High-quality Tape Recorder

1. Specification and design

*by J. R. Stuart**, B.Sc.*

Tape recorder construction has received relatively little attention over the years, and presumably one reason is the apparent complexity of the circuitry and alignment, compared with other items of domestic audio equipment. Two tape recorders have been described in these pages in a period of ten years, whereas several power amplifiers have been described in the last few months.

In view of the large interest in the construction of domestic audio equipment, it was decided to produce a design for a tape link which would be simple and cheap to build and easy to set up.

Reel-to-reel or cassette?

Continuing tape recorder development has resulted in commercial machines, using standard reeled tape, which give excellent performance at low speeds with or without crossfield bias.

Probably the most significant developments have been the large improvement in high-speed tape copying techniques, widespread acceptance of the Dolby noise reduction process, and the rapid growth of interest in four-channel stereo. These combine to create a situation in which tape will take over from disc as the major programme source particularly as no compatible coding can record four independent channels on a disc—although it can be done at the expense of crosstalk.[1]

It is now possible to manufacture a cassette tape to run at $1\frac{7}{8}$ i.p.s. which, with Dolby, gives a performance better than disc. However, at present no cassette tape transport is available which can offer the necessary low wow and flutter performance nor the retrieval capability of a high-quality deck of the conventional form.

The choice of a conventional deck for this design was made without hesitation, for the use of such a machine will not decline

*Marconi Instruments Ltd.

TABLE 1
Specification of the complete recorder

Bandwidth measured at −9 dB, C.C.I.R. replay:

15 i.p.s.	25 Hz	− 30 kHz	±1 dB
$7\frac{1}{2}$ i.p.s.	25 Hz	− 17 kHz	±1 dB
$3\frac{3}{4}$ i.p.s.	25 Hz	− 11 kHz +1	−2 dB
$1\frac{7}{8}$ i.p.s.	25 Hz	− 6 kHz +1	−3 dB

Distortion (at 1 kHz)

$7\frac{1}{2}$ i.p.s.	0 dB	1%	third harmonic	(reference level)
	+2.3 dB	2%	third harmonic	
15 i.p.s.	0 dB	0.7%	third harmonic	
	+2.3 dB	1.5%	third harmonic	

Dynamic range

56 dB	15 i.p.s. and $7\frac{1}{2}$ i.p.s.	(weighted)
54 dB	$3\frac{3}{4}$ and $1\frac{7}{8}$ i.p.s.	(weighted)

Crosstalk
−60 dB mono
−45 dB stereo

Amplifier hum and noise
below −66 dB

Input sensitivity
7 mV rms into 45kΩ or 600Ω
or 25 mV rms into 150kΩ or 600Ω
or 250 mV rms into 1.5MΩ or 600Ω

Output
25mV rms. Output Impedance < 100Ω
and 250mV rms. Output Impedance < 100Ω

Peak-programme meter
Switchable to measure record, replay and bias levels.

Cost
£20 + £85 14s 7d for the Brenell Mk 6 deck.

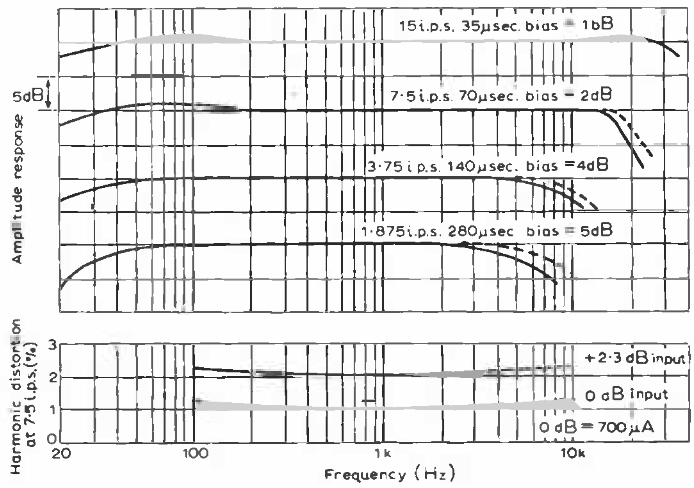


Fig. 1. Maximally flat frequency response.

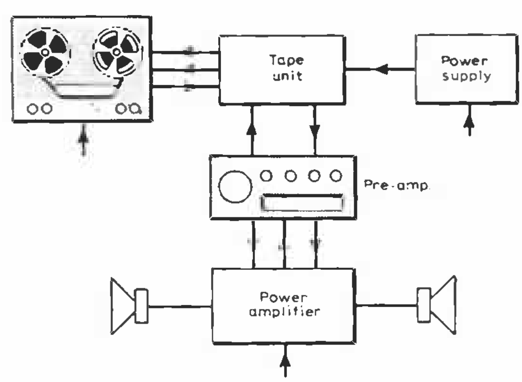


Fig. 2. Expected arrangement of the tape unit.

when live recordings are made for either amateur or professional applications, particularly those requiring editing. Further, many decks of this type are in use and may be adapted to this design.

Crossfield biasing was not considered in view of the extreme mechanical problems this would create for the constructor.

This tape recorder has been designed around the Brenell Mk 6 deck. Brenell Engineering Ltd have agreed to make this deck available in the required form.

Evolving a specification

Table 1 shows the performance of this tape recorder for the conditions described and Fig. 1 shows the frequency response for constant current record, C.C.I.R. play back at $7\frac{1}{2}$ i.p.s. and 15 i.p.s. adjusted for a maximally flat response.

Equalization is described in detail later along with the corresponding setting-up and performance details.

In evolving a design the primary considerations were
(a) simplicity of design consistent with high performance

(b) non-critical construction
(c) the use of readily available components
(d) a minimum number of adjustments (the circuits deliberately leave very few parameters undefined and all calibration can be done with a multi-meter, although the full procedure is described)
(e) design flexibility to enable ready extension to four-channel and cassette applications when such decks are available.

The unit described is a mains-powered tape link and is intended for use with an existing audio system of pre- and power-amplifiers, and mixer if required. Such a recorder receives its signal from the pre-amplifier or mixer and replays through the same system. Three tape heads are fitted to allow simultaneous recording and playback; this affords better performance and much extended monitoring facilities.

The unit is readily compatible with the designs published in *Wireless World;* in particular the signal levels have been chosen to match the Bailey[2] and Nelson-Jones[3] pre-amplifiers. Fig. 2 shows the expected arrangement.

It was decided that the standard tape recorder should be a stereo unit capable of recording or replaying mono on either of the channels, with extensive monitoring facilities.

In addition to the considerations above, the particular performance parameters are cost, bandwidth, dynamic range and simplicity, and to achieve a good overall performance these must be carefully examined at each stage of the design.

To achieve simplicity it has been necessary to produce non-critical alignment with the full manufacturers' spread of devices, and the construction is no more complex than a power-amplifier. A block diagram of the tape unit is shown in Fig. 3.

Bandwidth

The bandwidth of a tape recorder is determined by the tape transport mechanism at low frequencies, and at high frequencies, to a first order, by

(a) recording speed

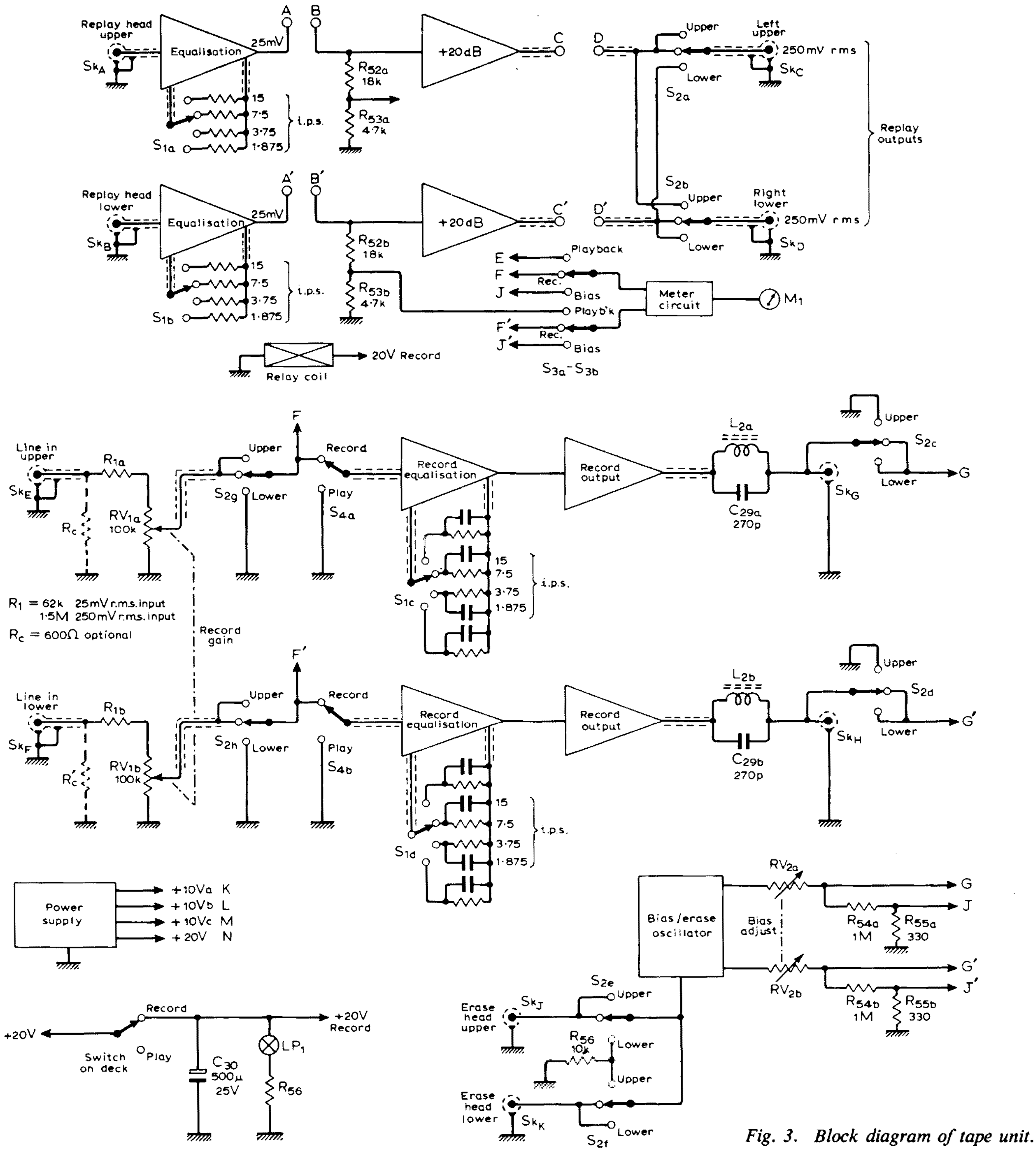


Fig. 3. Block diagram of tape unit.

(b) h.f. bias level
(c) replay head gap
(d) alignment of record and replay gaps
(e) equalization standard (I.E.C., N.A.B., D.I.N., C.C.I.R., N.A.R.T.B.)
(f) magnetic domain size on tape
(g) head losses (copper, and iron, and leakage).

Second order effects include the recording-head gap.

The Brenell Mk 6 uses Bogen heads which have a hyperbolic face to ensure good tape-head contact. They also have pressure pads which nevertheless seem to allow good low-frequency response as is seen from Fig. 1.

