Ceramic Pickups and Transistor Pre-amplifiers

Are they incompatible?

by B. J. C. Burrows, B.Sc.(Eng.)

Of the pre-amplifier designs published in *Wireless World* over the past eight years or so, Mr. Linsley Hood's[1] is the first to provide proper equalization for ceramic pickups. This article explains in greater detail how he derived his pre-amplifier replay characteristics and gives a new simple circuit for correct—yet adjustable—equalization.

Ceramic pickups work on the piezo-electric principle, as do crystal pickups, and thus they are basically alike. The likeness extends further since historically crystal pickups were the first to be developed and marketed on a commercial scale, and they were followed by ceramic pickups (which are more reliable than their elder brethren, being less affected by temperature and humidity extremes). Many of the traditions of crystal pickup manufacture were carried over to ceramic cartridges, such as built-in mechanical compensation, and perhaps ceramic pickup manufacturers assumed that their products would be used generally into a high-impedance amplifier as in the "crystal pickup plus valve amplifier" days. It is apparent that many people experienced difficulty in using ceramic pickups (which usually need an input impedance of twice that for crystal pickups) with transistor pre-amplifiers and this has resulted in a wealth of designs for high input impedance converters using f.e.ts etc. to overcome the problems. The author thinks that this is an unsatisfactory method and that better results will be obtained by re-thinking the problem from scratch. By looking at the basic operating principles of the pickup and comparing these with the requirements, a simple design may readily be evolved.

Piezo-electric pickups

Let us first have a close look at the important characteristics of piezo-electric pickups and contrast them with a typical magnetic pickup. As the name implies, the piezo-electric pickup depends upon the piezo-electric effect—that is, when certain crystals like Rochelle salt and barium titanate are strained (i.e. bent, twisted etc.) an e.m.f. is developed across the faces of the crystal. Conducting layers deposited on the opposite faces of the crystal with wires attached complete the piezo-electric transducer. The piezo-electric e.m.f. is proportional to the strain in the crystal element, so the e.m.f. depends upon the amplitude of movement of the device transmitting the force to the crystal. Thus, in the case of a ceramic pickup the e.m.f. produced by stylus movements is proportional to the instantaneous deviation of the groove from the unmodulated position, or as is commonly said, the e.m.f. is proportional to the amplitude of the groove. This is the first fundamental difference between ceramic and magnetic pickups.

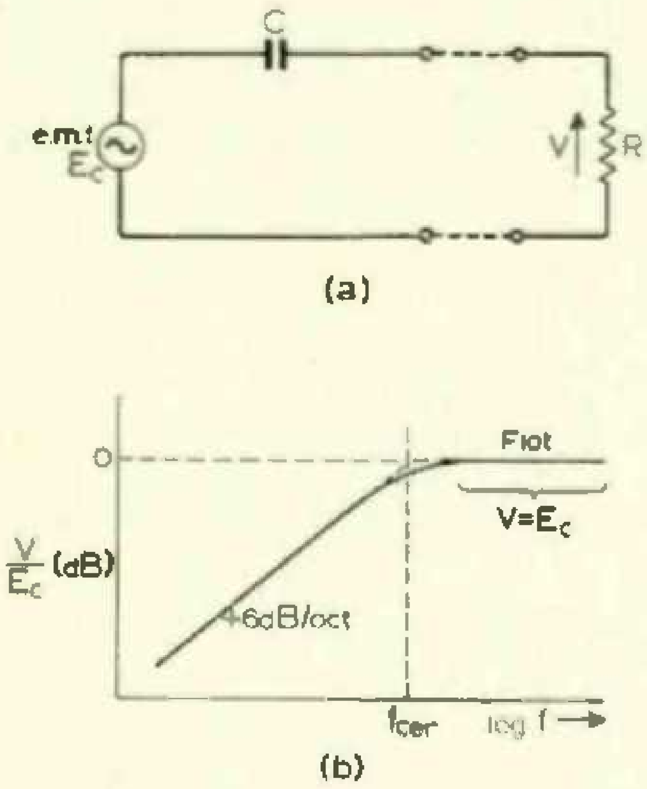


Fig. 1. (a) Equivalent circuit and (b) frequency response of piezo-electric pickup. $f_{cer} = \frac{1}{2\pi CR}$ (C in farads, R in ohms, f in Hz).

The second important feature is that the piezo-electric crystals are dielectrics and hence the conducting layers together with the crystal form a capacitor—typically 700 pF to 1500 pF which appears in series with the piezo e.m.f.*

We can draw an equivalent circuit for the pickup feeding into a resistive input impedance and this is shown in Fig. 1(a). The pick-up consists of a zero impedance generator in series with a capacitor. Fig. 1(a) will be immediately recognized as a differentiation circuit, that is, a high-pass filter whose cut-off frequency, called f_{cer}, separates a region of slope 6 dB/octave from a region of zero slope, as shown in Fig. 1(b).

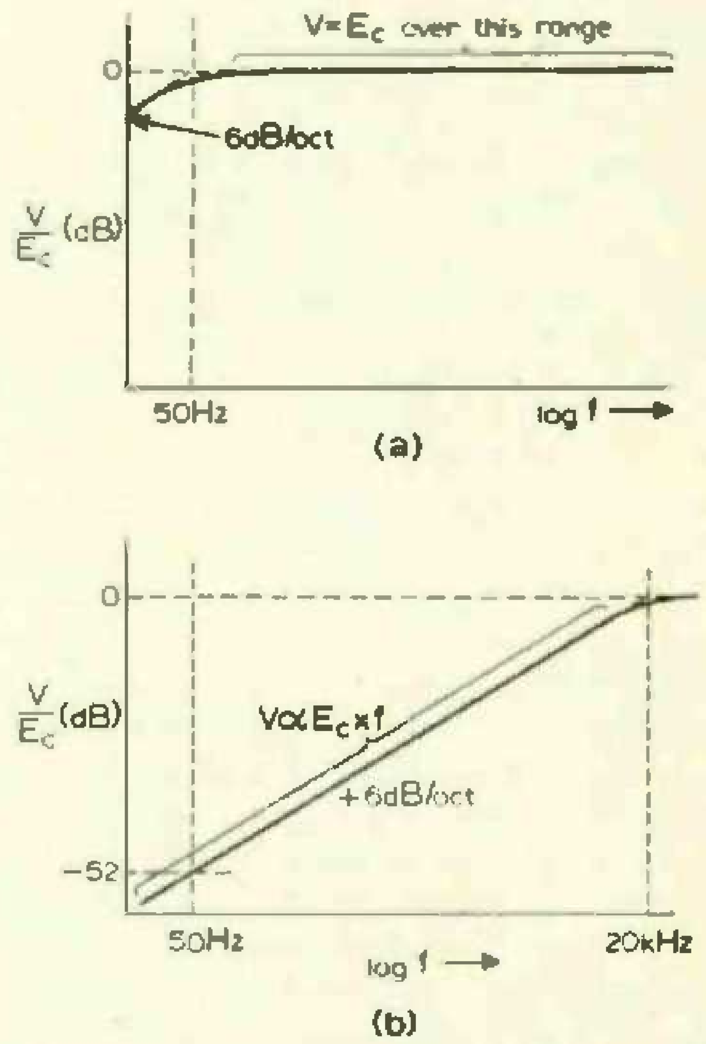


Fig. 2. (a) High-resistance loading, R = 4 MΩ and (b) low-resistance, "velocity" loading, R = 10 kΩ.

For example, if $C = 800$pF and $R = 4$MΩ, then f_{cer} occurs at 50 Hz. This will be termed high-impedance loading because the voltage developed across the load is substantially independent of R and is equal to E, the pickup e.m.f. over the whole audio frequency range. That is to say, the voltage at the amplifier terminals equals the pickup voltage. So, *if* records were recorded with a constant amplitude characteristic† a perfect piezo-electric pickup would require no further equalization.

An alternative method of operating the pickup is the "low-impedance loading" or "velocity loading" method. Here we choose R to place f_{cer} at the highest end of the frequency spectrum—say 20 kHz—where

*Sometimes the impedance of a pickup is quoted as, say, 2 MΩ. This practice is misleading, because owing to its capacitance the impedance is inversely proportional to frequency, and almost purely reactive. Obviously the pickup will have a reactance of 2 MΩ at only one frequency (~50 Hz). I think, too, that an impression exists that one has to "match" a pickup to an amplifier like matching a loudspeaker to the amplifier output stage. Perhaps matching is an appropriate expression for the pickup case, but the reasons that govern the choice of "matching" impedances are quite different in the two cases. [See p. 66—Ed.]

