Hi-Fidelity Phonograph Preamplifier Design

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A comprehensive discussion of the principles of determining component values to provide the compensation required, combined with practical pointers on construction.

SEVERAL EXCELLENT phonograph preamplifier circuits have appeared in the literature but it is difficult for the individual who is not a full-fledged audio engineer to find the information he may need for designing a high-quality preamplifier to meet his individual preferences, or to make desirable changes intelligently in equipment already on hand. This article aims to set forth in a summary fashion basic material which a technically minded audio hobbyist or an amateur engineer would need in the design or revision of quality preamplifying and compensating equipment. Rather than attempt a comprehensive survey of the problems and theory of preamplifier and compensation circuit design, attention will be confined to straightforward basic circuits.

Basic Amplifier With Degenerative Bass Boost

Figure 1 shows the basic circuit around which most high-quality phonograph preamplifiers are designed. Resistor R_2 provides degenerative feedback to set the amplifier gain to the desired value for high frequencies, reduce amplifier distortion in the high-frequency range, and extend the high-frequency range beyond that which could be obtained from the basic amplifier without feedback. R_3 provides degenerative feedback to set the maximum value of bass boost, reduce amplifier distortion at the extreme low frequencies, and extend the low-frequency range below that which could be obtained from the basic amplifier without feedback. R_3 may be omitted (made infinite) when compensation is desired down to a frequency requiring the full gain of the basic amplifier. C_t provides 6-db-per-octave bass boost as figured from the turnover frequency for which C_t is selected.

The first step in the design of a preamplifier is to design a basic amplifier which has sufficient gain to provide down to the lowest frequency of interest compensation for the highest turnover frequency to be used. Information on electrically correct turnover frequencies may be found in the literature, and it will be observed that there are combinaations of listening conditions, listener preference, and recording characteristics which may require turnover frequencies as high as 900 cps. As a 900-cps turnover requires approximately 29 db boost at 30 cps, the preamplifier gain at 30 cps must be the antilog of 29/20 or 28.2 times as great as in the high-frequency range if bass compensation is to be provided down to 30 cps for a 900-cps turnover. Since due to the action of C_t the gain only approaches the full basic amplifier gain as the frequency is reduced, in order to obtain good compensation down to a given frequency it is necessary to design for a frequency one octave lower. Thus for good compensation down to 30 cps for a 900-cps turnover one must have a basic amplifier with a gain at least 56 times greater than that required in the high-frequency range.

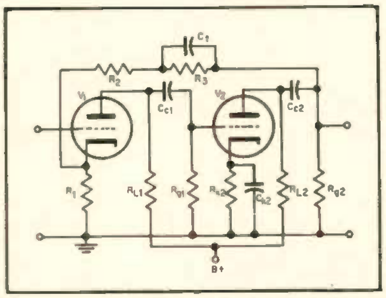

Fig. 1. Basic degenerative-bass-boost amplifier circuit. V_1 and V_2 and associated components, excluding feedback elements R_2, R_3, and C_t comprise the basic amplifier. Triodes are shown for simplicity.

A preamplifier designed for use with a "Williamson" type power amplifier and a G.E. magnetic cartridge should provide between one and two volts output for a 10-millivolt input at 1000 cps. If this preamplifier is to provide good compensation down to 30 cps for turnovers up to 900 cps it must have a basic amplifier gain of between 5600 and 11,200, with R_2 selected to obtain a gain of between 100 and 200 in the high-frequency range. If no turnovers above 500 cps are to be used, good compensation to 30 cps may be secured with a basic amplifier gain of between 3100 and 6300. High-level cartridges, such as Clarkstan and Pickering, require minimum preamplifier gains approximately only one-sixth as great.

