Modular Pre-amplifier Design

Optimally designed stages that may be used separately or in several different combinations

By J. L. Linsley Hood, M.I.E.E.

The type of distortion introduced by a class A transistor amplifier operating at low signal level will be predominantly second harmonic and inoffensive to the ear. Although harmonic distortion is a convenient thing to measure, and makes a reasonable yardstick for comparative purposes, at low levels its presence is less important than that of the intermodulation effects which it causes. When a complex signal is transmitted through a non-linear element, intermodulation products between the separate components of the signal are formed, and these are readily apparent in the final audible result as a 'blurring', and loss of separate identity, of the individual components which make up the whole. A measure of this is the ease (or difficulty) in distinguishing the words of a choral performance in the presence of an orchestral background, or in identifying the presence and nature of individual instruments in a large orchestra.

John Laurence Linsley Hood, born in 1925, was educated at Reading School, Acton Polytechnic, the Royal Technical College (Glasgow) and, after the war, at Reading University. In 1942 he joined the G.E.C. Research Laboratories at Wembley, working on magnetron development as junior member of a team. In 1943 he joined the R.A.F. in aircrew but was transferred to work on radar. He subsequently worked with T.R.E. (Malvern) overseas. After a return to university he joined the Windscale Research Laboratories of the Atomic Energy Authority. He has been in charge of the electronics team in the research laboratories of British Cellophane Ltd. since 1954.

Measurements by a number of workers[1] have indicated that the magnitude of intermodulation products can be much greater than that of the total harmonic distortion level, and the non-linearities which are likely to be of most importance in this respect are those at the low- and high-frequency ends of the audible range.

At the moment, the performance of audio amplifiers is much superior in this respect to that of f.m. transmissions, tape recordings, disc replay systems or loudspeakers. However, advances in the manufacturing techniques of gramophone records, pickup cartridges and loudspeakers have allowed a continuing improvement in the performance of these in harmonic and i.m. distortion, and it is clear that any amplifier

