A Versatile Tone Control Circuit and Preamplifier

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Summary—**A tone control circuit is described which allows a large choice in the high- and low-frequency attenuation or boost and in the position of the tone compensation curves over all the acoustic spectrum. These two controls, which are completely independent, are obtained with structurally simple RC networks. This tone control is included in a preamplifier for music reproduction. The compensation and equalization curves are reported in the paper and the characteristics of the complete preamplifier are described.**

Introduction

MODERN SYSTEMS of music reproduction are usually equipped with tone controls which are intended to compensate for room acoustics and system defects, or simply to introduce at the will of the listener attenuation or boost in the low- or high-frequency ranges of the acoustic spectrum. A good tone compensation can only be obtained with two separate and independent tone controls (bass and treble). Of course, the introduction of these compensations must leave unaltered the signal level in the midfrequency range. A flexible tone control circuit must allow a large choice in the high- or low-frequency attenuation or boost, and in the position of the compensation curves over all the acoustic spectrum. Some papers[1,2] have already described tone controls of this kind, but the circuits utilized were generally somewhat complicated.

In this paper it will be shown that it is possible to design comparatively simple circuits featuring the above characteristics. This aim can be achieved while the number of capacitors is minimized: in particular, an RC circuit with a single capacitor allows one to obtain, with various resistance valves, bass boost or cut as shown in Fig. 1 (page 196), all curves having the same turnover or roll-off frequency. Moreover, a change in the capacitance value leaves unaltered the attenuation or boost, but introduces a displacement of the complete "fan-shaped" set of curves of Fig. 1 along the frequency axis; that is, a displacement of the roll-off or turnover frequencies, that we shall here after simply call "critical frequencies." The same holds of course for the treble case (Fig. 2).

For a fixed critical frequency attenuation or boost can be varied in discrete steps (Figs. 1 and 2). For its accuracy, this kind of selection was preferred to a continuous one for professional equipment. In the preamplifier here described, the complete set of curves for a fixed critical frequency is composed of fifteen curves about 3 db apart, giving up to 21 db of attenuation or boost. A choice is allowed among three critical frequencies for both bass and treble compensation.

These tone controls were included in a preamplifier for music reproduction to be placed between a variable reluctance pick up (output level about 10 mv) and a power amplifier. which requires 200-mv input for full power output.

Tone Control Characteristics

In order to prevent interaction between bass and treble controls, these controls were placed into two separate stages. Each stage is composed of a cathode follower supplying a triode feedback amplifier (Fig. 3). Provided that the gain without feedback is high, the gain with feedback can be written, apart from a minus sign, as follows:

$$K = \frac{Z_1}{Z_2}. \tag{1}$$

The mid-frequency gain, where compensation is not required, was chosen to be equal to one; consequently in this frequency range Z_1 and Z_2 must be equal.

One can also observe that the desired boost and attenuation curves (Figs. 1 and 2) are symmetrical about the 0-db axis; it follows that a boost curve can be obtained from the corresponding attenuation curve by simply interchanging Z_1 and Z_2.

The Bass Control

Critical frequencies must be shifted at will, this requirement can be met if Z_1 and Z_2 are RC networks with only one capacitor in the two impedances. In this way one can vary attenuation or boost by changing some resistances and obtain frequency shifting by simply replacing one condenser, the two operations being completely independent. Moreover, these networks have a single zero-pole pair, and this meets the requirements of the tone control.

After some trials, the network shown in Fig. 4 was chosen. In this network, impedances Z_1 and Z_2 do not appear at a first glance, but they are immediately evident after a Δ/Y transformation. Referring to Fig. 3, one gets

$$Z_1 = \frac{R_1}{pC(R_1 + R_2) + 1}, \quad Z_2 = \frac{R_2}{pC(R_1 + R_2) + 1} \tag{2}$$

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[1] F. Langford-Smith, Ed., "Radiotron Designer's Handbook," Wireless Press, Sydney, Australia, pp. 660–661; 1953.

