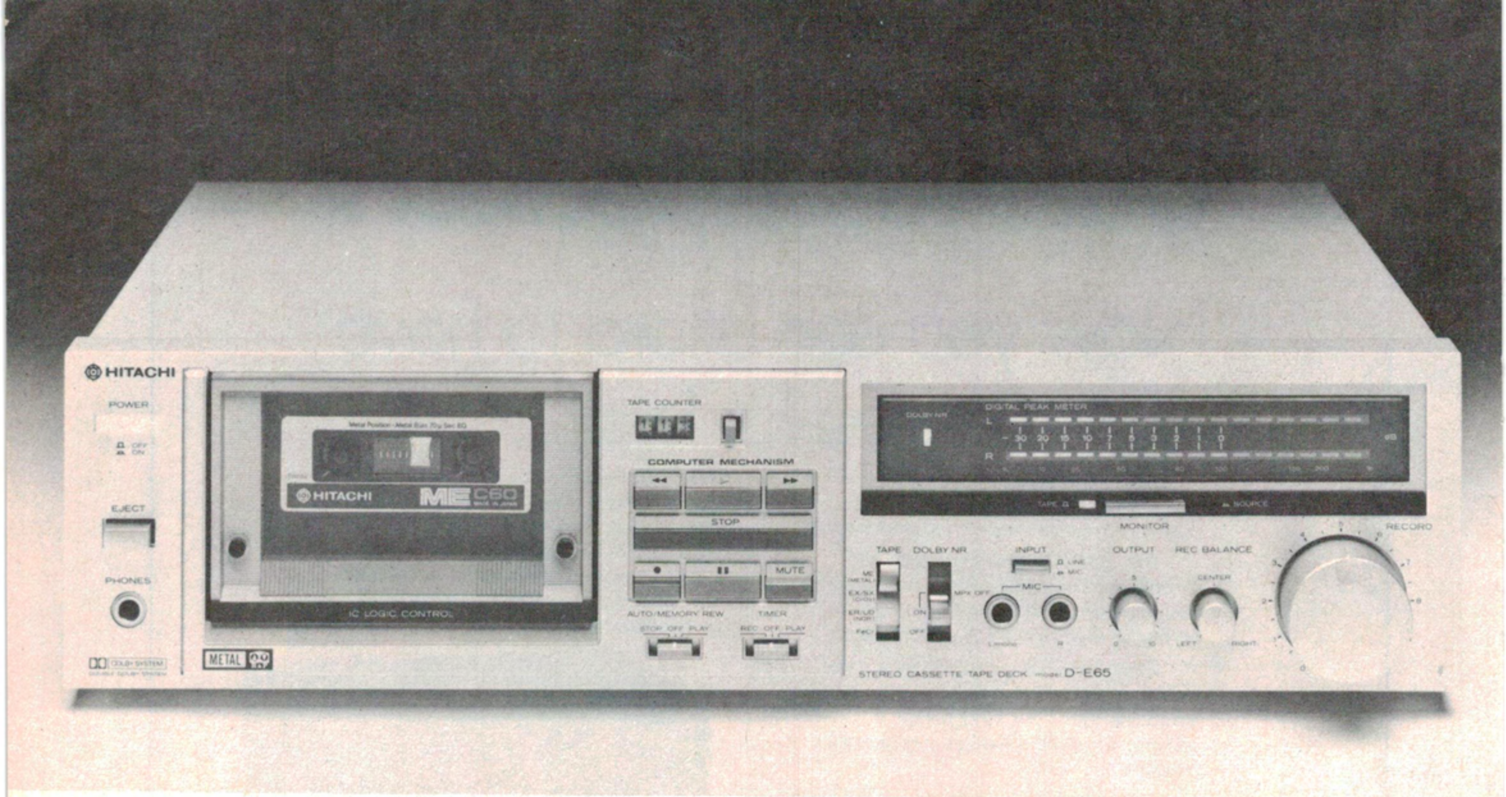


Modern tape recorder technology

Part 1

Reel-to-reel and cassette tape recorders released over the last few years feature electronic and mechanical facilities that offer the user incredible performance and versatility. The article covers the technology and techniques employed in modern analogue tape recorders, illustrated with partial circuits and mechanical diagrams.