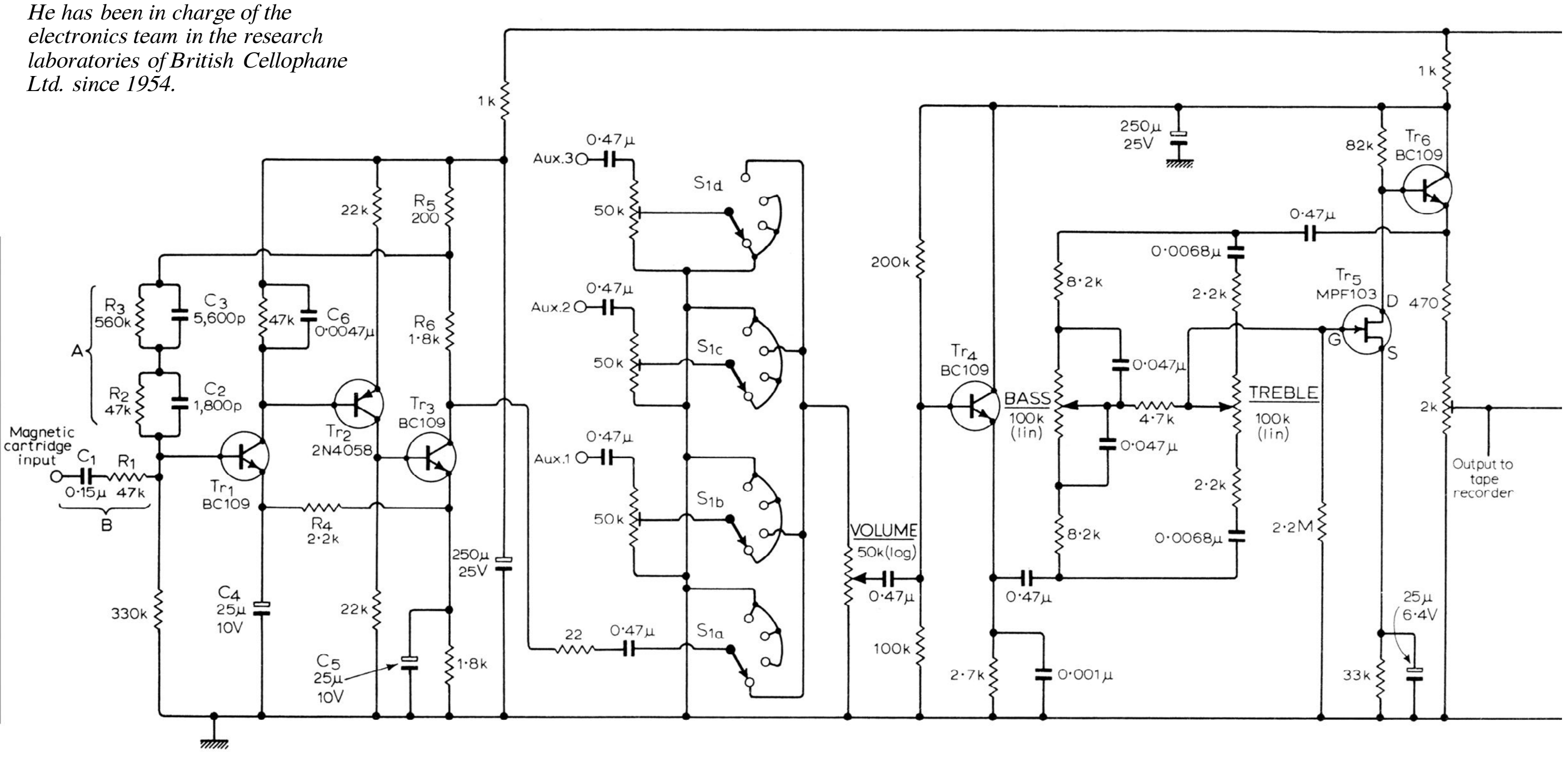


Fig. 1. A likely combination of stages.

design offered at this time should have a very high standard of performance if it is to remain of continuing value over the next decade.

The author has designed a range of high-quality pre-amplifier stages. Each stage performs its required operation with negligible noise and distortion. When joined together, as for example in Fig. 1, the total harmonic distortion level is below 0.1% over the frequency range 20Hz-20kHz, at any tone-control setting, and for up to 2V r.m.s. output. Each stage is capable of operating on its own and has an output impedance low enough for screened cable inter-connections to be made without high frequency loss.

Magnetic pickup equalization circuit

The required R.I.A.A. replay characteristic can be approximated by several different circuit arrangements. The most straightforward from the point of view of performance calculation is that shown in Fig. 2, employing a simple phase-inverting amplifier stage. If the gain of amplifier M is high enough, point Z becomes a virtual earth (see Appendix I), and the input impedance of the circuit equivalent to that of the input network B. The load resistance required by the pickup cartridge, usually 47-50kΩ, is provided by a suitable choice of R_1 With resistor R_2 equal to R_1, stage gain is given by $\frac{R_4+R_5}{R_5}$ at the mid point frequency (usually 1kHz) if the impedance of C_2 is large, and that of C_3 small, in relation to R_2. Since the voltage output to be expected from most good quality magnetic pickup cartridges is in the range 4-10mV for a 5cm/sec recorded velocity, a gain of 10 is adequate for this stage. The required replay frequency-response curve shown in Fig. 3 can be obtained by a suitable choice of C_2 and C_3. Since the two networks A and B determine the frequency response of this circuit, it is apparent that substitution of these can be made to provide a wide range of different performance characteristics without alteration to the circuit of the amplifier unit M.

The final circuit can be seen at the front of Fig. 1. Because phase inversion between input and output is required, and because the necessary gain is higher than can be obtained from any single transistor arrangement, a triplet circuit has been used.

