Low-noise cassette deck — postscript

Further details of circuit design and methods of obtaining an even better s:n ratio

by J. L. Linsley Hood

Nearly two years has elapsed since the publication[*] of this design, and while the basic circuit design still appears, in retrospect, to have been satisfactory, without many unforeseen snags, there are one or two areas where some improvements can be made, and where some additional information can, usefully, be given. Also, because of the enormous amount of development activity in tape recording, particularly in respect of cassette tape coatings, it seems useful to take a fresh look at the potential of this medium.

REDUCTIONS in the background noise level in both recording and replay processes are possible, giving a worthwhile improvement in signal-to-noise ratio.

Replay noise level

In the basic design of the replay amplifier an attempt was made to design a circuit in which the inherent noise level was as low as currently available devices would permit and, while in general this aim was achieved, the integrated-circuit amplifier in the output stage was overlooked as a new source of noise. This is because the relatively limited slew-rate of the 741 leads to intermodulation-type effects when it is fed with signals which are outside its effective linear pass-band. Since the input amplifying stage has a bandwidth in the MHz region, as designed, and the impedance (and hence circuit noise) of the replay coil increases with frequency, the input of the 741 is presented, quite unnecessarily, with a substantial amount of noise energy well above the required audio passband, and some of this is heterodyned down into the audible region.

Fortunately, the solution to this problem is a simple one — to ensure that the input circuit impedance does not increase too greatly with increasing frequency, which can be done by putting a small capacitor, in the range 680-820 pF, across the input to the replay amplifier, and to limit the bandwidth of the input stages of the replay amplifier to a value which does not greatly exceed the required pass-band. This can be done by putting a small capacitor (150-220pF) in parallel with the 47kΩ feedback resistor (R). An amended circuit diagram, Fig. 1, for the replay amplifier is given, showing these changes. The total improvement in CCIR weighted noise level of the replay amplifier, due to these changes, is about 2dB, and on the prototype and two other units so modified, one of which was made from a commercial kit, the replay amplifier noise level was 8-10dB better than that of the tape background — an adequate safety margin. This performance, however, also depends on the head type, and this is discussed later.

Zero-recorded-level noise background

In view of the good signal-to-noise ratios which had been achieved with the modified replay amplifiers, the major residual source of background noise on the final recording, ignoring that associated with the incoming signal, was that apparently impressed on the tape during the recording process. Since some of the recent tape types have an impressively low inherent tape noise level (the Pyral Maxima is particularly noteworthy in this respect) an investigation was made to identify the separate contributions to this.

Since the tape, as received, is bulk erased, while that following recording has passed the cassette recorder erase head, it seemed possible that this re-