†"Constant amplitude characteristic" means here that the records will have been recorded in such a way that a perfect zero impedance amplitude-sensitive pickup would produce a signal requiring no further correction before being amplified and fed to the loudspeaker.

R would equal 10 kΩ for a pickup capacitance of 800 pF as before. Referring to Fig. 1(b) again it can be noticed that if f_{cer} lies at 20 kHz, the whole of the audio spectrum lies on that part of the curve with a rising frequency response of 6 dB/octave. Only above 20 kHz is V equal to E, so at 50 Hz V is very low (approximately −52 dB). The name "velocity loading" has been given to this mode of operation because the output shows a rising response with frequency as obtained from a magnetic pickup under appropriate conditions (see below). One frequently comes across this recommendation: to give approximate "velocity loading" load a ceramic pickup with 68 kΩ! This recommendation is unjustifiable since the "velocity loading" will be effective only up to 2·5 kHz, and at 12 kHz, for example, 68 kΩ loading gives 12·6 dB less than true velocity loading.

Figs. 2(a) and (b) summarize the above ideas for a ceramic pickup of 800 pF operating into a load of (a) 4 MΩ and (b) 10 kΩ, while playing a constant amplitude recording.

Magnetic pickups

I hope the reader will forgive the rather lengthy discussion on piezo-electric pickups—a few quick words will sum up the essential features of magnetic pickups. A similar type of equivalent circuit may be drawn except that, first, the e.m.f. is proportional to the velocity of the stylus at any instant and, secondly, this e.m.f. can be thought of as a zero impedance generator in series with an inductance, typically 500 mH. Fig. 3(a) shows the equivalent circuit and Fig. 3(b) the frequency response of this circuit when stray capacitance is ignored. It is seen that up to f_{mag} the voltage V across the amplifier input equals E, the pickup e.m.f. Now, if we assume that such a magnetic pickup is used to reproduce from a constant amplitude record, E (the pickup e.m.f.) is directly proportional to the frequency f. E is rising at a rate of 6 dB/octave over the whole frequency range and therefore V will also rise at the same rate up to f_{mag} and then turn "flat" above it. This is shown in Fig. 4 for the case when R = 65 kΩ. By analogy with piezo-electric pickups, 65 kΩ loading would be termed high-impedance loading, because the audio range lies entirely in that region of the curve where the amplifier input voltage is equal to the pickup e.m.f. (which is proportional to frequency). Low-impedance loading is of no practical interest*, but intermediate impedance loading is practicable[2] and in this case f_{mag} is made 2100 Hz.

If Fig. 2(b) is now compared with Fig. 4 it is seen that they are identical in most respects, particularly in having the response $V \propto f$ over the whole audio spectrum. Both curves apply only to pickups on constant amplitude recordings. This means therefore

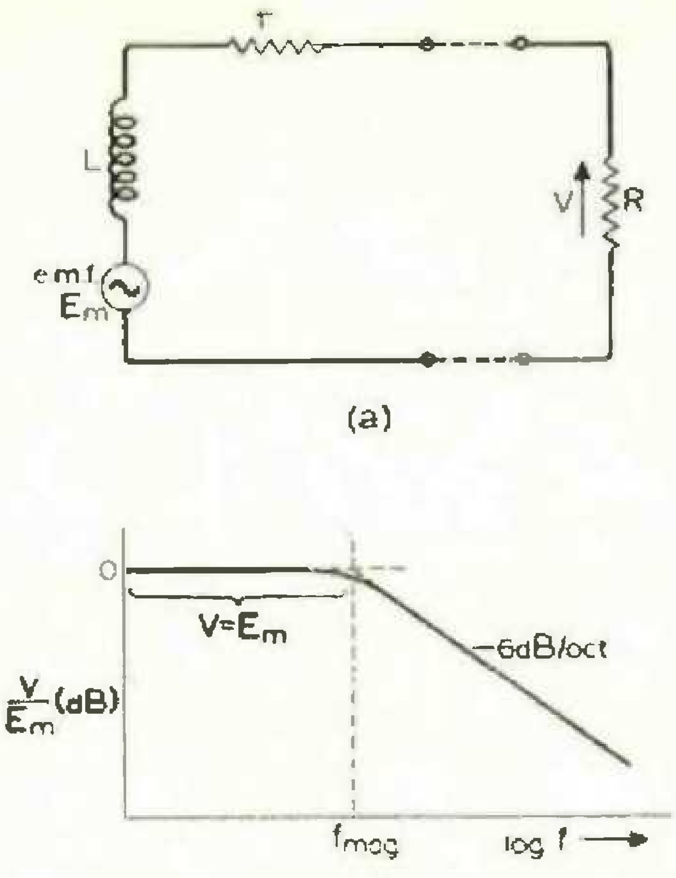


Fig. 3(a). Equivalent circuit and (b) frequency response of magnetic pickup. $f_{mag} = \frac{(R+r)}{2\pi L}$ *H. (R in ohms, L in henries).*

that an ideal ceramic pickup when velocity loaded (C = 800 pF, R = 10 kΩ) will require exactly the same frequency correction as an ideal magnetic pickup (L = 500 mH, R = 65 kΩ). This should make clear the use of the term "velocity loading" as applied to a ceramic pickup.

If we now wish to specify the gain/frequency characteristic of amplifiers for reproducing constant amplitude records using the pickup configurations shown in Figs. 2 and 4, we find that a "flat" amplifier characteristic is required for Fig. 2(a) and this is shown in Fig. 5(a). Both 2(b) and 4 require a gain falling at a slope of −6 dB/octave over the whole audio spectrum as shown in Fig. 5(b). (See last section for note about bass lift below 50 Hz.)

R.I.A.A. Recordings

Up to now we have considered constant amplitude recordings only and this is now a convenient point to introduce the complications caused by the real R.I.A.A. recording characteristic. The R.I.A.A. characteristic is usually given as a gain/frequency curve required to correct a *perfect magnetic pickup with a high-Z load*. Fig. 6(b) shows this curve. The author's preference, when considering ceramic pickups, is the replay characteristic for a high-Z loaded ceramic pickup which is given in Fig. 6(a). This form of the curve emphasizes the close approximation of the R.I.A.A. characteristic to constant amplitude recording apart from the 12·5 dB "coggle" in the curve between 500 and 2121 Hz. Thus it might be loosely assumed that an amplifier to replay from a ceramic pickup would require a gain/frequency curve like Figs. 6(a) or 6(b) depending on the loading employed. However, the historical development of piezo-electric pickups comes into play here, and as mentioned above the tradition of expecting piezo-electric pickups to be played into a high impedance load dies hard so we have the situation that almost all piezo-electric pickups have built-in compensation.

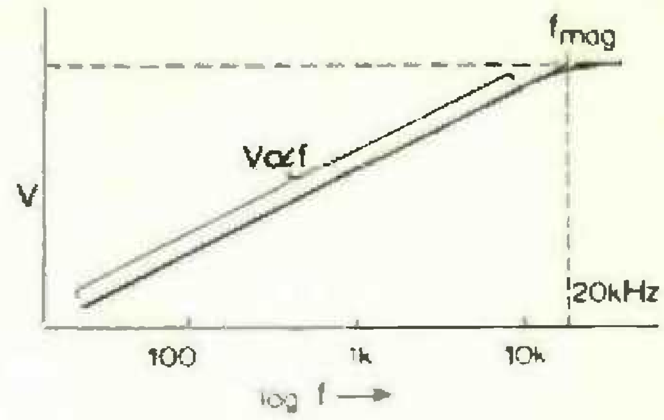


Fig. 4. High-resistance loading for magnetic pickup playing a constant amplitude recording. (R = 65 kΩ, L = 500 mH, f_{mag} = 20 kHz, E ∝ f over audio range.)