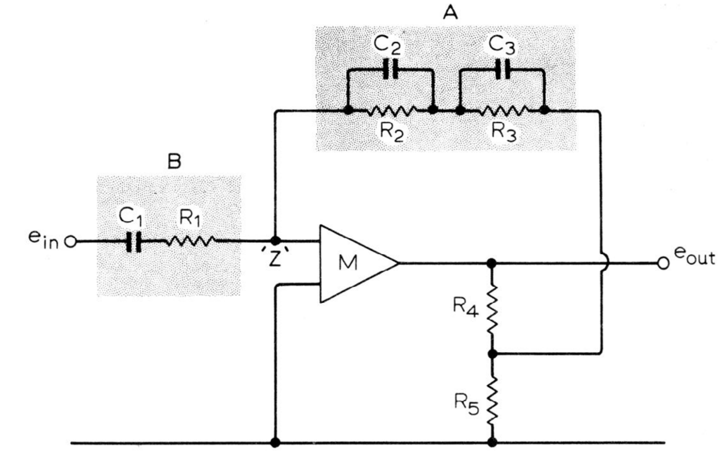


Fig. 2. Phase-inverting amplifier stage used to obtain R.I.A.A. replay characteristic.

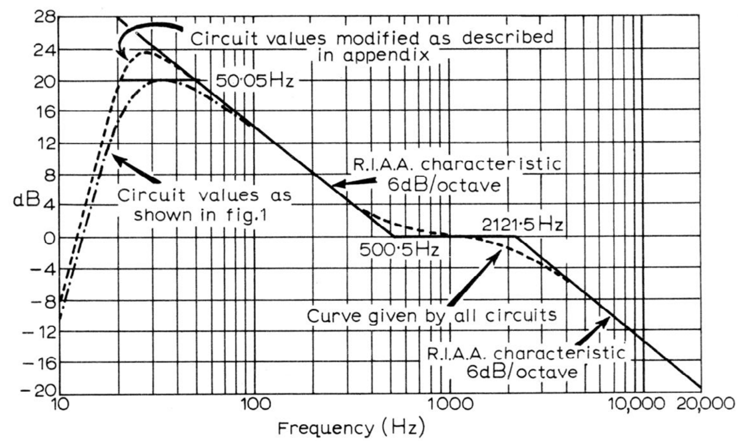
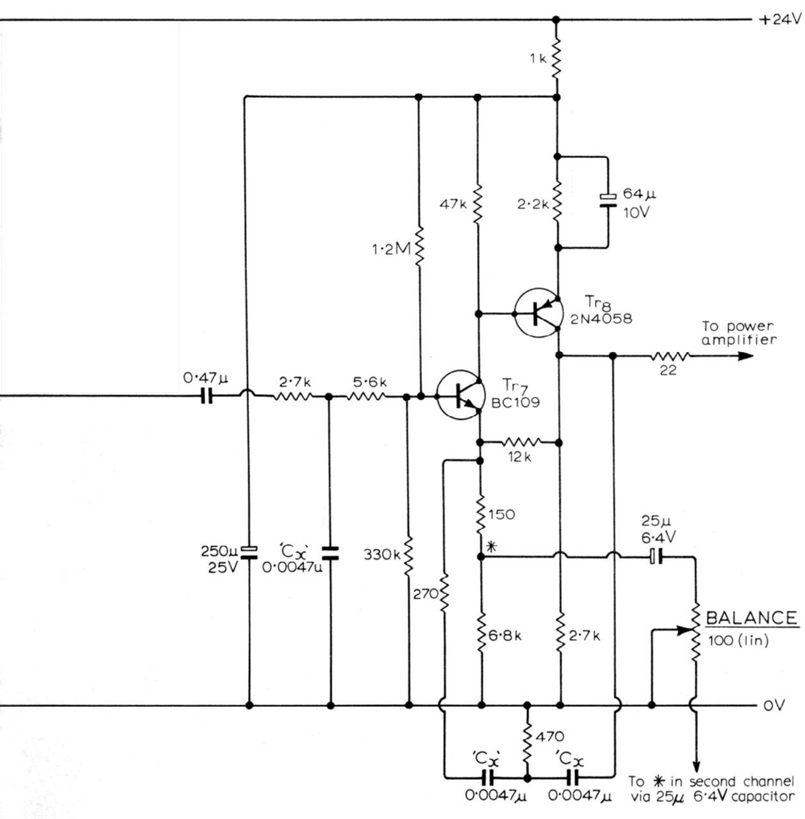


Fig. 3. Required R.I.A.A. frequency-response curve and circuit approximation to this.



Tr_1 and Tr_3 are high-gain, low-noise voltage-amplifying stages, and Tr_2 is a phase and voltage transformation stage allowing the input transistor to be used in its most linear region. The output transistor has a low collector load resistance, to reduce distortion to the lowest possible level.