In a given system the parameters which the designer may control are a, b, and e, and to some extent d.

Great care must be exercised in producing a bandwidth specification; it seems dangerous to rely as much as we do on these figures. The problem is that in most cases it is the published specification for bandwidth and noise which sells a tape recorder. The author feels that it is of limited value to reject a model with an upper −2dB point of 15 kHz in favour of one which has the same point at 22 kHz; the reasons are as follows.

The sensitivity of the human ear at 17 kHz is a mean of 10 dB below 4 kHz at listening level of 60 phons, and the 1% duration peak content in an orchestral piece at 15 kHz is 10 dB below 500 Hz[4]. It would seem that a variation of ± 2dB at 20 kHz should have little effect, particularly as the threshold of hearing at 20 kHz is at a loudness of 80 phons (Robinson & Dadson) and in the upper octave just noticeable distortion is greater than 1 phon.

The ear is however sensitive to transient 'slewing-rate' and to inharmonic products.

No recording system can easily retain the phase information required to reproduce the transient information in the way required; however a lot can be done to reduce the intermodulation products which are generated in the upper band. It seems evident that the perceived difference between the systems of different bandwidth, is due to distortion produced by the method of bandwidth reduction, causing intermodulation products to appear in the region 1–6 kHz, with obvious effect. Because the major control of bandwidth of a tape recorder is the high-frequency pre-emphasis, and since harmonic products in the upper octave are not retained, the intermodulation products here, and the bandwidth, are determined by the recording characteristic.

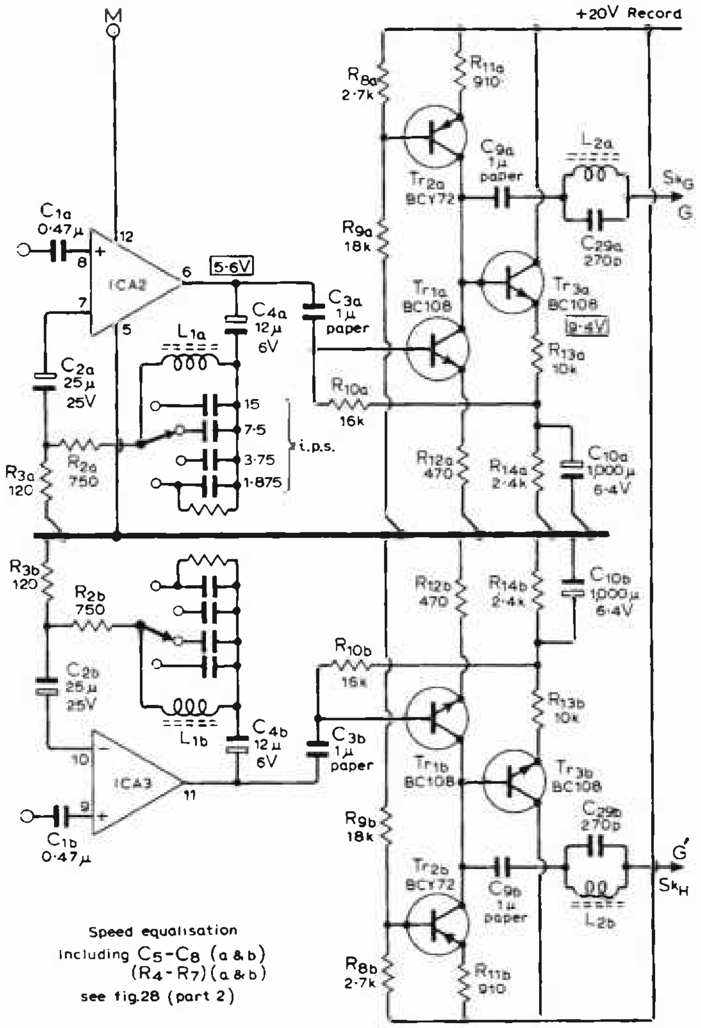


Fig. 5. Circuit diagram of recording stage.

Dynamic range

In a well designed tape recorder the dynamic range is determined by the tape and defined by tape overload and inherent background noise.

Sources of noise in the recorder are the amplifiers (more than 10 dB below tape noise in this design) and recorded noise by the bias and erase waveforms. In order to minimize this the erase waveform must be very pure and free from even-order harmonics.

Another source of noise is hum. However, careful power supply design and overall construction have reduced basic amplifier hum to less than −80 dB. The hum level appears far below the amplifier noise, and is inaudible in the author's set-up at a gain setting equivalent to 40W at a distance of 6 feet from the speakers.

Two-track operation was chosen to give a maximum dynamic range, however the Brenell Mk 6 deck is available with four-track heads and these may be used with no circuit modification giving about 3 dB less dynamic range.

Power supply

It was intended that the recorder should obtain raw d.c. from the power amplifier with which it is used, and a regulator is used to derive the system rail of +20 V. In case this power is not available a simple supply will be described in Part 2.

Choice of devices

The R.C.A. integrated circuit quad-amplifiers CA 3048 and CA 3052 were chosen for this design—which uses one of each. In

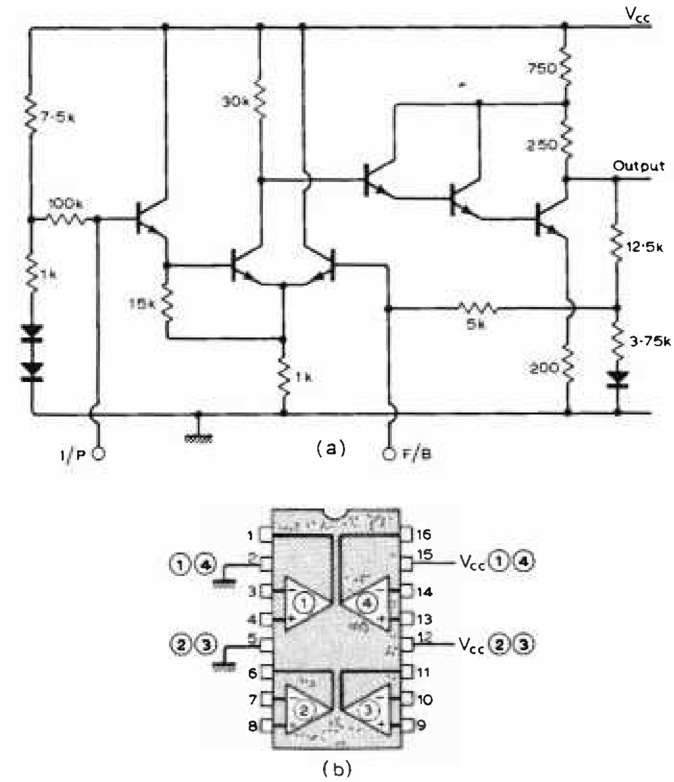


Fig. 4. Data on the i.c. linear amplifiers type CA3048 and CA3052; (a) the circuit diagram of each amplifier section (¼i.c.); (b) pin connections; and (c) performance details of each amplifier.

the author's experience they have a highly predictable, reliable performance and offer a saving of a very large number of discrete components. Although there is no reduction in cost, the reliability of one of these chips for home construction, when compared with the minimum equivalent of twelve transistors and associated components, is high. The circuits should be carefully checked however for the cost of mistakes could be higher. Fig. 4 (a) & (b) show the circuit diagram and specification for these devices. The transistors chosen are cheap silicon-planar devices of ready availability.

Recording section

The essential recording function is to produce a residual flux/input voltage transfer function which is linear with respect to amplitude variations.

In the mid-band residual flux relates linearly to applied flux, which is in turn proportional to the current flowing in the recording head windings, and so it follows that the recording current should be proportional to the signal voltage.

It is also necessary to modify the amplitude/frequency response of the recording stage to obtain the optimum bandwidth as described earlier.

The recording amplifier falls readily into two sections, namely the equalization and output stages.

Fig. 5 shows the circuit diagram for the stereo recording section. Reference to Fig. 3 shows that the record gain control is placed at the input to the equalization stage, i.c.A 2&3, to maintain optimum conditions of dynamic range and distortion. S_2 g & h, and S_4 a&b direct the input signals according to the selected function.

The open loop gain of i.c.A 2 & 3 is set to 45 dB by R_3, and the low-frequency gain of this stage is

$$\frac{R_2 + R_3}{R_3} \approx 7.25$$

This implies a sensitivity of 7 mV r.m.s. for 0 dB output level. Here 0 dB output was set for a flux density of 32 millimaxwells per millimetre of tape at +1 dB bias and $7\frac{1}{2}$ i.p.s.

The parallel tuned circuit formed by L_1, and C_{5-8}, increases the gain at the resonant frequency by an amount determined by R_{4-7}. Several combinations of frequency and boost may be used and these will be described in Part 2. Fig. 6 shows the frequency response of the equalizing stage when set for maximally flat response as in Fig. 1. This rising gain at high frequencies compensates to some extent for the losses in the recording head and tape, and ensures a 'constant induction' characteristic. Noise and distortion are both very low in this stage, distortion at 1 kHz is less than 0.01% at rated input, and the noise is more than 70 dB down.

As the CA 3052 amplifier can give 2V r.m.s. output with 0.65% distortion open loop, this equalizing stage is capable of producing 32 dB boost with less than 0.1% distortion. Because the recording head is a non-ideal inductor, it is an interesting problem to produce a 'constant current' drive at all frequencies in the pass-band; this implies an amplifier whose voltage gain is proportional to the head impedance.

A large number of designs have appeared, to produce this constant current drive for the head, and indeed to arrange this drive with a good 0 dB overload margin, to allow pre-emphasis, is quite difficult.

The Brenell Mk 6 deck is fitted with a Bogen UK202B record head, which has an inductance of 120 mH at 1 kHz and requires a recording current of 110 μA to induce a remanent flux of 32 mMx/mm; this head achieves its maximum impedance of 10 kΩ at about 14 kHz. Without pre-emphasis then the voltage across the head will be 1.1 V r.m.s. and as the output amplifier can provide 5.5 V r.m.s. across the head at this frequency the minimum pre-emphasis which can be applied to allow no overload at the 0 dB level is 14 dB at 14 kHz. It is worthwhile investigating the power-frequency spectrum of the signal source, as many music sources have maximum peaks at 15 kHz 10 dB below 500 Hz[4]. Thus if necessary a further 10 dB boost could be applied with less than 1% duration overload at these frequencies.