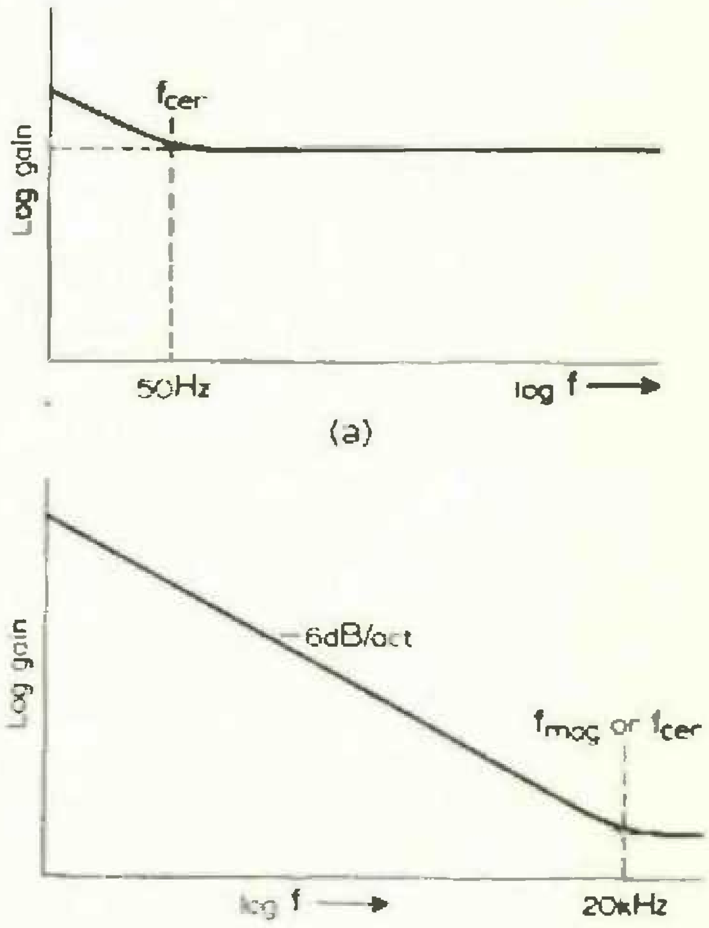


Fig. 5. Amplifier gain characteristics; (a) for high-Z piezo pickup (Fig. 2(a)) and (b) for low-Z piezo (Fig. 2(b)) and high-Z magnetic (Fig. 4) pickups. Note: These characteristics refer to ideal piezo and magnetic pickups playing constant amplitude recordings.

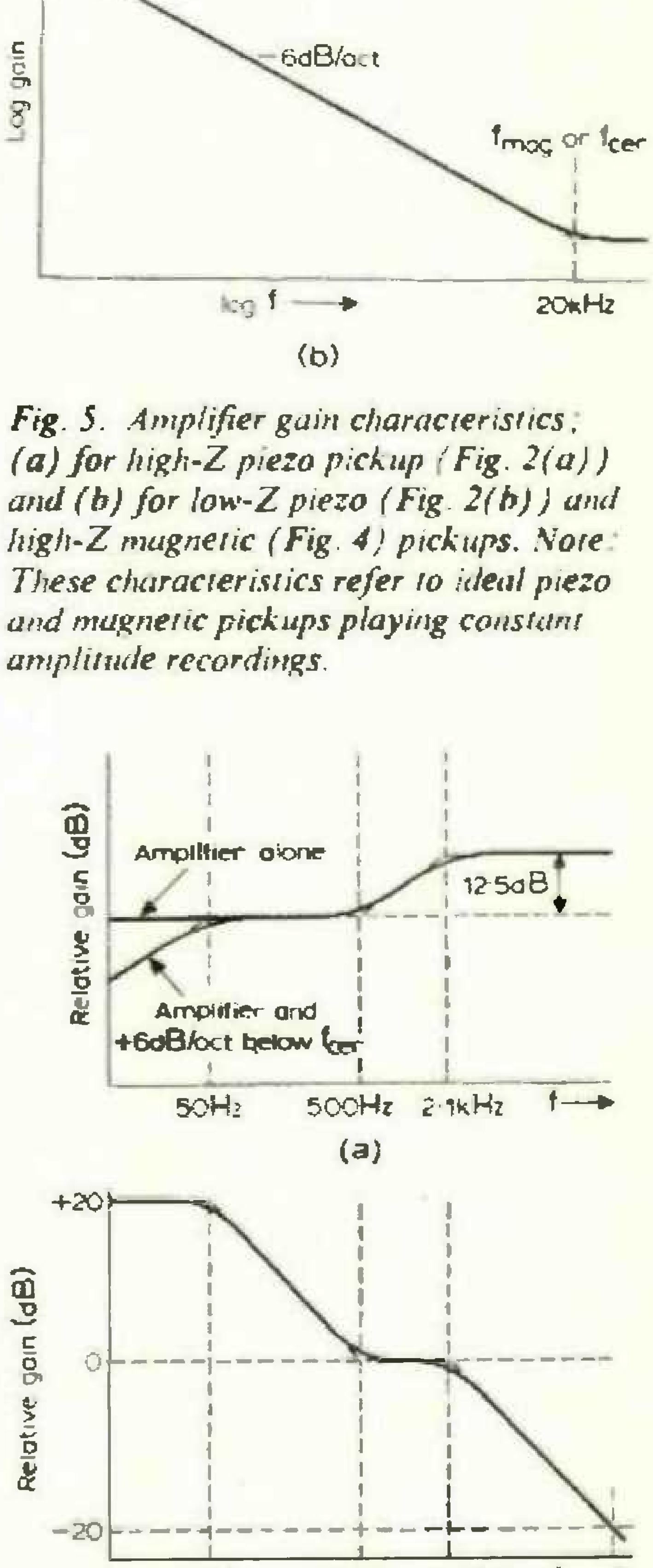


Fig. 6(a). R.I.A.A. replay characteristic (ideal ceramic pickup with high-Z load) and (b) standard R.I.A.A. replay characteristic (magnetic pickup into high-Z load).

*This is true because low-impedance loading would produce a very small output voltage although giving a flat frequency response in principle. A smaller output voltage would aggravate the noise problem, and in any case the value of R required to make f_{mag} = 50 Hz is 160 Ω which is already less than the actual a.c. resistance of the pickup coil! Intermediate loading is practicable though with many magnetic pickups.

The 12·5 dB lift in the higher frequencies is provided by built-in mechanical compensation and this means that the pickup can be played directly into a high-impedance "flat" amplifier and give acceptable results. On the other hand, no magnetic pickups incorporate mechanical equalization and so always need the full R.I.A.A. equalization as given by the curve in Fig. 6(b). But as practically all ceramic cartridges have the mechanical compensation the amplifier gain/frequency characteristic would have to be like Fig. 5(a) or 5(b), depending on the loading employed, *not* 6(a) or 6(b).

As nothing can be done about the built-in mechanical compensation, additional electrical equalization must be added to an existing amplifier if an attempt is made to "velocity load" the pickup and then play it through an amplifier with full R.I.A.A. magnetic equalization. Despite the mechanical compensation, no basic change in the equivalent circuit of the pickup is needed, the only difference is that the e.m.f. E is a function of frequency, but the pickup is still basically an amplitude sensitive device. I think there is a good case for marketing high-quality ceramic pickups with no built-in equalization, specifically designed to operate into the "magnetic" input socket of pre-amplifiers, whose input impedance is of the order of 50 kΩ.

This should have explained fully the derivation of the three curves in Fig. 5 of ref. 1 where circuits and curves are given for varying degrees of built-in mechanical compensation.

Curve 1—Full mechanical
Curve 2—50% effective mechanical
Curve 3—Zero mechanical

In this respect Mr. Linsley Hood's Fig. 5 arrangement is more flexible than his Fig. 4 circuit which assumes full mechanical equalization.

Medium-Z loading of magnetic and ceramic pickups

In the original version of the Tobey-Dinsdale pre-amplifier[2], an ingenious form of equalization was suggested for magnetic pickups with an inductance of the order of 500 mH. This depended on the concept of splitting the equalization into two separate sections, one providing the treble equalization above 2121 Hz and the other providing the bass equalization below 500 Hz. Treble equalization was obtained by setting f_{max} = 2121 Hz and reference to Fig. 5(b) will show that a flat amplifier characteristic is required above f_{max} for proper overall equalization. Below 500 Hz amplifier bass lift is required and this was achieved by frequency selective feedback using a virtual earth amplifier (see Appendix 1) where Z_2 consisted of a resistor and capacitor in series with a time constant of 300 μs.

This provides a gain/frequency characteristic as shown in Fig. 7, assuming Z_1 is resistive. Thus the combination of the two systems provides correct equalization. Pickups with inductances much smaller than 500 mH and/or with high a.c. resistances at 2 kHz cause difficulty with this method.