Brian Dance

THE FIRST tape recorder to be marketed was the open-reel type (also known as the reel-to-reel), but cassette recorders are now more popular for domestic use. Cassette recorders have the advantage of convenience, since it is much easier to insert the cassette than to thread a tape in a reel-to-reel recorder. The performance of the early cassette recorders with relatively narrow, slowly moving tapes was very poor, but this performance has greatly increased with improvements in tape heads, the use of chromium dioxide (CrO_2) and now metal particle tapes, etc.

Nevertheless, all professional tape recorders are still of the open-reel type. This type of recorder is more expensive than a similar cassette recorder, but provides better reproduction than many cassette machines, longer playing time, and a much wider range of facilities. An open-reel recorder normally offers a choice of tape speeds, the high frequency response improving with increasing tape speed. A modern open-reel recorder may provide a response level to within ±3 dB to beyond 20 kHz at a tape speed of 19 cm/sec and a response to about 18 kHz at half this speed, with the advantage of twice the playing time. In addition, open-reel recorders enable tape editing to be performed, while master recordings can be made with a multi-track system carrying any required information on one or more of the other tracks.

Cassette decks normally operate at the single speed of 4.75 cm/sec, but there are a few recorders (such as the Teac C-3X) which can also operate at twice this speed for optimum performance.

Frequency specifications of high-quality decks vary with the tape employed; for example, Optonica quote the following upper values for their RT-7070H deck, all for ±3 dB variation: (i) normal tape 16 kHz (ii) CrO_2 tape 18 kHz (iii) ferrichrome tape 19 kHz (iv) metal tape 20 kHz.

Apart from frequency response, the other parameters of open-reel recorders tend to be better than those of cassette types. For example, the wider tape used in the open-reel types helps to produce a better signal-to-noise ratio; in theory the double tape width normally used increases this ratio by a factor of $\sqrt{2}$, but in practice the improvement is usually greater than this. Open-reel decks usually provide less distortion, better stereo channel separation, less wow and flutter, etc.

The continuous playing time of a cassette tape is limited by the standard size of the cassette and by the impossibility of making a very thin tape adequately strong.

Sections of a deck

All recorders must employ a *tape transport* mechanism. The early recorders used a motor, sometimes synchronised to the mains, to drive a large fly-wheel which was coupled to the tape by means of a capstan wheel and a rubber pinch-wheel system. In some decks the same motor is used to drive the tape reels, whereas other decks use separate motors for this purpose. Thus there may be one, two or three motors in a deck. Brushless dc motors are now often used in high-quality recorders, since they generate minimum noise. In such motors a semiconductor circuit replaces the conventional carbon brush and commutator system for controlling the direction of current flow in each winding. Servo circuits (some incorporating a phase-locked loop) may be employed for accurate speed control.

The magnetic tape moves across the face of an erase head and normally at least one other head. This may be a record/replay head or separate heads may be employed for recording and replaying, depending on the class of recorder. The correct currents must be applied to the heads according to the mode of operation at the time, and many recorders employ complex logic systems for the control and switching of these currents.

The signal from a replay head is at a very low level and must be greatly amplified. In addition, frequency 'equalisation' circuits must be incorporated into both the recording and replay amplifiers so that the overall amplification of the complete record/replay system is flat across the audio range. Some form of noise reduction circuitry is almost essential for good reporduction from cassette recorders and is desirable for optimum results in open-reel equipment.

An oscillator operating at about 100 kHz is required for erasing and for providing the recording head with the bias required for low distortion.

Additional circuitry is needed to indicate (and perhaps to automatically adjust) the level of the signal being recorded so that the tape is neither overloaded (which would produce distortion) nor under-recorded (which would raise the noise level). Further circuitry is required on some recorders for adjusting the equipment for the particular type of tape employed. Thus it is not surprising that tape recorder circuitry is complex and that manufacturers are introducing microprocessor control in some models. The provision of such facilities as remote control adds further to the circuit complexity.

Erase heads

Erase heads must efficiently erase any signals previously recorded onto the tape; they normally have a slightly wider track than the recorded tracks so as to ensure that the whole width of the recorded signal is erased. A relatively wide gap of some 100 um to 1 mm is employed in the ferrite core so that the field is adequate.

