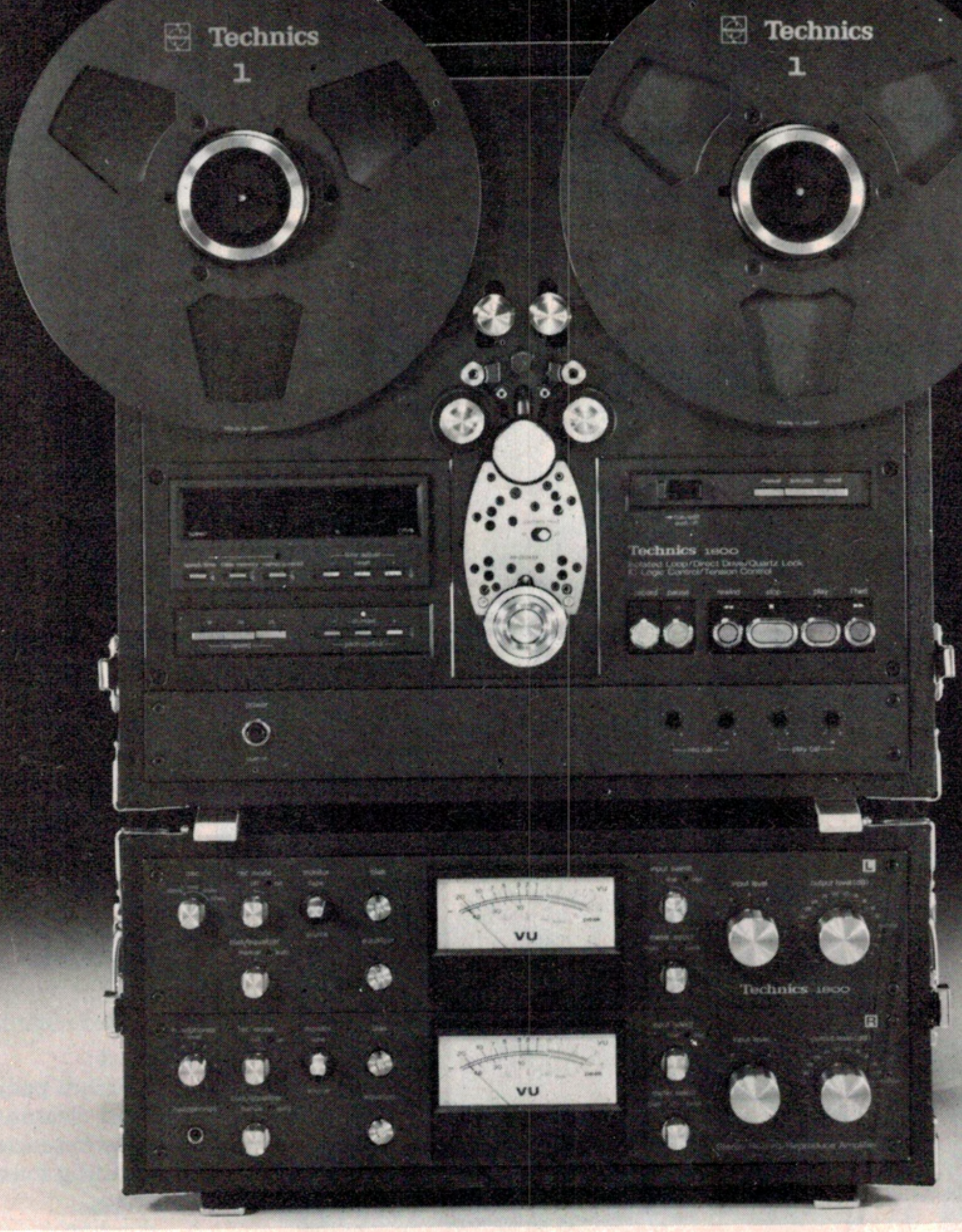
Recording tape and tape recording

If you're a newcomer to the popular pastime of tape recording and reproduction, here's a complete rundown on the technicalities



John Gardner

ALL HI-FI reproduction is dependent on the storage of information and its retrieval when required. Information stored on a gramophone record is in the form of a modulated groove, and the signal waveform is visible under a microscope or a powerful magnifying glass.

With tape recording, however, the signal is stored by a magnetic oxide that carries an invisible, varying magnetic pattern. To record and recover the information a series of energy conversions is necessary: acoustic-to-electric, electric-to-magnetic, and vice versa.

As with the disc system there are losses and technical inadequacies that have to be compensated for by equalisation. However, in tape recording, equalisation is not a single stage process with mirror image characteristics used on record and replay. Instead, it is a complex two-stage process applied partly when recording and partly on playback, to give an overall flat response. Before we discuss this in detail let us consider the nature of tape and of the recorded signal.