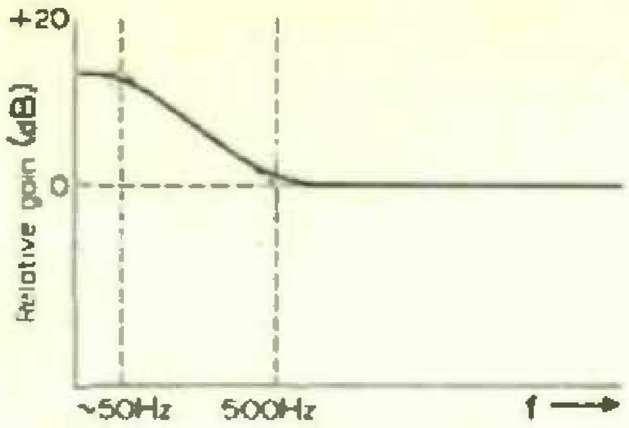
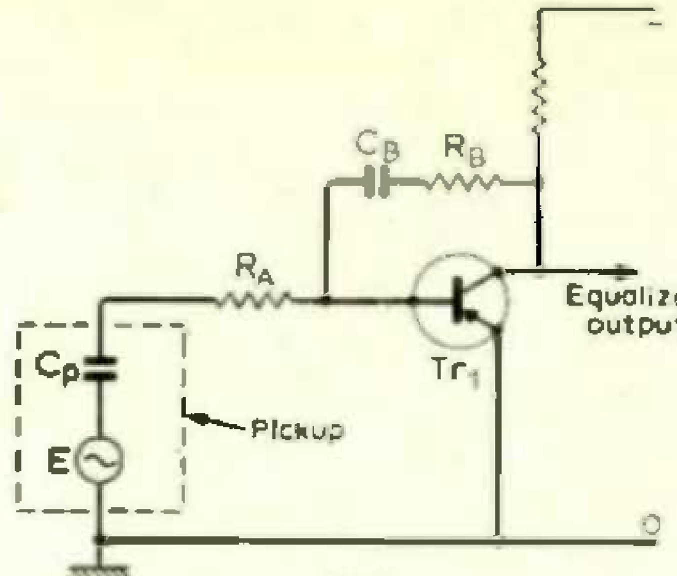
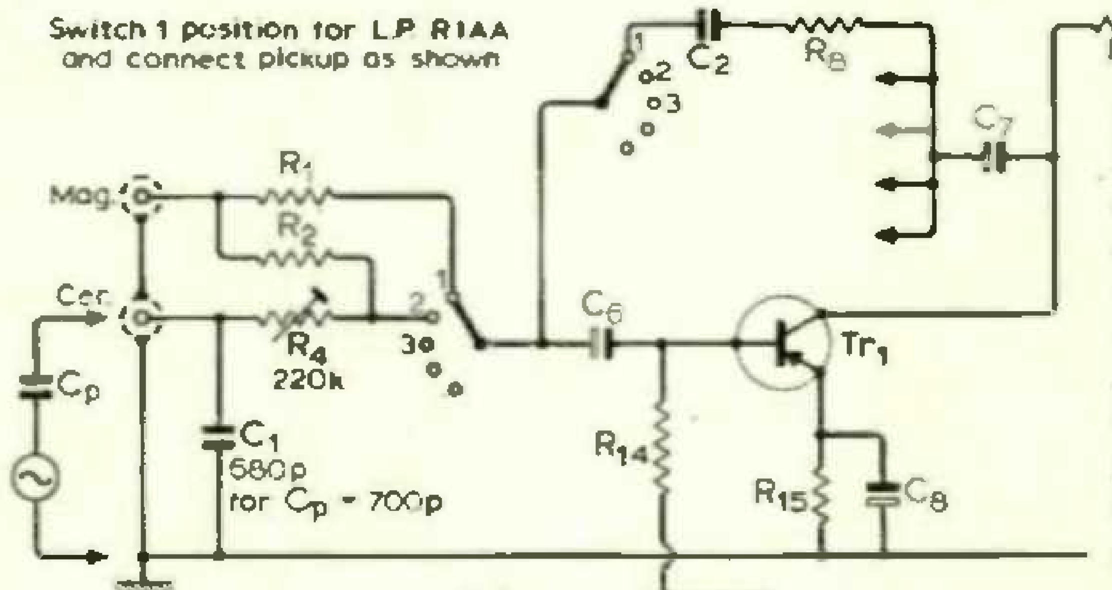


Fig. 7. Gain/frequency curve of pickup equalization feedback circuit of Ref. 2.



(a)

Fig. 8(a). Principle of equalization for virtual earth amplifier (see Appendix 1). No biasing components are shown.



(b)

Fig. 8(b). Modified Dinsdale Mk. I pre-amplifier. Notes: R_3 is omitted. Component values as in original unless shown. R_4 is a skeleton pot. The value of C_1 should be chosen to give a total capacitance C_t of $C_p + C_1 + C_{leads}$ about 1500 pF (±150 pF). C_{leads} is about 100 pF.

However, the critics of this system were unduly harsh and it is probable that the majority of stereo magnetic pickups will work satisfactorily with this form of equalization. Tests on the Neat V-70 and the B. & O. SP2 pickups, which are typical of the moving magnet and variable reluctance type respectively, have shown no decrease at all in channel separation using the E.M.I. stereo test disc TCS 101 when first one channel, then the other, is shorted. In a recent article in *Wireless World*[8] it was pointed out that magnetic imbalance of these types of pickup is very low, resulting in a separation of better than 40 dB from this cause alone. Thus any transformer effect (i.e. the current in one coil inducing a voltage in the other) would be of negligible proportions compared to the other causes of crosstalk—which are principally mechanical. Obviously the Decca *ffss* pickup is an exception since it has a sum and difference coil system, where the common coil would carry appreciable current through a common impedance.

When ceramic stereo pickups are operated into low-Z loads there is no risk at all of worsening the channel separation—indeed, some authors believe that low impedance loading improves the damping and hence the transient performance. This idea originated a long time ago[3], and as yet no evidence is forthcoming in support of this claim. Reference 3 contains many misleading and contentious remarks, and it is possible that pen was put to paper rather too hastily! Well, low-impedance loading is probably neither much worse nor much better than high-impedance loading, other things being equal, and if the reader will accept the idea of a 100 kΩ load, or thereabouts, it is very simple to design a circuit providing the necessary equalization. No doubt many readers have reverted to high-impedance loading after being dissatisfied with results from their pickup when operated into a magnetic input and the reasons for this should be clear from the above discussion.

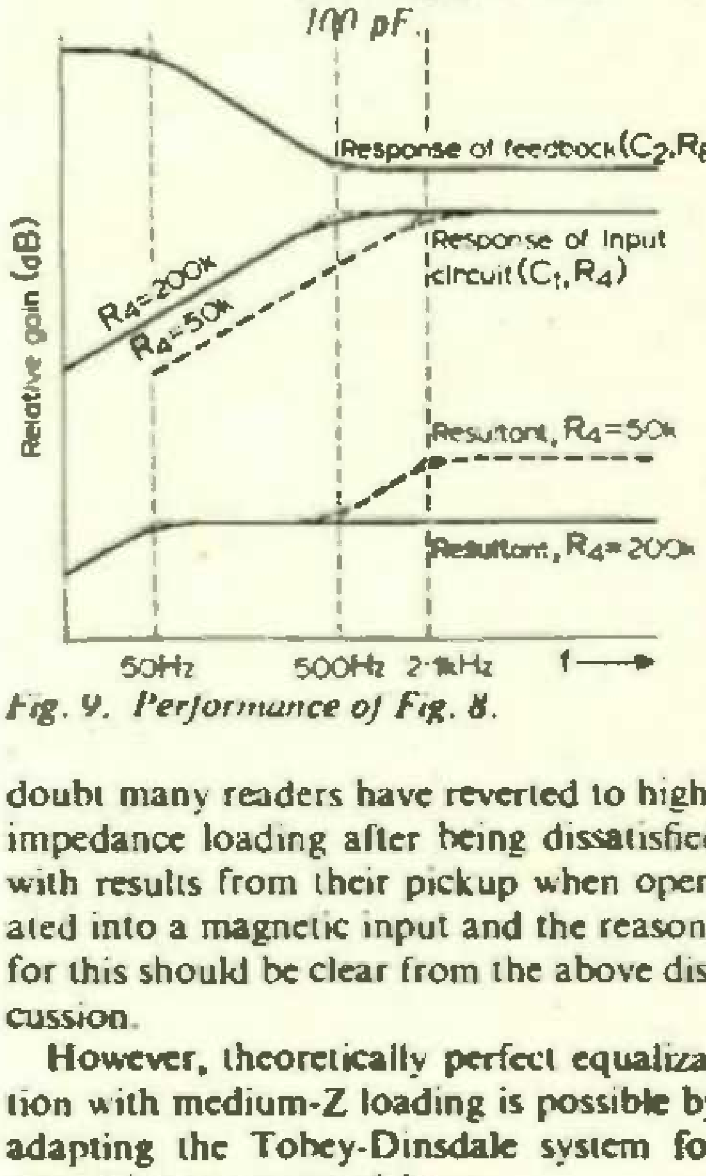


Fig. 9. Performance of Fig. 8.