[2] R. H. Rose, "An adjustable shelf-type equalizer with separate control of frequency and limiting attenuation and amplification," IRE Trans. on Audio, vol. AU-9, pp. 112–117; July/August, 1961.

where p is the complex frequency. The third impedance of the Y network appears in series with the grid and is then of no matter. The voltage gain K_b of the bass control can then be written as

$$K_b = \frac{R + Z_1}{R + Z_2} = \frac{p + \dfrac{R + R_1}{CR(R_1 + R_2)}}{p + \dfrac{R + R_2}{CR(R_1 + R_2)}} \cdot \tag{3}$$

With the substitutions

$$w_n = \frac{R + R_1}{CR(R_1 + R_2)}, \qquad w_d = \frac{R + R_2}{CR(R_1 + R_2)}, \tag{4}$$

one gets

$$K_b = \frac{p + w_n}{p + w_d} \cdot \tag{5}$$

In the mid- and high-frequency range ($w \gg w_n$, $w \gg w_d$), the gain is one as required; in the low-frequency range we obtain attenuation or boost if respectively $w_n < w_d$ or vice versa. The low-frequency gain can be written as the zero-pole ratio

$$K_{bb} = \frac{w_n}{w_d} = \frac{R + R_1}{R + R_2} \cdot \tag{6}$$

Let us examine the boost case. The fan-shaped set of curves can be obtained by changing the resistance values so as to satisfy (6) for the required gains, but w_n is to be held constant. These requirements can be met by setting $R = R_2$, from which one can deduce

$$w_n = \frac{1}{RC} \cdot \tag{7}$$

From (6) one then gets immediately

$$R_1 = (2K_{bb} - 1)R \tag{8}$$

where K_{bb} is the desired boost.

The attenuation case is met by setting $R = R_1$, from which we get

$$w_d = \frac{1}{RC} \cdot \tag{9}$$

From (6) we then obtain

$$R_2 = \left(\frac{2}{K_{ba}} - 1\right)R \tag{10}$$

where K_{ba} is the desired attenuation. If in (10) we make $R_2 = R_1$ and $1/K_{ba} = K_{bb}$, we obtain again (8). This means only that the same values of attenuation or boost can be obtained simply by interchanging impedances Z_1 and Z_2 as was already mentioned in the previous section.

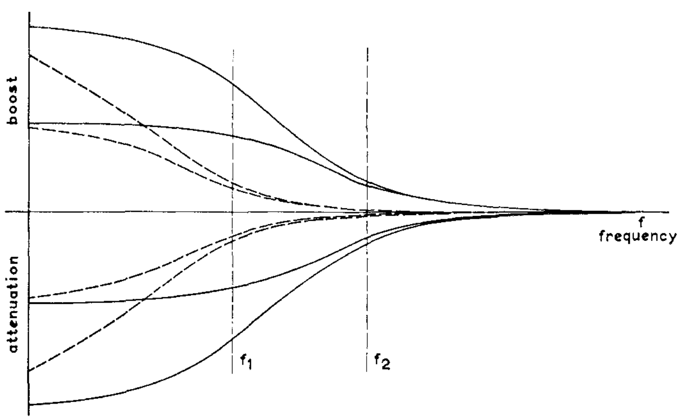


Fig. 1—Typical bass control curves. f_1 and f_2 are two critical frequencies.

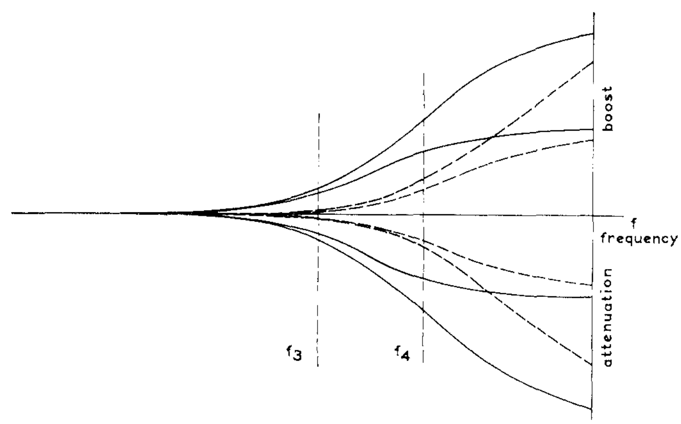


Fig. 2—Typical treble control curves. f_3 and f_4 are two critical frequencies.