Wherever possible the nature of the pre-emphasis has been designed to accept a 0 dB signal without overload. If this is not the case the amount of overload is stated. Traditionally 'constant

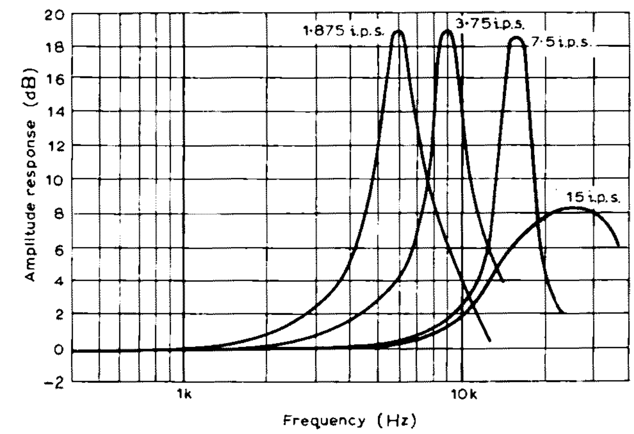
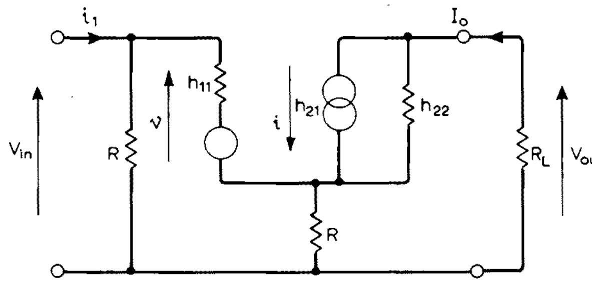


Fig. 6. Frequency response of recording pre-emphasis.



$$V_{in} = \left(1 + (h_{21}+1)\frac{R}{h_{11}}\right)V$$

$$I_o = h_{21}\frac{V}{h_{11}}$$

Then if $(1+h_{21})R \gg h_{11}$ $\quad \frac{I_o}{V_{in}} = \frac{h_{21}}{1+h_{11}} \cdot \frac{1}{R} \simeq \frac{1}{R}$

Fig. 7. Mid-band small-signal equivalent circuit of recording output amplifier.

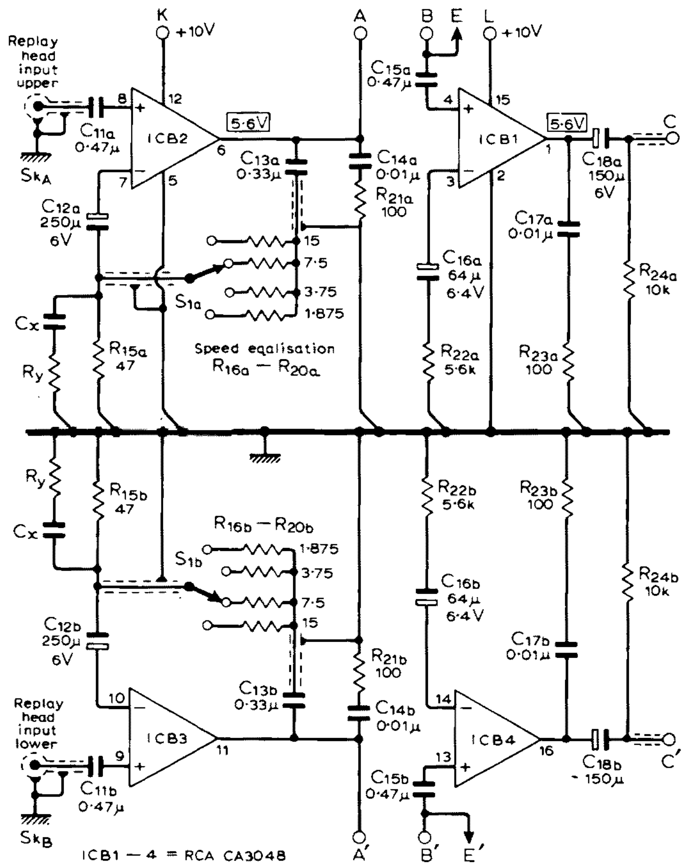


Fig. 8. Circuit diagram of replay amplifier.

TABLE 2 **(Replay equalization details.)**

speed	standard	time constants (μs) t_1	t_2	gain @ 1kHz (approx)	Cx μF	Ry μF	Rp	Rq	Rs	Rt	Rm kΩ	Cz
15 i.p.s. 38 cm/sec	CCIR/DIN IEC94* BSI (1970)†	35	∞	10	—	—	56	—	—	—	∞	s/c
	NAB, IEC (USA)	50	3180	12	—	—	100	—	—	—	9.5	10μ 6V
7½ i.p.s. 19 cm/sec	CCIR/DIN IEC94 (GB) BSI (1970)	70	∞	13	0.5	22	—	160	—	—	∞	s/c
	NAB, IEC (USA)	50	3180	12	0.5	22	—	100	—	—	9.5	10μ 6V
	IEC (FRANCE)	50	∞	12	0.5	22	—	100	—	—	∞	s/c
3¾ i.p.s. 9.5 cm/sec	CCIR	140	∞	15	1.0	22	—	—	390	—	∞	s/c
	BSI (1970) } IEC94 (GB)	90	3180	14	1.0	22	—	—	220	—	9.5	10μ 6V
	IEC94 (EUR)	140	3180	15	1.0	22	—	—	390	—	9.5	10μ 6V
		or 90	∞	14	1.0	22	—	—	220	—	∞	s/c
1⅞ i.p.s. 4.75 cm/sec	CCIR	280	∞	20	1.5	22	—	—	—	820	∞	s/c
	BSI (1970) }	120	1590	15	1.5	22	—	—	—	330	19	10μ 6V
	IEC94	or 120	∞	15	1.5	22	—	—	—	330	∞	s/c

* IEC94 inc. GB, USA, FRANCE.
† BS 1568 (1970). NOTE: Measurements on this unit used the CCIR replay time constants, and were made before the publication in September of BS 1568 (1970).

current' was obtained by generating a very large signal voltage, and then swamping the head impedance with a large series resistance. Although simple to implement with valves this technique is inefficient and inelegant, although there are no problems with bias rejection.

Others have made use of the high intrinsic collector impedance of a transistor, notable examples being P. W. Blick[5], J. B. Watson[6], and G. Wareham[7].

Certainly the best method of ensuring accurate 'constant-current' drive is to include the head in the feedback loop of a high gain amplifier. However, this gives rise to considerable problems of bias rejection, and for this reason this technique was not employed in the basic recording unit. It will however be described in Part 3.

The circuit developed for this recorder is simple but effective. Tr_1 is a common-emitter amplifier with local feedback in the emitter and this stage is biased by the current source Tr_2; this gives a high output impedance, and the load seen by Tr_1 is essentially the recording head. Fig. 7 shows the equivalent circuit of the output

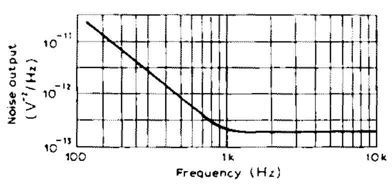


Fig. 9. Output noise spectrum of replay amplifier.

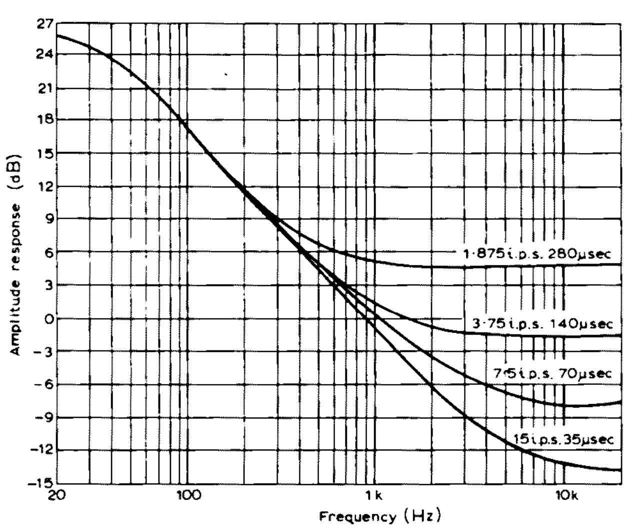
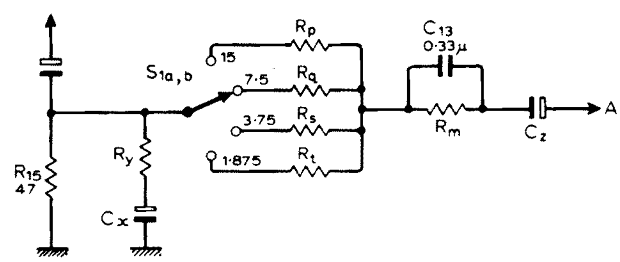


Fig. 10. Replay frequency response.



Equalization circuit referred to in Table 2.

stage for small signals at mid-band. The trans-conductance is given by $I_0/V_{in} = 1/R_{12}$. Tr_3 is an emitter-follower stage arranged to set the d.c. conditions in the amplifier. The d.c. stability is excellent, and substituting for Tr_1, transistors with h_{FE} between 30 and 475, causes a variation of only 200 mV on the standing d.c. level at the collector of Tr_1. Beware of measuring this with a meter of less than 10 MΩ resistance. The measured output impedance at 1 kHz is 420 kΩ, falling to 390 kΩ at 20 kHz. Maximum output is 5.6 V r.m.s. and clipping occurs symmetrically at an output of 18 V pk-pk.

The frequency response measured with a 2.2 kΩ load was flat between 30 Hz and 100 kHz with −3 dB at 10 Hz and 220 kHz. At rated output the distortion in the current waveform in the head at 1 kHz was 0.01%.

It is strongly recommended that capacitors C_1, C_3 and C_9 be paper or polyester. In particular any leakage in C_9 would cause a permanent polarization to build up in the recording head, degrading the performance. To avoid large currents flowing in the head during switch-on the d.c. level at the output rises slowly and the h.f. bias is arranged to decay slowly after switch-off to demagnetize the head.

Replay

Fig. 8 shows the circuit of the replay amplifier. It is arranged as an equalization stage and a 20 dB gain stage to raise the output level to 250 mV r.m.s. The input from the UK 202B replay head is 2mV r.m.s. for a 1 kHz tone recorded at 32 mMx/mm at 7½ i.p.s.

Careful power supply design has enabled a hum level of −80 dB to be achieved with a very low crosstalk. The amplifier crosstalk measured was −74 dB at 1 kHz, and −65 dB at 10 kHz, for rated output; distortion is less than 0.01% and is predominantly 2nd harmonic; the overload capacity is 17 dB at 1 kHz with 7½ i.p.s. equalization. To obtain the best signal to noise ratio in this amplifier the CA 3048 amplifier is used; it has a tighter noise specification than the CA 3052 and is slightly more expensive. The measured noise was 66 dB below 0 dB level with 7½ i.p.s. C.C.I.R. replay equalization in a 20 kHz band and Fig. 9 shows the spectral density of the noise output of the replay stage.

High-quality Tape Recorder

2. Construction

by J. R. Stuart, B.Sc.

Signal monitoring takes two forms in this recorder—A-B signal switching, and a peak-programme meter to read signal and bias levels.

Experience has shown that the most effective meter has a fast attack and slow decay time. This stabilizes the pointer and gives a pessimistic reading, reducing the risk of overload while maintaining wide dynamic range.

Probably the most difficult transient a music signal could provide would be of 25 s duration, being one half cycle at 20 kHz! Although this is unlikely the meter described was designed to attempt to cope with this. A circuit diagram is shown in Fig. 11.

For simplicity only positive-going peaks are read. It is a simple matter to extend the circuit to read positive and negative peaks, but no instances have been found to suggest that this should be necessary. The author has used a meter of this type for several years without problems.

As the input signal to the recorder is balanced, either from a programme source or mixer, it is not necessary to have two expensive meter movements. Instead a ganged record gain control is used and the meter circuit of Fig. 11 indicates on a logarithmic scale the peak value of whichever channel is the greater at any instant.