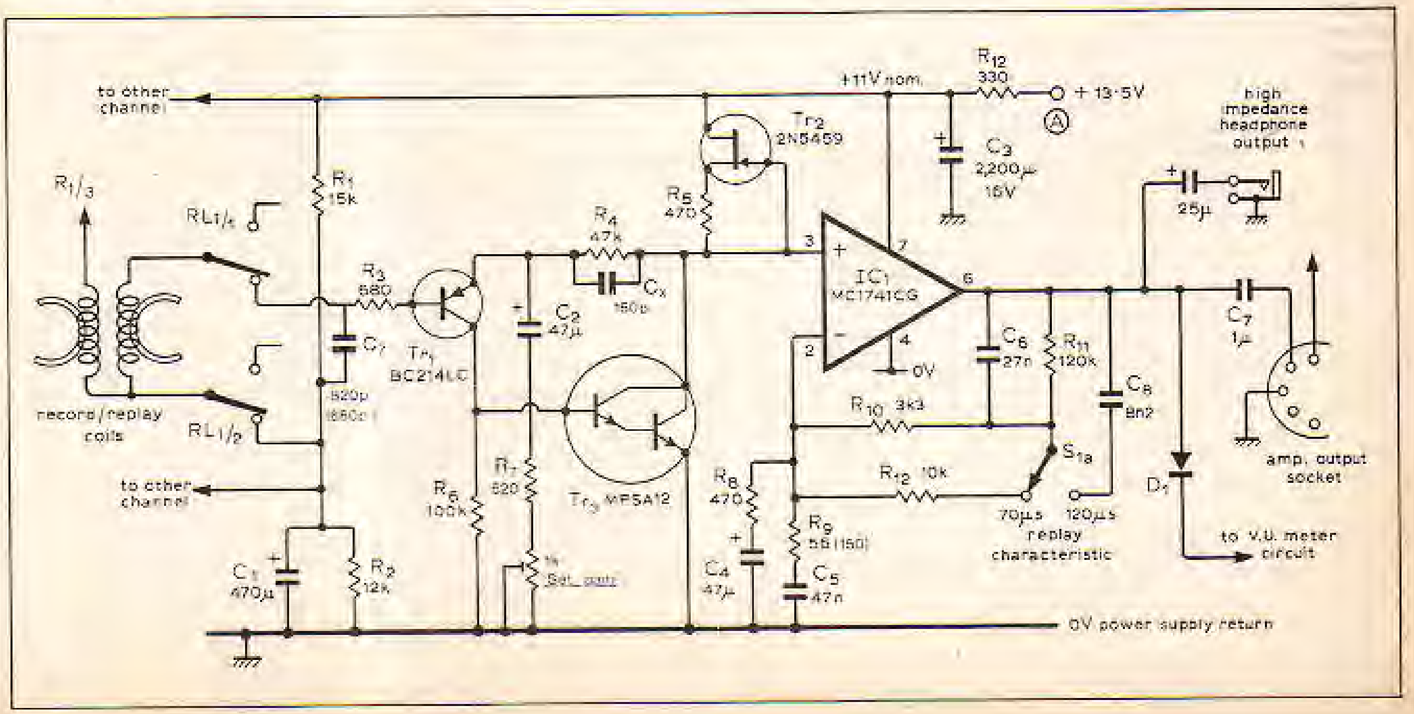

Fig. 1. *Suggested amendments to replay amplifier. Altered component values for 1.5 micron head-gap shown in brackets.*

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[*] Wireless World, May, June and August, 1976. High Fidelity Designs, 2nd edition.

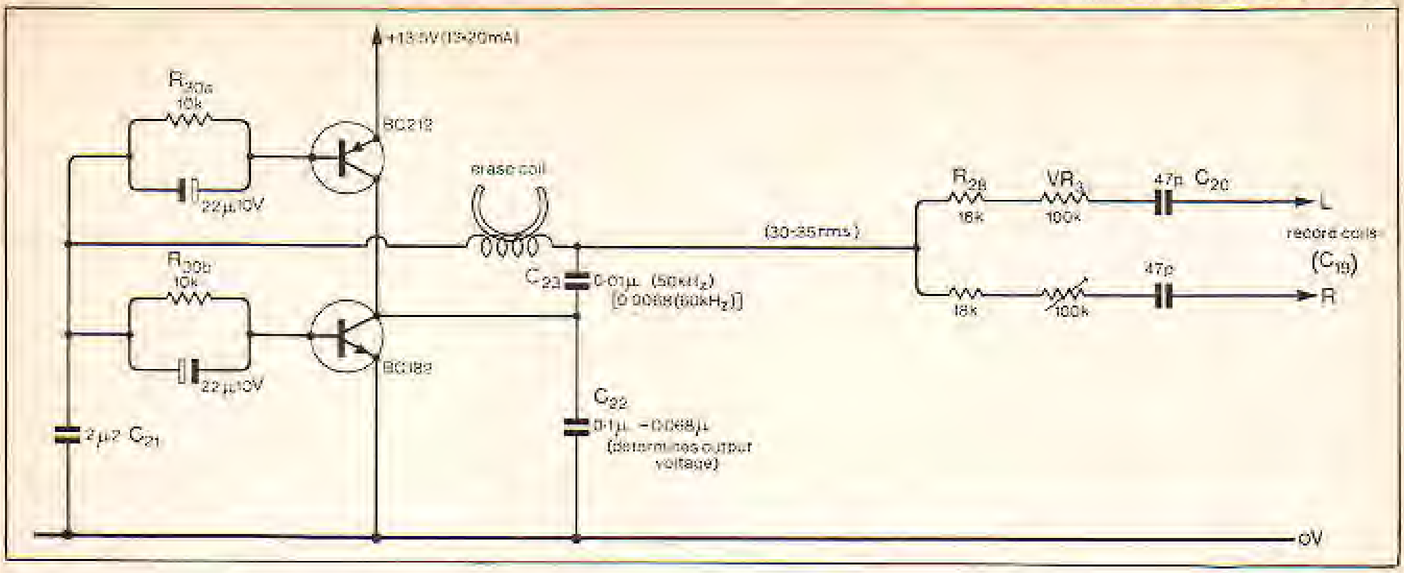

Fig. 2. *Alternative higher efficiency bias/erase oscillator. (Note: Output voltage can be increased, to 80V r.m.s., by increasing C_{22} and reducing R_{30a}, R_{30b} if needed for future tape types).*

erasure was 'wiping it dirty'. However, using a separate, though identical, bias oscillator, so that the on-cassette erase head could be disconnected, made no improvement in this respect. Indeed, the off-line oscillator was somewhat worse than the on-line one. Disconnecting the record amplifier also made no measurable improvement, while leaving the erase head in use but disconnecting the bias circuit from the record head left a tape noise level which was closely similar to that of the tape as received.

It was at this stage that the reason finally became clear. Typically, during recording, the magnitude of the h.f. bias waveform applied to the recording head in parallel with the signal is some 40-50dB greater than that of the signal. If the signal-to-noise ratio of the incoming signal is not to be impaired in the recording process, since the head is not able to discern the source of the signals which it receives, the s/n ratio of the bias waveform must be at least 60dB better than that of the record amplifier and signal source. It is probably this fact which has given rise to the widespread belief that good bias waveform purity is essential to low recorded noise level. Experimentally, it seems perfectly feasible to record with triangular and square-wave bias voltages (of the possible options a square-wave bias seems to have many advantages), non-sinusoidality seeming to be important only when this leads to bias waveform asymmetry and consequent even-harmonic distortion of the recorded signal. This arises because the recorded signal amplitude – in either direction – is bias voltage dependent.

