Preamplifiers and Control Units

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Sound—Chapter 6

A discussion of the reasons for preamplifiers, their requirements and how they fulfill them, and the circuit configurations that provide boost and cut of either treble or bass frequencies.

The simplest electrical phonograph system is one in which a very high output pickup is connected directly to the grid of a power amplifier tube. Crystal pickups with outputs of 3 or 4 volts, for example, are sometimes used to drive the grid of a 50L6 output tube (the 50L6 is designed to operate with relatively small input voltages) without intermediary voltage amplifiers.

Normally, however, the output of the pickup, whatever the type, is fed to a voltage amplifier. When this voltage amplifier is an extra stage, not used for other inputs such as tuner signals, it is called a *preamplifier*. Magnetic pickups require preamplifiers because of their low output voltage. Magnetic pickup voltages in the range between one and fifty millivolts are amplified to values of the order of one volt.

Special Tasks of the Preamplifier

The first job of the preamplifier, as described above, is to amplify the pickup voltage, without distortion. Unlike voltage amplifier stages in the amplifier proper, the preamplifier works with very small signals. Any stray noise or hum induced in the pickup, the pickup lead, the circuit components, or the tubes themselves may compete with the signal itself in magnitude, at least to the extent of providing an annoying noise background.

We have seen that FM broadcast standards for signal-to-noise ratio require that the noise be at least 60 db down from the signal, that is, that it be no more than one-millionth of the power of the signal. When the signal itself is of the order of a small fraction of a microwatt the power of stray hum and noise in the circuit must be kept low indeed in order not to intrude.

One special quality of good preamplifiers, therefore, is that they have very low noise and hum. Power amplifiers with signal-to-noise ratios of 80 db (100 million to one) or better are not too unusual, but we must lower our standards for phonograph preamplifiers, especially when using very low output pickups.

The next job of the preamplifier is to introduce the correct frequency discrimination to compensate for the bass attenuation and treble boost in the recorded signal—to *equalize* the output of the magnetic pickup. Since all records have not been made with the same frequency characteristics, most high fidelity preamplifiers have facilities for switching from one type of equalization to another, shifting the bass turnover and treble pre-emphasis frequencies, and in some cases the rate of boost or slope.

These switching facilities may be fairly simple—a single knob with four or five positions—or fairly complicated, with separate switching of bass and treble transition frequencies. Considering the fact that factors beyond the control of the phonograph operator, such as microphone position, recording studio acoustics, and so on, may have a greater effect on the over-all sound than the differences in recording characteristics between two companies, it seems sensible to favor the simpler arrangement. The general tone controls may be used to 'touch up" the sound to its most natural form, in any case.

The frequency response of a preamplifier is described by the curve of its equalization. The excellence of preamplifiers in this respect is indicated by the accuracy with which they adhere to the correct equalization curve. It is obvious that describing the frequency response of a preamplifier in terms of frequency extremes—20 to 20,000 cps, for example—would tell us nothing useful about the performance characteristics of the unit. What we want to know is whether the frequency response of the preamplifier is within, let us say, one db of the proper equalization at all points of the curve.

When the desired frequency response curve of a particular audio component happens to be flat (as in the case of a velocity pickup, power amplifier, or loudspeaker), it is unfortunate that the meaning of the phrase "frequency response" sometimes departs suddenly, and a meaningless recitation of frequency limits takes its place. But it is no less true here, than in the case of the equalized circuit, that a meaningful description of frequency response must tell us how accurately the output conforms to

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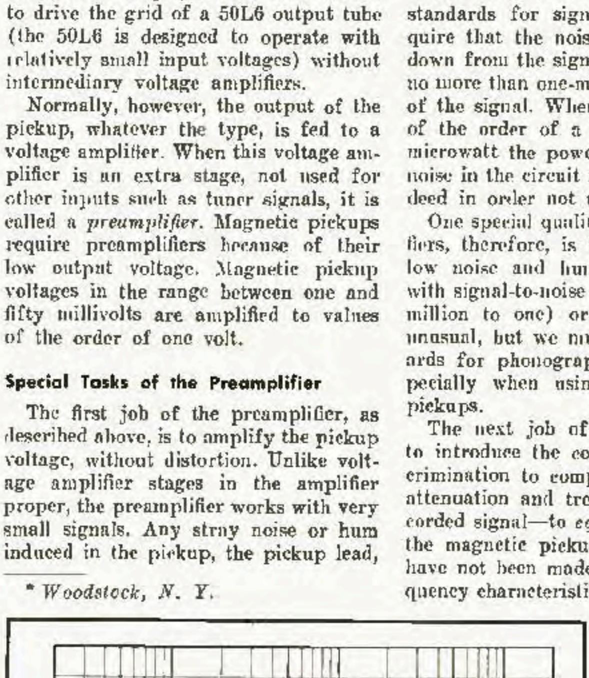
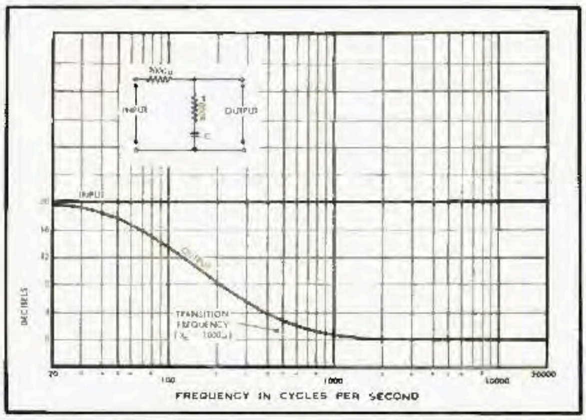


