Everyday Technology

# Sound Recording and Hi-Fi

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Drawings by Linda M. Trueman
and black and white photographs

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# Contents

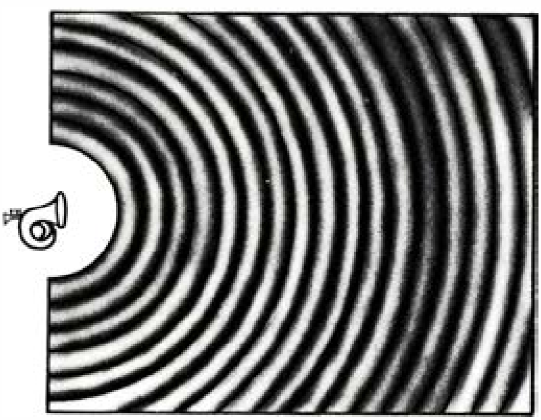
Sir Adrian Boult recording Bach's Brandenburg Concerto No. 5 in EMI's Studio One at Abbey Road, London.

# 1 About Sound

Air is seldom still. Masses of air in motion form winds. Even if the air appears to be still, it is usually conveying sounds which are the results of variations in pressure imparted to air by vibrating objects. Voices, machines, music and natural phenomena all produce sound in the same way—by setting up vibrations which in turn make sound waves, radiating in all directions.

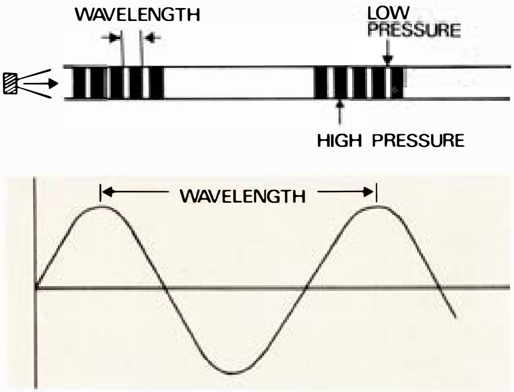
Silence would reign if there was no air or other medium to convey waves. But our world is a noisy one, and nearly everywhere the air particles are jostled to and fro as sounds pass. The jostling does not displace the particles along the wave: instead they are pushed this way and that, finally settling in their original positions when the sound energy has died away. In fact the wave is like the series of ripples caused when you drop a stone into water. These are most clearly marked where the stone is dropped but become less distinct as distance increases.

Sound waves radiate from a vibrating source, forming a pattern of pressure variations in the air.



All materials carry sound waves, and each conveys them at a different speed. As if that did not promise enough complication, each material will transmit sound at a speed which depends on the temperature. The speed of sound in air is about 343 metres per second at 20° C. It is slower when the air is colder; faster when hotter; faster still in hot, steamy conditions. Solids convey sound energy even more quickly. The velocity is approximately 1425 metres per second in water; 3400 metres per second in wood; 5100 metres per second in iron; 5300 metres per second in glass. In all cases the particles in the sound wave dissipate their energy in heat due to friction encountered in their movement.

Air particles in a sound wave are agitated at a certain rate and to a degree of complexity that depends on the nature of the sound. Some sounds are best described as pure tones, the kind of tone generated

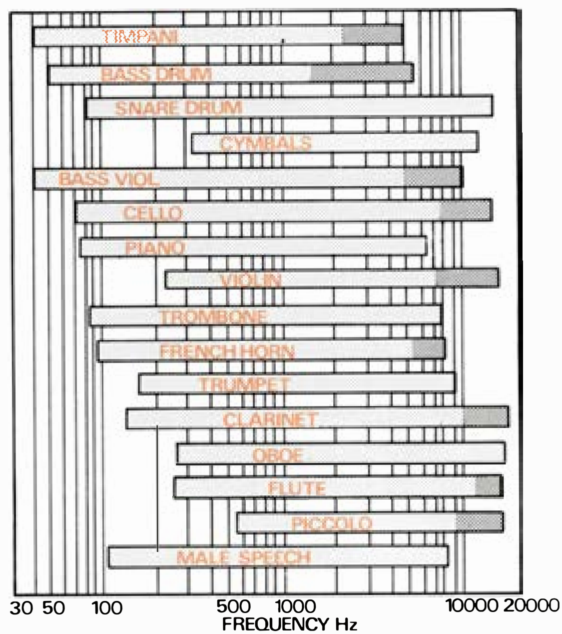



Another view of sound, represented as a longitudinal wave. A simple tone, or the corresponding signal in electrical form, can be drawn as a sine wave (below), and the wavelength as the distance between two comparable points on the wave.

by the measuring instrument used by the radio technician on his test-bench. The signal he generates in this way can be depicted as a 'sine' wave—a regular waveform. A tone carried in the air can be depicted in exactly the same way. The rate of repetition of the wave is known as the 'frequency' which, expressed as cycles of the wave per second, tells us the pitch of the tone.

In written form, particularly, it is now conventional to express the frequency in Hertz (Hz), named after the physicist Heinrich Hertz. A complete cycle of wave or tone (1Hz) is illustrated, and the distance between two comparable points on the waveform is termed the 'wave-length'. Knowing the speed (velocity) of sound we can calculate wavelength, simply by dividing velocity by frequency. So if a sound has a frequency of 30Hz (a very low note) its wavelength is roughly 11.4 metres. A high-pitched sound of 14,000Hz has a wavelength of roughly 2.5 centimetres. Obviously, if we know the wavelength we can find the frequency by the same procedure.

Musical sounds and common noises occupy a frequency range of about 20-20,000Hz. A typical range of hearing for an adult is 25-15,000Hz; the range narrows with increased age. Young children



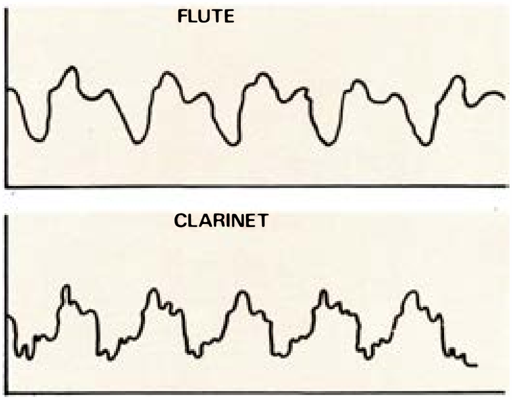

Frequency range of musical instruments and speech. An area in which harmonics are pre-dominant is shown at the high frequency end in many instances.

have the best hearing range, which may be at least 20-18,000Hz. Sounds of extremely low frequency—subsonic energy—are not really heard at all, but rather are felt with parts of the body provided the energy in the wave is strong. Pressure waves above the limit of hearing are termed 'ultrasonic' and have uses in industry. High-energy ultrasonics can be used for cleaning purposes, to detect flaws in metals, for a form of soldering, and in medical investigations.

Sound energy lacking regularity in its patterns is mostly categorized as noise—random energy with which modern life is only too well endowed. More acceptable, harmonious sounds strike equally complex patterns in the air but show a semblance of order when analysed. For instance, the note sounded by a musical instrument comprises a pure tone known as the 'fundamental' together with a number of 'harmonics', or overtones. The fundamental is the basic wave and determines pitch, and the harmonics modify the shape of the wave and impart to the note its characteristic quality, known as 'timbre'. So harmonics added to a fundamental produce a complex sound.

For example, a note with a fundamental of 50Hz could have second, third and fourth harmonics and their frequencies would be 100Hz, 150Hz and 200Hz respectively. Higher orders of harmonics might also be present. A simple musical note is that from a flute sounding the note C=256Hz. Predominant in its waveform (illustrated) are the fundamental and another tone an octave higher. The absence of odd-numbered harmonics accounts for the mellow sound of the flute. Other instruments yield quite different patterns, and on our identification of these depends our ability to name the instrument we are hearing. It enables us to distinguish between a flute and an oboe, a piano and a clavicord—or two voices.

In everyday life we experience an enormous range of sound intensities. A speaking voice half a metre from your head is two thousand times louder than a whisper from the other side of the room. An orchestra yields an intensity range of more than a million times the level of a whisper. If you have a taste for pop concerts and discotheques you may be subjected to even higher sound pressure levels. Sound raised in level to the ultimate, unbearable limit is felt as pain. You would reach this limit close to a jet aircraft accelerating to take-off.



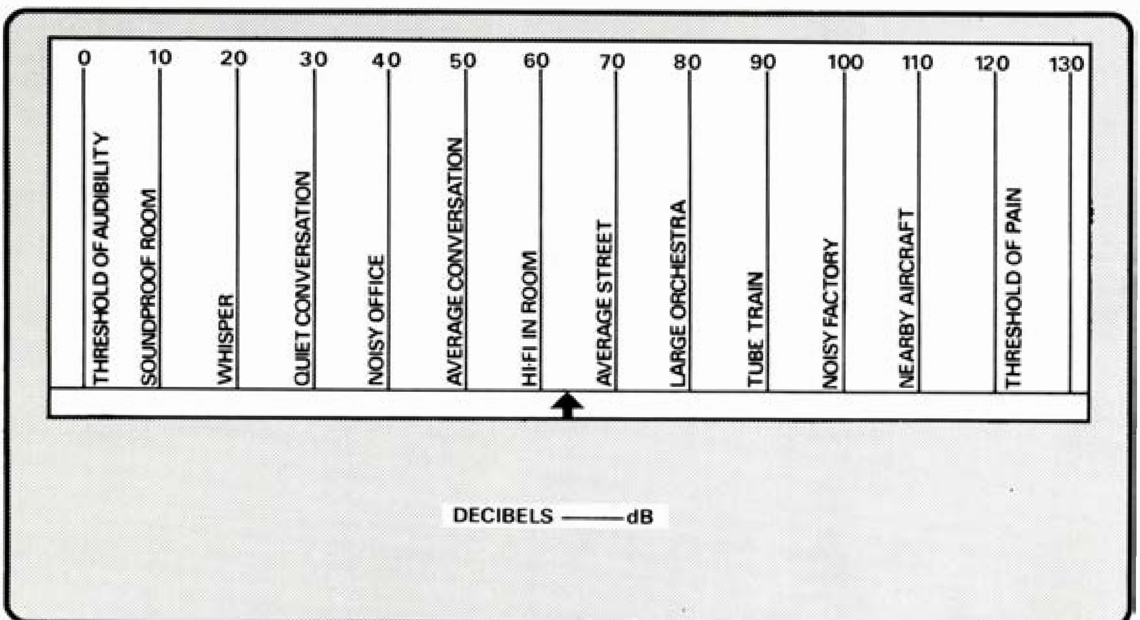

**Musical sounds consist of a fundamental tone and harmonics, together producing a complex waveform. Simple examples are the flute and clarinet notes shown here.**

Of course one is not allowed as close as that to a jet aircraft, but generally the wise person will guard against prolonged exposure to high-intensity sound. It is now beyond dispute that permanent damage to hearing can result.

Since we are concerned in this book with the organization and exploitation of sounds it is as well to realize that although sound pressure level is something definite we can measure (with a microphone and electronic equipment), our experience of sound depends on how close the source happens to be, and on our own sensitivity to sonic energy at various frequencies. A hugely powerful source of pressure waves will not be a hazard to our hearing if we are far enough away from it. Our ears and brain also insist that a sound at one frequency is not judged to be of the same loudness as one at another frequency. In fact we are very sensitive at mid-frequencies, so that a 3000Hz tone and a 100Hz tone give us very different impressions. Indeed, as listeners we are more concerned with our ideas of 'loud' and 'quiet' than with the physicist's measurements of intensity.

In most situations sounds reach us both directly and as a result of reflections from nearby surfaces. For instance, if a car passes you in the road you are likely to hear a lot of sound that reaches you in a direct route from the car to your ears as

Decibel level of sounds. Background noise is surprisingly great in situations we normally accept as quiet.



well as some that is reflected from the road and perhaps from the walls of nearby buildings. Sound bounces from surfaces to an extent that depends on the nature of those surfaces. Many noises pass through solid materials, of course, so that you will hear a passing car if you are in a room facing the road.

With this we reach the aspect of sound summed up in the word 'acoustics'. It is of importance to us in our enjoyment of music and in our assessment of sound recording. Although one may listen to music in the open air, where most sound reaches the ears directly (without reflections), it is more usual to listen in an enclosed space. We listen to a concert in an auditorium, and the proportions of direct and reflected sounds give us our impression of the 'acoustics'.

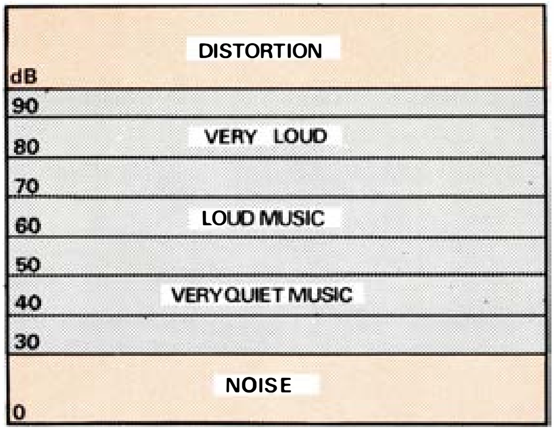
In this connection 'reverberation' becomes significant. It is the time taken for a sound to die away to a millionth of its original intensity. Clearly, the size and other characteristics of the space will influence this. An auditorium may have a reverberation time of, for example, 1.6 seconds at the mid-frequencies, while the figure for a domestic room may be 0.4 second. Figures differ for high notes and in the deep bass, and in practice the characteristic reverberation affects our impression of the way the music sounds.

## WHAT THE WORDS MEAN

*Signal* In sound recording, and indeed throughout communications, the concept of the 'signal' is of great importance. This term may be used to identify any recorded sound, or electrical voltage representing a sound, and generally it distinguishes information that is being manipulated. For example, a signal representing a musical note passes from a microphone through electrical circuits, there to be amplified and recorded. Subsequently the signal is reproduced at home and radiated by loudspeakers. The aim is to preserve the signal against adverse influences, so that it maintains its original characteristics.

*Noise* The term 'noise' describes not only a non-musical sound but also any quantity that is hostile to a wanted signal. Noise may arise anywhere in sound recording and reproduction, and it is not possible to transmit information without generating some noise. Disc records, magnetic tapes, circuits and devices—all contribute some noise. Therefore the extent to which wanted information overrides noise must always be of consuming interest. In this subject the expression 'signal-to-noise ratio' is frequently encountered and is a major factor in assessing the quality of system performance.

*Decibels* The huge ranges of sound intensities encountered in music, and the correspondingly wide range of signals involved in recording, lead to the use of inconveniently large figures, as we have seen. By a mathematical trick the figures can be fitted into a compact scale of decibels (abbreviation dB), equally useful for sounds, noises and electrical signals. Although the decibel has no meaning as an absolute unit it is useful when we compare one sound intensity with another. For example, the greatest intensity to which we could be exposed is in the region of 130dB (this is painful, damaging to the hearing,




In sound reproduction the practical dynamic range is limited by system noise on the one hand and power handling capability on the other. In this example the limits are about 30dB and 90dB, and the effective range is therefore 60dB.

and therefore to be avoided), and further down the scale a quiet conversation yields 30dB.

Expression of the apparent loudness of sounds is not quite the same: a different scale of 'phons', taking the peculiar characteristics of hearing into account, has been devised.

*Frequency response* Human hearing covers a certain frequency range, and musical sounds also embrace a range which, not surprisingly, is near to human capabilities. We impose more discipline on our arguments and measurements by specifying frequency 'response'. This enables us to show how much the sensitivity of hearing, or the performance of a sound system, fluctuates through a range of frequencies. The expression of response in the form 30-16,000Hz ± 2dB is precise and useful because it states that variations do not exceed 2dB one way or the other throughout the specified range.

*System* In many areas of engineering and industry a number of elements or units, each having a specific role, come together to form a working whole which we label 'system'. One of the most complex of systems is a computer, which incorporates electronic, mechanical and electro-magnetic parts, and the complete system performs complicated tasks. A sound recording system incorporates microphones, electrical circuits, amplifiers and a tape-recording machine. A hi-fi system includes a unit for replay of discs or tapes, an amplifier and loudspeakers.

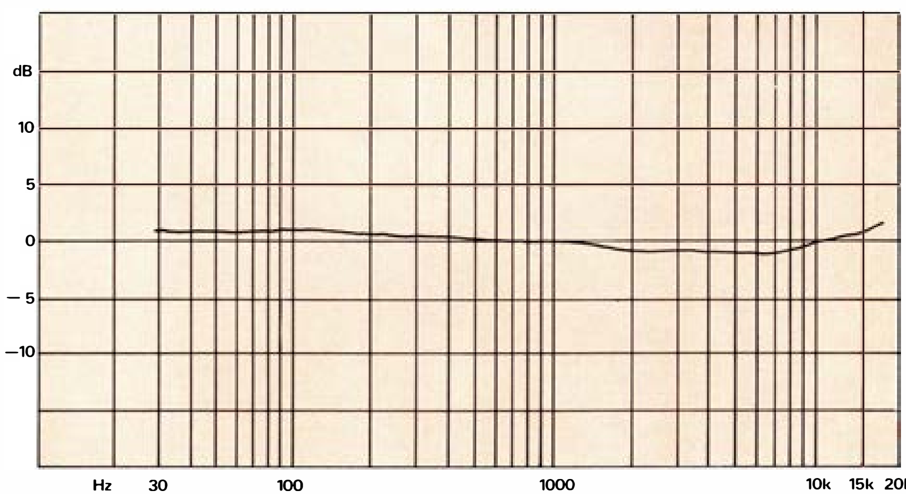
*Dynamic range* This term refers to the range of sound from the loudest to the quietest. A symphony orchestra at a normal listening distance would be found to have a dynamic range of about 80dB. Dynamic range in sound recording and reproduction is important to both designers and listeners; although it is difficult to encompass accurately the entire range of a large orchestra or an organ, a wide range is essential for realism and impact. Whether or not the quietest parts can be heard clearly via a sound system depends on the amount of noise that intrudes. Hence signal-to-noise ratio is firmly linked with dynamic range.