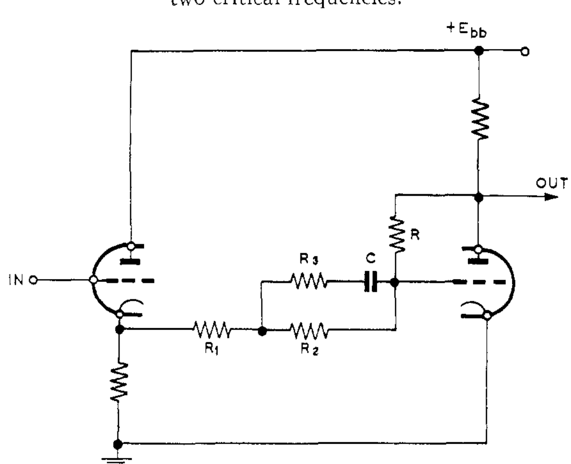


Fig. 3—Simplified diagram of the tone control circuits.

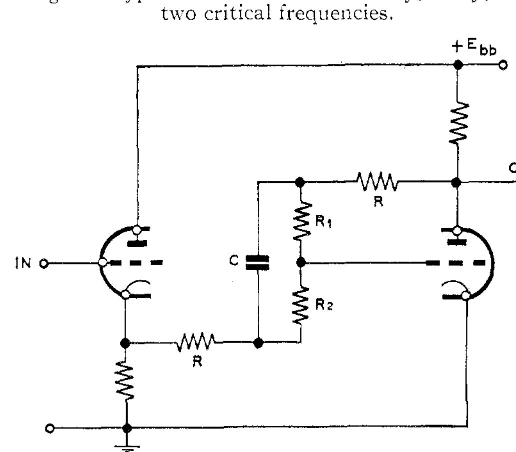


Fig. 4—Simplified diagram of the bass control circuit.

Eqs. (7), (8), (9) and (10) allow the determination of the circuit components. Fig. 5 shows the circuit diagram of the complete bass control, R is equal to 43 kilohms. The critical frequencies are 900, 440 and 200 cps, and attenuation and boost can be varied in 3-db steps. Figs. 6 and 7 show the complete set of experimental curves measured for two critical frequencies, 900 and 200 cps.

