Cassette tape decks

Magnetic recording, heads, HF bias, etc.

by NEVILLE WILLIAMS

For ultimate sound quality, cassette tape decks fall short of the standard set by compact disc players but they tend to make up for it in all-round utility. In this chapter, we take a preliminary look at magnetic recording and playback, before turning attention specifically to the compact cassette.

As with conventional "black" discs, magnetic recording and playback has its own colourful history, dating back over 100-odd years.

As long ago as September 1888, the magazine "Electrical World" published an article by Oberlin Smith, entitled "Some Possible Form of Phonograph". In it, he suggested coating cotton thread with steel dust, so that it could be used for magnetically recording sound.

Whether Smith ever pursued the idea is not known but, in December, 1898 Vlademar Poulsen quite independently filed a landmark patent in Denmark under the heading: "A device for effecting the storing up of speech or signals by magnetically influencing magnetizable modies".

In Poulsen's "device", referred to as the "Telegraphone", the signal was magnetically impressed upon, and recovered from, 0.5mm steel wire. It was envisaged primarily as an adjunct to the telephone, as a way of recording messages, but its development was hampered by a lack of convenient means to amplify the signals.

Wire recorders did ultimately find considerable use in the field during World War II but, even then, they proved to be rather trouble prone, due to the tendency of the fine steel wire to rust, tangle or break.

In Germany, meanwhile, a number of major companies, including AEG, I. G. Farben and BASF, had developed magnetically coated plastic tape, along with prototype but distinctly practical "Magnetophon" tape decks. The technology, however, remained largely unique to Germany until after the war, when it was taken up and developed on a worldwide basis.

Tape recording equipment soon became routine in broadcasting and recording studios and, at a non-professional level, found its way also into many homes during the '50s, mainly by reason of its novelty and potential utility.

However, as we shall see later, a proliferation of formats and speeds tended to confuse domestic buyers and to convince them that they would be better advised to spend their money on the then new LP discs. Tape recorders were in danger of missing out on the mass market — but more of that later.

Deck mechanics

It may be helpful to pause at this stage and take a look at the mechanical configuration of a typical tape deck, as illustrated in Fig.1. While it depicts a conventional "open reel" layout, it will nevertheless serve to illustrate the fundamental principles involved, largely irrespective of format.

During normal recording and playback, the tape is drawn from the supply spool (or reel) passing, thereafter, around a guide post (or roller) and across the face of at least two magnetic

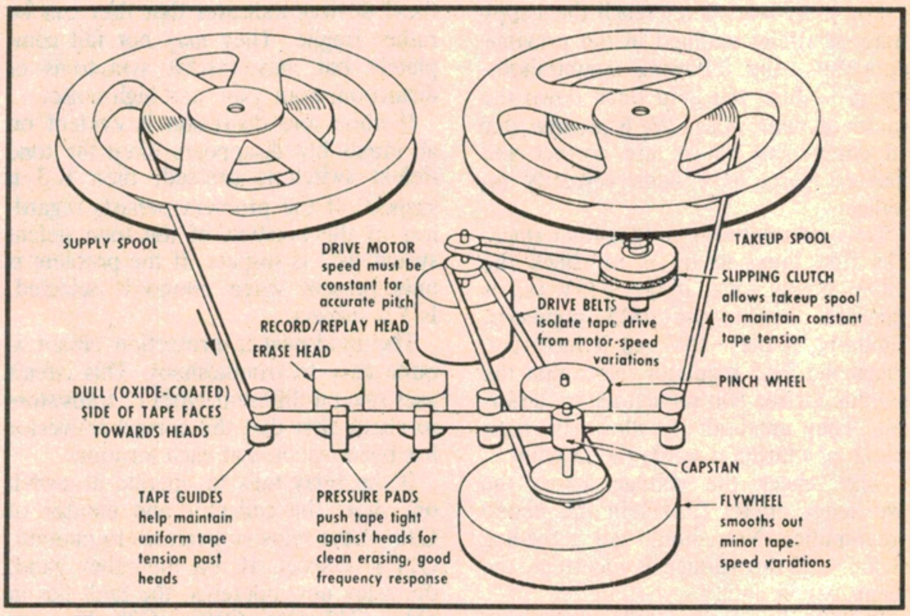
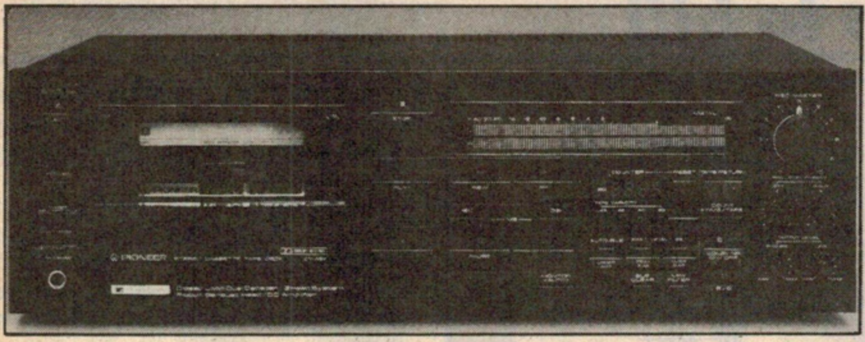


