AUDIO ELECTRONICS

JOHN LINSLEY HOOD

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Preface

The progress of 'audio' towards the still-distant goal of a perfect imitation of reality has been, and remains, inextricably bound up with the development of electronic components and circuit technology, and with the parallel progress in the various transducers and interface devices used to generate and reproduce electrical signals. However, while in the early years of audio almost all the development work was done in an empirical manner, with ideas being tested experimentally in the studios or listening rooms of those involved – for want of any better way of advancing the design technology – gradually, as our understanding of the technical problems and their solutions increased, the way in which the designers make their designs has become increasingly analytical and theoretical in its nature.

This change is as inevitable as it is predictable since there are many parts of this work – digital audio, for example – which can no longer be designed by any pragmatic 'suck it and see' method, and whose undoubted success has been entirely dependent on the correct outcome of theoretical calculations and predictions. Unfortunately, this has left a large number of music and hi-fi enthusiasts in the dark about what is actually being done to achieve the results they hear; and the occasional design errors made by the engineers, which have led to deficiencies in the reproduced sound, have left many listeners suspicious of what they no longer understand.

Design errors still do occur, just as they have always done, but now that the design and marketing decisions are no longer based on a judgement of sound quality made by a knowledgeable enthusiast/designer, there is a greater risk that equipment embodying them will find its way on to the dealers' shelves.

The various hi-fi magazines perform a useful task – irritating though they may be to those who already know everything – in drawing the attention of the engineers to the not entirely infrequent differences between what the specification implies and what the ear actually hears. However, the main requirement for the listener must remain a greater understanding of what is actually done, and how this will influence what he or she hears. This book is an attempt, in one small corner of this field, to reduce this gap between hearing and understanding.

John Linsley Hood

CHAPTER 1

Tape recording

THE BASIC SYSTEM

In principle, the recording of an alternating electrical signal as a series of magnetic fluctuations on a continuous magnetisable tape would not appear to be a difficult matter, since it could be done by causing the AC signal to generate corresponding changes in the magnetic flux across the gap of an electromagnet, and these could then be impressed on the tape as it passes over the recording electromagnet head.

In practice, however, there are a number of problems, and the success of tape recording, as a technique, depends upon the solution of these, or, at least, on the attainment of some reasonable working compromise. The difficulties which exist, and the methods by which these are overcome, where possible, are considered here in respect of the various components of the system.

MAGNETIC TAPE

This is a thin continuous strip of some durable plastics base material, which is given a uniform coating of a magnetisable material, usually either 'gamma' ferric oxide (Fe_2O_3), chromium dioxide (CrO_2), or, in some recently introduced tapes, of a metallic alloy, normally in powder form, and held by some suitable binder material. Various 'dopants' can also be added to the coating, such as cobalt, in the case of ferric oxide tapes, to improve the magnetic characteristics.

To obtain a long playing time it is necessary that the total thickness of the tape shall be as small as practicable, but to avoid frequency distortion on playback it is essential that the tape shall not stretch in use. It is also important that the surface of the tape backing material shall be hard, smooth and free from lumps of imperfectly extruded material (known as 'pollywogs') to prevent inadvertent momentary loss of contact between the tape and the recording or play-back heads, which would cause 'dropouts' (brief interruptions in the replayed signal). The tape backing material should also be unaffected, so far as is possible, by changes in temperature or relative humidity.

For cassette tapes, and other systems where a backup pressure pad is used, the uncoated surface is chosen to have a high gloss. In other applications a matt finish will be preferred for improved spooling.

The material normally preferred for this purpose, as the best compromise between cost and mechanical characteristics, is biaxially oriented polyethylene terephthalate film (Melinex, Mylar, or Terphan). Other materials may be used as improvements in plastics technology alter the cost/performance balance.

The term 'biaxial orientation' implies that these materials will be stretched in both the length and width directions during manufacture, to increase the surface smoothness (gloss), stiffness and dimensional stability (freedom from stretch). They will normally also be surface treated on the side to which the coating is to be applied, by an electrical 'corona discharge' process, to improve the adhesion of the oxide containing layer. This is because it is vitally important that the layer is not shed during use as it would contaminate the surface or clog up the gaps in the recorder heads, or could get into the mechanical moving parts of the recorder.

