of a sapphire. But do not fall into the trap of thinking (or being persuaded) that they are interchangeable. They are not; the reasons have been given in Sect. 5.77.

7.3 Reactive Wear

The second kind of wear is caused by the reaction between stylus and groove and is a measure of the difficulty which the stylus has in following the groove. If the pressure required to drive the stylus is greater than that which the walls of the groove are capable of imparting, then either the record or the stylus material must give way. When a fibre or thorn needle is used, the needle point goes; with a hard stylus, the record. In the old days, therefore, one used to consider the ability to play more than one side of a 12-in. record with a single fibre point without breakdown a good sign that one's apparatus was in proper mechanical condition. Anything that caused side pressure between needle point and groove was immediately suspect if fibre breakdown occurred.

7.31 Groove Amplitude and Curvature

From first principles, therefore, it is clear that reactive wear is most likely to occur at places where the groove has the greatest amplitude (i.e. excursion from the mean line) and where the curvature is sharpest. A saw-tooth wave-form, for example, with its sudden changes of directions, will be particularly difficult to negotiate. There will clearly be a tendency for the stylus to cut through the peaks and an even greater reluctance in the stylus to change its direction suddenly, and therefore if the peaks of two grooves happen to come close together there will be a tendency for wall breakdown from one groove into the next.

These characteristics have been beautifully illustrated in the photomicrographs taken by Mr C. E. Watts, and the author is greatly indebted to Mr Watts for the accompanying photographic illustrations. These show far better than mere words how great the strain between groove and stylus can be. The one which perhaps causes most food for thought is that at (*d*) in Plate VII. This was done by Mr Watts in January 1956 and represents a plucked double bass on Decca record LK 4115. The record had been played only five times with a good sapphire stylus in one of the best moving-coil pickups available. The playing weight was 7 grm. and the carrying arm used was perfectly free and gave minimum tracking error. Yet signs of wear, similar to the wearing away of the bank of a stream by a strong current, are well in evidence.

Mr Watts has now been able to set up the apparatus by which these photographs were taken in such a way that the actual tracking of the stylus in the groove can be observed whilst the record is being played. He reports that on occasions the stylus appears to be floating, without touching the walls on either side! Yet the ear does not detect anything different.

7.32 Groove Curvature and Stylus Acceleration

Perhaps the most informative work that has ever been done on the measurement of the stresses that actually occur between stylus and groove in playing ordinary commercial gramophone records was carried out in 1952–3 in the Cosmocord laboratories at Enfield, near London, under the direction of Mr S. Kelly. The characteristics of microgroove record grooves were microscopically examined and what was required of the stylus to enable it to track properly was precisely determined. This involved the effects of displacement, velocity and acceleration at different frequencies. At the low-frequency end, of course, the displacement was the controlling factor; at the high-frequency end, the groove curvature. The latter affects the stylus in the form of the acceleration required for change of direction or velocity of motion. (It is acceleration that makes you uncomfortable in a lift, a ship or a plane.) Since the stress set up will (according to Newton's second law) be proportionate to the mass to be moved and the acceleration required, determination of maximum acceleration was seen to be a matter of prime importance. Taking the acceleration 'g' of a body falling under gravity (981 cm/s) as the unit, the acceleration required at 10 kc/s, in a record with 12 db pre-emphasis at that frequency, was found to be of the order of

2,000 g. This meant that at 10 kc/s the mass which the stylus would appear to present to the groove would be 2,000 times the effective mass of the armature as it appears at the stylus. Where the pre-emphasis is greater than this, as it has been on some American recordings (see Chapter III), the acceleration is, of course, much greater.

At the low-frequency end, where the displacement of the stylus is what matters most, it is the compliance at the stylus tip that controls the ability of the pickup to track in the groove, coupled of course with the playing weight; in fact

$$\text{minimum playing weight} = \frac{\text{maximum displacement}}{981 \times \text{stylus compliance}}.$$

These investigations have led to an entirely new outlook on what is required of a pickup and have abundantly confirmed the qualitative analysis given by the present author in 1929 in *Modern Gramophones*, which indicated that to reduce reactive wear the essential condition is that the impedance of a pickup looking in at the stylus should be made a minimum; and that this would be secured if the design were such as to give the best reproduction of both musical notes and of transients.

7.4 Dust

So far we have said little about the effect of foreign matter in the record groove. This may be either atmospheric dust or record material worn from the groove. It will of course accentuate frictional wear, and it will also give rise to impulsive blows on the stylus which may affect reactive wear. For both reasons it will give rise to *noise*, i.e. a sound of indeterminate pitch, or rather one that has component frequencies extending throughout the scale.

In general, noise may be created either by the granular structure of the record or by dust; the latter is nowadays much the more important, especially with microgroove records whose material has a much finer granular structure and where the size of the groove is smaller and is therefore affected by smaller dust particles.

7.5 Surface Noise

It has long been known that the range of frequency response of a pickup and the nature of its high note resonance determine to a large extent the nature of the surface noise produced. Indeed some of us were able to develop a faculty of judging the response of a pickup by listening to the quality of the surface noise; in articles in *The Gramophone* written by the author in the nineteen-twenties and thirties numerous references to the characteristic qualities of surface noise will be found: e.g. the 'coarse sand-paper' noise denoting a peak in the 2,500 c/s region; the 'tearing of brown paper' noise, indicating a 3,500 c/s peak; the 'fish-frying' noise denoting a 5,000 c/s response and so on. The theme has since been developed and a record of 'white noise' (i.e. where the frequency components are fairly evenly distributed) is now available for the purpose from the Cook laboratories of Connecticut.

7.51 Impulsive Noise

The impulsive noise is more disturbing than the granular noise and a good deal of attention has been given to the question of its elimination. Perhaps the most intriguing line of approach was that suggested by Mr D. T. N. Williamson in a lecture to the British Sound Recording Association in 1953. He pointed out that impulsive noise consists almost entirely of ringing at the cut-off and resonance frequencies; and that stylus shape is of great importance. For reduction of noise he rejected the common expedient of reducing the frequency range (e.g. by means of a steep-cut filter in the amplifier system) as being very unsatisfactory, not only because of the curtailment of musical value involved but also because it has the effect of redistributing the pulse noise to the lower frequencies! He therefore suggested a novel form of 'feedback' which would tend to cancel out a noise pulse but not a musical note of more limited frequency spectrum! Those who were present at the demonstration agreed that the offensiveness of the 'plops' in record reproduction was substantially reduced.

7.6 Keeping Records Clean

The suggestion does not seem to have been developed, possibly because of its very ingenuity. A more hum-drum approach to the problem has, however, met with considerable success. This has been the devising of means to keep records free from dust. The problem is by no means so easy as it may seem at first sight. Just wiping a record with a cloth, a pad or a brush is not enough.

Not only does it often fail to remove the tiny particles that are resting in the groove, but in some cases it may even make matters worse by causing the record to attract more dust!

7.61 Effect of Static Electric Charges

Those of you who remember playing about with Wimshurst machines in your schooldays will recall the ease with which high electric charges could be induced on a surface of suitable material. Well, both shellac and vinyl of which records are made are suitable materials for this purpose and a non-conducting stylus such as a diamond or a sapphire is a suitable tool for creating the electric charge; and when a charge is accumulated on the surface the fine dust which lurks about in the atmosphere is readily attracted. Rubbing the surface with a pad with the object of cleaning the dust away may add to the electrification instead of removing the dust. That is why record makers recommend cleaning with a slightly damp cloth, for moisture has the effect of discharging an electrified surface. So-called 'anti-static' preparations are also on the market for treating record surfaces so as to discourage the formation of electric charges.

All these methods, however, are but partially successful. A more positive method is really required for preventing static charges at the very moment when they are liable to be created by the scraping of the stylus along the groove. Two methods have been proposed. One is to arrange for the air in the neighbourhood of the stylus to be 'ionised' by the presence of some radio-active material. The author has actually used radio-active Yttrium 90 and Strontium for this purpose with some success. Capsules of some radio-active substance for attachment to the pickup cartridge are available on the American market. A much neater and more effective method, however, would be to have the radio-activity either in the record material (thus protecting it from static charges from any source) or in the stylus itself; the latter of course would be the cheaper proposition. There is thus plenty of room for development of this idea.

7.7 Dust Removal

Another method, devised by Mr C. E. Watts, is known as the 'Dust-Bug'. For this a separate carrying arm is used with nylon bristles tracking across the record, either 90° or 180° from the pickup. These bristles also tickle the particles of dust from the groove (Plate VIII). Behind them is a pad made of plush which is damped with an anti-static liquid; diluted ethylene glycol is recommended. This pad not only discharges static but also picks up the particles of dust. Photomicrographs of part of a record before and after treatment in this way are shown in Plate VIII. The method is thus remarkably successful, the only objection to it, so far as one can see, being the fact that it requires a little extra effort.

Experiment with these methods shows quite conclusively that by keeping a record free from dust not only is surface noise reduced but the quality of reproduction is greatly enhanced, particularly in the treble; and record life is certainly prolonged.

As records are so expensive, surely a little trouble to keep them clean is worth while.

7.8 Record Storage and Indexing

Of course, if records are allowed to become electrified when they are being played they will attract dust even when in store, and insertion in the envelopes, or 'record sleeves' as they are often called, may scratch the surface. The application of an anti-static substance is thus advisable immediately after playing. In any case, records should not be stored in a dusty place. What they need is a moderate temperature and a dry atmosphere.

The main problems of storage are those of keeping the records flat and in such a way that the particular record one wants can readily be found with a minimum of handling. Recorded surfaces should never be touched by the fingers: the records should be held by the edge or between edge and label.

Obviously, too, the records should not be kept lying about or in piles; for that would entail much unnecessary handling. Storing vertically on edge with a uniform end pressure is much the best system. All the records that are stacked together must therefore be of the same size and a means must be devised of providing sufficient end pressure (which, however, need not be very much) whilst still making it possible to withdraw any particular record at will.

The best arrangement is to have a number of compartments, each taking 50 (or even 100) records with a double wedge as shown in Fig. 20. One wedge can be the end of the compartment or a partition between two compartments as shown; the other should be a sliding wedge of exactly the same taper. When it is slid into the compartment alongside the fixed wedge it provides the necessary end pressure; when it is pulled out the pressure is released and the record envelopes can readily be withdrawn.

The amount of taper given by a width of $\frac{1}{8}$ in. at the back and $\frac{1}{4}$ in. at the front for each sliding wedge, and $\frac{3}{8}$ in. at the back and $\frac{1}{8}$ in. at the front for the fixed partition gives ample pressure.

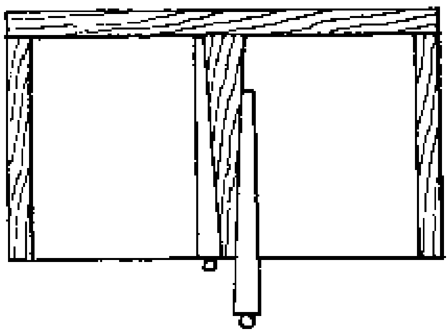


Figure 20
Record Storage Compartments with wedges.

Of course, each compartment must either be full of records or a temporary plywood or cardboard partition must be inserted at the end remote from the wedges and backed by large books so as to fill up the vacant space.

The record sleeves should be numbered (e.g. by sticking on auctioneer's printed lot tickets) at the top corners, and since these corners are empty it is easy, even when the wedges are inserted, to run one's finger along and find the right number. When the right envelope is identified the appropriate wedge is pulled forward a little way, the stack is freed and the wanted envelope withdrawn.

It is strongly advised that no attempt should be made to keep records grouped together in any sort of classification. That would mean leaving blank spaces in each section and thus defeat the main object of the system. Number the envelopes in the order in which you acquire the records and make your classification in an index book or card index. This may be quite a complicated affair with any number of cross-headings on the lines of the Decca Catalogue and there are on the market a number of Index Books designed for the purpose. But one can be content with something less elaborate in a small loose-leaf notebook, divided up into a few simple headings, e.g. Symphonies, Concertos, Other Orchestral, Organ, Chamber Music, Instrumental solos, Opera, Choral, Vocal. The Orchestral, Operatic and Choral sections can be subdivided into Composers arranged alphabetically thus:

SYMPHONIES

BEETHOVEN

Symphony No. 5. Kleiber, Decca ($33\frac{1}{3}$) 57

The remaining sections are perhaps best subdivided under the various artists or combinations, also arranged alphabetically.

The 12-in. records can be numbered from 1 onwards, the 10-in. from, say, 300 onwards, and the 7-in. from 500 onwards according to the number of records you have or hope to have.

The working procedure after the index has been made can be varied to suit the particular requirements. Normally, one looks up the index, finds the number, runs one's fingers along until that number is reached, releases the appropriate wedge, pulls out the appropriate envelope about half-way and takes out the record, leaving the envelope sticking half out of the shelf and simply crying aloud to be replaced when you have done with it. But if you are making up a programme for an evening's entertainment, the records can all be taken from the shelves in their envelopes and the numbers on them will facilitate replacement when the evening is over.

One elaboration in the index is well worth while, though it may entail a little research to begin with. That is to put down the date of the recording (or alternatively the date of issue) and the appropriate playback characteristic. To this you may even add notes about the best setting of the controls in your control unit.

7.9 Flattening Warped Records

If a proper system of storage is used records should not warp. If, however, through carelessness or for any other reason, you possess a warped record you would be well advised to flatten it before use. The process is the same for both shellac and vinylite records.

First of all get two flat sheets of glass (plate-glass is best) about 13 in. square, thoroughly clean and dry them and finally polish them with french chalk. Then hold the warped disc by its edge between the fingers of each hand with the surfaces of the record at right angles to the palms of the hands. With the surface of the record facing a gas or electric fire, and about 18 in. away, slowly rotate the record between the fingers until the surface becomes just warm. Reverse the record and treat the other side in a like manner, being careful not to get it too warm. This process releases internal strain.

Place the record between the two pieces of plate-glass, which themselves have been warmed (preferably just before or whilst you were warming the record), add a few large books or other weights on top, and allow to cool. If the record is not absolutely flat in 24 hours or so repeat the process.

7.91 Washing Records

Sometimes, through accident or neglect, records are allowed to become mildewed or otherwise smeared with dirt. Or the grooves may have been clogged with debris from a few breakdowns with non-metallic needles. Before playing with sapphire or diamond styli they must be cleaned, and a thorough washing process is advisable. The following method, though rather tiresome, should prove effective.

Make a mixture of 2 parts white vinegar and 1 part 3-in-1 oil. Shake this to an emulsion and rub into the grooves with a clean piece of fabric until no liquid apparently remains on the surface. Leave the record for a while—an hour or so if you have the time.

Then make a firm lather, with Teepol or other simple liquid or white detergent—not the blue or otherwise chemically treated variety—or even with shaving cream, and wash the disc thoroughly with it. Rinse with clean, tepid water and dry with a clean piece of flannel or other fabric. Then treat a vinyl (but not a shellac) record as usual with an anti-static liquid such as Clendisc or dilute ethylene glycol; and play through the disc several times with a Dust-Bug before allowing a hard stylus to touch the surface.

VIII

AMPLIFIERS AND CONTROL UNITS

8.1 Progress in Amplifier Design

Such progress has been made in the design of valve amplifiers since 1934 that they may now be said to be the least imperfect part of the reproducing chain. So far as frequency response is concerned, there is no difficulty in obtaining uniformity from 2 to 100,000 c/s or higher, and amplitude and non-linear distortion may be kept to quite small proportions, a total of 0·1 per cent between 30 and 20,000 c/s being easily realizable. It is only in the past few years, however, that these standards have been consistently achieved in commercial production. Indeed such a standard, though common enough in the laboratory, was hardly considered commercially feasible in the days before Mr H. J. Leak began to produce his 'Point One amplifiers' in 1945.

8.2 Functions of Amplifier

The function of the amplifier is to produce a power output to drive a loud-speaker system. To do that it must amplify the tiny voltages that are fed to its input from the pickup or other source; apply corrections to them to compensate for the recording characteristics and the pickup characteristics; provide facilities for control of volume, for emphasis or attenuation of bass or of treble or (sometimes) of middle register in any desired way; and use the voltages so obtained, amplified or otherwise dealt with to give the required power output. There are thus four distinct parts of the amplifier system: the control unit, the preliminary amplifier, the power stage and the 'power pack' which converts the electric power taken from the mains into the form required for the amplifier proper.

It is usual for the control unit and the preliminary amplifier to be combined on one chassis and the power amplifier and power pack to be on another chassis with a multiple cable connecting the two. But there is no reason other than one of practical convenience why the four units should be disposed in this way; and some well-known designs do in fact have all the units on one chassis. The main advantage of the dual chassis system derives from the fact that the power pack and power amplifier are both apt to be somewhat weighty affairs and to develop a fair amount of heat; it is convenient therefore to have them at the bottom of a cabinet in some position where the ventilation is good. The control unit and pre-amplifier, on the other hand, are quite light affairs and must be disposed in a convenient position for handling the controls. The disadvantage of the dual arrangement is that the necessity for a relatively long connecting cable adds its own problems to the design so as to avoid the risk of instability and high note loss; and of course it adds to the cost.

8.3 The Power Pack

The amplifier and control unit call for two sources of electric power: one at a low voltage but relatively high current to heat the filaments of the valves and one at a higher voltage and lower current to operate the electron stream from the cathodes to the anodes of the valves. With modern valves the former can be alternating current (A.C.), the usual voltage being 6·3; the latter must be direct current (D.C.), and the voltage required may be of the order of 60 upwards for the earlier valves and 300–400 for the output valves.

8.31 Mains Transformer

The first stage in the process is the conversion of the A.C. voltage of the mains to the appropriate values. This is done in the mains transformer. The current from the mains passes through the 'primary winding' and induces the required voltage and currents in the 'secondary windings', the two windings being on a bobbin which is linked by a laminated core of magnetic material. This core gets warm in operation and if it is skimped in size may become so hot that the windings of rather fine wire (which has to be used for the high voltages since many turns are required) will burn out. A good mains transformer is therefore both heavy and expensive. The voltages which it delivers are still alternating at the rate (in Great Britain) of 50 c/s which is the mains frequency.

8.32 Rectification and Smoothing

For the H.T. a D.C. voltage is required, so the appropriate output from the transformer is fed to a 'rectifier valve', or to a 'metal rectifier', which only allows current to pass in one direction and thus converts the A.C. into D.C. Even when full-wave rectification is used, there is still a ripple on the D.C. at a frequency double that of the mains supply, and if this is allowed to get into the amplifier system, as it sometimes does through faulty design or breakdown of some component, a hum at a frequency of 100 c/s is set up. This ripple must therefore be filtered or smoothed out. Chokes and condensers are used for this purpose; the former will pass D.C. but offer a high impedance to A.C.; the latter will block D.C. but offer a low impedance to A.C. and thus act as a by-pass to the ripple, and special types of electrolytic condensers have been developed for this purpose.

Nowadays there is no good reason why audible mains hum should be tolerated.

8.4 The Power Amplifier

Strictly speaking the performance of an amplifier cannot be studied without reference to the load into which it is working, and in the past it has been usual to assume this to be a resistance of low value. This does not correspond any too well with the characteristics of any type of loud-speaker, but one must start somewhere and this is the simplest assumption from which progress can be made. Provided we come back later and inquire what differences will be made by the actual departures from that assumption no harm will be done.

8.41 Types of Output

For the present, then, we will take it that from a signal of variable voltage at the input our output has to produce a certain power which will be expended in a device of low resistance and by that means the device will cause sound vibrations to be set up in the air whose wave-form will be an exact copy of the input voltage wave. The output will be in the form of a signal current flowing through that low resistance and our problem is that of providing a current of the proper strength and wave-form to give the required driving power.

The signal current is to be provided by the output stage of the amplifier, and that output stage must therefore present a low impedance to the load. Such an output stage might be obtained by having a lot of so-called 'power valves' connected in parallel but the arrangement would be most uneconomical and would lead to other special problems. The more practical procedure is to have an output stage of one or two such power valves and match the impedances by means of a 'step-down output transformer'.

8.42 Matching Impedances

We have here an example of a general principle in transmission of vibrations, whether electrical or mechanical: for the most effective transmission past any junction the impedance looking forwards must be the same as that looking backwards. If there is a discontinuity there will be reflection of energy and a consequent loss of transmission. If the transmission is from a higher to a lower impedance there will also be some distortion. So in the case of a mis-match it is better to have the lower impedance working at all frequencies into the higher impedance rather than vice versa. In the case of the junction between amplifier and loud-speaker, as we shall see, there is definite advantage, from the point of view of the performance of the loud-speaker, in modifying the output impedance of the amplifier even to the extent of making it appear to the loud-speaker as a short circuit.

8.43 Reversed or Negative Feedback

Fortunately this can be done in a manner which also improves the performance of the amplifier, both as regards frequency response and as regards non-linear distortion. The method was devised by H. S. Black in 1934 and was rapidly developed for high-grade laboratory amplifiers before the war; but its use in commercial amplifiers only dates from the Leak 'Point One' amplifier of 1945.

It is known as the principle of reversed feedback, or, more commonly, 'negative feedback'.[1] By this method a portion of the output voltage at the secondary of the output transformer is fed back to an earlier point in the amplifier where it will tend to cancel the signal. This means of course that within such a feedback loop the amplification will be reduced and a greater signal input will be necessary to give the required output. But that is a small price to pay for the benefits which the method supplies when it is correctly applied, e.g.:

(1) the frequency response and linearity of the amplifier and output transformer are improved;
(2) the response to transients is greatly enhanced;
(3) the output impedance of the amplifier is reduced to a small fraction of what it would be in the absence of feedback;
(4) the performance of the amplifier does not vary so much with changes in supply voltage or random defects.

But note the qualification 'when it is correctly applied'. In order that the required cancellation should take place, the phase of the signal feedback should be opposite to that of the normal signal at the point of connexion; and it should not change substantially with the frequency of the signal. There's the rub. Varying degrees of phase shift do occur from stage to stage within an amplifier, and if it should happen that at some particular frequency the signal feedback was in phase instead of out of phase with the input the result would be a tendency to instability or oscillation at that frequency and this would mar the performance at other frequencies as well.

8.44 Phase Shift

So means have to be devised of minimizing this variation of phase shift within the amplifier and possibly also of modifying the phases at different frequencies in the feedback circuit so as to obtain the same relation at the point of connexion to the input. When this is done a high proportion of feedback can be provided. If it is not done, even a small amount may lead to instability.

In many of the earlier designs of feedback amplifiers instability

[1] Strictly speaking, this refers only to 'voltage feedback'. It is also possible to have 'current feedback', and for that rather different conditions apply.

did in fact occur at very high and very low frequencies—of the order of 100 kc/s on the one hand and 5–10 c/s on the other.

It will be appreciated from this explanation that, other things being equal, the amount of negative feedback that can be safely applied in an amplifier is one of the criteria of good performance. Fifteen db negative feedback is good; 25 db is better; 30 db is excellent and 40 db is so difficult that only the most meticulous attention to phase shifts in every part of the amplifier will make it possible.

8.45 Output Transformer

It will also be appreciated that though negative feedback, skilfully applied, may improve the characteristics in an indifferent amplifier, it can never of itself make a good amplifier; it pays the greatest dividends when the amplifier is good to start with. In particular, it is important for such an amplifier to have a good output transformer in which the number of turns both in primary and secondary has not been skimped and the core is made of first-class material and is of ample dimensions. It must have a high primary inductance, but not too high primary resistance (hence, not too thin wire), a low leakage and high coupling to the secondary (hence, multiple, interleaved windings). For first-class results a comparatively large and weighty output transformer is a practical necessity. The modern 'C-core' material has effected some reduction in the core size and number of turns required to give the necessary inductance, but even so, one should look with some suspicion at an output transformer even for a nominal 10-watt amplifier if it could be contained in a casing of less than 3 in. cube. For a 25-watt amplifier a 5-in. cube is not unduly large.

Nowadays it is the general practice in quality amplifiers to have an output stage in 'push-pull', i.e. where two valves are operating in a sort of see-saw fashion. There are good technical reasons for this, principally because of the aid which that form of operation gives in securing the desirable qualities in the output transformer. But the addition of feedback can much improve the operation of the single valve pentode output, though it has not yet been widely adopted in small radio receivers and radio-gramophones; probably the fact that it throws away amplification and therefore requires more to start with is responsible.

8.46 Ultra-linear Operation

Until the past two or three years triode output valves were invariably used in quality amplifiers, in spite of the higher efficiency of pentodes, and beam tetrodes. The latter are prone to create third and fifth harmonic distortion and therefore to give a reedy quality to reproduction. The development of negative feedback has altered all that. By a cunning application of feedback over the output stage alone, in addition to a main feedback

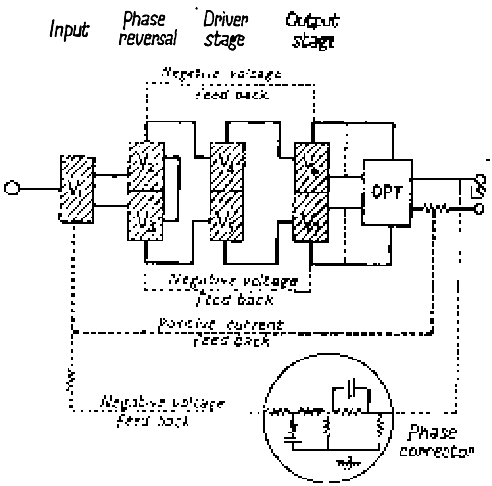


Figure 21

Schematic diagram of Power Amplifier.

loop over the last three stages of the amplifier, it has been found possible to make beam tetrodes behave with the qualities of triodes without sacrifice of all their efficiency as tetrodes. In this way, now known as the 'ultra-linear' system, beam tetrodes can be arranged to give twice the output power and with just as small a percentage distortion as when they are connected as triodes. Some notes on methods of achieving this result are contained in an appendix to this chapter. Here we will only remark that the provision of inner feedback loops within the main loop has been successfully employed in several different ways to improve the phase relations within an amplifier, thereby enabling the designer to increase the amount of feedback from the output transformer in the main loop.

Schematically the majority of designs follow the system illustrated in Fig. 21, though some omit the push-pull driver stage, and others use a single valve as phase-splitter instead of two valves in a phase reversing arrangement. Here the dotted lines indicate feedback paths that have been used. So far very little use seems to have been made of phase correctors, as shown in the circle; perhaps because each one would have to be specially worked out for the particular amplifier design.

8.5 The Control Unit and Pre-amplifier

The function of the control unit is to take the electrical signal from any one of its 'sources' (see Sect. 4.2), correct it for any frequency pre-emphasis or attenuation in the source, amplify the corrected signal as may be desired, and present a signal to the main amplifier in sufficient strength and of suitable quality to enable the latter to operate the loud-speaker system in the desired way. Thus all the modifications of the signal that one may want are made in this unit and not in the main amplifier. This makes it desirable to have separate bass and treble lift and attentuation controls independently of the frequency equalization devices. Steep treble cuts and rumble filters may also be incorporated as well as such devices as 'presence' controls which are supposed to give the illusion of being near to or at a distance from the orchestra.

8.51 Types of Control

There is thus room in the control unit for a wide degree of elaboration. Thus one might have:

(1) Input selector switch to change from one or more pickups, one or more radio tuners, tape-recorder and microphone, together with 'mixing' arrangements so that a commentary could be added to pickup or tape reproduction.
(2) Corrector circuits for different pickups.
(3) Record equalization switches. These might be labelled to suit particular types of recording, e.g. E.M.I., Decca, American Columbia, N.A.B., A.E.S., RCA Orthophonic (old and new!), N.A.R.T.B., R.I.A.A., each with its

separate standard and microgroove settings; or they might be sub-divided for different degrees of 'roll-off' and different 'turn-over' frequencies.

(4) A steep rumble filter, either fixed or variable between 20 and 40 c/s.

(5) A steep treble filter with cut-off beginning at different frequencies of say, 4,000, 5,000, 7,000, 9,000, 10,000, 12,000 c/s and with variable slope.

(6) A separate output for a tape-recorder as well as the output to the main amplifier.

(7) A treble lift and attenuator.

(8) A bass lift and attenuator.

(9) A volume control.

(10) A gain compensator control to depress middle register when volume is low.

(11) A 'presence' lift or drop.

8.52 Minimum Requirements

Each of these has been included in one or more commercial control units. To include all would make the unit look like a miniature switchboard. How to choose from the list is a matter of personal taste; all we can do here is to indicate the considerations that apply to each item, and to give a personal preference. Let us therefore go through the list in order.

(1) An input selector switch is essential and there is no intrinsic difficulty in having as many as ten or a dozen positions. As a minimum one would suggest: pickup, two radio tuners (A.M. and F.M.), tape, microphone. Mixing might well be done, if required, in a separate unit.

(2) Corrector circuits should not be incorporated but provision should be made for plugging in a three-pin screened can between the pickup input and the selector switch (third pin to chassis). This arrangement is far more versatile and positive.

(3) A limited number of record equalizers should be included. It is here that most differences of opinion occur. Some people prefer to have the widest possible range presented to them, so that all the thinking is done in advance. The neatest system for this is that adopted in the Quad II unit.

Here there are four button switches and any one, any two, any three or all four buttons may be depressed together. This gives fifteen possible combinations, any one of which can be picked out from a chart according to the type of record. Others prefer to have the simplest range and to make minor adjustments by means of the bass and treble controls. For this one would need two positions, L.P. and 78, each corresponding to the modern standard recording characteristic. But there is another useful compromise, namely, to add to this minimum the pre-standard extremes, namely, American Columbia L.P. (+16 db pre-emphasis at 10 kc/s) and original 78 (no treble pre-emphasis, but bass attenuation below 300 c/s). In the two latter cases the equalizer control can be combined with the input selector so as to reduce the number of knobs.

(4) A good turntable should not require a variable rumble filter; but the control unit might well have a permanent steep cut-off at 30 c/s.

(5) If pre-war records are to be played a steep cut-off at 3–4 kc/s for acoustic recordings, 5–6 kc/s for early electrics and 10–12 kc/s are useful adjuncts. Otherwise this control could be dispensed with.

(6) The separate tape output could be a jack permanently connected to a high impedance source in the control unit.

(7 & 8) Separate bass and treble controls are always desirable but repeated fiddling with them is to be deprecated.

(9) A volume control is essential.

(10) Can be dispensed with as 7 and 8 give alternatives.

