Accurate Record Equalizer

TRANSISTOR STEREO PICKUP PRE-AMPLIFIER CIRCUIT

By T. M. A. LEWIS*, B.Sc., A.R.C.S.

THE unit to be described is intended for use with high-quality magnetic pickup cartridges, and features unusually-accurate equalization for the standard microgroove recording characteristic. The signal-to-noise ratio is of high-fidelity standard and the total harmonic distortion is extremely low. Two of the pre-amplifiers can be used with stereophonic cartridges, provided the battery is decoupled so that cross-talk is minimized.

The specifications to which the unit was designed are:—

(1) Power supply 18V.
(2) Noise introduced by unit to be negligible under listening conditions.
(3) Equalization accuracy better than ± 1dB from 20c/s to 20kc/s.
(4) Total harmonic distortion $\leqslant 0.1\%$ at 100mV r.m.s. output.
(5) Gain at 1kc/s to be within $\pm$ 0.5dB of unity voltage gain when feeding a load $\nless 50\text{k}\Omega$.

As the results show, these specifications were achieved or bettered. The specification on equalization accuracy would seem unusually strict, but since the better magnetic cartridges available today have a frequency response which is flat within ± 1 dB from 30c/s to 15kc/s, it was thought worth while to aim for an equalization accuracy at least as good as that in specification (3). As far as the distortion figure is concerned, this would seem to be the accepted standard for high-fidelity reproduction.

Equalization.—Before describing the circuit, it is proposed to describe how the equalization is effected. The standard playback characteristic (B.S. 1928: 1960 and R.I.A.A.) can be written as the transfer function

$$f(j\omega) = \frac{K(1 + j\omega T_2)}{(1 + j\omega T_1)(1 + j\omega T_3)} \quad \ldots \quad \ldots \quad (1)$$

where ω is angular frequency ($2\pi f$), K is the gain at zero frequency, $T_1 = 3{,}180\mu$sec, $T_2 = 318\mu$sec, and $T_3 = 75\mu$sec.

Since it is necessary to use feedback to reduce distortion, the possibility of including the equalization components in the feedback loop was investigated. The type of feedback used was determined by the requirement that the unit should present a load of not less than 50kΩ to magnetic cartridges.

Two types of feedback are shown, in block form, in Figs. 1(a) and 1(b).

In Fig. 1(a), the closed loop gain will be Z_1/Z_2 and accurately defined, provided the open loop gain A is high, and that $Y_1 + Y_2 + Y_{in} \ll AY_1$, where Y_1 Y_2 and Y_{in} are the admittances corresponding to Z_1 Z_2 and R_{in} respectively. The closed loop input impedance will be approximately Z_2 since Point B is a virtual earth. Thus Z_2 must be greater than 50kΩ, which means that R_{in} must be of the order of 50kΩ. This can be achieved with an emitter follower, and this would be followed by a common-emitter stage to provide voltage gain. However, the open loop gain, as provided by just this one transistor, would not be sufficient to ensure accurate definition of the closed loop gain. Thus, without resorting to more than two transistors per channel this type of feedback is unsuitable.

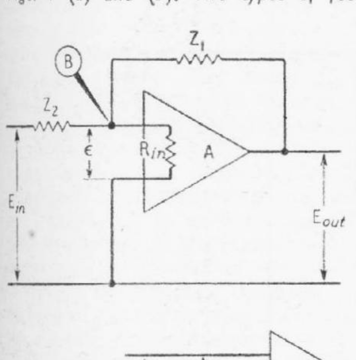
In Fig. 1(b) the closed loop gain will be $1 + Z_1/Z_2$ and will be accurately defined when the open loop gain is high. This being series feedback, the closed loop input impedance will be high enough to provide the correct loading for magnetic cartridges. The magnitude of the closed loop gain is always greater than unity, whereas the transfer function of equation (1) approaches zero as the frequency approaches infinity. Therefore, this type of feedback cannot provide the complete transfer function specified in equation (1). However, bass equalization is specified by the transfer function

$$f_b(j\omega) = \frac{K(1 + j\omega T_2)}{(1 + j\omega T_1)}$$

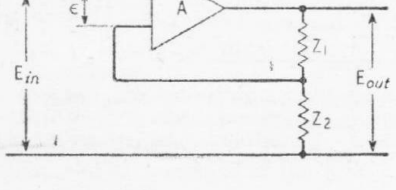
where K T_2 T_1 and ω are as before, and use of the network shown in Fig. 2 will produce the above transfer function.

