Cassette tape decks

Response, tapes, noise reduction, &c. Pt.2

In this further chapter, we move on from mechanical details, magnetic heads and HF bias to consider frequency response and compensation, noise reduction systems, &c. We also examine the signal paths through typical modern cassette decks with the aid of a schematic block diagram.

If the need for HF bias tends to confuse magnetic recording theory, so also do the measures necessary to achieve a reasonably flat overall frequency response. However, it is possible to explain what is involved, without getting too bogged down in technicalities.

If a tape recording head was simply fed with signal from an ordinary low impedance (constant voltage) amplifier stage, the current through the head winding — and therefore the ultimate magnetising force — would progressively diminish as the winding impedance increased with frequency.

As a result, in terms of remanent flux, the signal level on the tape would also diminish with rising frequency at a rate of approximately 6dB/octave, resulting in an impossibly small recorded signal at the upper end of the audio spectrum.

To avoid this difficulty, recording heads are commonly fed from a "constant current" source or one that exhibits a reasonably flat frequency/current characteristic.

Constant current feed can be approximated by using an amplifier stage with an intrinsically high output impedance, or by feeding the head from a generously designed voltage amplifier through a suitably large series resistance.

Recording characteristic

However, the matter does not end there. In a tape system, particularly one with narrow tracks and a low traverse speed, it is desirable to record the signal at as high a level as possible, right across the spectrum, to obtain the best signal/noise ratio.

This, in turn, calls for deliberate shaping of the recording characteristic to match the magnetic storage capability of the tape at low, middle and high frequencies — in short, to match its MOL or maximum output level, referred to in the previous article.

The solid line in Fig.1 shows the relationship between frequency and the ultimate signal level on the tape (remanent flux) which has been adopted as a standard appropriate to the compact cassette system, for normal ferric oxide coated tape.

It requires that, for a given level of input signal, the remanent flux should be flat over the range 50-1325Hz, where the MOL (maximum output level) is relatively high, with special provision for a 6dB/octave boost below 50Hz.

Above 1325Hz, where the MOL begins to taper off, the remanent flux is to be progressively reduced by 6dB/octave, on the assumption that the cut will be compensated by an equivalent degree of boost during playback.

In practice, incidental high frequency losses in the recording chain, including head and tape losses and those caused by the HF bias, may reduce the amount of treble cut that needs to be imposed. As a result, the actual recording amplifier(s) may end up with a response anywhere in the shaded area, depending on other factors.

One other point: "turnover" regions in response curves — where they change direction — normally involve the use of filters. Rather than talk in terms of the "corner" frequency in a rounded curve, engineers who design filters prefer to specify their mathematically based "time constant".

A time constant of 318μs is equivalent to a "corner" frequency of 50Hz; one of 120μs, to a frequency of 1325Hz. Keep the latter figures in mind; we'll be referring to them again later.