Recording tape consists of a thin, pliable base of plastic material, such as mylar or polyester. The base is coated with a magnetic oxide paste about four um thick (one um is one millionth of a metre), the constituents of which are the oxide itself, a binder, a solvent, and a lubricant.

During manufacture the oxide powder, which is in the form of minute needle-shaped particles (or magnetic domains), is given a type of 'grain'. That is, the particles have a common orientation. For some computer and video systems the grain is vertical — perpendicular to the direction of tape travel — but for conventional sound recording the grain is horizontal (Figure 1).

Aligning the particles in this way allows a more concentrated coating to be applied than would random application. For a given type of oxide and a given tape width, the thickness of the coating determines the maximum output possible from the tape.

The most commonly used oxide is gamma ferric oxide (Fe_2O_3) and, until about 1966, it was the only oxide regularly used in the manufacture of magnetic tape. Later developments were chromium dioxide (CrO_2), ferrichrome — a mixture of ferric and chrome coatings — and cobalt. More recently 'metal' tape formulations have appeared (see July 1979 ETI, p.159).

Early ferric tapes were noisy, had low sensitivity, and poor high frequency response. With improved manufacturing methods the tape was improved immensely and finer oxides, with more regular particle structure, were developed to give lower hiss, higher output levels, and better high frequency response.

Chromium dioxide enjoyed a popular vogue in cassette recording but, while it has a slightly superior high frequency performance at low speeds, it is more prone to distortion than ferric tapes and is now being superseded by ferrichrome. For reel to reel recording at speeds above 95 mm/s there is no advantage to be gained from the use of tapes other than ferric oxide.

Tape magnetisation

When tape is in a so-called demagnetised state the individual particles (domains), although physically aligned, have no common magnetic sense (Figure 2). The domains may be regarded as minute bar magnets, but when these are of random polarity, as with blank tape, the only output produced by the oxide is in the form of noise. To record a signal on the tape it is necessary to modify the distribution of polarity so that a magnetic analogy of the audio signal applied to the machine's input is written along the tape's length.

To store the input signal on tape it must be converted into a form that the tape will recognise and retain. This conversion is carried out by the tape head (Figure 3.), which is effectively a ring-shaped electromagnet. The audio signal, in the form of a varying voltage, is applied to the head winding.

Now, if a current flows through a piece of wire a magnetic field is created around the wire, and if the wire is wound into a coil this field is intensified. If a core, such as soft iron, is inserted into the coil it will become magnetised and remain so until the voltage applied to the coil is removed. A tape head is simply a variation of this idea with the coil curved to bring the two ends (poles) into close proximity.

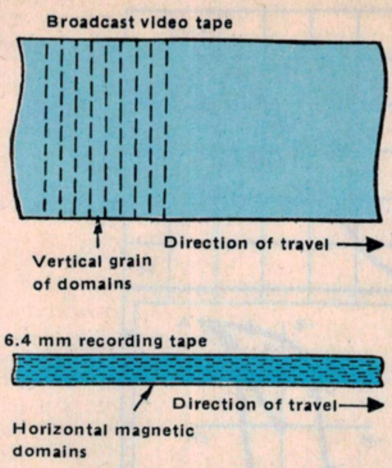


Figure 1. **During manufacture the magnetic particles are given a common orientation.**

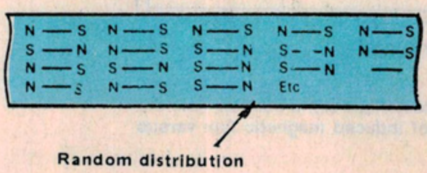


Figure 2. **An erased so-called demagnetised tape with a random distribution of domains.**

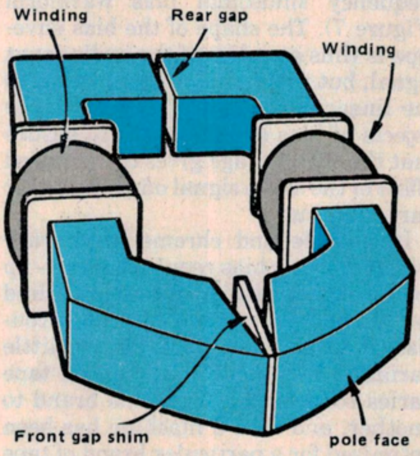


Figure 3. **A typical record/replay head.**

With a constant voltage applied to the coil, the iron core will have a North and South pole, rather like a horseshoe magnet. If the polarity of the supply voltage is reversed, the two poles will be reversed. If we substitute an audio signal, such as a sinewave, for the constant voltage, the poles will alternate in sympathy with the positive and negative half-cycles of the applied signal.