D.c. working-point stability is ensured by d.c. negative feedback through R_3 and R_2 to the base of Tr_1 and through R_4 to the emitter circuit of the same transistor. The circuit R_4, C_4 and C_5 also provides the feedback path necessary, in conjunction with the input capacitor C_1 to provide an 18dB/octave steep-cut rumble filter, with a turn-over frequency of 25Hz (see Appendix II), and an ultimate attenuation of more than 40dB at 8Hz.

Capacitor C_6 provides phase correction, and is essential for a clean square-wave response, and freedom from transient ringing, when used with a capacitive load.

The response of this circuit is particularly good, and it can deliver up to 1 volt output with distortion less than 0.02% from 100Hz to 10kHz.

Stages for ceramic cartridge equalization

Fig. 4 is an impedance conversion stage contributing less than 0.05% distortion at 1kHz and having a flat response from 35Hz to greater than 200kHz, with 18dB/octave roll-off below 35Hz. This simple stage may be directly substituted for the magnetic cartridge stage of Fig. 1.

Alternatively, should it be required that the pre-amplifier be able to cope with inputs from both magnetic and ceramic cartridges, then switchable equalisation networks for A and B can be provided. These are shown in Fig. 5. When used with a ceramic cartridge the output voltage is from 50 to 200mV. To preserve the required shape of the rumble filter characteristic it is necessary to alter the values of C_4 and C_5 from 25μF to 12.5μF. The pre-amp response is then as shown in Fig. 5, curve 1.

The performance of many ceramic pickup/amplifier combinations is disappointing in comparison with that obtainable from a good magnetic cartridge with a similar amplifier. This is sometimes due to the mismatching between cartridge and amplifier, or through inadequate input impedance provision (in the modification shown in Fig. 5 this is 4.4MΩ), or due to the failure of the piezoelectric element within the cartridge to provide the required equalization for the 12dB fall in voltage output anticipated when a recording having R.I.A.A. velocity characteristics is replayed on a displacement sensitive device. In the latter case, a very considerable improvement in the relative performance of the ceramic cartridge may be obtained by shunting part of the input resistor in the input network B by a small capacitor. Curves 2 and 3 in Fig. 5 show partial and complete correction respectively.

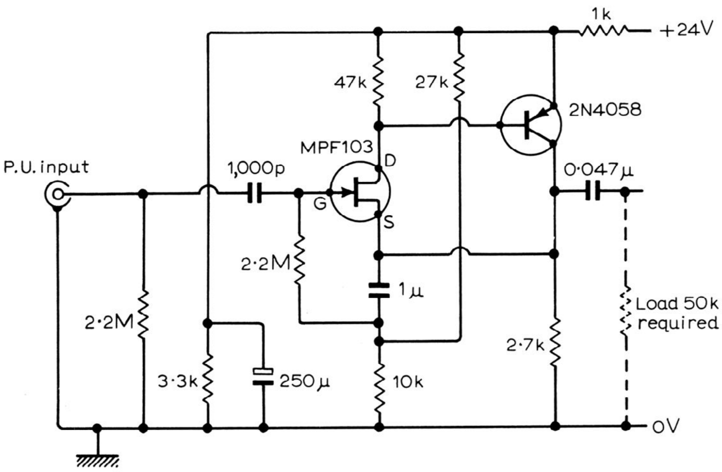


Fig. 4. Impedance conversion stage for use with ceramic cartridge. This may be directly substituted for the magnetic cartridge stage at the front of Fig. 1.