The selection of V_1, V_2, and associated components is best made from reference to the resistance-coupled amplifier data supplied by tube manufacturers. Because of the unbypassed cathode resistor the gain provided by V_1 will be

$$A_1 = \left[\frac{A_1'}{1+\left(\frac{R_1}{R_{L_1}}\right)A_1'}\right], \qquad (1)$$

where A_1' is the gain provided by V_1 with a completely bypassed cathode. C_{c_1}, C_{c_2}, C_{k_2}, and screen bypass capacitors if pentodes are used, must be selected to provide essentially uniform gain down to the lowest frequency f_L for which full compensation is desired. To accomplish this it is desirable to choose the value of C_c (in farads) so that the product $f_L C_c R_g$ is between one and two, and to choose C_{k_2} so that the product $f_L C_{k_2}$ is between one and two times the mutual conductance of V_2. In many cases adequate gain may be obtained without use of C_{k_2}. Data required for the selection of a pentode screen bypass capacitor is ordinarily not available, but one can usually make a satisfactory choice by requiring that the product of the bypass capacitance (in farads), the lowest frequency of interest, and the plate resistance of the tube when triode connected have a value between one and two. If it is not convenient to use capacitances as large as those required by the foregoing conditions, the situation may be relieved by providing around 10 db of feedback through R_3.

Once the basic amplifier has been designed to provide adequate gain for the maximum bass boost desired, the next step is to select R_2 so that the amplifier will give the right amount of gain for the high frequencies. At high frequencies (5000 to 10,000 cps) the gain is given by

$$A_{HF} = \left[\frac{A'_{HF}}{1+\frac{R_1 A'_{HF}}{R_1+R_2}}\right], \qquad (2)$$

where A'_{HF} is the gain of the basic amplifier when a resistance equal to R_1+R_2 is placed in parallel with R_{L_2}. The gain provided by V_2 under these circumstances is equal to the mutual conductance of V_2 multiplied by a resistance equal to the parallel combination of the plate resistance of V_2, R_1+R_2, R_{L_2}, and R_{g_2}. To obtain accurate 6-db-per-octave bass boost it is necessary for A'_{HF} to be large enough to make negligible the unity in the denominator of Eq. (2)—i.e., for A'_{HF} to be greater than $10R_1/(R_1+R_2)$. When this

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condition is satisfied Eq. (2) becomes

$$A_{HF} = \frac{R_1 + R_2}{R_1}. \qquad (3)$$

Since R_1 will usually be chosen from resistance-coupled amplifier data for proper biasing of V_1, one may write the following equation for R_2,

$$R_2 = R_1(A_{HF} - 1), \qquad (4)$$

where A_{HF} is now the required high-frequency gain—i.e., the gain without bass boost. If the loading effect of $R_1 + R_2$ keeps A'_{HF} from being large enough to render insignificant the unity in the denominator of Eq. (2), the situation may be remedied by connecting R_2 and C_t to an unbypassed cathode of a stage following V_2 (possibly a cathode follower output for the preamplifier).

The maximum gain available from the amplifier may be designated A_{LF} and is given by

$$A_{LF} = \left[\frac{A'}{1 + \frac{R_1 A'}{R_1 + R_2 + R_3}} \right], \qquad (5)$$

where A' refers to the normal gain of the basic amplifier without feedback. In practice the coupling and bypass capacitors often prevent realization of the full value of A_{LF}.

From the fact that a simple resistance-capacitance arrangement which will provide 6-db-per-octave boost computed from a turnover frequency f_t must give a 3 db boost at f_t,[1] one obtains the following relation for the selection of C_t.

$$C_t = \frac{1}{2\pi f_t (R_1 + R_2)}. \qquad (6)$$

[1] The boost will be very close to 1 db at $2 f_t$, 3 db at f_t, 7 db at $\frac{1}{2} f_t$, and 12 db at $\frac{1}{4} f_t$.