The strength of the poles at any instant will depend on the voltage of the signal, which in turn depends on the amplitude of the original sound. Because of a shim placed at the front of the head, filling the gap between the pole-pieces, the magnetic flux cannot easily pass from the North to the South pole. In fact, the reluctance of the shim (reluctance is the magnetic analogy of resistance) is so high that it is easier for the flux to complete the magnetic circuit by crossing the air space in front of the shim.

If a tape is passed over this concentrated magnetic flux the magnetic circuit is completed through the tape oxide. The effect of the varying flux on the moving tape is to produce a series of bar magnets along the length of the tape. The stronger the magnetising the greater will be the strength of the bar magnet so formed. The length of a particular magnet depends on the rate at which the applied magnetising force is changing polarity, and on the linear speed of the tape. (For example, at 10 kHz with a tape speed of 190 mm/s, the recorded wavelength takes up 0.019 mm of tape. Wavelength here is tape velocity divided by frequency.)

In the case of a sinewave input — as shown in Figure 4 — a wavelength consists of two bar magnets of equal length. The positive going half-cycle is represented by a North-to-South field, and the negative half-cycle by South-to-North field, although the opposite could equally well be the case.

So far the concept is relatively easy to grasp. An electrical signal is converted to a magnetic form and is effectively 'written' — in the form of a varying magnetic flux — on the tape oxide. It is then retained and at any time the message may be read by the reproducing system. What complicates the matter is that in both recording and ▶

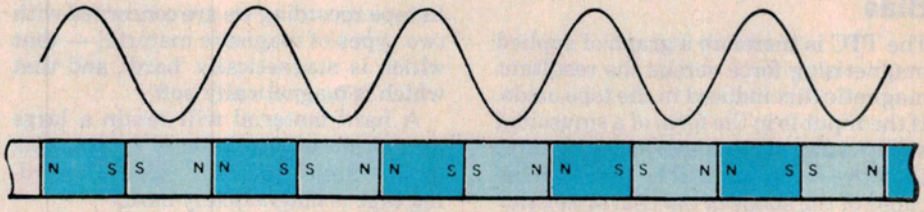


Figure 4. **A recorded tape has areas of magnetic polarisation corresponding to the positive and negative half cycles of the applied waveform.**

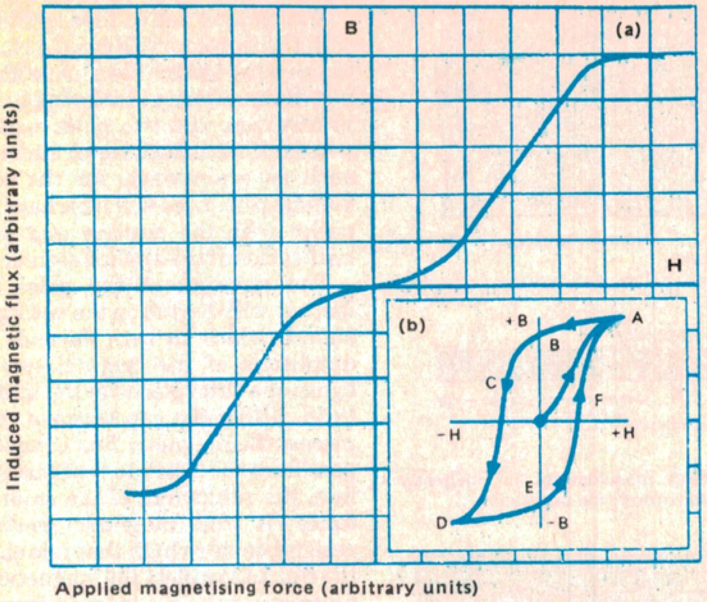


Figure 5. **The non-linear tape transfer characteristic (a) is derived from the hysteresis loop (see inset). It is a graph of induced magnetic flux versus applied magnetising force.**

replay the transfer from electrical to magnetic, and from magnetic to electrical energy is non-linear.

Transfer

Every tape has what is known as a tape transfer characteristic, which shows the relationship between the applied magnetising force (H) and the resultant tape flux (B). This characteristic will differ from one type of tape coating to another — a typical transfer curve is shown in Figure 5.

The characteristic is derived from a hysteresis loop, which describes the tape flux resulting from the application of one cycle of magnetising force to the oxide. For the sake of simplicity we will ask you to accept the derivation of the hysteresis loop, and from it the tape transfer characteristic (TTC).

The significant thing is the shape of the TTC itself. There is a discontinuity at the origin of the B-H curve, with a nearly linear slope in the central region of the positive and negative sections of the curve. Beyond a given point an increase of applied magnetising force gives no increase in the resultant tape flux: this is the point of tape saturation.

