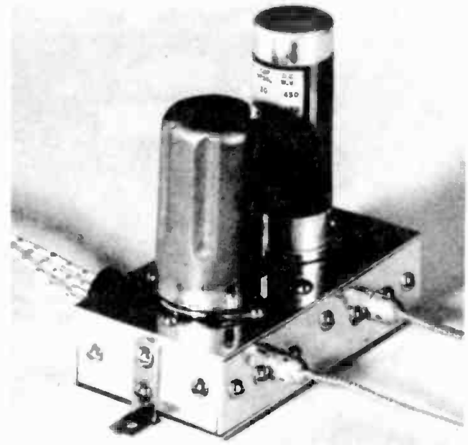
Feedback Preamplifier for Magnetic Pickups



RICHARD S. BURWEN

By using negative feedback for response equalization, this preamplifier design presents many advantages over previous types.

THE PHONOGRAPH preamplifier described herein shows how a feedback circuit can surpass conventional design in four ways and actually cost less to build. These points of superiority are:

1. Very low output impedance enables use of shielded coupling cable without causing severe attenuation of high frequencies.
2. Negative feedback reduces harmonic distortion.
3. Noise and hum originating in the preamplifier are also attenuated.
4. Simpler to build.

Proper reproduction from transcriptions and commercial records with magnetic pickups such as the General Electric and the Pickering requires that the low frequencies be boosted with respect to the middles and, in most cases, that the high frequencies be attenuated to offset the attenuation of lows and emphasis of highs put into the record in the process of recording. Since the output voltage of these pickups is small, especially at low frequencies, and as it is a good idea to isolate such low level circuits from the power amplifier and a-c supply components, a separate preamplifier unit has been designed which includes this equalization and thereby adapts the pickup to the medium level input of any flat amplifier. Selective feedback accomplishes the equalization.

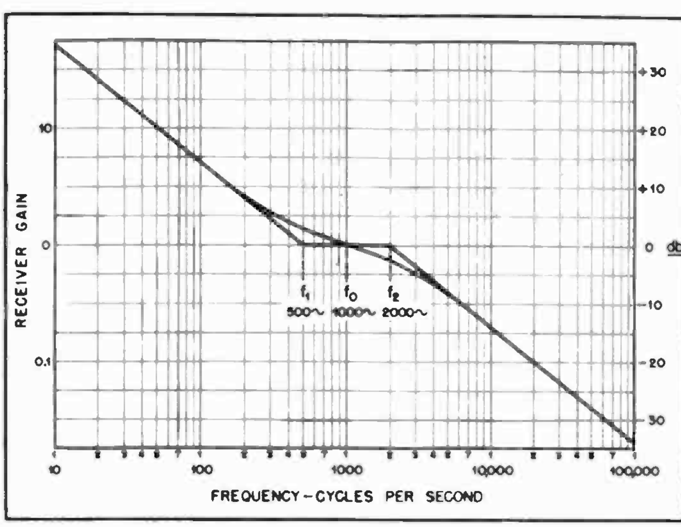
Designed around the G. E. variable reluctance pickup, the circuit produces the response characteristic shown as the smooth curve in *Fig. 1*. However, it is readily adaptable to other pickups and different degrees of high and low frequency compensation with the aid of formulas developed later on.

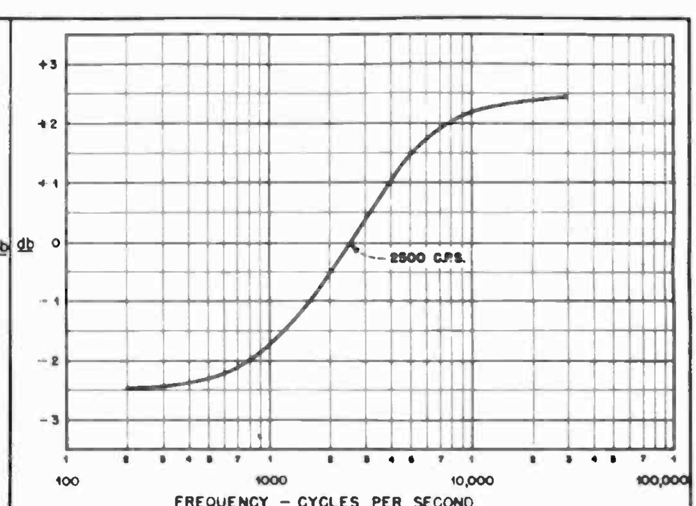
The curve in *Fig. 1* has been chosen as suitable for both transcriptions recorded with the N. A. B. characteristic and commercial records. Variations from the complement of this curve in the recording characteristics of individual records can be easily taken care of with the usual bass and treble controls elsewhere in the system. By continuing on straight instead of leveling off at 50 c.p.s. it provides 3 db more output at that point than the N. A. B. playback curve; this helps compensate for the deficiencies in many records.