Two steps can be taken to improve the oscillator signal-to-noise ratio: to improve its efficiency in terms of output-voltage swing for a given input power, and to reduce the proportion of wide-band noise generated by the oscillator which is transmitted to the record head along with the bias waveform. Improvement in the efficiency of the erase oscillator is effective in improving its s/n ratio because the transistor collector current is the major source of wide-band noise, assuming that the losses in the LC network containing the erase coil are small. An alternative oscillator circuit giving about 35V r.m.s. for about 12-15mA h.t. supply is shown in Fig. 2. The original circuit requires some 100-120mA for 30V r.m.s. Although the waveform purity of the two oscillator circuits is very similar, there is a small s/n improvement in the use of the later one.

The second possibility, that of reducing the component of oscillator noise within the audio pass-band which is fed to the record coil along with the 50kHz bias waveform, can be accomplished very simply by reducing the value of the coupling capacitor in the bias circuit (C_{20}) to the smallest value which will give adequate bias voltage; 33-47pF is suitable. This change is more effective in reducing zero-recorded-level noise than the improvement to the oscillator, and for those who have already built this cassette recorder, this is the only recommended change. Together, these modifications lead to about 1.5-2dB improvement in tape background noise level.

Although each of the changes suggested above will, in normal circumstances, lead only to a small, and perhaps imperceptible improvement in overall s/n ratio, taken together the improvement can be 2-3dB, which is worthwhile.

Factors affecting signal-to-noise ratio

In the earlier article, attention was drawn to the need to avoid excessive caution in the recording process, in that the overall quality of a recording in which the recording-level meter needles were occasionally driven 'into the red' would be likely to be much better than one in which, in the interests of low recorded distortion levels, the overload zone was always given a wide berth, and this point is worth restating.

However, it was expected, at the time of the earlier article, and this has been borne out by later experience, that the performance of the record/replay heads themselves would have a dominant effect upon the performance of the recorder. It seems, alas, to be a general rule that if a circuit design or process is evolved around some readily-available piece of commercial equipment or material, the publication of an article describing this will coincide with the discontinuation of the item upon which it was based.

Fortunately, in the case of the cassette deck, the Lenco cassette mechanism is identical mechanically, and at least as well made, as the Garrard unit upon which the prototype was based. However, the Garrard deck used the National Panasonic (Matsushita) record-replay head, type WY 435Z, which has a higher output and better h.f. response, and also a lower motor-noise pick-up, than some of the alternative types fitted in the Lenco unit. Luckily, it is a relatively simple matter to replace head units and to check the azimuth setting. Both the original head type and a superior unit of the same make are easily available so, in this particular instance, it is still practicable to copy the characteristics of the prototype if this is wished.

In view of the confusion which still seems to surround the design of cassette recording heads, and the relative merits of the materials used, it seems worthwhile to consider how these things will affect performance, and the basic characteristics of three different type record/replay heads are shown in Fig. 3. It can be seen from this that the use of a smaller head gap leads to a reduction in output at lower frequencies, but allows the increase in output with frequency to continue to a higher turn-over frequency. The use of 'hot-pressed' (polycrystalline) ferrite, which has lower eddy-current losses, gives an even better h.f. response for the same gap width than laminated Permalloy, but the lower magnetic permeability of the ferrite material leads to a further lowering of output at lower frequencies. Materials such as Super Permalloy and Sendust offer, respectively, improvements in wear resistance for the same permeability, and improvements in permeability for the same low level of eddy-current loss, with respect to ferrite. However, with available materials, there is a general trend towards lower output and less good s/n ratio as the h.f. performance of the heads is improved.

An additional factor, in the head design, which affects the output from the head is the extent of the magnetic shunt provided by the proximity of the internal pole faces within the head. As can be seen from the schematic representation in Fig. 4, the narrower this internal face is the better will be the head output — and also the more quickly the wear on the head face, due to tape abrasion, will impair the gap integrity. Happily, developments in tape coating technology (reductions in ferric particle size and improvements in particle size uniformity) have markedly reduced the abrasiveness of the tapes marketed during the last few years. Measurements made on the prototype unit over the last two and a half years and 1000-1200 hours of use, have shown little significant change in performance after the initial, fairly rapid, improvement in output — presumably due to an improvement in tape to head contact as the head is lapped in.

The two remaining important factors affecting s/n ratio are bias level and head magnetism. Taking the last point first, it cannot be stressed too strongly that inadvertent magnetism of the record/replay head — which can occur for a variety of reasons, and will most certainly arise if it is handled or remounted — will lead to a most substantial degradation of performance, both in respect of sensitivity and in respect of h.f. response, so that common prudence suggests periodic head demagnetisation, just to be on the safe side.

So far as the effect of bias is concerned, this was dealt with in the original article (Part 2) and the effects of changing bias voltage levels were shown graphically in the original Fig. 9. It can be seen from this that the use of too high a value of h.f. bias has a bad effect on the h.f. recording levels, due probably to partial re-erasure. While many of the modern tape types, such as ferro-chrome and cobalt-doped materials, benefit from somewhat higher levels (typically 7V r.m.s., measured across the record coil with a low capacitance h.f. probe), the several cases which I have encountered in which the record/replay performance was much below par were due either to undemagnetised heads or to excessive bias levels (in the 10-15V range!).