Referring again to Fig. 1(b) then, provided that the signal current in Z_1 is very nearly equal to that in Z_2 and provided the open loop gain A is high compared with the maximum value of the gain $G(j\omega)$ when feedback is applied (a function of

Figs. 1 (a) and (b). Two types of feedback amplifier.



(a)



(b)

* English Electric Aviation Ltd.

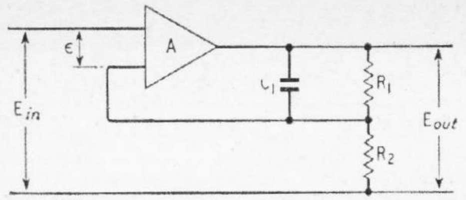


Fig. 2. Feedback amplifier providing bass equalization.

frequency), then $G(j\omega) = 1 + Z_1/Z_2$ to a high degree of accuracy.

In Fig. 2, Z_1 becomes R_1 in parallel with C_1 and Z_2 becomes R_2. Thus

$$Z_1 = \frac{R_1/j\omega C_1}{R_1 + 1/j\omega C_1} = \frac{R_1}{j\omega T_1 + 1}$$

where $T_1 = R_1C_1$

Therefore,

$$G(j\omega) = 1 + \frac{R_1}{R_2(j\omega T_1 + 1)}$$

$$= \frac{R_2(j\omega T_1 + 1) + R_1}{R_2(j\omega T_1 + 1)}$$

$$= \left(1 + \frac{R_1}{R_2}\right) \left[\frac{1 + j\omega T_1\left(\frac{R_2}{R_1 + R_2}\right)}{1 + j\omega T_1}\right]$$

This is of the form

$$G(j\omega) = K\frac{1 + j\omega T_2}{1 + j\omega T_1}$$

where $T_2 = T_1\frac{R_2}{R_1 + R_2}$ and $K = 1 + R_1/R_2$.

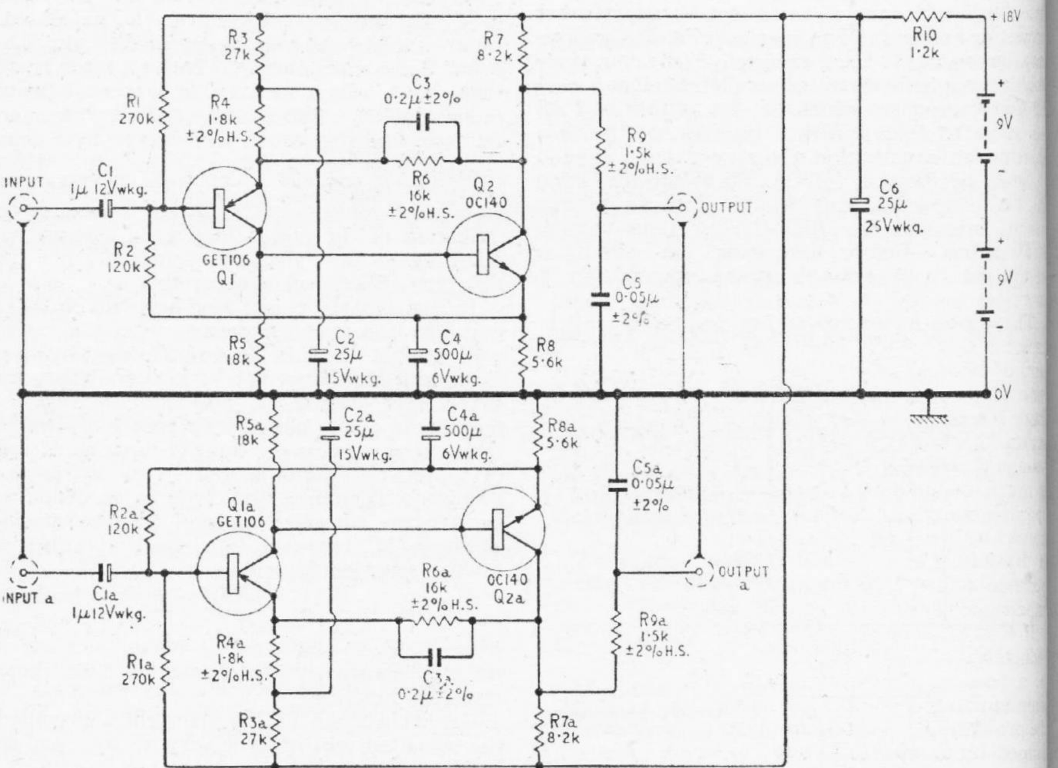
Thus if $T_1 = 3{,}180$ μsec, and $T_2 = 318$ μs[ec] then $G(j\omega) = f_b(j\omega)$. Thus bass equalization ca[n] be incorporated in the feedback loop.