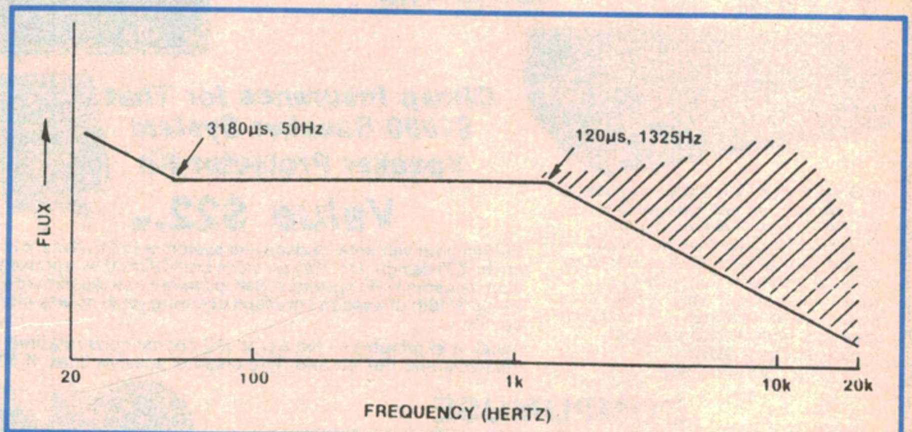
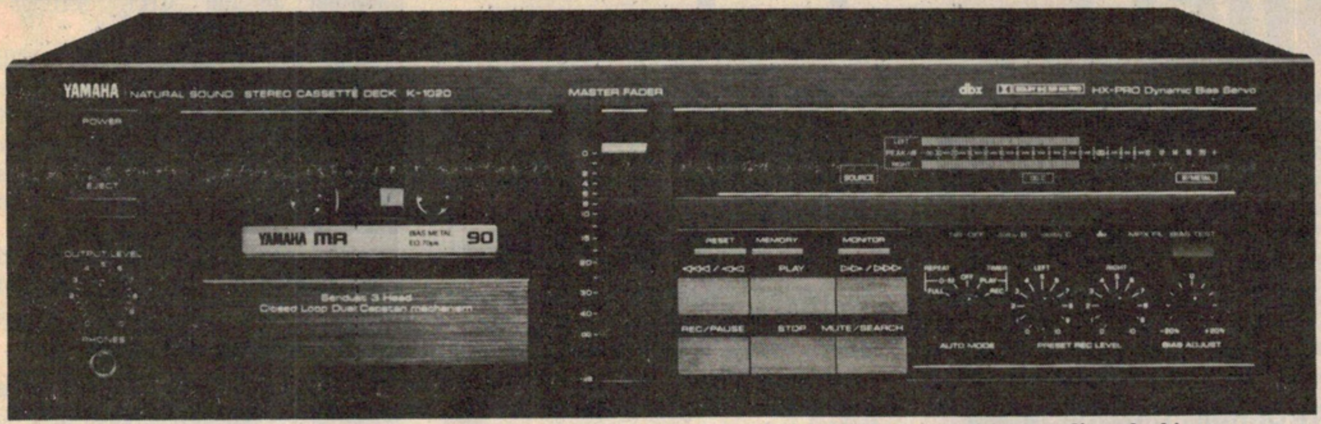


Fig.1: To match the remanent flux more accurately to the MOL of normal ferric tape, the recording amplifier includes bass boost and treble cut to produce the (idealised) flux curve indicated by the solid line.



The Yamaha K-1020 features dbx and Dolby noise reduction systems, and includes provision to adjust the bias.

Playback response

As with a magnetic phono cartridge, a tape head exhibits a constant velocity characteristic, delivering an output signal voltage which, for a given level of flux, rises with frequency at a nominal rate of 6dB/octave.

When playing back a tape, recorded as per Fig.1, it would obviously encounter a diminishing level of flux between 20 and 50Hz. Over this range, the rising response of the head would compensate for the diminishing flux, resulting in a flat signal output.

Over the range 50-1325Hz, where the remanent flux is constant, the head would deliver a signal rising by 6dB/octave.

Above 1325Hz, the flux again diminishes to 6dB/octave, which the head would reproduce as flat.

Re-plot these three segments, normalised to 1kHz-0dB, and you have the (idealised) signal voltage output from a compact cassette tape playback head as shown in Fig.2, drawn dot-dash and marked "From Head".

To modify this to a level signal to feed to a hifi system, the tape playback preamplifier would need to be compensated to provide a complementary response (again idealised) as per the dashed curve in Fig.2, marked "Amplifier Response".

A practical playback curve — minus the corners — for ferric oxide cassette tape, is shown in Fig.3, marked 120μs.

Compact cassette tape

After launching the compact cassette system in 1962, Philips made every effort to ensure that all equipment, cassettes and recordings would be essentially compatible, irrespective of their source.

Along with mechanical and physical specifications they supplied (or endorsed) ferric oxide calibration and reference cassettes to help equipment manufacturers observe common standards, particularly in respect to frequency compensation and bias level.

In the '70s, however, Japanese manufacturers, who by then dominated the compact cassette industry, began to release cassette tapes with a coercivity considerably above the European-based standard, along with decks providing a proportionately higher level of bias.

Why they did so is open to argument but it put European tapes at a disadvantage because, in Japanese decks, European tapes tended to be overbiased and to sound dull because of the adverse effect on treble response. By contrast, Japanese tapes were underbiased in European decks, sounding brighter as a result; that the distortion may have been higher, seemed to pass unnoticed!