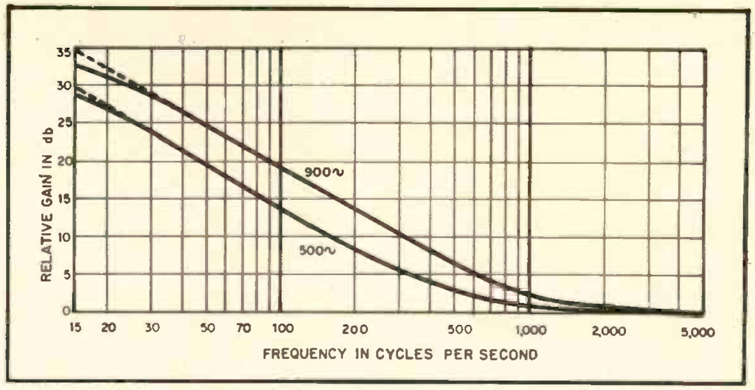

Fig. 2. Bass performance of pentode amplifier example discussed in text. Dotted lines indicate idealized 6-db-per-octave slope.

It will now be instructive to see how these principles are applied in selecting the components for a practical high-fidelity preamplifier for use with a GE cartridge and a "Williamson" type power amplifier. On consulting the resistance-coupled amplifier charts in a receiving tube manual one finds that a basic amplifier gain A' of approximately 18,000 may be obtained by using for V_1 a 6SJ7 with 180-v. E_{bb}, 0.5-meg. R_{L_1}, 2.4-meg. screen resistor, 2.0-meg. R_{g_1}, and 2410-ohm R_1 to obtain a gain of 95; and for V_2 a 6SJ7 with 180-v. E_{bb}, 0.5-meg. R_{L_2}, 2.2-meg. screen resistor, 1.0-meg. R_{g_2}, and 2180-ohm R_{k_2} to obtain a gain of 192.

For 10-db minimum feedback A_{LF} = 1800/(antilog 10/20) which is 5700. From Eq. (5) one finds that this requires 20 megs. for R_3, $R_1 + R_2$ being negligible in comparison with R_3. For A_{HF} = 100, Eq. (4) requires a value of 0.241 meg. for R_2. This provides at high frequencies a 45 db feedback in addition to the 6.8 db of current feedback on V_1 due to its unbypassed cathode resistor. For 900 and 500 cps turnovers Eq. (6) requires values for C_t of 740 and 1310 μμf respectively.

The actual performance of this preamplifier is shown in *Fig. 2*. The value chosen for A_{LF} was 35.1 db above that chosen for A_{HF}, an amount just equal to the boost required at 15 cps by a 900 cps turnover. The necessity for designing to a frequency one octave below the lowest frequency to which full compensation is desired is illustrated by the 900 cps turnover curve in *Fig. 2*.

In a preamplifier designed for use with a high-level magnetic cartridge, a value of but 15 for A_{HF} would be adequate. One could use the basic 6SJ7 amplifier discussed above with 33,700