In the tape coating process the magnetic material is applied in the form of a dope, containing also a binder, a solvent and a lubricant, to give an accurately controlled coating thickness. The coated surface is subsequently polished to improve tape/head contact and lessen head wear. The preferred form of both ferric oxide and chromium dioxide crystals is needle-shaped, or 'acicular', and the best characteristic for audio tapes are given when these are aligned parallel to the surface, in the direction of magnetisation. This is accomplished during manufacture by passing the tape through a strong, unidirectional magnetic field, before the coating becomes fully dry. This aligns the needles in the longitudinal direction. The tape is then demagnetised again before sale.

Chromium dioxide and metal tapes both have superior properties, particularly in HF performance, resistance to 'print through' and deterioration during repeated playings, but they are more costly. They also require higher magnetic flux levels during recording and for bias and erase purposes, and so may not be suitable for all machines.

The extra cost of these tape formulations is normally only considered justifiable in cassette recorder systems, where reproduction of frequencies in the range 15–20 kHz, especially at higher signal levels, can present difficulties.

During the period in which patent restrictions limited the availability of chromium dioxide tape coatings, some of the manufacturers who were unable to employ these formulations for commercial reasons, put about the story that chromium dioxide tapes were more abrasive than iron oxide ones. They would, therefore, cause more rapid head wear. This was only marginally true, and now that chromium dioxide formulations are more widely available, these are used by most manufacturers for their premium quality cassette tapes.

Table 1.1 Tape thicknesses (reel-to-reel)

Tape	Thickness (in.)
'Standard play'	0.002
'Long play'	0.0015
'Double play'	0.001
'Triple play'	0.00075
'Quadruple play'	0.0005

Composite 'ferro-chrome' tapes, in which a thinner surface layer of a chromium dioxide formulation is applied on top of a base ferric oxide layer, have been made to achieve improved HF performance, but without a large increase in cost.

In 'reel-to-reel' recorders, it is conventional to relate the tape thickness to the relative playing time, as 'Standard Play', 'Double Play' and so on. The gauge of such tapes is shown in Table 1.1. In cassette tapes, a more straightforward system is employed, in which the total playing time in minutes is used, at the standard cassette playing speed. For example, a C60 tape would allow 30 minutes playing time, on each side. The total thicknesses of these tapes are listed in Table 1.2.

For economy in manufacture, tape is normally coated in widths of up to 48 in. (1.2 m), and is then slit down to the widths in which it is used. These are 2 in. (50.8 mm), 1 in. (25.4 mm), 0.5 in. (12.7 mm) and 0.25 in. (6.35 mm) for professional uses, and 0.25 in. for domestic reel-to-reel machines. Cassette recorders employ 0.15 in. (3.81 mm) tape.

High-speed slitting machines are complex pieces of precision machinery which must be maintained in good order if the slit tapes are to have the required parallelism and constancy of width. This is particularly important in cassette machines where variations in tape width can cause bad winding, creasing, and misalignment over the heads.

Table 1.2 Tape thicknesses (cassette)

Tape	Thickness (μm)
C60	18 (length 92 m)
C90	12 (length 133 m)
C120	9 (length 184 m)

Tape base thicknesses 12 μm, 8 μm and 6 μm respectively.

For all of these reasons, it is highly desirable to employ only those tapes made by reputable manufacturers, where these are to be used on good recording equipment, or where permanence of the recording is important.

THE RECORDING PROCESS

The magnetic materials employed in tape coatings are chosen because they possess elemental permanent magnets on a sub-microscopic or molecular scale. These tiny magnetic elements, known as 'domains', are very much smaller than the grains of spherical or needle-shaped crystalline material from which oxide coatings are made.

Care will be taken in the manufacture of the tape to try to ensure that all of these domains will be randomly oriented, with as little 'clumping' as possible, to obtain as low a zero-signal-level noise background as practicable. Then, when the tape passes over a recording head, shown schematically in Fig. 1.1, these magnetic domains will be realigned in a direction and to an extent which depend on the magnetic polarity and field strength at the trailing edge of the recording head gap.