This induced BASF to release what they described as a "Japanese compatible" tape in 1977, the "Ferro Super LH1" with an optimum bias setting some 2dB above the European standard.

Since then, negotiations through the IEC (International Electrotechnical Commission) have secured greater cooperation between the various hardware and tape manufacturers, culminating in internationally recognised standards for tape equipment generally. Ferric cassette tapes which conform to the relevant standard are now normally endorsed "IEC Category I".

The IEC initiative should ensure more uniformity in the way tape performance is measured and rated, and greater compatibility between current model decks and current production cassettes in terms of the critical bias and erase levels.

Inevitably, however, some uncertainty will remain in regard to older equipment and with cassettes which are simply branded "normal bias" and "120μs", rather than "IEC I".

In practice, anyone with older equipment, aspiring to optimum, as distinct from purely routine, recording and play-

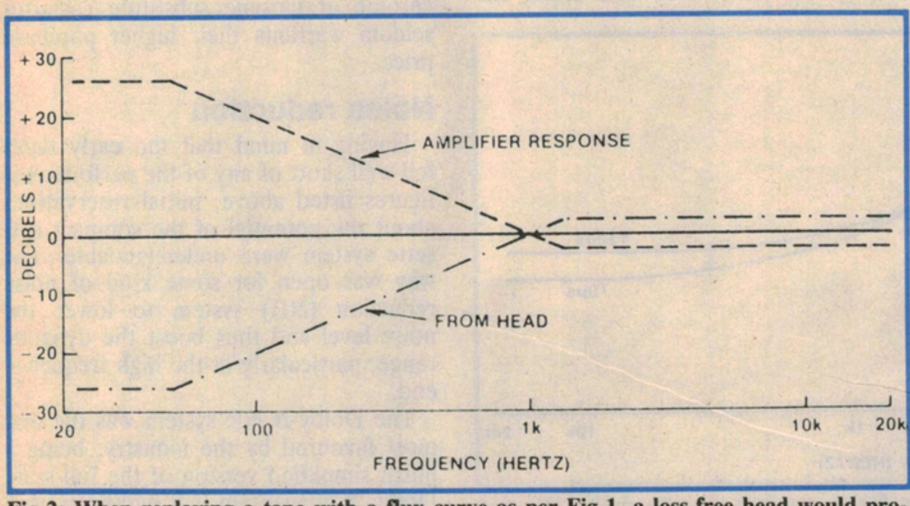


Fig.2: When replaying a tape with a flux curve as per Fig.1, a loss-free head would produce an output as drawn dash-dotted. For a flat overall response the ideal playback preamplifier compensation would be as shown dashed.

back must be prepared to exercise some judgment as to which cassettes seem best to suit their particular deck. They may or may not be the optimum choice for someone else!

Some up-market decks include facilities, manual or automatic, for optimising the bias level — and with it the HF response — for individual cassette tapes but, for many, such decks may be either too expensive or too "technical".

Chromium dioxide tapes

While ferric oxide coatings have been greatly improved over the years, other options have become available, the most notable being a chromium oxide formulation, introduced by BASF (under licence to Dupont) in 1971. It offered a higher MOL, particularly at high frequencies, greater dynamic range and a better signal/noise ratio.

Its coercivity was higher, however, calling for a substantial increase in both bias and erase levels. And, because its HF MOL was better, it was agreed that the frequency compensation could be modified to advantage by changing the record and playback time constant to 70μs instead of 120μs. The effect on the playback characteristic is shown in Fig.3.

The arrival on the scene of CrO_2 (chromium dioxide) cassettes caused considerable consternation and argument but, in due course, "normal/CrO_2" switching became a standard inclusion in most domestic cassette decks.

In fact, CrO_2 cassettes now carry identification slots at the back, adjacent to the breakout tabs. These are sensed by fingers in the cassette compartment of some decks to effect automatic tape select switching.

For a variety of reasons, many manufacturers did not take up a Dupont licence but, instead, sought to develop competitive "chromium substitute" formulations using specially processed ferric oxide "doped", for example, with cobalt. They use the "Chromium" switch setting for both recording and playback and are said to offer equivalent results — again a matter for individual judgment.