Bias

The TTC is therefore a graph of applied magnetising force versus the resultant magnetic flux induced in the tape oxide. If the input is in the form of a sinusoidal swing either side of the B axis (Figure 6) then the recording will be distorted because of the shape of the characteristic.

To overcome this distortion the input signal must be offset on to the linear part of the TTC. This is done by superimposing the audio signal on a high frequency sinusoidal bias waveform (Figure 7). The shape of the bias envelope is thus a replica of the audio input signal, but this signal is now applied to the linear part of the TTC. One of the objects of bias adjustment is to ensure that the bias voltage gives the required offset of the audio signal on to the linear part of the curve.

Iron oxide and chrome tapes vary widely in their bias requirements — up to 40 per cent more bias being required for chrome tape, which is more consistent than iron and shows little variation between brands. Ferric tape varies considerably from one brand to another, and once a machine has been optimised for a particular brand of tape it is advisable to stick to that brand unless there are compelling technical or economic reasons for doing otherwise. When the recording bias is adjusted it will be found that if too low an offset voltage is used the signal will be distorted: if it is too high, demagnetisation of the high frequencies will occur and the top response will be impaired.

Tape heads

In tape recording we are concerned with two types of magnetic material — that which is magnetically 'hard', and that which is magnetically 'soft'.

A hard material will retain a large proportion of any induced magnetism, which cannot be easily erased. Recording tape is magnetically hard.

A 'soft' material will react quickly to changes in magnetic force, but when that force is removed will retain very little magnetism. This ability to react rapidly to changing magnetic conditions is exactly what is required of a tape head which, consequently, is made from soft material. In this context hardness and softness are magnetic, not physical properties.

Three functions have to be performed by the tape heads, functions that are so individual that, if they are to be performed efficiently, require three independent heads — erase, record, and playback.

For economic reasons manufacturers often combine the functions of two of the heads, and fit machines with an erase head and a dual purpose record/playback head. Apart from the engineering compromises that such an arrangement necessitates, there are also operational disadvantages, the most serious of which is that the tape cannot be monitored during recording.

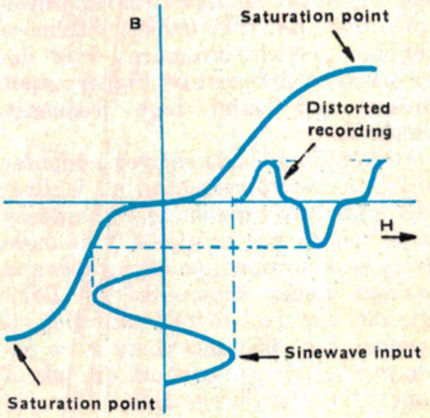


Figure 6. **Distorted recording results from non-linear tape transfer characteristic.**

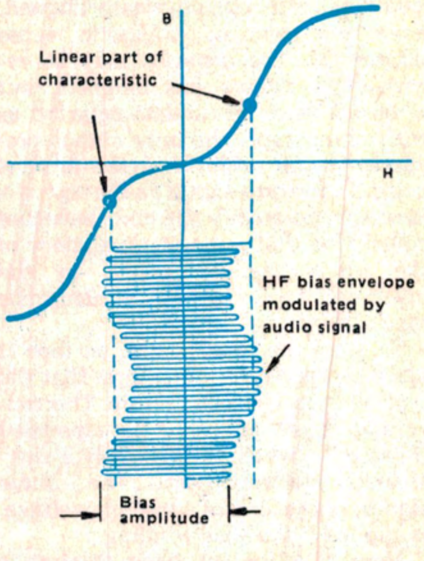
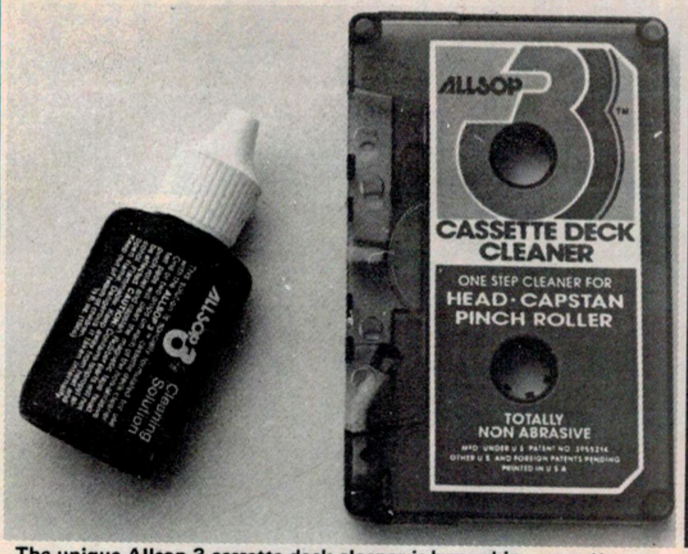