Two i.c. amplifiers, A1 & 2, are used to raise the OdB input signal to 1V r.m.s. These low output impedance amplifiers charge capacitor C_{23} to the peak positive value via D_1 or D_2 and as the forward resistance of the diodes is current dependent, the attack time will depend upon the amplitude difference between successive peaks, with a minimum value of around 20 s. The decay time is determined by the rate at which C_{23} is discharged by the high input impedance of the amplifier formed by Tr_4 and Tr_5. This impedance is nearly $\beta_4 \beta_5 R_{31}$ and the measured decay time is around 2s. Two zener diodes are included in the collector network to give a three-slope approximation to a logarithmic response; this approximation is good as can be seen in Fig. 12. Table 3 gives the meter calibration. The linearity is good and the meter response to continuous sine-wave is within ± 0.5dB from 10 Hz to 10 MHz.

To set-up the meter, switch on with the wipers of R_{29} and R_{30} set to ground, slowly rotate R_{29} until 2 μ A flow in the meter and then rotate R_{30} until the meter reads about 3 A. The circuit is now set and the calibration is determined by R_{25} and R_{31}.

As would be expected the super-alpha pair Tr_4 and Tr_5 exhibit some temperature sensitivity but the author has found no problems: R_{29} and R_{30} need never be touched after the initial set-up, provided $C_{22a,b}$ are paper or polyester capacitors and D_1 and D_2 silicon planar diodes. Small drifts in the standing current through the meter do not affect calibration, which is highly predictable.

Two schemes have been included in the basic recorder for A-B monitoring and the one chosen will be determined by the pre-amplifier with which the recorder is used. The essential difference is that one scheme includes the A-B switch in the recorder, in the other this switching is a pre-amplifier function.

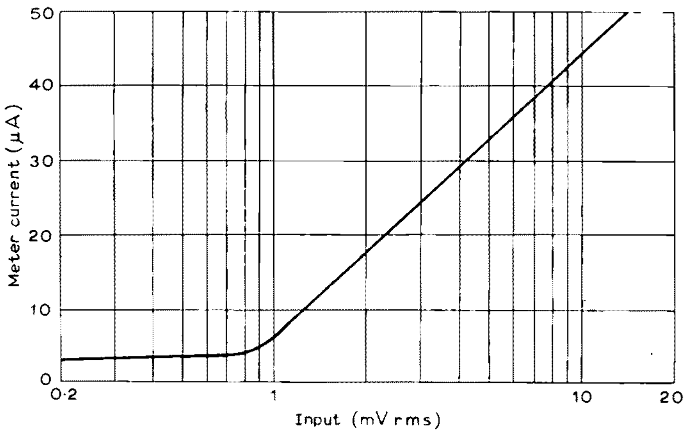


Fig. 12. Response of meter circuit.

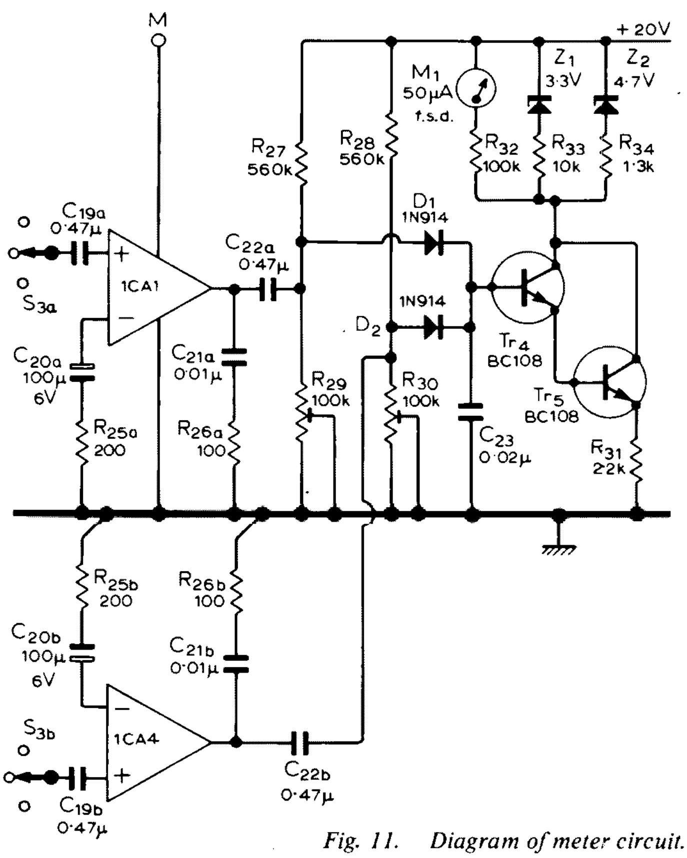


Fig. 11. Diagram of meter circuit.

TABLE 3 Meter calibration details

calibration current μA	calibration dB
50	+6
38.5	0
27	−6
16	−12
4.5	−18

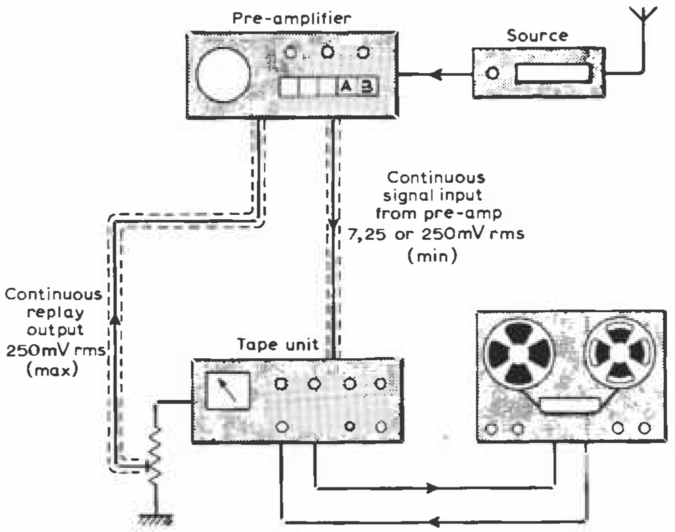


Fig. 13. A-B monitoring arrangement type 1. Input to top of RV_1 is 7mV. For output of 250mV r.m.s. link A + B, C + D: A′ + B, C′ + D′. For output of 25mV r.m.s. link A + D, A′ + D′; connect R to A.

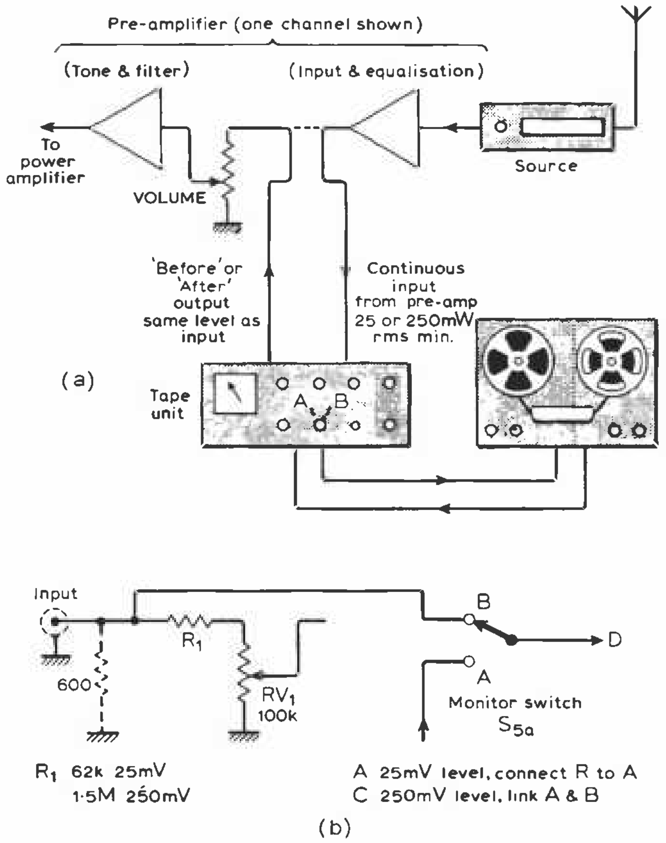


Fig. 14. A-B monitoring arrangement type 2. (a) The pre-amp is modified by breaking the lead shown dotted and re-routing as indicated. (b) Wiring for one channel.

Some amplifiers (Quad 33 and Leak for example) provide tape A-B switching. The scheme is shown in Fig. 13.

If this facility is not available then the scheme shown in Fig. 14 may be used; the input signal is passed to the recorder, which then either routes it back to the pre-amplifier 'B', or replays the signal on tape 'A'. The levels are arranged to be the same in this design, and the A-B function may be carried out at a 0dB level of 25 mV r.m.s. or 250 mV r.m.s. as shown in Figs 13 and 14, with reference to Fig. 3.

Bias and erase oscillator

As the bias network and erase heads present a reactive load to an erase oscillator it is a difficult problem to ensure that the calibration of the bias and erase current are retained on switching from stereo to single track recording. The most direct method of ensuring well defined currents is to use a master oscillator and two current mode output stages, this is described in Part 3: however the increased complexity and cost were not considered worthwhile in this recorder, in view of the excellent results which can be obtained, with care, from a multivibrator.

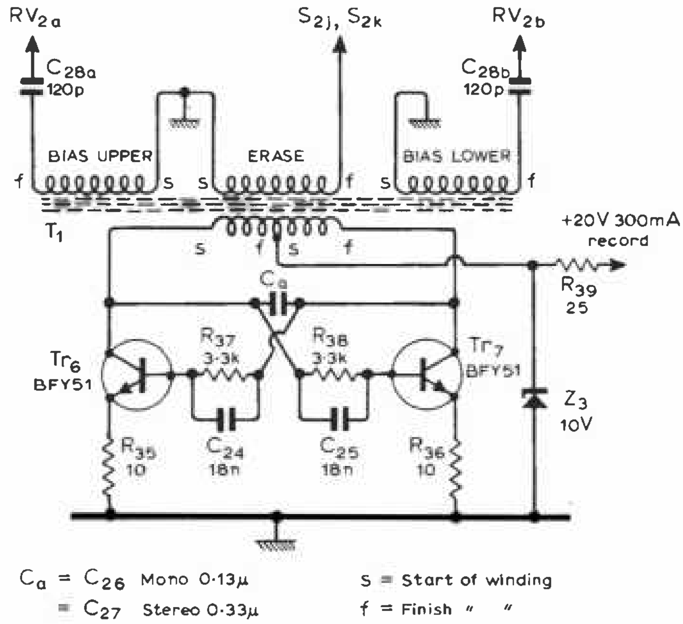


Fig. 15. Circuit diagram of erase oscillator.

Fig. 15 shows the circuit diagram of the oscillator. Although it does not operate in Class D[9] it is of a current switching type, the current being determined by the reflected load on the transformer primary and the supply voltage. Amplitude of oscillation is determined by Z_3. The Brenell Mk6 deck is fitted with Bogen UL290 erase heads. These require 70 V r.m.s. at a current of 45 mA (100 kHz) the equivalent loss resistance is 10 kΩ, giving a power of 500 mW per channel. Bias requirement for the recording head is 24 V r.m.s. at 9.7 mA for each channel.