Chromium dioxide and chromium substitute cassette tapes are now the subject of IEC "Category II" standards (Table 1).

GROUP	TAPE TYPE	BIAS	EQ.
IEC-I	Normal	Low	120μs
IEC-II	CrO_2	High	70μs
IEC-III	Fe-Cr	Medium	70μs
IEC-IV	Metal	150% higher than CrO_2	70μs

Table 1: Cassettes branded as above conform to IEC standards in respect to bias, erase, etc. Some may still be better than others, however, in terms of response, noise, distortion and MOL.

Some manufacturers, notably Sony and BASF, produced cassette tapes with a dual coating — a base layer of ferric oxide to accommodate low and middle frequencies and a thin surface layer of chromium dioxide for high frequencies.

Unfortunately, these so-called "Ferrochrome" cassettes do not fit either category I or II standards and are therefore strictly not compatible with either the "normal" or the "CrO_2" settings on current model decks.

They are subject to their own "IEC III" standards and, according to Technics, operate best with 70μs (CrO_2) equalisation, and a bias level somewhere between CrO_2 and ferric oxide. This precise combination is not available on many decks although, by chance, the ferrichrome formulation often appears to work well at one of the other settings.

Metal alloy coatings

Over the last couple of years, cassette tapes have been developed with a magnetic alloy coating based on pure iron (Fe) rather than iron oxide (Fe_2O_3). The new "metal" tapes exhibit much higher coercivity than even CrO_2, and offer a further increase in MOL and dynamic range at high frequencies.

By way of comparison, a modern high quality ferric oxide IEC-I cassette offers dynamic range figures of 58dB at 315Hz, 43dB at 10kHz and 38dB at 14kHz. For a high quality chromium dioxide IEC-II cassette, the equivalent figures are 63dB, 49dB and 44dB.

For an iron alloy coating, categorised IEC-IV, the figures read: 61dB at 315Hz; 53dB at 10kHz; 49dB at 14kHz.

However, metal tapes call for considerably higher recording, bias and erase currents, necessitating more generously designed heads and drive circuitry.

Older decks can play back an existing metal-tape recording on the CrO_2 position but are unlikely to be able to erase the tape properly or to supply adequate bias for an optimum new recording.

While most modern decks make adequate provision for metal coated cassettes, many claim that their reputed advantage over high performance chrome or chrome substitute cassettes seldom warrants their higher purchase price.

Noise reduction

Having in mind that the early tapes fell well short of any of the performance figures listed above, initial reservations about the potential of the compact cassette system were understandable. The way was open for some kind of noise reduction (NR) system to lower the noise level and thus boost the dynamic range, particularly at the high frequency end.

The Dolby-B NR system was the one most favoured by the industry, being a much simplified version of the full-scale Dolby-A NR system that had been used in professional recording and broadcasting situations since the '60s.

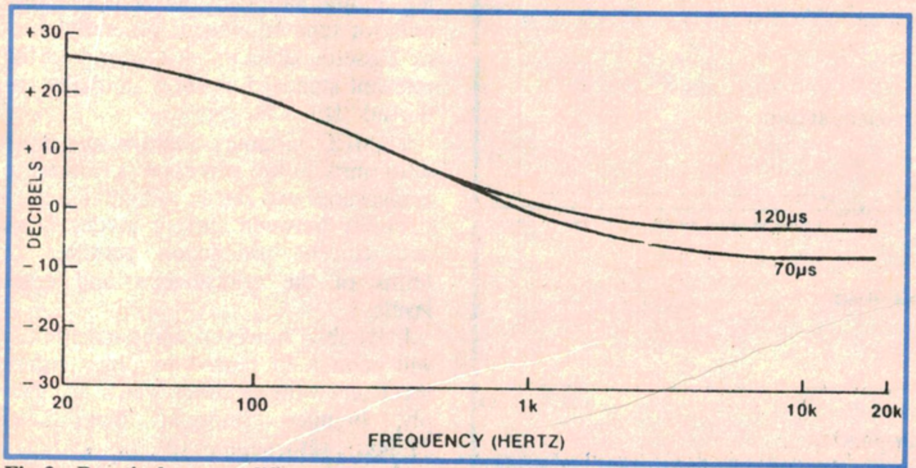


Fig.3: Practical preamplifier playback curves for a compact cassette deck. The one marked "120μs" is similar to the response curve in Fig.2 — minus the corners! The 70μs curve is as used for chromium and metal cassettes.