In the circuit of Fig. 3, the components corre[s]ponding to R_1 C_1 and R_2 in Fig. 2, are R6, C[3] and R4 respectively (and R6a, C3a, and R4a for th[e] other channel).

Treble equalization is accomplished by a simp[le] C-R network (formed by C5 and R9 in Fig. 3) wi[th] a time constant of 75μsec, which is equal to th[e] specified time constant. This C-R network is ou[t]side the feedback amplifier, and the time consta[nt] will not be materially affected by the low outp[ut] impedance of the amplifier. The load on the outp[ut] may be as little as 50kΩ without affecting equalizati[on] accuracy.

It should be pointed out that the accuracy [of] equalization depends on component tolerances [as] well as the amount of feedback.

Circuit Details.—The circuit diagram of t[he] pre-amplifiers is shown in Fig. 3. The transisto[rs] used are Q1, GET 106, a p-n-p low-noise transisto[r] and Q2, OC140, an n-p-n transistor. A p-n-p a[nd] n-p-n combination is used to facilitate direct coupli[ng]



Figs. 3. Circuit diagram of a stereo pickup pre-amplifier providing equalization for fine-groove records. All resistors ar[e] ¼W, ±10% (H.S. means high stability) and all capacitors ±20% unless otherwise shown. The GET106 may be replace[d] by an OC44, OC45 or XA102, but with a slightly higher noise level. The OC140 may be replaced by an OC139, but wit[h] more distortion.

TABLE I: EQUALIZATION ACCURACY

Frequency c/s	20	30	40	50	60	80	100	150	200	300	500	700	1,000
Error dB	−0.1	0	0	0	0	+0.1	−0.1	0	0	0	0	0	0

Frequency kc/s	1.5	2	3	4	5	6	7	8	10	12	14	16	18	20
Error dB ...	0	0	0	−0.1	−0.1	−0.2	−0.2	−0.2	−0.1	−0.1	+0.1	+0.1	+0.2	+0.2

between the stages. The direct coupling avoids the low-frequency attenuation and phase shift associated with a coupling capacitor, thereby reducing the possibility of motorboating. Bass and treble equalization are accomplished separately; bass equalization within the feedback loop, and treble equalization outside. The d.c. conditions are stabilized by two d.c. feedback paths.

The battery supply is decoupled by R10 and C6, so that cross talk is minimized. (Alternatively, the units may be operated from separate power supplies.)

Input Circuit.—The first stage stands at approximately 300μA under quiescent conditions, and the collector-base potential is approximately 3.5V. These conditions result in close to optimum operation of the GET 106 as far as noise level is concerned.

Although the input may be applied between the base of Q1 and earth, it is possible to make the input connection such that much more cable capacitance may be tolerated. In this case, the cable will be double screened and is connected as follows:—

(a) Outer screen: Between cartridge "earth" and earth on pre-amplifier.

(b) Inner screen: Left unconnected at cartridge end and connected to emitter of Q1 at other end.

(c) Inner wire: Between cartridge "live" and input to pre-amplifier.

These connections considerably reduce the effect of the cable capacitance, and enable longer cables to be used.

The reason for the reduction of the effect of cable capacitance is as follows. The cable capacity consists of two capacities in series, one between signal wire and inner screen, C_a say, and one between inner screen and outer screen, C_b say. The voltage across C_a, is very small compared with the input voltage (being ϵ in Fig. 1b), and therefore its effect is much reduced. The voltage across C_b will be approximately the same as the input voltage, but instead of being associated with an input impedance of 100 kΩ, C_b is now connected to the low impedance point at the emitter of Q1 (compare the impedance at the cathode of a valve).