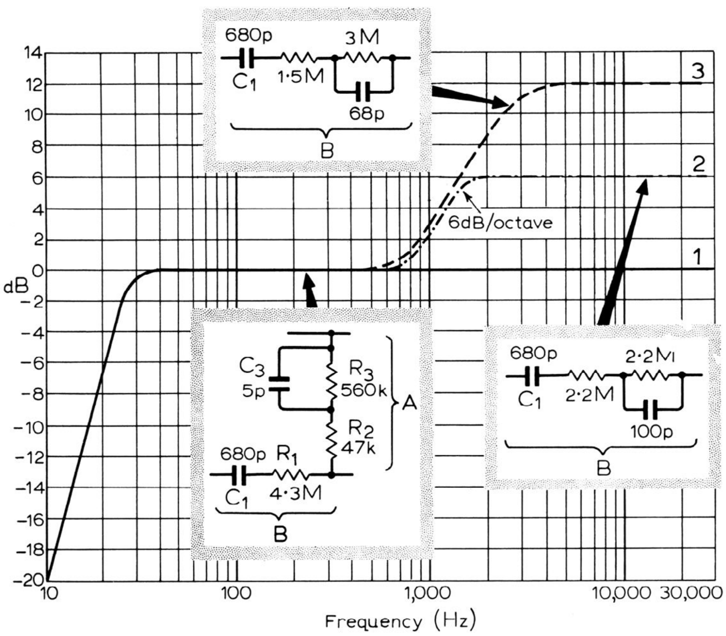


Fig. 5. Changes in equalization networks A and B of the magnetic cartridge input stage allowing direct use of ceramic cartridge. Components for network A are the same for the three curves show.

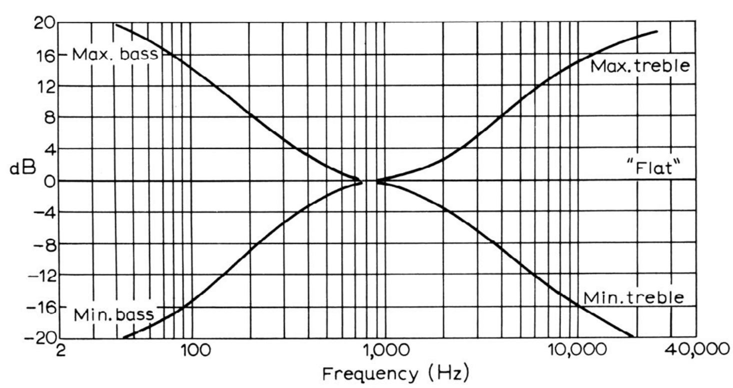


Fig. 6. Gain/frequency characteristics of the tone control stage.

Tone–control stage

The tone-control stage is of conventional type, and uses a negative feedback system derived from the design due to Baxandall[2]. However, it differs from normal practice in that a junction field-effect transistor is used as the active element. Field-effect transistors have both lower noise levels and better linearity than bipolar transistors, and in this type of circuit the high input impedance results in negligible loading of the tone-control network. The stage gain needed in this circuit requires a high value drain load resistor, and the f.e.t. must therefore be followed by an emitter-follower to provide the low output impedance desired for easy interconnection of the separate units.

If the feedback tone-control network is to perform satisfactorily, both the input and output impedances seen by the network at its ends must be low in relation to the network input impedance when the sliders of the potentiometers are at the position nearest to the point being measured. Some form of impedance conversion circuit is therefore also needed between the volume control and the tone-control circuit. An emitter follower is also used at this point. The 0.001μF capacitor in the emitter circuit of Tr_4 is to avoid the possibility of high frequency parasitic oscillation occurring if long screened leads are used to connect the base of Tr_4 to the volume control.

The input to this section is taken through a switch from the gramophone pre-amplifier section, and other inputs provided with preset gain-equalization potentiometers. The switch is arranged to earth the inputs not in use, to minimize break-through between programme channels.

The gain/frequency characteristics of the stage are shown in Fig. 6.

Low–pass filter circuit

The voltage amplifying stage preceding the main amplifier should include a steep-cut low-pass filter that can be set to remove unwanted high frequencies. This can be done either by a suitable *LCR* filter arrangement, or by an active filter giving an equivalent performance without the use of inductors. The circuit arrangements available for low-pass active filters are shown in Fig. 7. (b) is the well known circuit arrangement first employed in an audio amplifier design by P. J. Baxandall[3], and (d) is the unity gain rearrangement of this circuit introduced by Sallen and Key[4]. The frequency response of all of these circuit arrangements is similar, *mutatis mutandis,* to that shown in Fig. 8, and the circuit should be preceded or followed by a simple *RC* filter if the type of response shown in the dotted line is required.