Figure 7. **The distortion can be minimised by off-setting the audio signal onto a high frequency bias voltage.**



The unique Allsop 3 cassette deck cleaner is housed in a cassette case

The Nagaoka cleaning tape, from Goldring, employs a special tape

Tape Care Products

Cassette cleaners

Users of cassette decks can choose from a wide variety of special cassettes that make head cleaning as simple as playing a tape. But make sure you buy a reputable brand — some cheap head cleaners are abrasive and may damage your heads.

Bib's cleaning cassette contains a non-abrasive textile ribbon and simply wipes off a fluid that is sprayed on prior to use. **TDK** make a cleaning cassette that runs dry and will remove light to moderate dirt accumulations from the heads, capstans and pinch roller. The Nagaoka Cleaning Tape 4, distributed by **Goldring**, has a specially treated polymer tape to clean the heads and two felt pads for wiping the capstan and pinch roller.

Philips sell a kit that includes a cassette with a phial of cleaning fluid — you just put a drop or two of fluid on the textile tape before running it through your machine. For removing stubborn dirt deposits the kit also provides a few cotton buds. **Ralmar** have a number of cleaning cassette outfits ranging from a simple cassette and fluid combination to their deluxe kit which also includes a cutter and splicer for tape editing.

Last but certainly not least is the Allsop 3, available through **Communications Power Inc.**, which contains an oscillating mechanism that rubs felt pads to and fro against all the parts that accumulate grime.

The basic elements of a tape head have already been shown in Figure 3. In the case of the erase and record heads the flux due to the current through the windings induces a varying magnetic flux into the core. In the case of the replay head, the magnetised tape induces a varying flux into the poles, which produce an electromotive force (emf) in the windings, and hence an electrical output.

Of particular importance are the width and alignment of the gap, and the shape of the pole-pieces in contact with the tape. The width and alignment of the gap largely determine the attainable high frequency response, whilst the head contact area affects the low frequency replay response. In order to maintain precise head alignment some manufacturers construct the head block as a single unit with the heads rigidly fixed to a common, machined baseplate.

Erase head

It is a curious feature of the recording process that the bias waveform, which reduces distortion and enables a good recording to be made, also has the characteristics required to erase the tape.

The important factor for erasure is a high enough current to carry the tape into saturation at each reversal of polarity. It is not possible to demagnetise the tape — the particles are always polarised in one direction or another. However, if the distribution of magnetism is completely random, the effect is of a mutual cancellation within the tape, which thus has no external flux.

The object of using a high frequency erase current is that it subjects the individual domains to a large number of reversals of polarity in a short space of time. The tape is moved through a concentrated magnetic field, the effect of which progressively reduces as the tape leaves the head. Therefore the tape is firstly repeatedly saturated at each reversal of polarity as it crosses the head gap. Then the weakening field, as the tape leaves the gap, is unable to reverse all the particles in a given area, and the final polarity a particle adopts is not greatly influenced by the original signal polarity. The tape therefore has a random magnetic distribution and is said to be demagnetised.

In practice it is possible for some of the particles to partially recover their original magnetic sense. For this reason a second pass over the erase head is often necessary to obtain complete erasure. To increase the depth of erasure many tape recorders are now fitted with double-gapped erase heads that give a similar effect to two passes of the tape across the head. The erase gap may be as much as 20 um, although with a double-gapped head the second gap is usually considerably smaller. The erase frequency must be high enough to produce the rapidly reversing flux and to avoid the generation of spurious beat frequencies (with 19 kHz and 38 kHz signals from stereo tuners). It is usually in the region of 80 to 150 kHz.

Record head

Whereas at the erase head a saturating magnetic force is used to remove any existing signal waveform from the tape, at the record head a bias current of precisely controlled amplitude is mixed with the audio signal to minimise distortion of the audio waveform.

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Maxell's head cleaning kit is very comprehensive.

The TDK cleaning kit — simple and inexpensive.

Tape Care Products

Mind your heads!

NOTHING spoils the performance of a tape recorder so much as dirty heads. Even if you're not worried about high fidelity you *must* use something to clean the heads every so often, otherwise your tapes will sound *terrible*.

There's a variety of solvents and tools on the market, some of them simpler to use than others. At the most basic level you can use a cotton bud dipped in meths, but its better to use a specially formulated cleaning fluid such as that made by **Bib**. Or you can spray the heads first with an aerosol solvent, then wipe them off. **Dindy** and **Ralmar** both sell suitable spray cleaners.