However, theoretically perfect equalization with medium-Z loading is possible by adapting the Tobey-Dinsdale system for equalizing magnetic pickups.

Equalization of ceramic pickups—new method

Suppose we load a 1500 pF pickup with 200 kΩ. The formula by Fig. 1(b) tells us that f_{cer} = 500 Hz. Frequencies below 500 Hz suffer an attenuation of 6 dB/octave as shown on Fig. 1(b). Suppose also that we use a feedback circuit providing an amplifier gain curve as shown in Fig. 7, which gives a rising gain below 500 Hz. Combining these two circuits will provide a flat overall frequency response—which is what is required for a fully mechanically compensated ceramic pickup playing R.I.A.A.

recordings. The virtual earth amplifier as used in reference 2 works very satisfactorily when the input circuit is modified as shown in Fig. 8(a) which shows the outline system and (b) giving the detailed modifications. With a Sonotone 9 TAHC C_2 and R_8 were kept as 0·005 μF and 47 kΩ, and the only alteration was to include the preset R_4. The performance of the adapted circuit is shown by the full line in Fig. 9. Should the mechanical compensation not be fully effective the circuit can be arranged to give the full 12 dB lift by reducing the value of R_4 to 50 kΩ, which raises the turn-over frequency f_{cvr} from 500 Hz up to 2000 Hz as shown by the dashed curve in Fig. 9. It is obvious that any degree of mechanical compensation can be allowed for by tweaking R_1. This can be done quite easily by ear. If 200 kΩ is inconveniently high, the pickup can be shunted with extra capacitance, say 1000 pF, so allowing R_4 to be reduced, for the same product of $C_t \times R_4$. It is convenient to arrange for the feedback circuit to have its turnover frequency at 500 Hz because then inadequate mechanical compensation can be easily adjusted for. If it is known that the pickup is fully compensated any convenient value for $C_t \times R_4$ may be chosen.

Any feedback type pre-amplifier stage can be easily modified to provide correct ceramic pickup equalization using the basic method just discussed. The type discussed in Appendix 2 has appeared as the Dinsdale Mk. II[4]; this pre-amplifier can be modified to give excellent equalization as shown in Fig. 10. Another popular more recent *Wireless World* pre-amplifier design is the Bailey circuit[5], which also can be improved by greater attention to the equalization requirements. This design can easily be modified by, say, using the "Disc 1" position for a ceramic pickup and "Disc 2" for the magnetic. The circuit for the ceramic pickup will now appear as shown in Fig. 11. The circuits in both Figs. 10 and 11 are capable of the adjustment range as shown in Fig. 9 for the simpler virtual earth circuit. Each has an additional control R_3 of 10 kΩ to preset the overall gain to a suitable level for the particular pickup. Using this form of equalization for pickups, it is doubtful whether the performance of the modified Dinsdale Mk. II is in any way inferior to the modified Bailey because the feedback circuit in the Dinsdale Mk. II does not have a falling impedance with rising frequency any more. Instead, the impedance flattens off at about 9 kΩ and does not shunt the transistor load impedance excessively at high frequencies. The same is true for the other two amplifier circuits, of course.

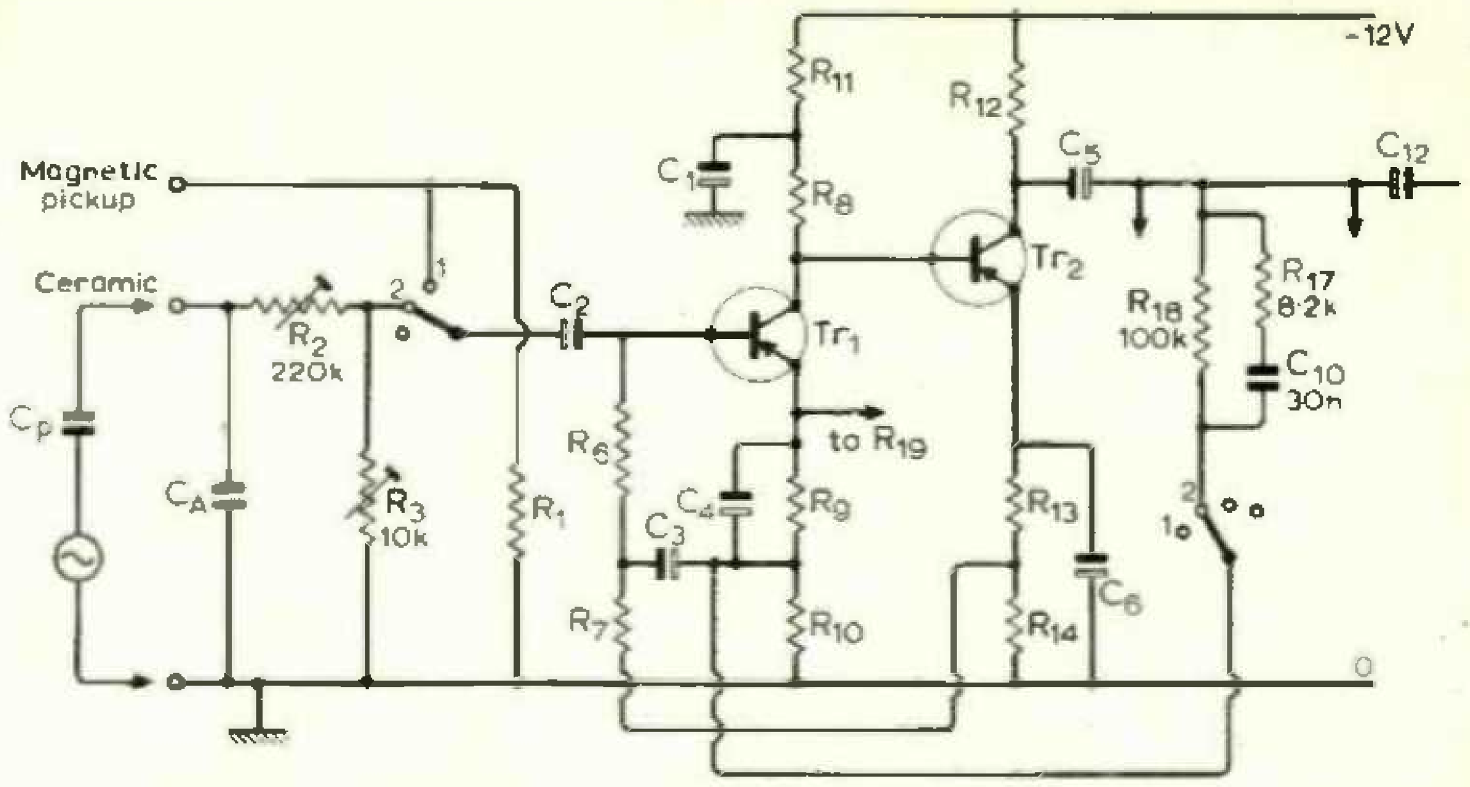


Fig. 10. Modified Dinsdale Mk. II for ceramic pickup equalization. Switch position 2 is now labelled ceramic pickup R.I.A.A. l.p. Note: Do not operate this circuit with C_{10} shorted and R_3 set to less than 3500 Ω or motor boating at 1 Hz might occur. To be safe, raise C_2 to 20 μF or more. $C_t = C_p + C_A + C_{leads}$ etc.; choose C_A to make $C_t \approx 1500$ pF (± 150); $R_{18} \cdot C_{10} = 3000$; $R_{18}/R_{17} = 12{\cdot}4$; C in μF; R in Ω; R_2 – set f_{cvr}; R_3 – set gain.