(11) Is of doubtful value.

Variation of frequency response, whether for record equalization or for bass and treble tone controls, is best carried out by special feedback circuits which produce a desired characteristic by cancelling what is not desired. Such circuits usually add to stability and are not prone to introduction of forms of distortion as are some boosting arrangements.

With all this wide variety of possibilities it is not surprising that there is a corresponding range of cost of control units. Some are so simple as to contain only one valve; others are so elaborate as to have as many as five valves though two are twin triodes in a common glass envelope. The principal purpose of increasing the number of valves is not so much to increase the amplification as to separate each type of control from another. In addition a highly desirable refinement is sometimes included by a valve at the end of the unit, connected in what is known as a 'cathode follower' circuit; this gives no amplification but rather throws some away to achieve its purpose, which is to reduce the impedance of the output from the control unit so as to avoid losses in the connexion from that unit to the main amplifier. In these circumstances the distance between the two may, if desired, be as much as 10–20 ft., but even for shorter distances there is much to be said for the arrangement.

8.6 The Menace of the Knobs

The provision of such wide possibilities of control and correction and modification has been one of the fundamental contributions to the art and science of sound reproduction; without them the limitations of the domestic radiogram would have continued to dominate the course of progress. But they can be very much of a menace unless intelligently used. The more experienced one becomes in playing records the more one learns to choose the appropriate settings and then to leave well alone. With modern records, certainly, it should only rarely be necessary to touch the bass, treble and filter controls once the settings to suit loudspeaker and other playing conditions have been decided upon. These should be once for all adjustments.

APPENDIX TO CHAPTER VIII

Fig. 22 (overleaf) Typical Ultra-linear Circuits

(*a*) Basic Circuit with screens fed from Output Transformer Negative Voltage Feedback only.
(*b*) Cathode coupled with Negative Voltage and Positive Current Feedback.
(*c*) Development of circuit at (*a*) above.

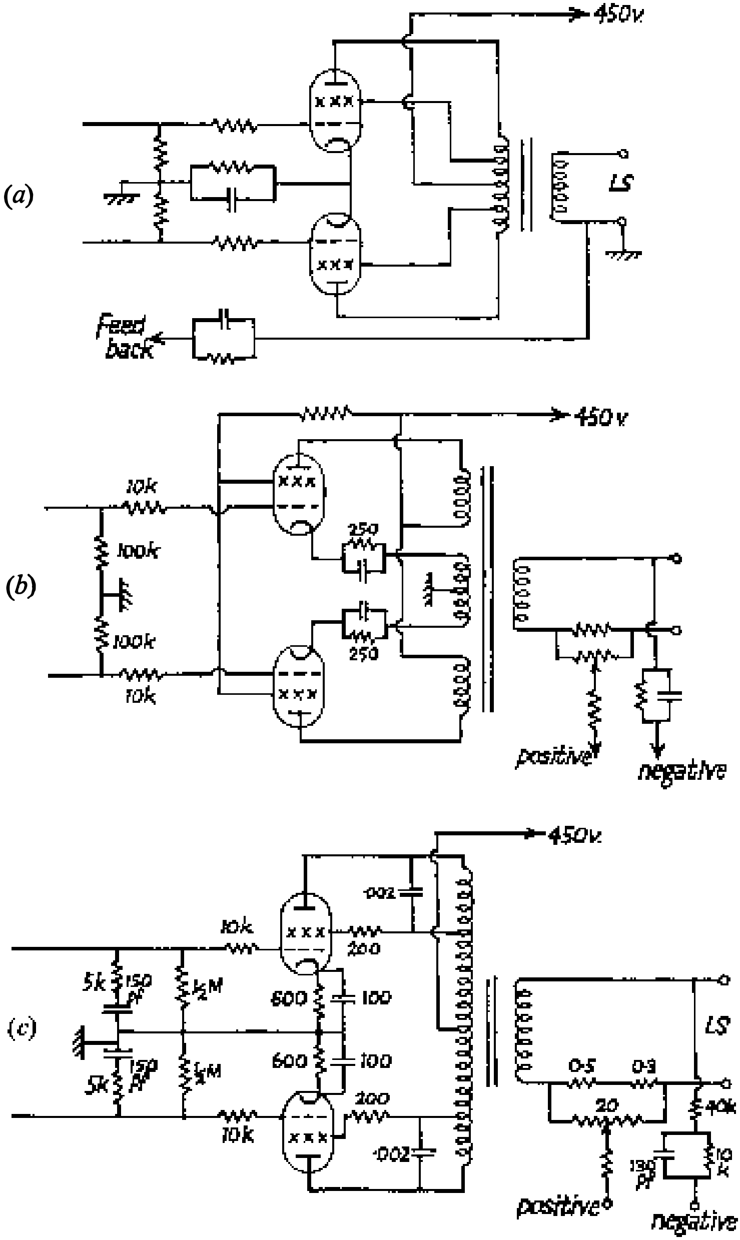

(a)
450v.
LS
Feed back
(b)
450v
10k
100k
250
positive
negative
(c)
450v.
·002
10k
200
5k
150 pF
½M
600
100
0·5
0·3
20
40k
10 k
positive
negative

Figure 22

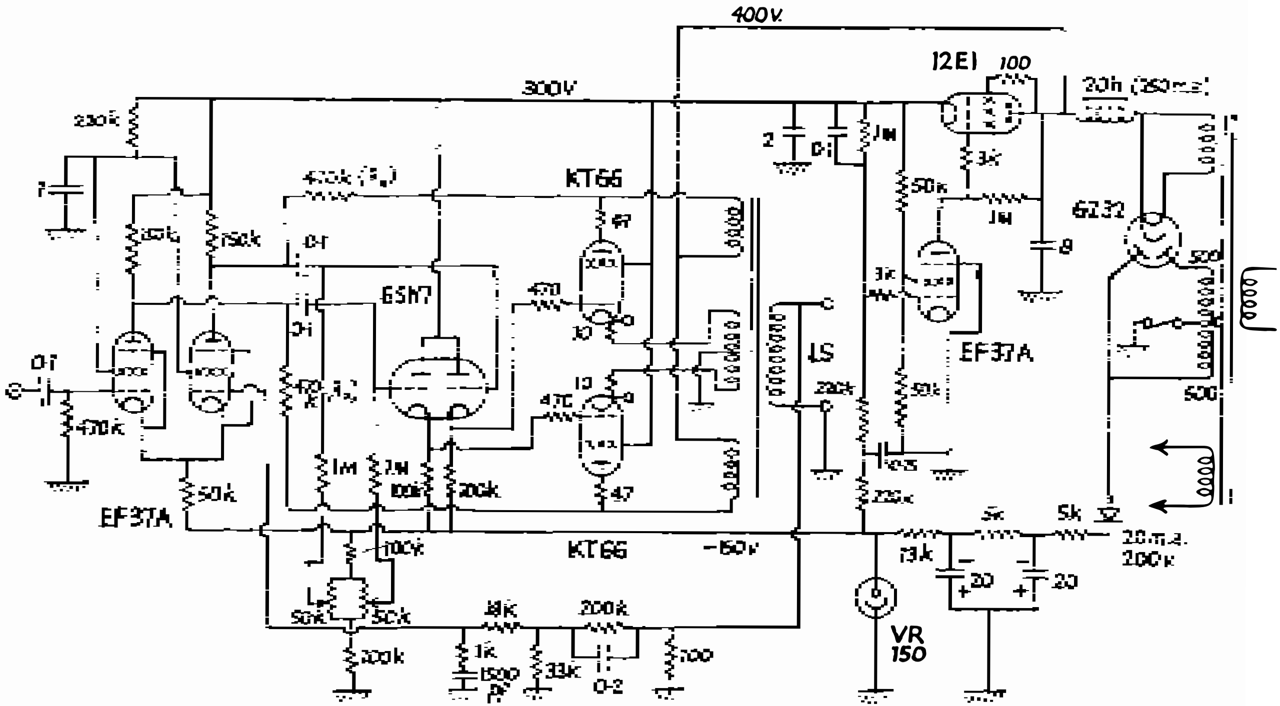


Figure 23

A no compromise Amplifier and Stabilized Power Pack. Ultra-linear, phase corrected, fixed bias, cathode-follower fed.

IX

LOUD-SPEAKERS AND ENCLOSURES

9.1 Theoretical Requirements

A loud-speaker may be regarded as the obverse of a pickup in that it is a transducer which converts electrical vibrations into the mechanical vibrations that create sound. But whereas the pickup is required to transform velocity of motion into electrical voltage, the loud-speaker is required to convert power. It must therefore be considered not only as a mechanical vibrator with an acoustic load upon it but also as a load itself upon the amplifier.

Our theoretical requirements of a loud-speaker may therefore be summarized as follows:

(1) Its electrical impedance looked at from the amplifier output should be as nearly constant as possible for all frequencies within the audible range—say 30–16,000 c/s. This electrical impedance will be determined not only by the electrical elements of the system (resistance, inductance, capacity), but also by the mechanical elements. That this must be so can easily be seen from the fact that (in the usual case) the mechanical motion starts with the motion of a magnetic element (an armature or a coil) in a magnetic field. Any mechanical impedance to motion will react on the motion of the magnetic element and this reaction will be the equivalent of an opposing, or in some circumstances assisting, electromotive force in the electrical driving circuit. The acoustical and mechanical vibrating elements (the acoustic and mechanical resistances in the form of damping, together with the masses and the compliances in the system) can therefore be translated into an equivalent electrical circuit into which the amplifier output is working. As is

usual in all such cases mass is equivalent to inductance, compliance to capacitance, and resistance to resistance. Velocity of motion corresponds to current and force to voltage (or electromotive force—e.m.f.).[1]

(2) The mechanical system must be capable of inducing acoustic power in the air. This acoustic power will be in the form of acoustic vibrations which should follow exactly, both in wave-form and in relative amplitude, the electrical vibrations at the output of the amplifier.

(3) We should arrange therefore for the equivalent electrical circuit to have a uniform frequency response throughout the audible range, without amplitude (or non-linear) distortion.

(4) To secure the necessary energy transfer to the air, the mechanical system must have an adequate acoustic load: pushing against nothing transfers no energy. With one exception to be noticed later, the transfer is made through some form of vibrating diaphragm or flat piston. It is found that to secure the required load two systems are possible: the diaphragm can exert a relatively small pressure over a large area or it can exert a larger pressure over a smaller area, the transfer to small pressure over a larger area being secured by loading the diaphragm with a horn of some kind. This horn is thus the acoustic equivalent of an electrical transformer.

9.2 Horn Types

The early loud-speakers consisted, in fact, of telephone earpieces loaded by a small horn. Even today public address systems may have loud-speakers using horn loading, and loud-speakers used in cinemas and in some domestic installations are based on the same principle. Great improvements have, of course, been made in the meantime both in the design of the driving unit and in that of the horn and various ingenious methods of folding horns to give the required characteristics have been devised. At first sight it would seem to be inevitable that the horn will have resonance effects of its own to be added to those of the driving unit, and certainly in the case of folded horns that is a problem that cannot be ignored. For a straight horn, however, there may be a long range of frequency

[1] See footnote to Sect. 5.41.

within which the horn acts as a purely resistive load on the driving unit and thus serves as an effective damping element on the resonances of the unit. Since this resistive load is entirely an acoustic resistance the efficiency of the system as a whole is relatively high. As much as 40 per cent of the electrical input energy may be converted into acoustic output. The range within which this highly desirable state of affairs exists is determined by the length of the horn and the size of its open end. If we wish to go very low in the frequency scale we must have a very long horn with a very large opening. It is this fact more than any other that has limited the use of horns in domestic loud-speaker systems. But an enthusiast in London has been known to erect a large horn, pagoda fashion, above the ceiling of a single-storied music room and the quality of reproduction was really 'out of this world' (see *The Gramophone*, July 1929). More recently another one, this time in California, persuaded his wife to go on a three weeks' holiday to her mother's and then proceeded to take out part of the end wall of their lounge to serve as the opening of a huge concrete horn which he built out into the garden with its driving unit in an underground chamber (*Audio Engineering*, July 1954). That is perfectionist indeed!

9.21 Direct Radiators

The most common domestic arrangement, however, has been the 'direct radiator' in the form of a cone (sometimes flared), flexibly mounted at its large end, and driven by a coil fixed to its smaller end and disposed in an annular gap in a magnet. This was the drive developed by Rice and Kellogg in 1925/6 but it had been patented by Siemens as long ago as 1877 (British Patent 4685). It has been so successful as to hold the field, quite undisputed, for the past thirty years. During that time permanent magnets have superseded the electromagnets that were used in the Rice-Kellogg and much development work has been done on the cone material, the 'surround' material (at the periphery) and on the arrangements for centring the coil in the magnetic gap. An analysis of the functions of the various elements has been carried out in great detail (see, for example, McLachlan & Yorke, *Journal*, B.S.R.A., May 1952); but in form the speaker has remained unaltered (Fig. 24).

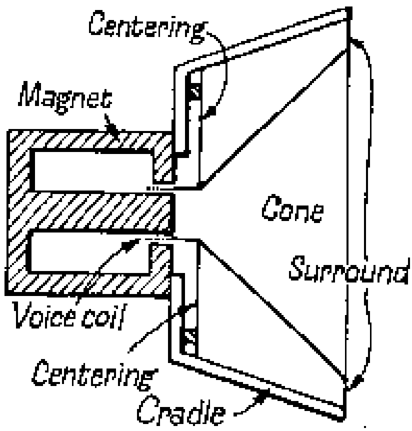


Figure 24
Moving Coil Loud-speaker Unit.

9.22 Diaphragm Resonances
It is not, and never can be, a perfect direct radiator unit. That is largely because the drive is not evenly distributed over the whole of the conical diaphragm but is concentrated round an annulus. The system is therefore essentially a resonant system and the requirements at the two ends of the scale are not really compatible with each other. At the low-frequency end large area (and therefore large mass) is needed; at the high-frequency end very low mass is required. Moreover, the cone itself breaks up into multiple vibrating areas so that one part can be moving in opposite phase to another at some frequencies and interference or cancellation of output occurs. Peaks in the response curve are thus inevitable. Again, the constraints that are applied to the motion by the surround, the coil centring and even the magnetic field give rise to a certain amount of non-linearity, and thus to harmonic and intermodulation distortion.

9.23 Phase Effects
All these are disabilities that can be minimized by suitable design as we shall see. But there is one fundamental problem which does not depend on the design, namely, the fact that the back of the

cone produces air waves behind the speaker opposite in phase from those produced in front: as the front is pushing and compressing the air, the back is sucking and rarefying it. So opposing trains of waves are set up and, depending on the wave-lengths involved and the distances round the unit from back to front, these two trains may add or cancel out, either wholly or partially. Means of separating the back from the front have therefore to be devised if notes of wave-length comparable to the distances involved are to be reproduced properly; and remember the wave-length of middle C (256 c/s) is 4 ft. 3 in. This is the 'baffle' or 'enclosure' problem which will be dealt with later in this chapter.

9.3 Design of Driving Units

First of all, however, we must consider the most important considerations that have been found to apply to the design of the driving unit.

9.31 Magnet

The higher the flux across the annular gap the better. Magnet material has been improved enormously during the past ten years, first by the invention of Alnico and latterly by the improved Ticonal and Alcomax alloys. These are alloys of iron with proportions of aluminium (8 per cent), nickel (14 per cent) and cobalt (24 per cent), but in the case of Ticonal and Alcomax the alloy is specially heat-treated in a magnetic field during manufacture. They are more than twenty times as efficient, magnetically, as the magnetic materials of twenty years ago.

Even so, increase of flux density beyond a certain value is more and more expensive. Doubling the number of lines across a given size of gap may increase the magnet cost by eight times.

Remember, too, that the diameter of the centre pole will determine what is the limit of flux density before magnetic saturation sets in, and that for a given flux density the *total* flux increases directly with this diameter.

It has also been found that the concentration of flux in the gap can be increased to a substantial degree by making the pole pieces of special material such as 'Permandure', or suitably shaped, e.g. a taper of 74° included angle is better than a square end.

9.32 Coil Size

So far as the diameter of the coil is concerned there is a competition between mass and electromagnetic efficiency. A 1-in. coil is half as heavy as a 2-in. coil for the same number of turns of the same gauge of wire but cuts fewer lines of force. Mass does not matter for low notes but it is important for the highs.

Length of coil (i.e. into the gap) is important: at all parts of its motion it should cut the same number of lines of force. So it should either be shorter or longer than the depth of the gap. In view of the mass relationships it is usually considered that for high notes the shorter coil is best; for lows, the longer.

Similarly, for high note reproduction a light coil is to be aimed at. For this reason aluminium wire is sometimes used, or better still, aluminium ribbon wound on edge so that no coil former is required. For a single-layer coil the ribbon may be cut in a lathe in the form of a helix from a hollow tube, coated with insulating material and then compressed back into tube form again.

9.33 Cone Shape and Size

The possible differences here are legion: wide-angled cones, narrow-angled cones, flared cones; outside diameter from 2 to 15 in.; radial or concentric corrugations.

Generally, of course, large cones favour bass notes and smaller cones the higher frequencies. Each cone has a fundamental resonance and a series of higher modes of vibration. Up to the fundamental the effect on the air as the cone moves is as though it were a piston of smaller mass and velocity. If the edge and centring constraints are arranged to give more of a plunger motion, the effective piston area is greater.

This also remains substantially true for vibrations up to nearly double the fundamental frequency, but as the second natural mode of vibration is approached the effect becomes much more complicated. Then wave motion is set up in the cone itself, the waves travelling outwards to the edge and then being partially reflected back again. The motion of an outer annulus of the cone may be completely out of phase with one nearer the coil and may thus be causing a rarefaction of air at the instant when the central portion is causing a compression.

Over the range where the cone moves as a piston the combination of its mass and that of the coil and former with the compliance of the surround will give a resonance at an even lower frequency. There is advantage in making this very low in the scale. This can be done by increasing either mass or compliance or both, but increase of compliance is always the best provided that motion in a straight line parallel to the magnetic gap is ensured; side to side flopping about is always bad.

A curved-sided cone extends the frequency range over which the cone moves as a piston but its effective piston area is less, and it is therefore less efficient for the lowest notes. The same sort of effect can be obtained by tapering the stiffness of the cone material from inside to outer rim, so that the edge is more compliant; this of course can be done by tapering the thickness of the material.

Corrugations or radial pleats may be pressed in the cone either to add rigidity and so raise the fundamental natural frequency up to which the cone acts as a piston or on the other hand partially to subdue one or more of the higher modes of diaphragm vibration. Similarly, parts of the cone may be specially stiffened by bakelizing. But procedures of this sort should only be adopted with the greatest circumspection. For corrugations, etc., introduce discontinuities and discontinuities are apt to lead to harmonic and intermodulation distortion. From this point of view a tapered transmission line is always advantageous.

The efficiency of the cone as a radiator of low notes increases of course with size, owing to increase of piston area. Thus the effective piston area of an 8-in. cone is about 28 sq. in., that for a 10-in. cone is 50 sq. in. and that for a 12-in. unit is 78 sq. in.

At one time hard, even bakelized, material was used for the cone, under the notion that stiffness was the main virtue to be aimed at. But that conception has now developed into two opposing points of view. In the one an attempt has been made to cover the whole audible range by the use of an 8-in. cone made of aluminium alloy and with peculiar local deformations to control frequency response and subdue intermodulation. By the other school, a softer self-damping material is favoured in large units designed to cover a range of low notes (onomatopoeically termed 'woofers') whilst stiff material used in small diameter units is preferred to cover the higher range of notes (again, somewhat aptly termed 'tweeters'). Some designers carry this idea even further and cover the middle register with units which they call 'squawkers'. As in the Goodmans' Midax, horn loading is an advantage for such units.

9.34 Multiple Cones

The direction of the frequency traffic between the separate units may be carried out either mechanically or in an electrical cross-over system. According to the first, a small bakelized cone of more acute angle is fixed to the coil former inside the larger cone, and

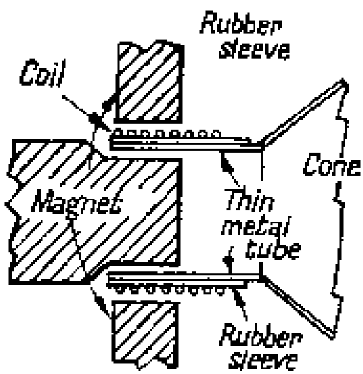


Figure 25
Barker Duode.

since it is intended only for high notes it can have a free edge. This system certainly strengthens the high-note response very considerably, but unless special care is taken in the design the high notes may be produced with slight differences of phase in the two cones (as well as local resonances in the small cone), and this seems, for example, to give a 'comb-and-paper' quality to the reproduction of strings. The critical features of this design seem to be the self-damping qualities of the large cone and the compliances at the joins of each cone to the coil former.

Another type of mechanical cross-over unit is to be found in the Barker Duode (Fig. 25). Here the former on which the coil is wound is a thin tube of aluminium and is separated from the coil by a thin, compliant sheath of rubber. At low frequencies the coil, sheath and former move as a whole to drive the cone; at higher frequencies the former begins to act as a short circuited secondary winding to the coil, thereby effectively introducing electrical damping, and ultimately the former alone drives the cone at high frequencies. The system thus has a differential mass according to the frequency. The characteristic feature of this unit is a particularly smooth response over the middle frequency range.

The electrical cross-over system has been so widely developed that it calls for a special section of this chapter.

9.35 Centring and Edge Suspension

The magnet gap in which the coil moves is made small in order to increase the magnetic efficiency. Clearances are therefore minute. Hence some centring device is essential to prevent the coil from fouling the magnet.

This centring device should be highly compliant along the axis and stiff in the plane at right angles to the axis. Its mass should be small and yet its self-resonance should be very low. Any restraint which it places on the axial motion of the coil should be constant over a large displacement.

At one time small 'spiders' inside the coil former were used for the purpose, but they were hardly compliant enough and their axial constraint was certainly not linear over large displacements. Nowadays large spiders or flexibly corrugated diaphragms to the rear of the cone are generally used. These have proved to be much more satisfactory but there are still too many badly designed spiders in use that produce non-linear distortion. The method preferred by the author is a string suspension arrangement supported from three screwed eyelets from the chassis, as shown in Fig. 26. This is adjustable by the screwed eyelets, is non-resonant, has a large linear axial throw, and the constraint it exercises on the coil former is applied tangentially and therefore does not tend to distort the former. Three-point suspension is used because only three points are needed to determine a plane; it is of course important that the plane should be at right angles to the axis so that there should be no twisting constraint; it is also highly desirable that the centre of gravity of the cone and coil should be in that plane. When these details are attended to no additional constraints are needed from the surround supporting the periphery of the cone, and this surround can be made so highly compliant as to be virtually a free edge for axial motion but an absorptive element for wave-motion in the material of the cone. In other words, the 'surround resonance', which is compounded of the mass of the cone and coil and the compliance of the surround and centring device, can easily be placed as low as 5 c/s, if desired. The value of this will be seen later when we come to consider the question of enclosures. The one troublesome feature of the arrangement is that string is apt to stretch when

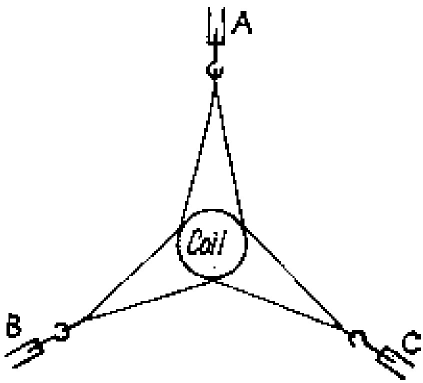


Figure 26

Adjustable String Suspension

Hooks at A, B, C are adjustable radially through sockets in cradle.

subjected to oscillating strains. This has not been found to be a serious matter if waxed-linen thread is used.

There are two types of surround in general use. The first is merely a system of soft corrugations in the cone material. This can be made sufficiently compliant to enable the L.F. resonance to be placed as low as 30 c/s. But some examples of this type are deliberately made rather stiff so as to give the effect of good bass power through a resonance at 70 c/s or above. Many people prefer to have a cloth or thin Linatex surround so as to have a highly compliant edge with absorption characteristics. For low-frequency units (woofers) that is certainly to be preferred. It is indeed possible in this way to obtain an excellent low-frequency response from an 8-in. unit, though of course its power handling capacity will be smaller than that of a 12- or 15-in. unit on account of its smaller piston area. The one disadvantage of a cloth surround is that it is rather more transparent to sound than the cone material. Treatment of the cloth with some form of gel (of a stable thinness) is therefore desirable.

In two modern loud-speaker units (Axiom 80 and Sound Sales) a free, periphery-centring device is employed so that there shall be a very large edge compliance. It is noteworthy that these two units have both proved to be highly successful with a long and smooth frequency range.

9.4 Multiple Speakers

The achievement of a long-frequency range with comparative freedom from harmonic and intermodulation distortion is, however, a matter of considerable difficulty notwithstanding all the mechanical ingenuity that has been lavished upon it. It is generally agreed to be preferable in practice to aim at limited ranges in two or more units and to station a policeman between the amplifier and the various units to direct the signal traffic between them. That policeman is known as a *cross-over unit*, and fortunately it can be designed so as to ensure free flow in each direction so that the impedance looking each way is as it should be.

9.41 Electrical Cross-over Units

In the appendix to this chapter, we illustrate some types of cross-over unit with values of components required for particular cases. There are four simple examples: quarter-section and half-section types with series and parallel connexions under each type. All can be satisfactorily used but on the whole the author recommends the half-section type and has a slight preference for the parallel connexion as leading to the most stable conditions in practical applications.

What is not usually remembered when a cross-over unit is installed is that there is a phase shift between the two sides and that this ought to be allowed for in the mounting, since otherwise there may be a partial cancellation of the response near the cross-over frequency. This, of course, may, or may not, be an advantage according to the characteristics of the speakers, and no hard and fast recommendation can be made other than that the various possibilities should be tried out in each particular case. Always the sensitive ear is the final arbiter.

Another point that has to be watched is the relative sensitivity of the two speaker units. If they are not balanced there may be a lifting or lowering of the general level of response above or below the cross-over point. It is therefore a good plan to connect a variable-level control across the input to that unit which is the more sensitive; if both units are moving coil cone speakers, that unit is likely to be the treble unit, but if the treble unit is a 'ribbon tweeter' (see Sect. 10.3) the control should be placed across the bass unit.

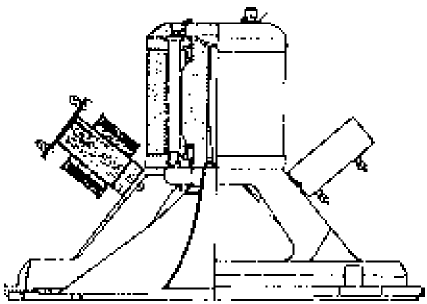


Figure 27(a)
Horn Loading of H.F. Unit. W.B. Dual Concentric.

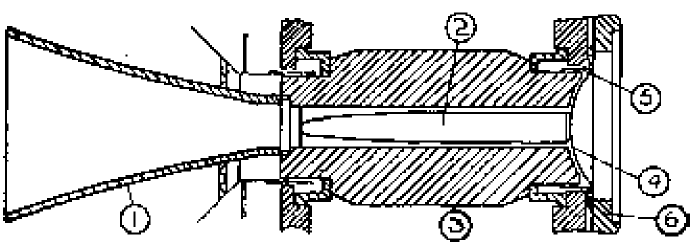


Figure 27(b)
Enlarged Section of High Frequency Unit.

(1) Horn; (2) Phase equalizer; (3) Magnet Centre Pole; (4) Diaphragm; (5) Speech Coil; (6) Clamp Ring.

9.42 Spacing of Speaker Units

Again, the relative placing of the two units calls for some thought. Some people prefer to have them co-axial so that all the sound appears to originate from the same spot (or open window, as the protagonists usually say). That system, however, can lead to untoward effects unless the H.F. unit is acoustically isolated in some way from the L.F. unit; this isolation, for example, might be a horn to load the unit (Fig. 27). Some, therefore, prefer to space the H.F. unit a little way from the L.F. unit and even to put baffles of various kinds in between. The ear is very accommodating and hardly notices a distance of a foot or so. Others, again, try to obtain a dispersion effect by separating the H.F. units by quite a large distance from the L.F. units. This gives a sort of full-bodied effect which is different from the binaural or stereophonic effects. Whether one likes it or not is a matter of taste. In the present author's experience it is much more likely to please if there is a substantial frequency overlap between the two units, e.g. if one reproduces up to, say, 5,000 c/s and the other from 500 c/s upwards.

9.43 More and More Speakers

Sometimes, in the expectation of achieving even greater smoothness of response and freedom from distortion, three or four or even more units may be used, each with its own limited range of frequency. Thus in the case just mentioned one might have a woofer going from 30 to 200 c/s with a squawker going from 200 to 1,000 c/s at one corner of the room, and a squawker going from 500 to 3,000 c/s with a tweeter dealing with the range above 3,000 c/s in another corner. A three-unit system disposed in the corner of a room is quite a common and successful arrangement. The possible combinations are legion.

Mr Briggs joyfully recounted to the author after one of his visits to America that at the New York Audio Fair an enthusiast had come to him with a photograph of his domestic loud-speaker installation: it covered one end of the room and comprised no fewer than twenty-one different units! (Plate XII.) That is one way of distributing the driving force over a large area; and it has other virtues, too, in that different units have their resonance points at different parts of the scale and connecting two units in parallel may improve the impedance load quite considerably. Series connexions, however, may intensify resonance, and when a large number of units is used a series-parallel arrangement is necessary to keep the resultant impedance within reasonable limits.

A multiple speaker system of this kind, besides being unwieldy, is at best a confession of failure. In so far as it succeeds, it does so by virtue of its inefficiency, each unit being considerably under-run for the production of a given volume of sound. In any case, it is generally better to limit the signal fed to a speaker to its most effective frequency range than to have all units connected (whether in series or parallel) so as to receive the full range.

9.44 Multiple Channel Systems

We have already described how such a sub-division can be effected by means of cross-over units. But these units contain inductances and capacitances and there is a body of opinion which disapproves of the addition of non-resistive elements to the output load of an amplifier. In such circumstances, it is argued, much of the value of a low-output impedance and a high-damping factor is lost.