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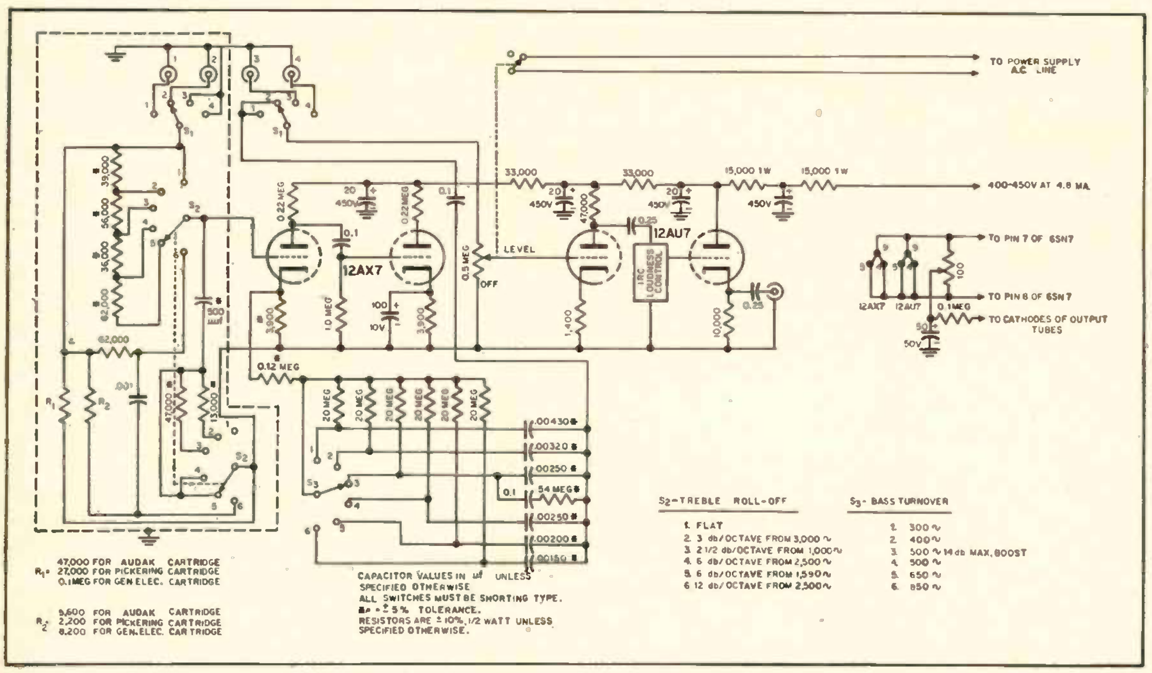

Fig. 3. Complete schematic of author's preamplifier with six bass turnover conditions and six roll-off positions.

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(*from page 20*)

ohms for R_s and 4 megs. for R_s to obtain good compensation down to 20 cps for a 900-cps turnover. Actually the 6SJ7 is a poor choice for V_1, for unless d.c. is used on the heaters one is likely to experience hum difficulties. The 6J7 would be more suitable in this respect, even though it will not provide quite as much gain. The high-level cartridge makes possible good bass compensation with a simple preamplifier using a twin triode such as the 12AX7, 6SL7, or 7F7. Triodes may be used in a preamplifier designed for use with a low level cartridge by following the basic amplifier with an additional stage of amplification as shown in *Fig.* 3. With a high-level cartridge the amplifier noise and hum level will be about 16 db lower with respect to the signal level than would be the case with the same amplifier and a low-level cartridge.

If the preamplifier is to provide for switching between various turnovers,

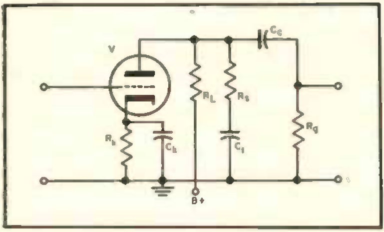

Fig. 4. Basic variable-load-impedance bass-boost amplifier circuit. Triode shown for simplicity.

the selector switch must be of the shorting type to avoid serious switching transients high-quality capacitors should be used for C_t, and a 10- to 20-meg. resistor must be placed in parallel with the selector switch for each switch position. These precautions are required because of the d.c. potential difference across C_t. The value of the switch-shunting resistors is not critical, but the combined resistance of all of them in parallel should be no less than about 40 times R_2.

The Columbia long-playing recording characteristic requires a 500-cps turnover with a maximum bass boost of about 14 db. For this compensation the capacitor used for C_t should have shunting it a resistor of such value as to provide in parallel with the resistor used for R_s an effective resistance for the R_s term in Eq. (*5*) that will give a value for A_{LF} which is five times the value of A_{BF} for the amplifier. To avoid serious switching transients a blocking capacitor should be placed in series with this resistor. This blocking capacitor should be chosen so that the product of its capacitance (in farads) and the lowest frequency of interest is at least equal to the reciprocal of three times the resistance of the shunting resistor in series with it.