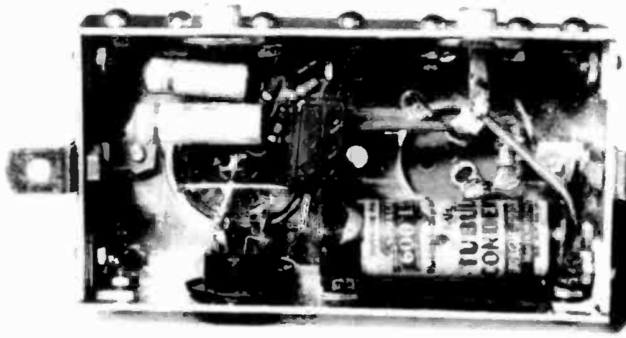
Design Considerations

The conventional method of accomplishing the job of this preamplifier might consist in using two high-μ triode stages with a resistance-capacitance equalizer between them. Although this arrangement may be fairly satisfactory provided all the stray capacities are kept to an absolute minimum, we immediately run into difficulty when we try to feed the output voltage through a shielded cable to the main equipment, since shunt capacity in the cable attenuates the high frequencies. We could compensate for

Fig. 1 (left). Play-back curve and its asymtotes for a cross-over frequency of 500 cycles. Fig. 6 (right). Curve showing equalization required to bring magnetic pickup (G. E.) up to flat response on a constant velocity basis.







Under-chassis view of preamplifier.

this loss within the amplifier, but then we would always have to connect the amplifier to the same cable or use a suitable coupling transformer, which would increase the cost.

Another disadvantage with conventional circuits, when the high-frequency roll-off part of the equalizer is inserted between stages, is that while tube hiss generated in the first stage is reduced, that generated in the second stage is not. A simple way of alleviating both these disadvantages would be to roll off the high frequencies at the plate of the second stage by means of a capacitance to ground instead of between stages; but new troubles arise from this expedient because this reactance, effectively across the plate load resistor, will seriously limit the signal voltage handling capability of the tube and greater distortion will result. If the high-frequency roll-off capacitor were connected between grid and ground, we have left a new point where stray capacities and Miller effect can cause unwanted attenuation of the highs.

Circuit

All these disadvantages are overcome in the feedback preamplifier circuit of *Fig. 3.* It uses the same number of parts, but capacitors in the equalizing circuit are smaller; several more advantages are incorporated in the design and construction. Feedback from the plate P_2 of the second triode V_2 to its own grid through the network consisting of R_5, C_3, and C_4 provides the proper frequency compensation. As a result of this feedback, the effective output impedance at high frequencies is of the order of a thousand ohms and the outgoing signal can be fed through a shielded cable or to certain types of tone control circuits that ordinarily require a cathode follower driver without fear of losing the high frequencies. Noise originating in the plate circuit of the last stage is fed back out of phase to its grid and noise and harmonic distortion originating elsewhere are reduced by virtue of the frequency discrimination. Harmonic distortion generated within the second stage is lowered by a factor of 6 at 30 c.p.s. and considerably more at higher frequencies. Only one point remains where stray capacities can cause appreciable unwanted attenuation of the high frequencies (the plate P_1 of the first stage) instead of two, and the feedback eliminates the possibility of high frequency oscillations due to stray capacitive coupling from plate P_2 to the grid G_1, rendering the mechanical layout less critical.

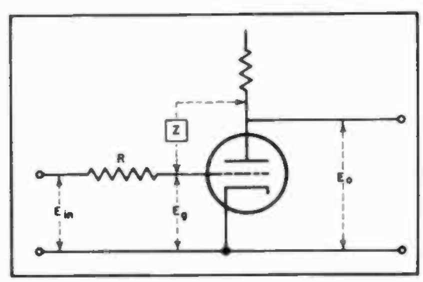


Fig. 2. Detail of feedback stage. Z represents the network R5, C3 and C4 of Fig. 3. R is approximately equal to R4.

Construction

The author's preamplifier was built on a 4 x 2 x 1 inch aluminum chassis with a bottom cover. The tube and the 1 x 3-inch aluminum can filter capacitor were mounted on top and the rest of the parts inside. Filament hum was minimized by completely eliminating filament wires, accomplished by feeding the power in through a miniature four-prong socket on the side of the chassis that had two of its lugs soldered directly to the filament contacts of the tube socket on the top of the chassis, the types 7F7 and 6SC7 tubes being conveniently designed with the filament prongs adjacent to each other. All the signal-carrying wires were kept down to less than a half inch in length and midget coupling capacitors were used so as to offer as little surface area as possible to the electrostatic field of the filament circuit and to prevent loss of high frequencies through capacity to ground. Hum is thus reduced to a low value provided that the center-tap and not one side of the filament supply be grounded, and this preferably by means of a potentiometer.