Since the actual output from the oscillator depends on the Q of the erase coil oscillatory circuit, there can be variations from manufacturer to manufacturer, and the coils fitted to the Lenco mechanisms tend to give a higher bias and erase voltage than that of the Garrard unit used in the prototype. This all to the good, but it is recommended that the bias adjustment pots (VR_3) be increased to 100kΩ from 47kΩ to give a wider adjustment range. It is appreciated that many constructors may not have access to suitable h.f. voltmeters for on-coil voltage measurements, but some simple practical experiments in recording a steady tone, using a prearranged programme of bias potentiometer adjustments, and choosing the setting which gives the highest output on the replay recording level meters — for a tone in the 300-1kHz range — will take one close to the optimum level, and such a test will compensate for variations in the bias requirements of differing types of record heads.

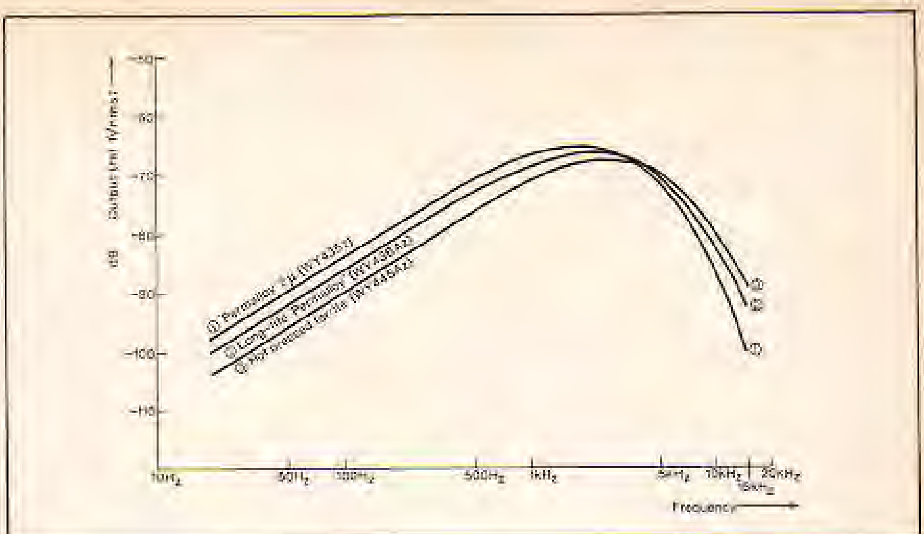

Fig. 3. *Record/replay head characteristics.*

Head replacement procedure. Many horrifying tales of gross head wear, due to the use of cheap tapes, chromium dioxide formulations, Permalloy heads, or excessive use of the recorder, have gained currency during the growth of popularity of the cassette medium, and many users must entertain some apprehensions about the inevitability of head wear incapacitating or impairing their machines, with the consequent need for specialist skills in head replacement. While the availability of a calibration tape, and a double-beam oscilloscope, makes this task a bit easier, simple alternatives will suffice.

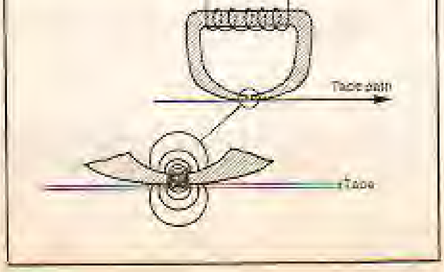

Fig. 4. *Schematic drawing of tape record/replay head, showing flux linkage in head and tape.*

Since many users will have built up their own library of tapes, recorded on their own instruments it will be more important when the time for head replacement approaches, that a replacement head should be in the same position as its predecessor, with respect to the tape, than that it should be in accurate 'azimuth' (gap verticality) and height conformity to the notional standard. A standard cassette recorded on their own machines will meet their needs. It is suggested that a range of frequencies from 300Hz to 10kHz should be recorded, with both channel inputs in parallel, at '0 VU'. (300, 1k, 3k, 6k and 10kHz for two minutes each will be adequate.) If the replacement head is in the same position as the head with which the test cassette has been recorded, the output of this tape will be of identical magnitude in each channel and the outputs will be in phase. Output magnitude can be checked from the recording level meters, and phase equality can be checked by a headphone or a.c. voltmeter across the two 'live' outputs of the recorder or subsequent amplifier. When the two signals are in phase, the voltage difference between the 'R' and 'L' channels will be at its least.

This test becomes more critical as the recorded frequency is increased, and as the higher frequencies are approached errors in azimuth also become apparent. If the gap between the replay head polepieces is not truly perpendicular to the direction of motion of the tape, the h.f. output will be diminished. If the condition of phase coherence between the two channels does not correspond to the maximum h.f. output, the original record head azimuth setting was probably in error. If phase coherence between channels does not correspond to amplitude equality between them, the replacement head centre height is incorrect, which can be remedied by the addition or removal of washers from the non-adjustable end of the head mounting. For the record, a relative positional (angular) error of less than 0.05° can be seen by phase coherence checks at 10kHz, which is well within the azimuth accuracy requirements for optimum h.f. output.