*Distortion* The aim in engineering sound systems and recordings is to minimize distortion and to preserve, rather than mutilate, the waveforms that represent the music. Taking just one aspect, it is possible (indeed, likely) that an inferior sound system would add harmonics of its own to the musical notes. As we have seen, recognition of harmonic patterns is of prime importance in music and obviously we must preserve their integrity. The production of spurious harmonics is bound to affect the timbre of the musical sounds. In a bad case the identification of details in the music becomes difficult, and serious amounts of harmonic distortion will inevitably prove fatiguing to the discerning listener.

*Technical abbreviations* Frequency is expressed in Hz (Hertz), and the abbreviation is placed after the number. Example: 100Hz. A quantity of a thousand is denoted by k (kilo): hence 2000Hz is commonly abbreviated to 2kHz. A million is rendered as mega, or M, so that 2 Megahertz becomes 2MHz. The unit of resistance, the ohm, is similarly treated, so that we find 47 kilohms or 47kohms for 47,000 ohms.

An electrical volt is represented as V. Small voltages are common in sound systems; hence the use of m (milli) to represent a thousandth in 2mV, and $\mu$ (micro) for a millionth in 2$\mu$V. An electrical watt has the symbol W.

The metric system is widely applied to recording, and small velocities encountered in records and devices are expressed in centimetres per second, abbreviated cm/sec.




**Frequency response can be stated in figures but a graph is more explicit. This graph supports the statement that the response is 30-18,000Hz±2dB. This means that departures from linearity (a straight line) do not exceed 2dB in either direction. Such a response is typical of a hi-fi pickup cartridge.**

# 2 Hi-Fi and Stereo

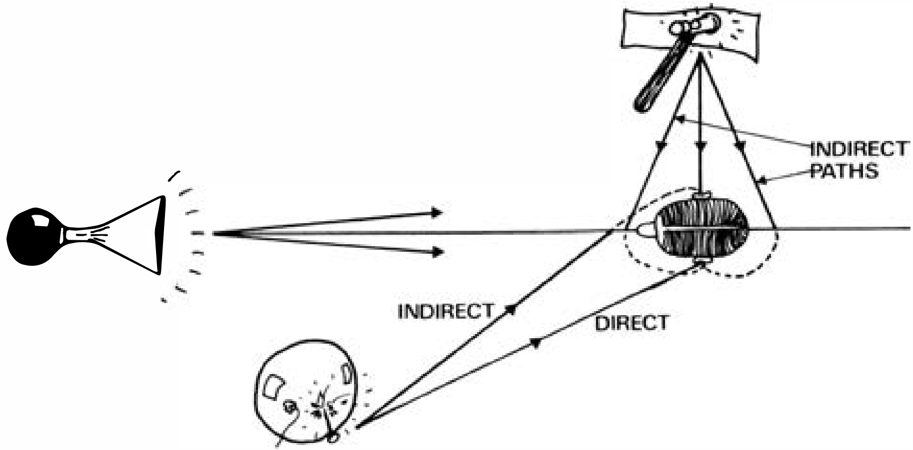
If you are at all interested in recorded music you will know that hi-fi has to do with realism in sound reproduction. You may also know that the neat little 'hi-fi' tag stands for high fidelity. The pursuit of realistic results with the aid of high fidelity equipment, and of course with the best available recordings, has grown in popularity during recent years until, now, it is a major part of the multi-million pound electronics and communications industries.

How high should the hi-fi be, you may ask. The truthful answer is: the performance can be as advanced as the technology currently permits. Obviously, since new developments arrive very frequently, we can always look forward to better sound quality. Equally obviously, not everyone can afford to pursue matters to the limit, for hi-fi at its finest is very expensive. On the other hand, an impressive degree of refinement is within the scope of very many music-lovers.

If the most advanced performance is difficult to define in simple terms, the less exalted level of quality within the grasp of every enthusiastic amateur is easier to explain in concrete, technical language. In fact there are some useful standardized methods of testing and describing the performance of equipment; many have been proposed by the German DIN standards body and others have been put forward in the United States and Great Britain. Not all the technical standards are accepted by all concerned with the design and use of equipment, but clearly it is better to secure some measure of standardization than none at all.

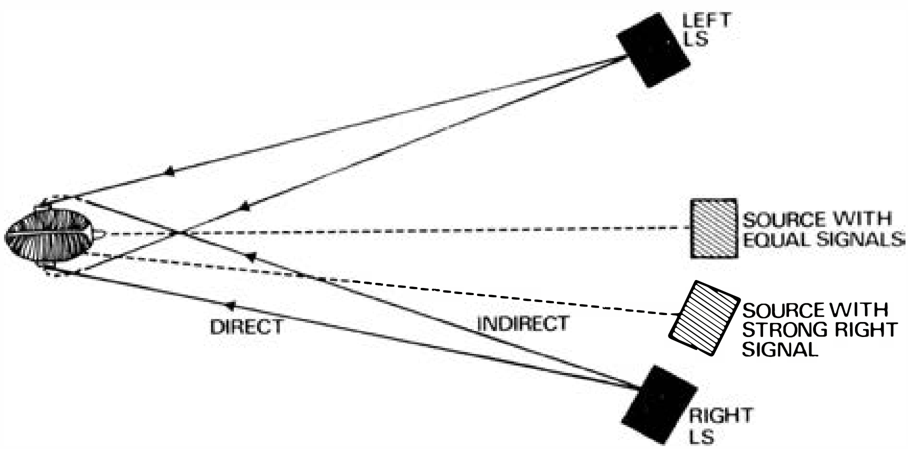
The final judgment of sound systems and recordings must be made by listening. Our ears and senses will tell us what is good and what to reject, and we shall succeed in this evaluation according to our experience of listening and our ability to criticize. With a little experience we can quickly detect that hi-fi starts where outmoded methods are found unrealistic. For example, no one who has come to accept even a modest standard of hi-fi sound quality can possibly return to the restricted, boxy or muffled quality of the average radiogram or small record player.

However, we cannot design and develop sound systems just on the basis of trying an idea, listening to the result and trying again. That would be a good way to get into a muddle. Hi-fi depends on the elimination or control of factors that degrade the quality of sound recording and reproduction, and therefore a lot of science, as well as some art, must feature in the work of development. In the simplest of terms: what we feed in at one end of a




How we listen. Distances from the ears to a source of sound are the same when the sounds come from straight ahead. Sounds from other directions take slightly different, indirect routes to each ear. The brain interprets such information and decides on the position of the sound source.

With stereo we hear many sound sources between the two loudspeakers, depending on the signals conveyed by the two channels from one moment to another. Two such 'imaginary' sources are shown, lightly shaded. In music reproduction the brain perceives a wealth of detail in the area between the loudspeakers.



system must emerge at the other end as little altered as possible.

Outstanding requirements include the reduction of distortion (mutilated waveforms are hostile to good music reproduction); the provision of the optimum frequency response (we require the sound to be smoothly presented throughout the audible range); and tight control of unwanted noise (any electronic or mechanical process will introduce some noise, but it must be minimized).

*Highlights of hi-fi*

No sooner had Thomas Alva Edison invented records and a gramophone to reproduce them, than others took up the theme and played their own variations. For instance, in 1877 Edison gave a public demonstration of his phonograph, using cylinder records; a decade later Emil Berliner introduced disc records, played on a different type of gramophone. Other enthusiasts, seeking to disperse the sound more widely, fitted multiple horns to their gramophones. This was soon followed by Valdemar Poulsen's Telegraphon, the forerunner of the present-day tape recorder.

The invention of methods of storing sound did of course constitute a major breakthrough in science and engineering, and since those days there have been unceasing efforts to improve the sound quality. What we now know as 'stereo', or stereophonic sound, was devised by 1930 in Britain; and the German development of tape recording, accelerated by the demands of the Second World War, proved to be the basis of the sound recording industry which has grown in such a spectacular way in the last few decades, during which pop music and complicated styles of entertainment have become part of everyday life. Without tape and stereo we would not be able seriously to aim at hi-fi performance.

If we can agree that high fidelity is synonymous with realism and that some comparison between 'live' and reproduced sound is implied, then it is fair to say that the challenge was accepted at least forty years ago—long before the technology was widely available to match the ambitions of keen listeners. The well known film *Fantasia* was exhibited with a form of stereophonic sound at a time when people were using ordinary mono (monophonic) gramophones, players and radio sets.

However, it was in the period following the Second World War, which saw the rapid growth of the electronics and engineering industries, that we find the true starting point of hi-fi and the complex sound recording techniques that have become so familiar. There was a much wider public interest in music and entertainment than ever before, and consequently a growing demand for records and radio and the means to reproduce sound in the home.

Many practically inclined enthusiasts, aided by knowledge gained in the armed services during wartime, constructed their own equipment and created a do-it-yourself market that has since become a familiar feature of audio and radio.

The availability of tape recorders in the postwar years and the subsequent introduction of long-playing records were, for hi-fi enthusiasts, highlights of the greatest importance. These were followed in 1958 by the introduction of stereo on LPs. Then there were the rapid development of lightweight pickups for records, the improvement of loudspeakers, and the hectic pace of development in electronics, during which transistors ousted valves in practically every kind of sound and radio system. All these events are in a general way familiar to students of the subject.

*Stereophonic sound*

It has been amply demonstrated in recent years that hi-fi and stereo go together to promote the best sound reproduction. High fidelity is concerned with a quest for quality, and stereophony is a technique that helps us record a wealth of musical detail. As we have seen, better recorded sound has always been the aim of discerning people; this was so long before stereo was available. But the introduction of stereo was vital in stimulating development of both sound systems and recordings. Without this there might well have been a period of stagnation.

We have not reached the end of the road, and new kinds of recording system are emerging to take us beyond any limitations on realism imposed by stereo. The nature of these innovations will be described later; for the moment it is more important to understand stereo, which is generally available on records and tapes.

First let us consider what we require of sound systems. If we are interested in music, opera, drama and entertainments of various kinds we must certainly welcome something better that a mere reminder of the tunes and rhythms and words. It is more enjoyable to hear plenty of detail and to have an impression of atmosphere.

Do we expect to transport the musical performance directly to the living-room, so that the performers seem life-size? A little thought must bring us to the conclusion that this is possible only for a solo musical instrument—and even then there may be restrictions on loudness. To set up the original image of a pop group or string quartet in the room is out of the question; and the idea of cramming in a symphony orchestra of a hundred musicians is laughable.

How, then, are we to produce realistic effects? It begins to look as if we shall have to exercise rather a lot of imagination to enjoy our recorded reminder of the original music-making. To be sure, a little imagination always helps, but fortunately the illusion of realism can still be ours provided we accept that the key to our enjoyment is to be transported to the place of the performance by virtue of a few technical tricks. If we can listen to the complex detail in the music and grasp the size of the performance, then our pleasure can be great. Indeed, a good test of serious sound reproduction is to judge the extent to which concert-hall or studio acoustics are conveyed along with the music, enabling us to disregard the limitations of the room.

This impression of a well-filled sonic image, endowed with information about the acoustics of the place where the sound was recorded (the overall effect is often called 'ambience'), is inseparable from stereo. Of course, the sound we can cope with at home is scaled down to suit individual conditions of listening, but the crucial test still lies in the revealing quality of the sound, rich in detail and accurate in tonal quality. In other words the sense of 'being there' can be very convincing.

Without stereo our chances of enjoying such an illusion would have been very slim. Formerly, despite attempts to improve the quality of audio equipment, all sound systems remained resolutely mono (monophonic). This is the single-channel recording or transmission of sound employing only one circuit or route from studio to listener.

With mono, all the details of the music and the 'ambience' are funnelled into one channel; there is no separation of any of these elements at any stage through the many links in the chain (tape tracks, electronic circuits, disc grooves, loudspeakers). This, in brief, was the principle applied in recording in earlier days and still employed quite widely in broadcasting. (A small radio or record player may be mono even now.)

Stereo requires two channels, as a minimum, at all stages in recording and reproduction, and it is the skilful use of these two separate yet associated routes for the signals that enables many realistic effects to be achieved. The numbers of loudspeakers or microphones in a system do not hold the key to stereophony. It is the twin-channel principle that determines what can be done.

For instance, a mono recording of opera will present the singers as if they are moving toward or away from you in a tunnel extending behind the loudspeaker. In stereo the stage is spread out between two loudspeakers and the singers are heard to move laterally according to the action of the opera.

Stereo's outstanding advantage can be summed up as follows. Quite simply, stereo permits ears and brain to work as they were intended, sorting out muddle and sifting details. By comparison, mono deprives us of the opportunity to work on the problem. The single-channel information is a confused mass from the start, and we cannot gain from it any aural clues to aid appreciation of essential details. Indeed, mono recording can be achieved in a studio (or by any tape recording hobbyist) with a single microphone functioning like a single ear and passing on a welter of information that defies analysis.

Although a stereo recording and reproduction system cannot match human hearing in ability to detect, analyse and compare, it can certainly assist awareness of direction, present information about acoustic characteristics and convey impressions of distance. To an encouraging extent we are able, with stereo, to pick out one strand of sound from another, appreciate movement of sound sources where this is appropriate, and gain a sense of perspective.

Given the finest sound reproduction it is possible to feel that one is 'listening through' the complex recording chain to the musical performance; awareness of the intervening processes is much reduced. All because our hearing is given a chance to function in much the same way as it would in everyday activities!

When the earliest investigators conducted their experiments they had only the simplest of basic requirements in mind. In particular they wanted to add an extra dimension to sound reproduction: this was envisaged as a horizontally spread-out stage on which the elements of the sound-source could be located in their correct relative positions. This feature has since become important: it is possible to present a symphony orchestra according to a concert-hall layout with violins mainly towards the left, basses and cellos towards the right, woodwind and brass and percussion disposed in between the extremes with an illusion of distance to aid realism by placing sections of the orchestra in depth.

An early experiment involved the relay of opera and other stage performances by wires to telephone subscribers. A Parisian engineer, Clément Ader, was in 1881 granted a patent describing this twin-channel service. Listeners were required to use headphones in order to follow the movements of the performers. In 1925 a German engineer proposed a method of broadcasting from the Berlin Opera and suggested that the two stereo channels should be conveyed by separate radio transmitters.

In 1930 experiments in the United States with microphones inserted in a dummy head led to a style of reproduction best heard on headphones. Then there was a celebrated relay of a concert in Philadelphia to a hall in Washington via telephone lines. Meanwhile in Britain, A. D. Blumlein of the Columbia Co. (it became part of EMI) devised a stereo recording and replay system and showed how twin-channel disc records could be made.

# 3 Studio to Listening-Room

Sounds of music we hear from our record player or hi-fi system have passed through many stages and taken several forms before we enjoy them at home. They were generated at another time and in very different surroundings from those in which we listen; and they have been passed on from link to link in a complicated chain. First they were electrical signals: then they became magnetic patterns on tape, only to be converted into a mechanical counterpart on the LP disc. Translation into an electrical form and finally into reproduced sound were the final stages.

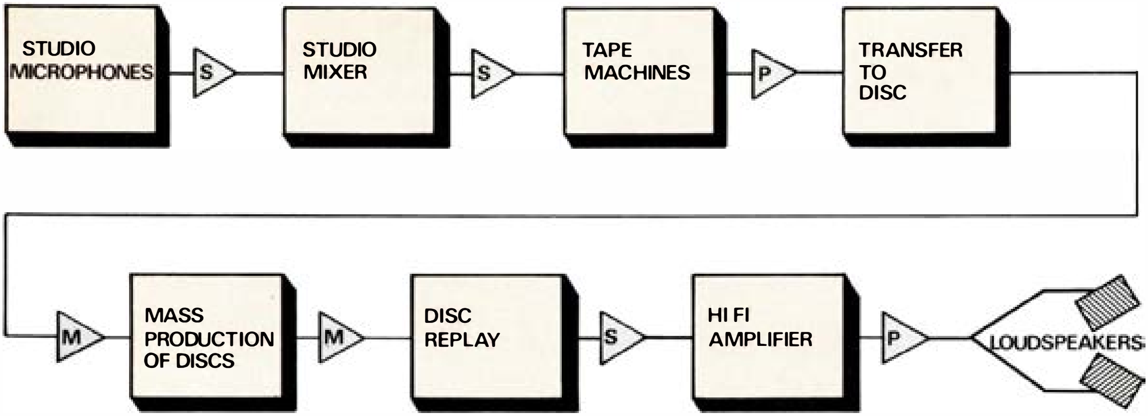
Is it not surprising that a reproduction worthy of comparison with live music can be attained? Yet we can aim at such comparisons when sound reproduction is at its most refined. In fact in these days of advanced hi-fi the true test is the credibility of 'canned music'. If the idea of a comparison between live sound and its recorded version can be taken seriously, and not dismissed as silly, then high fidelity is making progress.

At the one extreme, represented by the juke-box, credibility hardly enters into the matter. At the other it most certainly does—provided we observe precision, care and attention to detail. A great deal of science, and not a little art, must go into the finest sound recording and reproduction. This is true of professional tape recording, for example, and of the subsequent transfer to the master disc which is the starting point for record manufacture. Again it is true of the mechanical and electronic components that can reproduce records with such realistic results.

At the scene of the music-making, in the concert-hall or studio, we may have to revise our view to some extent. It is not that care over details is any less at the artistic end of the chain, but it is certainly true that the organization of large-scale recording often depends on facilities that are less predictable and controlled than the processes used once the music has been captured on tape.