According to this opinion it is a better practice to make the division into separate channels at an earlier point in the amplifier and at high impedance, and to have independent output stages matched to the particular range of frequency covered by the associated loud-speaker. In this way more accurate matching can be secured and the performance of each loud-speaker is improved.

In the Sound Sales Tri-Channel system separate amplifiers are used to feed three loud-speaker units. The bass amplifiers has an output of 22 watts, the middle range amplifier an output of 6 watts and the treble amplifier an output of 1 watt only. The tone control unit couples the three channels together electronically and in such a manner that the output of each channel can be varied in relation to its neighbour. There are thus bass, normal and treble controls and a master volume control which simultaneously varies from zero to maximum the entire output of the whole system. The balancing between the three channels has been very skilfully carried out so that there shall be no question of the response at various parts of the scale being increased or decreased by sudden steps.

The speaker units have also been effectively chosen for their particular purpose. The bass unit combines two speakers linked by an air column, and is designed to handle frequencies from

20 to 250 c/s. The middle unit can handle from about 50 up to 10,000 c/s. The treble unit is an electrostatic speaker shaped as a diffuser with a range from 5,000 to 25,000 c/s. All three units are disposed in a corner cabinet 43 in. wide, 25 in. deep and 31 in. high.

9.45 Lines of Progress

Recent developments of 'ribbon' and 'electrostatic' speakers, about which we shall have a good deal to say later, seem to have solved the problems of the treble range. It is indeed possible that the electrostatic type may even expel the moving coil speaker from its present domination at the lower end of the scale. At the time these notes are being written that is a matter of doubt and controversy; but if things do turn out that way then the problems relating to enclosures for loud-speakers may also be transformed, for these have special reference to the lower part of the scale; and in addition the practice of having three or more channels within the amplifier system may become more widespread.

9.5 Enclosures

If our loud-speaker were in the form of a pulsating sphere so that the air all round was being compressed at the same instant and then rarefied at the next instant, spherical sound waves would be radiated and no enclosure would be required.

But when we have a diaphragm moving to and fro, the air on one side is compressed at the instant when that on the other is being rarefied and the waves from the two sides are completely out of phase (they are sometimes said to be 180° out of phase). When the distance from back to front is a quarter of a wave-length the two waves will tend to cancel out; whilst at half a wave-length and a full wave-length they will reinforce. It is therefore necessary to separate the back waves from the front waves in some way. This can be done in three ways: complete physical separation, absorption of the back waves, or leading the back waves to the front in some sort of conduit so as to change their phase.

The only completely successful method is the first, but the second and third, even though only partially effective, have considerable advantages in domestic circumstances.

9.51 Infinite Baffles

Complete separation is secured by mounting the loud-speaker unit in a baffle whose dimensions are larger than the largest wave-length we want to reproduce. But the wave-length of 110 c/s is 10 ft., so trouble at and below that frequency must be expected if the baffle is less than 5–6 ft. across. A simple, plane baffle is thus no solution and to realize our purpose fully we must mount our unit in a wall or door between two rooms.

Ideally both rooms should be large and of unequal dimensions, but the size is not so important if they both contain absorbent material. The trouble usually is that sound is radiated in both rooms and one does not always want it in two rooms at the same time. If you happen to have a fairly large cloakroom or work-room or garage at the back of one of the walls of your lounge, then half your problem is solved. The rest follows if you can dispose your curtains and soft furniture in the lounge so that there is no strong reflection from the opposite wall. The photographs in Plate XII show an arrangement adopted by the author. Here the thickness of the wall between the two rooms was 17 in., so it was thought advisable to have an open-backed fibre-board box in the aperture between the two rooms. The box had a double bottom, double top and double side walls with slag wool lightly packed in between and the side walls sloped from back to front so as to give a wider opening at the back. Speaker units were mounted inside the box and on the fibre-board at the front, and the whole box slid into the wall aperture up against the decorative fret at the front.

This system has been in use for over twenty years and has proved completely successful. It is hardly suitable, however, for any but thick walls. Where the wall is only one brick (4½ in.) or even two bricks thick it would be better to use a different arrangement. The wall aperture should be of suitable size to accommodate all the units that are to be used, or are likely to be used. Thus, if there are to be three units, it might be 20 in. across by 30 in. high, at a distance of, say, 4 ft. from the ground. The loud-speaker units should be mounted on a thick baffle (e.g. of wood backed by fibre-board, or of Weyroc) fitting into this aperture with a moulding to close the gap all round. Between each unit a thick shelf should be fitted projecting to the rear. Thus there would be a horizontal shelf above the 'woofer' separating it from a compartment above divided vertically into a 'squawker' box and a 'tweeter' chamber. If desired the baffle and shelves could be cast in concrete with suitable holes to take small sub-baffles. In this way the unwanted effects of baffle resonance could be minimized. Suitable units for this scheme would be a 12- or 15-in. woofer with cloth surround, a 6- or 8-in. squawker again with cloth surround and a horn-loaded tweeter (which might be of the ribbon type) with cross-over at 400 c/s between the first two and 3,000 c/s between the second two. For decorative effect an open-weave tapestry could be hung over either back or front or both.

Whenever wall-mounting is used, a seeming reduction of bass power must be expected if full advantage of the arrangement is to be obtained. For not only are fortuitous (or infortuitous) peaks due to reinforcement of back and front waves avoided, thereby seeming to diminish the power at those frequencies; but other peaks due to self-resonance in the speaker units must also be either damped out or placed so low in the scale as to be ineffective. The damping is done partly by having magnet systems of high flux density and partly by having a high damping factor in the amplifier output. Apart from that, however, it is desirable to have the L.F. resonance of the woofer quite low in the scale (but not coinciding with any motor rumble). When these points are all attended to there is an 'attack', a definition in bass notes, a freedom from hang-over and an illusion of listening to a performance through a large doorway at the end of a concert hall, such as cannot in the author's experience be achieved by any other domestic system. Some critics have complained that this is only achieved at the expense of efficiency, particularly in the bass. But this is a matter that can easily be compensated by adjustment in the amplifier control unit, provided that the amplifier has adequate bass power (which largely depends on the size and design of the output transformer).

9.52 Long-Pipe Loading

Another way of achieving the same result, with some added efficiency in the bass, would be to mount the unit in a long pipe.

Almost every house contains a suitable pipe for the purpose were the trouble taken to adapt it. Most chimney stacks include flues for both ground floor and upper rooms but the latter are rarely used save as ventilators. If one of them were closed and the flue continued to the ground-floor ceiling, the loud-speaker could be mounted in it at an angle at ceiling height. The flue pipe would have resonances at a frequency corresponding to a wave-length of four times its length and at the odd harmonics of that frequency. Those harmonics, however, would be of diminishing strength and would be largely nullified by the usual irregular construction of the inside of the flue and the net result would be a fairly uniform loading on the back of the cone down to the very low frequency. If the flue were 10 ft. long (and it could easily be much longer) the resonances would be in the region 27, 80, 135 c/s, etc.

9.53 Short Pipes

A comparable system has been tried with shorter pipes standing upright on the floor of a room with the loud-speaker mounted on the upper face and directed upwards, either vertically or at an angle. But in this case it is better to treat the pipe as a vented enclosure (Sect. 9.6) with an open port at the bottom, or as an 'acoustic labyrinth'. In the latter case the length is arranged to be a quarter wave-length at a frequency a little way below the surround frequency of the unit. The energy radiated from the open end of the pipe is then approximately in phase with the radiation from the front of the unit and reinforcement occurs. Below the resonant frequency the two radiations are out of phase and partial cancellation occurs so that the response falls off rather sharply. Above the resonant frequency there would also be cancellation and cross resonances. To avoid or minimize these the pipe is lagged inside so as to absorb the radiation from the back of the cone at these higher frequencies.

A clever variant of this system devised by Voigt is to close the top of the pipe and mount the speaker unit one-third of the way along the pipe. This effectively suppresses the third harmonic. In this case, absorption from internal lagging can be very much lighter and is often omitted altogether.

9.54 Closed Box

But why should such absorption be necessary in any case? Why not just have a heavy closed box? Well there would be no objection at all if the box were big enough—as big as a room, for example. For then we should have our infinite baffle case over again, and the reaction on the back of the speaker unit would be small. In the ordinary case, however, the effect is very much as if an additional mass were added to the cone and its edge surround were made stiffer: it is like pushing against an elastic air cushion. This means, of course, that the L.F. resonance is lifted to a higher frequency and becomes more prominent. In a small box the lift may be as much as three octaves! In the radiogram cabinet of pre-war days a lift of an octave was not uncommon and the resulting effect was the bass thump between 100 and 150 c/s which gave rise to the advertising slogan: 'Listen to the Bass.'

Obviously, however, if the initial surround resonance is low enough the raising by even an octave may not be so objectionable. That would be the case, for example, if the initial resonance were in the region 15–20 c/s. But to the purist a sharp resonance even so low as 30 c/s is not a desirable feature for it can give rise to strong intermodulation effects from notes higher in the scale; and in any case the effect of the elastic control on the cone resonances above the surround resonance cannot be ignored. In all such cases it is well not only to introduce internal absorption but even to release the elastic pressure by spacing the unit away from the front of the box a little so as to cause a leak.

9.55 Internal Absorption

Several attempts have been made to secure complete absorption of the sound waves from the back of the speaker unit by various forms of lagging. None of them has been completely successful, for the effectiveness of absorbing materials falls off very sharply as we go down the scale, largely because of the longer wavelengths. With most of the usual lagging arrangements such as lining with felt or with bags of slag wool very little is achieved below about 100 c/s. Two systems have had a certain amount of success. In the one, the space in the cabinet behind the speaker unit is divided up into pockets each of which is loosely filled with light flock. The effectiveness of this depends almost entirely on the flock being set into agitation by the sound waves, so absorbing energy. If, however, the flock settles down into denser units the effectiveness is reduced; and in any case comparatively large, and rather cumbersome, cabinets seem to be necessary to secure sufficient absorption in the 50 c/s region. The other system uses baffling partitions of absorbent material with air spaces in between. Here again the efficiency falls off rapidly below 100 c/s. One cannot help but feel, however, that some development of this absorption idea, e.g. by following up Lord Rayleigh's demonstration of the damping efficiency of small tubes or channels (as in a haystack) should be possible. Some progress has been made in this way by the author in the use of layers of papier mâché egg-trays which can be so disposed as to form comparatively efficient damping channels.

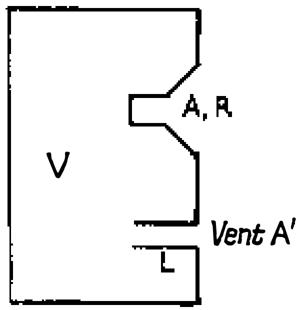


Figure 28
Vented Enclosure.

9.6 Vented Enclosures

A more usual way of avoiding the untoward effects of a closed cabinet has been to give it a vent. Presumably this was first thought of as a means of releasing the elastic air-pressure; but it was soon seen to have merits of its own. An enclosed cabinet with a small vent is in fact a type of resonator which was used by Helmholtz in his studies of the properties of sound. The frequency of resonance depends on the volume of the enclosure, the area of the vent and the length of the neck at the vent (Fig. 28). This neck may be either internal or external.

9.61 Reaction of Enclosure on Cone

Now when a speaker unit is mounted in such an enclosure the resonance of the enclosed air reacts on the cone and if that resonance is arranged to be close to that of the cone, the air presents a high impedance to the motion of the cone at that frequency, which otherwise would be the place where motion of the cone is easiest. The result is that the cone finds it easier to move at frequencies on either side of the surround resonance and instead of a single and rather large hump in the response curve at that frequency we get smaller ones on either side. If the matching of the two resonances is close, these two humps should be equal and symmetrical. If the air resonance is below the cone resonance then the lower of the two humps will be increased and the upper one reduced; and if the speaker magnet has a high flux density and the amplifier a good damping factor (through feed-back) then the upper hump may be flattened out.

9.62 Design Formulae

The air resonance of an enclosure can be calculated (approximately) by a formula due to Lord Rayleigh. The quantities we are concerned with are:

C=velocity of sound
f c/s=frequency of resonance
R in.=piston radius of cone
A sq. in. =piston area of cone ($=\pi R^2$)
A^1 sq. in.=area of vent
L in.=length of vent
V cu. in. =volume of enclosure, exclusive of neck.

Rayleigh's formula is:

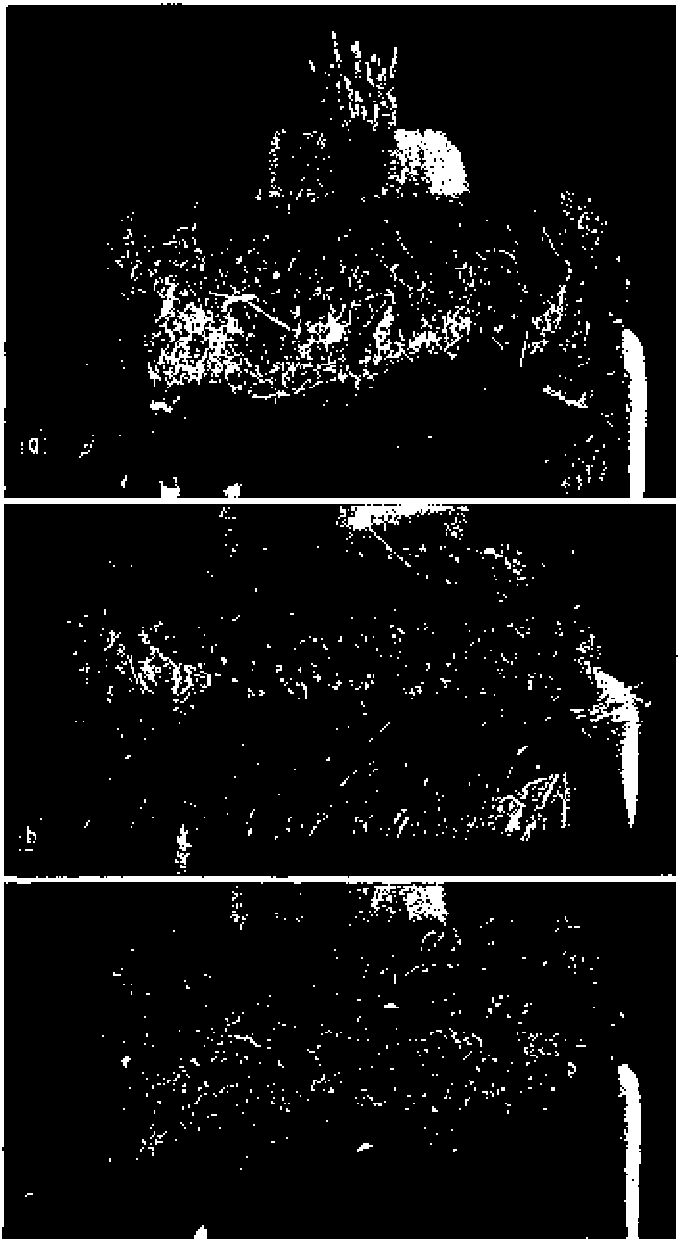
$$f=\frac{C}{2\pi}\sqrt{\frac{A^1}{V(L+1{\cdot}7R)}}.$$

So, if we put $A^1=A$ the formula gives:

$$V\times 10^{-6}=\frac{4{\cdot}66A}{f^2\times(1{\cdot}7R+L)}.$$

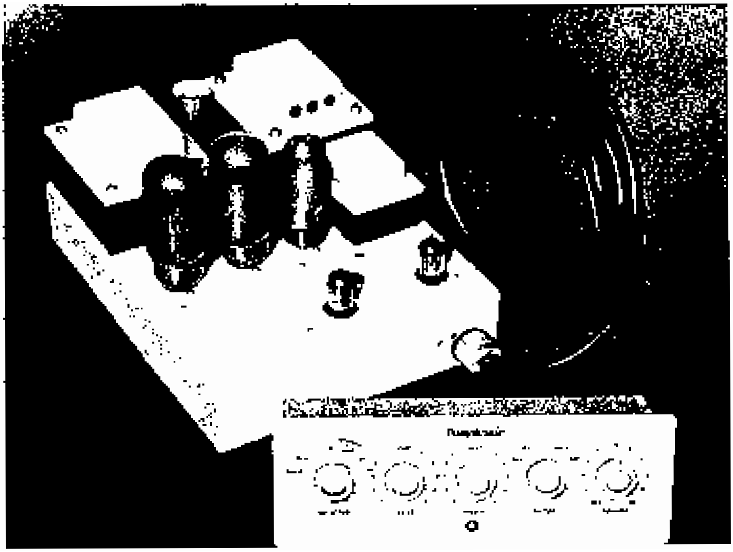
If we have an 8-in. cone with surround resonance at 64 c/s, we get the following values:

$f=64,\ R=3,\ A=28.$

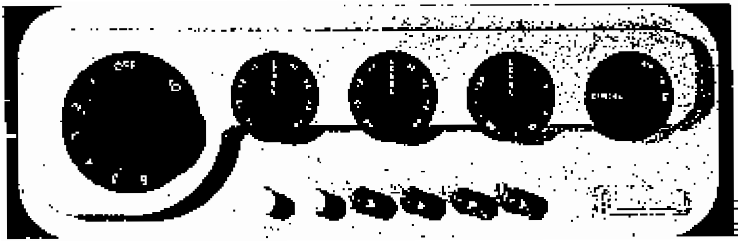


Wireless World

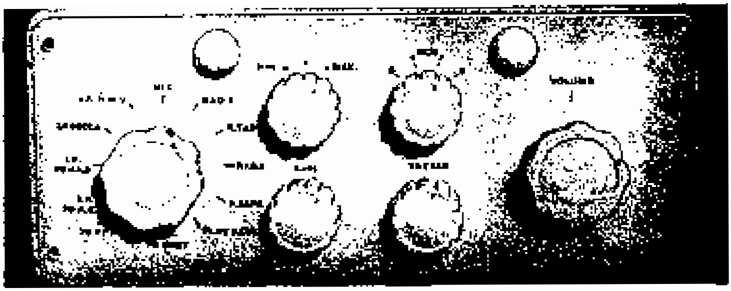
IX The Dust-Bug: particles collected on pad after (*a*) first playing; (*b*) immediate replay; (*c*) replay after storage



(*a*) Pamphonic Amplifier 1002 and Pre-amplifier 1002A



(*b*) Acoustical Quad II Control Unit



(*c*) Sound Sales Senior Control Unit

X CONTROL UNITS

If $L=0$, $V=6{,}440$ cu. in. $=3\cdot7$ cu. ft.
$L=3$, $V=4{,}025$ cu. in. $=2\cdot4$ cu. ft.
$L=5$, $V=3{,}220$ cu. in. $=1\cdot8$ cu. ft.

If however, $f=35$, $R=3$, $A=28$.

For $L=0$, $V=22{,}000$ cu. in. $=13$ cu. ft.
$L=5$, $V=11{,}000$ cu. in. $=6\cdot5$ cu. ft.
$L=10$, $V=7{,}300$ cu. in. $=4$ cu. ft.

Similarly for a 10-in. cone with surround resonance at 35 c/s,

$f=35$, $R=4$, $A=50$.

If $L=0$, $V=28{,}000$ cu. in. $=16$ cu. ft.
$L=5$, $V=16{,}000$ cu. in. $=10$ cu. ft.
$L=9$, $V=12{,}000$ cu. in. $=7$ cu. ft.
$L=12$, $V=10{,}000$ cu. in. $=6$ cu. ft.

In the case of this lower frequency, therefore, considerably larger enclosures with longer necks will be required.

If $f=35$, $R=5$, $A=78$ corresponding to a 12-in. cone, then:

For $L=0$, $V=31{,}200$ cu. in. $=18$ cu. ft.
$L=4\cdot5$, $V=22{,}800$ cu. in. $=13\cdot5$ cu. ft.
$L=10\cdot5$, $V=15{,}600$ cu. in. $=9$ cu. ft.

These calculations which, be it remembered, only give an approximation to the dimensions required, show clearly that if the resonances are to be kept very low, as is of course highly desirable, then the size of the enclosure must be fairly large. The use of a neck enables a substantial reduction to be made, but experience shows that long necks should be avoided. The author prefers to keep the length of neck below 6 in., though 10 in. is not unreasonable. Reducing the area of the vent also serves to reduce the required volume, and/or the length of neck.

It is always wise to have an enclosure larger than the calculation because that reduces the frequency of air resonance, and as a cone ages its surround resonance gradually goes lower in the scale.

There is no general consensus of opinion about the best position for the vent. The author prefers to have it low down and even in the bottom of the cabinet with the cabinet raised from the floor. In those circumstances the air space between floor and cabinet bottom acts as a neck to the vent and the distance from the floor should not be more than about 3 in. It is well to have a substantial strut between the bottom and floor just behind the vent.

9.63 Corner Cabinets

Several designs for vented, or 'bass-reflex' enclosures as they are more usually called, as recommended by manufacturers of loud-speaker units, are given in the Appendix. The most satisfactory types are undoubtedly the corner cabinets with brick or sand-filled front faces, for with these quite large enclosures can be economically obtained without the very real risk of setting up panel vibration. In the case of a sand-filled panel, the sand should not all be very fine, but it should be *quite* dry, so that motion of the sand within the wooden panels will absorb energy rapidly and so damp out any tendency to panel vibration.

A corner installation of this sort has the advantage that the acoustic energy is radiated into only 90° instead of 180° as it would be if the enclosure were placed against a flat wall or 360° if it were in the middle of the room. But it has one disadvantage in that all the 'eigentones' of the room, as they are called, are activated. These eigentones are the natural frequencies of the 'standing waves' that may be set up in the room by sounds being reflected to and fro from opposite walls: forwards and backwards, left and right and up and down. (See Sect. 9.8.)

9.64 Pedestal Cabinets

Notwithstanding its relative inefficiency, therefore, there is much to be said in favour of an enclosure placed more in the middle of the room and radiating horizontally. Such an enclosure, for example, is particularly successful in a small room; the author converted an old Victorian circular pedestal cupboard in this way, with an 8-in. speaker unit mounted in the top and pointing upwards to a solid conical reflector supported on dowels from the top circumference. A gilded gauze of expanded metal, taken round the dowels, gave a pleasing finish. The bottom of the cabinet was of course opened and spaced from the floor so as to make a suitable vent, and the door to the cupboard was made air-tight.

9.65 Internal Damping of Cabinet

With that design very little internal damping was required, the circular shape being particularly stiff and the speaker unit being mounted on the flat top. Usually, however, internal damping is desirable in bass-reflex enclosures, partly to minimize panel vibration and partly to damp out the higher modes of vibration of the enclosed air. The common practice is to line the faces of the cabinet with carpet felt. The author, however, finds this relatively ineffective, considering the amount of material that is used. A better plan is to use layers of thinner felt or blanket, lightly quilted together so as to leave large air spaces between the layers; or one or more layers of papier mâché egg-trays can be used. A horizontal partition of damping material across the whole of the cabinet and at about one-third of the way down from the top is always an advantage: it operates powerfully on the third harmonic.

Recently, another application of the principle of resistance damping has been proposed (*Wireless World*, January 1956). In this system an acoustic radiation resistance is applied to the vent, of a value related to the mass and compliance of the air chamber and, of course, to the resonant frequency of the speaker unit. This, it is claimed, enables a reduction to be made in the volume of the enclosure by as much as one-third; and at the same time the upper hump (see Sect. 9.61) in the resulting response is almost entirely suppressed.

9.7 Folded Horns

It has already been remarked that horn loading increases the acoustic efficiency of a loud-speaker very considerably, but that for reproduction of the deep bass a very long horn with a large opening is required. Ingenious methods have therefore been devised for folding a horn by partitioning the space in a comparatively small cabinet. The names Klipschorn and Jensen in America and of Mordaunt (Tannoy) and Ambassador in Great Britain have been associated with successful designs in this respect. In all these cases it has been found necessary to limit the frequency range over which the horn operates.

The reason for this limitation seems to be that a horn with multiple bends in it does not operate in any simple fashion, and certainly not in the same way as a long straight horn. In the latter case a nearly constant loading above a certain cut-off frequency can be obtained by making the contour follow a curve which is quite close to that known as the exponential or logarithmic curve. A correction has to be applied to take account of the fact that the sound waves in the horn begin to bulge out along the axis of the horn and emerge as spherical waves; though as shown in the author's previous work (*Modern Gramophones*, Chapter V) the correction is only a small one. But as soon as one starts to bend a horn cross-vibrations are set up and these all derive their energy from the main flow through the conduit. The notes of wave-lengths corresponding to those of the cross vibrations are thus filtered out of the main stream and whether any of them succeed in reaching the outer air again depends on the effectiveness of the cabinet itself as a radiator and upon the chances of phase cancellation.

A straight horn is essentially a non-resonant loading system; a folded horn is a combination of non-resonant loading with highly resonant loading. It follows that the only safe procedure is to measure the response of any particular design *a posteriori*, and modify it by trial and error. This, of course, requires elaborate measuring apparatus, including a 'dead' or 'anechoic' room, as it is sometimes called, which is beyond the resources of any but a properly equipped laboratory. The amateur is not recommended to venture on a construction of this sort.

9.71 Corner Horn

There is, on the other hand, a sort of cross between a bass-reflex cabinet and a straight modified exponential horn which is well within the capabilities of a handyman. This is to fix a quarter-section (longitudinal) of an octagonal exponential horn in the corner of the room with the small end close to the floor and the large end within a foot or two of the ceiling. The top corner of the room will then form part of the horn, and the speaker unit can be fixed on a baffle board inside the horn. This baffle board can either be a sloping one at the large end of the horn or a horizontal one inside the horn lower down (say about one-third of, or half, the way down). Suitable dimensions for the design of such a horn to operate down to 32 c/s are given in the Appendix to this chapter. For the faces of the horn even a pliant material will suffice since the speaker unit is so mounted that cross vibrations are not readily produced. Thus a suitable material is linoleum with the smooth face inwards. The outer rough face may be plastered or papered to match the room decorations. Each corner of the horn is built up from bent aluminium angle, 90° at the wall and 135° between front faces. Alternatively, tube may be used.

With this construction the horn rises up in the corner of the room like a lily, and since the large end is at the top little useful room space is taken up.

9.8 Room Conditions

Most of what has been said in this chapter about the performance of loud-speakers has ignored the effect of the room in which the playing takes place. It has been pointed out, however, that ordinary living-room dimensions are comparable with the wave-lengths of the low bass notes. A strong low-note response is therefore very hard to get in small living-rooms.

But that is not all. If the air in the room is sufficiently strongly excited room resonances will be set up in a rather complicated pattern (eigentones). The lowest frequency will be at a wave-length corresponding to twice the longest length of the room, and there will be others at double and three times that frequency, etc., and at frequencies determined by the width and height of the room. Thus:

Wall Separation	*Resonance c/s*		
8 ft.	70	140	210
10 ft.	55	110	165
12 ft.	46	92	138
16 ft.	35	70	105

The higher frequencies will be damped out comparatively easily by room furnishings. The really troublesome resonances are those in the first column, and between those frequencies and those in the second column the acoustic load presented to the speaker by the room will be very variable (and different according to the placing of the speaker in the room).

9.81 Special Conditions for Small Rooms

It follows from this that in small rooms it is wise to keep the volume-level quite low, particularly in the region below about

60 c/s. And, of course, the treble response above 10,000 c/s must be correspondingly balanced. But if the loudness-level is kept low more of the quiet lower bass and higher treble notes will sink below the threshold of audibility and a small correction for this is often applied in the amplifier.

It follows, also, that for use in a small room a high-powered amplifier and a powerful loud-speaker system in a large enclosure may be quite wasteful—and possibly even a menace, for the reserve of power will tempt the owner to turn up the volume. A hard and fast rule cannot be laid down, for so much will depend on the type of furnishing. If there is a wealth of heavy curtains and soft upholstery, then a larger volume and a longer frequency response, both in bass and treble, will be permissible. It is the author's opinion, however, that generally an output power of 20 watts from 40 c/s upwards is more than is ever likely to be required from an amplifier in any living-room whose largest dimension is less than 20 ft. For a room of, say, 15 ft. by 12 ft. by 10 ft. high, even 10 watts provides a good margin for reasonable volume from loud-speaker systems of average efficiency. Double these amounts may be justified in the case of infinite baffle mounting where the acoustic efficiency is roughly halved at the lowest frequencies.

9.82 Wall Reflection

One other point remains to be noticed about the position of the loud-speaker in a room. Since high notes are directive it is often recommended that the speaker should be pointed away from the listener and towards either a wall of a room (at an angle) or towards a corner, so that the listener only hears reflected sound. The argument does not apply in the same way to low notes but there is something to be said for the idea even there, so as to achieve a certain dispersion and avoid the impression that all the sound is coming from a small hole.

9.9 Summary

This chapter has been so long that a summary of the more important conclusions seems worth while.

(1) The optimum conditions for bass and treble are largely incompatible. Generally one requires small dimensions for

treble and large for bass. Many people, therefore (the author included), prefer to cover different parts of the scale with different units.

(2) The change-over from one to the other is usually performed in an electrical cross-over unit. But there are some designs which achieve a comparable result in the electromagnetic and/or mechanical drive.

(3) The larger the flux density in the magnet the better.

(4) For bass units, long coils (e.g. ½ in.) of large diameter (e.g. 2–2½ in.) are desirable. The corresponding magnets are, however, expensive.

(5) For bass units, cones from 8 to 15 in. external diameter may be used with a particularly free edge-surround.

(6) Centring arrangements should permit of a large axial throw without non-linear constraints.

(7) Flared shape gives longer range before cone breakup occurs. Straight-sided cones give greater acoustic efficiency over a smaller range.

(8) Most efficient non-resonant mounting is straight exponential horn; but size required for long range is usually prohibitive. Folded horns are efficient but resonant.

(9) Most practicable non-resonant mounting is infinite baffle (wall mounting between two rooms). This is relatively inefficient, particularly below surround resonance of cone.

(10) A reasonable alternative would be flue (long pipe) mounting.

(11) Short-pipe mounting leads to harmonics at odd multiples of surround resonance. Third or other harmonics can be suppressed by suitable positioning of speaker in pipe.

(12) Most serviceable form of enclosure for ordinary conditions is bass-reflex cabinet. Here again large cabinet is required for deep bass, but use of necks and acoustic resistances at the vent can keep the dimensions within reasonable bounds.

(13) Internal damping of cabinets always desirable to control resonances.

(14) Position of cabinet in room important both as regards efficiency and in matter of excitation of room resonances.