The dimensions and agreed heights for the EIAJ (Japanese) 'Y' type, and Lenco/Garrard, 'Z' type, heads are shown in Fig. 5, together with the mounting system employed on the Staar type mechanisms. National Panasonic (Matsushita Co., Ltd.) offer two heads, WY 435 Z (2 micron gap Permalloy) and WY 436 AZ (1.5 micron gap, long-life Permalloy) which are of a suitable type for the Garrard and Lenco mechanisms. The latter head is of a superior construction, having a somewhat higher specific output, which compensates in part for the loss in sensitivity due to the narrower head gap, and allows the record/replay frequency response to be extended to at least 15kHz with suitable tape types. If the changes noted above are carried out, the approximately 2dB loss in output due to the use of the narrower head gap can be accepted with a final s/n ratio no worse than that of the original specification and the advantage of a better overall frequency response. It may well be that there are other head units, either now or in the future, which will be superior in performance to the National Panasonic units referred to above, since this, like that of tape composition improvements, is a field in which intensive development work will certainly continue.

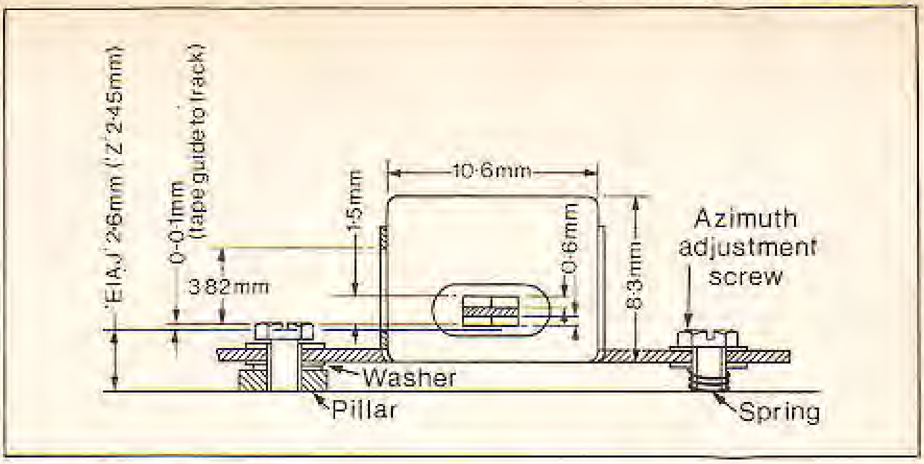

Fig. 5. *Specified dimensions for cassette record/replay heads and method of mounting used on Staar mechanisms.*

Some adjustments to circuit component values are desirable if the 2 micron gap record/replay head is replaced with a unit having a 1.5 micron gap width, and these suggested changes are indicated by the values shown in brackets in Fig. 1 and 6. In the prototype, with square-wave response adjusted to give minimal overshoot, the h.f. response with the 1.5 micron WY 436 AZ head is —5dB at 15kHz, ref. 300Hz, using Fuji FX tape. There is little doubt that the system could be made to yield a more uniform h.f. response than this, if required, by accepting a less well damped response to a square-wave signals, but earlier experiments indicate that the subjective response of the system is not improved by the attempt to obtain optimal flatness of steady state frequency response by sacrificing accuracy of transient waveform reproduction.

It seems probable that this is because the tape recording mechanism is truly a 'slew-rate-limited' one, in that there is a minimum and readily calculable time which is required for a point on the tape, travelling at 4.75cm/s (1⅞in/s) to pass the 1.5 or 2 micron (0.000059 or 0.000078in) head gap. This implies that, for an ideally perfect tape impressed with a recorded square-wave, the output from the system cannot 'slew' at a greater rate than the replay head