The advent of high coercivity tapes, especially metal tapes, has rendered erasure more difficult, so some manufacturers use a two-gap erase head of the form shown in Figure 1. The tape

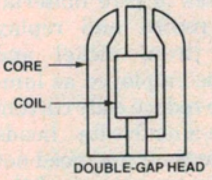
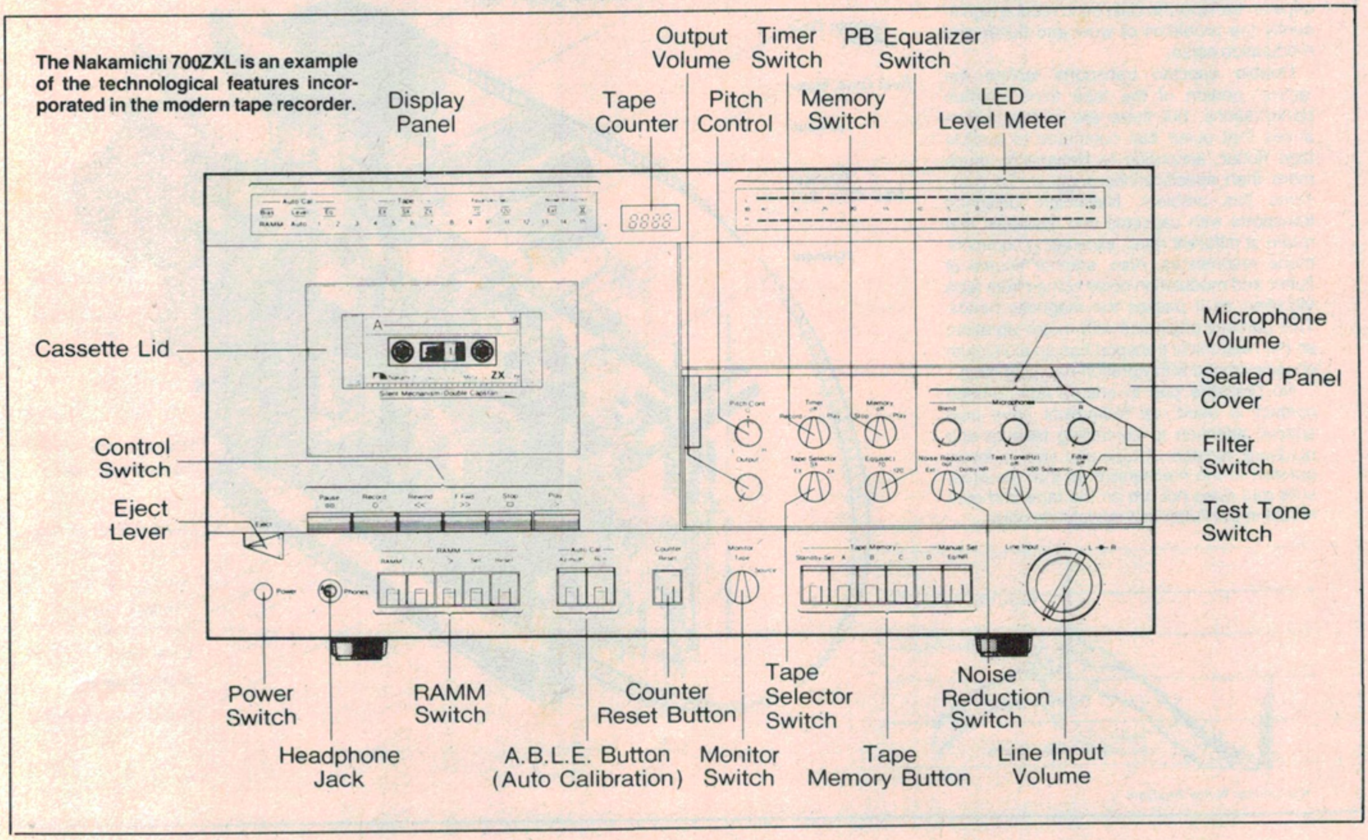


Figure 1. **A double-gap erase head (Teac).**

first passes across the one gap, which takes the material of the tape through several hysteresis cycles and greatly attenuates the recorded signal. The tape then passes over the second gap, which completes the erasure process. JVC employ erase heads with two gaps and claim that an improvement of some 10 dB is obtained in the signal-to-noise ratio in the case of a tape containing a 400 Hz note by the use of a dual gap head.