There is a general shortage of halls suitable for recording the most massive musical forces—opera and symphonies, for instance—and those that find favour for acoustical reasons may well be inconvenient from other points of view. Also, it is not unknown for a large orchestra to rehearse in one hall and record the music in another, and impressions of the sound produced are likely to vary from one place to the other.

Recordings of classical music are made in concert-halls, churches and cathedrals, stately homes, the assembly halls of local authorities,and universities and other institutions of education possessing spacious




**From studio to listener. Signals from microphones pass through the mixer and associated amplifiers and are recorded on tape. A master disc is cut and further processing leads to record manufacture. In replay, signals from the pickup are amplified and then reproduced by the speakers. S indicates that small, mainly low-voltage signals are passing. More powerful signals are shown by P. Mechanical operations occur at M.**

accommodation. One of the most familiar places where recordings take place is the Kingsway Hall, London, from which has emerged during the past twenty-five years or more a long series of highly successful classical recordings, some of them involving large choral forces in addition to full symphony orchestra. At first sight this Methodist meeting-hall seems unpromising, yet musicians, recording engineers and critics agree on the quality of the sound yielded by recordings made there.

Although a few recording companies have invested in small and medium-sized studios suitable for a wide repertoire, not many can boast purpose-built studios big enough to guarantee elbow room for the hundred or so performers of a symphony orchestra. Probably the best known example in the United Kingdom is EMI's Number One studio at Abbey Road, in north-west London. This is the biggest of several studios hiding behind the undistinguished but certainly famous facade which fronts administration offices and a maintenance workshop. One of the studios was the home—musically speaking—of the Beatles when they came to London. In fact the surrounding district has long been noted for its musical and artistic residents.

Of course, the facilities of a large studio complex are gauged to meet everyday needs. Next to the studio, separated from it by a window, is the control room housing an array of tape machines, signal mixers, amplifiers and loudspeakers, the latter allowing the recording to be monitored while it is being made. Contact between orchestral conductor and recording producer is maintained by intercom during the sessions.

By comparison the occasional use of an acoustically favourable hall may be most inconvenient. Some part of the recording equipment may be left as a fixture if the hall is used often, but otherwise mobile equipment is necessary and makeshift control room arrangements are devised. Closed-circuit television may be used to link a remote control room with the hall. Incidentally, recording organizations are not the only concerns with large purpose-built studios: the BBC's orchestral studio at Maida Vale, London, is the size of a concert-hall and elaborately equipped.

Generally, in recording large-scale musical performances the aim is to exploit the basic sound of the hall—its acoustical characteristics. The recording, if it is a good one, will yield the many qualities of the orchestra and these will be accompanied in stereo by the 'ambience' of the environment. Experienced listeners can tell if a recording was made in, say, the Kingsway Hall, for it will display a certain warmth of effect (that is, not too clinically revealing) without undue sacrifice of details.

They will also detect the difference between a recording made there and another made in the Concertgebouw, Amsterdam, or the Sofiensaal in Vienna. Some halls give splendid clarity yet do not permit the impact and weight of sound that would be heard at a concert; others err in the other direction, the degree of reverberation masking the essential details. So a feature of large-scale recording, especially of symphonic music, is the natural background of acoustics—the general resonance of the place—framing the

**Island Studio's mobile installation includes a 3M 24-track tape recorder.**

musical activity. You hear the acoustics just as surely as you hear the sound directly emitted by every musician in the orchestra. The art and science of the studio lies in balancing these components to best effect.

Another feature, and a very important one, is the very advanced musical knowledge of recording staff—studio engineers as well as producers—working on classical sessions. The contrast with the world of pop could hardly be more marked, for there the business of the recording companies has been to foster the talents of young musicians who often cannot write or read musical notation. Times change, of course, and trained musicians are active in pop and light music; but many groups work with experts who are alive to market trends and who can help to interpret the requirements.

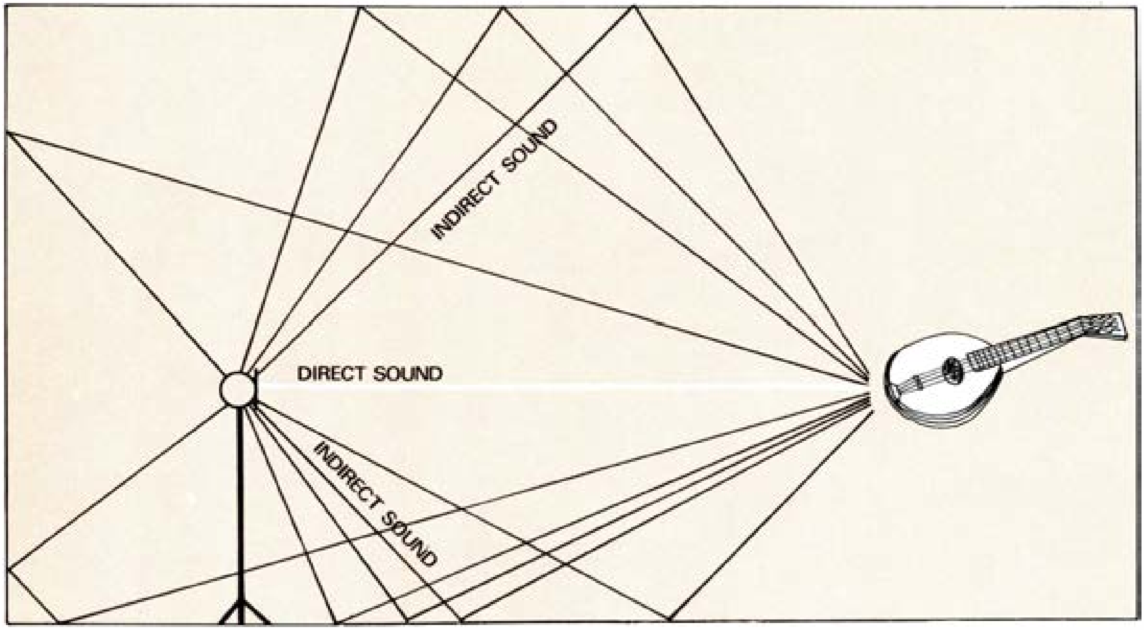
This mode of working has led to interesting technical features, particularly multi-track recording. Pop music would probably not exist without it, in fact. Again, the studios for pop groups and much light music differ from those for even the smallest classical music sessions. Pop musicians do not sit in a huddle in front of a conductor. A small, acoustically-dead studio is used, and the aim is a very tight sound which conveys no impression of the place in which the music was performed. Any 'acoustics' in the finished product will be attributable to electronic wizardry, under the control of the producer.

This union of music and technology is relatively new, having taken place in little more than fifteen years. Early in its development the producers found that acoustical and physical separation of musicians was the key to successful pop. Performers are shielded by acoustic screens (or even shut away in boxes) and each has a very closely located microphone the signals from which are directed to specific tracks on the tapes. In this way there is no interference between, say, the lead guitar and the drummer, or between the electronic organ and the vocals.

Isolated like this the performers have to wear headphones—communication being otherwise impossible. The system that links them all and records their many 'takes' during the session is of a highly technical and complex kind. Not surprisingly, studio staff have to gain a great wealth of technical knowledge—and musical expertise. Recent inquiry revealed that A-levels in appropriate scientific subjects were welcome, and indeed fairly common, in recording studios.

A comparison between the reproduction and the live original may become difficult to visualize. In the case of studio-engineered pop, at variance with any presentations of popular groups at public events, it is impossible to judge exactly *what* is the original. If the music arrived at the studio not on paper but in the form of ideas, there to be developed, tried out and engineered into a viable form by means of available technology, the question of a comparison hardly arises, for there are no stable reference points.

If that view of pop is not very easy for the beginner to grasp, a more general point about recording is comparatively simple. What all kinds of recording have in common is an in-built message concerning the producer's ideas. He has strong feelings




Recording in an enclosed space. Some sound reaches the microphone directly but the rest arrives after reflection from adjacent surfaces. Similarly a listener would hear a mixture of direct and reflected sounds.

about the characteristic sound—the trademark of the production, we may say. Once the decision has been made to give this effect or that, the results are unalterably there on disc or cassette. The sound may seem forward or loud or full of explicit details; it may be more distant and spacious or essentially alike. Whatever the quality may be, it cannot be modified to any great extent when the record is played at home. In short, the key to the quality of sound recording is always in the programme.

Reproduction in stereo yields a soundstage between the loudspeakers, and this horizontally spread image may be full of fine detail or seemingly more recessed, with a spacious sound corresponding to the nature of the hall in which the recording started its life. The better the equipment used for reproduction, the more truthfully such characteristics will be passed on to the listener. Particular features include accurate tracing of the record groove by the pickup, accurate translation of signals into sound waves by the loudspeakers, and low distortion in the system as a whole. The listening room also will affect the way in which the details in the recording are revealed to the listener.

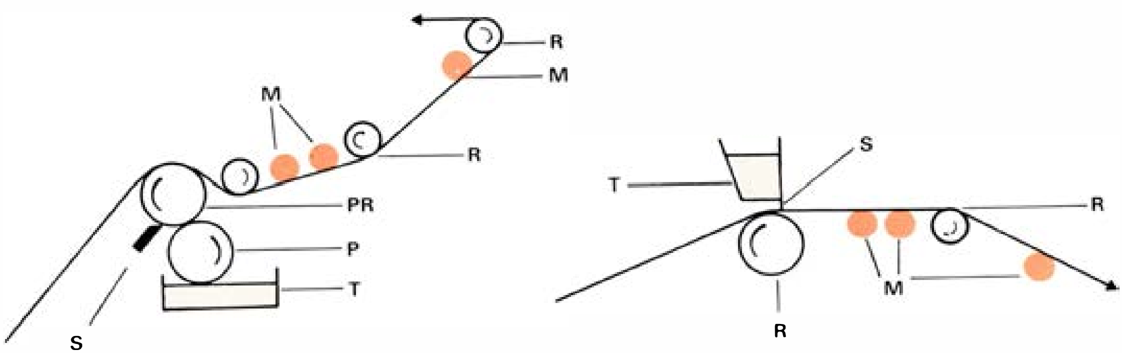
MAGNETIC TAPE RECORDING

Magnetic tape's popularity as a store for audio information is evident to every reader. The tape cassette recorder is as familiar as the transistor portable radio, and many enthusiasts use larger tape machines of open-spool design. A most significant factor is that the sound recording industry depends on the development of magnetic tape, for all recordings start as patterns in the tape's magnetic coating.

Development of tape depended in turn on an ability to make plastics films to carry the magnetic coating. Even before that stage was reached the value of continuous recording was recognized, and early recording machines employed steel wire or ribbon. The first, comparatively crude tape appeared forty years ago but it was not until a few years after the Second World War that tape for domestic use was introduced by BASF, the German manufacturer. Rapid development and refinement followed: tapes became thinner, so that longer playing times could be obtained from a given size of spool, and improved coatings were devised.

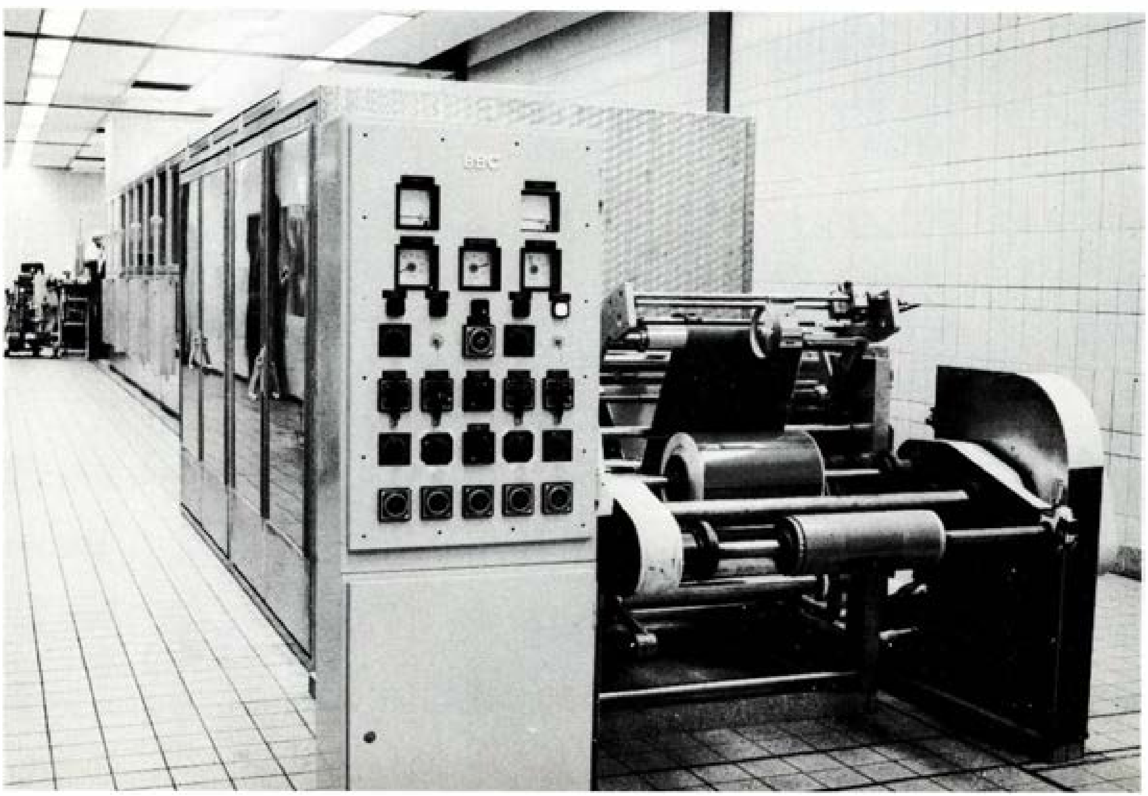
New plastics film materials were perfected. To the early acetate and PVC base materials were added polyester and other synthetics offering the advantage of greater mechanical strength and consistency. During little more than twenty-five years of fiercely competitive activity, involving industrial organizations in Europe, Japan and the United States, many special-

Two methods of applying coating dope (binder and oxide) to the plastics base in tape manufacture. In the rotogravure process (left) the printing roller P dips into a trough (T) of dope, which may then be transferred to a second roller PR. Scraper S removes surplus. Dope is held in fine depressions in the roller, from which it is transferred to the tape. Magnets, M, disperse the magnetic particles evenly. In the casting process, rollers move the tape along while dope reaches it from a tank. The magnets have the same function as before.



purpose tapes have emerged. Some are especially favoured by studio engineers, for example, and othere have been introduced to improve the results obtained from cassettes.

Nowadays the properties of coated tapes are so advanced that specialized types can be tailor-made for recording television signals. Indeed, video recording is a major innovation and one that we shall hear much more about—in education, commerce and industry—during the next few years. For sound recording, 'low-noise' tapes are particularly important, since the coatings are prepared in such a way that the noise content of recordings (the characteristic background 'hiss') is reduced. Signal-to-noise ratio is as important in tape recording as it is elsewhere in audio systems. A new tape coating incorporates chromium dioxide ($CrO_2$) particles to improve performance. Before long we may see a return to pure ferrous materials, this time in the form of specially shaped iron particles which, it is claimed, will surpass more exotic materials where the basics of performance are concerned. No doubt rigorous control of manufacturing processes will be a prominent feature of development, since finely divided particles



**Coated magnetic tape emerging from the drying tunnel at BASF's factory in Germany. After slitting to the required width, the tape is spooled and checked.**

of this kind could otherwise cause a risk of explosion. Tape coatings in layer form, involving two or more substances, are also being developed. The aim here is to exploit the properties of available materials such as chromium dioxide and ferric oxide in the most effective way.

Briefly, the recording medium for sound signals is a mass of particles mixed with a binder and applied very thinly to the flexible plastics tape. The precise nature of these particles is not significant, though they are, in fact, needle-shaped. It is essential to try to visualize that recording depends on the orientation of the particles in response to a varying magnetic field applied to them. The particles adopt patterns corresponding to the amplified audio signals passing through the tape recorder.

Of course, the particles are microscopically small and cannot be seen (although there are devices which can magnify and highlight the patterns). Students experimenting will probably be glad to take all this on trust, however, for they are well aware that, given a bar magnet and an ounce of iron filings, they can produce a variety of patterns—all of them related to the magnetic fields extending around the magnet. Orientation of the particles on tape depends on similar principles, though in this case the patterns correspond to constantly changing signals —all the frequencies and wavelengths of music.

Once the particles take up their positions they remain 'frozen', provided they are not exposed to any strong magnetic influence that could disturb them. Your carefully recorded tape could be ruined by bringing a strong bar magnet near it. The magnetic field would disrupt the series of patterns, blurring or destroying the recording.

Most recording tape for domestic use is 6.25mm (¼-inch) wide and made from a much wider sheet of coated film. Once a tape has passed its initial quality checks it is slit to the standard width and spooled. Tape for professional use, in recording studios and for computers, is made wider (25mm—an inch or more) and, by way of contrast, that for cassettes is 3.125mm (⅛-inch) wide.

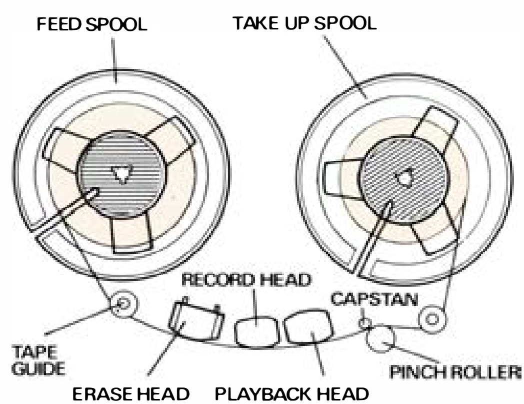
# 4 The Professionals

In sound recording there is much common ground between the professionals and hi-fi enthusiasts. Some of the principles well-known to studio personnel are exploited by keen hi-fi users, and some of the finest hi-fi equipment for the home is familiar to those who make their living in the world of sound.