In order to minimize interference from Droitwich transmissions, or harmonics of 38 kHz from stereo decoders, the oscillator was designed to run at 107 kHz. This frequency is set by the total effective primary inductance of T_1 and C_a; which is switched to keep the frequency constant for mono or stereo recording. On mono a 10 kΩ load is switched across the erase head to keep the bias and erase currents unchanged, see Fig. 2. L_{2a} and L_{2b} form high impedance tuned rejectors to keep the h.f. bias out of the recording stage, some 100 mV pk-pk of bias waveform appears at C_9.

The bias current is set by the capacitors C_{28a} and $_b$, and the ganged potentiometer RV_2 gives +3, −5 dB variation in the bias current, around 0.7 mA. As the loaded Q of the tuned circuit is around 30 the third harmonic distortion should be less than 0.4%. In fact because the driving waveform on the transistor bases is not square the distortion is about 0.1%. This is quite adequate for a bias waveform and the author can detect no increase in the noise on virgin tape when the oscillator is switched on, in fact the increase is just less than 1 dB. C_{30} ensures that the bias decays slowly to demagnetize the recording heads. Winding details for all coils are given in Table 4.

Power supply

During playback the quiescent power requirement is about 60 mA at +20V and this rises to about 500 mA during recording. Fig. 16 shows the circuit of a regulator which will accept 30-60V d.c.

TABLE 4 Winding details for inductors

L_1	100 turns 36 s.w.g. enamel covered wire.
L_2	275 turns 36 s.w.g. enamel covered wire.
T_1	Primary 5 + 5 turns 26 s.w.g. enamel covered wire, bifilar wound. Erase winding 100 turns 34 s.w.g. enamel covered wire. Bias winding 100 + 100 turns 36 s.w.g. enamel covered wire, bifilar wound. Separate each winding with one layer of Sellotape or similar.

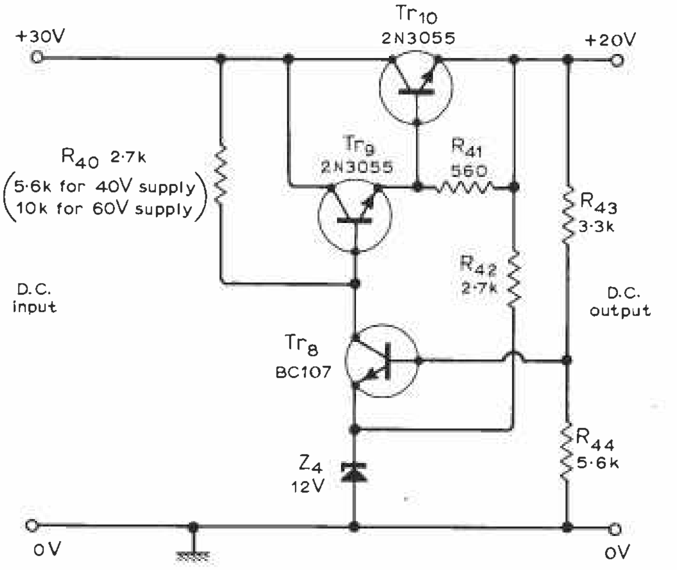


Fig. 16. Power supply input regulator. R_{40} must be altered as shown if higher supply rails are employed.

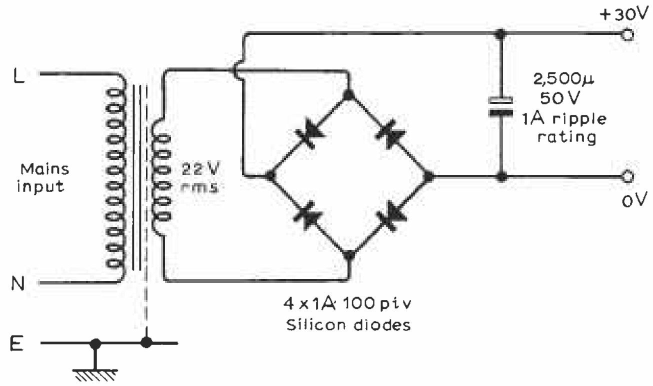


Fig. 18. Main supply circuit.

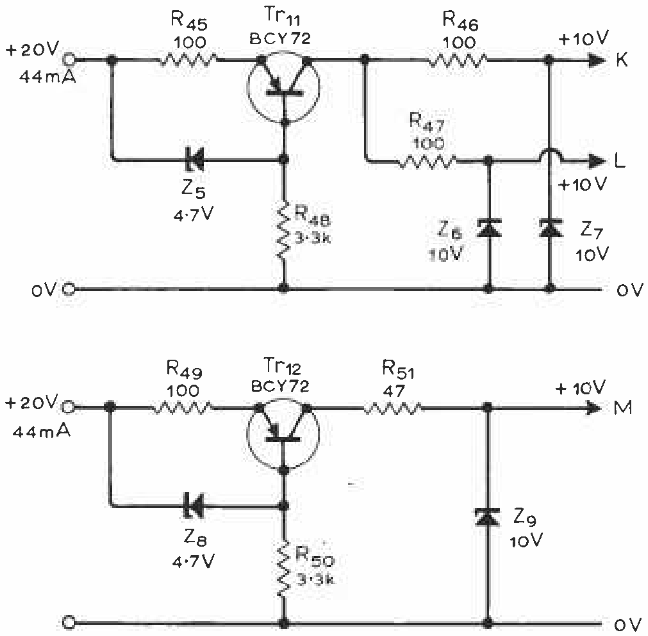


Fig. 17. 10V supply regulators.

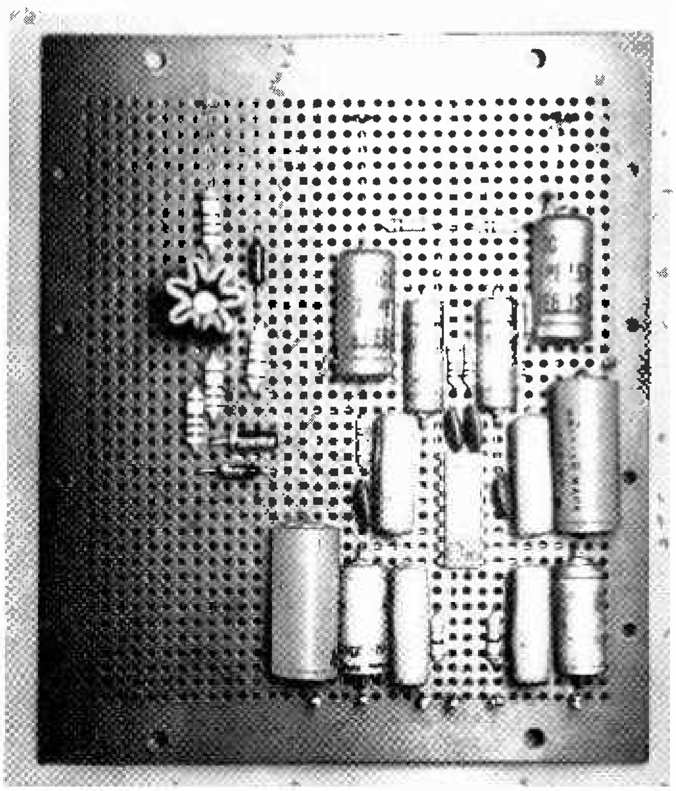


Fig. 19. Replay amplifier board.

input to give a 20V supply for the recorder. Tr_{10} should be mounted on a heatsink, or bolted to the chassis, with mica insulation to allow a safe operating temperature.

The integrated circuits use three separately derived +10V supplies to ensure stability and low crosstalk; the circuit is shown in Fig. 17. Tr_{11} and Tr_{12} are arranged as current sources. This affords protection to the i.c. and the effect of the low zener slope resistance with the high impedance of the current source is to reduce ripple by more than 66 dB. Tr_{11} and Tr_{12} should be fitted with cooling clips as they dissipate 160 mW each. Fig. 18 shows a simple power supply which may be used if d.c. is not available from the power amplifier.

Construction

The recorder unit circuits are built into an enclosed metal case. This affords rigidity and adequate screening. If a mains transformer is required it is recommended that this is not mounted in the case, but away from the unit and deck to maintain the low hum figures. A front panel carries all the controls detailed in Fig. 3 and the recording-level meter.

The circuits are built up on three Lektrokit boards 4in × 4¾in. The first board, which is shown in Fig. 19, carries the replay circuits including i.c.B and the regulator Tr_{11} which derives the +10V supplies for K and L in Fig. 8. (Pt. 1).

No special precautions need to be taken with the integrated circuits; the networks C_{14}, R_{21} and C_{17}, R_{23} reduce the gain above 200 kHz. Stability is independent of layout.

Fig. 20 shows the second board which carries the meter circuits, record equalization and output stages, including i.c.A. Layout is again non critical.

The third board shown in Fig. 21 holds the erase oscillator, bias rejection and the regulator Tr_{12} to power i.c.A. In the author's version the 20V regulator of Fig. 17 was external, however there is plenty of room to mount it on this third board. All equalization components are mounted on the switch S_1. To obviate any earthing or hum-loop problems the course adopted was to common on each board all earth and supply points and arrange only one connection to be made to these two rails. This means that the earth and supplies are common to the two channels but only one earth and supply lead is used per board. All signal leads in the unit are screened as indicated in Fig. 3 and the braid is earthed at only one end, that being the source. A wiring diagram is shown in Fig. 22.

It is not necessary to screen the circuits from each other. The erase board and the replay amplifiers should be arranged to be as

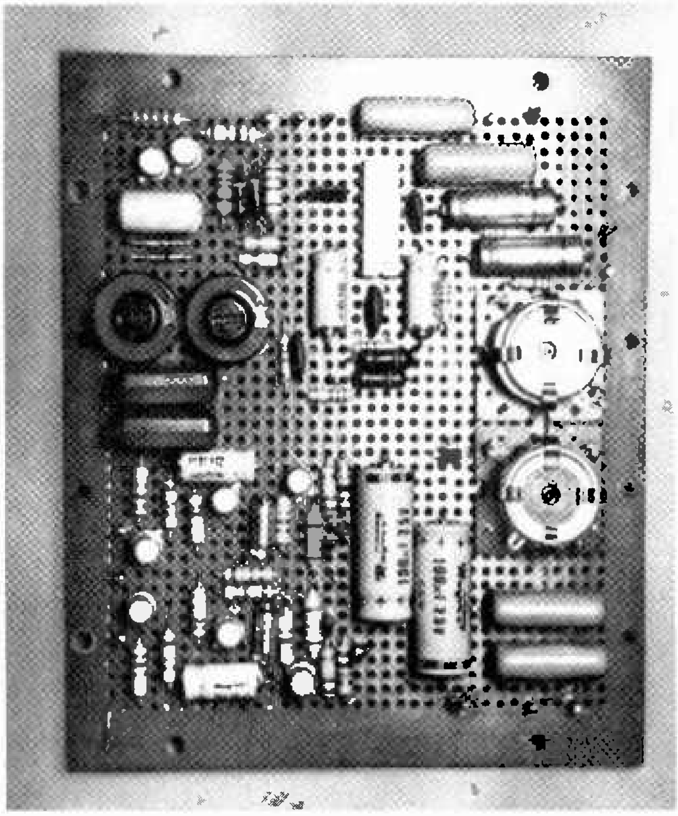


Fig. 20. Recording and meter drive circuits.