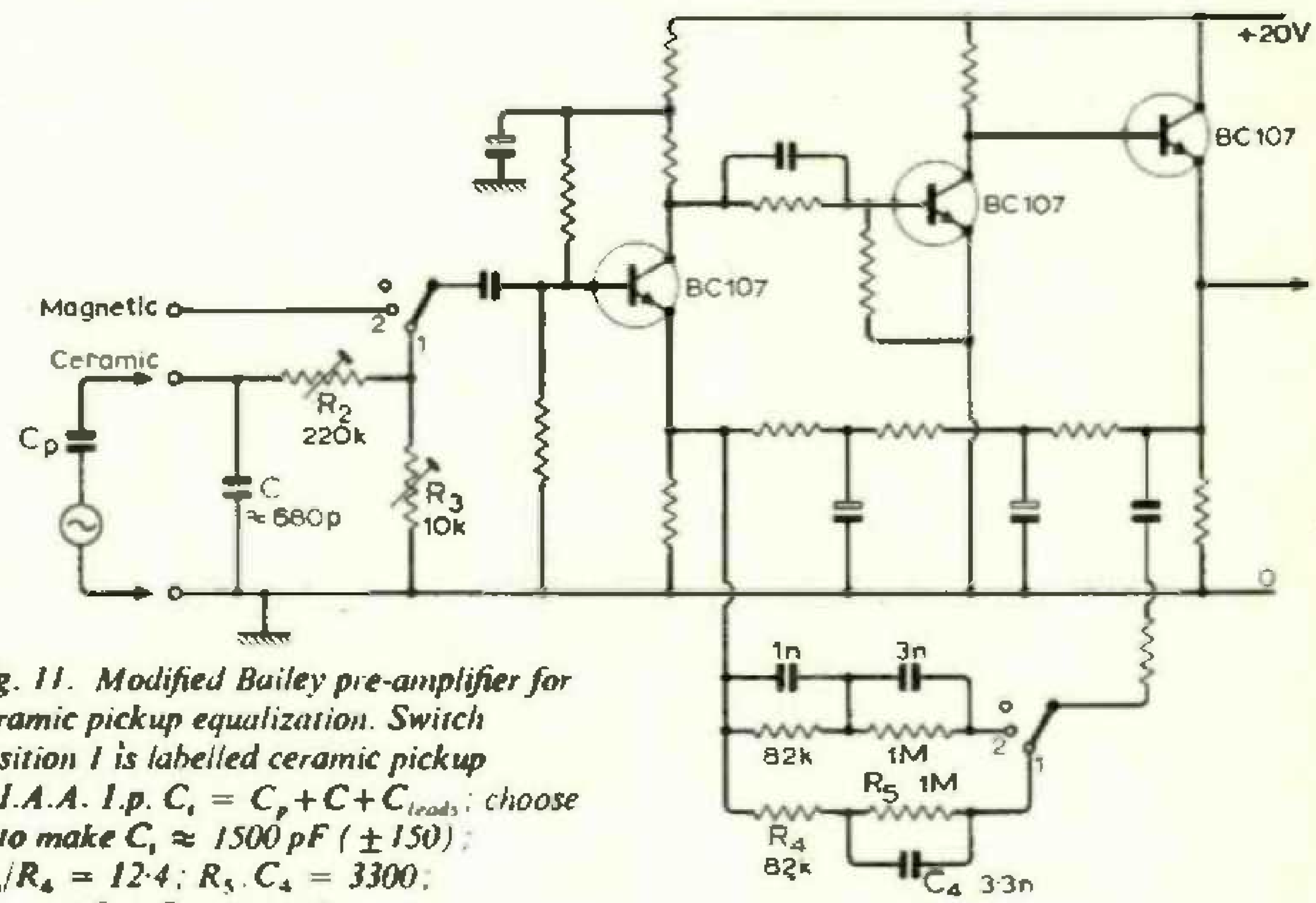


Fig. 11. Modified Bailey pre-amplifier for ceramic pickup equalization. Switch position 1 is labelled ceramic pickup R.I.A.A. l.p. $C_t = C_p + C + C_{leads}$; choose C to make $C_t \approx 1500$ pF (± 150); $R_5/R_4 = 12{\cdot}4$; $R_5 . C_4 = 3300$; R_2 – set f_{cvr}; R_3 – set gain.

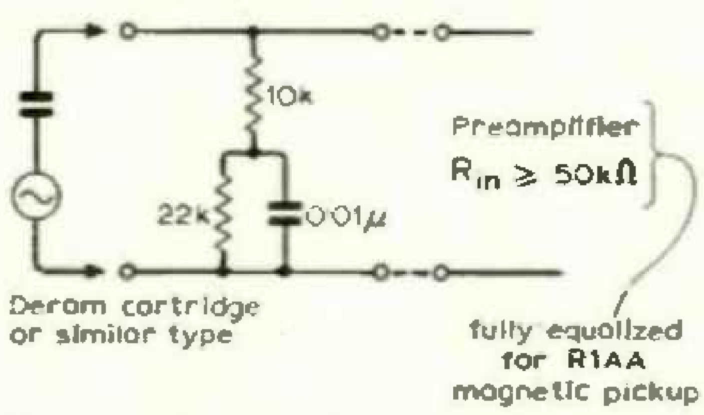


Fig. 12. Circuit for "velocity" loading and decompensating a ceramic pickup.

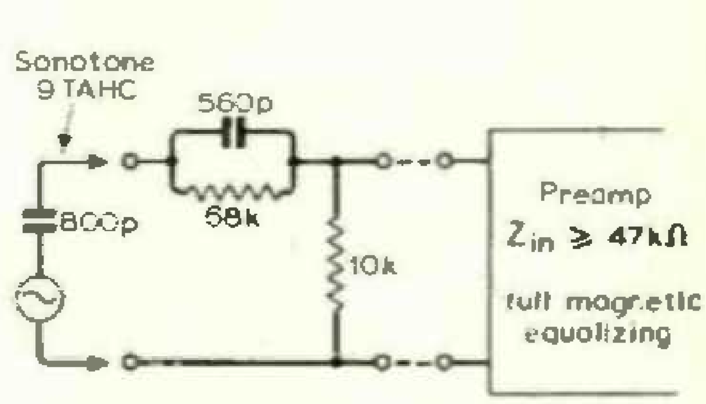


Fig. 13. Circuit for "velocity" loading and decompensating Sonotone 9 TAHC.

Equalization of ceramic pickups: alternative circuits

Circuits requiring no internal modifications to the pre-amplifier fall naturally into two main groups:
(1) add-on high input impedance f.e.t. and boot-strapped circuits
(2) circuits adapting magnetic-cartridge inputs by "velocity loading" the pickup and decompensating for the mechanical compensation.

I shall confine the discussion to the second group since adequate information is already available for the first group.

One of the best known circuits for decompensating the mechanical equalization is due to J. Walton (Fig. 12). This is an ingenious circuit. It provides "velocity loading" of the pickup over the whole audio frequency range but the effective load impedance for the pickup is higher at low frequencies than at higher frequencies, therefore a relatively larger signal is produced at low frequencies than at high. This circuit allows the Decca Deram to be connected successfully to a fully R.I.A.A. compensated magnetic input of R_{in} approximately 47 kΩ or so. An alternative circuit, which was provided in a private communication, for decompensating the Sonotone 9 TAHC pickup is shown in Fig. 13, and although seemingly very different from Mr. Walton's circuit, achieves the same objective.

These circuits probably function quite well, but there is the possibility of a big build-up of errors in the mechanical compensation, the decompensation and the amplifier equalization characteristic. By comparison the circuit of Fig. 8(a) is very simple, gives less risk of accumulated errors, and allows adjustment for degrees of mechanical compensation. The one main shortcoming of this simple circuit is the lack of loop gain to stabilize gain at low frequencies. In this respect the Dinsdale Mk. II and Bailey pre-amplifiers are superior. Rumble filtering is a good feature to include as well. If the Dinsdale design of main amplifier is used, or the Bailey amplifier with the recent modification[6], then rumble filtering is not so necessary since these amplifiers have a built-in high-pass characteristic.

Further notes

(1) It may have occurred to the reader that an even simpler form of equalizer is possible, consisting of a virtual earth amplifier with just a capacitor in the feedback circuit as in Fig. 14. Though superficially very attractive, this circuit is not very satisfactory owing to the shunting effect of C_2 on the transistor load resistor at high frequencies, and the difficulty of adjusting the compensation. Stabilization of low-frequency gain would be desirable, so requiring a resistor shunting C_2 and perhaps C_1, thus making the circuit no simpler than the adjustable circuit of Fig. 8. On the other hand, the simple circuit of the form of Fig. 8 is eminently suitable for a multi-transistor virtual earth amplifier and is a simpler way of achieving proper ceramic pickup equalization than Mr. Linsley Hood's circuit (Fig. 5 of ref. 1).

(2) Pickups of very low or very high outputs may cause difficulty through lack of gain, or overloading and some further notes might help to provide solutions for particular problems.