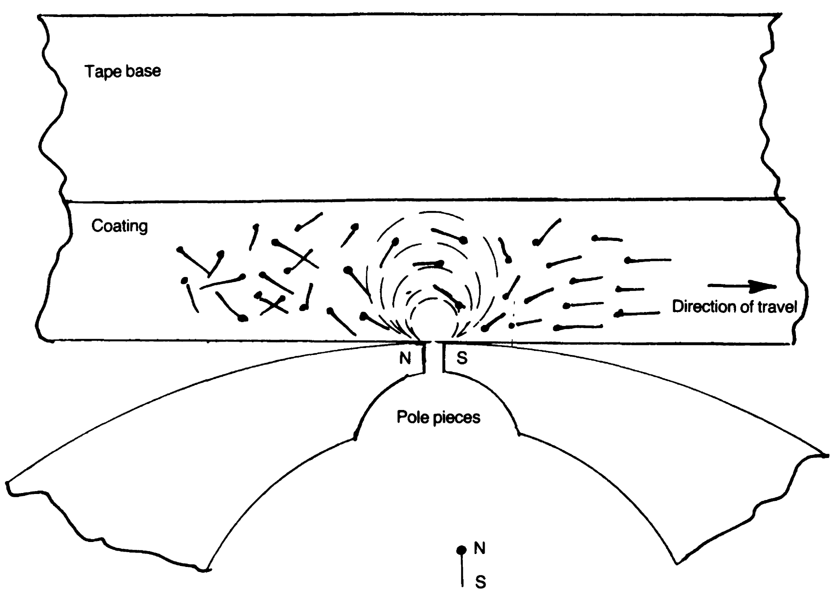

Fig. 1.1 *The alignment of magnetic domains as the magnetic tape passes over the recording head.*

This is where first major snag of the system appears. Because of the magnetic inertia of the material, small applied magnetic fields at the recording head will have very little effect in changing the orientation of the domains. This leads to the kind of characteristic shown in Fig. 1.2, where the applied magnetising force, (*H*), is related to the induced flux density in the tape material, (*B*).

If a sinusoidal signal is applied to the head, and the flux across the recording head gap is related to the signal voltage, as shown in Fig. 1.2, the remanent magnetic flux induced in the tape – and the consequent replayed signal – would be both small in amplitude and badly distorted.

This problem is removed by applying a large high-frequency signal to the recording head, simultaneously with the desired signal. This superimposed HF signal is referred to as 'HF bias' or simply as 'bias', and