The Dolby-B NR system operates mainly above 1kHz, as indicated by the lower curve in Fig.4. This is the region where the tape MOL is lowest but, by reducing the high frequency noise level — apparent as tape "hiss" — by up to 10dB, the subjective dynamic range can be increased by an almost equal amount.

Fig.5 illustrates how Dolby-B operates. A typical audio signal, as fed to a tape recorder, contains high level passages (A) which pose no real problem, because they are loud enough to override or "mask" the tape noise. It is the low-level segments or passages (B) which are at risk.

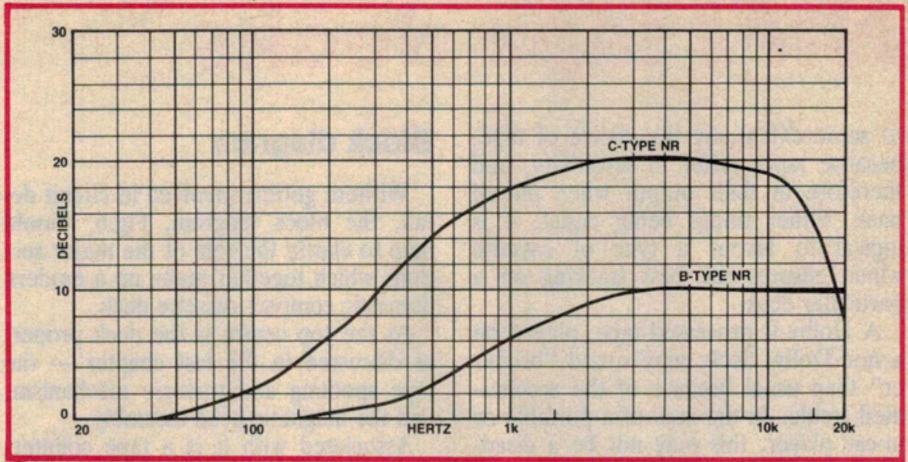


Fig.4: Dolby-B NR (lower curve) operates mainly over the frequency range above 1kHz. Dolby-C (upper curve) is one of a number of more ambitious NR systems which are now being included in some up-market compact cassette decks.

From the input preamplifier, the input signal passes to a Dolby-B processor which, these days, is normally concentrated in a single dedicated IC. Without modifying the higher level segments, it senses and progressively boosts the treble component of weaker segments by up to 10dB — from (say) B to B'. In so doing, it effectively compresses the HF dynamic range by that amount.

The processed or "Dolbyised" signal is then passed to the cassette record/replay section, which typically introduces a noise component about 45-50dB below the nominal maximum recording level. Hopefully, the noise (shaded in Fig.5) will be below the weaker but now artificially boosted treble component of the signal.

During playback, signal from the head circuitry again passes to a Dolby NR stage, often the same one as used for recording but now switched to playback mode.

As before, it senses the weaker segments but, this time, restores them to their orignal level (from B' to B) effectively returning the dynamic range to what it was originally.

In so "de-emphasising" the lower level segments, the system also attenuates the tape noise (C to C') so that, as implied by the diagram, the recovered audio signal has a considerably reduced noise content and a subjective dynamic range up to 10dB better than indicated earlier for cassette tapes without noise reduction.

Rated overall S/N ratio figures for a typical modern compact cassette deck using CrO_2 tape and maximum input level (A weighted) read: Dolby NR out — 57dB; Dolby NR in — 67dB (above 5kHz).

For Dolby-B NR to be fully effective, it is important that the recording and playback levels "track". In other words, that the level of signal passing through the Dolby processor during playback should be the same as that when recording.

In most decks, this can be checked by first carefully monitoring the level during a test recording and noting the deck's meter or bargraph readings for high level passages. During playback, the readings should be identical or at least very similar.

Some cassette decks include special provision for adjusting the Dolby level — a procedure normally set out in the user manual. In most decks, however, the playback and signal meter levels are preset at the factory but they should be re-checked after head replacement or other major service which could affect the gain through the relevant signal paths.