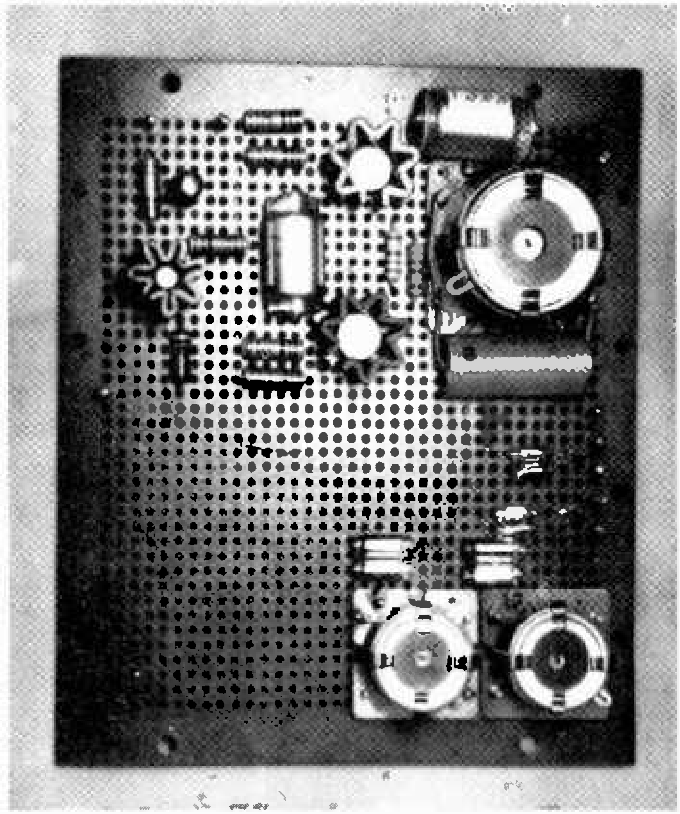


Fig. 21. Construction of erase oscillator.

far apart as possible but otherwise the layout is a matter of convenience. Inputs and outputs use Belling-Lee coaxial sockets for economy and good reliability. The Brenell deck supplies coaxial plugs on the record and replay heads, however the erase leads will have to be fitted with coaxial plugs.

Switching

Switching is carried out at the front panel and on the deck, the only switch which is repeated is the speed change. This was done to avoid the inevitable hum pick-up which would occur switching signals at the deck, and also it would not be possible to cater for the four speeds as the Brenell Mk6 deck uses a three-way switch with two capstans to provide $1\frac{7}{8}$, $3\frac{3}{4}$, $7\frac{1}{2}$ or $3\frac{3}{4}$, $7\frac{1}{2}$ and 15 i.p.s.

The record-play function is only required to switch the inputs to the recording equalization and to provide a 20 V rail to the recording circuits. For simplicity the Brenell deck is modified to give this +20 V rail when it is switched to record—which has an interlock button; the signal switching is then performed by a small low current relay, S_4.

This modification is necessary because in standard form the record-off-play switch on the deck is arranged to short the erase heads on all but the record position. This is not desirable as it would inhibit the decaying bias waveform. Fig. 23 illustrates the modification. The spare wafer is used to switch the +20V supply.

Testing and setting-up

It is recommended that the circuits are tested individually before final power supply connections are made. D.C. levels should be checked using a good multimeter; check all supplies, and the output of each i.c. amplifier, which should be around +5.6V in each case. The d.c. conditions of the recording output stage can be checked by measuring the potential on the emitter of Tr_3. This should be about +9.4V. If any discrepancy is noted, switch off immediately and check the circuit. Set up the meter as described. This may now be used when adjusting the bias rejection; otherwise use a high input impedance millivoltmeter or an oscilloscope. The bias rejectors L_2 allow a 5% adjustment of inductance and this should be more than enough to accept the expected uncertainty of oscillator frequency. Loose wiring or winding on L_2a or $_2b$ may move the resonant frequency, in which

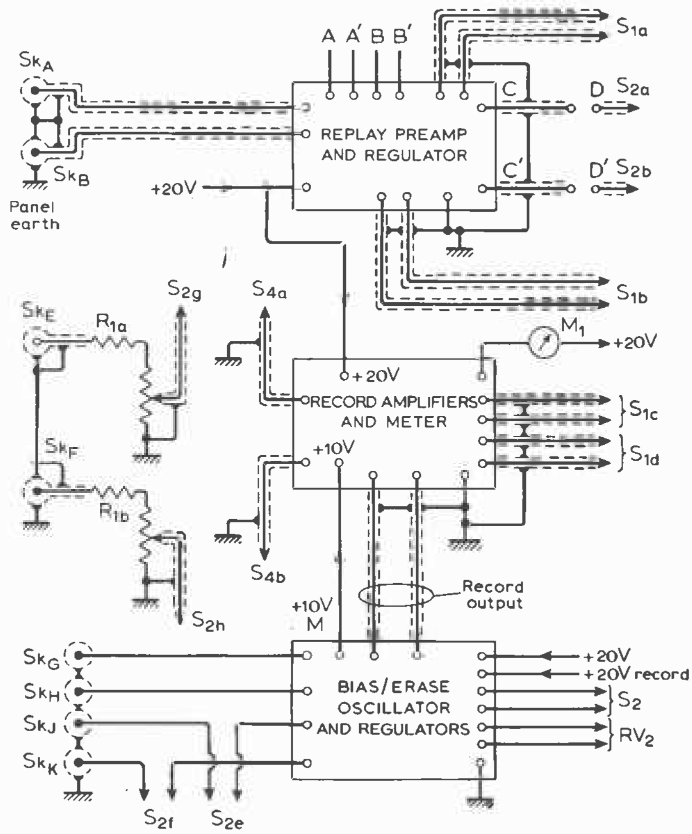


Fig. 22. Overall wiring diagram.

TABLE 5 Recording pre-emphasis component valves

speed	boost frequency	amount of boost	C_1 nominal	R*	overload margin of boost
ips	kHz	dB	μF	kΩ	dB
15	28	8.6	0.01	2.4	+5
7.5	15.5	18.25	0.02	22	−4
3.75	9	19.0	0.05	27	−5
1.875	6.5	19.0	0.08	27	+1

* depends on final Q of L_1

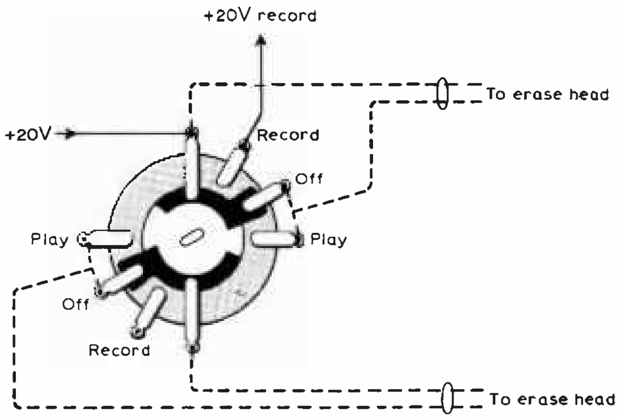


Fig. 23. Switch modification for Brenell Mk 6 deck. Remove wires shown dotted and add the wires shown solid.

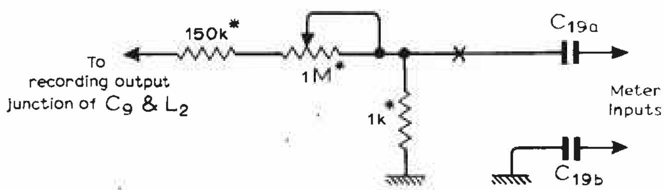


*Fig. 24. Arrangement of meter to set up bias rejection. Begin with the potentiometer set to maximum, then reduce as null is approached. Components marked * are required only for setting up.*

case *C* will have to be adjusted to find the null. Switch to record and using the arrangement of Fig. 24, or by another means, adjust L_2a and $_2b$ for a minimum bias voltage at the recording amplifier—with all erase and record heads connected. The meter may now be wired, according to Fig. 3. Check that bias is present at the correct level and that about +3 −5dB variation is available. The recorder is now set up and ready to operate.

Choice of recording standard

Several replay standards can be used and these are shown in Fig. 10. The choice will depend upon the tapes to be replayed. All the measurements given here use either the C.C.I.R. standard or C.C.I.R. with high frequency lift. On replay some high-frequency boost can be applied by connecting *Cx* and *Ry* of the values given; note that this network must be switched for each speed requiring an extra two poles on S_1. If tapes recorded to a different standard are to be used this lift must not be applied; however for recordings made on this machine the boost will compensate replay head losses at high frequencies and enable a true 'constant-induction' recording characteristic to be used, with less chance of high frequency overload.

It must be understood that having chosen a replay characteristic, then although a good approximation can be made, the amount of recording pre-emphasis which must be applied depends upon the tape used, the bias level—which incidentally will be different for each speed—and the form of response which is required, see Part 1.

Two examples are given here, maximally flat response with C.C.I.R. playback, maximally flat response with C.C.I.R. and high frequency lift. These two give low intermodulation distortion at high frequencies.

The component values are given in Table 5. The first response is shown in Fig. 1 and the dotted curve gives the response with high frequency lift on playback. With careful construction there is no reason why these specifications should not be met.

REFERENCE

9. Baxandall, F. J., "Transistor LC Sine-wave Oscillators", I.E.E. paper 2 978 E, February 1960.

Corrections to Part 1 on p. 595

Component List

Capacitors

C_1*	0.47μ paper†	C_{16}*	64μ 6.4V
C_2*	25μ 25V	C_{17}*	0.01μ disc ceramic
C_3*	1μ paper	C_{18}*	150μ 6V
C_4*	12μ 6V	C_{19}*	0.47μ paper
C_5*	0.01μ disc ceramic	C_{20}*	100μ 6V
C_6*	0.02μ disc ceramic	C_{21}*	0.01μ disc ceramic
C_7*	0.05μ disc ceramic	C_{22}*	0.47μ paper
C_8*	0.08μ disc ceramic	C_{23}	0.02μ disc ceramic
C_9*	1μ paper	C_{24}	18n polystyrene
C_{10}*	1000μ 6.4V	C_{25}	18n polystyrene
C_{11}*	0.47μ paper	C_{26}	0.13μ 2% paper
C_{12}*	250μ 6V	C_{27}	0.33μ 2% paper
C_{13}*	0.33μ paper	C_{28}*	120p polystyrene
C_{14}*	0.01μ disc ceramic	C_{29}*	270p polystyrene
C_{15}*	0.47μ paper	C_{30}	500μ 25V

*two required †or plastic in each case

Semiconductors

ICA	CA3052	supplied by A. Marshall	Tr_{11}	BCY 72	with cooling clips
ICB	CA3048		Tr_{12}	BCY72	
Tr_1*	BC108		$D_{1,2}$	1N914	
Tr_2*	BCY72		Z_1	3.3V 400mW	
Tr_3*	BC108		Z_2	4.7V 400mW	
Tr_4	BC108		Z_3	10V 1W	
Tr_5	BC108		Z_4	12V 400mW	
Tr_6	BFY51	with 5 cooling clips	Z_5	4.7V 400mW	
Tr_7	BFY51		Z_6	10V 400mW	
Tr_8	BC107		Z_7	10V 400mW	
Tr_9	2N3055	plus insulation	Z_8	4.7V 400mW	
Tr_{10}	2N3055		Z_9	10V 400mW	

* two required

Resistors All ¼W 5% carbon unless otherwise stated.