(15) Corner position most efficient, but excites more room resonances.

(16) In small rooms the power must be kept low, particularly in

bass; how low depends on absorption efficiency of room furnishings.

(17) Generally, for speaker systems of normal efficiency an amplifier output of 10 watts (0·1 per cent distortion) is ample for small rooms and 20 watts (likewise, 0·1 per cent distortion) for larger rooms. For wall mounting, however, double these amounts is not unreasonable.

APPENDIX TO CHAPTER IX

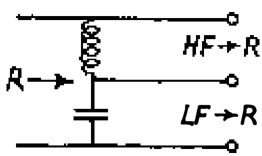
Figure 29

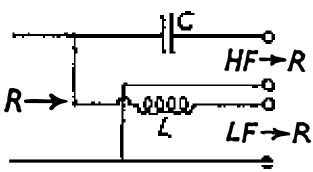
Cross-over Units.

f—Cross-over frequency.

Series *Parallel*

1. Quarter Section



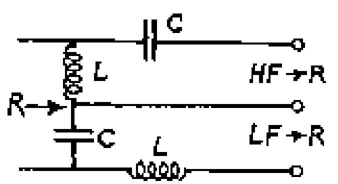


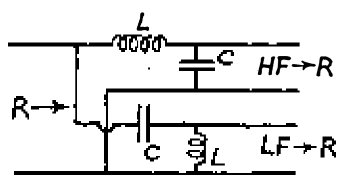
$R=6{\cdot}28fL=1/6{\cdot}28fC.$

For R=15 ohms

	L (mH)	C (mfd)
350	7	33
700	3·5	16
1400	1·75	8
2800	0·9	4

2. Half Section





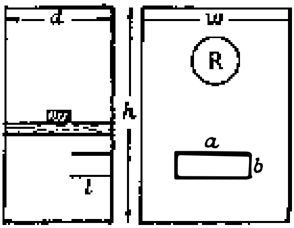
$0{\cdot}707\ R=6{\cdot}28fL=1/6{\cdot}28\ fC$ | $1{\cdot}414\ R=6{\cdot}28fL=1/6{\cdot}28fC$

	mH	*mfd*	*mH*	*mfd*
350	5	44	10	22
700	2·5	22	5	11
1400	1·25	11	2·5	5·5
2800	0·7	5·5	1·25	3

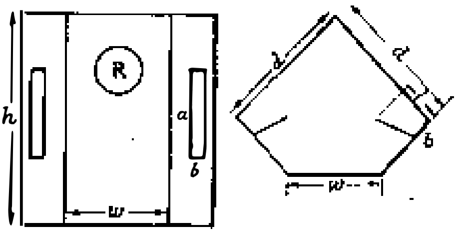
Figure 30

Designs for Vented Enclosures.

(a)



(b)



(*a*) Basic Pattern.

Table of Dimensions

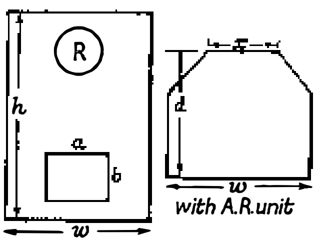
2R	8	10	12	15
*f*c/s	64	35	35	35
h	30	33	36	39
w	18	24	27	30
d	12	15	15	18
a	8	10	12	15
b	3	4	5	6
l	0	9	11	12

(*b*) Tannoy Pattern.

Table of Dimensions

2R	8	10	12	15
*f*c/s	64	35	35	35
h	30	33	36	39
w	12	14	16	18
d	14	16	16	21
a	10	11	13	18
b	1½	1½	2	2
l	2	3	4	4

(c)

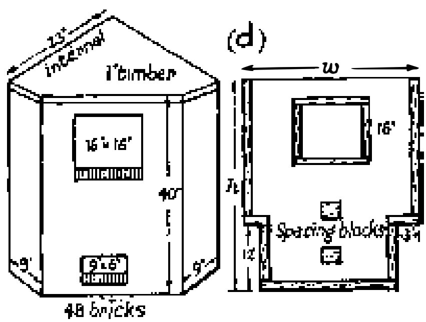


(*c*) Goodmans Pattern.

Table of Dimensions

2R	10	12
*f*c/s	20	35
h	36	36
w	18	18
d	10	13
x	10	10
a	12	10½
b	7	10
A.R.U.	180	172

(d)

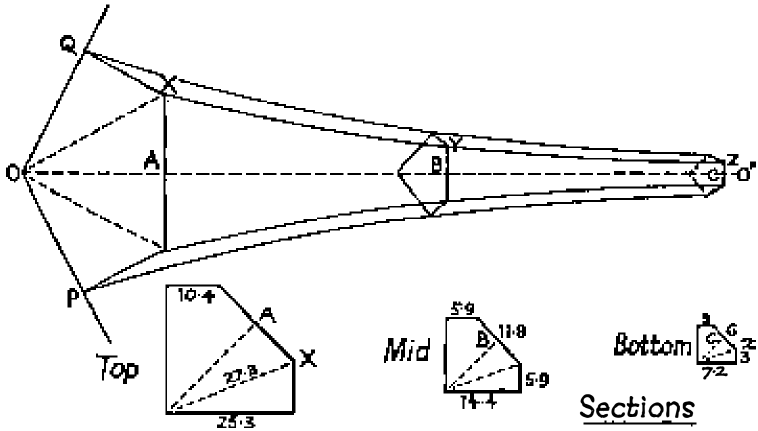


(*d*) Wharfedale Brick Enclosure and Sand-filled Corner Panel.

Front and Rear Panels: ¾ ply.
Spacing fillets and blocks:
1 in. thick.
Top board: 1 in. thick.

	8 in.	10 in.	12 in.	15 in.
h	30	36	40	40
w	30	30	30	36

Figure 31
Exponential Corner Enclosure.
(See Sect. 9.71.)



Speaker Unit mounted facing upwards either at top (at an angle) or on baffle at mid-section.

Dimensions in Inches

Distance from Top	*Corner to XYZ*	*Corner to ABC*	*AX etc.*
0	27·3	25·3	10·4
8	24·5	22·6	9·4
16	21·9	20·2	8·4
24	19·6	18·2	7·5
32	17·5	16·2	6·7
40	15·6	14·4	5·9
48	13·9	12·8	5·3
56	12·4	11·5	4·75
64	11·0	10·2	4·2
72	9·8	9·2	3·75
80	8·7	8·1	3·3
88	7·75	7·2	3

Horn cut-off 32 c/s.

X

LOUD-SPEAKERS: SPECIAL TYPES

10.1 Avoidance of Resonance

The last chapter should have led the reader to the conclusion that the two main problems in connexion with loud-speakers are, first, the difficulty of radiating enough acoustic power to the open air and, second, the existence of resonances both in the driving unit and in the enclosure which is used to build up the power.

To radiate power from a diaphragm one has to have either a large area or a concentrated acoustic load. The latter means a large horn; the former leads to difficulties in the breaking up of the diaphragm into resonant modes of vibration.

Are there any alternatives? Yes, there are two. The first is to do without a diaphragm or other solid material vibrator altogether. The second is to devise a means of distributing the driving force uniformly over the surface of a large diaphragm.

10.2 The Ionophone

One means of causing an electrical vibration to produce a direct acoustic effect is to harness it to a 'corona discharge'. There are several known methods of producing such a discharge. The one used in the Ionophone is the invention of M. S. Klein of Paris.

In this a small quartz tube is used, one end of which is open and the other is drawn down to a neck in which an electrode, known as an Kanthal electrode, is fitted. Outside the neck is a counter electrode; and between the two a radio frequency oscillation of high voltage is applied. This causes a glow discharge within the tube whose intensity is proportional to the instantaneous value of the radio frequency voltage, so if the radio frequency voltage is modulated at an audio frequency the glow will vary in sympathy.

As one end of the tube is closed at the neck by the Kanthal electrode, air-pressures are set up in the tube by the glow discharge and these air-pressures vary with the audio modulation. The range from the quartz cell is in fact from zero frequency up to the limits of audition, and is linear (Fig. 32(*a*) and (*b*)). So the open end of the tube may be connected to an exponential horn and will produce sound whose frequency response will be determined by the characteristics of the horn. Since there is no material vibrator other than the air, there need be no resonances or amplitude distortion, and transients should be perfectly reproduced.

In practice, the size of horn that is convenient for ordinary domestic use will limit the possible range in the bass, and the commercial version of the Ionophone is designed for use as a tweeter with a cross-over at 2,000 c/s. A very high radio frequency of the order of 27 mc/s is used so as to avoid interference with radio or television broadcasts.

10.3 The Ribbon Speaker

If a thin, corrugated ribbon of aluminium or aluminium alloy is disposed longitudinally between the poles of a magnet and a signal current is passed through it, it will move to and fro in the field and the driving force can be arranged to be sensibly uniform over the whole of the surface (Fig. 33). Anything but a small ribbon, however, would call for a very large magnet and the cost of a magnet increases according to the cube of its weight. The use of this form of drive as a direct radiator is therefore out of the question.

But the system has been successfully adapted as the driving unit in a small horn, and at a competitive cost as a transducer for frequencies above about 3,000 c/s. It could also be applied, at a not unreasonable price, to reproduce frequencies down to 1,000 c/s, if that were thought worth while. Reproduction of lower notes would, of course, lead to difficulties about the size of horn required.

For high notes, however, the distribution of the driving force over the whole area of the ribbon leads to a smooth, non-resonant

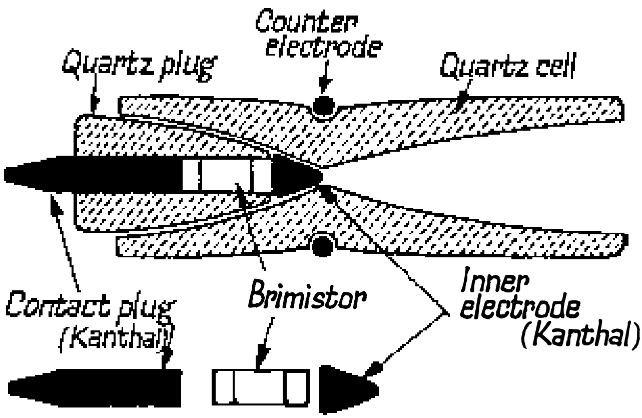


Figure 32(a)
Details of Quartz Cell.

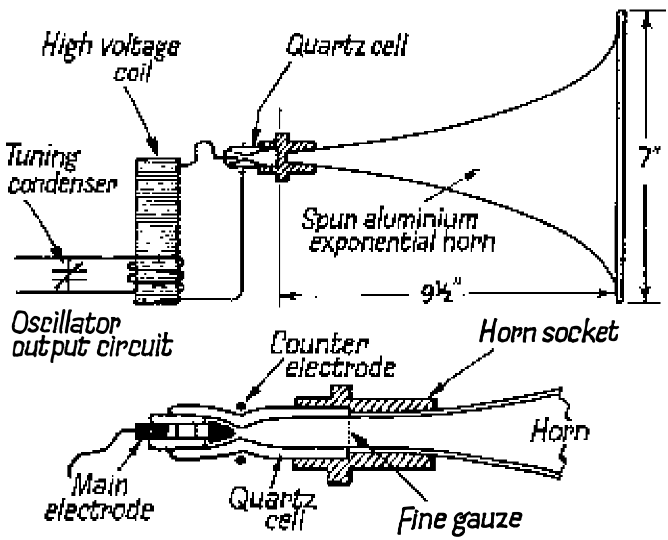


Figure 32(b)
Details of Ionophone Assembly with output circuit of oscillator.

response which guarantees the success of this device as a tweeter.

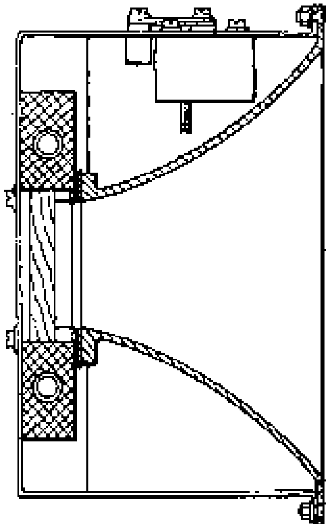


Figure 33
Kelly Ribbon Speaker.

10.4 Electrostatic Speakers

The most advanced development of non-resonant loud-speaker radiators has come from a new application of the electrostatic principle. How this has come about is an interesting example of technological development, for the principle was first applied to loud-speaker design over thirty years ago and then practically abandoned after only a few years' trial.

Suppose we have a thin metal diaphragm stretched on some form of support so as to rest within a few hundredths of an inch from a rigid plate. If a 'polarizing' voltage is applied between the two the diaphragm will move towards the plate under the influence of the electrostatic force thus created, and unless the freedom of motion is constrained (e.g. by stretching the diaphragm) it will move into contact. But if sufficient tension is applied to prevent the collapse then it will take up a position of equilibrium determined by the electrostatic pull and the tension. Suppose now the polarizing voltage is varied slightly ('modulated') by the superimposing of a signal voltage upon it. Then the diaphragm will move to and from the plate in response to this signal voltage and an electrostatic acoustic transducer will be formed (Fig. 34).

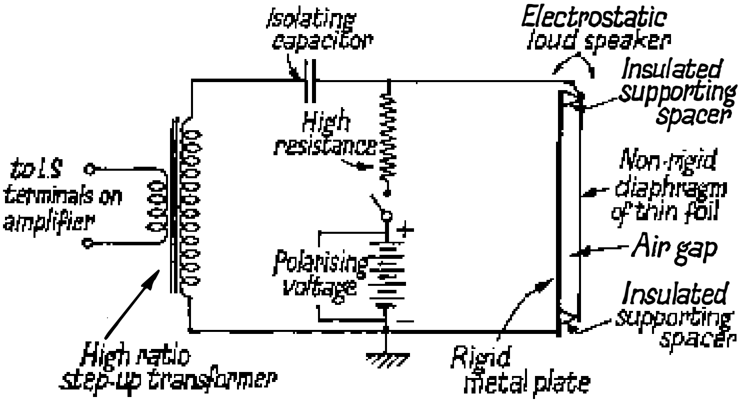


Figure 34

Schematic drawing of single-sided electrostatic loud-speaker.

10.41 Early Types

This was the basis of design of the first electrostatic loud-speakers. The use of a stretched diaphragm, however, did not take advantage of the fact that the electrostatic force between the diaphragm and the plate was distributed over the whole of the surface. The device was still a resonant one because of the different modes of vibration of the diaphragm. But there were even more serious disabilities:

(1) Except for very small signals there was not a linear relationship between output and input. This was partly due to the cushioning of the air behind the diaphragm, and partly to the relationships between tension and electrostatic force. Moreover since the force varied as the inverse square of the distance, the unit was an efficient generator of several harmonics.

(2) The tensioning of the thin diaphragm was appreciably affected by temperature and this of course led to irregularity of performance.

An improved version used two perforated fixed plates with the tensioned diaphragm between them, and was operated on a push-pull principle. Here is an extract from a report made by the present author in 1929 on one such design (*The Gramophone*, May 1929):

> 'The London Editor (Mr Christopher Stone) and I attended a demonstration of a loud-speaker of a type which is new to this country. It is known as the *Oscilloplane* and is operated electrostatically. Two perforated plates are connected to the secondary terminals of an output transformer and between them is a stretched metal diaphragm which has a high polarizing voltage. The alternations of charge on the two plates cause the diaphragm to vibrate. The nature of the room in which the demonstration was given and the excessive volume produced hardly permitted us to form a fair judgment of the quality of the reproduction. The impression we received was that whilst low notes were well cared for the high notes as evidenced by the characteristic quality of a violin were not adequate.'

10.42 Recent Research

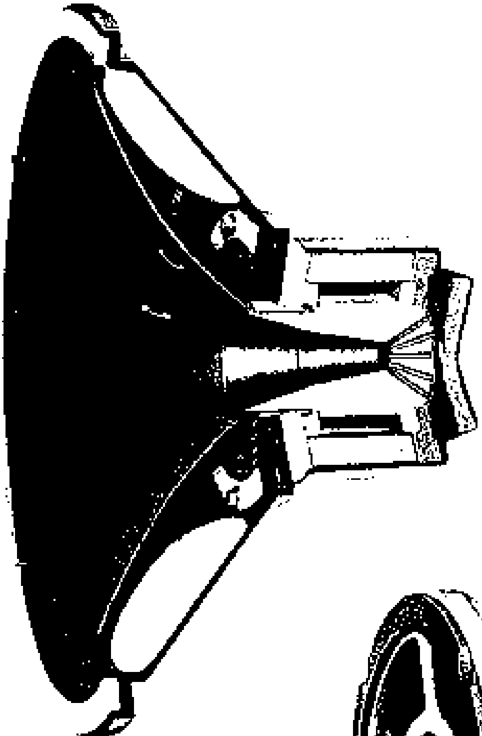
This quotation is particularly significant in view of the fact that it is a development of this particular system that has led to the elimination of the very serious disabilities mentioned above. But in the modern example the diaphragm is not stretched but is held in position between the two plates (which are made acoustically transparent) by insulating spacers. It is actually a sheet of tough flexible plastic coated with a conducting material which is extremely thin. The thickness of the diaphragm is less than a thousandth of an inch.

10.43 Uniform Push-Pull Drive

Here is an extract from a description of the new design and its mode of operation from the pen of Mr H. J. Leak (*The Gramophone*, May 1955).

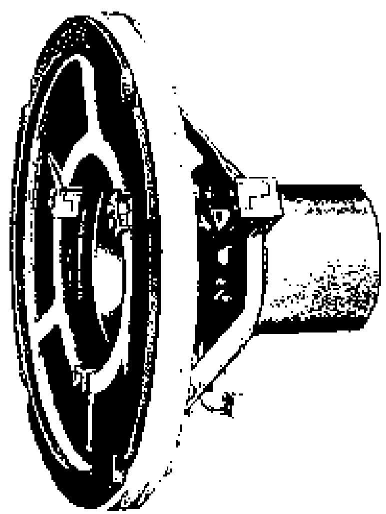
> 'If in the absence of a signal from the amplifier we switch the polarizing voltage into circuit, the diaphragm will *not* move towards either plate, because it is subjected to equal and opposite electrostatic forces from each plate. This means that the diaphragm need not be stretched to resist the static forces, thus removing one cause of the non-linearities inherent in the single-sided loud-speaker. Another important feature of the

(*a*) Wharfedale 3-in. Tweeter

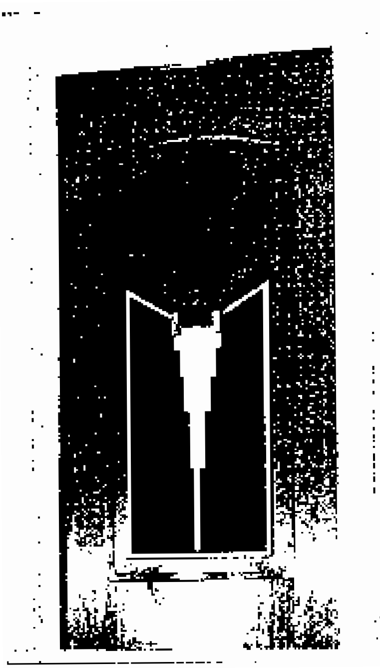


(*b*) Tannoy Dual-Concentric Loud-speaker

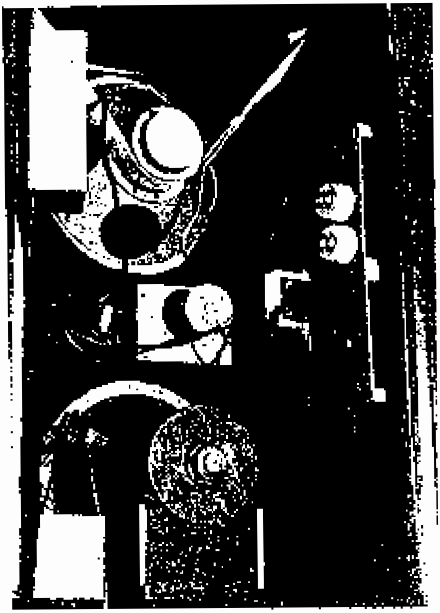
(*c*) Axiom 80



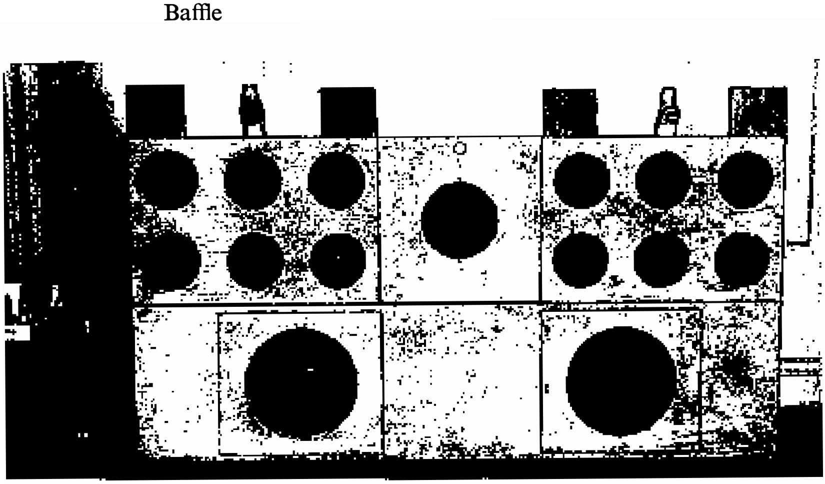
XI LOUD-SPEAKER UNITS



(*a*) Fret in front of Infinite Baffle



(*b*) Box in wall for Infinite Baffle



Budd-Meyer photo

(*c*) American Domestic Installation comprising twenty-one loud-speakers

XII LOUD-SPEAKER SYSTEMS

push-pull assembly is this: if the diaphragm is moved towards one plate it does not upset the condition of equal and opposite forces acting upon it, provided that the charge is maintained, and this can easily be ensured by making the resistance in series with the diaphragm of sufficient magnitude to give a long time constant.' (Fig. 35.)

'Under the above conditions the loud-speaker is an almost

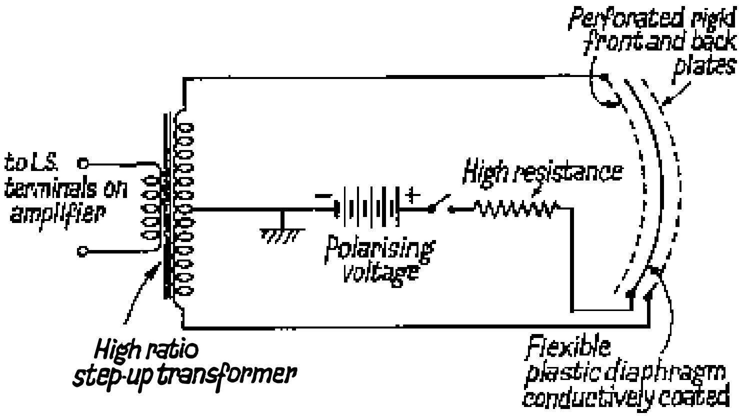


Figure 35

Schematic drawing of balanced push-pull electrostatic loud-speaker.

linear device, and harmonic distortion is extremely low. An unusual feature of this push-pull device is that the 2nd harmonic will always be greater than any other; furthermore, it can be shown that if the 2nd harmonic is reduced all the higher harmonics are reduced simultaneously!

'At volume-levels sufficient for a small hall, the particular type of loud-speaker illustrated in Plate XIV(*a*) has a measured distortion content over its working range of approximately 0·1 per cent!

'Fig. 36 shows that the frequency response of the loud-speaker in the horizontal plane is excellent, and the high-frequency response is maintained off the axis because of the curved construction. However, in the vertical plane the response will be more directional if the total area of the diaphragm is used as the radiator for high frequencies. Broader directivity can be obtained by sub-dividing the diaphragm areas through electrical dividing networks connected to tappings on the transformer. A further advantage can be obtained from this expedient because it tends to minimize the variation of load impedance with frequency.

'The acoustic output from this type of balanced push-pull electrostatic loud-speaker is of the same order as from the conventional cone loud-speakers. Its sensitivity is therefore satisfactory, in direct contrast with the single-sided system.'

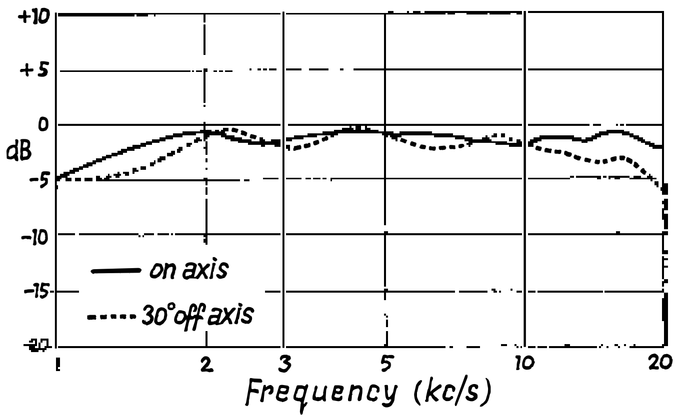


Figure 36

Frequency response curve of the balanced push-pull electrostatic loud-speaker illustrated in Fig. 35.

10.44 Electrostatic Tweeter

The particular design which Mr Leak was describing in the above extract was only a little more than a square foot in area and was only intended to deal with the frequencies above 1,000 c/s. To extend the range into the bass region would call for a considerable increase of area and for other novel techniques. These have been studied during the past three years by Mr P. J. Walker of the Acoustical Manufacturing Company of Huntingdon, England, and by Mr D. T. N. Williamson of Ferranti Ltd., Edinburgh; and it has been publicly demonstrated at the Audio Fair, London, in April 1956, that a solution has been found which is acceptable for home conditions.

10.5 Design for Wide-Range Electrostatic Speaker

The principles involved were described by Mr Walker in three articles published in *The Wireless World* (May, June and August 1955). The analysis is highly technical in character and must be regarded as beyond the scope of this book. The important conclusions can, however, be stated in comparatively simple terms and as it is clear that they will have an important influence on future development some account of them should be included.

The electrical impedance of an electrostatic speaker is, of course, capacitive in character, being determined by the spacing between the fixed plates. This impedance is matched to the amplifier at a very high frequency and determines the upper limit of the range over which the speaker gives uniform output. If the matching frequency is lowered an octave and the range so reduced then a gain of 3 db in efficiency over that range will be secured.

At the other end of the scale the limiting frequency for uniform response is determined by the diaphragm stiffness required for stability. If the spacing between the plates is doubled the stiffness can be halved and the low-frequency cut-off goes down an octave, but the polarizing voltage required on the diaphragm is also doubled, and there is also a loss of 3 db in efficiency.

One can thus rob Peter to pay Paul at each end of the scale. It is found that for satisfactory efficiency a uniform range of only 5 octaves is possible. Thus, if the upper frequency limit is 16,000 c/s the uniform acoustic output from the diaphragm will only go down as far as 500 c/s (16,000:8,000:4,000:2,000:1,000:500). The range is useful enough for a tweeter but some 4 octaves short of what is required for an all-range speaker.

Of course, a separate electrostatic speaker may be designed on the same principle for 4–5 octaves at the low end, say from 40 to 1,000 c/s. Thus a two-unit system can cover the full range.

10.51 Advantages of Strip Design

The analysis goes on to show the advantage of departing from a circular shape for the diaphragm and concludes that a desirable shape is that of a strip large in length compared to one-third the wave-length of the lowest frequency of interest and of a width small compared to the wave-length at the highest frequency of interest. Such a strip has the following advantages:

(1) the air resistance even at low frequencies is sufficient to develop adequate power for a reasonable diaphragm amplitude;
(2) there is good dispersion for several octaves;
(3) the narrow diaphragm enables other units to be placed close to it;
(4) the frequency limitations, amplitude at the low end, and directional problems at the high end, fit in nicely with the 5-octave range for satisfactory efficiency.

Different strips covering different ranges (determined by spacing and matching frequency) can be placed side by side, and the range of 5 octaves can thus be extended by having suitable cross-over frequencies.

10.52 Rear Loading

Mr Walker proceeded to show that several different forms of rear loading of the diaphragm would be possible. In particular, an enclosure in the form of a double wall 5 in. deep can be designed to give practically perfect results. Such a form is clearly feasible in cinemas, ballrooms and other places of entertainment but has obvious disadvantages for home use, where one wants a small, compact unit.

10.53 Doublet Design

Consideration was therefore given to the properties of a 'doublet' source, i.e. a diaphragm radiating on both sides. Our past experience has led us away from that idea because of the variation of acoustic load due to phase relationships when a small unit in a baffle is used. When the drive is extended to cover the whole of the baffle area the position is radically altered, particularly when the construction is that of strip units progressively increasing in plate spacing and area from the centre line. Each strip will have a resonant frequency when the reactance of the diaphragm stiffness equals the mass reactance of the air load. If this is placed below the frequency range of the strip, the radiation of the adjacent strip carrying a lower frequency range reacts with it and prevents the application of any effective mass. Only the resonance applying to the last strip with the lowest range can therefore be activated and this of course is placed at the lower limit of response (say, 30 c/s). Above that limit the doublet has no resonance and the effect is therefore quite different from that of a moving coil loud-speaker on a baffle.

The domestic form of the electrostatic loud-speaker has thus taken the form of a sort of curved fire-screen some 3–4 in. deep from back to front and measuring about 2 ft. 6 in. by 2 ft. (Plate XIV(*b*)). It cannot radiate sound in the direction of its surface, either horizontally or vertically, and therefore cannot excite room resonances in those directions. Since it is portable it may be placed in a position for minimum eigentone excitation in the remaining direction.

10.6 Avoidance of Room Coloration

With this type of loud-speaker, therefore, it is possible to avoid room coloration to a very remarkable degree. Some people may regard the resulting quality as rather 'cold'. It is certainly analytical in that it gives full expression to the studio acoustics in a recording. The first experience of the author in this respect is worthy of mention. In March 1956, Mr Walker invited him to his home to listen to the domestic model before its first public demonstration. He took with him some newly issued operatic records that had only just arrived and had not yet been played. After an overture, which was magnificently rendered by the electrostatic speaker, came a soprano solo, and it was at once evident that the singer was using a different microphone some distance from the orchestra; and this dichotomy persisted throughout the record. On returning home the author proceeded to play the record on a standard equipment with a moving coil loud-speaker, cross-over and tweeter and the voice became more or less fused with the orchestra. It seems therefore as though the electrostatic speaker will be a ruthless critic of recording methods. This, of course, will be all to the good in the long run.