Two of the leading cassette makers sell complete head cleaning kits that can be used for both cassette and reel to reel machines. **TDK's** kit has a fluid that you spray onto the end of a cleaning probe. When the probe gets too dirty, you just snip off the end and extend the wick. The kit also includes a little mirror so you can check the heads really are clean.

Maxell's kit comes in a neat plastic box and includes fluid, mirror, straight and angled probes with discardable felt pads and a brush. **Bib**, who specialise in tape and record care products also do a kit of this kind, as do **Tandy**.

Remember, when you clean your heads, not to forget the capstan and pinch roller too. Dirt on these will soon be transferred to the heads and you'll be back where you started.

The record head gap is much smaller than the erase head. It must be small enough to produce a high flux density, but wide enough to allow for a number of changes of polarity of the bias waveform. Depending on the bias frequency, tape speed, and gap dimension, each domain is subjected to around 10 cycles of bias current. Again, the bias results in a polarisation of the magnetic domains but, because of the presence of the audio signal, as the bias field diminishes, so the polarity of the domains is increasingly influenced by this varying signal.

Thus, instead of the tape reverting to a natural state it is magnetised according to the amplitude and frequency of the applied audio signal. This means that the tape is recorded as it is leaving the head gap, and the gap itself is not too critical as far as the audio waveform is concerned. A typical record head gap for a machine running at 95 and 190 mm/s would be six um.

The relationship between the current in the head winding, the permeability of the core, and the flux concentration at the gap is not linear. To overcome this a high reluctance rear gap is used that is analogous to a constant current resistor. The reluctance of the rear shim is so high in comparison with the rest of the magnetic circuit that it swamps any variation in the permeability of the core material, and a virtually linear flux is produced at the front gap. The rear gap is usually about 10 times that of the front.

Replay head

A tape head is a piece of precision engineering. In the case of a replay head the tolerances are so closely defined that there is virtually no margin for error. Even a slight departure from specification can lead to a major loss of performance.

One of the most crucial dimensions is that of the replay head gap. Due to the nature of the head material, the flux coupling with the poles, and the head-to-tape contact area, the effective gap may be as much as twice the physical gap. Because the replay head tolerances are so tight, if a dual purpose head is constructed it will, to all intents and purposes, be a replay head.

The output from the replay head depends on the efficient coupling of the surface induction on the tape with the head and its associated preamplifier. A replay head core has extremely high permeability — several thousand times that of air — so that the tape flux at the point of intimate contact with the head will seek the easy path through the head core.

The changing flux pattern as the tape moves across the scanning head results in an emf in the head windings, a voltage that increases with frequency because it is proportional to the rate of ▶

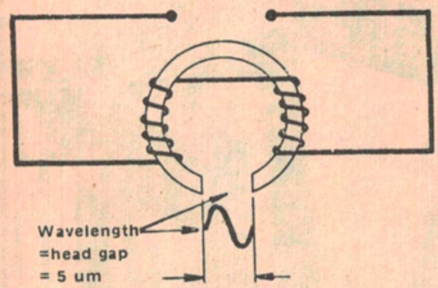

Figure 8. **When the recorded wavelength equals the replay head gap there is no flux linkage with the head core and consequently no output.**

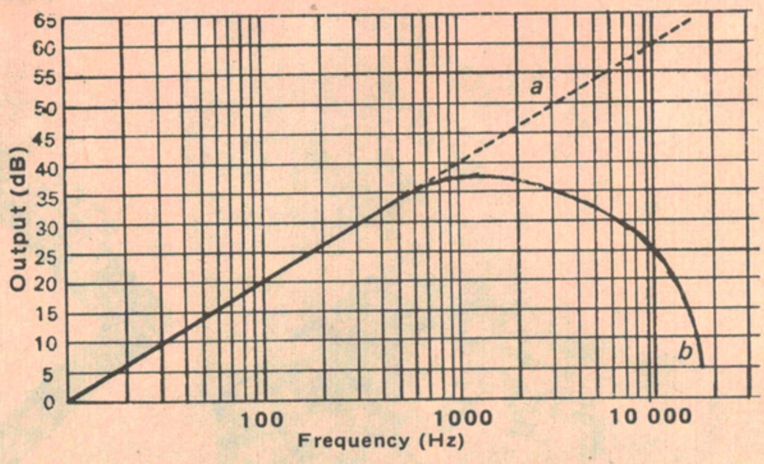

Figure 9. **Replay head responses — (a) ideal response and (b) practical response with head losses.**