Hum

It must be pointed out that no amount of care in construction can completely eliminate hum that originates within the tube itself and that where the utmost of fidelity is required the six-volt tube should be replaced by the twelve-volt heater types to reduce current consumption, so the filaments may be heated by a 150 ma direct current supply.

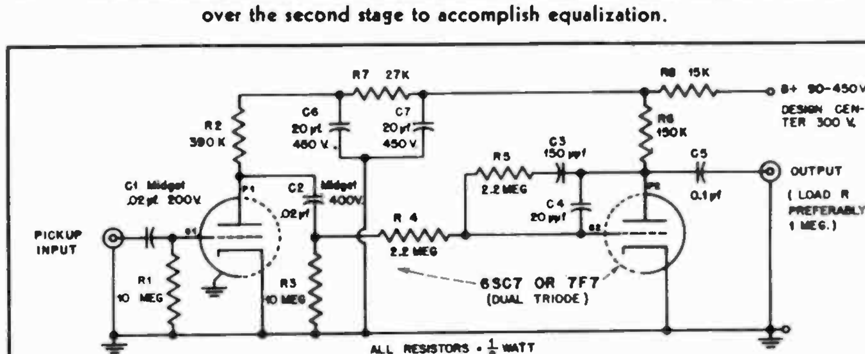
Of the tubes indicated the 7F7 is the one around which this circuit was designed. It was chosen on account of its high gain and low harmonic distortion,* the total r-m-s distortion for the preamplifier is estimated to be around 0.1 or 0.2 per cent on peaks. The gain is such that with the G. E. pickup, instantaneous peaks seen on an oscilloscope reach five volts on loud records. However, the amplification with the type 6SC7 was found to be nearly the same and the measured plate voltages turned out to be a little closer to the desired values. The 6SC7 is also cheaper and, in the cases of the particular pairs of tubes compared, less microphonic than the 7F7.

Equalization

Equalization to flat response from the majority of lateral records and transcriptions requires that the gain rise at a rate

*Sylvania Electric Products Inc., Technical Manual, Resistance Coupled Amplifier Data

Fig. 3. Complete schematic of the magnetic pickup preamplifier, using negative feedback over the second stage to accomplish equalization.



of 6 db per octave below some frequency which we shall call f_1 and that the gain fall off at a rate of 6 db per octave above some frequency which we shall call f_2. In addition, there may be a frequency at the low end where the gain begins to level off again which we will consider later. Actually, the bends in the curve at these frequencies are very gradual so that they can be made with simple resistance-capacitance networks and the slope only approaches 6 db per octave at a considerable distance from the bend. The two frequencies f_1 and f_2 vary with different manufacturers, and if we were to construct a network for every combination of f_1 and f_2 in present-day records we would indeed have a large number of networks. The simple way out is to build a single network having f_1 and f_2 representative of a large number of records and leave the rest to be taken care of by ordinary bass and treble balancing controls elsewhere in the equipment. The smooth curve in *Fig. 3* has therefore been chosen with $f_1 = 500$ c.p.s. and $f_2 = 2000$ c.p.s. It corresponds closely to the present N. A. B. characteristic.

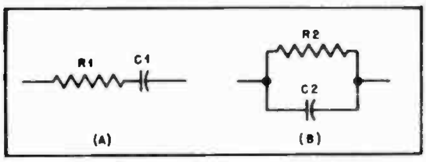


Fig. 4, In (A), network for bass boost only. $X_{C1} = R_1$ at f_1 (Fig. 1). In (B), network for high frequency attenuation only. $X_{C2} = R_2$ at f_2.

Mathematically, the simplest way to attain this curve is in two steps, first by boosting the lows and then by attenuating the highs in two separate consecutive amplifier stages. By replacing our Z in *Fig. 2* with the network A or *Fig. 4* we can attain the 6 db per octave slope at the low end. The turnover frequency f_1 is the point at which the reactance $X_{C1} = R_1$. A 3 db rise occurs at this point to effect the gradual bend, and the slope approaches nearer and nearer to 6 db per octave as the frequency goes down because the impedance becomes very nearly that of the reactance X_{C1}, which doubles in every octave. Above f_1 the reactance is small compared to R_1 and so the impedance approaches R_1, resulting in constant output.

High-Frequency Attenuation

The high frequencies can be attenuated at a rate approaching 6 db per octave above f_2 by replacing Z with the network B of *Fig. 4* where $X_{C2} \doteq R_2$ at f_2. Below f_2, X_{C2} becomes large and the impedance approaches R_2; above f_2, where the effect of R_2 becomes small, it approaches X_{C2}. By passing the signal through a stage containing network A and then through a stage containing network B we get the combination of these two curves, the same one as in *Fig. 1*. The straight lines, called asymptotes, show the limiting value of the slope.