10.7 Practical Considerations

A few words should be added about the practical operation of a speaker of this type. Being a capacitive device and voltage operated rather than current operated, it has a high impedance; and since the matching to the amplifier has to be different for the different strips, a special form of transformer is necessary. It is probable, therefore, that in due course amplifiers with special output arrangements will be designed to suit electrostatic loud-speakers. For the present, however, the procedure will no doubt be to interpose the special transformer between the low impedance output of a conventional amplifier and the speaker. This transformer will be one of the principal items of expense in the electrostatic speaker equipment.

The other will be the device required for giving a static polarization to the diaphragm. For the low frequencies a very high voltage will be required owing to the larger spacing between the plates; probably several kilovolts. But no current will be required and therefore the unit can be made of very high impedance making it quite safe to handle. In the first instance a rectifying unit from the supply mains similar to those used in some TV receivers will be used; later, it may be, some development of what has been known for a hundred years or so as the 'Zamboni pile' will be found suitable. (It was used for a similar purpose in the infra-red telescopes—'sniperscopes'—designed during the war.) Apart from these two items the electrostatic speaker can be a less expensive device than any other form of loud-speaker because of the ability to dispense with a large, rigid, and therefore costly cabinet.

At the moment it is in its infancy. One does not even know how reliable and robust it will be over long periods of use. Only experience can decide questions of that sort. But, already, the quality has proved to be such that no obstacles are likely to be allowed to stand in the way of its proper fulfilment.

XI

PLANNING A HIGH-FIDELITY EQUIPMENT

11.1 Economic Considerations

In the last few chapters we have been considering the units that go to make a reproducing system from a somewhat academic point of view. In planning a domestic equipment other factors, economic and severely practical, must be taken into account. Of these the principal ones are the purpose for which a reproducer is required, the amount of money one can afford, whether one would prefer to spend more money on records and have a lower standard of quality, and the size of the room in which the equipment will be used. Linked with these questions is another consideration of almost over-riding importance: are any, and if so which, parts of the standard equipment in use at present likely to be superseded before long? If so, it is obviously economical to make do for the time being with a relatively inexpensive piece of equipment in that particular respect and to choose the rest, if possible, so that when the improved part becomes available it can be substituted at the minimum of cost and trouble.

Before we begin to consider the detailed planning of our budget, therefore, let us look at these preliminary matters.

(1) If you have a small room—say 120–180 sq. ft. by 10 ft. high—then you will be wise not to attempt to have a heavy bass response. Be content to have a falling response below 60 c/s and a corresponding attenuation above, say, 11,000–12,000 c/s. This will limit the cost of the loud-speaker system considerably. It will also enable you to make do with an amplifier of somewhat lower power: a so-called 10-watt amplifier should be sufficient. Many people would be content with 6 watts, but in that case unless the bass response

were further restricted the average volume-level would have to be kept distinctly low if distortion were not to be encountered, if only instantaneously, on some loud passages; and this would mean that some of the softer passages would sink below the threshold of audibility.

If, however, you have a room of say 20 by 15 ft., or if you decided to have a speaker mounted in a wall, as an infinite baffle, you could effectively use an amplifier of 20 watts or more.

(2) The best of the modern amplifiers have attained such a high standard that there is little scope left for improvement. A little extravagance here may therefore be well justified later on when other parts of the system are improved.

(3) Pickups, too, are nearing the limit of development. The improvements to be expected during the next two years or so are a larger voltage output whilst still maintaining a uniform frequency response over the audible range with negligible distortion, and ability to track at lower playing weights—say down to 2 grm. There is some recent (though not at present conclusive) evidence that when playing weights under 2 grm. are used there is a spectacular reduction in record wear. Output level does not matter very much with modern amplifiers.

(4) Loud-speakers in their enclosures are still the weakest link and it may be that the development of the electrostatic type will initiate another revolution just as the moving coil type did in 1926. If, however, it proves to be unkind, relatively, to too many existing recordings, that revolution may well be delayed. The possibility, however, adds a special difficulty to the choice of a loud-speaker system, for hitherto the combinations with a full range and minimum distortion have cost two or three times as much as the most elaborate amplifiers and their associated control units. A sacrifice of range and power in the bass, however, whether for the reasons given in (1) above, or because the lady of the house requires it, or for any other reason, enables considerable savings to be made, since in that case smaller units and less elaborate enclosures will suffice.

11.2 Balancing the Budget

The balance of the budget is therefore likely to be different in the near future from what it has been in the past few years. Not so long ago the recommended proportions would have been something like this:

Amplifier and control unit	20–30 per cent
Turntable	10–15 per cent
Pickup and carrying arm	10–15 per cent
Speaker system	30–60 per cent

11.21 First Attempts and Trial Balances

Moreover, the purchaser would have been advised to decide first of all on his loud-speaker and cabinet, then on his turntable and pickup and lastly on his amplifier and control unit. For the future, the choice will not be so straightforward and several trial budgets will probably be necessary before a final choice can be made. Here are a few suggestions:

(1) Choose the best transcription turntable that you think you may be able to afford.
(2) Decide what type of pickup and arm you would prefer.
(3) Decide what amplifier and control unit seems most suitable for type of pickup.
(4) See what amount (if any) you will have left over for loud-speaker and enclosure.

11.22 Where to Economize

You will no doubt find that you have not enough money to do all that you would like to do, so you will have to go over the items again. But do not attempt to economize by having an inferior turntable. Only the best is good enough; but that need not be the most expensive if you are careful in choosing a particular unit and do not assume that every unit of the same type will function perfectly. It is true that transcription turntables are more uniformly satisfactory than others and that the more expensive ones receive a more meticulous factory inspection. But it is not unusual to find that a good sample of a cheaper type will be perfectly satisfactory in all essential respects.

Similarly, choose the best type of amplifier (and control unit) in the first instance that you think you can afford. But remember that the price you will have to pay will depend to a large degree on whether you want versatility in the control unit to suit various types of pickup.

If you have a fancy for a moving coil pickup, which is probably the most nearly perfect type at present, you must expect to pay a lot more for it and its matching transformer than for a variable reluctance type. The crystal type on the other hand is relatively cheap, especially having regard to its high output, and there are several cartridges available at present which are but slightly inferior to the best moving coil pickups.

Again, although it is a joy to have a transcription type of arm with its precision workmanship and facilities for accurate adjustment to suit a variety of conditions, other types of arm are available that are quite satisfactory for prescribed conditions.

11.23 Typical Balances

If you have up to £200 available you might make the following allocations:

Turntable	£25–£30
Pickup and arm	£20–£30
Amplifier and control unit	£40–£45
Loud-speaker units	£30–£40
Enclosure	£20–£50

If you have £75–£100 to spend the following would be more appropriate:

Turntable	£20
Pickup and arm	£10–£20
Amplifier and control unit	£20–£30
Loud-speaker units	£15–£20
Enclosure	£10–£25

By extreme economy it is, however, possible to manage a reasonably satisfactory system for as little as £50, e.g.:

Turntable and arm and pickup	£20
Amplifier	£18
Loud-speaker	£10
Home made Enclosure	£1

In all the above cases nothing has been allowed for cabinet to house the amplifier and turntable since these can often be accommodated in existing furniture. Quite satisfactory console cabinets are, however, available for about £12.

11.3 Figures of Merit

In choosing particular units for a trial budget you will, of course, look first of all at the makers' specifications and try to award figures of merit. Here are some general hints on the characteristics to look for.

11.31 For Amplifiers

(1) *Frequency range* should be linked with a figure of plus or minus so many decibels to indicate smoothness within the range; the smaller the plus and minus, the better. The range should not be less than 30 to 16,000 c/s, plus and minus 3 db. A range $\pm$ 1 db from 30 to 16,000 c/s is better than $\pm$ 3 db from 10 to 50,000 c/s. The most satisfactory specifications give a guarantee such as this:

$\pm$ 0·2 db from 20 to 20,000 c/s
$\pm$ 1 db from 10 to 100,000 c/s.

The principal advantage of this extended specification is that it tends to show that the amplifier is not on the verge of instability at high and low frequencies (but see (3) below).

(2) *Percentage distortion* should be less than 0·1 per cent and should be quoted at different power levels and preferably also at different frequencies. The more complete specifications will give both the percentage of harmonic distortion and that of intermodulation distortion. The former is less objectionable than the latter.

(3) *Negative feedback:* 15 db is good, 25 db is better, 35 db is superlative. But it should be over the whole of the frequency range, and should not make the amplifier unstable even with an inductive or capacitive load.

(4) *Noise and hum* should be better than —80 db at full output.

(5) *Damping factor* should be greater than 20.

11.32 For Control Units

See Chapter VIII for controls required. Note particularly the input voltage required to give full output from amplifier. For the best crystal pickups this should not be larger than 50 mV. This value might also be suitable for moving coil pickups provided a good matching transformer is used. It is too small for direct connexion of the best variable reluctance pickups; for these a sensitivity of 10 mV is desirable though 20 mV will suffice for some. Note, too, the impedance for the various types of input. For microphone, radio and tape inputs an impedance of the order of 1 megohm is usual, 3 mV sensitivity for microphone and 100 mV for the other two. It is an advantage for the output from the control unit to be via a 'cathode follower' valve, but this is not essential.

Notice the type of input connectors required. Screwed terminals can lead to hum unless there are adjacent earth terminals for each; coaxial sockets are ideal but relatively large and expensive. Small 'phone jacks' serve nearly as well.

You will, of course, assess the decor and the visibility of the markings according to your own taste.

11.33 For Turntables

'Wow' and 'Flutter' and 'Rumble' are highly important. The wise buyer tests the particular unit for all three before concluding a purchase.

'Wow' shows itself in variation of pitch on a long drawn-out note.

'Flutter' shows itself in a faster vibrato on steady notes, e.g. soprano or flute.

'Rumble' is a low-frequency growling noise, caused by motor vibration. To test, see whether you can feel any vibration when you put the tips of your fingers on the motor plate when the motor is running. If it is appreciable, then reject that particular unit. A more exacting test is to stand a pile of pennies on the motor plate up to the height of the turntable and adjacent to it. Rest the stylus of a pickup on the pile and set the motor running. There should then be no deep hum from a loud-speaker even when the amplifier is at full volume.

Check the accuracy of speed by counting the revolutions per minute at all three speeds. It should not be more than 3 per cent out. The purist will insist on less than 1 per cent.

In the best units a heavy 12-in. non-magnetic turntable is used; 5–8 lb. weight is desirable.

The rubber driving wheel should be retracted out of contact with the turntable when the motor is not running.

11.34 For Pickup Arms

Test for possibility of accurate tracking by measuring the *linear* offset (see Fig. 15). It should be between 3 and $3\frac{3}{4}$ in.

For setting, measure a distance of 2·5 in. from the corner along one edge of a sheet of paper. With the pencil mark over the centre of the turntable spindle, place the stylus of the pickup on the corner (so that it is now 2·5 in. from the spindle). Look along the edge of the paper which is at right angles to that which passes through the spindle. The axis of the pickup should be upon that line.

Test both horizontal and vertical bearings for freedom. The slightest 'stiction' will cause severe record wear. Floppy bearings should also be avoided.

A spring-type weight adjustment is not as a rule so satisfactory as a counterbalance weight since it may cause a resonance effect in the audible scale or accentuate rumble. It is more kind to warped records, but of course they should be avoided or cured.

11.35 For Pickups

For *all* pickups, whatever the type, the important criteria are:

(1) Output in millivolts at a stated load impedance from a standard record, e.g. Decca LXT 2695—10 cm/sec. velocity. If the millivolts are low (e.g. 3 mV) the impedance should also be low (say 2 ohms). In that case the voltage output can easily be stepped up to, say, 50 mV by means of a matching transformer. If the load impedance is of the order of 50,000 ohms the output should be greater than 10 mV.

(2) Low-equivalent mass at stylus. This determines high-frequency response and tracking grooves of high acceleration. An equivalent mass of not more than 2 mg. is quite feasible (but not usual!).

(3) High lateral compliance at stylus. This determines low-frequency response and tracking. A compliance of 5×10^{-6} cm./dyne is not too much to ask for.

(4) Playing weight of not more than 7 grm. on L.P. records is desirable.

(5) Standard stylus. A design which is based on a diamond stylus is best, *ceteris paribus*. If a sapphire is used it should be readily replaced and in such a way that one can be certain that the stylus will not be canted over in the groove.

(6) Vertical compliance, either by cantilever or otherwise, should be sufficient to avoid 'needle chatter'. A value of 5×10^{-7} cm./dyne is not unreasonable.

(7) Frequency response should be from 30 to at least 16,000 c/s, plus or minus not more than 3 db. For the best moving coil types the response will be 25 to 20,000 c/s, plus or minus 1 db.

(8) Distortion content should be less than 2 per cent.

11.36 For Loud-speakers

Ultimately, the choice of a loud-speaker, more than that of any other unit, depends on listening, listening and listening in conditions as nearly as possible similar to those which you will have in your own home. Probably that is because the response of all speakers is so far from being perfect, and faults that offend one person may not affect another. It is a fairly general experience that women's ears are more sensitive to faults, and particularly those that occur at the ends of the scale, than are those of men. It is a good idea, therefore, when you plan an excursion to some showroom or demonstration where loud-speakers can be heard, to arrange to take with you a lady who is accustomed to listen to music.

11.4 Listening Tests

Do not try to judge a speaker on its reproduction of queer noises, including under this head the noises made by some of the devices used by jazz bands. For there is no standard of queerness and many of the noises may be made to sound even more queer, and perhaps even more like what you may think they ought to be, if the reproducing system has faults of the most vicious kind. Thus, overloading and other forms of non-linearity can produce some very queer noises.

Again, do not be deceived by a salesman or anyone else into listening to test records consisting of pure tones from one end of the scale to the other. Such records have their value for measurement purposes, but they are positively misleading for aural judgements.

The most satisfactory procedure is to listen first of all to a record of the human voice at normal speaking level. Choose a record of some public speaker whose voice you know, e.g. Decca LK 4050 or H.M.V. (H) Alp 1043. Try to set the controls (or have them set for you) so that the voice sounds natural, without chestiness or over-sibilance, yet with the fricative and labial consonants, the p's and b's and t's and l's, all distinct and clear. If you can achieve success in this attempt the loud-speaker will probably do well in the remaining tests.

Next, whilst leaving the controls set as before, listen to a violin solo, preferably of someone whose playing you have heard at a concert, and see whether you can recognize the accuracy of the string tone with the requisite amount of 'guttiness', and perhaps even shrillness on some sharp notes, but without 'comb-and-paper' effect.

Listen, too, to the pianoforte and notice whether the attack sounds right on sharp chords. Pay particular attention to the characteristic singing quality of soft passages and whether the tone becomes hard rather than more sonorous during crescendos; or on the other hand whether there seems to be a hang-over leading to a muddy quality. (If there was no chestiness in a male voice this type of hang-over is unlikely.)

Pass on to chamber music—a trio of violin, 'cello and piano is good—and satisfy yourself that the characteristic quality of each instrument remains distinct.

For all these tests no change should be needed in the setting of the controls. Later, if you like, you can try the effect of increasing the volume or slightly adjusting bass and treble controls, so as to see whether critical adjustment is necessary to secure satisfactory quality, but note the original settings and come back to them.

Next, try an orchestral or piano concerto record. Volume setting has to be altered in order to obtain the most realistic effect, because you will have no prior knowledge of the recording level; but be wary of putting the volume control too high in the first instance, especially on soft passages. Notice, first, the overall impression of the orchestra and second, whether the various instruments stand out in some sort of perspective. Benjamin Britten's *Young Person's Guide to the Orchestra* is a useful piece for this test, since it contains clear-cut passages for all instruments, both solo and in combination. Then play the end of the Third Movement and straight through the Fourth Movement of Beethoven's Fifth Symphony. The Kleiber record made by Decca is probably the most suitable. See whether you can get a sense of the haunting delicacy of the bridge passage between the two movements and whether the terrific crescendo into the Fourth Movement is taken with clearness and without strain. Continue the Fourth Movement, watching for clarity and resolution between the various sections of the orchestra, and then at the end look out for those staccato chords which will test the transient response to the full.

Finally, listen to the voices, both solo and in combination, in an operatic record, or better still in the *Dies Irae* section of Verdi's Requiem Mass (the D.G.G. record is very suitable for this). Once you have heard this record well reproduced and have realized that there need be no 'tizziness' even when the combined volume-level becomes high and that throughout there is a superb balance between the voices, without edge or cracking or shrillness; once you have heard these things you will have a sound basis for judgement of any other reproducer.

There are many other tests that can be applied by the process of listening, e.g. by comparing the reproduction from the Vox record DL 130, but if and when you have gone through what has already been described you will have a sound basis for differentiation. Remember that if any particular quality hits you, whether it be a heavy bass or an edge to a tenor or soprano note or merely a certain coarseness, there is something wrong. Good reproduction should seem effortless and non-fatiguing.

11.5 What to Look For

Subject to this final arbitrament of your own and your lady's ears, there are a few suggestions that might well be made for guidance.

(1) There are a few inexpensive 8- and 10-in. loud-speaker units which have a particularly smooth middle register from about 500 to 3,000 c/s and a good, if more peaky, response both above and below those limits. It is therefore a good proposition to start with one of these units as an all-range speaker and later, if circumstances permit, add a tweeter to cover the region above 3,000 c/s and later still, a woofer to go below 500 c/s.

(2) For tweeters the most satisfactory are the Ionophone, the large push-pull electrostatic type, or the ribbon type. These have no treble peaks. They are relatively expensive, however, and there are cheaper 'pressure-type' units and small direct radiators which are reasonably good.

(3) Whereas the 8- and 10-in. units, previously mentioned, have only 1-in. coils and small magnets, the most efficient woofers have large magnets and coils of 1½–2 in. diameter. The cones are usually 12 or 15 in. in outside diameter. They cost much more, of course, and it is more economical and sometimes just as satisfactory to use two smaller units in series or parallel, being careful to see that the combined impedance is right (two 7½-ohm units in series would match up in a 15-ohm circuit).

(4) If you are able to have a hole in the wall between two rooms, the question of enclosure need not worry you. This is the cheapest and most satisfactory form of mounting. But you will need more bass power in your amplifier to give the same seeming volume.

(5) After this, probably the best form of enclosure for a woofer is the corner horn. But it cannot really be inexpensive.

(6) The bass-reflex cabinet if properly balanced can run it very close. If an extended response in the bass is aimed at, such a cabinet must be large—as much as 9 cu. ft. or more. For a small room, however, excellent results can be obtained from a 4–5 cu. ft. cabinet and an 8-in. unit, provided that attention is paid to the damping in the cabinet.

11.6 The Old Story

One final word of advice—in repetition of what has been said several times before.

In a small room do not attempt to have a heavy bass response. Let it taper away below about 60 c/s. Otherwise, what you will get will not be worth having and will only become wearisome.

XII

INSTALLATION AND MAINTENANCE

12.1 Principles of Installation

In choosing the various items of equipment you will no doubt have had in mind some general idea of how and where you will instal them. The loud-speaker will of course be either in a wall, the door of a closet or in a corner baffle or enclosure. The amplifier and control unit, the turntable, the F.M. tuner (and possibly also the tape recorder) will be housed in a separate cabinet or on built-in shelves or something of that sort, with at any rate a moderate provision for record storage close by. Some people like to have them in a low trolley which can be moved across the room into proximity with the user's armchair; but that is only feasible when the floors are level or when special provision is made in the trolley for *ad hoc* levelling of the motor board.

12.11 Levelling a Turntable

This matter of levelling of the turntable is one of the most important items in the installation; and it must be a dynamic levelling and not merely a static one such as one would get with spirit-levels.

12.12 Side Pressure

In the chapter on pickups it is explained that when the side pressure between stylus and groove walls exceeds a certain amount, there will be a tendency for the stylus to ride up the wall of the groove. The result will be distortion at the best, but it may also be excessive record wear culminating in the ejection of the stylus at high velocity from the groove. If there is any permanent side pressure due to faulty levelling or stiff bearings in the carrying arm, there is clearly less margin for the reactive forces generated by the stylus. This is explained more fully in Chapter VI.

12.13 Dynamic Levelling

So once it has been checked that the bearings are not stiff or uneven, the process of dynamic levelling aims at balancing out all the permanent forces that lead to side pressure. The criterion obviously is: will the stylus stay put on a blank record when the turntable is moving? Fortunately for this purpose many of the old 78 r.p.m. records had no run-in grooves on the outside of the record and no run-out groove at the inside near the label; better still, some of them were single sided and had a completely plain, unrecorded surface on the back. So to get an accurate dynamic level, put one of these records on the turntable, start the motor and put the pickup down carefully, first on the outside unrecorded rim, and check whether there is a tendency for it to move inwards or outwards: it must be done gingerly since it would probably damage the stylus if it were allowed to be thrown off the edge of the record. Next, see whether there is a tendency for inward or outward swing on the unrecorded surface near the label.

If the turntable is statically level and the bearings of the pick-up arm are exactly vertical and horizontal there should be a tendency for inward swing at both places; and if the tracking error is small at all points the inward pressure should be the same. To correct this, the obvious plan is to tilt the motor board slightly so that the spindle is at a slightly higher point than the outside groove along the tracking arc of the pickup: so that the stylus has to move slightly uphill, as it were, in its path across the record. If the pickup arm is flexibly mounted on the motor board a slight tilt of the vertical axis would tend to the same result; but this is somewhat risky since it may mean that the stylus will not enter squarely into the groove. This latter point should therefore be carefully watched by placing a small mirror on the turntable, resting the pickup on it (turntable stationary) and observing the stylus angle.

Similarly, if there is a tendency for outward swing (which is unlikely) a tilting of the motor board in the reverse direction will be called for.

It may be found, however, at the first attempt, that there is a greater tendency for inward swing at the outside of the record than at the inside. This means that the part of the motor board where the carrying arm is mounted is higher than at the spindle and the remedy is to tilt it the other way.

By this process of checking and adjustment it is possible to ensure that there is no tendency at all for inward or outward swing at any part of the record.

Do not neglect this adjustment, and recheck it from time to time. It will avoid a lot of heartburning and record wear. It applies, of course, whatever sort of mounting is provided for the turntable and motor. But it is likely to be of the greatest importance if that mounting is in a moveable unit such as a trolley, or a drawer or a portable record player. In all these cases it is a wise precaution to arrange from the start that the turntable is dynamically level when the surround to the motor board in the carrying case is statically level as shown by a small spirit-level placed on it in two directions at right angles. The manufacturer could not possibly secure this in advance; but you can, and you will save expensive records if you do.

12.2 Position of Carrying Arm

The dynamic levelling process applies at whatever position the carrying arm is mounted on the motor board. Sometimes that position is fixed by the makers of the turntable unit. If, however, you have a choice then there are one or two points that should be borne in mind in fixing the position:

(1) It is best that the pickup head should not pass over the driving motor during its transit across the record.

(2) To obtain the minimum tracking error for standard arms the mounting position should give the required overlap when the stylus is carried across to the spindle. The required overlap depends on the amount of linear offset of the arm and can be determined from the table in the appendix to Chapter VI. As a check, use an alignment protractor, or a piece of foolscap with lines drawn on it at right angles, to ensure that the tracking error is zero at a radius of 2·5 in. from the centre of the spindle.

(3) If the arm has an overhang for weight adjustment behind the horizontal bearings, it is a good plan to mount it across the front of the cabinet with the bearings on the right. One can then lift the pickup from the record by pressing down

on the overhang with the right hand and catching hold of the pickup in the air with the left. This saves a lot of fumbling and consequent damage.

(4) In its off position the pickup head should not be above the on-off switch, since it is important that the motor should always be switched off there, thus retracting the driving wheel, and not at some external switch (e.g. on the amplifier).

(5) On the underside of the motor board adjacent to the base of the pickup it is useful to have a small screened box into which a coaxial socket has been mounted. The connecting lead from the pickup is usually a very thin screened wire and if you allow this to trail about you will encounter trouble sooner or later. Therefore, terminate this lead at the coaxial socket inside the small screened box and take the connexions on from there by means of a coaxial cable and plug. The pickup arm (if metal) and probably also the motor unit should be earthed at this screened box and not elsewhere. But experiment with places for earthing the motor unit to give minimum hum.

12.3 Input Connexions to Control Unit

The control unit and tuner will, of course, be mounted in an accessible position. All input connexions to the control unit must be in screened cable, and preferably in low-loss coaxial cable, with the screen earthed to the chassis of the control unit. If it is desired to insert any pickup compensation unit between the pickup and the input to the control unit, this should be in a screened box and close to the control unit so that the coaxial lead from the box to the input terminal is as short as possible. This applies also to the matching transformer between a moving coil pickup and the control unit, with the additional precaution in this case that the screened box containing the transformer should be made of mu-metal and its orientation may be of importance relative to the direction of the turntable motor, the mains transformer on the amplifier chassis or any other unit that has a magnetic field.

With modern amplifiers and control units the most meticulous precautions are advised for all input connexions, both in screening and in properly bonded and, if necessary, soldered joints. Only in this way can one reasonably expect to obtain a silent background, free from hum, crackles and other distracting noises.

Remember, a completely silent background means everything to the quality of reproduction at both ends of the scale. You just cannot obtain a clean reproduction of the double basses in an orchestra, with every note separate and distinct, if they are overlaid with hum. Any attempt in such circumstances to increase or extend bass response is worse than futile.

12.4 Amplifier Connexions

The connexion from control unit to the main amplifier is sometimes made by a screened multiple cable provided with the amplifier and sometimes by a single coaxial cable for the audio signal and separate cables for the low- and high-tension electrical supplies. If, however, no connecting cable is provided, the important thing to remember is that the signal lead should be by coaxial or screened cable and the H.T. + by separately screened cable, whilst the L.T. is by heavier gauge flex. The earth connexion carrying signal current should be made by an insulated wire and not by the two screens, which should be connected only to the negative input socket.

12.5 Position of Amplifier

Subject to two important considerations the main amplifier can be placed in any convenient position. But remember that the rectifier and output valves develop quite a lot of heat and therefore the place chosen should give good ventilation: valves and all other components last longer if they are not allowed to overheat. The second point to remember is that the mains transformer, choke and output transformer can produce a strong magnetic field and it is therefore well to keep the inputs to the control unit and particularly any input transformer, whether for microphone, pickup or tape, well away from them. Having regard to these points a position low down in a cabinet seems to commend itself; but do not put the amplifier flat on a shelf so that no air can circulate underneath it; put it on cross runners so as to allow about 1-in. gap underneath. Power and rectifier valves should be vertical.

12.6 Power Supply Connexions for External Units

Some amplifiers or control units have special output arrangements to supply power to other units. Thus there might be an A.C. mains outlet so that the gramophone motor might be switched on and off at the main amplifier switch. But do not use it in this way: any temptation not to use the motor switch which also retracts the driving wheel should be avoided. Similarly, be particularly careful about using the H.T. and L.T. external supplies for tuners. The H.T. output may be of too high a voltage and require the insertion of a 'voltage-dropping resistance' and the 6·3-volt A.C. output may be centre tapped either to earth or to some point of positive D.C. potential within the amplifier, and this may not suit the particular tuning unit.

The author prefers in all cases to have a separate 'power pack' for external tuners. There is, however, no objection to taking the A.C. mains supply for such a power pack from the supply on the main amplifier or control unit, so that all these should be controlled by the same on-off switch.

Near the point where the A.C. mains supply enters the cabinet it is well to have twin fuses, one in each lead: 5-amp fuses are usually adequate. Another desirable addition at this point is a high-frequency mains filter. There are many TV sets in use which inject high-frequency oscillations into the mains and these sometimes interfere with feedback amplifiers, some of which indeed may be on the verge of instability at very high frequencies. Such amplifiers have been known to give a ghostly output of a television sound programme even when no tuner is connected!

These installation suggestions may seem rather elaborate and most of them you will not find in any book of instructions, which usually try to make it appear that putting a hi-fi installation together, with its thought-out collection of plug-in units, is mere child's play. But it is a significant fact that most of the correspondence received during the past few years by the author as Technical Editor of *The Gramophone* has been concerned with faults due to insufficient care in connecting up. These may not have appeared at the start, but you can depend upon it that slipshod work will sooner or later lead to trouble which then may not be easy to diagnose.

12.7 Periodic Overhauls

Again, sufficient attention is not usually given to the need for a periodic overhaul. 'I have had this set for five years, old chap, and it has never given any trouble: I have not even had to change a valve!' By that time, no doubt, the power output had decreased to a small fraction of its original amount and the distortion had mounted to 10 or 20 per cent. For adequate maintenance, then, pickup, turntable, amplifier and control unit should be serviced by a competent engineer not less than once a year. There has been a dearth of competent servicemen but gradually quite a number of firms have begun to specialize in the sale and service of high fidelity equipment. It will pay you handsomely to find out such a firm and to make friends with them in all your dealings.

12.8 Fault Diagnosis

The necessity for regular maintenance service does not on the other hand do away with the desirability of being able to recognize faults as they occur. Let us therefore look at a few of the most common.

12.81 Hum

This can be of two kinds. The first is of steady pitch of the mains frequency or of twice the mains frequency (i.e. 50 or 100 c/s) and may be due to having multiple earthing points, with 'earth loops' as they are called between them, unsatisfactory placing of components that are sensitive to a magnetic field, inadequate screening of leads or components that are at high signal potentials or even to faulty valves or other components. Sometimes reversing one or more pairs of A.C. connexions may work a miracle; and remember that if you have three power connexions, e.g. to amplifier power pack, to gramophone motor and to tuner power pack, there are eight possible combinations. Thus:

(*a*)	(*b*)	(*c*)	(*d*)	(*e*)	(*f*)	(*g*)	(*h*)
1,2	2,1	1,2	1,2	2,1	2,1	2,1	1,2
3,4	3,4	4,3	3,4	4,3	3,4	4,3	4,3
5,6	5,6	5,6	6,5	5,6	6,5	6,5	6,5

The second kind of hum is of varying pitch and is most probably due to faulty valves.