If C is the effective cable capacitance, and L the inductance of the cartridge windings, then there will be a peak in the output at a frequency which is approximately $1/2\pi\sqrt{LC}$, if the input impedance of the pre-amplifier is so high that the resonant circuit formed by L and C is underdamped. But C, the effective cable capacitance, is now very small, and with usual values of L, the peak in the response will occur at a frequency well above audibility, and the output will fall off thereafter.

D.C. Conditions.—The potential at the first base is set by the potential-dividing chain of resistors R1, R2, and R8, which take approximately 30μA from the supply. By defining the potential in this manner, d.c. negative feedback is applied from the emitter of Q2 to the base of Q1, thus stabilizing the collector current of Q1. By using static complementary symmetry, direct coupling between Q1 and Q2 is achieved, whilst maintaining the correct potentials so that the feedback from collector of Q2 to the emitter of Q1 may be direct coupled.

The unit should in general be capacitively coupled into the succeeding amplifier, but the capacitor need not be larger than 0.5μF, provided that the load is not less than the recommended lower limit of 50kΩ. (The load will be the input resistance to the next amplifier.)

Performance.—The performance of the pre-amplifier is shown in Tables 1 and 2.

Table 1: Equalization Accuracy.—This was measured using average samples of the transistors specified, and Table 1 shows that the accuracy was ± 0.2dB from 20c/s to 20kc/s. (This accuracy may be more conveniently expressed as ± 2 centi-

Table 2: Miscellaneous Tests and Measurements

(1) A large amplitude signal at 0.1c/s caused very little ringing or overshoot.
(2) When a square wave of 5V peak-to-peak at 20kc/s was applied at the input the output showed no trace of ringing or overshoot.
(3) A resistor of 560Ω was placed in series with the battery supply, and the equalization, even at bass frequencies, was completely unaffected.
(4) A load of 3,300pF at the output caused an attenuation of 1dB at 20kc/s.
(5) Input Impedance: 75kΩ at audio frequencies.
(6) Output impedance: 1.5kΩ at audio frequencies.
(7) Maximum input at 30c/s, before clipping: 200mV r.m.s. Maximum input at 15kc/s, before clipping: 760mV r.m.s.
(8) Total consumption (2 pre-amplifiers): 2.6mA.
(9) Equalization accuracy completely unaffected when unit was at 60°C for one hour.
(10) The clipping level was reduced by 1dB under the conditions of (9).
(11) When the supply was reduced to 7.5V, equalization accuracy was ± 0.6dB, and the total harmonic distortion, measured at 3.5kc/s and 100mV r.m.s. output, was $\leqslant$ 0.05%.
(12) Cross talk between the units was better than 55dB below 100mV r.m.s. at audio frequencies.
(13) The measured gain of the unit at 1kc/s, feeding a 56kΩ load, was + 0.1dB relative to unity voltage gain.

bels!) The accuracy was also measured using transistors different to those specified, having current gains of 15 and 30 for Q1 and Q2 respectively, and was found to be within ± 0.5dB from 20c/s to 20kc/s. It should be noted that these values of current gain are lower than the manufacturer's published lower limits for the transistors specified. As noted previously, the accuracy of equalization depends upon the tolerances of R4, R6, R9, C3 and C5.

Distortion.—The distortion was measured at 3.5kc/s because a filter was available which attenuated the signal at 7kc/s by 70dB relative to the signal at 3.5kc/s. Thus a signal of 3.5kc/s with very little harmonic content was available. The distortion output of 100mV r.m.s. was unmeasurable, so the figure at 150mV r.m.s. output was measured, and found to be less than 0.015% total harmonic. When the output is 150mV r.m.s. the input is approximately 300mV r.m.s. which is of the order of ten times the peak output available from a magnetic cartridge and a microgroove disc at 3.5kc/s.

Table 2: Miscellaneous Tests and Measurements.—Results (1) and (2) show that the pre-amplifier is very stable. Result (3) shows that the unit's performance will not deteriorate as the battery ages (i.e. as its internal resistance gets higher). Result (6) indicates that screened cable up to 15 feet in length may be used at the output. Result (7) shows that the pre-amplifier will handle signals from a typical magnetic cartridge at well below clipping level. Results (9) and (10) show that the unit is unaffected by temperatures of up to 60°C (which is 140°F). Result (11) shows that the performance is but little affected by the supply voltage in the range 7.5 to 18V.

Noise.—To measure noise levels of better than − 60dB with respect to 100mV r.m.s. requires a very sensitive valve voltmeter. The most sensitive valve voltmeter available had a full-scale deflection of 1mV r.m.s., and when the input of the pre-amplifier was terminated with a 600Ω wirewound resistor, the noise level did not register.