Variable-Load-Impedance Bass Boost

A simple, commonly-used type of bass boost circuit is shown in *Fig*. 4. R_k, R_L, and R_g may be selected from resistance-coupled amplifier data to provide the maximum gain desired at the lowest frequency of interest. The requirements on C_c and C_k are the same as discussed for the basic amplifier in the degenerative-bass-boost circuit. The high-frequency gain is given by the product of the mutual conductance of the tube and a resistance equal to the parallel combination of the plate resistance of the tube, R_L, R_s, and R_g. The required value for C_t may be computed from Eq. (*6*) by substituting R_s for $R_1 + R_2$. The maximum gain should be at least 6 db above, or two times greater than, that required for the greatest bass boost desired, if a 6 db per octave slope is to be followed to the lowest frequency of interest. A 6SJ7 operated to obtain a maximum gain of 200—46 db—will provide for a high-frequency gain of about three and

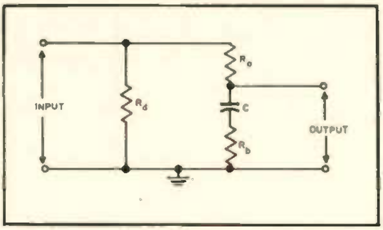

Fig. 5. Treble roll-off circuit. R_a selected for cartridge damping and/or to obtain roll-off rates between 6 and 12 db per octave. R_b selected to obtain roll-off rates less than 6 db per octave.

full bass compensation down to 30 cps for a 900-cps turnover when used in this simple circuit. There will be, of course, no degenerative feedback to provide for low distortion obtainable with the previously discussed system. For a 500-cps turnover compensation may be carried about one octave lower, or about 6 db more gain may be provided for the high frequencies.

By following a degenerative-bass-boost amplifier with a stage of amplification containing variable load impedance bass boost with a very low turnover frequency—50 cps, for example—extra boost for the low bass may be obtained if desired.

Treble Compensation

For a 6 db per octave roll-off, the simplest treble compensation is obtained by selection of the resistance shunting the magnetic reproducer cartridge.[2] Neglecting the effects of cartridge internal capacitance (usually negligible in the audio range), 6-db-per-octave attenuation will be obtained as figured from a frequency equal to 6.28 times the cartridge inductance in henries divided into the sum of the internal resistance of the cartridge and the effective external resistance shunting it. One can select the roll-off frequency by adjustment of the preamplifier input resistance with either a fixed position switching arrangement or a continuously adjustable potentiometer control.

A more flexible treble roll-off circuit

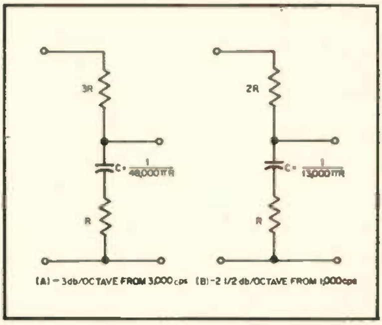

Fig. 6. Circuits for commonly used roll-off less than 6 db per octave. (A) is accurate within ± ¼ db to 15,000 cps. (B) is accurate within ± ¼ db to 10,000 cps and gives 1 db less than ideal attenuation at 15,000 cps.

is shown in *Fig*. 5. R_d is usually selected for cartridge damping in accordance with the recommendations of the cartridge manufacturer. If R_b is zero, an attenuation at 6 db per octave will be obtained as figured from a frequency equal to the reciprocal of the quantity 6.28 times the product of R_a in ohms and C in farads. R_a should be large enough so that its parallel combination with R_d acting in connection with the cartridge inductance will not cause appreciable additional high-frequency attenuation, unless a roll-off rate greater than 6 db per octave is desired. To accomplish this the resistance of R_a and R_d in parallel should be at least 125,000 times the cartridge inductance in henries. *Figure* 6 gives data for selection of components for treble roll-off at less than 6 db per octave as required by some RCA Victor and some British 78 rpm recordings.