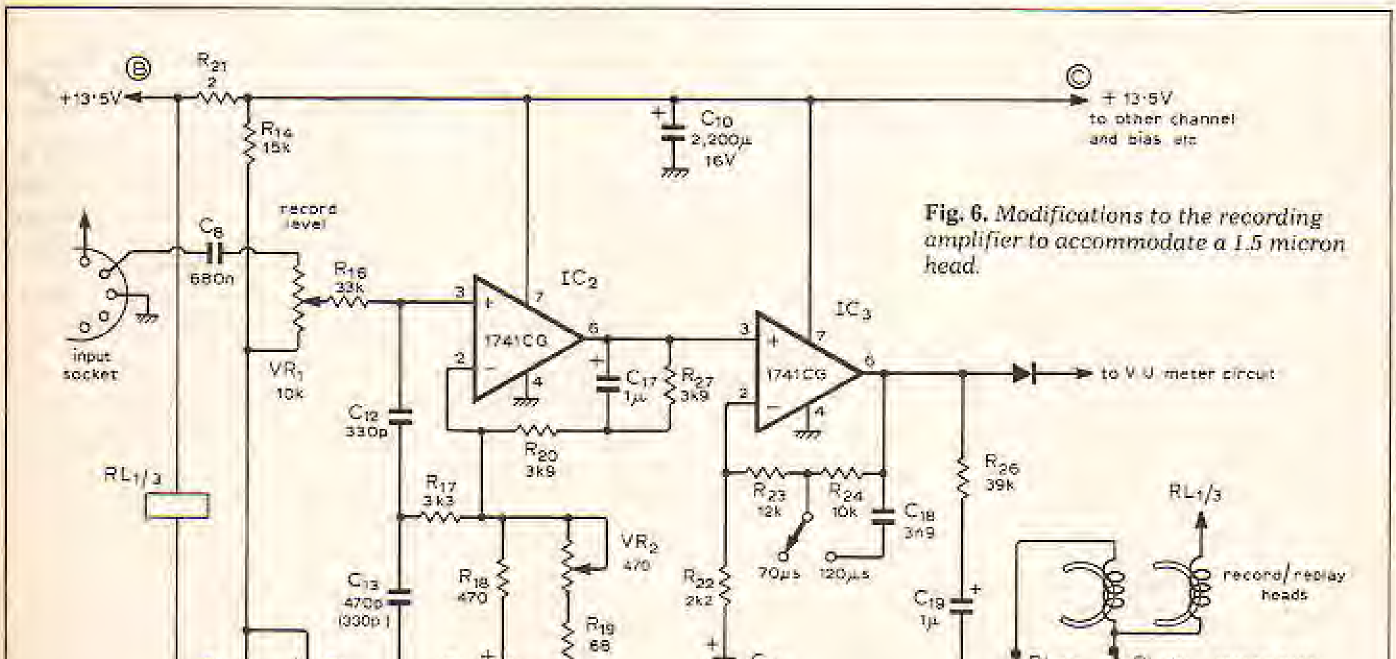

Fig. 6. *Modifications to the recording amplifier to accommodate a 1.5 micron head.*

geometry will allow, so that, if a greater input signal is impressed on the system, in the attempt to achieve improved h.f. response, the only likely effect will be to convert waveforms into a triangular shape, with a consequent increase in h.f. intermodulation distortion.

Hart Electronics of Oswestry have agreed to stock equivalent units to the Matsushita WY 436 AZ 1.5 micron head for those constructors interested in making the substitution.

Choice of h.f. bias frequency

The original choice of bias frequency (50kHz) was simply that of the recommendations of Garrard Ltd, the manufacturers of the original cassette mechanism. There is a considerable tradition in the high-quality tape recorder field that the bias frequency should be at least five times greater than the highest intended recording frequency. This arises because the action of the bias waveform is effectively to sample the signal waveform at the bias frequency, and it is plausible that the desired waveform cannot be reconstructed accurately unless there is an adequate number of samples within one cycle of the highest required frequency.

However, experimental results obtained with differing bias frequencies – obtained by using differing values of C_{23} – show that on the tapes used the remanent recorded flux and hence the s/n ratio for a given recording level, decreases significantly as the bias frequency is increased to 60 or 75kHz, so that even though a wider bandwidth can be obtained with alternative head units a change in bias oscillator values is not recommended. Some support for retaining the original 50kHz bias frequency is given by the observation that some very high quality audio systems are based on sampling rates which are lower than this. For example, the current BBC f.m. stereo radio transmissions have an L-R sampling frequency of 38kHz; the digital encoding process, by which the p.c.m. signal is transmitted over cross-country land-lines, uses a 32kHz sample rate; and the very highly regarded Denon p.c.m. encoded gramophone recordings employ a sample rate of 47.25kHz. I accept the qualification that square-wave sampling and sine-wave biassing may not be equivalent and since a square bias waveform (in effect, a triangular current waveform) appears to work quite well I intend also to explore this approach.

Dubbing

If it is desired to 'over-dub' an existing recording, without erasing the existing material, this can be done by the use of a coil other than the existing erase head in the bias oscillator circuit, so that the erase head can be switched out of circuit. Although, in principle, any coil of suitable Q and an inductance of 1mH could be used for this purpose, the simplest approach is to use another, similar, erase head, mounted in a convenient position remote from the deck and connected to a change-over switch.

Miscellaneous design oversights

It is, I suppose, inevitable, following the contemplation of a design for a couple of years, even without the benefit of criticism in print, that the designer will feel that there are certain aspects which could have been done better.

Gain adjustments. Apart from the changes in bias oscillator, feed capacitor and adjustment potentiometer value noted above, and the modifications to the replay circuit noise bandwidth limiting components, I feel I should have provided some means for adjustment of the relative channel sensitivities in the record and replay amplifiers, in order that the effects of component value errors could be removed. This can be done by making the lower feedback resistor, R_7, in the replay amplifier variable over the range 820-1k8 ohms, in either one or both channels, which can be done conveniently by altering the value of R_7 to 820 ohms, and putting a 1kΩ preset pot. in series with this. A good quality unit such as a cermet type, should be used for this duty to avoid worsening the input noise level.