Most hum and other noises in an amplifier or control unit, however, are due to more subtle causes. The logical and systematic way of tracing them is to earth the grid of each valve in succession, beginning at the output valves. If the hum disappears then the fault is before that earthing point; if it persists it is after that point. If it continues but at reduced strength it is most probably due to faults in the rectifier valve or other components (e.g. electrolytic smoothing or decoupling condensers) in the power pack. In the case of an R.F. tuner, see what happens when a 0·1 mfd. tubular paper condenser is connected across the electrolytic. If it cleans up the hum you will obviously leave it there, but it may be wise none the less to change the electrolytic. If you can, try changing the rectifier valve as well and have the old one tested on a valve tester.

If the hum or other noise is due to a faulty valve it will usually be found that the culprit is either the first valve in the control unit or the valve immediately preceding the bass and treble controls. So it may save a lot of trouble in the long run if you have spares of these two valves always available.

Sometimes a kind of hum may be caused if there is too high an impedance across the grid circuit of the control unit, e.g. if a high impedance pickup is connected without proper matching. This usually means that there is some positive feedback tending to instability in the control unit. This may often be cured by connecting, say, a 220,000 ohm resistance in the lead from high impedance pickup to grid and a 22,000 ohm resistance directly between grid and earth of the first valve. But this, of course, will reduce the input from the pickup to valve to 1/11 of its former value.

12.82 Acoustic Feedback

Other growls and queer noises may be caused by motor rumble (see Sect. 6.9) or by 'acoustic feedback'. The latter is caused by the sound from the loud-speaker reacting either by direct transmission, or by reflection from the walls or floor, on the pickup or valves. The effect may be a build-up of either a persistent growl or just a muddy bass. In radiograms where the speaker is in the same cabinet as the pickup and pre-amp there is very little that the user can do about it beyond mounting the pickup arm on a resilient support and making sure that none of the valves is microphonic (tap them and see whether they produce a pronounced ring in the speaker). Where the speaker is in a separate enclosure it should not be difficult to find relative positions which will minimize the trouble.

12.83 Instability

Perhaps the most difficult form of low-frequency trouble, which might be variously described as hum or growling or rumble or boom, is due to instability in the amplifier. Sometimes this is revealed when the stylus is gently flicked with the volume control well up. If the sound is more than a single staccato swish in the loud-speaker then the amplifier is suspect. Incipient high-frequency instability in the amplifier produces quite different effects, from screech in the treble to a certain 'tizziness' on the strings. If there should be instability in the amplifier the best advice for the ordinary man is: consult an expert; and, please, not just by correspondence for such faults must be analysed on the spot.

12.84 Intermittent Noises

One of the easiest troubles to diagnose, but which on the other hand may not be easy to find, is an intermittent crackle, e.g. when someone walks heavily across the room or strikes the amplifier cabinet. At once the suspicion arises: bad contact. The next step is to go about tapping a wire here or shaking another there—with an insulated rod, of course. Sometimes, however, the bad contact is in a valve holder or a dirty valve pin. It is not a bad practice to scrape the valve pins occasionally with a pen-knife, being particularly careful not to bend them. Sometimes the intermittent contact is inside a component, e.g. a condenser, intermittently shorting to case, or even a broken wire inside a length of insulated sleeving. It may be the very devil to find.

12.85 Voltage Checks

A fault which suddenly appears is usually less difficult to find, provided it persists, than one which has grown up gradually.

Usually only a thorough check with instruments will reveal the latter. Hence the peculiar value of a regular service check. Sometimes, however, a voltage check with a high resistance voltmeter at special points marked on the circuit diagram in the makers' instruction book may yield valuable information. Thus, if the voltage is low at one place and not at another one would suspect a leaky by-pass condenser or, more rarely, a faulty resistance. The standard voltage at various points should therefore be ascertained when the amplifier is new.

12.86 Blown Fuses

Suppose, again, that a fuse suddenly blows. What would you do? Well, fuses do go wrong sometimes so I suppose you would replace the fuse. If it blows again, what then? Replace it and before switching on remove the rectifier valve. If it blows again the fault is clearly either a short circuit in the mains lead or in a filament circuit or the mains transformer, including that of the pilot bulb. If it does not blow, the fault was probably in the rectifier and replacement will effect a cure. If it doesn't, take out all the valves except rectifier and outputs. If fuse still blows, replace output valves. If after that you still have trouble call in a serviceman.

12.9 Pickup Faults

Faults in pickup cartridges usually reveal themselves unmistakably by reduction of frequency response or harshness; there may even be a tendency to jump the grooves or to stick in the same groove. If this occurs, suspect, first of all, the bearings of the carrying arm. In one make of arm that the author has found to give repeated trouble in this way the cause was ultimately traced to a silicone grease that had been used to give a slight damping effect at the bearings; in practice the damping had become sticky. The second suspect is the damping in the pickup itself. If the design makes use of little pads of rubber or plastic, or of rubber or plastic sleeving round a bearing, remember that these will deteriorate in use. Unfortunately, a number of modern pickups still depend for their range and freedom from distortion on the achievement of critical damping, whether by means of rubber, plastic or grease.

Again, if an armature or cantilever of a magnetic pickup is displaced from its neutral, central position between two magnetic poles the resulting distortion may be pronounced. The remedy, of course, is gently to re-centralize the reed with a pair of non-magnetic tweezers, or buy a new pickup!

XIII

TAPE RECORDERS

13.1 Magnetic Recording

Some general considerations about the value and use of magnetic tape recorders have already been mentioned in the first chapter. We now proceed to consider problems relating to their design and operation.

It will probably come as a surprise to many people to learn that the idea of magnetic recording is almost sixty years old, a device for recording on steel tape or wire having been patented by the Dane, Vlademar Poulsen, in 1898. For many years it remained just a scientific toy, notwithstanding the improvements that were made by Blattner and Stille in Germany, and the transformation that valve amplifiers made to the prospects of success. The modern development was due to the pressure of the Second World War, particularly in Germany, and in particular to the production of a plastic tape coated with a ferric oxide powder. After the war the allies appropriated this invention, along with others that the Germans had evolved during the war, and thereafter development continued at a rapid pace.

13.11 Magnetic Tape

Magnetic tape, then, consists of millions of microscopic magnetic particles arranged at random on the surface of a plastic ribbon. When this ribbon passes a magnet the pattern of the magnetism of these particles is altered by the lines of force produced by the magnet. The design of a magnetic tape recorder thus depends on that of a 'recording head' in which the presence of electric signals, corresponding in wave-form to the sound pressures in the microphone at the beginning of the chain, produces a variable magnetic force to alter the pattern of these tiny magnetic particles as they pass along in front of it. A schematic diagram is seen in plan in

Fig. 37. It will be seen that the orientation of the magnetic particles is accomplished by the variation of the magnetic field across a thin gap in the magnetic circuit.

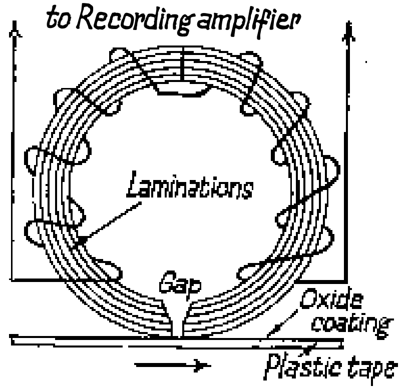


Figure 37
Tape Recording Head.

13.2 Tape Transport

From this it appears that the two fundamental requirements are, firstly, that the tape should be carried across the gap at a predetermined speed and, secondly, that the gap should be such that the magnetic effect of it on the tape should follow closely, and in a determinate fashion, the variations of signal in the coil. Normally, the tape speed is constant at so many inches per second (i.p.s.).

13.21 Speed Constancy

For musical reproduction a variation of speed of 0·3 per cent is perceptible to the ear (Sect. 2.6), and the better instruments therefore aim at keeping any variation to less than half this amount.

To secure constancy of speed to such a close limit the tape must clearly be controlled, not by the spool on which it is wound or unwound, but by some mechanism along its length as it passes the magnetic gap. This mechanism is usually in the form of a heavy non-magnetic capstan wheel against which the tape is pressed by a rubber drive wheel. The linear speed of the tape is then determined by the diameter and angular speed of the capstan.

13.22 Capstan Drives

Some machines have a large diameter capstan with a low speed of rotation; others have a smaller diameter and a higher rotational speed. With the latter a direct drive from the shaft of a motor may be feasible, but the tolerances in the dimensions are extremely small—less than 1/10,000 in. for a 0·2 per cent peak flutter. With the former, some mechanism for reduction from the speed of the driving motor becomes necessary. Gear wheels have proved to be expensive and unreliable, so a friction drive similar to that now used for gramophone turntables has been developed, and this permits of a ready adaption for change of speed from one standard to another.

13.23 Standard Speeds and Responses

The standard speeds now used are 30 i.p.s. and 15 i.p.s. for professional equipment and 7½ i.p.s. and 3¾ i.p.s. for domestic equipment. With the higher speeds a better treble response can be obtained. At one time it was reckoned that the limit of response was 1,000 c/s for each inch per second of tape travel. That is, the upper limit for 7½ i.p.s. would be 7,500 c/s. With modern machines and tapes, however, nearly double this range can be obtained.

13.24 Tape Tension

As the tape is unwound from one spool it passes along a line containing the magnetic heads and the capstan drive and thence to the take-up spool. It is therefore essential that the latter should also be driven at a speed consistent with the capstan drive. This requirement gives rise to quite troublesome mechanical problems. Ideally, the tape should be in uniform tension throughout its length between the two spools so that the tape motion may be controlled only by the capstan.

This ideal has not yet been achieved, so the alternative has been followed in practical designs of introducing a fairly large frictional drag on the tape by means of frictional pads close to the magnetic heads. This, of course, is just another application of an old principle: what you cannot avoid (i.e. difference of tension, in this case) make negligible.

Obviously, when the tape is moving from left to right, as it usually does, there must be a small forward tension to the right and a back tension to the left. These tensions may be supplied by separate motors from that which drives the capstan; but in some designs they have been provided by a semi-rigid transmission from the same motor. But that is not all. For convenience, a fast wind or rewind, both ways, is required and the same spool driving device, be it a separate motor or a transmission from the common motor, should be adaptable to provide that fast drive as well.

13.25 Spool Drives

Much ingenuity has already been devoted in various inventions to these forward and backward drives so as to secure reasonably consistent tensioning, both on the slow-playing motion and on the fast wind and wind back. At one time it was not unusual for the tape to spill off the spools and to become entangled, and what could be more annoying than this? Any unit which shows the slightest tendency to spill out the tape should be forthwith rejected. With modern designs there is no need whatever for this to happen. It is a poor design if it is even possible. Moreover, the tensioning and the braking should be such that a uniform and regular spooling should result even from a fast wind. If the tension is too small the tape will be too loose on the spool and will slip in storage; if it is too tight there will be a tendency for it to stretch to the detriment of the musical time intervals.

13.3 Magnetic Heads

The same magnetic head can be used both for recording and for playback. But the best professional models separate the two functions and have different heads, spaced a few inches apart. There are two advantages in this: first, the optimum gap for playback is not the same as that for recording though the difference is not very great; and second, it is an advantage in professional circumstances to be able to play back *from the tape* through a monitor system so that an imperfect recording may be immediately rejected. For domestic apparatus these advantages are not usually considered to be sufficient to outweigh the additional expense of the additional head, and a single, compromise design is usually adopted. This in fact limits the possible high-frequency response, and it may therefore be that one day we shall see high fidelity models made available with separate recording and playback heads.

13.31 High-Frequency Bias

One of the major advances in magnetic recording was made when, in 1941, the Germans re-applied an earlier American discovery of adding a high-frequency 'bias' signal to the tape as well as the audio signal. This bias seems to make the magnetic particles much more amenable to change of pattern! It is found, however, that the optimum high frequency varies appreciably with the type of tape: one make may require more than another. It also varies with the impedance of the recording head. A bias of 50 kc/s is commonly used; but for a frequency response up to 15 kc/s it is an advantage to have a still higher bias frequency; 100 kc/s is not too much. Moreover, a relatively high voltage should be available at that frequency and the wave-form must be particularly pure. It is here, in fact, that some of the better types of tape recorder score over their less expensive competitors: to provide adequate bias of the required purity one should use a small power valve oscillator at a relatively high voltage; push-pull oscillators are particularly effective.

13.32 Magnetic Pole-pieces

Another crucial feature of a good design is in the shape and finish of the pole-pieces forming the magnetic gap in the recording replay head. The high-frequency loss is considerable during replay if the width of the gap is comparable to a quarter wave-length of the signal on the tape. At a tape speed of 7½ i.p.s. the quarter wave-length of a 10 kc/s signal is $0{\cdot}19 \times 10^{-3}$ in. The width of the gap should therefore be substantially less than this. A gap of 1/10,000 in. is not impossible, with edges as nearly parallel as makes no matter and with a high degree of surface polish.

13.4 Recording-Replay Characteristic

Even with the best finish, however, the undoctored recording-replay frequency characteristic on a magnetic tape is nothing like uniform throughout the scale. At the low end there is a 6 db per octave rise in output with increasing frequency followed by a much larger fall above about 4,000 c/s due to losses in the tape and in the recording process (Fig. 38). These losses must be corrected either by pre-emphasis before recording or boosting in replay or both. The correction for high note loss used to be

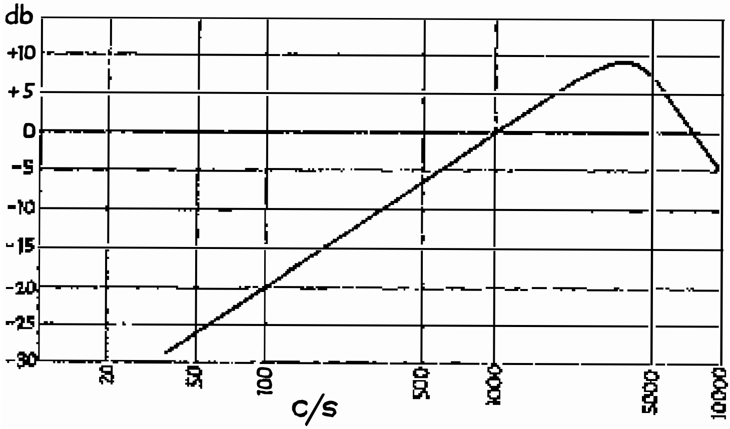


Figure 38
Uncorrected Response from Tape and Magnetic Head.

divided between the two in some instruments; the correction for low note loss has to be made in replay only, because the high energy contained in low notes may saturate the tape.

13.41 Equalization for Tape Losses

The standard adopted by the British Standards Institution for this purpose is the same as that recommended by the International Consultative Committee for Radio-communication (C.C.I.R.). The compensation for treble losses has now to be made in the recording amplifier; that for bass losses is made in the replay amplifier as shown in Fig. 39.

Unfortunately, some domestic recorders, and particularly those made some years ago, do not follow this standard. The result is that tapes recorded on some machines will not play back on a standard machine without special frequency adjustment. In that case, too, the standard commercial tapes will not play back, without special frequency compensation, on the non-standard machine.

It is therefore highly important for a purchaser to make sure in advance that the machine he proposes to buy both records and plays back in accordance with the C.C.I.R. standard (Fig. 39).

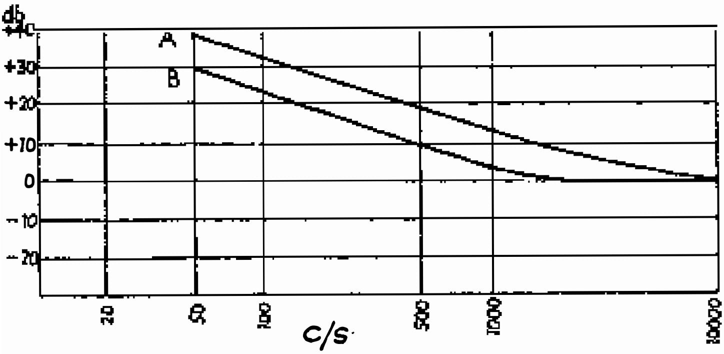


Figure 39

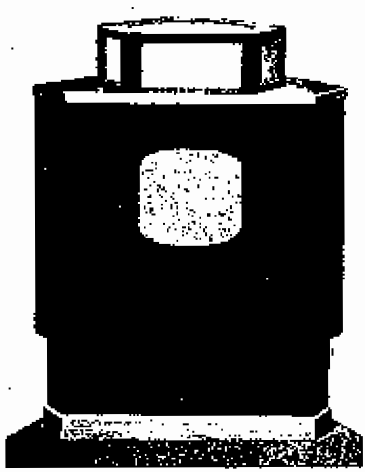
Standard Replay Characteristics.

Curve A: 30 in./sec. and 15 in./sec.

Curve B: 7½ in./sec.

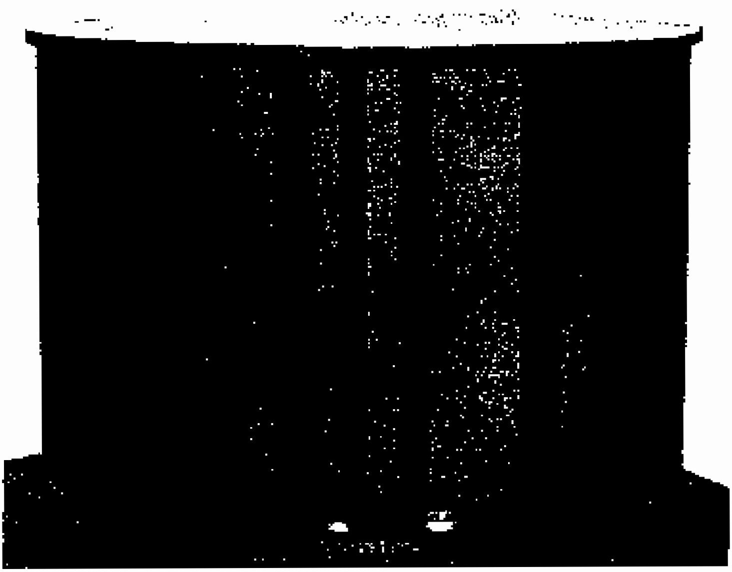
13.42 Azimuth Alignment

Another cause of difference in playback characteristics between two machines can arise from the alignment of the heads. According to the standard specification the magnetic gap should be exactly at right angles to the direction of motion of the tape. If it is tilted ever so slightly a substantial loss of high-note response may result: an error of 1° may cause a loss of over 10 db at 12 kc/s, whilst a 5° error may cause a loss of 20 db at 10 kc/s. The best modern instruments therefore incorporate some means of 'azimuth adjustment' as it is called. The adjustment is made in practice by measuring the electrical output from a standard tape on which a pure high-frequency note has been recorded. Various frequencies have been used for this purpose but probably the most satisfactory 'alignment tape' has a wave-length of 0·001 in. The azimuth adjustment is correct when the maximum output from this tape is obtained.



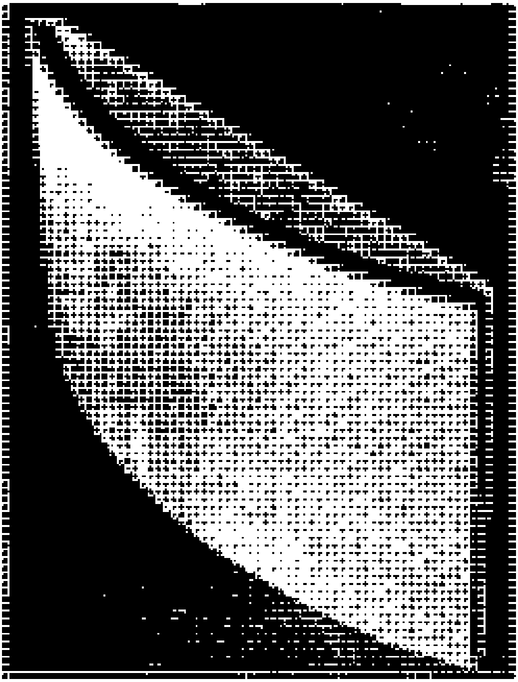
(*a*) Wharfedale Three-
Speaker System

(*b*) Pamphonic Victor
Loud-speaker

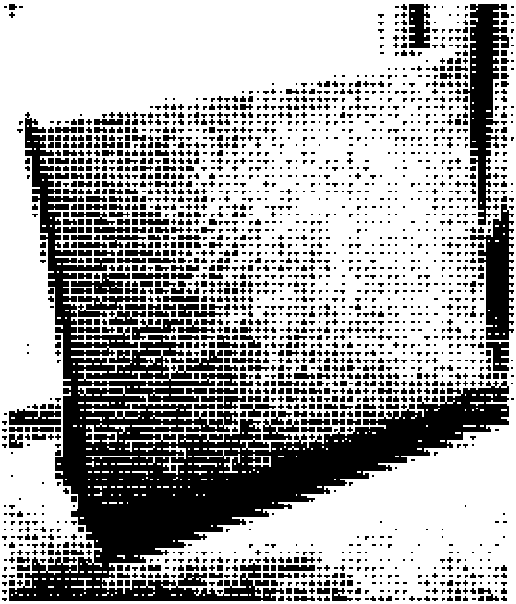


(*c*) Sound Sales Tri-Channel System

XIII LOUD-SPEAKER SYSTEMS



(*a*) Leak Electrostatic Loud-speaker



(*b*) Acoustical Electrostatic Loud-speaker

13.43 Checking Wow and Flutter

Another use for this tape is to check tape speed accurately. For if the tape is running at $7\frac{1}{2}$ i.p.s. the frequency produced is 7,500 c/s, and in general the frequency produced in kc/s is equal to the tape speed in inches per second. So by comparing the audible frequency with some standard a rapid check of tape speed is possible.

Instruments for measuring 'wow' and 'flutter' have also been designed on the same principle and consist essentially of what is really a F.M. tuner, but built so as to tune to the expected audio frequency instead of to radio frequencies. If the audio note from the tape is unsteady in frequency this constitutes frequency modulation, which can be detected and shown on a meter.

13.5 Erasing

Before recording takes place it is now universal practice to 'wipe the tape clean' by means of an 'erase head' which is activated by a high-frequency current. This cleaning current is automatically applied to the erase head whenever the machine is switched over to the recording position. This switching operation can therefore be quite a risky business: if it is done inadvertently it may obliterate part of a very good recording. Precautions are therefore usually taken to ensure that one has to think twice before going over to 'record' position; sometimes this is done by incorporating a special locking device, but on at least one recorder a link has to be inserted in the line between the H.F. oscillator and the erase head before the latter can be brought into action.

13.6 Tape Specifications

The dimensions of magnetic tape have now been pretty well standardized throughout the world. It is $\frac{1}{4}$ in. wide and is normally supplied for domestic purposes in 5- or 7-in. spools, containing respectively 600 or 1,200 ft. of tape. Some machines, however, will take spools up to $8\frac{1}{2}$ in. diameter, containing 1,750 or 1,800 ft. of tape. Recently, a thinner tape has been produced to give about one and a half times the standard length on each spool.

13.61 Playing Times

The playing times for one unwinding of a spool are therefore as shown in the following table:

			$3\frac{3}{4}$ *i.p.s.*	$7\frac{1}{2}$ *i.p.s.*	15 *i.p.s.*
5 in.	Standard Tape	600 ft.	30 min.	15 min.	$7\frac{1}{2}$ min.
	Thin Tape	900 ft.	45 min.	$22\frac{1}{2}$ min.	11 min.
7 in.	Standard Tape	1,200 ft.	60 min.	30 min.	15 min.
	Thin Tape	1,800 ft.	90 min.	45 min.	$22\frac{1}{2}$ min.

13.62 Twin Tracks

In domestic instruments only half the width of the tape is used in each transit, and the spools can then be reversed and the other

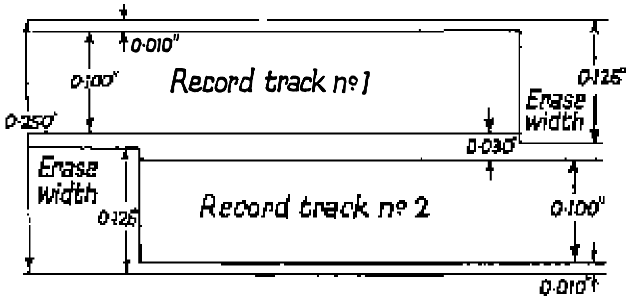


Figure 40

Dual Track Dimensions.

half recorded in the reverse direction. In these circumstances, of course, the playing time for each spool will be double that given in the foregoing table.

13.63 Recording in Both Directions

Reversal of spools, however, may take a considerable time and instruments are now available which will record (and replay) both from left to right and right to left, the top half of the tape being recorded from left to right and the bottom half in the reverse direction. In that case a practically continuous recording can be made for the two halves, the change-over time being only a fraction of a second. This is a great boon when one is recording, say, an opera, for it often seems to happen, such is the cussedness of things, that a single act lasts rather longer than one track of a reel of tape. The procedure then is to look out for a short interval—the end of a solo, or chorus or whatever it may be—to make the change. Later, if desired, the length of tape beyond the change-over can be cut off.

13.64 Editing

This consideration leads to another which illustrates both the versatility of a tape recorder and the limitation of a twin-track as compared with a single-track machine: the facility for 'editing'. This arises from the fact that, with care, two pieces of tape can be spliced together in such a way that the join cannot be heard. So additions can be made to a recording, unwanted sections cut out or minor alterations made without the change being apparent in the final result. You can cut out anything you don't want, from a click or single word to a complete section of the recording. Or you can rearrange the sequence of various recordings into whatever programme you like.

13.65 Splicing

Moreover, the pieces of tape cut out can be joined together and used again. Precision 'tape slicers' are now available for the purpose at a very reasonable price.

The splicing of single-track tapes is thus a matter of simplicity, which is one of the reasons why recording companies always use single-track machines. (Another is that signal/noise ratio is better in that case.) With twin-track machines, editing is not so easy. But it is still possible, provided one decides in advance to use only one track of a new spool of tape for any recording which may subsequently require editing. Then, after the editing has been carried out, the second track can be filled in for recording another programme which does not require editing.

13.66 Cueing

To be fully effective this facility of editing really calls for another device which, unfortunately, is rarely provided (at all events in a convenient form) on domestic machines: a 'cueing' indicator.

Such a device is clearly desirable, apart altogether from editing, in order that one may readily pick out any part of a recording one wishes. Most machines have a radius scale marked either on the deck or on the spokes of the spool; but these are altogether too rough to be very ready. The most satisfactory device is a clock or other form of counter worked by a belt or friction drive from the capstan. But it would also be an advantage for precision measurements if a scale were printed on the back of the tape; the fact that part of it might be cut out in editing would not really affect its usefulness.

13.67 Recording-Level Meters
Another device which should be regarded as an essential for all tape recorders is a recording-level indicator. This can be in the form of a 'magic eye' which is commonly used in the better types of radio tuners. The 'twin shadow' type is better for this purpose than the single shadow. The minimum recording-level is then indicated by the beginning of the first shadow and the maximum level by the complete closure of the second shadow. But the most satisfactory type of indicator is undoubtedly a peak meter which gives a quantitative measure of the recording-level.

13.68 Printing
The effective life of a tape recording cannot at present be estimated with any certainty. In laboratory conditions tapes have been played many thousands of times with no appreciable deterioration of the music. And it is clear that recording companies and broadcasting corporations would not be likely to keep their master recordings on tape if deterioration were a serious problem. There is, however, one matter in this connexion which does give cause for some care: the possibility of magnetic 'printing' from one layer in a spool to the next during storage. This partly depends on the thickness of the tape, but more on the magnetic properties of the oxide coating in low-induction fields. With modern tapes the print is less than 60 db below the direct recording after a few days contact. But the ratio might be appreciably greater if contact were maintained over a considerable period. For this reason some authorities advise periodic respooling of tapes, whether by replay or by deliberate unwind and rewind.

13.7 Stereophonic Tapes

The production of commercial stereophonic tapes (see next chapter) may have a profound influence on the future design of domestic tape recorders. On these tapes both tracks are recorded simultaneously, the top track from one microphone and the bottom track from another, but with a determinate phase difference between the two. For reproduction, therefore, one needs a double recording-replay head, feeding into separate amplifier and loud-speaker systems. By suitable switching arrangements the same head could be used to record and replay as ordinary twin-track system with reversal of tape direction as described above (Sect. 13.63), and it could be so used even though, in the first instance, expense precluded the installation of a second amplifier and loud-speaker system.

13.8 Minimum Requirements

The minimum requirements for a tape deck in the near future are therefore likely to be:

(1) 'Wow' and 'flutter' content less than 2 per cent.
(2) Playing speeds: $7\frac{1}{2}$ and $3\frac{3}{4}$ i.p.s.
(3) Frequency response: 40 to 12,000 c/s $\pm$ 3 db at $7\frac{1}{2}$ i.p.s.
40 to 8,000 c/s $\pm$ 3 db at $3\frac{3}{4}$ i.p.s.
(4) Double record/replay head (top and bottom) with gap of not more than 0·0002 in.
(5) Motor reversing for record/replay in either direction.
(6) Quick wind and rewind.
(7) Adequate braking to obviate tape spill.
(8) Space for $8\frac{1}{2}$-in. spools.
(9) Accurate tape position, or cueing, device.
(10) Max./min. recording-level meter.
(11) Safety device to prevent inadvertent erase.
(12) R.F. bias of pure wave-form at 80–100 kc/s.

13.81 Switching

There is room for difference of opinion at present about the type of switching control that is most satisfactory. For ease of operation many people prefer the push-button type but that usually means either relatively long wiring or an extremely compact amplifier unit arranged to be close to the tape deck. Both can lead to serious difficulties in the matter of hum-level; and the latter may also make servicing more difficult. For these reasons some manufacturers favour controls that operate through a mechanical linkage for then the switches may be located close to the electrical circuits affected and the wiring can be kept short. Whichever system is adopted there can be no dispute that a hum and noise level of better than —50 db at full power is needed. This is a very exacting requirement and can only be achieved if the utmost care is taken in the design and layout of the pre-amplifier.

13.82 Transistorized Amplifiers

Because of this exacting requirement some manufactures are now turning to the use of transistors in the early stages of the replay amplifier and it may be that their use in the recording amplifier as well will be favoured before long. Since their current requirements are so economical, small, long-life batteries could be used to operate them and the saving in weight as well as hum-level would be attractive.