Circuits in Figs. 10 and 11 are not likely to be troubled in this way owing to the presence of the adjustable R_3. If the pickup output is low, R_3 may be increased up to 50 kΩ max., which might then require $R_2 = 0$. An alternative method to increase the gain is to alter the values of the resistors and capacitors in the feedback circuits (R_{18}, R_{17}, C_{10}) in Fig. 10; or the equivalent ones (R_4, R_5, C_4) in Fig. 11. The ratios between the component values must be maintained, however, as given by the formulae at the side of each diagram. In general, raising the resistor values increases the gain and lowering them reduces it. The equalization will not be affected by such changes.

The circuit in Fig. 8(b) is not quite so simple, as no one component can be varied easily to alter the gain. Shunting the pickup with a capacitor will neither raise nor lower the overall gain, because the attendant alteration of R_4 to preserve the same f_{cer} will exactly neutralize the change. However, if a series capacitor is used and a shunt capacitor as well to keep the same effective source capacitance of 1500 pF, effective gain reduction can be achieved without raising R_4 at all (Fig. 15). For $C_{tot} = 1500$ pF with $C_p + C_{strays} = 800$ pF, $C_s = 390$ pF, $C_1 = 1200$ pF, gain is reduced by a factor of 3 compared with the gain when C_5 is not used, and the pre-amplifier would not be overloaded by operating from a pickup with an output of 1·25 V max!

An alternative method is to alter the values of the feedback components (C_2 and R_8 in Fig. 8(b)). In general decreasing R_8 lowers the gain, and increasing R_8 raises it. However, this causes a change in the magnetic pickup gain as well as the ceramic pickup, so it is best avoided.

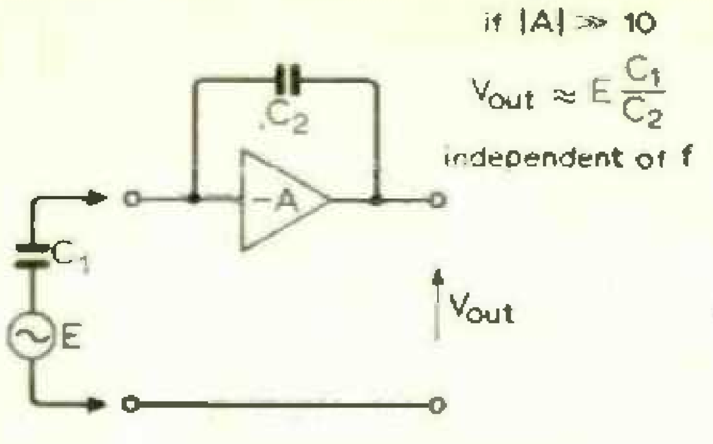


Fig. 14. A simple but impracticable equalization circuit.

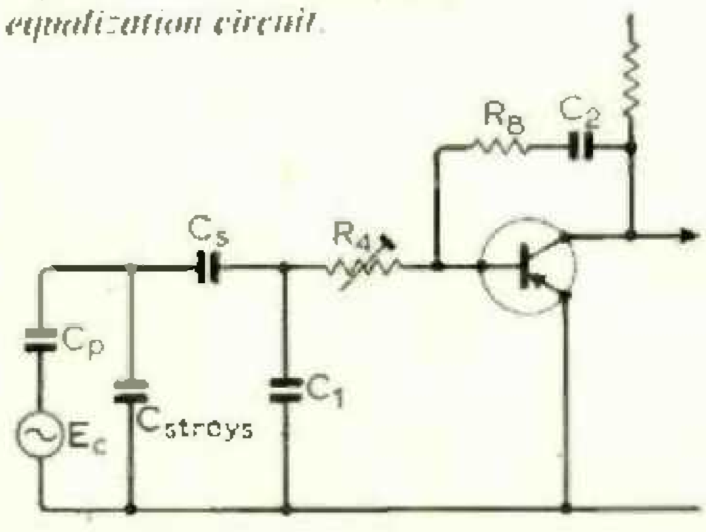


Fig. 15. Curbing high output pickups by including series and shunt capacitance. Effective capacitance value for calculating f_{cer} is C_{tot} which $= \dfrac{(C_p + C_{strays}) \times C_s}{C_p + C_{strays} + C_s}$

Finally, the pickup output may be shunted directly with a resistor, R_3, which would be connected between the left side of R_4 in Fig. 8(b) and chassis. To preserve the time constant once more, this resistor would have to be shunted by a capacitor C_1 larger than normal so that

$$(C_p + C_1) \times \frac{R_3 R_4}{R_3 + R_4} = 318\,\mu s$$

That is, if R_3 equals 200 kΩ, and R_4 is 200 kΩ, thus giving a parallel combination of 100 kΩ, $C_p + C_1$ would have to be made equal to 3000 pF or so.

A word of warning, do not attempt to shunt virtual earth amplifiers by putting a resistor between the virtual earth point (see appendix 1) and real earth. The loop gain of the amplifier is reduced, making the circuit more susceptible to transistor gain variations and the gain/frequency curve will be less exact.

(3) Response below 50 Hz. Referring to Fig. 6(a) which shows the replay characteristic for a piezo-electric pickup playing R.I.A.A. recordings, the curve implies that bass lift is recorded below 50 Hz, since, theoretically the replay characteristic should drop off below 50 Hz at 6 dB/octave. This is probably not done by many recording companies because of the allowable maximum recorded amplitude which is less for the lower frequencies.* Thus a flat gain is probably required below 50 Hz, down to say 20 Hz, below which a fall of 18 dB/octave to reduce rumble is beneficial. Too few pre-amplifiers include adequate rumble filtering. The author recently has had to modify a valve stereo amplifier of a very well known make on account of its extended low frequency response—flat to less than 10 Hz!

On balance it is better to dispense with the luxury of "flat to 20 Hz" and allow the theoretical 6 dB/octave below 50 Hz (R.I.A.A.) aid the rumble reduction, leaving only 12 dB/octave to be added elsewhere, say, by a couple of differentiation circuits in series between the pre-amplifier and main amplifier, unless the main amplifier itself has a high pass characteristic.

In principle, the simple equalization circuit of Fig. 8(a) would give a flat response down to zero frequency. This is not true of Fig. 8(b) owing to the limited gain of a one transistor amplifier, and also to the feedback deliberately introduced to give a high pass action. With a high gain amplifier and no anti-rumble feedback, C_2 would need to be shunted by 560 kΩ to give a turnover frequency of 50 Hz.

Bass roll-off would not be achieved by putting a capacitor of 0·01 μF in series with R_4, although it was this method, in effect, that was suggested recently[7]. Since the 0·01 μF is in series with the pickup capacitance and the pickup capacitance is only 700 pF or so, the 0·01 μF capacitor would have only a 7% effect on the turnover frequency of the pickup in conjunction with the amplifier input resistance. (f_{cer} would be about 1·5 kHz, and not 50 Hz.)

(4) Magnetic pickups playing into high resistance loads. Manufacturers of magnetic pickups commonly state that their products should be loaded with not less than 47 kΩ. Many reports on magnetic pickups refer to the problem of the pickup inductance and lead capacitance giving a resonant effect on frequencies about 15 kHz to 20 kHz. In the case of pickups with an inductance of about 500 mH it is advisable to use no more than 50 kΩ since then the Q of the LCR circuit is about 1 which almost entirely suppresses the resonance effect.

(5) The capacitance of the connecting leads to a ceramic pickup are of no consequence since the capacitance simply adds to the source capacitance of the ceramic pickup and does not cause resonance effects.

(Please see p. 80 for Appendix)

*See for example, "Measuring pickup performance", J. Walton, *Wireless World*, December 1967.

REFERENCES

1. J. L. Linsley Hood, "Modular Preamplifier Design", *Wireless World*, July 1969.
2. R. Tobey and J. Dinsdale, "Transistor High Fidelity Preamplifier", *Wireless World*, December 1961.
3. Elwin O'Brien, "High Fidelity Response from Phonograph Pickups", *Electronics*, March 1949.
4. J. Dinsdale, "Transistor High-Quality Audio Amplifier", pt. 1, *Wireless World*, January 1965.
5. A. R. Bailey, "High-performance Transistor Amplifier", pt. 2, *Wireless World*, December 1966.
6. K. Clayson, Letters to the Editor, *Wireless World*, October 1969.
7. F. Jones, "Ceramic Pickup Inputs", *Hi-Fi News*, January 1969.
8. S. Kelly, Stereo Gramophone Pickups, *Wireless World*, December 1969.

notch of low-pass type is obtained, Fig. 8(d).

$$V_N = V_C + a_3 V_L = (1 + a_3 p^2 T^2)\, V_C \quad (39)$$

Similarity if $a_3 = 1$ and $a_3 < 1$, an unsymmetrical notch of high-pass type is obtained, Fig. 8(e). The notch summing amplifier is not always required in a filter having several factors, because the summation for one stage can be made at the input of the following stage.