Of course, the differences rather than the similarities are important when we study the techniques underlying the production of records and tapes. For instance, most active users of audio equipment are familiar with microphones, and it is true that the microphone that helps you record voices or music for your own pleasure is the same in principle as its counterpart in the studio. The difference would be appreciated if you actually had to buy one, for the development and manufacture of specialized microphones is expensive, a very refined example costing more than £100.

Again, tape recording is the same the world over, but the complex machine for a studio costs many thousands of pounds and the engineer who runs it will use hundreds of poundsworth of tape in a busy week. The most expensive tape is the wide (25mm or more) variety used for multi-track work. Any recorded spools that finish up as rejects are simply waste; for technical reasons they must be reused. Tape for non-professional use is standard-width (6.35mm), cheaper, and users often record on it a second or third time.

The centre of attraction in the studio control room is the tape machine, and linked with it, the mixing desk. Amplifiers, loudspeakers and a spare tape machine may also be found but the recording and mixing consoles form the heart of the system. Out in the studio the balance engineer positions

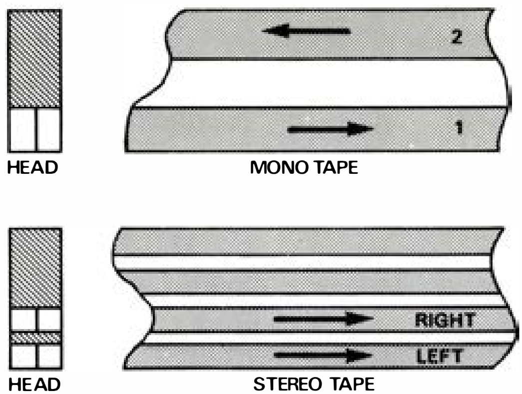



A tape deck consists of the mechanical parts of a recorder. Tape runs from left to right, drawn by a capstan against which presses a pinch roller. Guides keep the tape in the correct path as it passes the heads.

Mixing desk at Advision Studios, London. Each microphone input from the studio is subject to a wide range of control.

the microphones, the number of which depends on the type of session. Pop group musicians each have their own microphone, and as already explained the contribution of each player is widely separated, acoustically and in every other way, from that of the others. In addition some of the most modern electronic instruments are directly linked to the control-room installation.

For orchestras in classical sessions a large number of microphones is involved: there may be more than twenty, some covering the scene from a distance and influencing the spacious 'ambience' in the recording, others close to the sections of the orchestra, and a few picking up soloists. Two or more will be used for recording a piano recital in stereo. Whatever the arrangement, the outputs of the microphones are fed to the mixing desk where



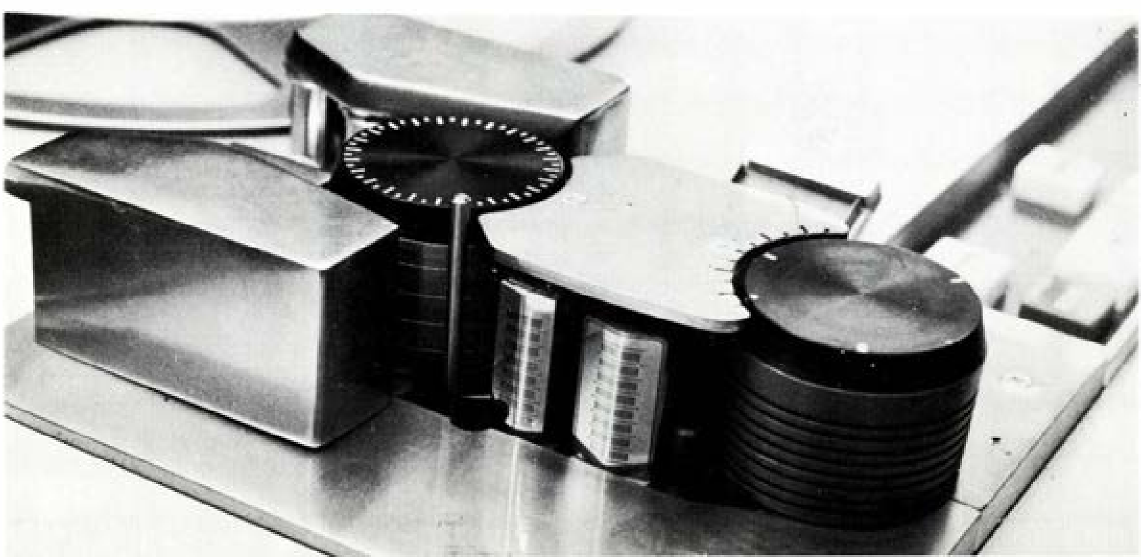

Track system for cassette recorders. For mono, one track is recorded in each direction of travel. For stereo four tracks are recorded but used in pairs. The two tracks needed for stereo channels are adjacent, and one pair is recorded in each direction.

Multi-track recording heads on a 3M studio tape machine.

the overall balance and many fine details of the recording are determined by the producer and studio staff.

As every keen tape-recorder user will know, two tracks are recorded within the width of standard tape for stereo (if the machine allows for four tracks, only two are used at a time). Exactly the same method can be, and sometimes is, used for studio recording. During the last few years, however, multi-track recording on wide tape has been increasingly used for classical music because of its versatility. Four-track, eight-track and sometimes sixteen-track techniques give producers immense scope in influencing the presentation of complex detail in large-scale orchestral music.

The first step is to record a section of the musical work and monitor it via loudspeakers in the control room, possibly while the musicians rehearse. In this way the conductor, producer and engineers can judge overall balance and sound quality, deciding on any adjustments to be applied. Meanwhile the correct functioning of all equipment can be checked. Although

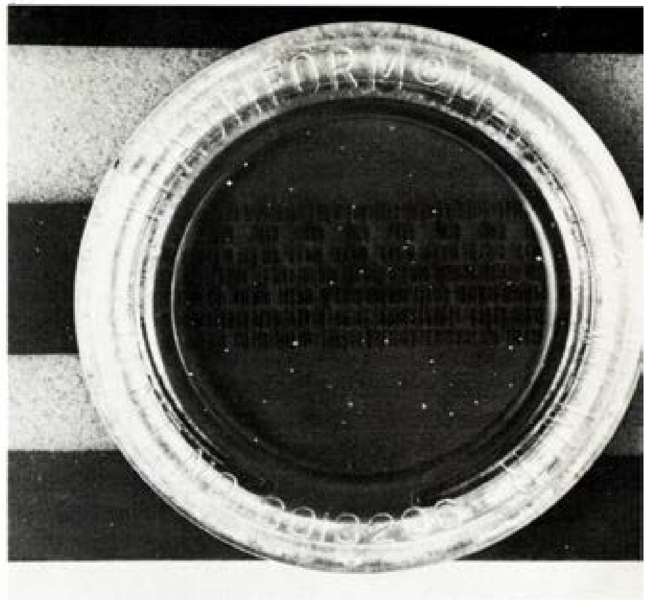


professional equipment is robust and reliable, faults are not unknown and spare parts must be at the ready. As some engineers have found, a tea-break can provide extra time for fault location!

The length of time needed to record, for example, a Brahms or Beethoven symphony may vary a certain amount from company to company and must depend on the facilities available, but usually the job would be spread over six to nine hours. Recording a three-act opera might be spread over two weeks but the work would not proceed as suggested by the score and libretto. Soloists might be available only at certain times, and their parts would therefore be recorded during a particular day or two; then purely orchestral interludes could be recorded as a group, and so on. Skilled tape editing would later put everything in the right order.

Multi-track techniques are most firmly associated with pop music and some kinds of light entertainment. Tape machines with as many as sixteen or even twenty-four tracks on 51 mm (2-inch) tape are taken for granted. The tape runs at 38 cm/sec (15 inches per second). Multi-tracking is essential to such music for, as we have observed, the performances do not exist in any formal shape—only as ideas—before the musicians reach the studio. There they develop and adapt their effects as they go along. Experiment, monitoring and repetition can mean that recording a pop single takes several hours, or much longer in some cases.

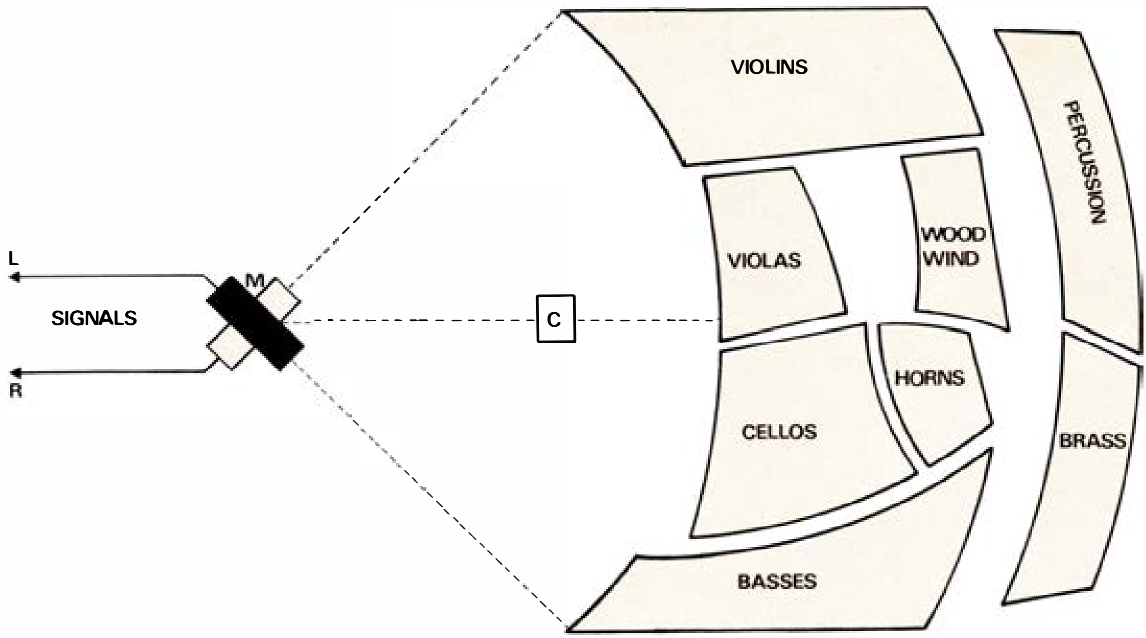
For light music and popular recordings, involving numerous microphones each very close to a musician, the tape tracks might be employed along these lines: track 1 bass guitar, 2 drums, 3 guitar, 4 piano, 5 and 6 electronic instruments, 7 and 8 wind instruments, 9 and 10 strings, 11 percussion, 12 and 13 vocals. In a sixteen-track system one of the remaining tracks could be reserved for a soloist and the others kept free.



Scotch magnetic tape viewer reveals the pattern of the recorded signals on a multi-track tape.

With the tracks finalized to the liking of all concerned, the music-making is complete and the rest of the work is done by engineers and the producer after the session. Mixing, bringing together and adjusting the sounds of all the musicians, is undertaken as necessary, and artificial reverberation (echo) added. General tone 'colour' is influenced at this stage.

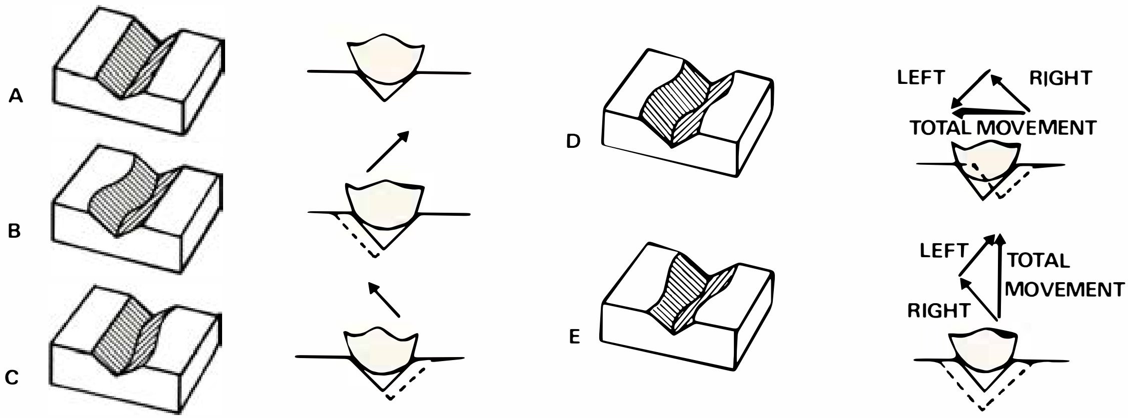
Finally the multi-track recording is reduced to two-tracks (for stereo) by a very




**Simplest way to record an orchestra is with a crossed pair of microphones, M. The left microphone is most sensitive to sounds from the violins; the right is most sensitive to sounds from the basses. Sounds from straight ahead encounter equal left/right sensitivity. The conductor is at C. More complex arrangements involve many microphones, each covering a section of the orchestra. Soloists have separate microphones.**

critical process of copying on to another tape, the studio master. This may seem drastic after all the work expended in multi-tracking, but the characteristics of the mixed-down original are reflected in the final version; and in any event a twin-channel master is required for copying on to the master disc that starts the chain of processes leading to record manufacture.

Already complex, installations for pop recording and such work as television and radio commercials tend to become even more elaborate. At the same time it is required to speed the studio work to meet demand. A recent innovation is a computer-like system that enables the studio staff to programme the mixer settings. Combinations of settings can be stored in the system's 'memory', with the result that subsequent adjustments and experiments can be assessed against the originals. Complicated mixing procedures formerly taking days of patient work can be




How stereo discs are recorded. A, blank groove, no signals. B, left channel carries signal, and stylus is moved as shown. C, right channel carries signal. D, channels carry equal signals, which are in phase (in step) so that groove swings from side to side. E, channels carry equal signals which are in opposition, so that groove moves the stylus vertically. The stylus is moved in these and other directions when tracing music.

completed in a few hours, and better control of all actions is assured.

A feature of many recent popular records—as well as some classical ones—is the use of synthesizers. Firmly a part of studio technology, these devices can contribute an enormous range of tone qualities and yield sounds that range from sonorous and organ-like to brassy or percussive. A synthesizer can be made to sound like a traditional instrument, but generally the aim is to explore new timbres and effects, not otherwise readily generated.

Such instruments incorporate oscillators to generate signals and filters to influence and shape the waveforms. Every change of signal waveform represents a shift of tonal quality, and changes can be as rapid and spectacular as the performer demands. Probably the best known synthesizer is the Moog, which looks rather like a telephone exchange sprouting a keyboard. Sequences of sounds are picked out and monitored by the performer: when perfected these are recorded on an adjacent tape machine. There are now so many types of specialized electronic instruments that recording producers bring them together in 'orchestras' to the exclusion of traditional sounds.

Yet another vital element of the studio equipment is the noise-reduction system used to to reduce the background noise (largely hiss) inseparable from tape recording. The Dolby system, an Anglo-American development named after its inventor, Dr Ray Dolby, is widely used to ensure a substantial lessening in hiss without affecting the music. If this was not used, the noise would be present through all stages and thus be reproduced from LP records. Indeed, hiss does sometimes intrude on new and otherwise normal LPs that have not been subject to a noise-suppression system. The Dolby 'A' system was designed for professional use, but there is also a 'B' system, which is simpler and intended for domestic use.

How do the professionals acquire their skills? It is not unduly unkind to suggest that sound studios have often seemed content with a chicken-and-egg situation. They could not profitably engage inexperienced people; but how could would-be sound engineers gain experience without working in studios? There has been a lack of organized training (except in the BBC) and facilities to provide formal qualifications.

As long ago as 1946 the composer Arnold Schönberg suggested that there should be university courses for 'sound-men', designed to embrace musical and technical aspects. One such course was indeed started at that time in Germany, and the Tonmeister (sound-master) concept gained ground with other courses following in Europe. In 1970 the University of Surrey (Guildford, England) added to its Bachelor of Music course a new course for a degree called BMus (Tonmeister). This takes in such subjects as electronics, acoustics and sound recording techniques as well as musical studies.