Record and replay heads

A head designed purely for recording purposes usually has a gap width of between three and 30 um. However, a playback head must have a smaller gap, since this gap should be appreciably smaller than the wavelength on the tape of the highest frequency to be replayed. Gaps of less than 1 um are often used. The head is screened in mu-metal to prevent pickup of stray mains hum fields. ▶



The Nakamichi 700ZXL is an example of the technological features incorporated in the modern tape recorder.

Record/playback combined heads involve some compromises in their design, but are used in many cassette decks where space is limited. It is even possible to include an erase and a recording head in one unit.

Three main classes of core material are employed in record and replay heads. Permalloy (iron, nickel and molybdenum) can be employed as laminated thin sheets to reduce eddy current losses. Manganese-zinc-ferrite heads are more resistant to wear and need not be laminated, as the resistivity of the material is much higher. Many manufacturers now favour the use of a material known as 'Sen-alloy' because of its relatively high saturation permeability (see Figure 2), which facilitates the production of a relatively high field in the head gap for recording with high coercivity tape.

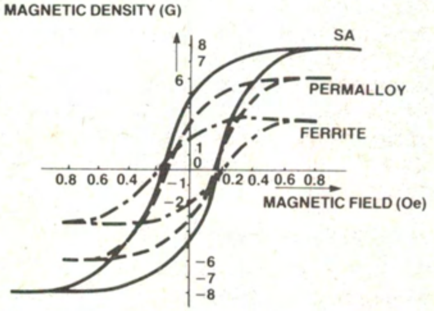


Figure 2. **Hysteresis loops of various tapes showing the high saturation density of JVC's SA type.**

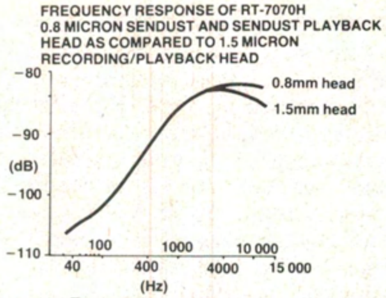


Figure 3. **Frequency response of a 0.8 um-gap head compared with a 1.5 um-gap head (Optonica).**

Sen-alloy has been known for well over 40 years, but its original form proved almost impossible to machine owing to its extreme brittleness. However, this problem has now been overcome and 'Sendust' heads are used in cassette decks by Pioneer, Optonica, etc. Accurate machining is especially important for the playback head, where the gap may be less than 1 um. The Pioneer RT-7070H cassette deck employs a recording head with a 3 um gap and a playback head with a 0.8 um gap; the response of a system with this playback head and with a 1.5 um head used for both recording and playback is shown in Figure 3.

An important factor in the choice of head material is the rate of wear, which is typically of the order of 1 um or more per thousand hours of use, depending on the tape speed. When a head undergoes wear, the gap increases, as shown in Figure 4, and this will impair the frequency response of a replay head. JVC employ six permalloy laminations in their SA heads, with a heat-bonded Sen-alloy gap/guard which has the hardness of ferrite and is therefore very wear-resistant. Permalloy itself has poor

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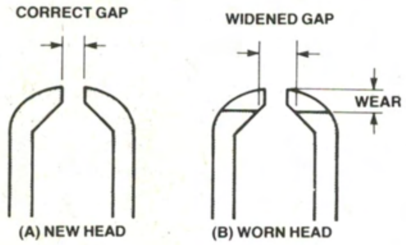


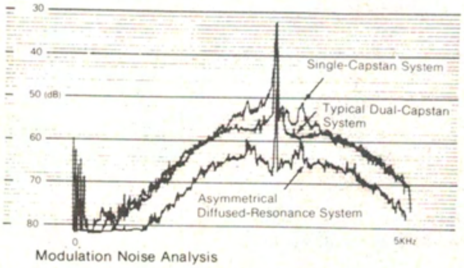
Figure 4. **Effect of head wear on gap width (Teac).**