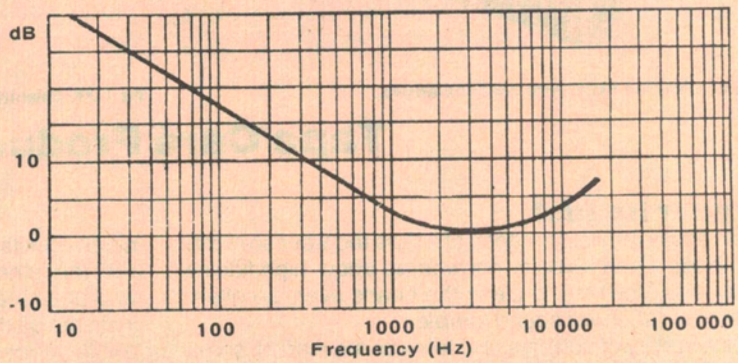

Figure 10. **Theoretical response of the replay amplifier.**

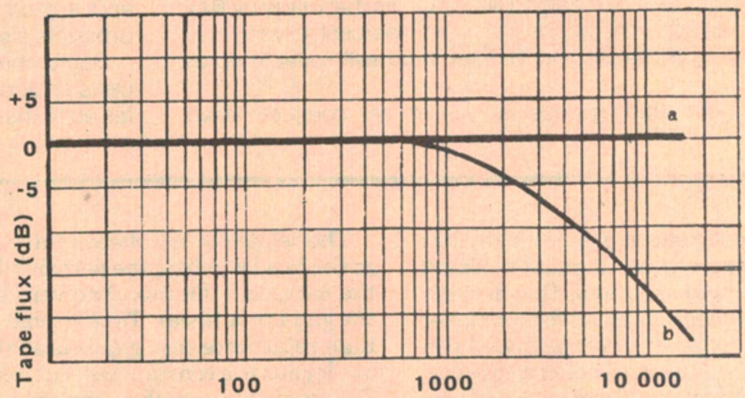

Figure 11. **Ideal recorded tape flux (a) and typical tape flux allowing for head and other losses (b).**

change of flux. Hence, doubling the frequency will double the output from the head — in other words the output from an ideal head would rise at 6 dB per octave.

In practice a straight line graph is not realised, and the 6 dB per octave slope is only achieved at low and mid frequencies. At the upper end of the audio spectrum a point is reached (Figure 8) where the recorded wavelength is comparable with the effective gap of the replay head. When this point is reached the variation of flux will occur within the gap dimension and consequently there will be no output from the head. The frequency at which this happens is known as the extinction frequency, although the ideal slope does not suddenly fail as the extinction frequency is reached. As shown in Figure 9, it begins to roll off at about half the extinction frequency.

Now we can see the problem in perspective. To achieve a theoretical extinction frequency of 20 kHz at 190 mm/s the effective gap should be 9.5 um, giving a physical gap of about 5 um. The response of the head may not be as good as the theoretical figures given above, but in general the head with the narrower replay gap will have the better high frequency response.

Replay system

We have briefly discussed the principles of the recording and replay processes. Let us now consider how the replay and recording chains are interlinked and equalised so that a flat overall response can be obtained.

We have already referred to the extinction effect, which is a major cause of high frequency loss. In addition to this, when the recorded wavelength is very short the individual poles are in such close proximity that some of the flux fails to emerge from the surface of the tape. Instead, it completes the magnetic circuit through the oxide and so does not energise the tape head. Other losses are due to imperfect head-to-tape contact, and coupling losses between the head and preamp. At the bass end, where the wavelength is long compared with the head gap, the output may fall at a rate greater than 6 dB per octave as part of the flux path is through the air.

To compensate for the response at the head it is apparent that the replay amplifier must have an initial slope falling at 6 dB per octave, it must flatten out in the mid frequency range and then add a degree of boost at the top end to compensate for the head losses. Figure 10 shows the theoretical response of the replay amp.

Record system

The signal current is fed through a resistor to the head winding and mixed with the bias waveform. The value of the resistor is such that it is well in excess of any change in impedance of the head (which increases with frequency). The effect is that variations of ▶

head impedance are minor in comparison with the value of the feed resistor, resulting in a constant current input to the head. Thus, for a signal of given amplitude, the head current is constant regardless of frequency.

In theory this would appear to give a constant level of magnetic induction on the tape oxide. Again the ideal is not realised because of high frequency losses (Figure 11). In the main these are due to partial erasure of the signal by the bias, the falling permeability of the tape with increasing frequency, and poor head-to-tape contact. To compensate for these losses the theoretical response of the record amplifier should be the inverse of Figure 11. In fact it is not quite this simple.

If sufficient pre-emphasis were applied during recording to give constant tape flux with frequency, the tape would saturate at high frequencies. Also, as we have seen, the response of the replay head is not flat, and the response curve of Figure 10 would not produce a flat output from a tape flux that held constant with frequency.