# 5 Music on Record

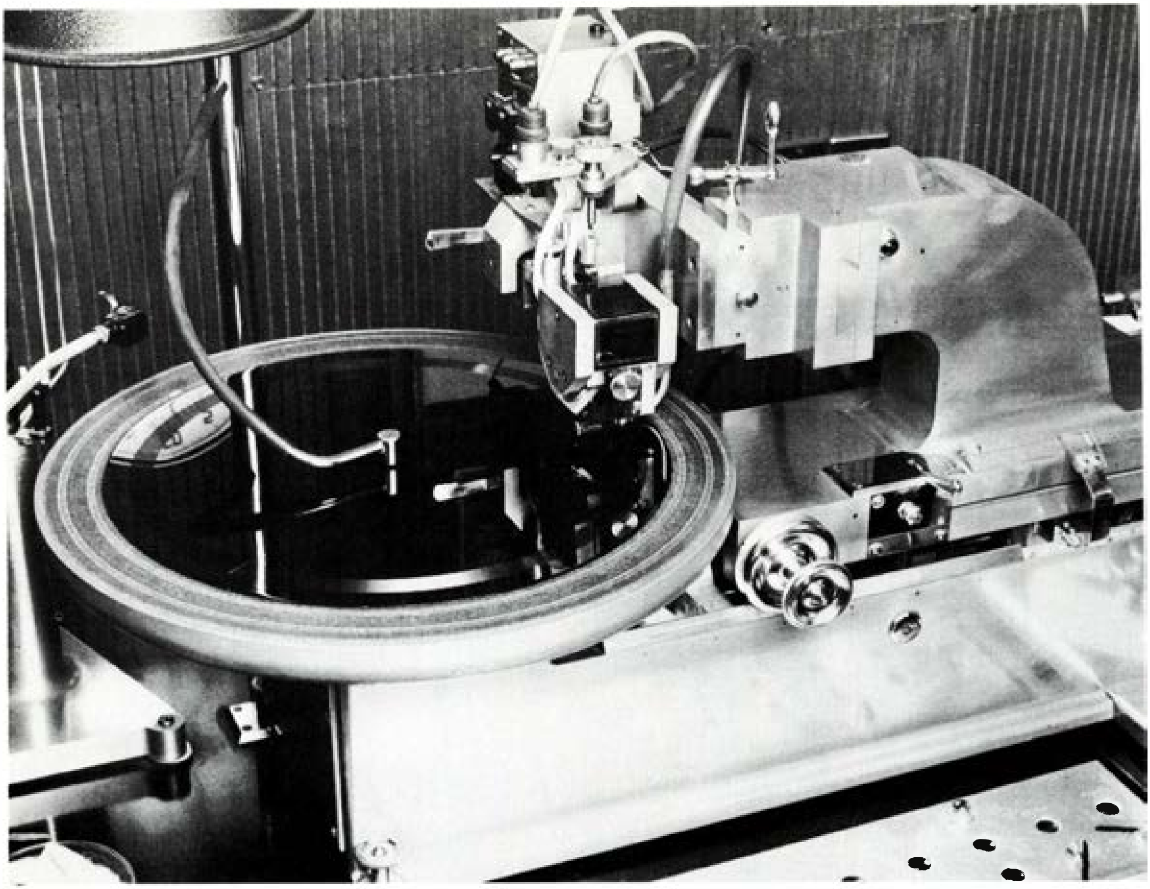
In recent years we have seen a boom in recorded music and entertainment. Few homes lack a record player of some kind, and there has been an upsurge of interest in sound reproduction at the hi-fi level of quality. To most people recorded sound means the ever-popular LP disc and, for pop music, the 'single'—a term applied by the record trade to the 7-inch 45 rpm disc. Cassettes of tape have made great headway in a short time, of course, but still the sales of music on tape are only a fraction of those achieved with discs.

Obviously the disc record had a good start and a huge repertoire has been built up. Discs are by now a highly developed product, yet they are easily mass-produced at a high rate of output to meet demand. Again it is obvious that everyone is familiar with the use of discs; they may one day find a tape format just as convenient, but that is certainly not true so far. Cassette and other tape enthusiasts will rightly observe that you can record on that medium yourself—something you cannot do on discs.

Most important, though, is that the disc, especially the LP, faces a large and very competitive market, so that it finds sales at many price levels. Newly recorded music involving leading orchestras and famous names will nearly always reach the market at top prices, but there are many reissued recordings on LPs, most of them stereo, which in the United Kingdom sell at about £1. If these were derived from tapes recorded ten years earlier—a typical situation, in fact—the sound may not be up to current standards. But there is no denying that good value can be obtained through 'budget' shopping.

Where hi-fi is concerned, the LP remains the focus of attention. A very high standard of sound quality is yielded by discs at their best, and it is necessary to spend a disproportionate amount on cassette or other tape equipment to ensure consistently good results to rank with those achieved with LPs. Indeed, many users of modest hi-fi systems have never heard *all* that is on the LPs they buy, such is the wealth of detail and the extended frequency range that may be recorded.

With such claims for quality in mind we can go on to look at the precision operations that produce discs and, later, the key to success in reproducing them. The studio master tape marks the transition between the recording art and the processes involved in factory production of LPs and singles. As we have seen, the results of all the studio work are, for stereo, reduced to

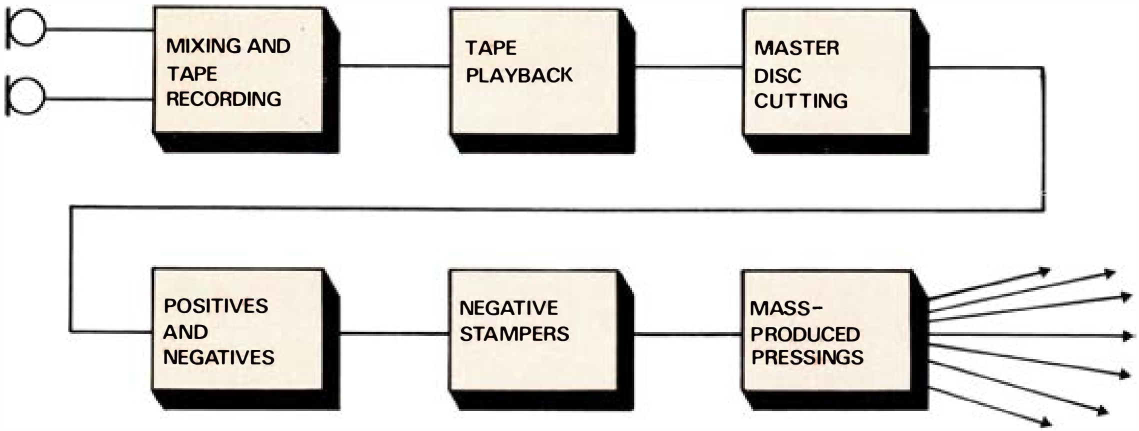


**Scully master-cutting lathe at Pye Studios, London. The stereo head is cutting the groove in the lacquer master disc.**

a twin-channel tape, and this is committed to the tender care of the experts who cut the master disc.

Disc cutting is a very special process requiring expensive equipment, experience and flair. As one enthusiast commented, it demands the right balance of science, artfulness, intuition and strong black coffee. The basic feature is the transfer of the taped programme to a cutting lathe, an elaborate and massive turntable with which is associated a cutting head designed to form the spiralling groove in a blank disc.

This blank is a mirror-smooth plastics lacquer coating on an aluminium core, and




**Disc production sequence. Microphones are connected to the tape machine via the mixing desk; signals from tape replay are applied to the disc cutter; and subsequent processing yields stampers for use in mass-production of records.**

before cutting it looks like an over-size, unrecorded LP (it is about 355mm, or 14 inches, in diameter). Studio staff often use the word 'acetate' because the disc has for long been made from cellulose acetate, but sticklers for the truth will wish to know that there has been a change to cellulose nitrate.

Cutting must be carefully planned and tended with eyes and ears on the type of programme being recorded, for every detail of information in the newly formed groove will reappear in the finished product. The cutting head is like a pickup in reverse, for it contains electro-magnetic parts that receive the stereo input and vibrate with the power needed to drive a hard-tipped stylus into the lacquer blank. Considerable force is needed, and the amplifier driving the cutter may have a power of 300 watts or more.

The cutting stylus is a sapphire-tipped tool with sharp, chisel-like contours that can form the V-shaped groove. To help it through the master disc its temperature is raised by a heating coil. As the lathe rotates, the stylus first forms the run-in groove at the edge of the disc and then goes on to cut the music waveforms. Although the recorded groove remains nominally V-shaped its dimensions vary to some extent, but this is more readily seen in the drawings which should be studied. With a little patience one can visualize the stylus tip moving in response to complex music signals: it will move from side to side, up and down, and in many intermediate directions. It will have to change from one mode to another with extremely high velocities.

At the end of the side the stylus cuts the run-off, as well as a locked groove into which the record-buyer's pickup will safely run if he happens to be out of the room when the music has stopped. Some of these procedures can be made largely automatic. That is true of the cutting of banding grooves that separate short items on one side of a disc, and of the spacing between the spirals of the groove.

However, the master cutter must watch everything closely and his decisions may make all the difference between a disc that is a pleasure to hear because of its low distortion, and one that is disappointing due to insufficient loudness or other disadvantages. As it happens, a whole disc side of quiet music can have a longer playing time than a side of loud music, for which groove spacing must be more generous; so clearly, playing time is always an important factor in producing discs.

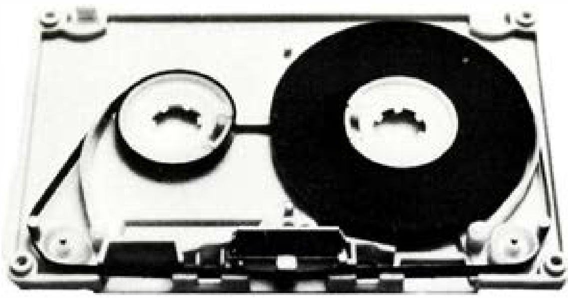
Readers with a flair for figures will be interested to know that the groove spiral of an LP may be cut at 300 or more turns per inch of disc surface. Dimensions are a little more than 0.002in. (two thousandths of an inch) across the top of the groove; the depth of the 'V' is about 0.001in. The length of the spiral, from disc edge to run-off groove, approaches half a mile taking into account the tortuous wigglings of the music waveforms cut into the disc by the stylus. In playing the resulting LP the pickup stylus faces accelerations in the region of 1000*g* and the pressures at the point of contact of stylus and groove are reckoned in tons per square inch.

Master discs are cut on one side only, so that two masters are needed to initiate the two sides of an LP. These are sent to a department of the factory where the first job is to clean them and then coat them with an extremely thin film of silver. A well-known property of silver is its ability to conduct electricity; and that is essential because the process that follows is a specialized form of electro-plating. Suspended in a bath, the silvered disc is given a thick coating of nickel. The process is similar in principle to the chromium-plating of motor car parts.

Split away from the master disc, the nickel is a 'negative' with ridges that stand out and correspond in every detail to the groove in the original. At this stage the copy is very vulnerable, so a further nickel disc is formed by plating. This of course is a 'positive', with grooves, and from it are produced more nickel negatives for use as stampers in record production. Stampers are made for each side of the LP (or single) to be manufactured; they are trimmed to size and have a hole punched in the centre.

Production procedures vary to some extent from company to company according to the degree of automation applied to them, but the central feature is the press which moulds the disc from a cake of plastics material, carefully formulated and very precisely weighed (about 160 grams of plastics for an LP is typical). The material is vinyl plastics with carbon black and other additives. It is possible to use other colours, and children's records have been produced in red, blue, green and yellow. Experimental discs have been made with startling mixtures.

In each part of the press is clamped a stamper, one for each side of the disc; the labels are placed on them in such a way that they will be pressed into the plastics, the cake of material is inserted, and the press is closed. Moulding takes place in about half a minute during which time the



Cassette with the lid off. This BASF Special Mechanics cassette embodies improvements designed to ensure free running of the tape.

press is first heated to make the plastics flow over the stamper surfaces, and then cooled to set the finished disc. The 'pressing', as the disc is called, is taken out, trimmed round the edge, inspected, and placed in its liner and sleeve. Samples are taken for close inspection and playing.

It must be evident that, although manufacture has been referred to as mass production, not very many pressings can be moulded in a working day by one press. Such a rate of output would not match the demand for rapidly selling pop discs or favourite classical releases. Fortunately a series of stampers can be made and a row of presses kept busy on one record. It will be evident, too, that the large amount of nickel used must raise problems in these days of mounting costs and shortages. Not surprisingly, the recycling of vital materials is being carefully considered.

There is no counterpart to this mass production in the manufacture of music tapes, whether these are cassettes or in any other format. Obviously the tape has to be obtained and loaded into cassettes; recording is then a separate operation to be accomplished as quickly as possible. Music cassettes are in fact recorded in batches by running them on slave machines linked to a master on which a studio tape is replayed. Everything possible is done to hasten this duplicating process (high-speed transfer, for example) but manufacture is inevitably slow and subject to more difficult factors than those intruding in disc pressing. Costs are rather high, and big-name cassettes sell at higher prices than discs.

# 6 Hi-Fi Systems

If you have studied the basic principles described so far and find yourself in sympathy with the aims of the professionals and the hi-fi enthusiasts, you should find that the technical considerations that follow in later chapters will fall into place without great effort. Good sound reproduction obviously demands a solid technical basis, and details are vitally important.

Technicalities, however, are not essential as an introduction. High fidelity is to some extent a matter of good housekeeping and a feeling for quality, and most keen listeners can quickly grasp what is involved. In brief, we have to apply the best of modern techniques to scientifically correct groundwork. Unfortunately the results of our efforts can seldom be cheap; in fact the standard achieved is generally proportional to expenditure.

For hi-fi systems the rule is that optimum performance depends on the assembly of purpose-built units into a working installation. The emphasis is on functional units, each doing its job efficiently when linked to the rest of the system. Few manufacturers make every item in a system, and so the usual procedure is to choose a unit for its own merits and at the same time ensure that it is a fitting partner for others to be coupled to it. Obviously some planning must precede the choice of functional units.

Most readers will know that the elements of a system for stereo discs consists of a turntable with a pickup, an amplifier to give control over the programmes and generate power, and a pair of loudspeakers to reproduce the sound when driven by the power from the amplifier. Clearly, these three main functions could be performed by an all-in-one radiogram of the old school—any cheap outfit, in fact.

However, we are interested in quality. For instance, we demand that our LPs remain in new condition after many playings, and we want the pickup to extract the wealth of detail impressed in the grooves. We shall object to speed fluctuations and background noises from the turntable, so it seems the engineering must be good. We want our amplifier to generate enough power without introducing objectionable distortions, and we expect our loudspeakers to accept the power while also displaying elegantly smooth frequency response, minimal distortion and a wonderfully realistic stereo image.

It would be a very unusual radiogram that could measure up to such severe demands. In truth, there is no such machine. Long ago it was accepted that unit hi-fi, a chain made from strong links, was the solution, both in terms of engineering and in every other way. This is true whether the programmes come from discs, tapes or any other source. It was also accepted that systems tailored to a price (as radiograms are) were unlikely to be the most successful.

In a highly competitive market, however, there is scope for equipment at many levels of price and quality. You will be well aware that there are keen customers for both Minis and Mercedes—and each person has his specific reasons for his choice. As things have turned out modest, low-powered hi-fi systems can be assembled for little more than the price of a radiogram. At the other extreme it is possible to spend the price of a high-performance car on systems that exploit modern technology fully. The question to be asked is, where does the money go? The answer will emerge as we survey the details of the equipment.

To begin with, the money *should* go primarily towards technical details that enhance sound quality, and only secondarily towards 'gimmicks'. With this in mind it is often pointed out that any new experience of sound recording and reproduction depends on the ears and brain, and that the best system is the one that most pleases the senses. This seems reasonable; obviously the listener must be satisfied, no matter how many impressive performance specifications are claimed by the manufacturer.

On the other hand such arguments can be put forward to sway inexperienced buyers, who may be urged to disregard all the 'difficult' figures which offer clues to quality in favour of a decision based entirely on listening, possibly done under adverse or unfamiliar conditions. But top quality sound, especially stereo and its recent offshoots, has to be 'learned'—one

A modern cassette unit for use with hi-fi systems, the Yamaha TB-700. It incorporates Dolby noise-reduction circuits.

has to get used to it—and few people could trust themselves to invest in complex equipment without any kind of investigation of specifications, performance or reputation.

An interesting example concerns the choice of loudspeakers, which by general agreement is peculiarly difficult. Some keen listening to a selection of the great variety available will reveal what every sound engineer knows: each model sounds a little or very different from the next, whatever the published figures may suggest.

The purchaser will have to face the fact that there is no absolute 'best' among any selection of rather good loudspeakers, and after careful study he will allow personal tastes to clinch the matter. However, he cannot ignore a few basic technical points, the most prominent being the ability of the speaker to handle enough power for his purposes.

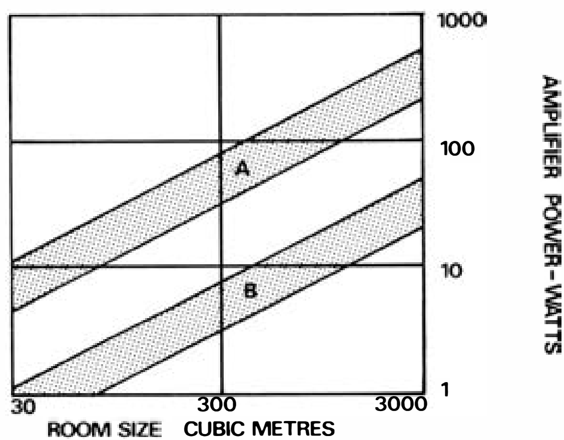
Contrast pickups and loudspeakers and a new aspect comes to light. Both these components exhibit characteristics that can directly affect tonal quality. It is possible to assess them separately, in isolation, and thus one might choose a very good pickup and, perhaps on another day, excellent speakers. Since both items have a way of influencing audible results, it may be that the two working together produce a distinctive sound that is neither expected nor liked.

This is discovered by listening to the complete system, but examination of technical performance may in any case yield clues to likely clashes of personality. For instance, if the speakers' frequency response is rough and peaky rather than smooth, and a comparable effect is found in the pickup, then it is quite likely that the distinctive combination will prove tiring to the ears.

This brings us to one of the most important points of all. Any high quality sound reproduction that is to serve a wide variety of music and other sounds should be as non-commital and lacking in 'personality' as possible. It is more correct to talk of this as the professionals do and refer to the degree of 'coloration' of the sound. A loudspeaker, for example, that gives a very coloured account of the programme fed into it must be deficient to some extent, for it is not an accurate device. It may sound impressive at first hearing (all glossy treble and booming bass) but experience will show it is difficult to tolerate because it is not honest.

Coloration is essentially a distortion, hostile to the characteristic timbres of sounds. A perfect system would preserve timbres and the reproduction would be lifelike. But unfortunately nothing is perfect and there are opportunities for distortion to intrude all the way back through the chain of recording and replay. It can start with the studio and with the microphones. The aim is clear, though: good systems do not impose audible contributions of their own. Instead, they are unobtrusive and allow the music to speak for itself.