Fig.1: The basic mechanism of an open-reel domestic tape deck. A compact cassette deck is similar in principle, except that the tape is totally enclosed and the rest of the mechanism is scaled down to size.



Manufactured by Pioneer Electronic Corporation, the model CT-A9X (BK) cassette deck is typical of modern upmarket machines. Among its many features are three heads, a quartz PLL-controlled direct-drive capstan motor, Dolby B & C noise reduction, and automatic bias adjustment.

heads (Erase and Record/Play). Depending on deck geometry, the tape may be held in contact with the heads by natural tension and/or by felt-surfaced pressure pads, as shown.

On leaving the head assembly, the tape is gripped between a free-running resilient "pinch" wheel and an accurately ground capstan, the latter sharing a common drive shaft with a flywheel and pulley, belt-driven by a constant speed motor. To the right of the capstan, the tape passes around a further guide post (or roller) to the take-up spool, also belt driven by the capstan motor.

For the tape to run smoothly, the supply spool must maintain an even back tension, calling for some kind of friction brake. Equally, the takeup spool needs to be driven by a very smooth slipping clutch, to maintain an even but adequate takeup tension.

Should the supply or takeup tension vary erratically, it can affect the speed of the tape past the heads and cause "wow" — a relatively slow variation in the pitch of the recorded sound, as mentioned previously in the context of disc players.

Equally, eccentricity or unbalance in the capstan can produce a rapid variation in tape speed (therefore in pitch), described as "flutter" — an effect to which tape is prone, because of its low inherent mass (therefore inertia). As normally measured and specified, wow and flutter should not exceed 0.1% RMS for good quality reproduction.

Spooling provisions

While Fig.1 depicts the tape traverse configuration for normal record or replay functions, it does not show any provision for spooling the tape at high speed in either direction — in short, for "fast forward" and "rewind".

In many decks, the facility is provided by means of additional belts, pulleys and idler wheels, actuated directly by panel tabs and levers, which serve to retract the pressure pads and to spool the tape rapidly from one reel to the other.

More pretentious decks use "feather touch" panel buttons in conjunction with electronic "logic" circuitry and solenoids to operate the mechanism. Either way, it needs to keep the tape under sufficient tension to ensure even winding and prevent spillage.

A still further approach is to use one or more motors, separate from the capstan drive, to drive the spools. With two such motors, either one can operate at normal power for fast forward or rewind, while its opposite number can have just enough voltage applied to apply torque in the opposite direction, thus maintaining tension on the tape.

While up-market decks commonly feature "feather touch" logic control and multiple motors, it does not follow that less pretentious models need be open to question. The "bottom line" is whether they operate smoothly and reliably, providing a good, clean signal, free from perceptible wow and flutter.

Speeds and formats

In the immediate post-war period, it was common practice to use the full width of 0.25in (6.3mm) tape for a single mono track in the interests of good signal/noise ratio, and to run the tape at 15 inches per second (38cm/sec) or higher for adequate frequency response.

As tape technology improved, decks were released which had two and, later, four tracks side-by-side on the tape — used in some models for mono, in others for stereo.