Listening Tests.—The unit was tested in conjunction with a Decca "ffss" stereophonic cartridge, an SME arm, and Leak power amplifiers, and the quality was clean and smooth throughout the audio range. The unit did not introduce audible noise when connected to the above equipment. Even when the supply was decreased to 3V, the difference in quality was only just noticeable.

Construction.—The layout is not critical, and the results should be within the design specifications in all cases. (In fact, the equalization accuracy should always be better than ± 0.5dB from 20c/s to 20kc/s.) When two pre-amplifiers are built for a stereophonic cartridge, then the signal-carrying wires of the separate pre-amplifiers should not cross or come near to one another, so that cross-talk is minimized. Also, as shown in the circuit diagram, the battery should be decoupled via R10 and C6 so that cross-talk due to an impedance in the battery, which is common to both channels, is less likely to occur.

The frequency response of the pre-amplifier may be made flat by omitting C3, C5 and R9, in which case the voltage gain will be 10 at all audio frequencies. The output impedance will then be close to zero, and the input impedance will remain at about 75 kΩ.

The pre-amplifier would seem to satisfy every requirement for reproduction of the highest standard and the equalization accuracy is better than in any amplifier known to the author.

Credit is due to D. A. Smith, late of English Electric Aviation Ltd., for helpful suggestions during the design of the unit.

Industrial Groups—V

AT the annual general meetings of both **Camp Bird Ltd.** and its associates **Hartley Baird Ltd.,** shareholders asked if a list of companies within each group could be included in future annual reports. These suggestions were readily accepted by the respective chairmen, John Dalgleish (Camp Bird) and A. W. M. Hartley. As it will be nearly a year before effect can be given literally to these requests, we feel we may be doing a service to readers by publishing a list of companies in the Camp Bird Group of which Hartley Baird is a member.

Camp Bird is an old-established mining company with interests in Colorado and Canada but during the past few years its operations have been widened considerably and the group of nearly 40 companies now includes manufacturers of electrical, electronic, plastics and mechanical equipment and cold-forging plant.

John Dalgleish, the present chairman and managing director, joined the group when his company, Sapphire Bearings Ltd. was acquired. Sapphire Bearings, which was started in East London in 1952 with one machine for grinding sapphire tips for gramophone styli, became in three years "the largest sapphire engineering factory in the world." Its title was changed to E.V. Ltd. but is now operating as Electronic Reproducers (Components) Ltd.

Four years ago the Hartley Baird Group was acquired by Camp Bird. It was in 1954 that Baird Television Ltd. was amalgamated with the Hartley group of companies and the group became known as Hartley Baird. It continued for some time to produce domestic television receivers with the trade name Baird, but it will be recalled that Hartley Baird recently sold Baird Television Ltd. to Radio Rentals who now use the trade name Baird for their sound and television receivers.

We conclude this very brief and abridged history of the Camp Bird Group with some figures from the 1959-60 accounts. The group's share capital and reserves total £3,879,786. Its fixed assets are £2,296,417. The 1959-60 trading profit was £295,323 compared with £366,345 the previous year. The group, however, incurred a consolidated loss of £163,028 (after taxation and the transfer of £278,898 to capital reserve) against the previous year's profit of £272,151. The group's present constitution is:—

Camp Bird
Camp Bird Finance
Camp Bird Industries
Camp Bird Investment Trust
Camp Bird Mining
Camp Bird Securities
Cold Forging
Coolers & Venders
Creston Electric
Electronic Reproducers
Electronic Reproducers (Components)
Grahams Trading Co.
Hanworth Engineering (Aircraft)
Inductoforce
Kelly Acoustics
Lambert & Son (Eastcheap)
Limit Engineering Group
Limit Manufacturing Co.
Limit Sales
Limit Tools & Gauges
A. Prince Industrial Products
Rubber Plastics
Tenaplas
Vending Supply & Service
West European Industries

Hartley Baird
- Baldwin, H. J., & Co.
- Baldwin Central Products
- Baldwin Durawire Cable Co.
- Baldwin Engineering Equipments
- Duratube & Wire
- Hartley Installations
- National Rejectors
- Salopian Industries (Metals)
- Thermat
- Waldogram Properties
- Wireohms (Universal)