The amount of power needed for hi-fi is sometimes the subject of controversy. Few reasonable people would deny that professionals may have valid reasons for installing powerful equipment, and most know that arrays of high-powered amplifiers and speakers are used at pop festivals (though the links with hi-fi are tenuous). But still the hi-fi enthusiast is thought eccentric if he seeks an amplifier that is well related to his needs. Surely he will either blow




A guide to hi-fi planners: amplifier power related to room size. Band A covers most requirements, including orchestral and organ music. Band B would be adequate only for instrumental music and speech.

everything up, break the windows or frighten the neighbours!

In fact the finest systems have generous power ratings—and with every good reason. Quite simply, there should be an adequate power reserve to meet all exigencies without the onset of distortion. This does not imply an unreasonably high sound level; unholy dins are not the speciality of hi-fi users. Further, the power rating you want depends on the size of the space to be filled with sound and on the input the speakers need in order to emit adequate sound pressure levels.

As it happens, many of the finest and most costly loudspeakers exhibit low efficiency; and this is just another way of saying that a big input produces only a small output (an efficiency of one per cent is typical). It is one of the worries of engineers that all the clever things they do to improve loudspeakers turn out to be at the expense of efficiency.

There is little sign that the trend will be reversed, and as things stand some speakers need an input of 20-40 watts if they are to generate realistic sound volumes. The highest outputs they can produce are *not* the average outputs used for music in the home; rather it is a matter of accommodating big peak powers when these are demanded.

The size of the room influences power in the most direct way. A small, low-power system intended for a room in a small flat will sound highly stressed and probably distorted if pushed to the limit in the spacious lounge of a large house. For stereo in a small room of about 35 cubic metres (about 1,200 cu.ft.) an amplifier power of 15 watts per channel is a reasonable estimate. A medium-sized room of 70 cu.m. demands more power. Not surprisingly, amplifiers rated at 60W or more per channel are now quite common for inefficient speakers installed in the largest domestic rooms.

Such figures are associated with the reproduction of a wide variety of programmes. Perhaps we can agree that the typical listener enjoys orchestral and organ music (high power) and speech (low power), and that he may wish to range across the classics, light music, pop and drama.

This brings us to a consideration of dynamic range—a range of loudness to be reproduced realistically. Oddly enough, the most massive orchestral music does not necessarily involve the widest range of dynamics. A classical string quartet may make greater demands but much depends on the way it is recorded. Most pop music has a narrow dynamic range; this is particularly true of 'rock' music, which is consistently loud and requires adequate power handling ability in the loudspeakers.

Reproduction of a wide range implies that quiet passages will be heard in all their detail despite the intrusion of local background noises. When the music swells into a great crescendo we still expect the detail but we also require low-distortion sound. This is the kind of thing that makes severe demands on hi-fi systems.

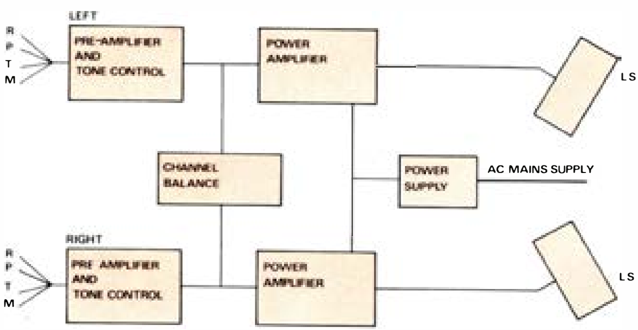
On one occasion (a quiet evening, for instance) a power rating of 20W per channel may prove adequate in a particular room for wide-range music. On another occasion, possibly on a summer's day with the windows open and noises heard from outside, the volume control setting must be a little higher for the same clear reproduction. A small adjustment, enough to make an audible difference, approximately doubles the power demand, so that 20W becomes 40W.

Programmes from discs and tapes are of course the focus of attention in this book, but we must acknowledge the BBC's VHF/FM broadcasts as another source of high quality sound. Hi-fi enthusiasts whose interest is mainly in recorded material often turn to FM radio as a welcome extra for their systems. Manufacturers smooth the way by providing radio tuner units to match hi-fi systems, and there are also complete receivers which combine the stereo amplifier and tuner in one unit.

At one time the only broadcasts were those on medium and long waves (and on short-wave for adventurous listeners). Those continue, of course, but reception is subject to a great deal of interference and noise, and the crowded wavebands impose severe limitations on sound quality. VHF/FM radio is of much higher quality and by its nature rejects most of the interference that would spoil the enjoyment of music.

Recording Verdi's Don Carlo at the Assembly Hall, Walthamstow, London. Soloists, chorus and the Covent Garden Orchestra are directed by Carlo Giulini.

FM transmissions are short-range, and many stations are necessary to give good national coverage. The BBC, like authorities in other countries, has extended its transmitter network, and many of the broadcasts are in stereo. A high proportion of recorded material is broadcast but there are many 'live' transmissions from concert-halls, studios and theatres. A highlight for music-lovers has been the stereo broadcasts of Prom concerts from the Royal Albert Hall, London. For London and part of the south-east, signals are conveyed by lines to a transmitter at Wrotham, Kent.




Main features of a twin-channel stereo amplifier. Inputs from the programme sources are applied to left and right channels: R radio, P pickup, T tape recorder, M microphone.

# 7 Playing Records

Playing records is an enjoyable leisure pursuit, especially if you genuinely love music, poetry and drama. You can also learn a language or follow some other course of instruction. Not only is all this pleasant and convenient, but it is also simple. Why, then, do some people appear to complicate what is basically uncomplicated?

Even the most advanced hi-fi system for discs is simple in principle—elegantly simple when function is allowed to determine its form. Precision is the outstanding technical requirement, and it is the emphasis on detailed technical points that may convey an impression of complexity, especially when high fidelity reproduction is studied.

The answer, then, is that insistence on precision and attention to detail enables very fine sound reproduction to appear easy and effortless. Only in recent years have the means for securing such results been properly developed. With the present great interest in high fidelity it is widely understood that special measures are needed to extract from the record grooves everything that is impressed in them.

Extraction of information has always been arranged in the same way. At first a gramophone was used; later this item of equipment became known as a record player. The hi-fi enthusiast talks about his pickup and turntable. Whatever the equipment, a stylus (formerly called a 'needle') traces the information in the groove, and the pickup holding the stylus is free to track the record while generating signals corresponding to the contents of the groove.

These few requirements, simply expressed in a few words, lead us to some vital technical matters. Success—or lack of it—depends on the degree of accuracy with which the stylus traces the groove. Then the pickup must respond with the least possible distortion, moving across the disc freely and without damaging it. A turntable is involved, and this must rotate at constant speed and without generating noise that would interfere with the music.

While the recorded modulations pass it at constant speed the stylus moves with high velocity; as the waveforms change, sudden reversals of direction are imposed on the stylus, subjecting it to enormous acceleration. Huge pressures exist between stylus and groove. Yet it is now quite common to find pickups tracking with a downward pressure of only one gram (1g). Even lower pressures are possible.

Provided the pickup is in every way suitable for efficient tracking at low pressures, the wear of the groove will be negligible and the stylus tip, invariably a precisely shaped and polished diamond in the best pickups, will have a long life. Typical stylus life is five-hundred hours of use (that is, 1,500 sides of LP discs), assuming a pickup of advanced type, used on clean discs. After that, stylus replacement—usually a simple matter—is necessary. Inspection of the diamond tip under a microscope can yield clues to wear or damage.

A pickup for a hi-fi system may in rare cases take the form of an integral arm and head, but much more often the 'business' end of the pickup is purchased separately as a 'cartridge'. Typically this very small, precision-engineered item is an electromagnetic device incorporating miniature coils and a magnetic system of some kind within a metallic shield. Into the cartridge body is fitted the stylus assembly, the really critical part on which delicate groove-tracing depends.

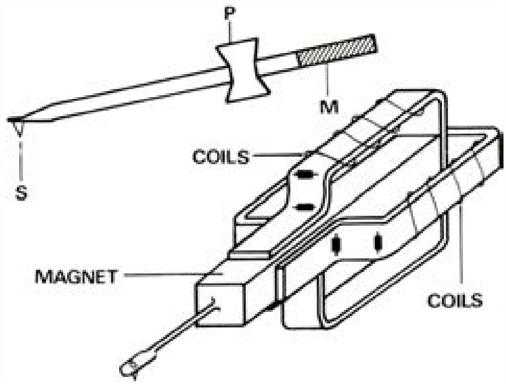
Most often the stylus is an extremely small but rigid tube with the diamond tip at one end and a magnetic material at the other. Somewhere along its length it is pivoted in a resilient suspension so that it is free to move but takes up a central attitude after each and every time it is disturbed. Vibrations of the stylus, due to groove-tip contact, are translated into electrical signals by virtue of the electro-magnetic principle employed. Thus the cartridge is a generator of electricity, but its output is very feeble—typically 5mV (five thousandths of a volt).

Purely mechanical aspects are particularly important in such an arrangement. Intimate and constant contact of stylus tip with groove is essential. Loss of contact is known as mistracking and is likely to be heard as a form of distortion. This implies that the stylus tip must fit the groove accurately. Again, the stylus as a whole must be extremely light: this is evident because of the stresses to which it is subjected. The lighter it is, the more readily it can be shifted by the groove. Its pivot must hold it while accepting the downward pressure that keeps the tip in contact with the groove.

As if these demands were not severe enough, the passage of the stylus across the spiralling groove depends on the freedom with which the entire pickup can move. A pickup consists of a cartridge and an arm, and this latter component's job is to carry the working parts unobtrusively.

Any keen observer will discover that a disc is never absolutely flat, and that small lateral and up-and-down motions of the rotating disc must be allowed for. Therefore the pickup arm must not impede such movements: its pivots must be free from friction so that the stylus does not encounter forces it cannot overcome. Further, the arm cannot be very massive if a delicate, light cartridge is to be used. All the care lavished on a cartridge is wasted if the inertia of the arm imposes its progress across the disc.

This picture, obtained with an electron microscope at Hull University, England, highlights the relationship between diamond stylus and disc groove.

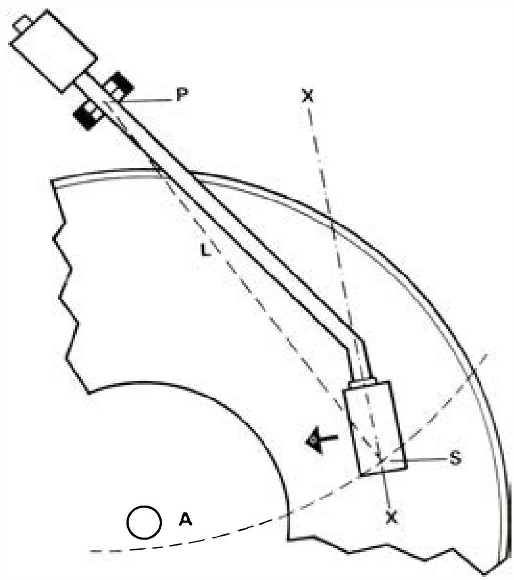



Principle of the moving-magnet cartridge. The stylus is fixed to a small magnet, which moves in relation to the pole-pieces, setting up a voltage in the coils. Also shown (top) is a stylus comprising tip S, rubber suspension pivot P and magnet M.

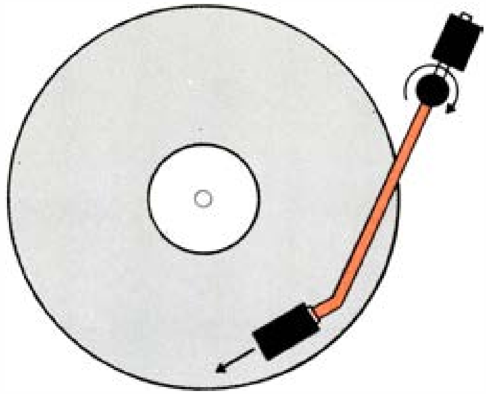
An interesting aspect of pickup behaviour can be studied with any conventionally designed pickup which is pivoted at one point so that the stylus tracks across the disc in an arc. Due to the friction of the groove rushing past the stylus tip, the pickup is subjected to a slight inward force which pulls it towards the centre of the disc. Obviously this means that the stylus tip bears a little more heavily on the wall of the groove nearest the disc centre than on the other wall. It is also evident that a sideways thrust of this kind must be overcome by extra downward pressure to maintain groove-tip contact.

This lateral, inward force is known as 'bias'. If a pickup is designed to perform at 1g pressure, then any small disturbance can represent a substantial proportion of the pressure. Consequently neutralisation of the bias is considered imperative with modern pickups, and indeed nearly all good pickup arms incorporate bias-correction devices which impose a slight outward force to balance the inward pull. When this is done in a precise way, by checking the pickup's performance on a special test disc, the effect of bias is eliminated and tracking pressure can be reduced to a practical minimum.

A pivoted pickup has a bend in the arm and the stylus tip falls a small distance




A pivoted pickup arm is installed so that stylus S moves on an arc as it tracks across the disc. Axis X-X through the cartridge or head is offset from the rest of the arm. L is the nominal length of the arm, from stylus S to pivot P (typically 220 mm).



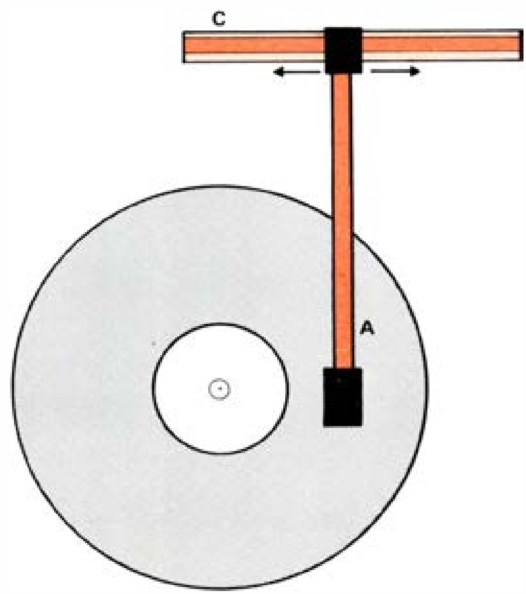
How bias affects a pivoted arm. Friction of the groove past the stylus tip causes a slight pull, tending to force the pickup inward. A slight outward pull, applied by a suitable device, can neutralise this effect.

beyond the centre of the disc, the aim being to align the cartridge so that its attitude is as nearly as possible a tangent to the groove. This curious geometry enables the pickup to track without introducing severe distortion. However, a short, straight arm would be ideal and indeed is possible as long as it can be moved bodily across the disc, keeping a tangent to the groove.

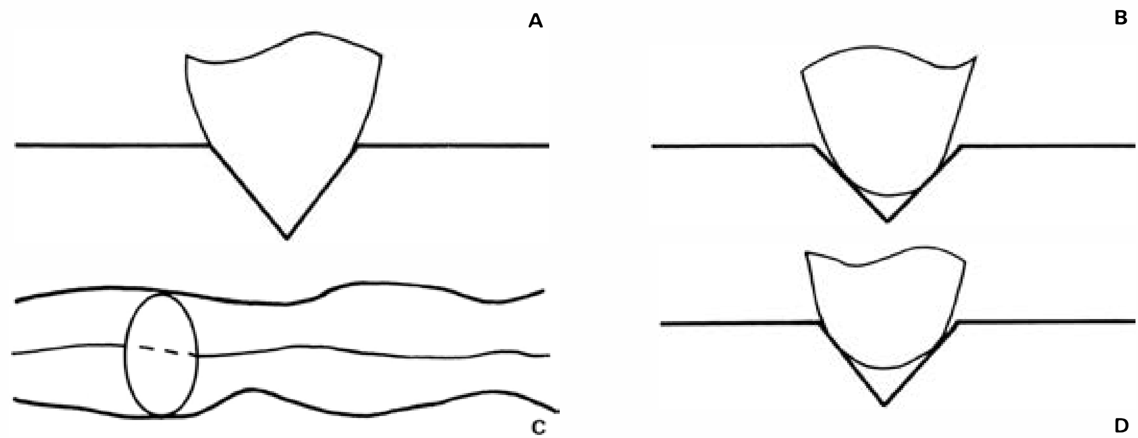
Pickups of this kind do exist, but they bring some complications. The simple pivoting arrangement of the ordinary arm is replaced by a mechanism that carries the pickup as a whole across the disc, reflecting precisely the motion of the disc-cutter that formed the master lacquer in the studio. In this case there is no bias of the pickup.

Any turntable has to satisfy two main requirements so far as performance is concerned. Adequately suppressed noise is important (that is, best possible signal-to-noise ratio) and the mechanism must not exhibit speed fluctuations that would be heard as waverings of pitch. Special attention to these matters is needed if the turntable is to be of service in a high quality system. In fact the mechanism should be so unobtrusive that the user is largely unaware of its action.

Pitch variations are aptly termed 'wow and flutter'. Wow is a relatively slow variation of pitch, and flutter is a faster fluctuation; both may be caused by




Radial-tracking pickup. A straight arm A carries the cartridge radially across the disc. Carriage C has to allow smooth transit of the pickup and is more elaborate and costly than the pivoting arrangement of a conventional arm.




A sharp cutter forms the groove A in the master disc. A conical stylus tip rides in the groove as shown at B, but this causes some distortion. This can be reduced by an elliptical tip which fits more precisely into groove shapes as at C. Its major dimension rides accurately across the groove as at D.

mechanical faults or inadequacies in design. Fortunately it has not proved difficult to reduce these errors to such a low order that they will not interfere with musical enjoyment. Much headway has been made with the reduction of noise, or 'rumble', which may be generated as vibration in the electric motor or elsewhere in the mechanism, but the problems have been greater.