13.83 Complete Amplifier or Pre-amp only?

When we consider the amplifier requirements in detail we find two schools of thought again. Those who attach more importance to the recording than to the reproducing facilities, and therefore visualize everyone going about with a tape recorder as they do with a camera, consider that the recorder should be a comparatively light, compact, self-contained instrument from microphone to loud-speaker. Those who regard the tape recorder as part of a high fidelity installation lay stress on the fact that a good output transformer and loud-speaker system, and even a power pack to supply an amplifier of adequate power, cannot be light and portable, and therefore that an internal loud-speaker cannot do more than serve as a monitor; moreover, they argue, very few people really want to carry a recorder about in the same way that they carry a camera: people's voices and the noises of modern life are not nearly so attractive or memorable as the views of nature. If a monitor is required, a pair of stethoscope headphones will serve without all the weight and complication of transformers and speakers.

At the moment the former school is dominant, but there are signs of a swing over to the latter and as soon as the use of transistors becomes more general a change of popular favour to the second school seems likely.

13.84 Output Connexions

Fortunately for the high fidelity enthusiast, provision is made in nearly all current designs for the output from the playback pre-amplifier (i.e. after equalization correction has been applied) to be taken off at high impedance before the output stage of the recorder amplifier. This high impedance output can be fed directly to the control unit of a high fidelity amplifier and the enthusiast's conscience is thus preserved. Do not, if you can avoid it, take the output from the 'external loud-speaker' socket of the recorder except for the simple purpose of feeding an external loud-speaker directly. That can give better quality than the small internal loud-speaker, it is true; but nothing comparable to what can be achieved by the high impedance transfer.

13.85 More Desirable Qualities

So we now have several more items we can add to our list of desirable qualities for a tape recorder viz:

(13) The hum/noise-level should be better than —50 db at full power.
(14) Quality of output should not be sacrificed to portability.
(15) A battery operated, transistorized pre-amplifier is an advantage for replay and, as soon as it becomes feasible and reliable, for recording as well.
(16) A high impedance, high-quality output should be available for use with high fidelity amplifiers.

13.9 Hints on Use

Now to conclude this chapter a few words on the use of a tape recorder. It is such an exciting instrument that the temptation is to start, as soon as you get home, to record in the way that you saw the salesman demonstrate. And, by the way, do not in an excess of enthusiasm buy the most expensive microphone that he has to sell. Only if you have facilities for recording musical performances in large-scale conditions are you likely to need an expensive 'ribbon' microphone with its associated transformer.

For ordinary home conditions much cheaper types are quite adequate. There is, for example, a crystal 'insert' available which can be used in a hand-torch type of rubber container and will give a level response up to 10 kc/s and few amateurs are likely to need anything better than that.

Having got your recorder home your first step should be to study the instruction manual most carefully. Don't risk expensive damage by lack of study. The author knew of one enthusiast who connected up straightway from the output of his amplifier control unit since that seemed to have adequate signal voltage and a special 'tape output' had not been catered for; but he had overlooked that there was a D.C. voltage superimposed on it and that just ruined the input valve of the recording amplifier and damaged some of the precision resistors as well.

13.91 Microphone Input

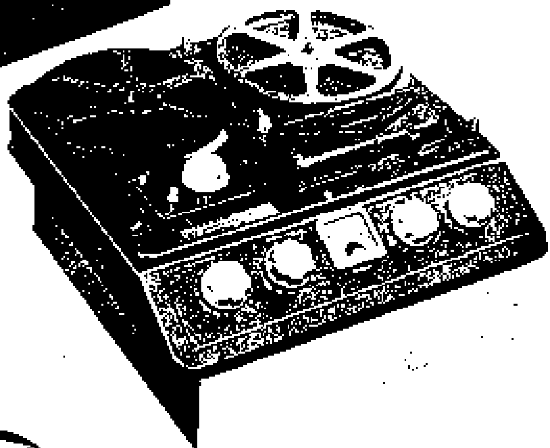
To familiarize yourself with the controls, first of all try to play back from the tape supplied with the instrument. You will probably find that the thoughtful manufacturer has recorded a few bars of music for that very purpose. Then, before changing to expensive commercial tapes, try recording with a microphone. This will make you familiar at the start with the use of the safety device. So you will pick up the microphone, set the machine to record and say a few halting words. You will soon come to a dead stop for lack of something to say and then, to relieve your embarrassment with the assembled company, you will proceed to rewind the tape and go on to replay. After the first few words you will be certain that something is wrong with the microphone or the recorder or both, because your voice could not possibly sound so awful as that! But, wait a minute. Ask your wife, or your husband as the case may be, if that is really how you do sound. You will soon be persuaded that you are not really so golden-tongued as you imagined, and thereafter will be able to record with greater confidence and fluency.

13.92 Radio Input

It is a good plan at this stage to transfer your tape spool to the right-hand spindle and rewind on to an empty spool on the left. This allows the tape tractor mechanism to warm up and it also

(*a*) H.M.V. Tape Player Model 3031

The Gramophone Co. Ltd



(*b*) Ferrograph 66, designed for installation in furniture

(*c*) Collaro Tape Transcriptor

XVI Copying Recorded Tapes: a view of the plant where H.M.V. and Columbia High Fidelity Tape Records are produced *E.M.I. Ltd* loosens the tape on the spool and rewinds at the appropriate tension for your particular machine. After you are satisfied that all is running smoothly you can proceed to the next stage.

This is to connect up the recorder to a radio input. The best way is to connect to the 'tape output' from your amplifier control unit; all up-to-date control units have such a provision and this will enable you to record from either radio or disc—assuming, of course, that a radio tuner is also connected up. But be quite sure you are connected to the appropriate input of the tape recorder.

13.93 Setting the Controls

Set the tone controls of your control unit to the level position. Later on, when you become practised, you may be able to have a little treble boost, but don't try to boost the bass before recording. If you do you will run a risk of tape saturation. Switch on your amplifier and tuner, set the recorder to the record position but with its volume control at zero. Do not, to begin with, start the tape in motion.

Now gradually turn up the volume control and watch carefully what the level indicator is doing. Adjust the setting of the volume control on your amplifier control unit until the level is such that you can get full range of control from minimum to maximum on the recorder volume control. Note particularly the position of this volume control when the level indicator just gives its maximum recording-level reading on the loudest passages. Now turn the recorder volume control back to zero again and wait until just before the radio programme you would like to record is due to begin. Then set the tape running and just before the programme starts turn up the volume control to the optimum recording-level that you have previously noted. All this time, of course, you will have been listening to the radio programme through your ordinary amplifier system and will thus know what is happening on the radio even at the times when you are not recording.

It is well to practice this method of recording until you can make all the preliminary adjustments without having to think about them. Progress is measured not by what you do but by the number of things you can do without thinking. By confining your practice to recording from the radio you will not be doing unnecessary damage, as you might if you were to get practice from recording from discs. It is time enough to start with transfers of this sort when you are quite familiar with the habits of your recorder.

13.94 Transfer from Discs

But why transfer from discs at all? And what about copyright? (See appendix to this chapter.) Well, provided you are transferring for your private and personal enjoyment and experience and not for any public performance or commercial purpose, you will not allow these recondite matters to worry you. All you will be concerned about will be to achieve a recording that will at any rate be the equal of the original disc. If the latter is old or somewhat worn you may be able to improve on the original by judicious use of the tone and filter controls on your amplifier control unit. Subject to that adjustment, the method and connexions for recording are the same as for radio.

It has been suggested by a writer in the American magazine *High Fidelity* that there is a special advantage in transferring to tape even from brand new discs. His argument is, briefly, that one plays records in spasms. At first, when a record is new, one gives it repeated performances until it begins to lose its freshness. One then puts the record away and does not come back to it, maybe, for months. How much better it would be to store the record, unworn and in its pristine beauty! So the writer recommends the following procedure. On acquiring a new record, clean it thoroughly and play it through with the recorder connected up. Watch the recording levels carefully, but do not pretend on this first playing to make a proper recording. This should be done, with all the skill and knowledge of the record that you have acquired, when you play the disc through a second time. After that, the disc can be put away in the store cupboard. Subsequent playings can then be done from the tape, with the happy knowledge that you are not causing any more wear. If you grow weary, temporarily it may be, of that particular performance, or if you run short of tape and need a spool for some special recording, you can wipe out your tape record in the security of having the disc safely stowed away in good condition. Or if you think fit, you can retain your tape recording and sell the disc with the assurance that it is in mint condition.

13.95 Tape Storage

As regards storage of tapes there is little at the moment that can be said. We have already noted the possibility of magnetic printing. It remains to be added that magnetic tape dislikes heat and damp and 'smog', and positively loathes such things as power transformers and fluorescent lighting fixtures. So a tape storage cabinet should be in a cool, dry place and away from these other objectionable items.

After all, as the aforesaid writer remarks, a tape recording, though a scientific miracle, is nothing more than a magnetic pattern which 'finds its source, voice and death in other magnets. Perhaps some day the scientists will give it a built-in sense of discrimination, a morality; but until then the only solution is to keep it carefully away from stray magnetic fields.'

APPENDIX TO CHAPTER XIII

HOME RECORDING AND THE LAW[1]

(Reprinted, by permission, from *The Wireless World.*)

Until the domestic tape recorder became commonplace, the legality or otherwise of making recordings from broadcast transmissions was largely an academic question. The number of people capable of cutting a good disc was never significant, but now, with the help of a modern tape machine, almost anyone living in an area served with a good signal can, by choosing the best of the B.B.C. transmissions, make a recording that compares well with the average long-playing disc. The small amount of skill needed is easily acquired by many ordinary listeners, and the gear needed is neither highly complex nor unduly costly. Is there any legal barrier in the way of making recordings 'off the air' in this way?

The question of copyright as it effects home recording has already been discussed in this journal. But there are other considerations, and the whole matter has been revived by a B.B.C.

[1] *Wireless World*, Vol. 59, No. 12 (December 1953).

statement published in *Radio Times* of October 23. The statement reads:

> 'We have been asked to remind listeners to B.B.C. programmes that in view of the provisions of the Dramatic and Musical Performers' Protection Act, 1925, it is, in certain circumstances, an offence to make recordings by means of tape equipment or otherwise of any dramatic or musical work broadcast by the Corporation without the consent in writing of the performers. Moreover, the making of unauthorized recordings of any copyright material included in B.B.C. programmes may also constitute an infringement of the provisions of the Copyright Act, 1911.
>
> 'The Corporation cannot undertake to secure the consent of performers and owners of copyright material on behalf of parties wishing to record programmes broadcast by the Corporation.'

That statement, though strictly accurate so far as it goes, tells only a part of the story, and is liable to confuse the great body of listeners and potential home recordists.

Let us first consider the effect of the Dramatic and Musical Performers' Protection Act. True, that Act makes it an offence to record directly or 'indirectly' (e.g. through broadcasting) or to sell, hire or use for public performance any recording made without authority. What the B.B.C. statement does not mention is the highly relevant proviso that the home recordist has a valid defence if he can prove that the recording was not made for 'purposes of trade'. Thus it is quite clear that the private individual who makes a recording for his private use—and not for gain—does not commit any offence under the Act.

The ordinary home recordist's position under the Copyright Act is almost equally clear. The essence of the matter is that, for an infringement to be committed, the recording must be played back in circumstances that introduce some element of 'public performance'. In defining the word 'public' the law takes quite a narrow view; for instance, performance in a club to which members only were admitted would almost certainly be ruled to be in public. Also it is not necessary for an admission charge to be made in order to bring the performance into the 'public' category. What seems quite certain is that playback of a recording made 'off the air' is not an infringement if done in the recorder's own home, with an audience limited to his family or intimate circle of friends.

All this seems to be in accordance with common-sense, and we believe that neither performers nor copyright holders are likely to suffer in the long run through the growth of home recording. Indeed it may stimulate public interest in what they have to offer, just as broadcasting stimulated the sale of gramophone records.

There remains the possibility that the law of copyright may soon be altered, but that seems unlikely to affect the position. The present Act is overdue for revision, but the Report of the Copyright Committee, 1952, on whose recommendations the revision will presumably be based, did not touch on the subject of recording 'off the air'.

Finally, it should be emphasized that those who use the B.B.C. transmissions without authority to make recordings for sale or public performance do most certainly infringe the law, and no doubt the B.B.C. warning was directed against those who are 'pirating' the Corporation's transmissions in this reprehensible way.

THE COPYRIGHT BILL, 1956

Note by L. Wilson, M.A., Barrister-at-Law

Since the *Wireless World* note was written a new Copyright Bill has passed most of its stages, and it may be expected to become law late in 1956, replacing the Act of 1911.

The existing law, as outlined in the *Wireless World* note, is broadly reproduced in the new Bill. The Dramatic and Musical Performers' Protection Act, 1925, will remain substantially as at present; and there will be no infringement of copyright if B.B.C. or I.T.A. programmes are recorded for private purposes, i.e. provided the records are not sold, hired or 'played in public'.

One important change is that for playing such records in public the only permission required will be that of the B.B.C. or I.T.A. as the case may be; it will no longer be necessary to secure the consent of the performers or owners of copyright, so long as the recording was not made for 'purposes of trade'.

XIV

1-D, 2-D, 3-D OR 4-D?

14.1 Binaural Listening

It has long been recognized that sound reproduction by the usual methods is lacking in spaciousness, even with the best equipment; and that it fails to convey the sensation of motion, as when a singer walks across a stage.

The explanation usually given, by analogy with the visual experience of a flat picture, is that we are listening monaurally and that to appreciate a sense of direction we need a binaural system.

But such a description is manifestly wrong, for quite obviously we do listen with two ears.

What matters, someone will say, if the effect is the same? But the effect is not quite the same and the distinction is of some importance.

14.2 Double Channels

If it were not so then the only way of achieving any semblance of stereophony would be to have two microphones simulating a human head in recording, with separate recording tracks, separate pickups (or magnetic transducers) in reproduction feeding separate amplifiers and separate earpieces closely coupled to one's head. And even then true correspondence with the original listening conditions would not be achieved, since the dummy head containing the microphones would not move in accordance with the psychological reactions of the listener; and our chance of having swivelling dummy heads which could be moved by some sort of precognitive telepathy seems rather remote!

Of course, such is the enterprise of man, the experiment has been tried, minus the telekinesis, and has proved successful. It was in fact first carried out in 1881 at the Paris Opera House, using telephone earpieces, and it has been repeated several times since. But its public value, beyond confirming a fairly obvious technological expectation, was nil.

14.3 Analysis of Hearing

What was needed was a much more thorough analysis of the process of hearing, so that the various functions of listening to an orchestra spread out in the orchestral pit in front of an operatic stage could be simulated by a different, and more practical, method. In such an analysis very little could be taken for granted on *a priori* grounds. It is still something of a mystery, for example, how it comes about that when a loud-speaker produces a complex sonorous vibration the ear sorts its components out and recombines some of them into a violin note, others into a piano note and so on, and then hears all those notes separately in a musical ensemble. There is no more *a priori* reason to suppose that the ear is capable of doing that than of thinking that it should be able to sort out the mixture from a number of microphones distributed about the stage. And indeed it does do something of the sort, as we have already noted in connexion with infinite baffle mounting and with the all-wave electrostatic loud-speaker, provided that excessive room resonances are not set up. Moreover, a sense of spaciousness and perspective can be simulated to some extent even in a single-channel system of transmission such as we normally use, by the simple device, described in Sect. 9.4, of having two loud-speaker systems spaced apart, one responsive to the bass and middle frequencies and the other responsive to the middle and upper frequencies. But that device does not give any illusion of motion.

To get such an illusion along with the spaciousness, the only successful method, so far, has been to have at least two independent channels of transmission from microphone through separate sound tracks and separate amplifiers to separate loud-speakers (not necessarily, be it noticed, to separate earpieces).

14.4 Stereophonic Recording

The fundamental research that has led at any rate to a partial achievement of stereophonic sound was carried out in the first instance by Blumlein in the British Columbia Graphophone Company's laboratories in 1929–31 (British Patent, 394, 325); and later by a group of American telephone engineers at the Bell Telephone Laboratories.

Blumlein used two separate channels but recorded both in the same groove by an ingenious combination of 'lateral' and 'hill-and-dale' methods (see Sect. 4.1). But after Columbia was amalgamated into E.M.I. the method does not seem to have been pursued. The method of phase differentiation and microphone placing worked out by Blumlein has, however, been revived by E.M.I. in connexion with the new 'stereosonic' tape records. Experimenters are also busy developing the combined hill-and-dale and lateral system of recording. Other experimenters are developing a system in which two different sets of modulation are impressed on a 'carrier modulation' which is recorded in a single groove. It may therefore be that we shall see a successful commercial disc system within the next few years.

14.41 Multiple Channels

The Bell Laboratories experiments, on the other hand, seemed to show that there was advantage to be gained in having more than two independent channels and led to the use of multiple recording tracks on film, and latterly on magnetic tape. Hence the 3-D sound one can hear in Cinerama and some other film shows, where as many as five separate channels may be used to produce the rather terrifying effects.

Some American recording companies have also produced twin channel discs in which separate lateral-cut grooves are used for each channel. This, however, is so wasteful of playing time that it seems probable, unless indeed the single groove system can be satisfactorily developed, that the future of stereophonic recording for domestic use will lie with the double track magnetic tape system, in which both the upper and lower tracks on a twin-track tape are recorded and reproduced at the same time. This system has the advantage of being a straightforward application of stereophonic principles without any complications that arise owing to the difference of groove speed (linear) at the inside and outside of the record. The success that has already been achieved by the E.M.I. 'stereosonic' tapes and by G.E.C. in Great Britain, and by the Philips Research Laboratories on the Continent, seems to show that a new era is dawning in sound reproduction.

14.42 Stereophonic Effects at Low Frequencies

At present, however, there is some controversy still unresolved about the extent to which low-frequency components affect the result. Philips claim that frequencies below about 500 c/s hardly affect the stereophonic response, but this view is not shared by the E.M.I. engineers, who maintain that the separate channels should be maintained throughout the scale. There are also differences of microphone placing in recording. E.M.I. have two directional microphones at right angles and one above the other. Philips have continued the older idea of having the microphones like ears in a dummy head. American companies space them 10 ft. or more apart.

It is possible, of course, that more than one double-channel system, especially as regards spacing characteristics of microphones, may lead to successful stereophony. Once it is appreciated that what is now being attempted is not to reproduce binaural listening but to simulate it in different conditions, the possibilities of combining phase and loudness relationships (which are the important elements in direct binaural listening) are manifold. There is thus considerable scope for development of the stereophonic system.

14.43 Improvement of Quality

Two conclusions, may, however, be set down with some confidence as a result of the experience already gained with the E.M.I. system. The first is that stereosonic reproduction improves the listening quality far more than an extension of frequency range in single channel reproduction. It adds both a clarity to the treble and a richness and definition to the bass which becomes 'alive' rather than mechanistic. It is on record that the audience which took part in the Bell Telephone Laboratories experiments preferred a stereophonic reproduction with a frequency range of only 3,500 c/s to a single channel reproduction extending over 15 kc/s. This does not mean, however, as has been sometimes assumed, that the longer range does not add anything to stereophony. It does. It adds that last touch of realism that is so impressive. But it also demonstrates the futility of defining 'high fidelity' reproduction, as is so often done, by reference only to the frequency range.

The second conclusion, in the author's opinion, is that the stereophonic effect can be completely overlaid in an ordinary living-room if the volume of the reproduction and particularly the bass response, is too great. That indeed is a mild way of describing the distressing massacre that occurred at one demonstration at which he was present. In true stereophonic reproduction the bass sounds solid and clear, not resonant and reverberant.

14.5 What is 3-Dimensional Sound?

So far in this chapter we have avoided the challenge of the chapter heading. Yet the term '3-D sound' is being used so loosely nowadays that one should try to form some realistic conception of what it means, or should mean. Strictly speaking, one supposes, the music we hear in the concert hall or opera house is 4-D: it has one dimension in time and three in space. But the time dimension is apt to get mixed up somewhat, at the listener's ears, with the spatial dimensions; and from this point of view it is pertinent to notice that the time dimension, which is the most important in musical appreciation, cannot be perceived at its full value unless *all* the spatial dimensions are there as well.

In ordinary single channel reproduction, where our sound comes from almost a point source, the loud-speaker, there are no dimensions in space at all but only the one in time. It is as though all the sounds were collected from space and poured into a funnel to be dispersed again at the other end. It is thus only 1-D.

14.6 Illusion of Motion

Stereophonic reproduction with two microphones at a distance apart and two channels adds one dimension of space to the time dimension and may thus be described as 2-D. It can simulate motion across a stage from right to left or left to right, but it does not distinguish between up and down. Thus, the orchestra in an operatic excerpt seems to be on the same level as the chorus and not in a separate enclosure in front of the stage.

14.7 Illusion of Depth

Curiously enough, however, in both 1-D and 2-D reproduction, as so described, there may be a partial illusion of depth from back to front. So perhaps we ought to modify our nomenclature and call them $1\frac{1}{2}$-D and $2\frac{1}{2}$-D?

How then is 4-D or even 3-D to be achieved?

14.8 The Cinema and the Home

So far, the so-called examples of 3-D sound such as one hears in cinemas give the listener the impression of being in the middle of the reproduced sound. That is because the loud-speakers operated by one or more of the multiple channels of the recording have been disposed at the sides of the auditorium. The effect is startling enough, but is it what we want for music? Is not the 'stereosonic' system with its two channels and two speaker systems much nearer to the ideal? It may even be that a third speaker with a special mixture from the two channels (and possibly also a limited range), disposed between the other two and on a different level, will give just that extra illusion of a vertical dimension that seems to be needed.

In any case, having regard also to the economic aspect, such a system would seem to be more promising for use in the home than ever the cinema system could be. Even a double-channel system is likely to cost not less than $1\frac{2}{3}$ times as much as a single-channel system. Moreover, the commercial future both for tape records and for disc records must lie in the home and not in large places of entertainment, and as already noted a different kind of balance is needed in home conditions if the stereophonic effect is to be preserved and the overall effect to be non-fatiguing.

Though much more experiment is no doubt needed to determine the optimum conditions for home listening, it seems pretty clear that fundamental alterations in the present stereosonic system are not likely to be called for. Development in the foreseeable future will be a gradual building-up process and not a further major change of system which could be rather expensive. Always the eyes of the recording companies will be on men and women, and particularly on women, in their domestic surroundings and not in their more gregarious habits.

So, as they say in the House of Commons, 'Who goes home?'

GLOSSARY

A.C. Alternating current, i.e. a current which changes its direction regularly. In Great Britain the mains frequency is usually 50 c/s, and the direction changes twice as rapidly.

ACOUSTIC FEEDBACK. The transfer of physical vibrations from the loud-speaker back to an earlier point (e.g. microphone, pickup, carrying arm or valve) in the sound system.

A.E.S. Audio Engineering Society of America. Usually applied to the recording characteristic recommended by that Society.

A.F. Audio frequency. A vibration that can be detected by the ear. The term may be applied either to sound vibrations or to electrical vibrations. The range may reasonably be considered to extend from 16 to 20,000 c/s.

A.M. Amplitude modulation. The older system of radio broadcasting in which the audio frequencies are impressed on the carrier wave by varying its amplitude.

AMPERE. The practical unit of electric current.

AMPLIFIER. An electric apparatus which increases the amplitude of the electrical vibrations that are fed into it. A *voltage amplifier* increases the voltage of the signal without necessarily increasing its power. A *power amplifier* increases the power level of the electrical vibrations so that they are strong enough to operate a loud-speaker. Power amplifiers usually have several voltage amplifier stages followed by a power output stage.

AMPLITUDE. The peak measure of a vibration.

AMPLITUDE DISTORTION. Occurs in any transmission system when the output amplitude does not bear the same ratio to the input amplitude for all values of the latter. It is also called non-linear distortion. It produces both harmonic distortion and intermodulation distortion.

ARMATURE. Vibrating element in magnetic pickup.

ATTENUATION. Reduction in voltage, intensity, amplitude or loudness. The opposite of amplification.

AZIMUTH ALIGNMENT. Adjustment of the angle of the magnetic gap in the record/playback head of a tape recorder.

BACKGROUND NOISE. The unwanted noise in a system whether or not a signal is present.

BAFFLE. A partition used to modify or restrict the distribution of sound. Usually refers to a partition which separates the waves generated by the front and back of a loud-speaker.

BASS REFLEX. A loud-speaker enclosure which has one or more openings approximately equal in total area to the area of the opening in which the loud-speaker is mounted. From these openings the sound generated by the back of the speaker is allowed to emerge in such a manner as to reinforce the bass response over a limited range.

BEATS. Periodic variations of loudness due to interference of two notes of slightly different frequency.

BIAS. 1. The superposition of a voltage (usually D.C.) on an electrical vibration. 2. The superposition of a magnetic field on a magnetic signal in magnetic recording. *R.F. bias:* a bias derived from a radio frequency voltage, usually above 50 kc/s.

BINAURAL. Applies to the process of hearing with two ears. It is *not* the same as stereophonic.

CANTILEVER. Vertically compliant link between stylus and armature in pickup.

CAPACITOR—CONDENSER. An electrical device consisting (in its elementary form) of two plates with an insulator (dielectric) between them. When inserted in a circuit in which D.C. is flowing it will stop the flow; but it will allow A.C. to pass, presenting only an impedance to the passage: the higher the frequency of the A.C. the better the passing action.

CAPACITY—CAPACITANCE. The measure in farads (or more usually in microfarads) of a capacitor.

CARTRIDGE. Another name for a pickup which converts the mechanical energy imparted by a record to a stylus into electrical energy. It may be magnetic (moving coil or variable reluctance), crystal or ceramic.

CATHODE. The negative element of an electrical device as opposed to the anode which is positive. In an electronic valve (or vacuum tube) it is the element from which electrons are emitted.

CATHODE FOLLOWER. A valve circuit in which the output is taken from a resistance in the cathode lead, instead of from the anode. Its special value is that it has a low output impedance.

CERAMIC. A piezo-electric element manufactured to take the place of a single crystal. Usually made of Barium Titanate.

CHASSIS. The metal box or framework on which an amplifier is built.

CHOKE. An inductor, used to pass D.C. and stop A.C.

COMBINATION TONE. A tone produced by the interaction of two tones in a non-linear device. Its frequency is the sum or difference of the two. Also called summation tone or difference tone.

COMPENSATOR. An electronic circuit to modify the frequency response in a pre-determined manner.

COMPLIANCE. The opposite of stiffness. It is the analogue in a mechanical device of a capacitance in an electrical circuit.

CONDENSER. See Capacitor.

CONSTANT AMPLITUDE. The disc recording characteristic in which the groove displacement is proportional to the signal amplitude.

CONSTANT VELOCITY. The disc recording characteristic in which the lateral velocity of the stylus in the groove is constant. The groove displacement is inversely proportional to the signal frequency.

CONTROL UNIT. The part of the amplifier system which contains the controls such as selector switch, bass and treble controls, volume control, equalization controls, filter controls. Is usually combined with the pre-amplifier.

CORNER HORN. A type of enclosure for a loud-speaker, built up in the form of a folded horn and utilizing the junction between two walls in a room as part of the horn.

CROSSOVER NETWORK. A combination of inductors and capacitors which separates the high frequencies from the low frequencies and feeds them respectively to the tweeter and woofer units.

CRYSTAL (PIEZO-ELECTRIC). A small slab of material (usually

Rochelle salt) which converts mechanical motion into electrical voltage or vice versa.

C/S. Cycles per second the measure of frequency.

CURRENT. The flow of electric charges in a circuit. Measured in amperes or milliamperes.

CURRENT FEEDBACK. See Feedback.

CYCLE. One complete repetition of the changes which take place during the period of a recurring variable quantity, e.g. a complete revolution. One cycle of an alternating current occurs each time it changes from maximum in one direction, reverses and reaches maximum in the opposite direction, reverses again and rises to the maximum in the original direction.

DAMPING. Limitation of the amplitude of a vibration by the effect of resistance or viscosity or friction in absorption of energy.

DAMPING FACTOR. In a power amplifier, the ratio of the load impedance to the amplifier output impedance.

DAMPING RATIO. In a power amplifier, the ratio of the load impedance to the circuit impedance, i.e. the sum of the amplifier output impedance and the load impedance.

D.C. Direct current, i.e. current that flows continuously in the same direction.

DECIBEL. A (logarithmic) measure of relative power levels used because the ear measures differences in sound level by proportions and not arithmetically. A power ratio of 2 to 1 corresponds to a decibel difference of about 3. A power ratio of 10 to 1 corresponds to 10 db and a power ratio of 1 million to 1 is equivalent to 60 db.

DE-EMPHASIS. A form of equalization complementary to pre-emphasis.

DIFFERENCE TONE. A combination tone whose frequency is the difference between the two generating tones.

DISTORTION. Mutilation of a signal by discrimination against some frequencies or by the introduction of spurious frequencies, e.g. non-linear or amplitude distortion (including harmonic distortion and intermodulation distortion), frequency distortion, phase distortion. See Sect. 4.7.

DUBBING. The copying of a recording or, more accurately, the combining of two or more recordings into a composite recording.

DYNAMIC PICKUP. Moving coil or ribbon pickup.

DYNAMIC RANGE. The difference in db between the loudest and softest passages in a musical performance.

EFFICIENCY. Of a device is the ratio of the output power to the input power, or (in the case of an amplifier) to the power taken from the mains.

E.M.I. Electrical and Musical Industries Ltd. A British Company which amalgamated The Gramophone Company (His Master's Voice), The Columbia Graphophone Company, The Parlophone Company and the Marconiphone Company.

EQUALIZATION. The process of restoring the proper frequency balance to music from disc or tape records. Disc records are made with treble range emphasized so as to reduce surface noise and bass range restricted so as to save groove spacing. When they are played the proper balance must be restored. Tape equalization consists in boosting both treble and bass to compensate for the tape and recording head characteristics.

ERASE HEAD. The magnetic head in a tape recorder that erases any previous recording on the tape. It is activated by a high-frequency alternating current.

EXPONENTIAL. Flare (of a horn or loud-speaker cone) which follows the mathematical curve known as exponential or logarithmic curve.

FARAD. The unit of capacity. It is so large that a microfarad (i.e. one millionth of a farad) is the practical unit.

FEEDBACK. An arrangement whereby part of the output signal of an amplifier is fed back into an input section. When the output pulses are of the same phase as the input so that the effects are additive, the feedback is positive; if they are in opposite phase, the feedback is negative. Positive feedback causes the signal to 'pile up' and leads eventually to oscillation. Such an arrangement is said to be unstable. Negative feedback on the other hand reduces the amplification but reduces the distortion and improves the frequency response—provided of course that it is used properly. Feedback of either kind may be obtained from the output current or may be proportional to the output voltage. Negative voltage feedback and positive current feedback both reduce the output impedance of an amplifier and a combination of the two may be devised to give a zero or even a negative output impedance, and so increase the damping factor to infinity or the damping ratio to unity.