Equalisation

What is required is a two-part compensation process, part of which is applied on recording and part on replay. The result should be a flat response over a given frequency range. However, because the losses vary not only with frequency but also with tape speed, the equalisation must be switched to give the optimum response curve for each tape speed.

Anyone with a turntable expects to be able to replay any gramophone record and to achieve a consistent standard of reproduction. Similarly it should be possible to replay a tape recorded on one machine on any other machine. Without this requirement each designer could equalise for the various losses in any way and, provided the machine had an overall flat response, the customer would be happy — until attempting to replay someone else's tape on that machine!

Obviously a standard is required, but to what does it refer?

It describes the recording characteristic, which is a curve of recorded tape flux level against frequency, and when plotted appears as in Figure 12. Tape flux is measured in nanowebers per metre (nWb/m) of track width, and recording characteristics are commonly referred to in terms of the circuit time-constants that would produce an impedance curve of the same shape.

The problem is to arrive at a recorded tape flux (not frequency response) as per Figure 12, having taken account of the various losses in the recording system. To do this the designer usually begins with the replay system, knowing that if a calibration tape can be replayed accurately, one of the variables is fixed — replay equalisation. A recording amplifier can thus be devised that will produce the tape flux levels shown in Figure 12. If the sums have been done correctly a flat overall (record-replay) response will result.

To summarise this rather complex process: there are losses during the various energy conversions in the record and replay chains. Equalisation circuits are used during record and replay, such that an overall flat response is obtained. Because the losses in the system vary with tape speed, a family of curves is required if a machine has more than one speed.

To ensure that tapes can be interchanged it is essential that a tape recorded on one machine shall be reproduced satisfactorily by another. For this reason specific recording characteristics have been adopted, and provided a machine conforms to the appropriate standard, compatibility will be achieved. ●

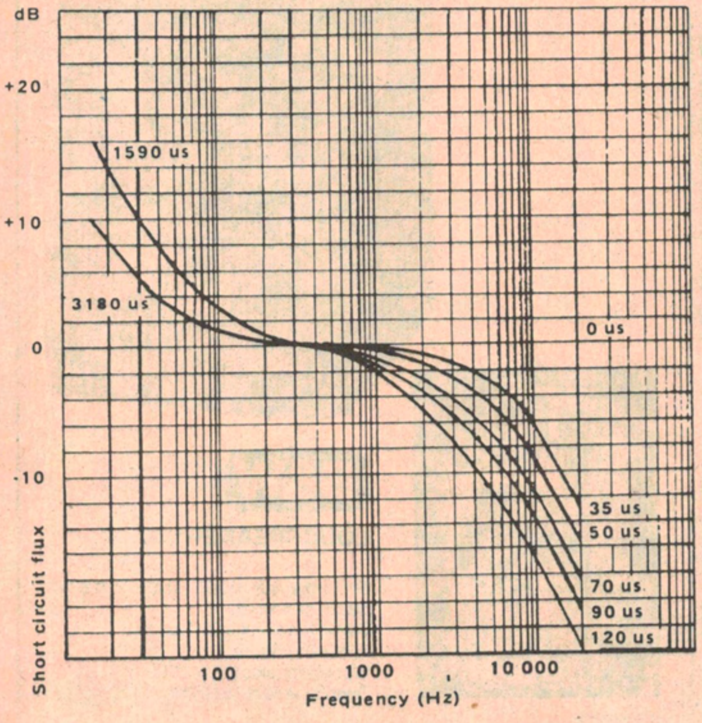

Figure 12. **Recording characteristics to BS 1568: 1970.**

FIRMS MARKETING TAPE CARE PRODUCTS

Bib Hi-Fi Australia, 43 Birmingham St, Alexandria NSW 2014. (02)667-2750

Communications Power Inc., P.O. Box 246, Double Bay NSW 2028. (02)357-2022

Dick Smith Electronics, P.O. Box 321, North Ryde NSW 2113. (02)888-3200

Dindy Marketing (Aust.), P.O. Box 55, Rushcutters Bay NSW 2011. (02)33-5293

Goldring Audio Industries, 69 Clarence St, Sydney NSW 2000. (02)290-1455

Maxell: Hagemeyer Aust. BV, P.O. Box 307, North Ryde NSW 2113.

Philips Service, 443 Condord Rd, Rhodes NSW 2138, (02)73-0231

Ralmar Agencies, 23 Atchison St, St. Leonards NSW 2065. (02)439-6566

Tandy Electronics, P.O. Box 229, Rydalmere NSW 2116.

TDK Australia, 4 Dowling St, Woolloomooloo NSW 2011. (02)358-2088