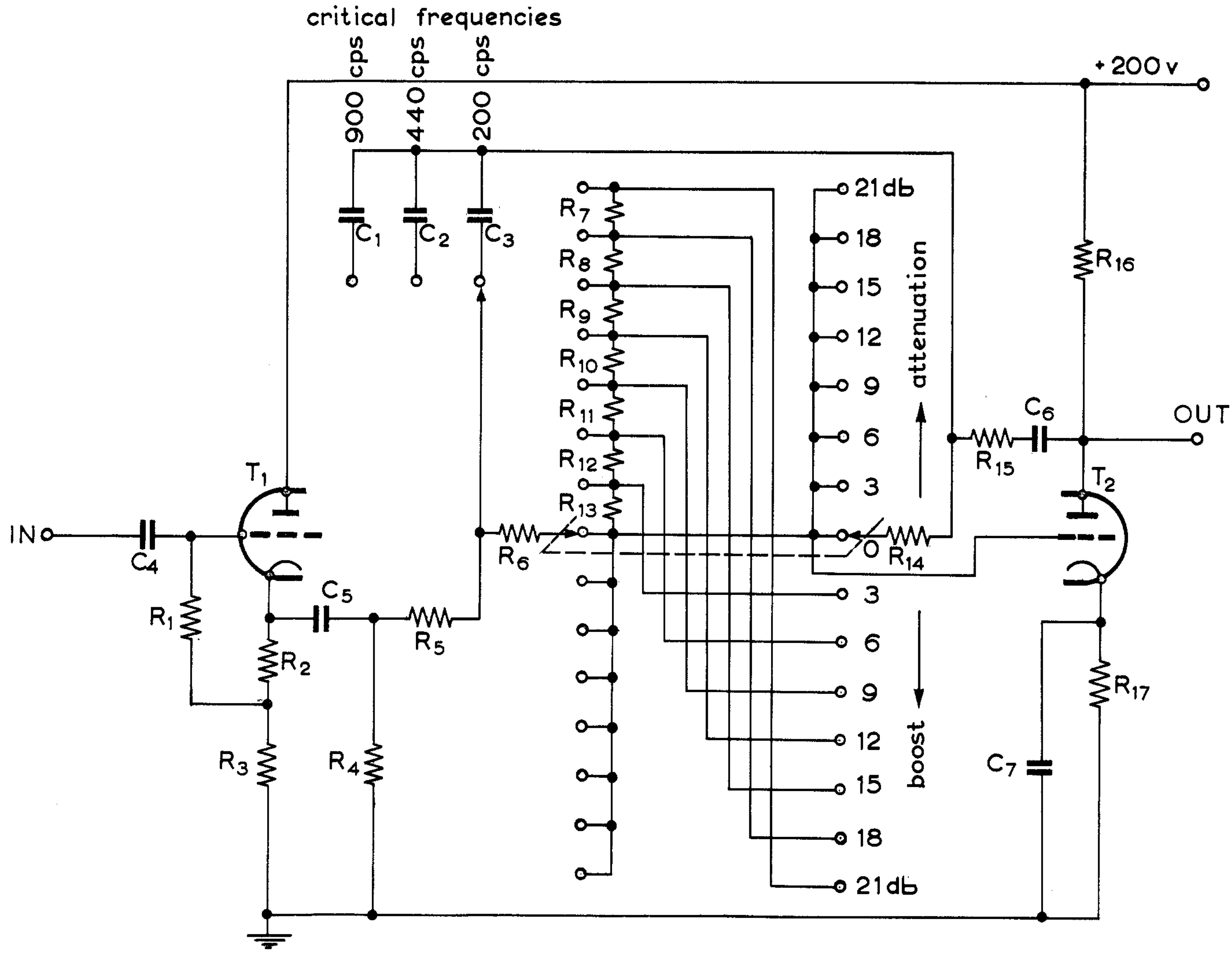
The Treble Control

The treble control was designed again according to the diagram of Fig. 3. Now low-frequency gain must be one, the other general requirements being the same as for the bass control.

A simplified diagram of the treble control for the boost case is shown in Fig. 8, one of the two feedback impedances is a pure resistance. One can write

$$Z_1 = R,$$

$$Z_2 = \left(R_1 + \frac{R_2R_3}{R_2+R_3}\right)\frac{p + \dfrac{R_1+R_2}{CR_1(R_2+R_3)+R_2R_3}}{p + \dfrac{1}{C(R_2+R_3)}}. \quad (11)$$



Components Values

$R_1 = 0,47$ MΩ	$R_{15} = 43$ kΩ
$R_2 = 680$ Ω	$R_{16} = 100$ kΩ
$R_3 = 100$ kΩ	$R_{17} = 680$ Ω
$R_4 = 0,22$ MΩ	
$R_5 = 43$ kΩ	$C_1 = 4,7$ nF
$R_6 = 43$ kΩ	$C_2 = 10$ nF
$R_7 = 300$ kΩ	$C_3 = 22$ nF
$R_8 = 200$ kΩ	$C_4 = 2,2$ nF
$R_9 = 150$ kΩ	$C_5 = 4$ μF
$R_{10} = 100$ kΩ	$C_6 = 0,47$ μF
$R_{11} = 75$ kΩ	$C_7 = 100$ μF
$R_{12} = 51$ kΩ	
$R_{13} = 36$ kΩ	$T_1 = \frac{1}{2}$ ECC 83
$R_{14} = 43$ kΩ	$T_2 = \frac{1}{2}$ ECC 83

Fig. 5—Complete diagram of the bass control.