For a given overall stage gain, type (b) gives a much better distortion factor near the region of cut-off than (a), and (c) is marginally better than (b) when used with non-linear amplifier elements. The particular advantage of (c) however, is that it can be used conveniently with a very low-distortion two-transistor circuit.

The final stage, with the filter circuitry, is shown in Fig. 1. As a matter of practical convenience, the component values of this circuit have been chosen so that the required low-passresponse is obtained when all of the capacitors *'Cx'* are of equal value to each other. The frequency response obtained with a given value of *'Cx'* can be found from Fig. 9. The user can interpolate between these to obtain turn-over frequencies at any points to suit his own requirements. If a ganged selector switch is employed to give a range of turn-over frequencies, the switch arms (moving contacts) should be connected to the junction of the resistors in the *RC* filter and to the 470Ω resistor in the main filter network. In Fig. 1 the 0.0047μF capacitor for *'Cx'* results in response being 3dB down at about 18kHz. With good quality programme sources this is a recommended capacitor value.

With capacitors of zero value, the response of the circuit is flat to about 100kHz. The user should however arrange for the response to falloff above 25kHz. (It is unlikely that the listener will find anything to gain from the parts of the sonic spectrum beyond this point.)

The optimum performance of this particular type of circuit arrangement is obtained when the overall gain is about 50 with feedback. A 20-40mV input is therefore adequate for this stage for the output voltagesrequired.

The distortion level of this circuit is less than 0.03% at 2 volts r.m.s. output or less, at any frequency within the pass band. The output impedance is less than 150 ohms over the range from 20Hz to the cut-off frequency selected.

It is convenient, for several reasons, to operate at the 60-100mV level through the tone-control stages. At this output voltage level the distortion introduced by an RC coupled f.e.t. stage is less than 0.1% even without feedback, so that the maximum 'lift' settings of either 'bass' or 'treble' controls cannot give rise to unacceptable levels of distortion. It is also large enough for the noise and inevitable 50Hz pickup to be unobtrusive. Some attenuation is therefore desirable between the tone control unit and the steep-cut filter circuit. This is obtained by the preset 2kΩ potentiometer in the tone control circuit, which provides a convenient means for setting the overall gain of the amplifier system, and also as a coarse 'balance control' in a stereo system. Fine balance between channels is obtained by adjusting the 100Ω balance potentiometer in the output stage. This alters the stage gain over the ratio 6 : 10.

Constructional notes

The constructional technique used by the author in building the prototype of this amplifier is similar to that used in the 10-watt class A design described in *Wireless World* in April 1969, with the separate units laid out in mirror image form, as a stereo pair on a single 4in x 4¾in s.r.b.p. pin board. Two units of each type can be accommodated on each board, laid out more or less in the form of the circuit diagram (or its mirror image).

In general, reasonable care should be taken to separate input from output leads, and where the boards are to be mounted as a group within the same box, it would be wise to interpose a sheet metal screen between them.

The units are separately decoupled by 250μF capacitors from a common 24-volt line, derived from a zener diode stabilised *RC* filter power supply. This supply is separate from the main amplifier, and a 30mA output is ample. Details of a suitable power supply are given in Fig. 10. The expected working voltage on each of the unit sub-rails is about 15 volts.

Apart from the input transistor in the gramophone pre-amp unit (Tr_1) for which the BC109 is to be preferred, there is no particular reason why any modern silicon planar types should not give an indistinguishable performance. For example, the n-p-n types could be 2N3904, BC107/8/9, 2N3707 or BC184Ls. Similarly, the p-n-p types could be 2N4058, 2N3906 or BC214Ls.