R_1*	see Fig. 3	R_{21}*	100	R_{41}	560
R_2*	750	R_{22}*	5.6k	R_{42}	2.7k
R_3*	120	R_{23}*	100	R_{43}	3.3k
R_4*	2.4k	R_{24}*	10k	R_{44}	5.6k
R_5*	22k	R_{25}*	200	R_{45}	100
R_6*	27k	R_{26}*	100	R_{46}	100
R_7*	27k	R_{27}	560k	R_{47}	100
R_8*	2.7k	R_{28}	560k	R_{48}	3.3k
R_9*	18k	R_{29}	100k pre-set	R_{49}	100
R_{10}*	16k	R_{30}	100k pre-set	R_{50}	3.3k
R_{11}*	910	R_{31}	2.2k	R_{51}	47
R_{12}*	470	R_{32}	100k	R_{52}*	18k
R_{13}*	10k	R_{33}	10k	R_{53}*	4.7k
R_{14}*	2.4k	R_{34}	1.3k	R_{54}*	1M
R_{15}*	47	R_{35}	10 ½W metal oxide	R_{55}*	330
R_{16}*	see Fig. 8.	R_{36}	10 ½W metal oxide	R_{56}	to suit bulb
R_{17}*		R_{37}	3.3k	RV_1	100k log 2-gang
R_{18}*		R_{38}	3.3k	RV_2	50k lin. 2-gang
R_{19}*		R_{39}	25 5W w/w		* two required
R_{20}*		R_{40}	2.7k		

Inductors

L_1 Plessey 905/1/01581/006 μe 18mm pot core with base and clips, or Mullard LA2532. Two required.

L_2 Plessey 905/1/01581/009 μe 18mm pot core with base and clips, or Mullard LA2538. Two required.

T_1 Plessey 905/1/01613/008 μe 26mm pot core with base and clips, or Mullard LA2332. One required.

Switches etc.

S_1 4-pole 4-way (minimum, see text) make-before-break
S_2 9-pole 3-way make-before-break
S_3 2-pole 3-way break-before-make
S_4 low-current relay 2-pole change over.
S_5 required for A-B monitoring arrangement type 2. 2-pole 2-way break-before-make
Bulb (6V 40mA: R_{56}=330)
Lektrokit board ×3 plus pins.

High-quality Tape Recorder

3. Extensions and modifications

by J. R. Stuart, B.Sc.

The variable high-frequency bias allows optimum recordings to be made with a variety of tapes and speeds, and it is a simple matter to reset any bias condition with the meter. Although the A–B monitoring allows an excellent attempt to be made by ear, it is not always straightforward to discover the required bias initially. In particular, if the recording is to be replayed on another machine, it may be necessary to bias for maximum sensitivity, minimum distortion, or some arbitrary standard.

The normal criterion for low tape speeds is to increase the bias until the sensitivity at 1 kHz is 1 dB below maximum. To allow easy setting of this bias current many high-quality recorders include a 1 kHz reference oscillator.

Such an oscillator would either be an *RC* arrangement with amplitude definition and stabilization provided by a thermistor or field-effect transistor, or a current switching *LC* oscillator[9] of the type shown in Fig. 25. The output of this oscillator is well defined by the dynamic impedance of the tuned circuit and the tail current. However the values of *L* and *C* required do not lead to accurate prediction of the frequency of oscillation.

To calibrate the recorder using a reference, switch the meter to record and set the input level to −6 dB, then, while recording, switch the meter to replay and adjust the high-frequency bias for the required sensitivity. Note the bias voltage.

It is probable that in a large number of applications a simple stereo signal is not available. This will certainly be true of live or special-effect recordings, and for these a linear mixer is essential.

Fig. 26 shows a mixer which could be built as part of the recorder unit. For simplicity a CA 3048 integrated quad amplifier has been used, giving two inputs per channel. By extrapolation, further addition of i.c.s will give the required number of inputs.

The i.c. should be powered by a regulator identical to that shown in Fig. 17. Output *M* is satisfactory providing that it is not intended to cascade amplifiers in the same chip—to do so may cause low-frequency instability, so the dual output regulator (*K*, *L*) should be used.

This mixer is intended for a 250 mV rated output, with a 12 dB overload margin. R_x defines the gain of each mixer stage and a range of values is given in Fig. 26. However, if at any time high sensitivity is required, better noise performance would result from a lower gain mixer feeding the 25 mV input.

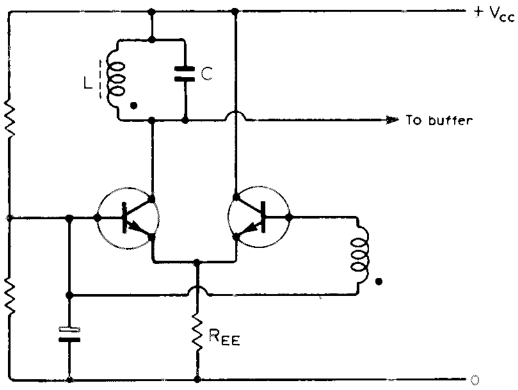
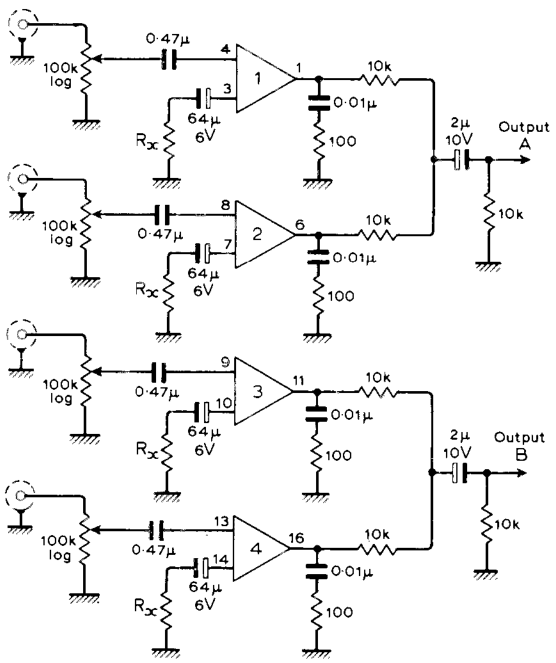


Fig. 25. A current-switching oscillator.



R_x	Stage gain (dB)	Mixer gain (dB)
∞	12	6
5·6k	20	14
2·2k	26	20
1k	30	24
560	36	30
390	40	34
56	50	44

Fig. 26. Circuit of a linear mixer.

Superimposition was at one time a common facility on good quality recorders. However, this is extremely unsatisfactory as each recording erases to some extent the high frequency information of the previous recordings. By rearranging the track-switching and making use of the mixer and the logarithmic meter, signals may be superimposed by recording from one track to another. This allows the quality of the initial signal to be maintained through several superimpositions. For this two switches replace S_2, one for record and the other for replay.

Discrete component version

Some constructors may prefer to build discrete amplifiers in place of the integrated version recommended and described in parts 1 and 2. This could be suitable for a mono record-only machine where all replay equalization is performed in the pre-amplifier.

A discrete-component replay amplifier is shown in Fig. 27 and the circuit values for equalization are given in Table 6.

Transistors Tr_{13-15} form a direct-coupled triple with a mid-band open-loop forward voltage gain of around 80 dB; the closed loop

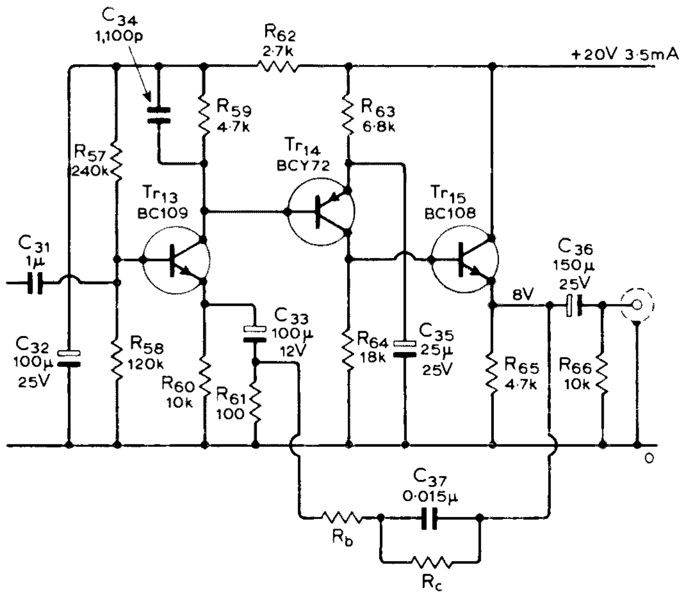


Fig. 27. A discrete-component replay amplifier.

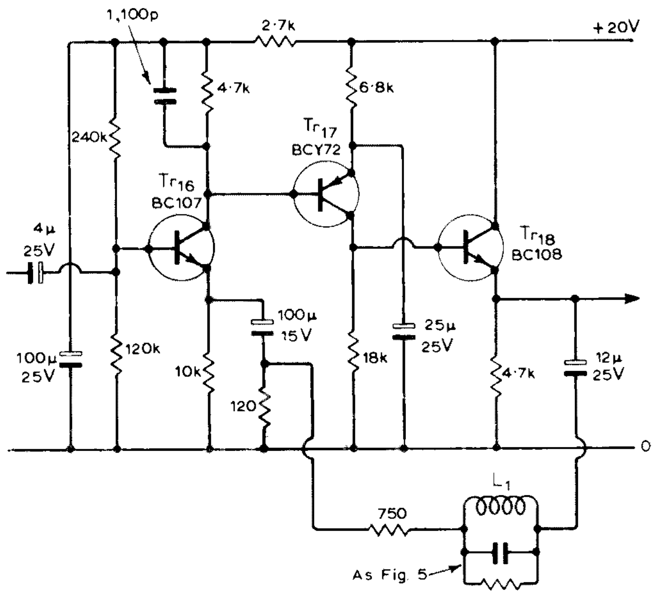


Fig. 28. Recording equalized amplifier.

gain has been arranged to give an output of 250 mV r.m.s. at the rated input, with a signal-to-noise ratio of 70 dB.

Capacitor C_{31} should be paper or plastic to ensure low leakage and avoid polarization of the head, C_{34} stabilizes the loop at high frequencies and the maximum output is 4·5 V r.m.s.

There should be no discernible differences between the performance of this amplifier and the integrated version.

The recording pre-emphasis pre-amplifier can be replaced by the amplifier shown in Fig. 28. This is very similiar in performance to that of Fig. 27 and the equalization components will be identical to those used in the integrated version. By replacing the equalization network with a 17 kΩ resistor the amplifier of Fig. 28 will have a forward gain of 140, to drive the meter.

Record output

It was stated in part 1, that the best method of ensuring a constant-current recording characteristic, is to include the head in the feedback loop of a high-gain amplifier. Such an arrangement is shown in Fig. 28. The performance of this circuit is excellent. Measured total harmonic distortion in the current waveform was less than 0·01 % at an output of 140 μA r.m.s.

However the problem of bias rejection is considerable and it is strongly recommended that only an experienced constructor, with access to a good oscilloscope, should attempt this type of output stage. The problem arises because the rejection must take place at an input, where only 50 mV r.m.s. bias will switch the amplifier output between the rails.