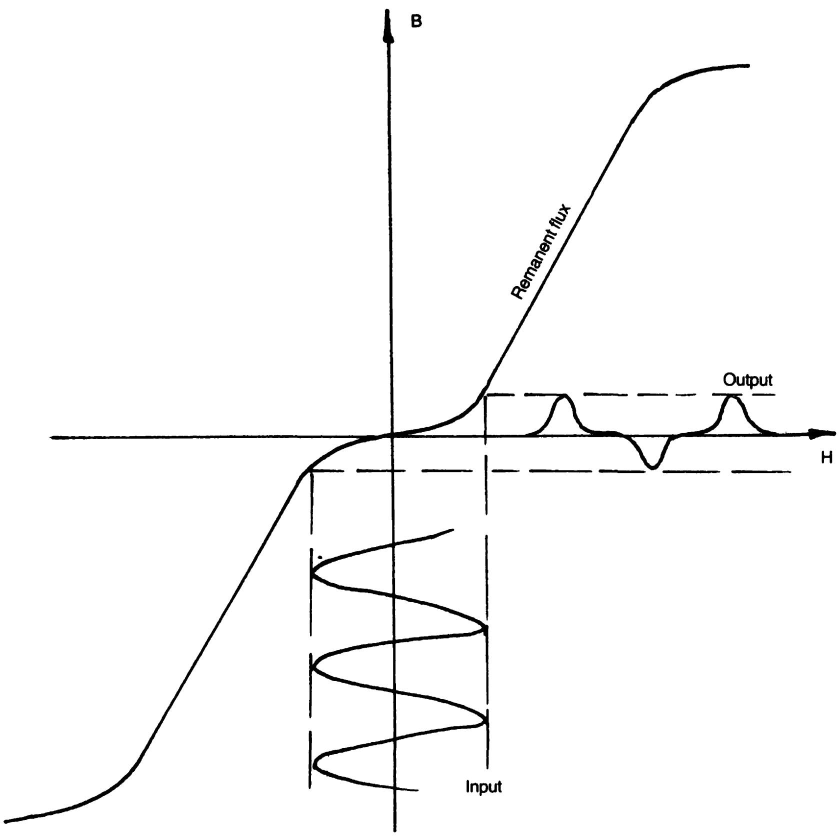

Fig. 1.2 *The effect of the B-H non-linearity in magnetic materials on the recording process.*

will be large enough to overcome the magnetic inertia of the domains and take the operating region into the linear portion of the BH curve.

Several theories have been offered to account for the way in which 'HF bias' linearises the recording process. Of these the most probable is that the whole composite signal is in fact recorded but that the very high frequency part of it decays rapidly, due to self cancellation, so that only the desired signal will be left on the tape, as shown in Fig. 1.3.

When the tape is passed over the replay head – which will often be the same head which was used for recording the signal in the first place – the

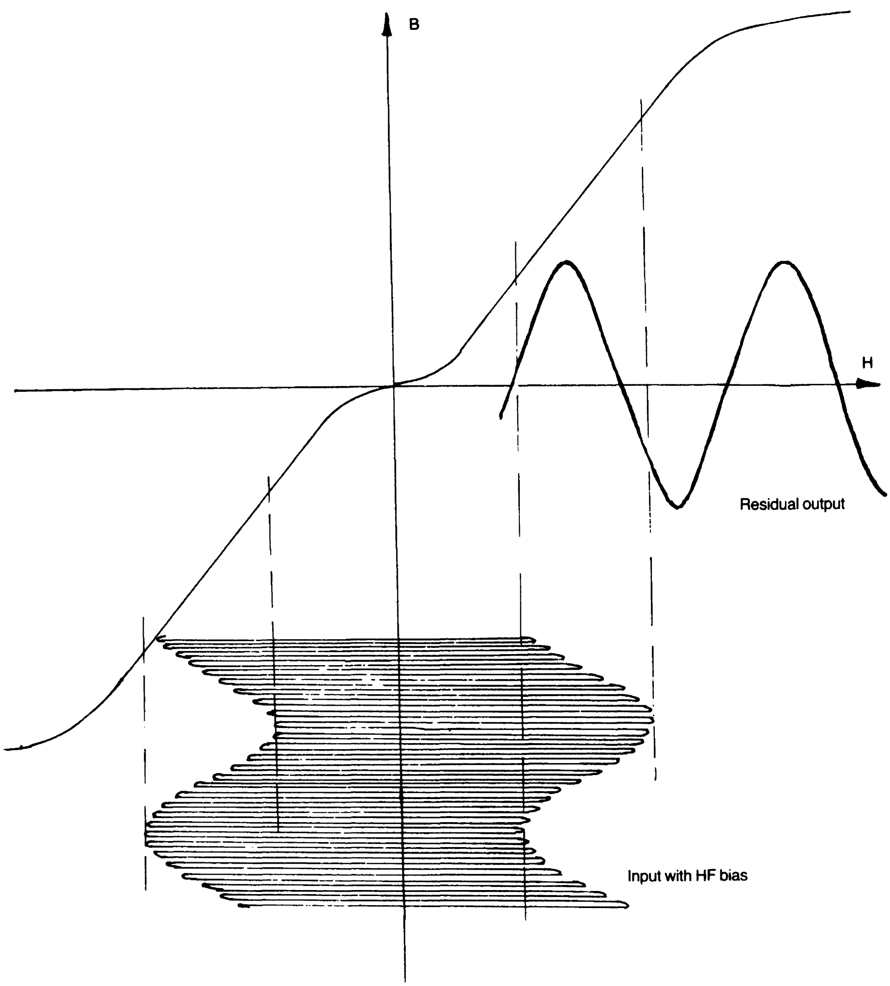

Fig. 1.3 *The linearising effect of superimposed HF bias on the recording process.*