Although, in many cases, the use of ¾ watt resistors is sufficient,

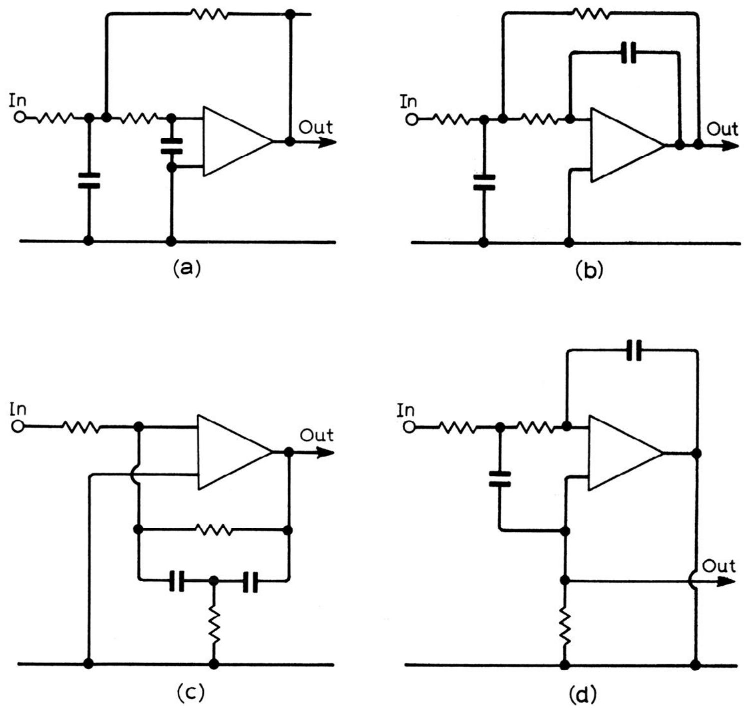


Fig. 7. Circuit arrangements for active low-pass filter design.

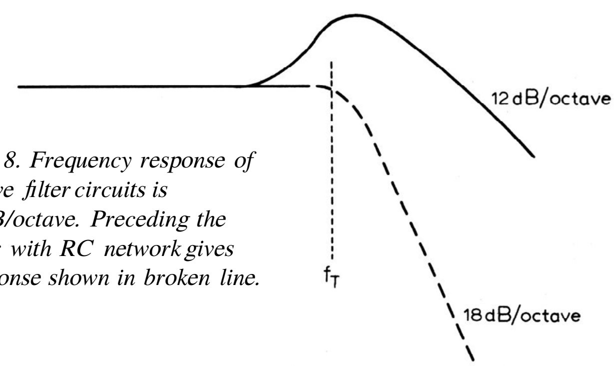


Fig. 8. Frequency response of active filter circuits is 12dB/octave. Preceding the filter with RC network gives response shown in broken line.

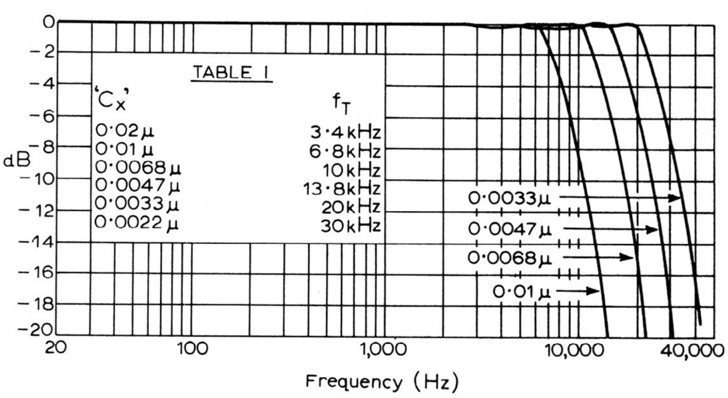


Fig. 9. Graph and table of turn–over frequencies for different value of 'Cx'.

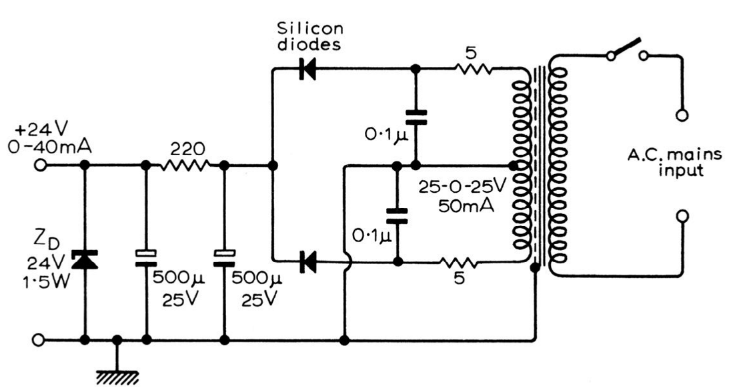


Fig. 10. Suitable power supply for any combination of stages.

it will probably be found simpler to use $\frac{1}{2}$ watt units throughout. 5% tolerance carbon film resistors are to be preferred.