At one time turntables for hi-fi were engineered in such a way that the drive from the motor was transmitted to the rim of the turntable platter by a rubber 'idler' wheel. Mechanisms of this kind are still made but an alternative belt-drive system has become popular and exerted a beneficial effect on noise content. A rubber belt, linking the motor with some part of the platter, can help to isolate sources of vibration.

Although belt-driven turntables are now widely used, another development has emerged. This is the 'direct drive' unit in which the motor shaft is a continuation of the turntable's centre-spindle and no other moving parts are involved. Thus the motor runs at the record speed (33 or 45 rpm) and this arrangement, if well engineered, promises a very low level of vibration and noise. With this type of machine and certain examples of belt-driven turntable is associated an electronic control system designed to give the necessary change of record speed and also maintain stability of running.

The majority of turntables are supplied complete with pickup arms. In this case the purchaser is as interested in the pickup's characteristics and fitness for purpose as he is in the qualities of the turntable. If such a combined player does not measure up to his expectations there is an alternative. It is possible to choose a separate turntable on its merits and then get to work to install an equally carefully chosen pickup arm. Care and attention to detail are necessary in bringing the parts together to make a working installation.

Records will remain in unblemished condition for a very long time if played on the best modern equipment. Careful handling is essential, however, and the discs should be stored where they are protected from dust and extremes of temperature. The ideal housing is a cabinet that keeps LPs upright in compartments. Sloppy storage is likely to cause warping. The recorded surfaces of discs must not be handled, as fingermarks not only contain tiny particles but also attract more contamination.

As most users know, static electricity builds up very easily on discs, just as it does on some other synthetic materials. It happens all the more quickly if discs are handled carelessly. Unfortunately, static attracts particles from the atmosphere. It is also unfortunate that, even in the present state of the technology, the dispersion of static charges is not easily achieved. Aware that the removal of dust is desirable, some users rub discs in an attempt to clean off the particles, but this has an abrasive effect and can only serve to provoke a larger static charge—and more dust.

Another misguided approach to record cleaning is the application of moist cleaning aids. The most likely result of this is the formation of microscopically small amounts of mud, which dries and causes a higher noise level as the stylus tip traces it.

If dust falls on discs when they are exposed on the turntable (even if they are dust-free when in storage) much of it can be removed by a dust-collecting device which tracks across the surface at the same time as, but remote from, the pickup. (Devices on the market do in fact look like miniature pickups and are mounted near the turntable in similar fashion.) This does not influence the static, but it clears away the debris that static may have attracted.

It is no longer possible to think only in terms of discs when we are considering recorded music. A tape of music is a 'record', and some listeners prefer tape records to discs. In particular, stereo cassettes are usually the equivalents of stereo LP discs, and a few of the major recording organizations release a proportion of their records in the cassette format soon after releasing the LPs.

Obviously the difference is in the means of playing the records. Everyone is familiar with the portable, transistorized cassette machine; it needs no special comment here except for a reminder that its role is one of inexpensive entertainment rather than serious sound reproduction. More costly machines, better equipped and more substantial in construction, can be associated with good sound systems, including those of high fidelity calibre.

The usual scheme is a tape unit which will record and replay cassettes while linked to a hi-fi system. A unit of this kind has neither loudspeakers nor the output circuits capable of generating power to drive these. Such facilities are already part of the hi-fi equipment and therefore redundant in a tape machine. This arrangement was already commonplace in open-spool tape machines and was the obvious solution for cassettes. Noise-reduction systems, notably Dolby, are widely applied.

For the keen user the attraction of a cassette installation is the facility for recording as well as replay. The careful user of high-grade equipment can make recordings of excellent quality, although the cost of advanced types of machine and special grades of tape may be high. (Tape units cost £100-200, and some range up to £800 or more.)

However, commercial music cassettes—that is, tape records—by recording concerns such as Decca and EMI seldom yield such good results. At the present stage of development it is beyond dispute that the best discs give better sound quality than the best music cassettes, particularly in respect of distortion and frequency range. Of course, one must use replay systems of comparable cost and performance to make a fair comparison. Further, music cassettes are more expensive than their LP disc counterparts.

Finally, there is an alternative tape device known (confusingly, alas) as a 'cartridge'. This incorporates an endless loop of tape and can accommodate several stereo programmes. Because of its capacity it has become popular in tape players for cars. However, it has not become generally acceptable for high quality sound systems and there has been little development to help it in that direction. Cassettes and cartridges are not interchangeable within one audio system since the mechanisms to run them are entirely different.

# 8 Loudspeakers and Rooms

Most interested listeners and hi-fi enthusiasts can soon understand the principles of loudspeakers. There have been few really fundamental changes in loudspeaker design during many years, and the typical speaker box system is thoroughly familiar to those who buy audio equipment.

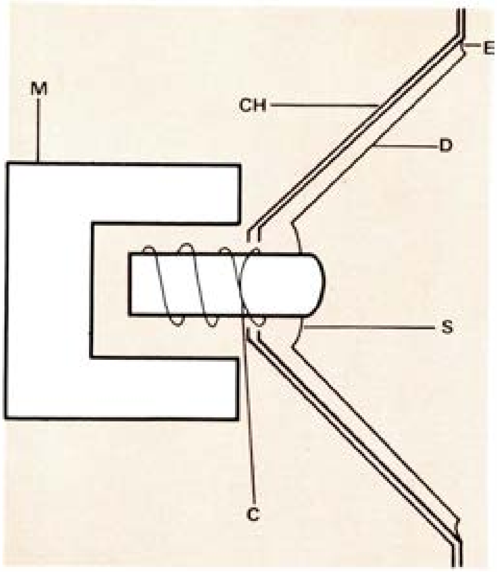
Consisting of an 'enclosure' (cabinet) in which one, two or more electro-magnetic drive units are arranged, the loudspeaker holds no great mystery for the student of audio. Each drive unit responds to the signal fed to it, and it does that by vibrating a cone or diaphragm to and fro, thus radiating sound. It is all quite easily visualized.

Evaluating the qualities of the loudspeakers, however, is to some extent subjective. If one lines up a selection of speakers, comparing them in a fair and reasonable way, each sounds a little different from the next. There are contrasts, sometimes great but more often quite small, between their characteristic sounds—overall tonal quality, the way details emerge, the quality of the bass sounds.

Not surprisingly, choice must depend on personal taste, and for the inexperienced the identification of what is right or wrong, good or bad, can become difficult. Experience of 'live' sound, and in particular of degrees of coloration—degrees of untruth—will influence attitudes. Little wonder that particular, predominant qualities of sound win strong support; users of certain types of speaker are inclined to become partisan or unreasonable in their arguments. Others dismiss the whole subject as too 'personal' for serious discussion.

Fortunately the designers do not take the same view. Most aspects of loudspeaker performance can be tackled without immediately resorting to subjective assessment, although careful listening by experienced pairs of ears must soon follow. A speaker is a transducer, that is, a device converting one form of energy into another—electrical signals into sound waves. It is essential to be able to measure how accurately the device manages such a conversion. Its frequency range can be measured; so can its ability to accept powerful inputs or the distortion it generates while working.

In all this the focus of attention is usually the moving-coil drive unit, which is made in various sizes and qualities to suit the application. It is similar to an electric motor fed with alternating current, but instead of rotating parts there is a coil which moves to and fro in the magnetic field created by the poles of a permanent




**Principle of speaker drive unit. M magnet. CH metal chassis. E flexible edge surround. D diaphragm, or cone. S central suspension. C coil.**

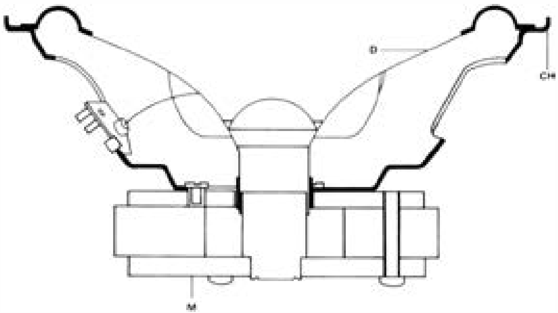
magnet. To the coil is coupled a diaphragm which, forced to vibrate by the coil, radiates pressure waves at frequencies corresponding to the signals arriving at the input.

The simple example in the illustration has a flexible surround to the circular diaphragm, to enable this part to move and vibrate, and a suspension, near the coil, again to permit movement but also to hold the assembly in the correct position. The system depends on a balance between free movement and constraint. Study of such a system soon brings us to an important characteristic, the resonance of the diaphragm and its associated parts.

The suspension and surround are springy, and the diaphragm has some weight. As with any such combination of mass and spring, there will be an oscillation when the system is set in motion. That is, pronounced natural resonance will be observed at a particular frequency which depends on the mass and the springiness (more precisely, its compliance). In the same way the wheel of a car and the suspension holding it will yield troublesome resonances unless these are damped out.

In a big drive unit, made for bass reproduction, the resonance shows up at a low frequency, usually at or below the lower limit of the audio spectrum to be

**A direct-drive hi-fi turntable of the most advanced kind, the Toshiba SR-510. The turntable platter is driven by the motor without any intermediate pulleys or belts.**




Section view of a KEF 8-inch drive unit. D diaphragm. CH chassis. M magnet assembly. The edge surround is very compliant and made of synthetic rubber.

handled. For example, it may be at 20-40Hz. This, however, is arrived at by testing the unit as it stands, without putting it in an enclosure. In this instance the resonance is pronounced and violent, giving the impression that the speaker is out of control.

One purpose of putting the drive unit in an enclosure is to restrain the behaviour of the diaphragm where it resonates. The rear of the unit is then faced with a mass of air which, depending on details of design, places the resonance under control. At the same time the effect of the new, enclosed conditions is to force the resonance up in frequency. The resonance is now that of a system formed by drive unit and enclosure. Whereas the unloaded unit may resonate at 20Hz, the system resonance may appear at 60Hz.

Another purpose of the enclosure is to enable bass sounds to be generated effectively. A drive unit by itself cannot produce audible low-frequency tones, since the waves from the front of the diaphragm or cone would simply pass round to the back, the result being cancellation of the output. At these low frequencies the wavelengths are greater than the dimensions of the diaphragm, and the waves have no directional property.

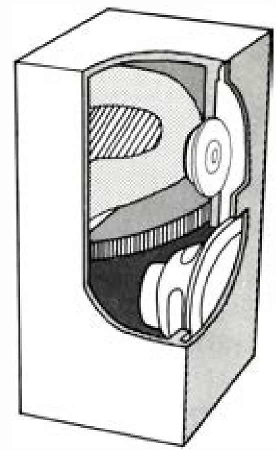
Mounting the unit in one wall of an enclosure isolates front and rear sound outputs, enabling the bass sounds to be propagated in the surrounding air. Indeed, the unit could be mounted in a hole in a baffle—such as a large board—to facilitate bass output, but this would have to be very big indeed to prevent interference between front and back at the longest wavelengths. As a matter of interest a drive unit could be set in the wall of a room (two units for stereo) but such an inflexible arrangement would not suit many listeners. Cabinet enclosures are the usual solution.

Generally, low frequencies are generated by large diaphragms, and high frequencies by much smaller and lighter diaphragms, well related to the very short wavelengths involved. Mid-frequencies can be handled most effectively by something in between. Consequently drive unit design is a specialized business and most good loudspeaker systems employ two, three or more units, each handling a part of the range to which it is best suited. It does not follow that the use of an imposing array of hardware in a cabinet *makes* a fine speaker, But it is true that a massive 305mm (12-inch) unit, robust enough to handle large bass inputs, cannot respond to high notes.

Key to success in this input sharing arrangement of multiple drive units is a circuit known as the ‘crossover’ network. It is incorporated in the speaker enclosure. The power from the amplifier is applied to the crossover circuit, which passes on an appropriate part of the frequency spectrum to each unit. Thus a filtering action is needed: the bass drive unit receives only the powerful signals which it is intended to handle; the mid-range unit deals with another sector.

The more delicate high-frequency unit, known as a tweeter, receives only a small part of the range which it can accept without stress. It would be damaged by low-frequency inputs. In this connection we should note that in orchestral programmes substantial energy is concentrated in the bass and part of the mid-range, while the extreme treble, conveying few fundamental tones (but many harmonics), radiates far less power. This is reflected in loudspeaker design: if the system is intended to handle up to 50W, the bass drive unit will have this capability, the mid-range unit would have a lower capacity, and the tweeter by itself would be rated at a few watts.

Accurate stereophonic reproduction demands that the pair of loudspeakers should be similar. In particular they should be similar in sensitivity, so that the same output—measured as sound pressure level—is obtained from each when a specific input power is applied. Otherwise adjustments will be needed to equalize them. Then the frequency response should be similar in the two, otherwise a lack of balance in the stereo will be evident. Such points are normally well taken care of when a pair of the same model of loudspeaker is specified for a stereo system.



**Cutaway of a two-unit loudspeaker. Internal sound-absorbent materials – typically foam plastics – impose damping and absorb rear radiation from the bass unit.**

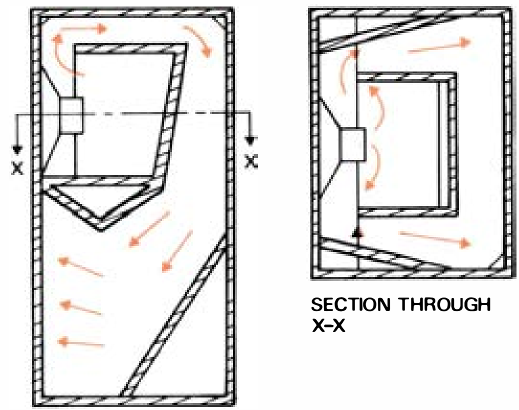
Just as important is the similarity of dispersion of sound. This is a special requirement in the upper part of the frequency range. If one speaker radiates a narrow beam of sound and the other a wider beam, the stereo image will be confusing and distorted. Very precise matching is achieved with the best systems.

However, with a few loudspeakers the aim is to give a widely dispersed output. Although most speakers radiate frontally in a controlled pattern, the 'omni-directional' types disperse their output all around, and sound reaches the ears after reflection from nearby walls, ceiling and objects in the room. Obviously this makes the speaker performance dependent on the room. In exchange the designers assure us of a spacious effect and less audible emphasis on the presence of the speakers. Unfortunately this method confuses stereophonic information, as properties of stereophony carried in the programme are masked in the reflected sounds.

Although nearly all loudspeakers are of the moving-coil type, There are a few exceptions. In the electrostatic speaker a very light plastics film is coated to make it electrically conducting and arranged as a diaphragm between perforated metal plates. The movements needed to radiate sound are caused by electrical charges set up between diaphragm and fixed plates. A large example radiates from front and rear and can be made to reproduce a wide frequency range without the use of an enclosure.

Another device, this time without any moving parts, is known as an 'ionophone'. In this, a continuous electrical discharge creates a region of ionized air, and this is acted on by the input signal so that pressure waves are generated. The discharge is set up in a small quartz tube and to its open end is joined a horn, the function of which is to couple the tube to the surrounding air and enable sound waves to be propagated.

Finally we return to complete loudspeakers of the more customary type and visualize them in the listening room. The sound we hear is influenced by the properties of the room; the tonal qualities of the sound and the accuracy of the stereo are affected by the way the speakers are placed and the extent to which reflected sounds mix with those reaching our ears directly from the speaker-fronts. Air in the room is agitated by the speakers and resonances are provoked.

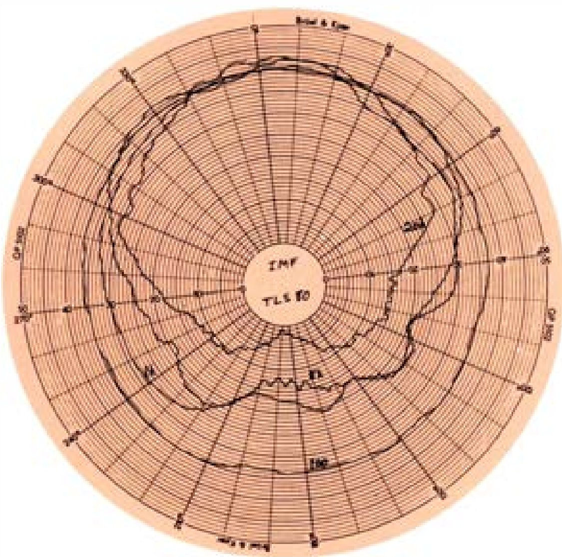



Horn loudspeaker in which the rear of the drive unit is coupled to the outside air via a folded horn-shaped passage in the cabinet.

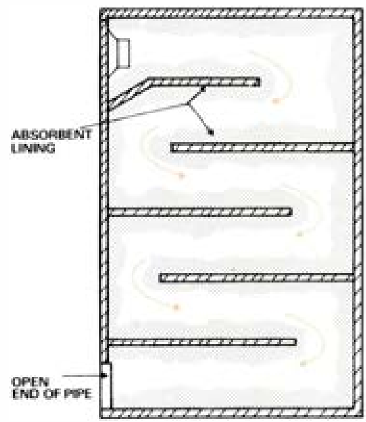
Such effects can be checked by alternative listening with a very good pair of headphones. Without necessarily raising the question of personal preference for speaker or headphone reproduction, it will be realized that room effects will be excluded. The private world of headphones often gives a different view of the qualities of stereo programmes.

The acoustics of rooms can be modified to some degree, but big changes are not possible without structural alterations. For example, extra sound-absorbing materials such as curtains and carpets can help to deaden a 'lively' room in which reflections have been found to muddle the sound. Floorboards with spaces under them may cause a boom unless the speakers are moved to more secure positions or raised so that they do not provoke resonances in hidden nooks and crannies.