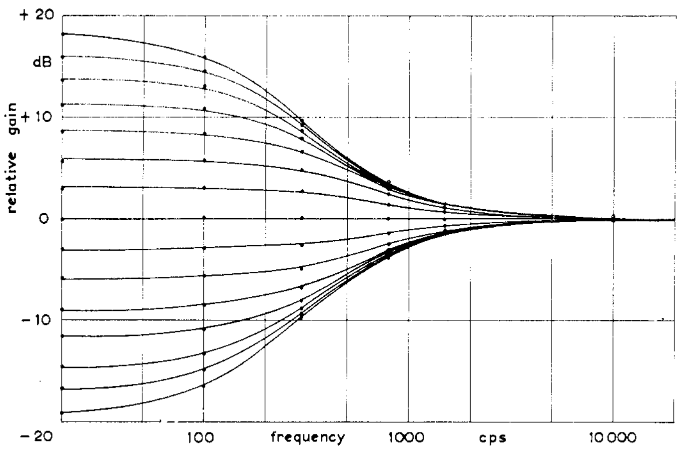


Fig. 6—Bass response curves. Critical frequency is 900 cps.

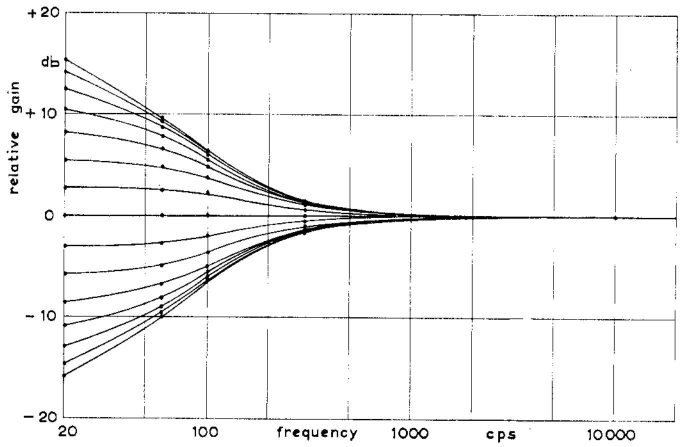


Fig. 7—Bass response curves. Critical frequency is 200 cps.

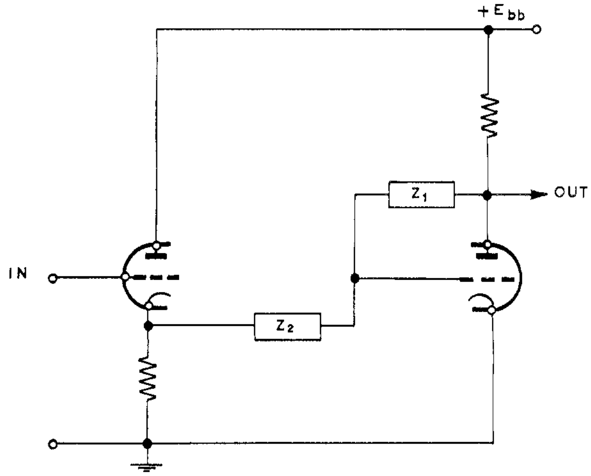


Fig. 8—Simplified diagram of the treble control circuit.

Then, in the boost case, the resulting gain is given by

$$K_{tb} = \frac{Z_1}{Z_2} = \frac{R}{R_1 + \frac{R_2 R_3}{R_2 + R_3}} \cdot \frac{p + w_n}{p + w_d} \quad (12)$$

where

$$w_n = \frac{1}{C(R_2 + R_3)}$$

and

$$w_d = \frac{R_1 + R_2}{CR_1(R_2 + R_3) + R_2 R_3}. \quad (13)$$

Low-frequency gain is one if $R_1 + R_2 = R = \text{constant}$.