At the same time, tape speeds were progressively reduced to 19, then 9.5 and 4.8cm/sec.

As if that wasn't enough, some decks required that the tapes be spooled with the magnetic layer facing out rather than in (as in Fig.1).

While professionals and devotees were able to cope with all this, it is of little wonder that the proliferation of speeds and formats, and the "fiddling" nature of open-reel decks prejudiced their appeal to other potential buyers.

Appreciating the problem, various companies came up with prototype tape cassettes and cartridge formats but none of their efforts achieved sufficient acceptance.

Ironically, it was Philips that finally hit the jackpot with an "unofficial" concept, developed by an engineering group in Eindhoven that was supposed to have been concentrating on a quite different project — a tape dictation machine.

No less ironically, when Philips showed it to the Japanese, Sony in particular induced them to licence its manufacture, gratis, in return for the support necessary to have it adopted as a world standard! (See EA for March '84.)

The compact cassette

And so the compact cassette format came into being in the early '60s, as an inexpensive, easy-to-use, general-purpose audio recorder, excellent for speech and with a performance on music promising enough to qualify as medium-fi.

Initially, hifi devotees scorned it because of its narrow tracks (four tracks on 3.8mm wide tape) and its low speed (4.8cm/sec), seemingly condemning it permanently to a poor signal/noise ratio and a limited frequency response.

What few foresaw was the acceptance which the format would win, the rivalry that would develop between manufacturers and the intensive research and development that would ultimately boost it from a medium-fi role to a place in domestic hifi installations, worldwide.

As will be apparent from Figs.2&3, the compact cassette format is broadly similar to the open reel approach, as already described, except that the supply and takeup spools are smaller and, along with the tape, tape guides and pressure pad, are totally enclosed in a cassette housing.

The tape itself never needs to be touched and the cassette can be slipped into or out of the deck at any time without threading or rewinding — an obvious boon to non-technical or handicapped users.

When pushed into place, the spool hubs engage matching supply and takeup spindles. At the same time, a hole in the cassette admits a capstan spindle to a position just behind the tape, which is accessable, coated side out, through slots in the front of the housing.

When the "Play" button is activated, the heads move forward against the coated surface while, at the same time, the pinch wheel presses the tape against the drive capstan. For fast forward and rewind, they are disengaged, allowing the tape to be spooled at high speed, as described for Fig.1.

An important feature of the compact cassette system is its mono/stereo compatibility. The heads are so positioned that, in mono mode, the R/P head imposes a track 1.5mm wide along one edge of the 3.8mm tape. In stereo mode, a dual head assembly with its gaps aligned, one above the other, impose two tracks in the same area, each 0.6mm wide and 0.3mm apart.

If a stereo recording is played in a mono deck, the mono head scans both tracks and produces a sum (L+R) signal. Conversely, a mono recording played in a stereo deck produces identical signals in the respective channels.

Flipping a cassette over in a deck, exposes the alternative edge of the tape to the head gaps for recording and/or playback. The tracks can be protected against accidental erasure by breaking out small tabs at the rear of the cassette. (Fig.3)

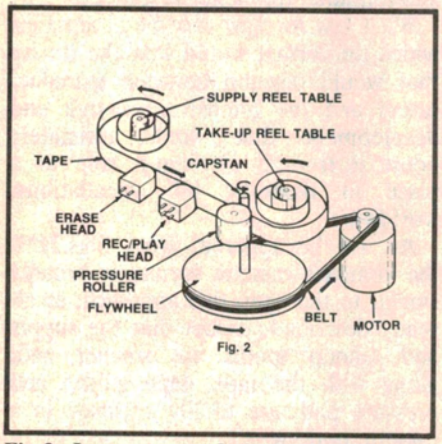


Fig.2: In a cassette deck the heads are in front of the tape and cassettes are accordingly spooled with the magnetic coating facing outwards. DD (direct drive) capstan motors are now commonly used rather than belt drive, as shown. (Technics diagram.)