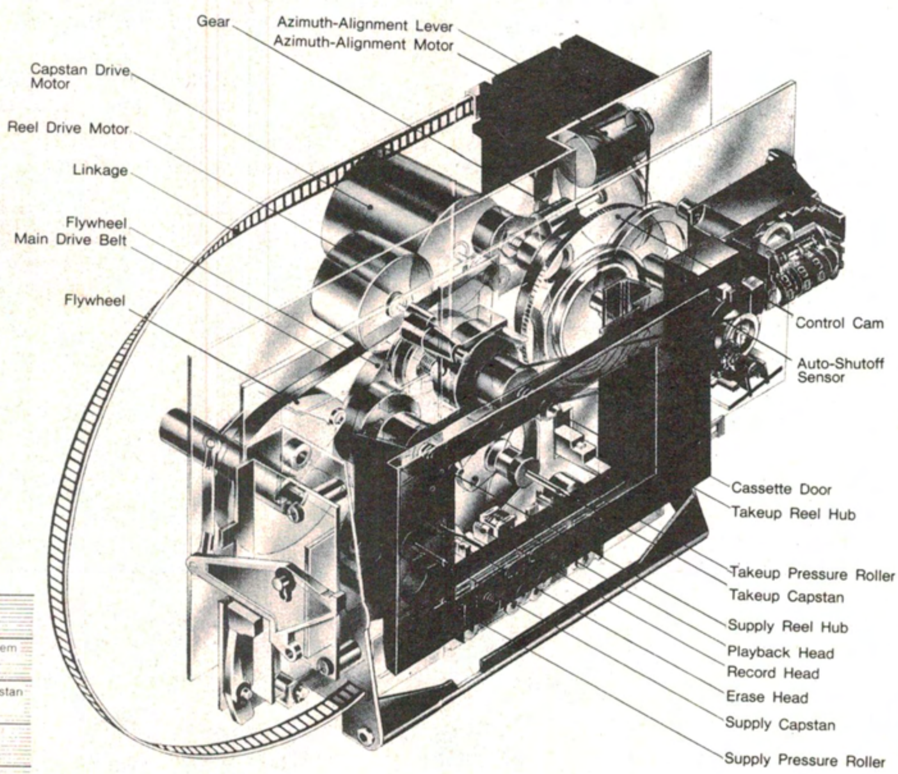
'DIFFUSED RESONANCE' CASSETTE TRANSPORT

Developed and manufactured by Nakamichi, and introduced barely three years ago, the 'asymmetrical, diffused resonance, double capstan transport' is claimed to reduce significantly the problems of wow and flutter and modulation noise.

Double capstan transports isolate the 'active' portion of the tape from reel-hub perturbations, but there are mutual resonances that occur that contribute to audible tape flutter, according to Nakamichi, much more than specifications suggest. To overcome this problem, Nakamichi designed transports with capstans and flywheels that rotate at different rates, eliminating common-mode resonances. Also, another source of flutter and modulation noise comes from tape vibration as it passes the magnetic heads. This partially originates with motor vibration, so the Nakamichi transport has an aluminium chassis coated with vibration-damping resin.

No pressure pad to ensure tape-to-head contact is used, as Nakamichi have paid special attention to controlling take-up and holdback tension. A tape-pad lifter is incorporated in the mechanism so that the pressure pad does not rub on the tape and contribute to the flutter and modulation noise.





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Technics top-line RS-M270X cassette deck features both Dolby and dbx noise reduction systems.

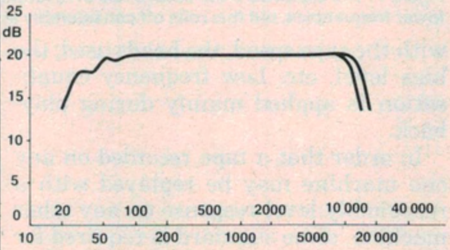


Figure 5. **Frequency response of JVC SA head with iron oxide and with chrome tape. Chrome tape has extended frequency response.**