Noise and Hum Reduction

If the preamplifier is laid out and wired carefully, hum and noise may be reduced to a negligible level by simple

[2] Norman Pickering, "Effect of load impedance on magnetic pickup response." AUDIO ENGINEERING, Mar. 1953.

means. Resistor noise will ordinarily be unnoticeable; the ultra-perfectionist may practically eliminate it by using wire wound resistors in the plate circuit and any unbypassed portion of the cathode circuit of the first stage. Most of the hiss noise from an amplifier usually comes from the first tube. Tube noise varies greatly between tube types, and between individual specimens of a given type. Unless a selected low-noise tube is used, tube noise will usually be less in a preamplifier employing a triode in the first stage than in one using a pentode. If the first stage is to use a pentode it is well worth while to use the 1620 or the 5879 for their low microphonism, hiss, and hum. Where a low-noise triode is desired one can use the 12AY7 or a triode-connected 5879.

The most obvious and straightforward way of eliminating hum arising in the cathode circuits is to use direct current heater power. D.c. for heaters may be obtained from a full-wave dry disc bridge rectifier with a simple capacitance filter of between 1000 and 5000 microfarads. The rectifier will require an r.m.s. input voltage about 50 per cent greater than the required filament voltage. One should provide a variable series resistance between the rectifier and the capacitor so that the filament voltage may be adjusted to the proper value. With this arrangement a standard 12.5-volt transformer may be conveniently used for a 6.3-volt d.c. heater supply.

If one is not so unfortunate as to get a poor tube in the input stage, hum due

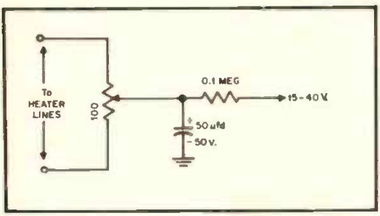

Fig. 7. Hum reduction circuit. Neither of the heater lines may be grounded, and a center tap on the transformer should not be used. Potentiometer is adjusted for minimum hum.

to a.c. heater operation may usually be eliminated by the simple arrangement of *Fig. 7*. The value of the bypass capacitance is not critical (values less than 1.0 μf have been used successfully). Satisfactory hum reduction may often be accomplished by eliminating the balancing potentiometer and connecting the positive bias to the center tap of the filament transformer. When the balancing potentiometer is used it is well to locate it and the associated bypass capacitor near the first stage of the preamplifier, as it takes the place of the usual grounding of one side of the heater line.

Illustrative Preamplifier Circuit

As an illustration of the principles discussed in this article, *Fig.* 3 gives the schematic of an easily constructed preamplifier designed for use with the author's Ultra-Linear Williamson power amplifier. This preamplifier has ample gain for use with a low-level GE reluctance cartridge and carries compensation fully down to 30 cps for the highest turnover frequency. At maximum gain settings approximately one-third volt input on the high-level inputs 3 and 4 will drive the power amplifier to full output. The author's unit is completely contained within a 10×4×2½ inch aluminum box. In constructing the preamplifier it is important to keep to a minimum the stray capacitances in the treble compensation circuits and in the input connection to the 12AX7. If the preamplifier is to be used only with a Pickering cartridge, or any other make of similarly low inductance, it would be well to double the compensation capacitor connected to the first 12AX7 grid to 1000 μμf and reduce to one-half the values given for all the compensation resistors connected to the treble switch points 2, 3, 4, and 5, thus reducing stray and input capacitance problems.

In the author's opinion, any adjustment of the system frequency response beyond the simplest that will compensate for the recording characteristics of the disc being played will deteriorate the transient response. As a concession to situations in which simulated live program loudness is undesirable or unpermissable, the circuit of *Fig.* 3 has been designed to incorporate an IRC loudness control. For this control to function properly the level control must be set to give simulated live program loudness with the loudness control at its maximum setting. Much of the criticism of loudness controls has come from failure to do this.