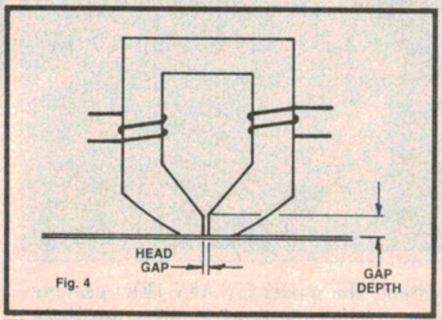


Fig.4: The head gap is discussed in the text. A deep gap takes longer to wear down but can adversely affect head performance.

Magnetic heads

Conceptually, as in Fig.4, the magnetic heads used in a tape deck are disarmingly simple, involving suitably shaped pole pieces, and windings by which electrical signals can be fed into or recovered from the magnetic system. An active gap is provided at the front, over which the magnetically coated tape passes, while one or two passive gaps serve to stabilise the permeability.

In the early days of magnetic recording, with 6mm wide mono tracks and high tape traverse speeds, the heads could be relatively primitive in their construction, to the extent that enthusiasts often used to contrive their own from a discarded transformer lamination and a few metres of fine wire!

But those days are no more. With track widths down by 10:1 or so and speeds by at least 4:1, modern heads require extreme precision in their manufacture, because of their diminutive size and the need to ensure the most efficient possible signal transfer from head to tape and vice versa.

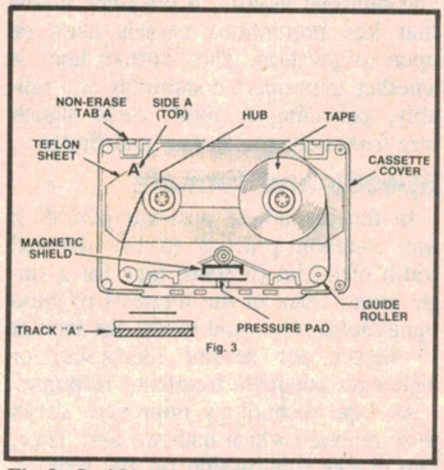


Fig.3: Inside a compact cassette. Looking down on side "A", the appropriate breakout tab and the position of the A-track(s) is shown. Flip the cassette over and the "B" side, tab and track(s) occupy the same relative positions.

Record and/or Play heads for stereo compact cassette decks pose a special problem because they have to be stacked one above the other, with their gaps aligned vertically and only 0.3mm apart.

Fig.5 gives a general idea of how a modern stereo head might be assembled. The coils for the respective channels are mounted as close together as possible but the relative position of the active gaps depend on the use of specially shaped front cores.

A variety of materials have been developed over the years for cores and pole tips, with a view to combining acceptable wear resistance with good magnetic characteristics. By way of example:

PERMALLOY, an iron alloy containing nickel and molybdenum, was very popular in the early stages, and is still used in some professional decks because of its outstanding magnetic characteristics. It suffers the disadvantages, however, of inferior wear resistance, even in "high hardness" form.

FERRITE (HPF, GX) consists of powdered metal oxides (MnO, ZnO, NiO and Fe_2O_3). It has a glass-like surface finish with outstanding wear resistance and lends itself to very precise assembly. Its magnetic performance in actual use is claimed to be excellent.

SENDUST (SX), an alloy containing iron, silicon and aluminium, is also very hard, although with somewhat lower wear resistance than ferrite. It is created by many manufacturers with superior magnetic properties, including low distortion, and is often preferred on that account for record and/or play heads.

Head functions

Most compact cassette decks use two heads only, as in Fig.2: an erase head and an R/P (Record/Play) head, mono in the case of basic equipment, stereo otherwise. However, separate Record and Replay heads can be accommodated, either by combining them in a single assembly or by making use of one of the spare access slots in the front of the compact cassettes.

Salient features of the various heads, as used in domestic cassette decks, can be summarised as follows:

An introduction to hifi

ERASE HEADS wipe out previously recorded signals, leaving the track marginally neutral and ready for re-use. In a cassette deck the erase spans one half of the tape, preparing it either for a mono recording or for twin stereo tracks which occupy essentially the same space.

Erasure involves feeding the head with a high level supersonic sine wave between about 50 and 100kHz (typically 85kHz). The head gap is relatively wide (up to 100μm) ensuring that the high frequency magnetic field will thoroughly penetrate and saturate the magnetic layer on the tape.