If the phonograph turntable produces an excessive amount of rumble, common to the cheap types, it may be necessary to choose a gain reduction factor of about 10 for a leveling off point of 50 c.p.s. and in addition lower the values of all three coupling capacitors C_1, C_2, and C_5. The N. A. B. playback curve has a leveling off point at 50 c.p.s., but this is usually taken care of by the deficiencies in the recordings and the associated equipment, particularly the loudspeaker.

Pickup Response

So far the actual response of the phonograph pickup has not been taken into account. The author tested two G. E. cartridges on the Columbia 10004-M frequency record and on H. M. V. constant tone frequency record numbers D. B. 4034 and D. B. 4035 which according to the label are accurate to within 0.2 db and whose light patterns tend to confirm their accuracy. Agreement was close between the cartridges and fairly good between the Columbia and the British records. The general trend of the curves was that of a roll-off 3 db down at 3000 c.p.s. reaching a maximum dip of 5 to 6 db and then rising again at 10,000 c.p.s. On the Columbia record 10,000 c.p.s. was only 3 db down. Discontinuities in the curve of the British records, which take four sides to change from 8500 c.p.s. down to 500 c.p.s., prevented determination of an exact curve for equalization to flat response, probably on account of the inability of the large point radius to reproduce high frequencies as efficiently at the center of the record as at the outside grooves.

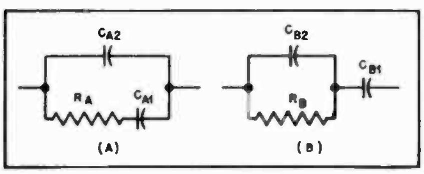


Fig. 5. Network (A) to boost bass and attenuate highs; and (B) equivalent circuit of (A).

So far as the author has been able to determine the resistance-capacitance equalizer curve which comes closest to bringing the output up to flat response is the one shown in *Fig. 6*. In ordinary amplifiers it is achieved by means of the simple 5 db equalizer in *Fig. 7* having a half-loss frequency of 2500 c.p.s. This curve seems to be a happy medium since 10,000 c.p.s. will be up about 2 db at the outside of a record and will be down slightly at the inside.

A word of caution might here be mentioned in connection with the use of long shielded cables between the pickup and amplifier. On account of the 100 mh inductance of the magnetic pickup and the capacitance of the cable, a ten-foot shielded cable will add another 2.5 db to the output at 10,000 c.p.s.

Fortunately, we can compensate for the pickup characteristic without adding anything to the preamplifier. It happens that if we design the equalizing network for a high-frequency turnover point $f_2 =$ 3560 c.p.s. instead of 2000 c.p.s., the curve of the pickup will subtract from that of the equalizer and produce almost exactly the curve we originally intended in *Fig. 1*. For the two equalizer networks of *Fig. 5* we have.

$$R_A C_{A1} = 318 \text{ microseconds}$$
$$R_A C_{A2} = 52.0 \text{ microseconds}$$

and

$$R_B C_{B1} = 274 \text{ microseconds}$$
$$R_B C_{B2} = 44.7 \text{ microseconds}$$

The gain $\quad A_o = \dfrac{Z_o}{R}$

at f_o, now 1336 c.p.s., was chosen to be slightly less than unity to permit a gain reduction of at least 50 times and a departure from the asymptote of not more than 0.5 db at 30 c.p.s. for the entire preamplifier. Network A was more easily fitted by standard values of resistors and capacitors, making allowance in C_{A2} for the plate to grid capacitance of the tube and socket.

For use with other magnetic pickups having a higher output than the G. E., it is suggested that the first stage be eliminated and the pickup connected directly from ground to the Pl side of coupling capacitor C_2 in *Fig. 1*. The output can be brought up sufficiently by selecting a higher value of $\dfrac{Z_o}{R}$ provided a higher leveling off point can be tolerated. Another pickup will of course require different equalization at the high end. A worthwhile addition to the circuit that will make for more pleasing reproduction from worn records would be a switch that would shunt a resistor and capacitor in parallel across the pickup or several pairs so as to cut off the high frequencies fairly sharply at selected points in the manner described in the preceding article starting on page 48. The pre-

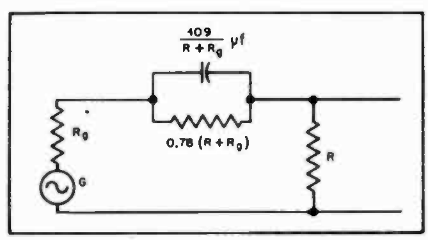


Fig. 7. Interstage equalizer for flat response from G. E. or similar magnetic pickups. Rg represents the internal resistance of the driving amplifier.

amplifier can be powered with plate supply voltages other than 300 volts; in fact, there is little difference between operation at 90 volts and that at 450 volts. But, in general, the higher the voltage, the less the distortion.