A similar relative gain adjustment can be made in the record amplifier if the value of R_{22} is reduced to 2k2, and a 1kΩ pot. is placed in series with it at the earthy end. This can then be used to set the relative record levels to equality at the l.f. (say 300Hz) end of the spectrum, as indicated on the meters – assuming that these have already been correctly calibrated – while the h.f. pre-emphasis trimmer pot., VR_2, can be used to achieve record level balance between channels at the h.f. end (say 10kHz). These suggested changes are shown in Fig. 1 and Fig. 6.

Bias oscillator. In the bias oscillator circuit (the original Fig. 7) the lower potential divider capacitor in the Clapp oscillator (C_{21}) was shown as 2.2μF. With some erase heads, this did not give enough circuit gain to ensure that the oscillator would always operate. A 1μF capacitor in this position gives a greater tolerance of erase coil characteristics variations. This change was shown in the reprint* and is recommended for adoption in future units employing the original oscillator circuit design.

Meters. Some justified criticism has been received concerning the tendency of the recorded level meter needles to hit their limit stops on switch-on. This type of behaviour is difficult to avoid entirely, but it can be minimised, if necessary, by reducing the slightly over-generous value of the rectifier circuit series capacitor (C_{26}) from 10μF to 2μ2F.

Headphone amplifier. I also regret that the input p-n-p transistor in the Class A headphone amplifier was incorrectly labelled BC182L instead of BC212L. Any small-signal p-n-p device will serve, since its application is a very uncritical one.

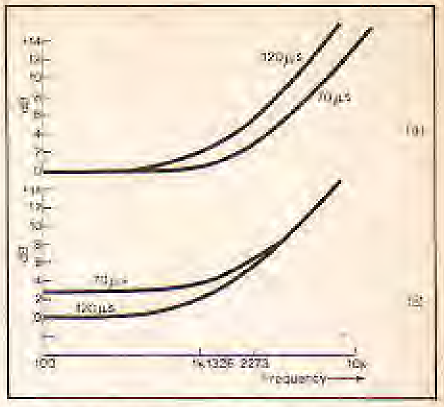

Fig. 7. *Effect of recording pre-emphasis 'time-constants'.*

Replay equalisation

Not entirely unexpectedly, I have come in for a certain amount of 'stick', both in correspondence and in the Letters columns, for my advocacy of the 70μs record/replay characteristic for general use. I note, however (with a certain amount of inward satisfaction, since it is nice occasionally to be right) that much of this has stemmed from a failure to understand just what the record/replay equalisation compensations are introduced for, or how they are derived. To shed a certain amount of extra light on what is obviously a somewhat shadowy area, I have appended a simplified analysis of the situation below, which can be omitted by those familiar with the subject.

In an ideal world of perfect magnetic tapes, and replay heads with complete external flux linkage and infinitesimally small pole-piece gaps, a tape could be recorded at all desired frequencies at a constant magnetic flux level, at some convenient value a little below the tape, or head, saturation level, and this would be found, on replay, to have generated an electrical output which increased linearly with increasing frequency, in such a manner that a doubling of frequency would cause a doubling of output, as defined by the classical laws of electromagnetic induction. A replay output which was constant, independent of frequency, could be obtained by a simple replay equalisation circuit which gave an output, starting at some conveniently low frequency, which decreased at a rate of –6dB/octave.

However, because of shortcomings in the tape and head characteristics, at the h.f. end of the recorded spectrum, it is customary to incorporate a degree of recording h.f. pre-emphasis, starting, in the case of the Phillips cassette system,

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* High Fidelity Designs – a book of reprinted Wireless World articles on audio equipment construction.

at 1-2kHz. The actual pre-emphasis characteristics are defined by a specified time-constant, having the agreed values of 70 and 120μs. This can be converted into a known ±3dB point by the relationship $f = 1/2\pi CR = 1/2\pi \times$ time const. which gives +3dB values for the 70 and 120μs characteristics of 2273 and 1326Hz respectively, leading to the type of recording pre-emphasis characteristics shown in Fig. 7(a). If it is assumed that during recording the recorded signal levels are adjusted so that the recording level meters achieve the same recorded levels on peaks, and if it is assumed that this is mainly influenced by the greater signal level of the pre-emphasised region, the effective recorded level will, in reality, be that of Fig. 7(b). In the case of the 70μs characteristic, this assumes that the h.f. losses will be less, requiring less correction, and permits the recording of all frequencies below the 2.2kHz turnover point at about 3dB higher level than is the case for the 120μs characteristic.

If a similar characteristic were to be adopted on replay, the effect would be to arrest the downward slope of the replay characteristic at a turn-over point of 2273 or 1326Hz, beyond which the response would be level. In practice, however, the equalisation adopted is the recording one, and the replay characteristics are then corrected in the light of the experimentally derived replay-head/tape characteristics, so that the final record-replay frequency response is acceptably level. This usually involves some additional replay treble lift, to compensate for the finite replay-head gap width. The overall residual advantage is, therefore, due to the greater signal level in the mid-range frequency band, on the 70μs equalisation, due to the decision to adopt a lesser degree of h.f. boost, which gives about a 3dB benefit in terms of signal to noise ratio. Since tapes, and heads, are no less able to accept a given magnetic flux density at 300Hz than at 10kHz (in fact rather the converse), the imputation of a less satisfactory recorded distortion level due to this technique appears ill-conceived.