All-pass response, second-order,

$$\frac{1 - \frac{1}{q} pT + p^2T^2}{1 + \frac{1}{q} pT + p^2T^2} V_{in} = V_L - V_R + V_C \quad (40)$$

is easily obtained by adding all three primary outputs, as the output proportional to V_R already has the necessary relative sign reversal. Note: the relative magnitude of the contribution from the tuned-circuit output is V_R; i.e., qV_R/q.

The effect of parasite phase lags

The effect of parasitic phase lags, provided they are small, can be estimated as shown in Part 5. In the absence of such lags $1/q = \tan\theta$, where θ is the phase margin at ω_C, and therefore for $q \gg 1$, $1/q$ is approximately equal to the phase margin (measured in radians). Parasitic phase lags, by reducing the margin, increase the effective q, and are in effect negative loss factors. When the time constant of such a lag, t, is small compared with T ($T = 1/\omega_C$), its phase lag in radians at ω_C is t/T, and equn. (18) may be further modified to

$$\frac{1}{q} = \frac{1}{q_i} + \frac{1}{q_r} - \sum \frac{t}{T} \quad (41)$$

Lags inside the amplifiers may to a first approximation be taken as divided by the loop gain, which for the integrators is the amplifier gain.

Because the product of the gains of two amplifiers can be drawn on, the two-integrator loop is particularly suitable for realising high Q factors (tens rather than units). This means that $1/q$ may well be small, and then for accurate design unwanted phase lag must be very small compared with the design value of T. In consequence very high values of Q factor are more practicable at low frequency.

When q is low, quite simple amplifiers with perhaps only one stage of gain may be used. This could be the case in, for example, a variably tuned audio-frequency filter. And because the bandwidth of such an amplifier could easily be large compared with the corner frequency of the filter, parasitic lags should be negligible. It will be useful, therefore, to consider in more detail the situation where finite (and rather low) zero-frequency gain is the major imperfection. This will be taken up again in the next article.

REFERENCE

[1] E. F. Good: "A two-phase low-frequency oscillator", *Electronic Engineering*, April and May 1957 (Vol. 29, pp. 164–169, and 210–213).

Continued from p. 60

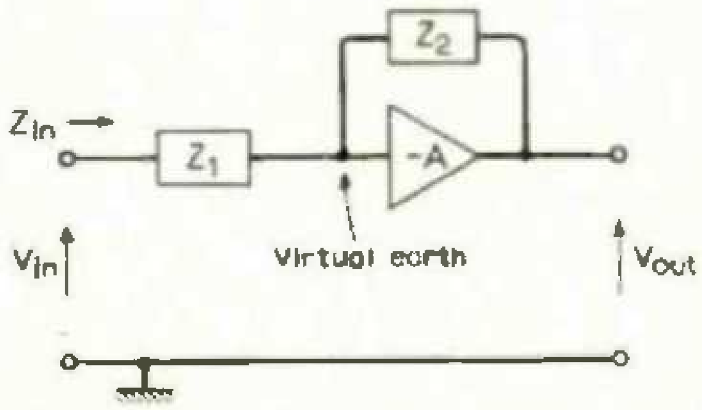
Appendix to Ceramic Pickups & Transistor Pre-amps

(1) Gain and input impedance of virtual earth amplifiers

For high gain amplifier

$$\frac{V_{out}}{V_{in}} = \frac{Z_2}{Z_1}$$ Junction of Z_1 and Z_2 is a virtual earth

$$Z_{in} \approx Z_1$$
$$Z_{out} \to 0$$



Amplifier is phase inverting, e.g. one high gain transistor in common emitter mode.

A clear understanding of the operation of the equalization circuit put forward in this article is gained by thinking of the ceramic pickup capacitance as being a part of Z_1:

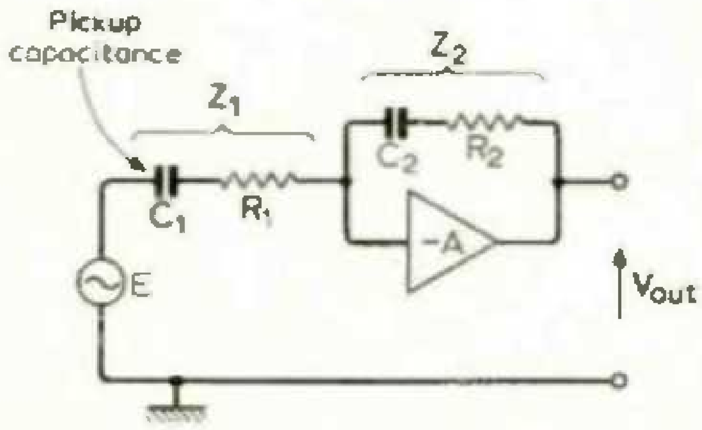
if $R_1 \times C_1 = R_2 \times C_2$
then Z_2/Z_1 = constant, *independent* of f.

Therefore V_{out}/E = constant over whole frequency range, which is the requirement for a mechanically compensated pickup. The virtual earth amplifier was used in the Dinsdale Mk. I pre-amplifier and more recently in the Linsley Hood pre-amplifier.

(2) High input impedance feedback amplifier

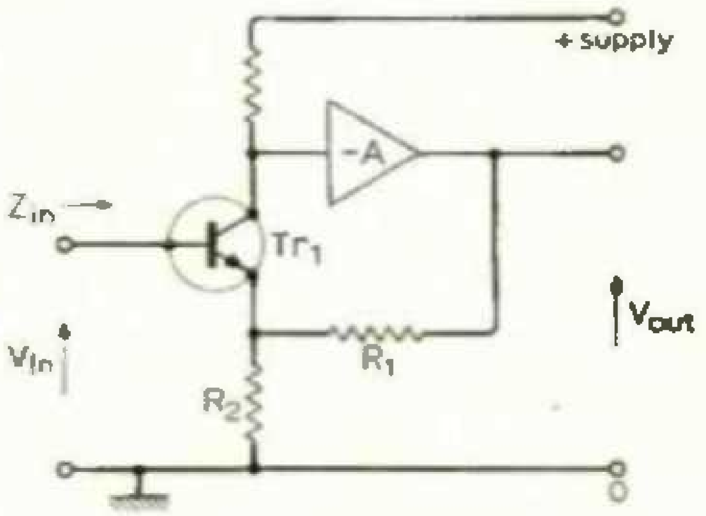
For large value of total gain

$$\frac{V_{out}}{V_{in}} = \frac{R_1 + R_2}{R_2}$$



In general, $\frac{V_{out}}{E} = \frac{C_1}{C_2}$ *at l.f. and* $\frac{V_{out}}{E} = \frac{R_2}{R_1}$ *at h.f.*

If the amplifier $-A$ consists of a transistor (Tr_2) in common emitter configuration and the current gain of Tr_1 and $Tr_2 = \beta$, Z_{in} tends to $\beta^2 \times R_2$ shunted by R_{bc} and the Miller capacitance of Tr_1.



Total gain = gain of $Tr_1 \times |A|$.

This system is used in the Dinsdale Mk. II pre-amplifier where $Z_{in} \approx 500\,k\Omega$ but it is of course frequency dependent; so normally Z_{in} is shunted by a resistor to stabilize the input resistance to 100 kΩ.

The Bailey pre-amplifier is a development of the Dinsdale Mk. II and an improvement has been made by adding an emitter follower after the second common emitter amplifier transistor to reduce the shunting effect of the feedback network (a frequency sensitive circuit in place of R_1) at high frequencies.

Corrections & Amendments

Pickup Characteristics (December): Garrard point out that the output voltage of their cartridges should have been quoted in volts (not mV) and at 1 kHz at 3.54 cm/sec.

Thermistor Hygrometer (December): The U.K. distributors of the Philco Ford op. amp. PA 7709-39 are Electronic Component Services (Worcester) Ltd, 63/6 Foregate Street, Worcester, and not as stated on p. 558.

Electronic Metronome (January): Resistor R_6 should be connected directly to the collector of Tr_2. The junction of VR_1 and R_5 should not be connected to the transistor.

Low-distortion Bias and Erase Oscillator (January): In Fig. 4 the 470 Ω resistor in series with S_3, should be connected to the collector of 2N3704 and not the emitter as shown.