Fig. 6—1. Resistive voltage divider. The input is attenuated by a factor of ten (a 10 to 1 voltage ratio is 20 db), but there is no frequency discrimination.



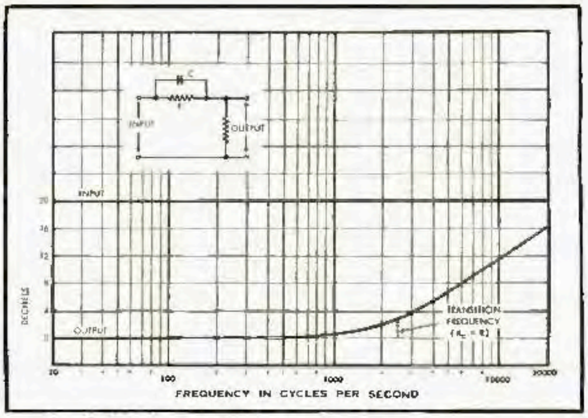


Fig. 6—2 (left). Resistor-capacitor voltage divider, and resulting bass boost. Fig. 6—3 (right). Treble boost circuit.

the ideal (in this case flat) at every point of the curve.

In summary, then, the preamplifier must amplify the magnetic pickup output voltage to a value comparable to the output of the tuner or of a crystal pickup—roughly half a volt to a volt—without the introduction of significant distortion or noise, and it must accurately equalize the output of the pickup to the reciprocal of the frequency characteristic of the particular record. High quality preamplifiers may be expected to keep harmonic distortion at a small fraction of one per cent, to keep the noise at least 60 db below the signal, and to provide an equalization curve accurate within half a db or so of the theoretical curve, over the entire audio spectrum.

The preamplifier should also provide the proper resistance "termination" for the pickup, as discussed in a previous chapter.

Frequency Discriminating Circuits

Frequency discriminating circuits—equalizers for preamplifiers, or variable tone controls—may be of the feedback or direct type, but in either case the basic circuit element is the *voltage divider.*

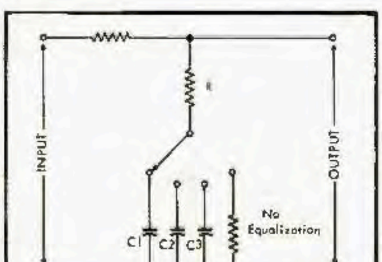


Fig. 6—4. Circuit for bass boost equalization with provision for changing transition frequency. The capacitors have different values, such that $X_c = R$ at the desired turnover frequency.

A resistive voltage divider is illustrated in *Fig.* 6—1. If the series resistor is 9,000 ohms, and the shunt resistor is 1,000 ohms, as shown, the output voltage of the network will be just one-tenth of the input voltage, or 20 db down. Since resistors do not change their value with frequency, the same attenuation will occur at all frequencies. The frequency response of this resistive circuit is plotted in the graph of *Fig.* 6—1; it can be seen that the "curve" for output voltage has not changed from the curve for input voltage, except that it is reduced in amplitude by a factor of ten.

Now consider the circuit of *Fig.* 6—2, in which the lower arm of the divider has had a capacitor added in series. At very high frequencies the *reactance* of the capacitor (analogous to a.c. resistance) is negligible—the capacitor acts as though it were shorted out. The attenuation of the circuit at these frequencies will therefore be substantially the same as in *Fig.* 6—1—by the full factor of ten, or twenty db.

As the frequency is lowered the reactance of the capacitor will increase. It will begin to affect appreciably the impedance of the lower arm of the voltage divider, and the ratio of the two arms: thus it will also affect the amount of attenuation.

At some lower frequency the reactance of the capacitor will be equal to 1,000 ohms, the value of the resistor in the lower arm. This is taken to be the point at which the frequency discriminating characteristics of the circuit take hold (although it can be seen that the change is gradual), and is called the *transition frequency.* In the case of the circuit under discussion it is the frequency at which bass boost is considered to begin, and corresponds to the bass turnover frequency of the recording characteristic.