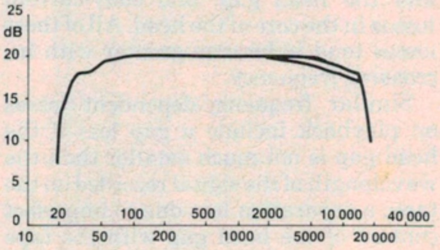
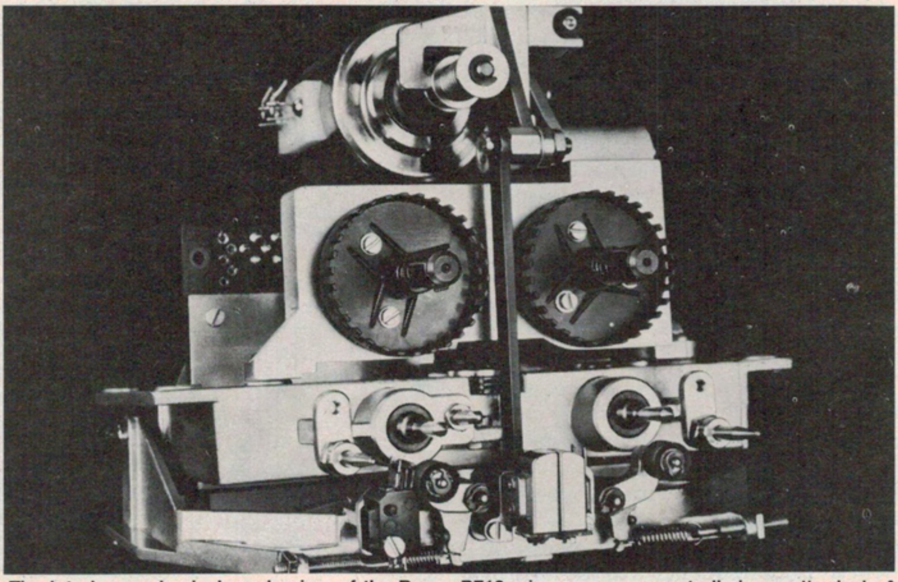


Figure 6. **Frequency response of the same head with the same tape types after 3000 hours' use. Note that the frequency response with ordinary oxide tape commences rolling off in the 2 kHz region.**

wear resistance. Figure 5 shows the frequency response of a JVC SA head for a normal iron oxide tape and for a chrome tape, while Figure 6 shows the same characteristics after 3000 hours' use.

Equalisation

Let us imagine a tape has been recorded at various frequencies with the amplitude of the current passing through the recording head kept constant and independent of the frequency. When the tape is replayed, the magnetic flux in the replay head will vary at a rate proportional to the frequency. The signal voltage produced by the head is proportional to the rate of change of the magnetic flux and can therefore be expected to be proportional to frequency; that is, the amplitude of the signal from the head rises at 6 dB/octave. ▶



The interior mechanical mechanism of the Revox B710 microprocessor-controlled cassette deck. A four-motor drive is employed with electronic rather than mechanical brakes. Motor speed is controlled by two PLL circuits.

At low frequencies this rise is indeed found, but at the higher frequencies a smaller rise is observed until at very high frequencies the reponse falls off with increasing frequency. This is due to increasing losses at higher and higher frequencies in both the recording and replay process; this is admirably demonstrated by the curves of Figure 7. During recording the losses include some demagnetisation as the tap magnetised by the signal is slightly demagnetised by later parts of the signal; a self-demagnetisation loss due to the effect of nearby parts of the magnetised tape; a thickness loss arising from the fact that the whole thickness of the tape coating cannot be in contact with the head gap; a separation loss due to imperfect contact between the tape and the head gap; and eddy-current losses in the core of the head. All of these losses tend to become greater with increasing frequency.

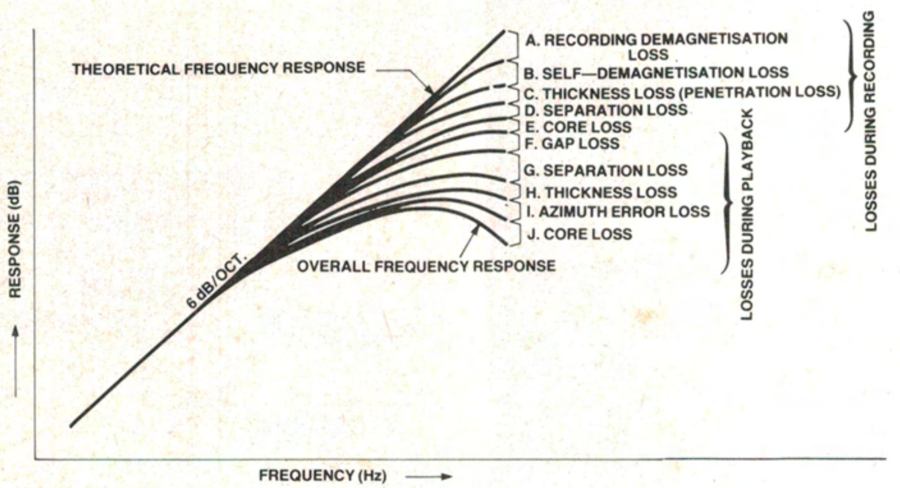
Similar frequency-dependent losses on playback include a gap loss if the head gap is not much smaller than the wavelength of the signal recorded on the tape; a separation loss due to imperfect contact of the head gap with the tape (this is a much larger effect than separation loss on recording, since even a separation of some microns due to dirt, etc. can greatly reduce the head terminal voltage); a tape thickness loss arising from the fact that only the top surface of the magnetised coating can be in contact with the head gap; an azimuth loss if the head gap is not perpendicular to the direction of travel of the tape; and an eddy-current loss in the material of the replay head core. These losses again all increase with frequency, as indicated in Figure 7.