Erase and bias oscillator

Although the oscillator described in part 2 performs very well on mono or stereo, a direct method of ensuring that bias and erase current calibration is retained in all modes, is to employ a separate output stage for each erase head, synchronizing these outputs by a master oscillator.

Considerable thought was given to the output stage. Class A and B were ruled out directly because of cost, and as it is extremely

TABLE 6. Equalization details for Fig. 27

time constants μs	R_b Ω	R_c Ω
35+ ∞	2·2 k	∞
50+3180	3·3 k	220 k
70+ ∞	4·7 k	∞
50+ ∞	3·3 k	∞
140+ ∞	9·1 k	∞
90+3180	5·6 k	220 k
140+3180	9·1 k	220 k
90+ ∞	5·6 k	∞
280+ ∞	18 k	∞
120+1590	8·2 k	110 k
120+ ∞	8·2 k	∞

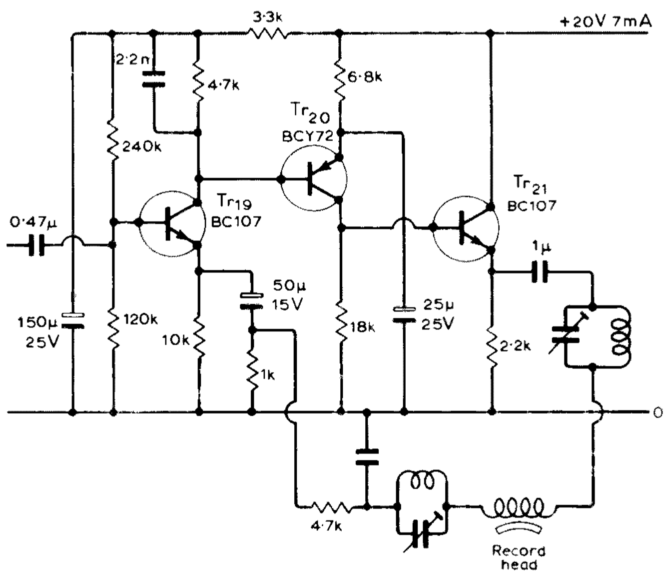


Fig. 29. A feedback recording output stage.

difficult to predict the performance of a class C amplifier, a current switching design was evolved. Fig. 30 shows an erase oscillator of this type; only one output stage has been drawn but several may be driven from the master oscillator without modification.

Transistors Tr_{22} and Tr_{23} form an emitter-coupled multivibrator which runs at 93 kHz. Tr_{24} is a buffer, the output of which is arranged to have a positive maximum a few hundred millivolts above V_{ref}.

Frequency of oscillation is stabilized by the two zener diodes, and the long-term drift is less than 0·1 %. A current, defined by V_{ref} and R_m, is switched alternately between Tr_{25} and Tr_{26} and its magnitude must be arranged so that these transistors nearly saturate at the required output level.

In order that the bias waveform will decay slowly at switch-off, the time constants are arranged so that the multivibrator continues to oscillate on frequency until C_m has been discharged, allowing an exponential decay in the output current.

The transformer primary must have a high unloaded Q, and to achieve low distortion the loaded Q factor must be at least 10. The amplitude of the nth harmonic in the output for an ideal current-switching operation is

$$\frac{100}{(n^2-1).Q_l}\ \%$$

where Q_l is the loaded Q factor. A good L/C ratio is necessary to allow reasonable loading of the tuned circuit. In Fig. 30 measured values for Q were 90 unloaded and 30 loaded, however the final values are considerably affected by construction, in particular long cables connecting the oscillator to the head can radically modify the levels.

Modification for alternative heads

The designs described in these articles were intended to be used with the Brenell Mk 6 deck, which incidentally, uses the same heads as the Mk 5 range. However a large number of readers may possess perfectly good decks which have recording, replay and erase heads whose parameters are very different from the Bogen heads.

It is expected that a large variety of heads can be accommodated with a few component changes, the critical parameters for the various heads are as follows:

(a) recording—a.f. current (μA)
—bias current and voltage
—bias frequency
—inductance
(b) replay —playback level at 1 kHz, 7·5 i.p.s. and 32 mMx/mm
(c) erase —voltage and current.

In Fig. 7 the transconductance of the output stage was expressed as $1/R_{12}$. Thus the input sensitivity can be deduced for any output current, and by calculation the constructor can decide whether or not sufficient output voltage swing is available. The recording sensitivity may be deduced as the pre-emphasis low-frequency gain is 7·25.

The only modification to the replay amplifier would be to adjust the forward gain to change the sensitivity from 2 mV.

As the open loop gain of the input i.c. is only 50 dB it is not advisable to attempt to increase the closed-loop gain by more than 6 dB although it may be reduced by some 10 dB. Any further adjustment should be made in the gain stage by adjustment of R_{22}, as described in Fig. 30.

The closed loop gain G of the amplifier shown in Fig. 36 is given by

$$G = \frac{R_c}{R_d} \cdot \frac{\dfrac{R_b + R_c + R_d}{R_c} + j\omega t_1}{1 + j\omega t_2}$$

if $A \gg G$

where t_1 is the upper time constant $= C_a(R_b + R_d)$ e.g. 70 μs, 140 μs
and t_2 is the lower time constant $= C_a R_c$ e.g. 3180 μs.

The appropriate equalization values may thus be determined.

It is not so simple to calculate the component changes to the erase oscillator.

Ensure that Tr_6 and Tr_7 are allowed to saturate. If this is not the case excessive power will be dissipated probably resulting in device failure. Beware also of raising the supply voltage above 15 V as the theoretical peak collector potential could be $\pi \times$ supply voltage.

Mono and four-channel

To construct a single channel version of the recorder it is necessary only to re-arrange the i.c. amplifiers for one i.c., and to modify the erase oscillator. The author suggests that i.c. amplifiers 2 and 3 be used for the replay section and 1 and 4 for recording pre-emphasis and meter circuits. A block diagram is given in Fig. 32. For those wary of modification, the erase oscillator can be built in standard form with C_{26} and R_{56} permanently wired in. See Figs 3 and 15. Otherwise R_{56} may be omitted, along with one bias winding, and the circuit operated from a lower supply—around 7 V.

Only one bias chain will be used in the meter; thus R_{28}, R_{30} and D_2 are omitted, and the current will be set to 3 μA by R_{29}.

At the time of writing the author knows of no source of decks fitted with four-track heads, for four channel recording, however it is straight forward to multiply the circuitry to cater for this—at any point in the future the replay and recording amplifiers can be duplicated, but the erase oscillator must be replaced by a design similar to Fig. 30, or by a more powerful version of Fig. 15. There are no strong arguments for re-arranging the i.c.s. The CA 3048 lends itself to a four channel cassette replay system, although at present no deck of suitable quality is available.

The author thanks Brenell Engineering Ltd, for valuable assistance given during the development of this recorder.

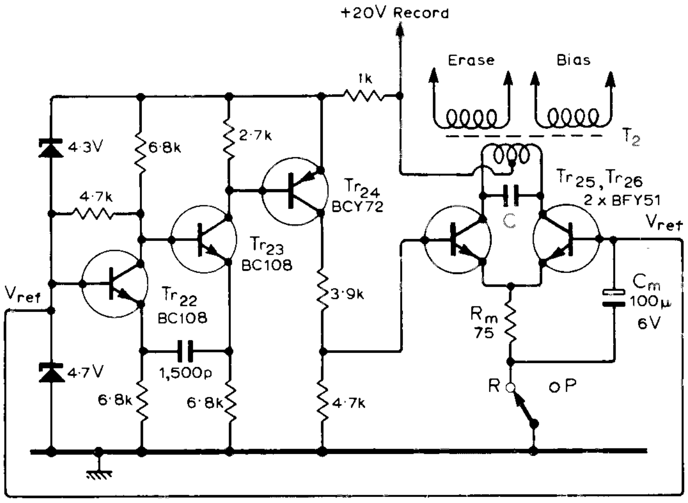
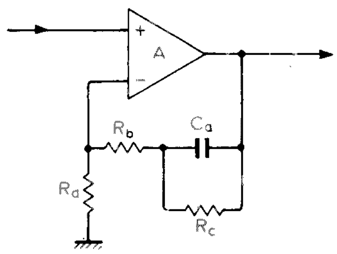


Fig. 30. Circuit diagram for an erase-bias oscillator.



$$G = \frac{A}{1 + A\beta} \simeq \frac{1}{\beta} \text{ when } A \gg G$$

$$\beta = \frac{R_a(1 + j\omega C_a R_c)}{R_c + (R_b + R_a)(1 + j\omega C_a R_c)}$$

Fig. 31. Replay amplifier equivalent circuit.

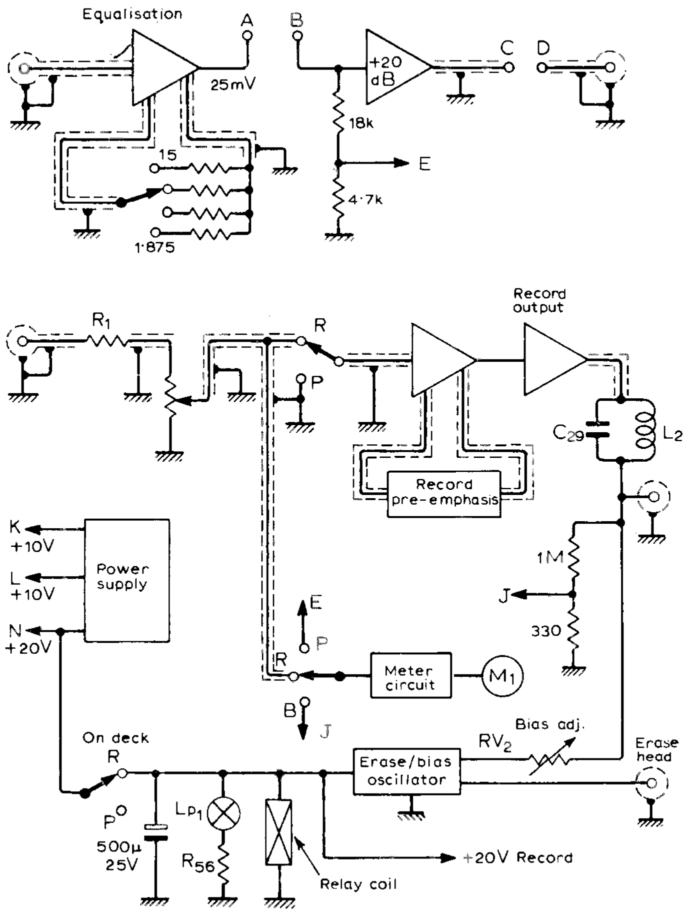


Fig. 32. Block diagram for mono.

Corrections to Part 2 on p.32

Corrections

High-quality tape recorder. The following points should be noted with respect to part 2 (December). On p.587 the symbol μ was omitted in col.1 line 9 and col. 2 lines 4 and 15. On p.588 col.2, line 16 should read '24V r.m.s. at 0.7mA'. In the captions to Figs. 13 and 14 'connect R to A' should read 'connect R_{56} to A'. Table 5 is referred as Fig. 28 on Fig. 5. In Fig.15 the erase output should go to S_{kj} and S_{kk} —the first k is drawn as a 2. Table 2 (part 1 November issue) gives R_y as μF instead of Ω