As the frequency is lowered further the total impedance of the voltage divider's lower arm increases more rapidly. The attenuation of the circuit is decreased progressively until finally, at very low frequencies, the voltage divider lets through practically all of the input voltage, as illustrated in the graph of *Fig.* 6—2.

We call such a circuit a "bass boost" network, but obviously we have really boosted nothing. What we have actually done is to attenuate a whole band of frequencies, and then to selectively let a part of the attenuated frequency spectrum back in.

The same circuit configuration as that of *Fig* 6—2 may also be used for treble attenuation, by choosing the circuit values so as to shift the entire curve to the right (upwards in frequency). A treble boost or bass attenuating network, on the other hand, must work in an inverse manner. Application of the same sort of analysis to the circuit of *Fig.* 6—3 as was used above will show the reader why the circuit of *Fig.* 6—3 can be used for treble boost or bass attenuation.

The task of providing switching facilities for choosing different turnover frequencies now appears quite simple. All we have to do is to change the value of capacitor for each switch position, as is done in the circuit of *Fig.* 6—4.

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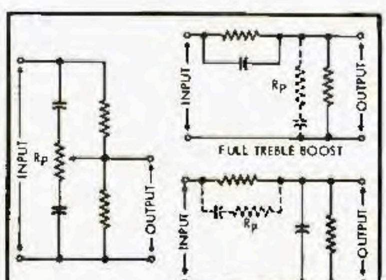

Fig. 6—5. Continuously variable treble tone control. Equivalent circuits for maximum boost and cut are shown, with significant elements at that point shown in heavy line.

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Tone Controls

The fixed equalizers which have been so far discussed are designed to compensate for known frequency curves built into the record. There are also many conditions affecting frequency response which are not known beforehand by the circuit designer. These include room acoustics (discussed in more detail in a later chapter), deficiencies in associated equipment which may unduly boost or attenuate portions of the frequency spectrum, changes in over-all volume which change our bass hearing sensitivity, and variations in program material caused by differences in microphoning, studio or hall acoustics, and so forth.

We cannot hope to compensate accurately for all such conditions, but flexible tone controls, intelligently designed to approximately correct for conditions typically encountered, can help a lot. These tone controls work on the same principle as the frequency discriminating voltage dividers discussed previously, with the difference that the rate of boost and cut, or the transition frequencies, or both, are controllable.

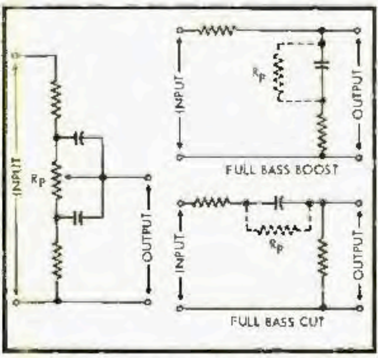

Fig. 6—6. Continuously variable bass tone control. Equivalent circuits for maximum boost and cut are shown, with significant elements at that point shown in heavy line.

Figure 6—5 illustrates a treble tone control, and the equivalent circuits for maximum treble-boost (slider at the top of the potentiometer) and maximum treble-cut positions (slider at the bottom of the potentiometer). *Figure* 6—6 illustrates a bass tone control, also with equivalent circuits for maximum bass boost and maximum bass cut.

The effectiveness of a tone control is determined by the extent to which it affords accurate compensation for varying conditions. It has been the writer's experience that this object is best served by tone controls with either varying transition frequencies, or with transition frequencies which are some distance from the audio spectrum mid-point, say

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500 cps for the bass and 3,000 cps for the treble. In any case the way *not* to judge the "effectiveness" of a tone control circuit is to twist the knobs all the way in each direction and to see how unnaturally screechy and boomy the sound can be made. Tone controls which really work where they are needed, without unduly affecting the mid-range, usually have a less dramatic but far more musical effect, even in their extreme positions.

Loudness Control

We have seen, in discussing the Fletcher-Munson effect, that as the overall volume of sound is decreased our bass hearing sensitivity is reduced significantly. In listening at volume levels lower than that of the original music, then, the original tonal balance will be changed, and we should be able to introduce compensatory bass boost. Some people like to do this themselves, with the bass control; others like to have it done automatically, by a bass boost circuit tied to the volume control. In the latter case the volume control becomes a "loudness" control.

Control Units

Control units performing the functions of preamplification and control of bass, treble, volume, and record equalization are available commercially as separate units, and also in combination with the tuner, the power amplifier, or even the record player. There is really no inherent advantage of one scheme over another, except for operating convenience, if the design is properly executed. Placing the control elements near power transformers or phonograph motors increases the hum problem, but this does not imply that the more difficult solution will be any less satisfactory.