Dolby tracking can also be affected,

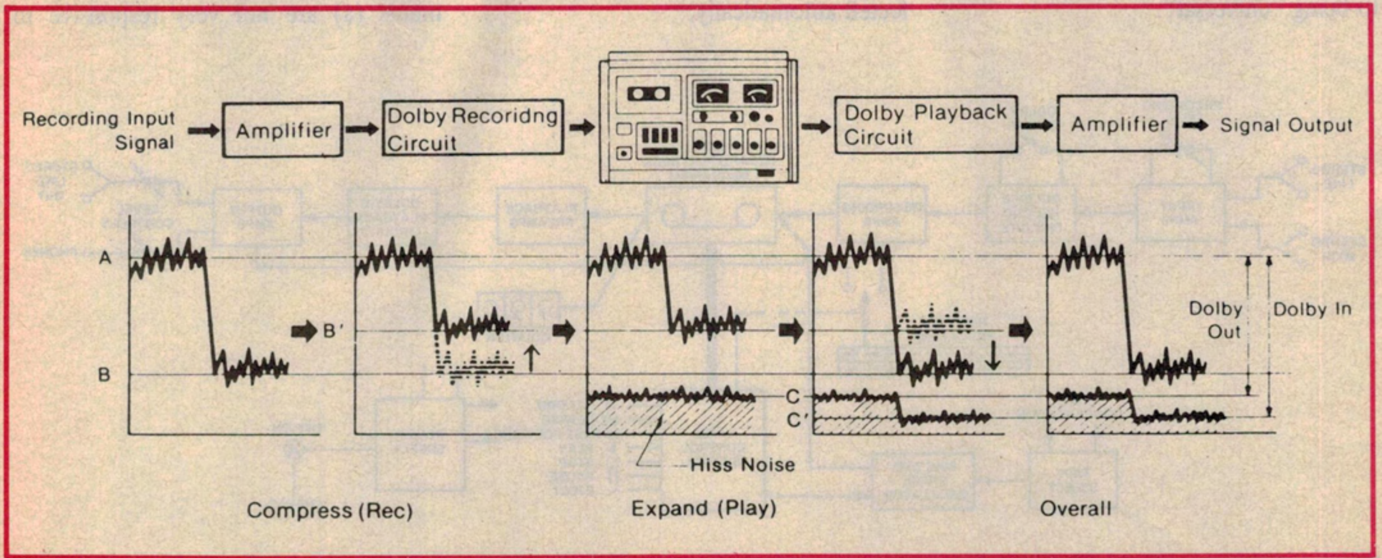


Fig.5: Reproduced by courtesy of National Panasonic Australia, this diagram illustrates the operation of the Dolby-B noise reduction system, as currently included in the majority of domestic cassette decks.

to some extent, by the choice of tape, because tapes differ in sensitivity, and therefore in their output when played back. Other things being equal, it is logical to favour a type of cassette which ensures the best tracking on a particular deck.

A Dolby-B processed tape, played on a non-Dolby deck, may sound "brighter" than usual because of the accentuated treble. In the case of a portable or in-car player, this may not be a disadvantage but, if it is, the effect can be made less obvious by turning down the treble control, as necessary.

Playing a non-Dolby tape with the Dolby switch on may reduce the hiss but at the expense of normal treble response. Don't do it unless you happen to like it that way!

In addition to Dolby-B, some up-market decks include more elaborate NR systems, such as Dolby-C, ADRES, and dbx. Of these, dbx is of particular interest because it compresses the overall dynamic range on recording by 2:1, expanding it by the same amount on playback. Manufacturers claim that a dbx-equipped cassette deck can directly accommodate the 90+dB dynamic range of compact discs.

However, because of the more extensive signal processing employed by these more ambitious NR systems, recordings using them can only be heard to advantage on the same or a similarly equipped deck.

As yet, Dolby-B is the only cassette NR system which can lay any real claim to being "universal".

Block diagram

Without getting involved in circuit detail, the block diagram, Fig.6, should help to clarify the role of the major sections which together make up a modern domestic compact cassette deck.

At the top centre is the deck proper, as discussed in the last chapter — the tape spooling and traverse mechanism, and the magnetic head assembly.