Loudspeakers in or near room corners radiate more bass into the room than they would in other positions, and experiment with positioning is advisable in order to arrive at a compromise balance between treble and bass. Indeed, speaker positions are rarely predictable and brief trials are needed to find a natural acoustic solution. However, they must be spaced apart for stereo, usually by two to three metres, and possibly angled inwards towards the listening area. In its turn the listening area should be roughly as far from the speakers as they are apart. Bearing this in mind, loudspeakers can be free-standing, placed on shelves or mounted on the wall, depending on their size and shape.

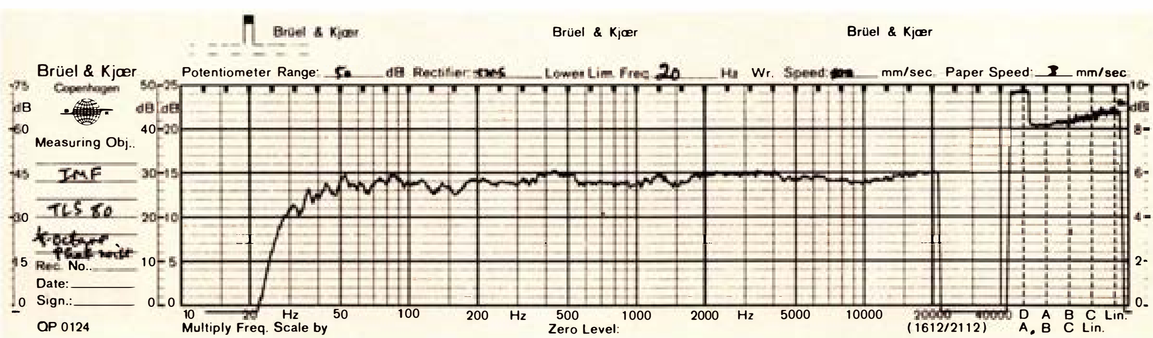



The loudspeaker must be visualised at the centre of this polar response, which reveals the dispersion of sound output at specific frequencies.




A labyrinth offers progressive absorption of sound energy along a complex, folded passage-way containing sound-absorbent material.

Frequency response of a hi-fi loudspeaker produced as a pen-trace by an automatic instrument. The speaker was set up in a measuring chamber with the microphone 1 metre from it.



# 9 Sound in the Round

Nearly all domestic sound systems are stereophonic. As explained earlier, a stereo sound-stage can be created between a pair of loudspeakers provided two channels of recording and reproduction are employed. However, more elaborate systems, requiring extra channels of reproduction and terminating in more than two loudspeakers, are emerging.

Clearly these new complications must be shown to offer major advantages if twin-channel stereo, now accepted by the majority, is to be challenged. And what is so lacking in stereo that changes have to be made? Obviously some need for change is felt; this is indicated by the popular use of such terms as 'quadraphonics', with its implication that four channels are involved.

The need for four channels of recording is in fact highly questionable, although an advanced system may have four loudspeakers—a very different matter. The limitations of stereo, however, are evident enough. One has only to listen to it critically after a visit to a live performance in a good hall. The front-located image is the problem, of course. Information about the hall or studio acoustics—the so-called ambience—is included in the image and therefore cannot be presented naturally as a well proportioned mixture of direct and reflected sounds.

If the ambience can be presented in a room in a way that suggests the all-pervading acoustics of the recording location, the listener will gain a much more striking impression of being present where the music is performed. It is not a matter of spreading musicians all around the listener; obviously one faces the performers in most conventional hall and theatre layouts. But one's natural acceptance of hall acoustics is all part of the experience of listening in an auditorium: it is essential to the atmosphere of the occasion and is irrevocably bound up with the brain's sensing of small details.

It is right, therefore, to seek a system of reproduction that creates such an impression of ambience and acoustic detail. Since an element of enveloping acoustics is involved, the systems under development have a 'surround' characteristic and show a move away from the exclusively front-located source of sound. Additional loudspeakers are located towards the rear or sides of the listening area.

Unfortunately, although the objective of more realistic sound reproduction is reasonable, there is a considerable state of confusion among recording producers using the new techniques, and an even greater confusion in the technology. At present a number of competing but dissimilar recording systems are being canvassed by organizations in the States and Japan, and no measure of standardization has been reached. It is possible, but not practicable, to assemble a hi-fi installation that can take all basic systems into account.

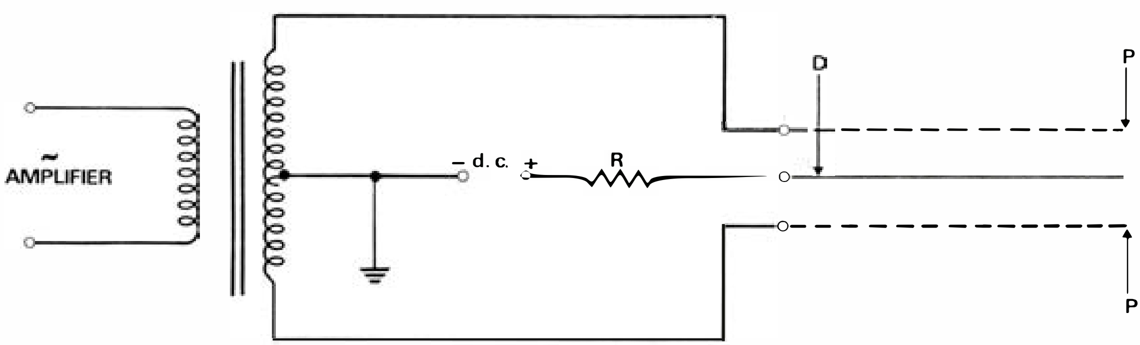
Widespread misunderstanding is highlighted by the terminology, headed by the inappropriate 'quadraphonics', a Latin-Greek hybrid which fails to convey an idea of the true requirements. The basic disc recording medium offers two channels, not four. In fact, two commercially used discs, the SQ type devised by CBS and the QS type adopted by record companies in Japan, the United Kingdom and elsewhere, are simply twin-channel but include mixed-in information that has to be decoded for reproduction by a four-channel amplifier feeding four loudspeakers.

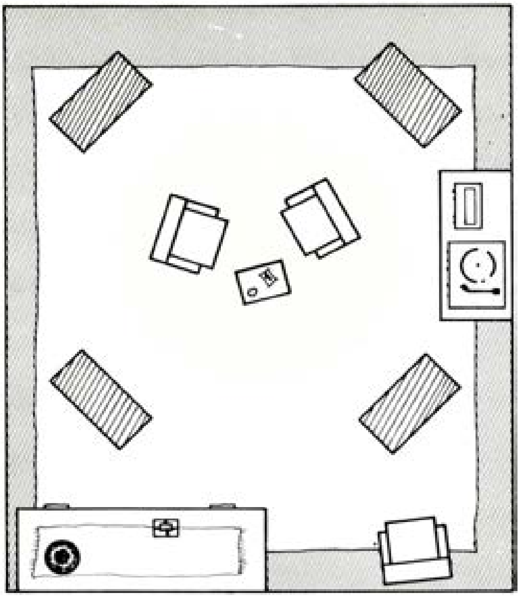
In the electrostatic speaker the diaphragm, of flexible plastics film with a metallic coating, is held between perforated plates. A d.c. polarising supply applied via resistance R maintains a state of tension between the elements, and subsequently this is varied by the amplifier signal, which is applied via a transformer.

Another system, the CD-4 type developed by RCA and Japanese Victor, again has two basic channels, but to these are added two more which appear in a higher frequency range and have to be decoded for the amplifier channels to handle. There is also a British system which again is simply twin-channel but made to carry additional information. This system is called Ambisonics, a term suggesting a serious attempt to present the ambience we require.

Further misunderstanding is shown by the types of surround-sound effect yielded by many recordings that have reached the market. With four-loudspeaker reproduction of these it is discovered that producers try to give the listener a sense of involvement by placing sound sources on all sides. This creates a number of stereo images between pairs of speakers around the room and demonstrates the failure to understand how a concert-hall effect should be contrived.

Realistic re-creation of music-plus-ambience is not possible with 'quadraphonics' of that kind, although directional surround effects may have uses in light





**Possible speaker arrangement for a four-outlet surround sound system. A large central listening area can be created.**

entertainment. On the other hand it has been demonstrated that recording techniques giving natural ambience are also capable of conveying the unsubtle effects producers require for entertainment and experimental work.

As you follow the development of new techniques, it would be well to remember that four recording channels are not required for an improved realism. (If they *were* required, they could most easily be provided on tapes.)

You should also remember that there is no logical link between the number of channels and the number of loudspeakers. It happens to be convenient in most instances to use four loudspeakers, although this requirement alone may well account for some inertia on the part of listeners who are well satisfied with high quality stereo. Since for a high quality surround system the loudspeakers must be identical in most respects, and since fairly large speakers may already be in use in a hi-fi stereo installation, it is clear that both budget and space problems will arise.

# 10 Listening and Choosing

If you wish to learn more about high quality sound reproduction, you will want to know where you can go to hear the latest equipment. The first and obvious answer is to visit a hi-fi showroom, preferably one with a good stock, a specialist staff and facilities for demonstrations.

Such is the popularity of recorded sound that nearly all large towns and some small ones have hi-fi specialist retailers, and most of them can demonstrate complete systems or individual items of equipment. Some of the smallest concerns can offer a good service; knowledge of the subject and an ability to act as a consultant does not depend on the size of a retailer's business.

Remember, though, that the job of the salesman is to make a sale, and that his determination to do so may be apparent in various ways. On the one hand he may appear particularly loyal to just one or two types of equipment; on the other hand he may have at his disposal facilities for rapid switch-over comparisons of an extensive variety of products. Try to steer the middle course and hear equipment that is well related to personal needs and your bank-balance.

This is particularly vital for the explorer who lacks experience of analytical listening. Too great a choice is likely to lead to confusion; lack of decision about the amount of money you wish to spend can make life even more complicated. Opportunities to preview a wider variety of equipment are offered at exhibitions, of which several are held each year in London and elsewhere in the United Kingdom. At these you will be free of pressure to buy, but the conditions are crowded and sometimes tiring. However, you can inspect and hear the latest innovations, ask questions and collect technical data.

Some enthusiasts with a strong musical interest will discover they have a great deal in common with others who support gramophone societies. At many of these you will find hi-fi equipment in use. Hi-fi societies flourish in a number of universities and colleges. Retailers, too, organize musical evenings occasionally to show off their stock and interest local people in sound reproduction.

A wealth of background information is published by specialist journals catering for hi-fi and record enthusiasts. Among their functions they aim to present news from the audio industry and report the latest developments in recording; they also cater for the equipment buyer by publishing the results of tests on pickups, loudspeakers, amplifiers, tape machines and other units. In addition to advising those spending money on audio, they keep interest alive by explaining the technology in detail.

So far only the traditional approach to buying has been mentioned. It is logical to listen carefully, seek advice if necessary, and then decide on the equipment that will meet your requirements. Retailing has been associated with this approach. In recent years, notably since the abolition of resale price maintenance, we have seen fundamental changes. Although the maker of the equipment can quote a recommended retail price, the supplier to whom you go for the goods can sell at a lower price. Consequently recommended prices have little meaning nowadays.

As with a wide variety of everyday goods (washing machines, refrigerators, heaters, furniture) sound equipment is sold by discount suppliers in a competitive market at attractive prices. There is a choice to be made: some suppliers offer facilities formerly associated with retail showrooms, many others do not. The implication is clear. The buyer may have to learn enough about his prospective equipment (by studying the journals and manufacturers' literature) to reassure him before deciding on a discounted purchase.

Listening is learning, and this process quite naturally involves the use of words to characterize the sound quality. With a little experience you will be able to recognize specific characteristics to convince you that the reproduction is an honest representation of musical sound. Smooth, clear and natural sound is the aim. If the tonal quality pleases you, and if all the expected details are in place, you are probably listening to high fidelity.

Many words are used, and most of them reflect an attempt to be helpfully descriptive. If the sound is said to be 'glassy and hard', or 'nasal', or 'veiled', or 'forward and explicit', you will probably not take long to reach a conclusion about the contrasts the commentator has tried to describe. Such expressions as 'harsh treble' and 'boomy bass' are unequivocal: these qualities indicate gross deficiencies, and sound of that kind would certainly not be emitted by a professional orchestra playing in a reasonably good hall. Such deficiencies are forms of coloration—that is, lack of fidelity, for which either the equipment or the programme is to blame.

One of the most useful terms, particularly in connection with loudspeakers, is 'transparency'. It was suggested earlier that a good reproducer would pass on the details of the programme withour colouring them. Another way of putting this is to say that the equipment is transparent to the signals fed into it. Indeed, listening to very fine loudspeakers one is reminded of their function as windows through which earlier stages in the processes of recording can be observed.

Finally a special aspect of home hi-fi warrants special mention. Experimenters and hobbyists have always been active in this field, and manufacturers respond to their needs by providing kits of parts and a variety of individual components, accessories and practical advice. The handy enthusiast can save money by assembling many of the units for his system. A range of kit amplifiers, receivers and loudspeakers is marketed, and there are a few turntables and tape machines. Loudspeakers represent the most popular do-it-yourself activity these days.

# 11 Sounds of the Future

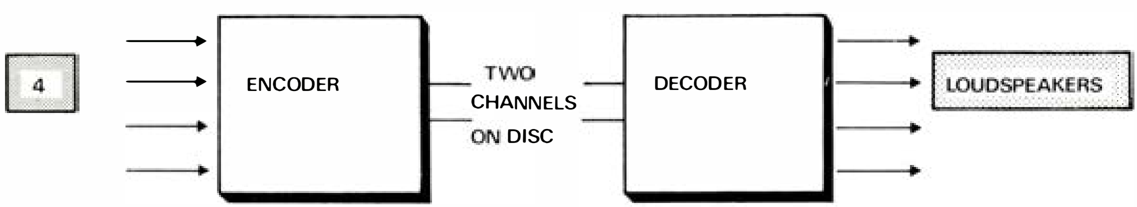
Surround-sound systems, at present the basis for further development, will inevitably become a normal feature of high-grade sound reproduction once agreement has been reached on methods of recording. Stereophonic sound, although promising clear advantages when it was first introduced, did not gain very rapid acceptance, and it is apparent that more elaborate multi-channel arrangements will not reach their final form without commercial and technical wrangles.

Methods of recording so far proposed, though to some extent capable of presenting additional acoustic information to enhance concert-hall effects, do not represent the ultimate in refinement. For example, the processes of human hearing, wider ranging than those of any computer, operate on information that helps us interpret the height of sound sources. Such data are not processed in recording systems as they are now advocated, but there is no reason why they should not be taken into account eventually.

Recording organizations, learning from the experience of an LP disc boom, believe that surround-sound systems are best promoted on the basis of disc recording. Existing 'quadraphonic' recordings all appear on the market as discs. However, taped music (cassettes, especially) is under constant development, and the future of surround-sound may well rest on magnetic recording. In the shorter term the LP disc maintains its influence, and this record format probably has another decade of general use before it.

The recording of pictures is of increasing interest in education, science and industry, and inevitably home video systems will be placed within reach of many potential

In this system for surround sound four inputs are encoded in the studio in such a way that the information can be accommodated in the two channels of a disc record. Subsequent decoding presents four outputs for amplification and speaker reproduction.



users. Most video recording depends on magnetic principles, especially the use of tape in cassettes, but other methods are possible. Some authorities believe the disc, obviously popular for music, will also be the solution for video. Lessons learned from computer technology may be applied in domestic systems.

Any system designed for video must also embrace sound channels, conceivably surround signals of very high quality. It is not difficult to imagine an advanced system in which 3-D video is supported by surround-sound reproduction. An intermediate stage might be a wall-mounted colour display accompanied by a refined form of stereo sound.

Meanwhile the improvement of audio systems, from recording methods to home hi-fi equipment, continues steadily. Twin-channel stereophony is susceptible to further refinement as other methods are investigated. The 'hardware' of hi-fi reveals worthwhile advances as pickups track more securely at featherweight pressures and loudspeakers sound more honest and musical.

Miniaturization is an outstanding feature of electronic devices: its merit is best appreciated in terms of reliability, convenience and ease of manufacture rather than in the cultivation of smallness for its own sake. There is no special merit in very tiny hi-fi: controls, cables and connections have to be manipulated by fingers, and there is little prospect that they will shrink to match a miniaturized technology!

Probably the ideal is a sound system that rivals the 'live' event in its realism and immediacy. It will introduce behind-the-scenes complications yet give the impression that all the barriers have been swept aside. At its best it will appeal as a dependable service, unobtrusive but always there when one wants it. The means to the end are always tantalizingly close, and there is a great deal of work—and sheer fun—awaiting those who will attend to the details.

# Index

Everyday Technology

**Sound Recording and Hi-Fi**

Sound recording and reproduction have long fascinated both ordinary listeners and professionals who have sought to bring recorded music to higher standards of realism. In recent years the art and science of hi-fi has won a wide following, and it is this area which receives close attention in this book. It is well illustrated and offers facts about acoustics, explains stereo and hi-fi principles, and describes the complex chain of events from microphone to listening-room. Recording studio practice and record manufacture are included, and there is no shortage of how-it-works information. The most modern developments in cassettes and surround sound are covered. It is well gauged for the young reader and recommended to anyone requiring a concise introduction.

**Everyday Technology Series**

*Television* John Clark
*Sound Recording and Hi-Fi* Clement Brown
*Computers* John Clark
*Jets* John Taylor

ISBN 0 460 06430 4

*Cover illustration:* Recording session for Mozart's Mass in C minor in a South London church. Picture courtesy EMI Records Ltd.