F.F.R.R. Decca recording characteristic for 78-r.p.m. records.

FIELD. The effective area of influence of a magnetic or electrostatic or other force.

FILTER. A circuit which transmits one or more frequency bands and attenuates other frequencies. There are three standard kinds: Low-pass, in which frequencies below a limiting frequency are passed and those above are attenuated; high-pass in which frequencies above a limiting frequency are passed and those below are attenuated; and band-pass in which there is an upper and lower limiting frequency. See also Rumble Filter, Scratch Filter.

FLUTTER. A variation of speed of a turntable or tape at a rate above 20 c/s.

FLUX DENSITY. Lines of force per unit area in a magnetic gap.

F.M. Frequency modulation. A system of radio broadcasting in which audio frequencies are impressed on the carrier wave by variation of its frequency. The system provides a wide range of audio frequency transmission with very little background noise.

FREQUENCY. The rate at which a periodic phenomenon occurs; in sound, that rate of air vibration which determines the pitch. Measured in cycles per second (c/s), kilocycles per second (kc/s) or megacycles per second (mc/s).

FREQUENCY CUT-OFF. The frequency of transition from transmission to attenuation.

FREQUENCY DISTORTION. Discrimination of an amplifying system in favour of some frequencies.

FREQUENCY DOUBLING. See harmonic distortion.

FUNDAMENTAL FREQUENCY. The frequency of a complex note which determines its pitch.

HARMONIC. A component of a complex note having a frequency which is a multiple of the fundamental frequency.

HARMONIC DISTORTION. A form of non-linear or amplitude distortion consisting of the production of spurious harmonics of the original tone.

H.F. High frequency, e.g. above A.F. or at the upper end of the A.F. range.

HIGH-PASS FILTER. See Filter.

HILL-AND-DALE RECORDING. A system of recording in which the groove modulation is at right angles to the surface of the record.

HORN. A tube for transmission of sound in which the cross-sectional area increases progressively from the throat (small end) to the mouth (open end).

IMPEDANCE. The opposition in an electrical circuit to the flow of alternating current. The term includes both resistance and the reactance effect of inductance and of capacitance. Like resistance, it is measured in ohms. By analogy, mechanical impedance relates to the opposition to mechanical vibration and includes the effects of friction and mass and compliance.

INDUCTOR. A circuit element, derived from a coil of turns of wire, which passes lower frequencies and opposes higher frequencies. *Inductance* is measured in henries and corresponds to mass or inertia in the mechanical analogue.

INTERMODULATION DISTORTION. A form of non-linear or amplitude distortion which shows itself in the production of summation and difference tones.

I.P.S. Inches per second. Used in reference to tape speed. Sometimes written in./sec.

KILO. One thousand, e.g. kc/s—kilocycles per second.

LATERAL RECORDING. The usual form of disc recording in which the groove modulation is radial and parallel to the surface of the record.

L.F. Low frequency. See A.F. (audio frequency).

LOAD. The device which is fed with energy, e.g. from an amplifier.

LOUD-SPEAKER. A transducer which converts electrical energy into mechanical motion which in turn creates sound.

LOW-PASS FILTER. See Filter.

MEGA. One million, e.g. mc/s—megacycles per second.

MICRO. One millionth part of.

MICROPHONE. A transducer for converting sound waves into electrical vibrations.

MILLI. One thousandth part of.

MODULATION. 1. The superposition of a wave of one frequency upon another, usually higher, frequency. 2. The impression of audio frequencies upon a groove.

N.A.R.T.B. National Association of Radio and Television Broadcasting (of America). Applied to a recording characteristic recommended by the Association.

NEGATIVE FEEDBACK. See Feedback.

OFFSET ANGLE. The angle between the direction of the vibration axis of a pickup and the line joining the stylus to the pivot of the carrying arm.

OFFSET (LINEAR). See Fig. 15, p. 82.

OHM. Unit of resistance or impedance.

OSCILLATION. A vibration of a system generated by the system itself. Usually unwanted.

OSCILLATOR. An instrument that produces variable frequencies for test purposes.

OVERTONE. A tone in a complex note whose frequency is higher than but not necessarily a multiple of the fundamental.

PARTIAL. A pure tone component of a complex note. Upper partial equals overtone.

PEAK. 1. A maximum value attained by a periodic quantity. 2. A point in a frequency response where the level rises sharply above the general level.

PERIOD. The time taken by one complete cycle of a periodic quantity.

PERIODIC QUANTITY. A quantity whose values recur after equal intervals of time.

PHASE. The fraction of a whole period that occurs between two instantaneous values of a periodic quantity.

PHASE DISTORTION. Reproduction with a time interval between tones which originally occurred at the same time.

PICKUP. A transducer which converts the mechanical vibrations of the stylus into electrical vibrations.

PIEZO-ELECTRIC. The property of certain materials, usually crystals, to create an electric voltage when subjected to pressure or strain.

PITCH. The quality of a musical tone which determines its position in the musical scale.

POSITIVE FEEDBACK. See Feedback.

POWER FACTOR. See Watt.

POWER PACK. A device that converts the electrical power from the mains into the electrical power, both D.C. and A.C., for operation of an amplifier.

PRE-AMPLIFIER. A unit that provides preliminary amplification to bring weak signals up to a satisfactory level to operate a power amplifier. Usually combined with the control unit.

PRE-EMPHASIS. Introduction of additional amplification over a range of frequency, e.g. treble pre-emphasis in recording (to minimize surface noise) and in F.M. transmission (to override atmospheric noise).

PUSH-PULL OUTPUT. An arrangement of two valves in an output stage in which one operates on the positive half of a signal whilst the other operates on the negative half. This is then reversed on the next half-cycle.

REACTANCE. The property of a capacitor or inductor to limit the passage of an alternating current. It varies with the frequency of the current. Reactance does not consume power.

RESISTANCE. The property of a resistor to limit the flow of current, whether A.C. or D.C. It is independent of frequency and always consumes power.

RESPONSE. The reaction of an amplifier or transducer to a range of frequencies. A flat or uniform or level response means the absence of any accentuation of, or discrimination against, particular frequencies but an equal treatment to all.

REVERBERATION. Persistence of sound in an auditorium due to repeated reflections. Reverberation time of a room is the time it takes for a sound (usually assumed to be 1,000 c/s) to fall to one millionth of its original intensity, i.e. by 60 db.

R.F. Radio frequency. A frequency well above audio frequency (A.F.) and extending up to 30 mc/s.

R.I.A.A. Radio Industries Association of America. Applied to a particular recording characteristic.

ROLL-OFF. A term used to denote the amount of de-emphasis required to correct for the pre-emphasis given to high notes in disc recording.

RUMBLE. A low-frequency noise generated by the motor or driving links in a turntable and transmitted to the pickup.

RUMBLE FILTER. An electrical filter designed to attenuate rumble.

SCRATCH FILTER. An electrical filter designed to attenuate surface noise of a record.

SIGNAL. The electrical impulses fed to an amplifier from a pickup, a microphone, a radio antenna or a tape deck.

SIGNAL/NOISE RATIO. The ratio between the wanted signal and the background noise. Usually expressed in db.

SQUAWKER. A loud-speaker designed to cover the middle register —leaving the bass to a 'woofer' and the treble to a 'tweeter'.

STEREOPHONIC. Sound reproduction giving illusion of depth and breadth.

STROBOSCOPE. A device for measuring the speed of an object by means of flashes of light at a known frequency.

STYLUS. The rounded point that tracks in a record groove.

STYLUS FORCE (OR PRESSURE). The mean force exerted by the stylus at right angles to the surface of the record. The playing weight.

SUMMATION TONE. See Combination Tone.

SURROUND. The flexible outer edge of a loud-speaker cone.

SURROUND RESONANCE. The low-frequency resonance of a loud-speaker cone created by the combination of the compliance of the surround and the mass of the cone.

SWINGER. A disc record in which the spindle hole is not at the exact centre of the recorded spiral.

TRACING DISTORTION. A form of non-linear distortion caused by the difference in the shapes of the recording and reproducing styli.

TRACKING ERROR. The deviation expressed in degrees of the stylus rocking axis in a pickup from exact tangential alignment with the groove being played. This is the same as the angle between the direction of lateral vibration of the stylus at any point and the radius of the groove at that point.

TRANSDUCER. A device to receive energy from one system and to supply energy to another in such a way that the desirable characteristics of the input energy appear at the output. It may be used for transfer of one type of energy to energy of the same type but more usually it refers to change of type, e.g. electrical to mechanical or acoustical or vice versa.

TRANSIENT. A pulse in which the intensity changes over a wide range in a short time.

TRANSISTOR. A tiny semi-conductor device which can amplify an electric vibration.

TURNOVER. The point in the lower frequency range where the recording signal is decreased in amplitude so as to conserve recording space.

TURNTABLE. A heavy flat disc with its driving motor, used to rotate records for playing.

TWEETER. A loud-speaker designed to reproduce high frequencies only.

TWIN-TRACK. A method of recording on magnetic tape in which only half the width of the tape is used at one time.

VENTED ENCLOSURE. See Bass Reflex Enclosure. An enclosure at the rear of a loud-speaker with one or more apertures or vents from which sound emanates after undergoing a change of phase.

V.H.F. Very high frequency. Used to denote the broadcasting bands between 30 and 300 mc/s.

VOLTAGE. The electrical force which drives an electrical current through a circuit. Voltage is the analogue of pressure.

VOLTAGE FEEDBACK. See Feedback.

WATT. The unit of electric power. For D.C. it is the product of the volt (pressure) and the ampere (current). For A.C. it is that product multiplied by a fraction, known as the power factor, which represents the amount by which the pressure and current are in or out of phase.

WATTLESS CURRENT. An alternating current in which the power factor is zero.

WAVE. A disturbance which travels through a medium, although the actual motion of the particles of the medium may be small. A *longitudinal wave* is one in which the particle displacement is to and fro along the direction in which the disturbance is travelling. A *transverse wave* is one in which the direction of particle displacement is at right angles to the direction of travel of the wave.

WAVE-FRONT. Any surface over which the disturbance has the same phase at the same instant, e.g. the surface of peaks or of troughs in the wave.

WAVE-LENGTH. The distance between two successive wave-fronts (or peaks or troughs). It is equal to the velocity of the wave divided by its frequency.

WHITE NOISE. Noise whose frequency spectrum extends uniformly throughout the musical scale. It is of particular use for testing amplifiers and loud-speakers.

WOOFER. A loud-speaker designed to deal with low frequencies only.

WOW. A variation in pitch occurring at a rate below 20 c/s.

ADVERTISERS' ANNOUNCEMENTS

INDEX TO ADVERTISERS

E·M·I RECORDING & REPLAY CHARACTERISTICS

"HIS MASTER'S VOICE"
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During the past few years, various writers and circuit designers have published data concerning the frequency characteristics which should be adopted when playing discs records. Unfortunately, there is little agreement between these sources, and consequently a great deal of confusion exists as to what curves should be used. No doubt this is partly due to the rapid evolution of the modern microgroove record, the optimum recording characteristics of which have gradually changed in accordance with the enormous improvements which have taken place in the mechanical design of pick-ups. This improved pick-up design has also made it possible to modify the recording characteristic of the 78 r.p.m. disc, so that a very appreciable reduction in surface noise can be obtained, while still maintaining a wide frequency range.

The recording characteristics used by the E.M.I. Record Division have been stabilized, and since no change is contemplated in the future, the information given here can be used with complete confidence.

MICROGROOVE 33⅓ and 45 R.P.M.

The replay characteristic for microgroove recording is the sum of a 75 microsecond top fall, a 318 microsecond bass rise, and a 3180 microsecond bass fall.

COARSE GROOVE 78 R.P.M.

The replay characteristic for coarse groove recordings is the sum of a 50 microsecond top fall, a 450 microsecond bass rise, and a 3180 microsecond bass fall.

CORRECTION NETWORKS

The correct replay curve can be obtained electrically by cascading separate circuits each providing the individual time constants given in the definition above, providing they are so arranged that no mutual interaction is caused, or else a combined network can be used which by itself will produce the complete replay curve. The figure below shows the individual time constant networks and also the combined network.

Since the impedances of the combined networks shown follow the same frequency response as the desired replay curve, they can be used in any circuit where the impedance of the network controls the frequency response, e.g., as part of a potentiometer, or as a feedback impedance. Of course, due allowance must be made for the impedances from and into which the network is operating.

The replay characteristics announced here are in complete accordance with those for fine groove and coarse groove recordings as published by the British Standards Institution in their British Standard 1928:1955 for gramophone records and reproducing equipment.

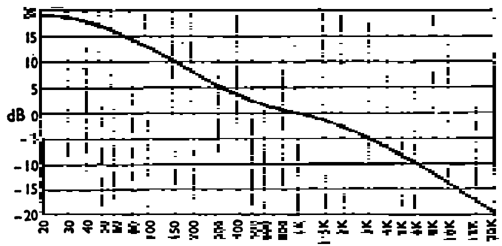

Fig. 1. Replay characteristic for micro-groove records. *(Frequency in c/s.)*

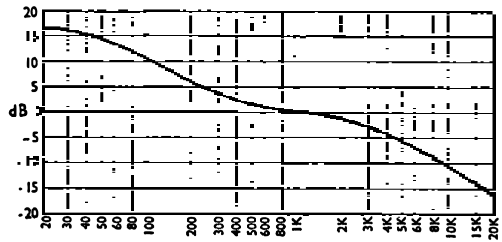

Fig. 2. Replay characteristic for coarse groove records. *(Frequency in c/s.)*

NOTE: The above information applies to records made throughout the world by the E.M.I. Organisation, with the exception of those of Oriental and African Native music.

$33\frac{1}{3}$ and 45 r.p.m. records. Overall replay characteristic dB	Frequency c/s	78 r.p.m. records. Overall replay characteristic dB
18.7	30	15.7
17.0	50	14.1
13.2	100	10.3
8.3	200	5.9
5.6	300	3.6
2.7	500	1.6
0.1	1000	0.1
— 2.5	2000	— 1.3
— 4.6	3000	— 2.7
— 8.1	5000	— 5.4
—13.6	10000	—10.4
—17.1	15000	—13.7

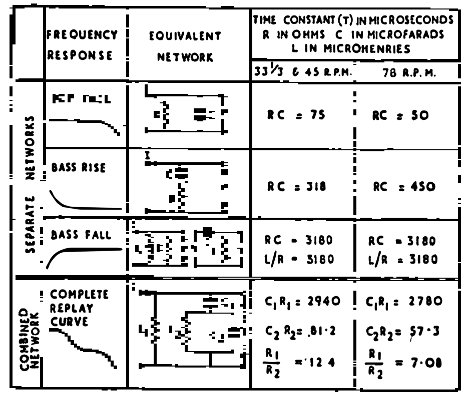

Fig. 3. Derivation of replay characteristics.

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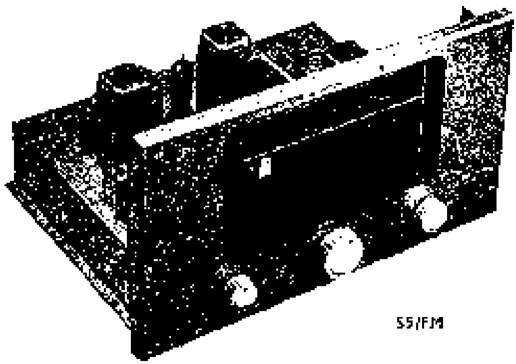

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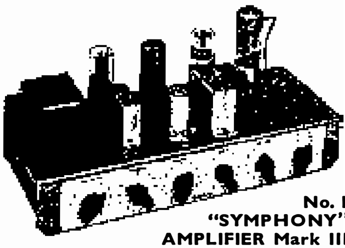

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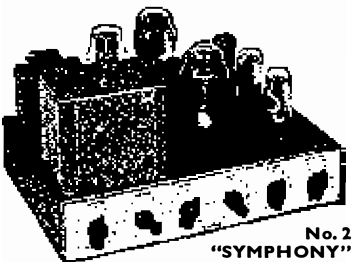

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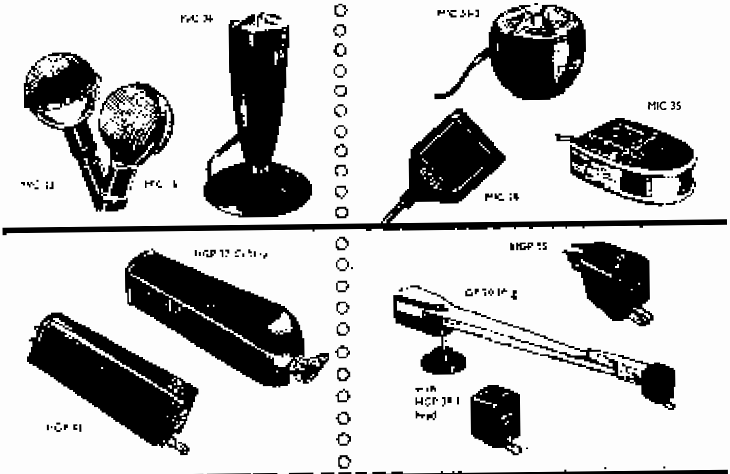

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ACOS microphones and microphone inserts are widely used in disc and tape recording, P.A. systems, amateur and professional broadcasting, acoustic measurement and industrial noise measurement. There are hand, desk, stand and lapel models and retail prices for complete microphones range from £1.5.0 to £12.12.0.

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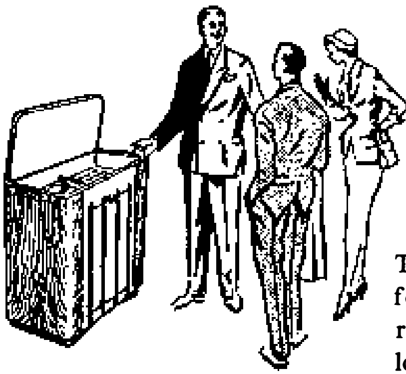

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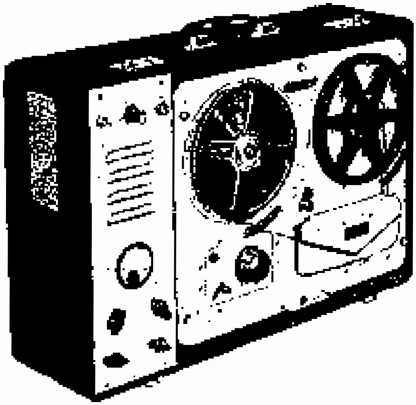

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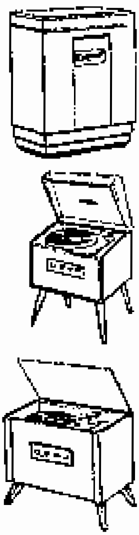

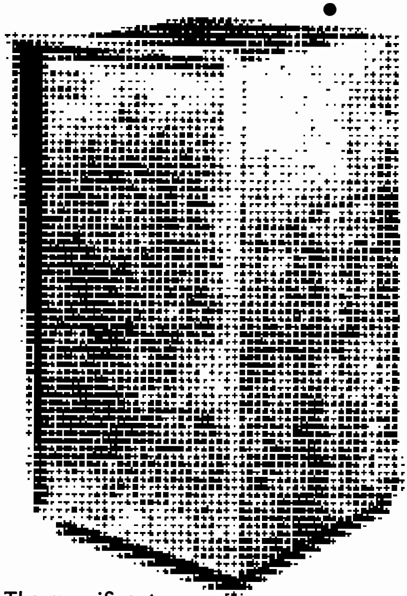

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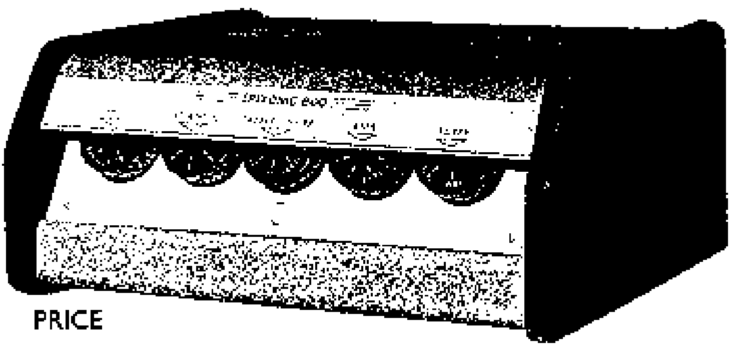

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THE TRIXONIC '800' HIGH FIDELITY AMPLIFIER

The new Trixonic '800' amplifier is the result of long research which has been aimed above all at the requirements of the home music lover. Thus, an important feature is the LOW-LEVEL COMPENSATION incorporated in the loudness control, which maintains a correct tonal balance throughout the scale at even the quietest listening levels—an outstanding advantage for flat-dwellers and those who are compelled to 'keep the volume down'. The 4-position pickup equalizing plug will cater for all types of pickup available and dispenses with the extra cost of matching units. The amplifier is in one compact casing, so that it can be either cabinet-recessed or placed on a shelf or table with equal ease.

The many vital and yet unpretentious advantages of this amplifier are already giving great musical enjoyment to many people. A full technical specification and description is available which will introduce you to better listening as *you* want it.

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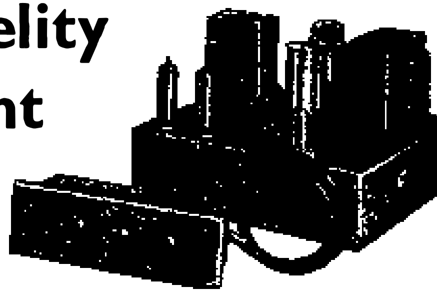
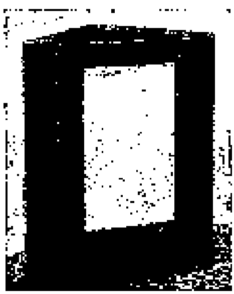
The New W.B.12 High Fidelity Amplifier Price £25





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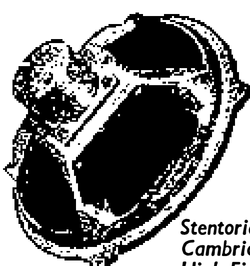
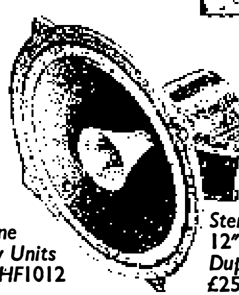


Stentorian Cambric Cone High Fidelity Units
The famous HF1012 at £4. 19. 9
Others from 47/6



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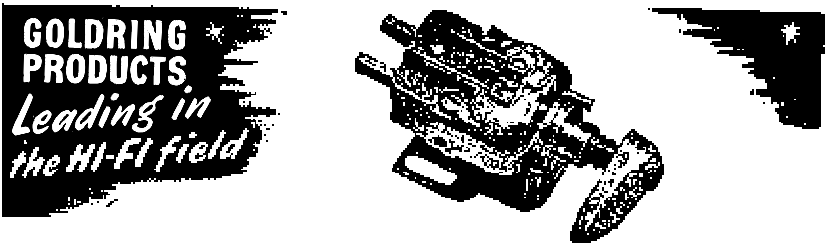

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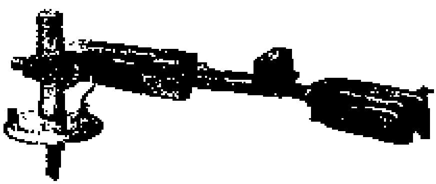

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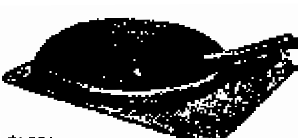

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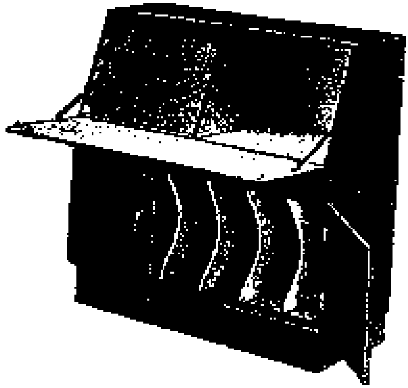

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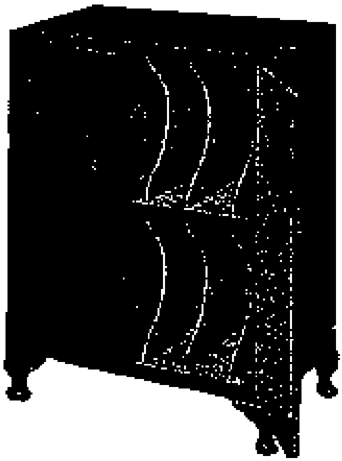

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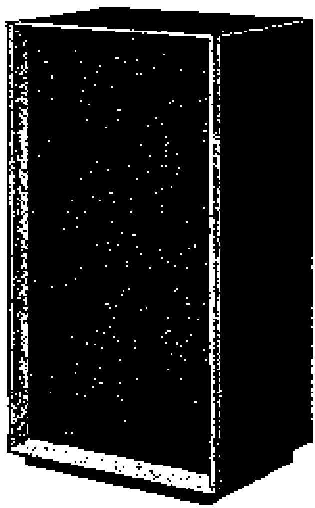

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We specialise in Speaker Enclosures, corner and rectangular, embodying Messrs. Goodmans Acoustic Resistance Unit and so reducing the size of the cabinets by a third.

Included in our range are numerous General Purpose Cabinets in widths of 17″, 30″ and 33″, which can be modified to special requirements, and apertures cut to templates.

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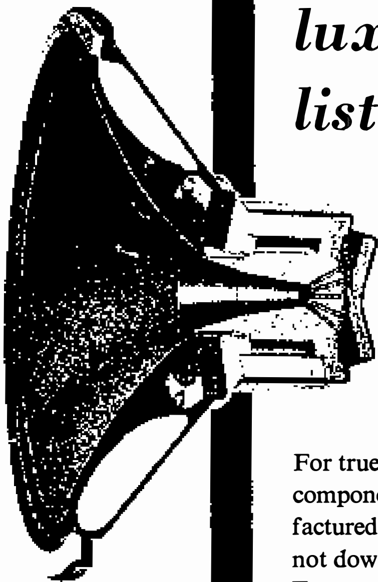
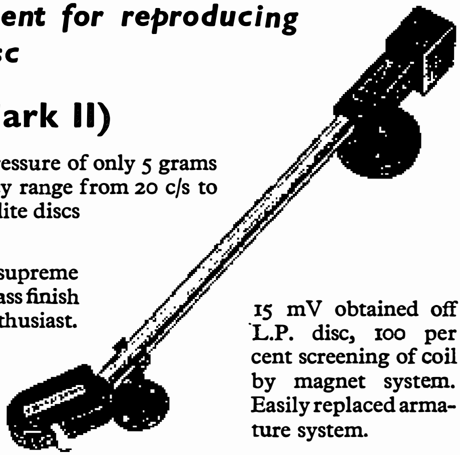


Connoisseur

Fine equipment for reproducing sound on disc

Pick-up (Mark II)



has a downward pressure of only 5 grams and has a frequency range from 20 c/s to 20 kc/s on soft vinolite discs at $33\frac{1}{3}$ r.p.m.

This is the unit of supreme quality and high-class finish for the Hi-Fi enthusiast.

15 mV obtained off L.P. disc, 100 per cent screening of coil by magnet system. Easily replaced armature system.

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A hand-built product which meets with the most stringent requirements.

Three speeds with 4 per cent variation by mechanical means. No braking action applied to motor.

The motor is a synchronous hysteresis type, running in substantial phosphor-bronze bearings.

The motor will remain in synchronization with 25 per cent variation of line voltage.

Heavy full-sized die-cast platform, $15\frac{3}{4}'' \times 13\frac{1}{2}''$.

This unit is being used in considerable numbers by Recording Studios and Sound Installations.

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15 in. 25 watts.

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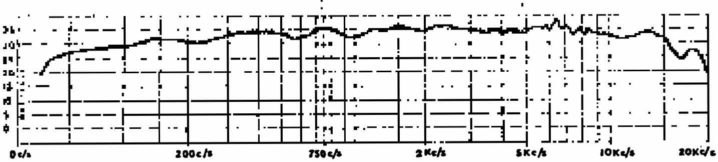
High efficiency pressure-driven reproducer covering the treble register from 2,500 c.p.s. to 16 kc/s. Impedance 15 ohms at 10 kc/s.



Response Curve of the 25 watts system illustrated.

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See Section 9.33

The GOODSELL

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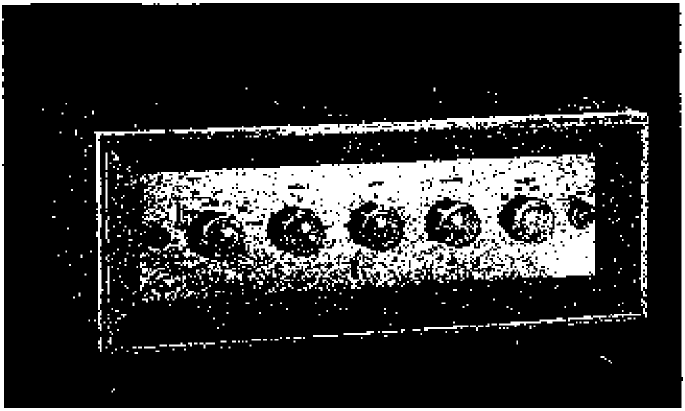

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THE GRAMOPHONE HANDBOOK

Percy Wilson, M.A.

Technical Editor, *The Gramophone*

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Though even the most expert technician will find much to ponder over in its suggestions for development and future progress, the book is intended mainly for the ordinary man of an inquiring turn of mind, who wants to know something of the ideas behind this modern development of so-called High Fidelity reproduction of sound. So it describes the fundamental principles of reproduction and the equipment that is used to give realistic results. The principles and performance criteria of pickups, amplifiers, loud speakers, and tape recorders are all dealt with in some detail and there are valuable chapters on record wear and care of records, on planning a High Fidelity equipment, on installation and maintenance and on the prospects of stereophonic reproduction. A comprehensive glossary containing explanations of more than 150 of the most common technical terms is included.

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