Associated with it is a tape counter, most commonly a mechanical unit (Fig.7) belt driven from one or other of the spool tables. Such devices are not true "footage" counters, since the reading varies with the diameter of the tape roll, but they are useful, nevertheless, in keeping track of items on the tape.

Below the deck mechanism are the touch button panel controls and the now almost routine electronic "logic" control circuitry, which relays user instructions to the tape mechanism while, at the same time, blocking obviously impossible commands — like simultaneous REW and FF!

As well as activating the tape mechanism, the control system simultaneously sets up the electronic signal circuitry as required for the various modes: Record, Play, Pause, Stop, Rewind and Fast Forward plus, in some models, Cue and Review.

Separate switches are normally provided for supplementary functions such as: Mains off/on; Dolby off/on; Peak Limiter off/on; Cassette Eject; Tape Select (Normal, CrO_2, Metal) — if not effected automatically.

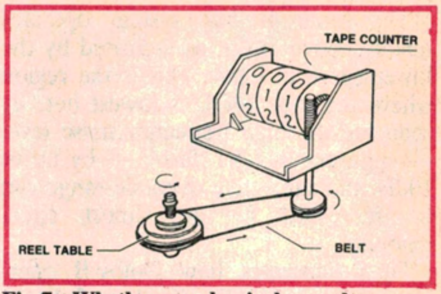


Fig.7: Whether mechanical, as shown, or electronic, normal tape counters driven by a reel table are not "footage" counters. They count revolutions!

Signal paths

Domestic cassette recorders normally provide input facilities (without mixing) for medium impedance dynamic or electret stereo microphones, and for flat response, medium output ("Line") sources, commonly accessed via the "Tape Out" sockets on the associated hifi amplifier.

With the deck in RECORD mode, the L&R (Left & Right) input signals are fed through input preamplifiers to the twin Dolby-B processors which may, in turn, be switched in or out of circuit, as desired.

The signals then pass to suitably compensated recording amplifiers, at which point a feed to the Level indicators allows the signal amplitude to be observed and suitably adjusted by means of the Record or Input Level controls.

Fig.8, by the way, reproduced from Technics literature, emphasises the need to keep the peak signal amplitude within limits, as normally discussed in the user manual accompanying each deck.

In general, mechanical meter movements (a) are not very responsive to

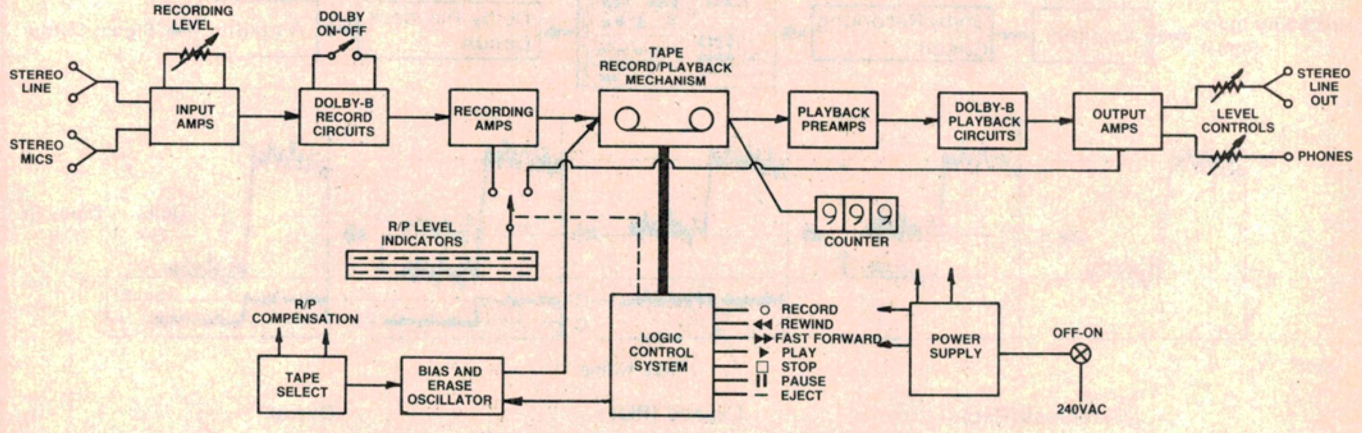


Fig.6: A modern, conventional cassette deck, depicted in block schematic form. Separate Record and Playback amplifiers are shown but the same amplifier components are often used and simply switched, as necessary, to fill both roles.