Passing across the gap, the magnetic particles are typically subjected to 200-odd cycles of erase energy, rising from a low level to full saturation and then diminishing to zero, leaving them magnetically inert.

Erase heads commonly use ferrite cores, being provided in many cases with twin parallel active gaps to ensure more effective erasure — a particular problem with tapes using pure metal particles.

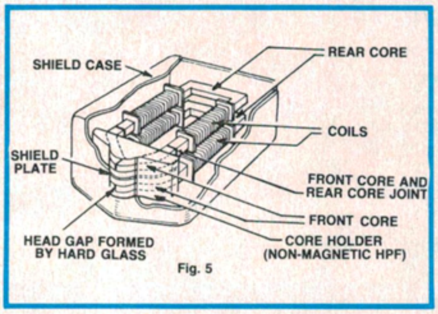


Fig.5: Imagine this stereo head reduced in volume to less than one-half cubic centimetre and you have some idea of the precision required in production. (Technics diagram.)

RECORD ONLY heads may use sendust, preferred for its magnetic properties, or ferrite for its wear-resistant, mirror-like surface. The gap is nominally set at around 1μm but the effective gap width depends on the material, the precision of the pole faces and the signal frequency.

In general, the narrower the gap, the better will be the high frequency response — provided the playback gap is also precisely perpendicular to the tape path; in short, provided there is no azimuth error relative to the tapes being played.

RECORD/PLAY heads involve design compromises which can often be handled more easily with sendust rather than with ferrite. In particular, the gap has to be wide enough to avoid head saturation and to ensure adequate penetration of the tape coating when recording; yet it must not be so wide as to unduly compromise treble response during playback.

Superficially, azimuth error is not a great problem with an R/P head which is only ever used to play its own cassettes. But it is important if the cassettes are to interchange between decks.

In practice, manufacturers of current model cassette decks would appear to have achieved an excellent compromise with the design of R/P heads — sendust or ferrite— such that they can typically rate the frequency response as 20-16,000Hz ±3dB.

Tape recording "bias"

If a normal audio signal is fed to a Record or R/P head and a magnetic pattern imposed on a tape, the recording would be found, on replay, to be seriously distorted.

Without venturing too deeply into magnetic theory, Fig.6a suggests, in graphical form, the relationship between the magnetising force (H) — or (say) the current through a recording head — and the remanent flux density (Br) of the tape coating; in effect, the flux density which remains after the particles have moved out of the magnetising field.

Starting from zero (H=0) the remanent flux (+Br) rises slowly at first as the current is increased (+H). The relationship thereafter becomes substantially linear until Br flattens out, indicating magnetic "saturation", beyond which there is no further increase remanent flux, irrespective of magnetising current.

The behaviour for −H and −Br is similar, producing an overall B/H characteristic with a pronounced discontinuity in the centre. Fairly obviously, a sine wave input signal fed, to the recording head, will produce a distorted magnetic resultant on the tape, as shown.

The effect can be countered by using "DC bias", obtained with the help of a permanent magnet or by passing direct current through the head, along with the signal. Re-centring the signal on a linear portion of the curve (dotted in 6a) avoids the distortion but restricts operation to half of the transfer characteristic.

More seriously, the movement of up to 1500 billion particles per second across the replay head, all magnetised with a similar polarity, produces a cumulative noise effect, resulting in a very poor signal/noise ratio, ie, a noisy recording.

High frequency bias

Modern practice is to use high frequency (supersonic) bias, normally obtained from the same source as the erase frequency, and fed to the recording head along with the audio signal. The result is depicted graphically in Fig.6b.