The frequency response will also fall at very low frequencies where the wavelength of the recorded signal is comparable in size with the dimensions of the complete playback head.

In order to obtain an overall frequency response which is level over the required audio bandwidth, it is obviously essential to employ recording and replay amplifiers in which the frequency response of these amplifiers is suitably tailored to achieve the desired 'flat' overall characteristic. This frequency compensating process is known as 'equalisation'.

Much of the high frequency equalisation normally takes place during recording, since this results in the high frequency signals being recorded at a higher level on tape, with the result that a better signal-to-noise ratio is obtained on playback. Tape noise is most prominent at high frequencies in the form of a 'hiss'.

The equalisation required varies with the tape speed, the heads used, the bias level, etc. Low frequency equalisation is applied mainly during playback.



FREQUENCY RESPONSE AND VARIOUS LOSSES

Figure 7. **The expected 6 dB/octave rise in recording and playback frequency response occurs over the lower frequencies, but this rolls off considerably at the higher frequencies due to various losses.**

In order that a tape recorded on any one machine may be replayed with a reasonably level response on any other machine, some standard is required for the equalisation system for each tape speed. As an example, the NAB (National Association of Broadcasters) playback equalisation standard for 19 cm/s tape speed is shown in Figure 8. It may be noted that the centre part of the curve is straight, with the 6 dB/octave fall which compensates for the rise in Figure 7. However, the response at the lower and upper parts of the curve is tailored by means of RC time constants of 3180 us and 50 us respectively. This same standard is also specified for 38 cm/s, whereas at 9.5 and 4.75 cm/s the time constants are 3180 us and 90 us to produce treble lift at lower frequencies. Somewhat similar standards have been adopted in Europe and Japan.

The standard replay characteristic is for an ideal head system, but the limitations of practical heads are compensated in the playback amplifier. Hence the characteristic of a practical amplifier is modified at high frequencies, as shown by the dashed line of Figure 8.

In practice, a tape designed in accordance with the appropriate standard is played back and the playback equalisation circuit is adjusted until a flat response is obtained at the output of the circuit. A tape is then recorded and the recording equalisation circuit is adjusted until a flat response is obtained when the tape is replayed.

It should be noted that no *recording* frequency characteristic is specified as a standard, since tape and head performance can vary considerably. Any type of recording equalisation characteristic can be employed, provided that a level overall response can be obtained when used with a standard playback system. ●

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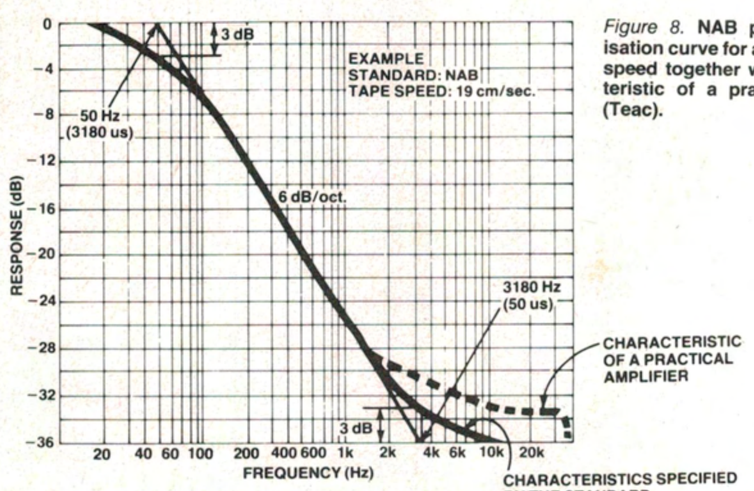

PLAYBACK EQUALISATION CURVE

Figure 8. **NAB playback equalisation curve for a 19.5 cm/s tape speed together with the characteristic of a practical amplifier (Teac).**