HIFI tape decks

transient peaks and it is wise to limit visible excursions of the pointer to the 0dB mark. Fluorescent bargraphs (b) display transients much more effectively, such that they can be allowed to reach (say) +5dB.

Reverting to Fig.6, the signals are duly fed to the respective L&R windings of the Record or R/P head, along with HF bias from the erase oscillator, at predetermined levels governed by the setting of the "Tape Select" switch: Normal, CrO_2 or Metal.

(In most cases, the Tape Select switching also changes the Record and Playback compensation from 120 to 70μs or vice versa.)

In the Playback mode, signals from the Replay or R/P head pass first to compensated preamplifiers and then on to the Dolby-B processors which, again, can be switched in or out of circuit, as appropriate.

The signals are then fed to an output amplifier stage, at which point their amplitude can again be observed on the Signal level indicators. As mentioned earlier, it should match the recording level, indicating that the signals through the respective Dolby processors are tracking correctly.

The output amplifier also supplies signal to the phones and to L&R Line output connectors, either directly or via level controls, normally operating after the point at which the signal level is measured.

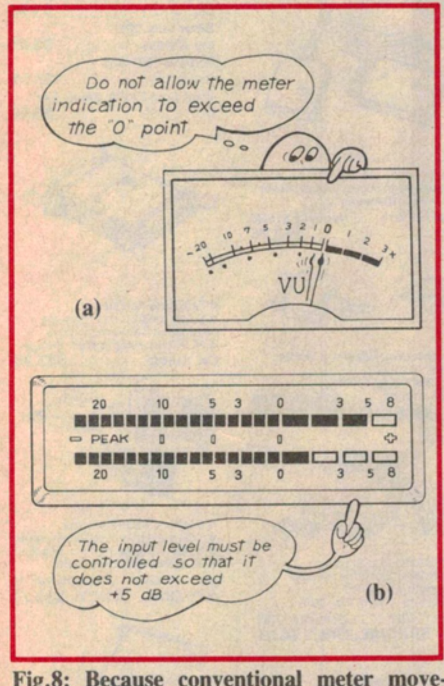


Fig.8: Because conventional meter movements do not display transient peaks very well, their readings have to be interpreted more cautiously than those of the electronic bargraph level indicators.

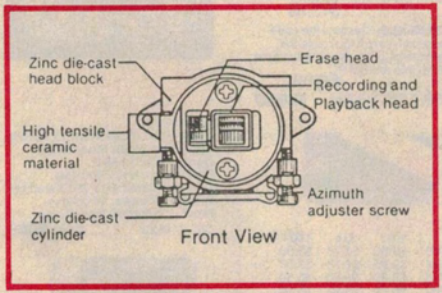


Fig.9: Designed by Akai, this rotating head assembly can flip over automatically at the end of a tape to provide bi-directional continuous play. The alternative is to use extra fixed heads with switching.

For the sake of clarity, completely separate amplifier chains have been shown for the Record and Playback modes. This would, in fact, be normal for decks fitted with separate Record and Playback heads, so as to allow the recording to be monitored directly off-tape a split second after imposition.

This obviously is not possible in decks using a combined R/P head, monitoring being confined to the input signal. In such a case, sections of the amplifier chain may well be switched from one role to the other. However, with ICs being cheap, the designers may prefer to provide separate amplifier chains in order to minimise the need for complex mode switching.

But, these days, cassette decks come in all shapes and sizes, from exotic — and expensive — high performance audiophile models to diminutive personal players.

Somewhere in between are models featuring auto reverse and continuous play, and still others with twin deck mechanisms, to facilitate cassette dubbing, at either normal or accelerated traverse speeds. In the latter case, the individual functions are similar to those depicted in Fig.6, except that there are more of them, possibly "tailored" to cope with signal frequencies artificially boosted by the higher traverse speeds.

To cover all these variants would involve far more space than is available but what has been said should clarify the basic principles and lead to a better understanding of what cassette decks are all about.