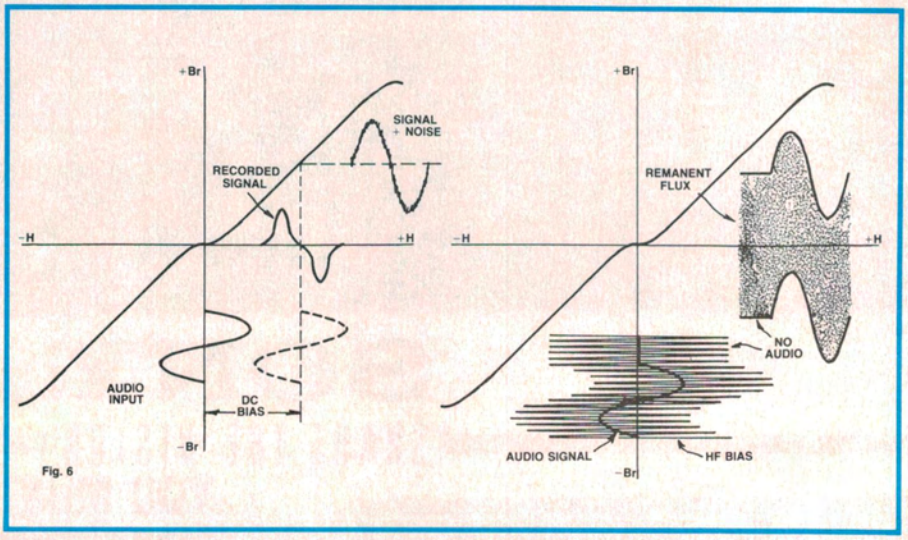


Fig.6: Without the use of some form of magnetic bias (a) the recorded signal is badly distorted. The use of high frequency (supersonic) bias (b) overcomes the problem but the bias amplitude is critical to the end result.

When there is no audio present, the tape particles are simply cycled through a portion of their B/H characteristic at the bias frequency.

At 85kHz, the relationship between the current and the remanent flux may not be as simplistic as depicted but, more to the point, the remanent flux will be symmetrical, as shown, with a similar distribution of particles magnetised +Br and −Br. Passing over the replay head, their noise contributions will tend to cancel, rather than add, resulting in a much better S/N ratio.

When an audio signal is present, as depicted, it adds arithmetically to the high frequency signal, moving it alternatively into the +H and −H regions. This, in turn, affects the remanence so that, instead of being in a state of balance, the flux alternates into the +Br or −Br regions, with a contour conforming to that of the audio waveform.

A replay head interprets this shift in aggregate flux as an audio signal — with a residual HF component — and delivers a corresponding output voltage from its associated winding.

Bias amplitude

If the HF bias is to play its intended role, it must obviously have the correct amplitude relative to the particular B/H curve. In short, for any given recording head, the amplitude of the bias current must produce a magnetising force appropriate to the tape coating being used — a requirement that is not easy to quantify.

For efficient recording of high frequencies (circa 10kHz) a sharply defined magnetising field is required, most easily realised by using a relatively small bias amplitude and thus restricting the field to the immediate vicinity of the recording gap.

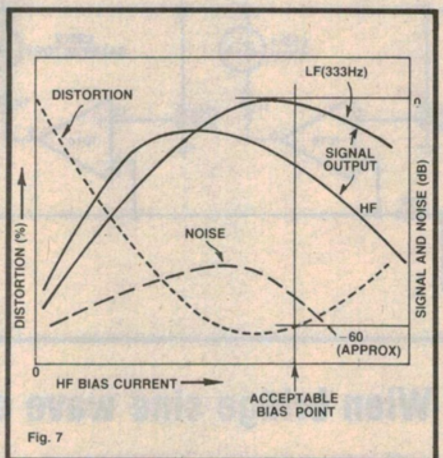


Fig.7: Indicating factors which need to be considered when selecting the HF bias level. The curves are illustrative only and vary in detail with the nature of the magnetic coating.

For middle and especially for low frequencies, a higher level of bias is desirable to ensure greater penetration of the magnetic layer, yielding higher signal output (therefore a good S/N ratio) and minimum distortion.

The nature of the compromise is illustrated in Fig.7, which shows the maximum output level (MOL) for high frequencies (8-10kHz) occurring at a much lower bias current than for a low/middle frequency (333Hz). A simple compromise between the two is not the answer because, while it offers low distortion, it also coincides with a region of high noise!

Standards and procedures have been adopted by the industry to define optimum bias, which are beyond the scope of this article. However, as implied by Fig.7, the optimum bias current is usually marginally above the setting that produces maximum output level for a frequency at or close to 333Hz.

We shall be referring again to HF bias when discussing actual cassettes.