The author has mounted the gramophone pickup equalization circuit in a separate small diecast box, immediately under the gramophone turntable unit, so that the leads from the gramophone are taken at a low impedance from the output of this unit. This has been very effective in reducing the hum picked up on the output leads to an imperceptible level.

Appendix I

The use of 'virtual earth' (null seeking) amplifier circuit arrangements is superficially ill-advised with input elements such as pickup cartridges, because it appears that as the operating frequency is increased, the input half of the balancing limbs will also change, with a resultant change in the gain of the circuit. In particular, a magnetic pickup cartridge may have an inductance of some 300-800mH and the impedance of this will exceed that of the input circuit in the range 12-20kHz. This should clearly reduce the gain of the system by reducing the ratio of A to B.

However, on reflection, it can be seen that the amplifier operates as a null generating device, sensitive only to the current flowing in the input circuit to the 'virtual earth'. As the operating frequency increases, so the current flow through R_1 will decrease, but so it would in any case, regardless of the amplifier, were the element simply connected across network B as the load recommended by the cartridge manufacturers (at these frequencies the impedance of C_1 can be ignored), and the voltage across R_1 measured by a perfect voltage amplifier. The decrease of current input into a given resistive load from a source having series inductance is simply an unfortunate fact of life, from which one cannot escape, whatever one's technique of measurement, and high impedance voltage amplifiers connected across the load, or low impedance current amplifiers connected in series with it, are alike in this respect, except that with transistors, the latter are a bit easier to contrive. The same argument is also applicable, in the appropriate context, to high impedance capacitative elements such as piezo-electric pickup cartridges. Once again, the voltage amplifier and current amplifier see the same phenomena in identical form. The necessary, and inevitable, corrections can be accomplished simply by the tone-control settings.

Appendix II

Although the R.I.A.A. replay characteristic suggests an approximately flat velocity response from 20Hz-50Hz, this would effectively imply recording bass lift in this region, and the author suspects that this is not done, a constant modulation characteristic being used instead. The author has therefore, for his own use, modified the values of the feedback elements as follows: R_5 -470 ohms; R_6 -1.5k ohms; C_1 -0.47μF; C_3 -6800pF; and C_6 -6800pF. These changes maintain the velocity response flat down to 25Hz, with a rapid rumble attenuation below this frequency. Unfortunately the mid point gain of the circuit is reduced to 5, and some additional amplification is therefore needed if it is desired to avoid working with the tone control circuit at the 20mV level. The simple floating emitter collector-follower circuit of Fig. 11 is therefore interposed, without coupling capacitors, between the output series resistor and the collector of Tr3. The distortion contributed by this is less than 0.05%.

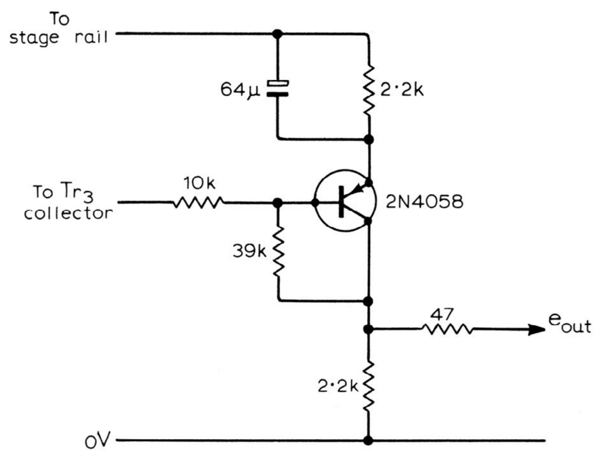


Fig. 11. Floating emitter collector–follower circuit referred to in Appendix II.

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2. Baxandall, P. J., "Negative-Feedback Tone Conrtol", *Wireless World* October 1952.
3. Baxandall, P. J., "Gramaphone and Microphone Pre-amplifer", *Wireless World,* January 1955.
4. Sallen, R. P. and Key, *E. L., I.R.E Trans. Circuit Theory*, March 1955, p.74-85.