Technical inaccuracies

It is a matter of genuine concern in the preparation and publication of technical articles that inaccuracies of fact or terminology should be avoided. With the best will in the world, however, inadvertent errors do creep in, and, in the case of the original articles, there are three corrections I would like to make concerning the 'VU' nomenclature.

'VU' levels. If one constructs a piece of equipment which has signal level indicating instruments, which have calibrations ranging from −20 to +3, and which their manufacturers have labelled 'VU', then, so far as the signal levels indicated by these instruments are concerned, one is rather in the position of Humpty Dumpty — ". . . 'when I use a word,' Humpty Dumpty said in a rather scornful tone, 'it means just what I choose it to mean, neither more nor less' . . ." — so that although '0 VU' has a precise and specific meaning in the recording studio and sound engineering field (that of a signal level equivalent to 1 milliwatt in a 600 ohm load, or 0.775 volts r.m.s.) the '0' level on one's own instruments may, for practical reasons, be quite different from this.

Since I intended to redefine this level, for the purposes of this design, as being a level of 2.25 volts r.m.s., at 600Hz, as measured at the output of IC_3 in the record amplifier, it had been my intention, in the original article, to refer to VU levels, in this context, only within inverted commas, in order to indicate my temporary misuse of the definition. However, this I found, in print, that I had failed to do, and for this I apologise.*

Mr. Warren, writing from Australia,[1] did indeed reproach both *Wireless World* and me, respectively, for permitting and committing the solecism of referring to the recording level instruments as VU meters at all, in that this term should only be applied to instruments having certain, internationally agreed, standards of impedance, sensitivity and ballistic response, which the simple instruments I had described did not, and were not intended to, meet. I accept this rebuke, and am happy to substitute the somewhat more lengthy term 'recording level meter' for these display instruments. However, these strictures could be more widely spread, in that there are a large number of commercially available instruments which have signal level meters referred to as VU meters, which also fall a long way short of the international standards. While it is obviously desirable to prevent the corruption of specific descriptions by their careless use, I suspect that this particular case is going to prove a difficult battle to win.

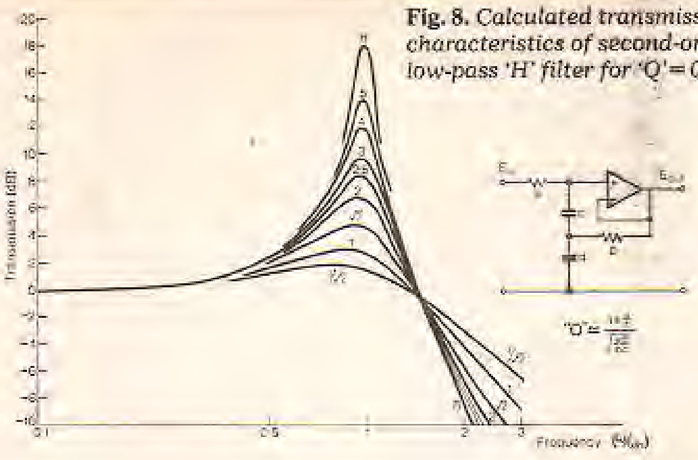

Fig. 8. *Calculated transmission characteristics of second-order low-pass 'H' filter for 'Q' = 0.707−8.*

Finally, in describing the technique which I had adopted to generate the desired recording pre-emphasis characteristic, I showed a family of curves in my Fig. 15, as being typical of the type of response which would be generated by the use of an under-damped second-order low-pass filter, for various values of 'Q'. Although the mathematical derivation of the transmission characteristics of such filters is relatively straightforward, and in the case of the circuit which I used, is shown elsewhere,[2] the plotting of the frequency response, for various values of Q and frequency, is a laborious task in the absence of a suitable computer programme, so, since an illustration was required, I used that of the active lead + lag system, for which I had previously determined the frequency response characteristics, and which are similar to those of the system I had actually used, though not identical. It had been my intention, in the text, to make clear the fact that the curves were typical rather than actual. Mr Good[3] has drawn my attention to my error in this, so, by way of penance, I have calculated the actual performance characteristics, and show these in Fig. 8. For convenience in calculation I define Q and 1/n in these graphs.

Because of the influence of the lag network, (VR_2, R_{12} and C_{13}), on the operation of the circuit, the actual resonant frequency of the circuit is lower than the value calculated from R_{16}, R_{17}, C_{12} and C_{13}, and decreases in frequency as well as increasing in magnitude, as the value of $VR_2 + R_{12}$ is reduced. This is a convenient characteristic from the point of view of suiting the h.f. equalisation peak response frequency to the characteristics of the heads in use, and is an additional reason for choosing this type of circuit in preference to the more conventional inductor based systems.

References

1. Warren, E. G., *Wireless World*, "Letters". p.46. Jan. 1977.
2. Linsley Hood, J. L., *Electronic Engineering*, July 1976, pp.55-58.
3. Good, E. F., Private communication.

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* Examination of the original shows that Mr Linsley Hood did use quotes. In an excess of editorial zeal they were deleted — we are sorry for this. — P.R.D.