On the other hand, the requirement $w_n = \text{constant}$ can be met in (13) only if $R_2 + R_3 = \text{constant}$. We assume $R_2 + R_3 = R$; it follows also that $R_1 = R_3$. The high-frequency gain can be written as

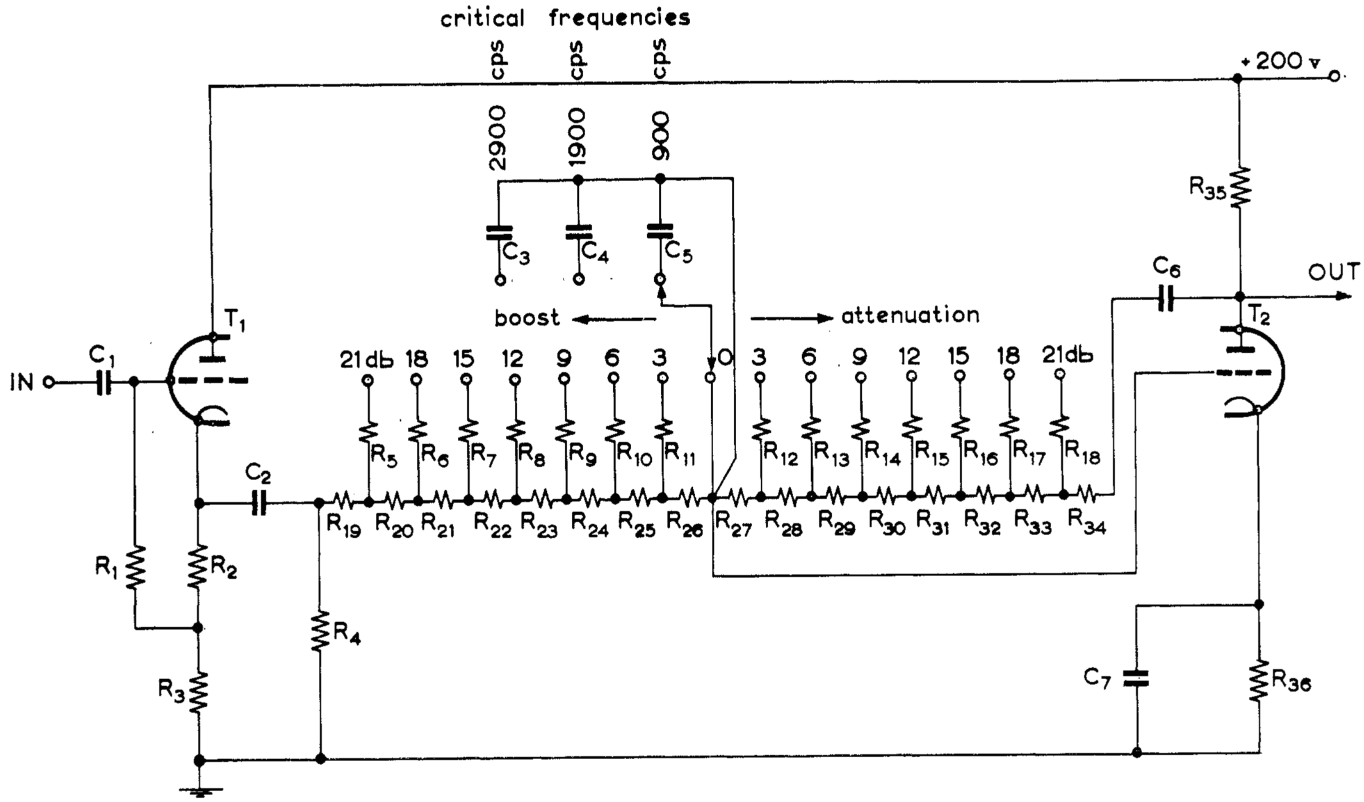
$$K_{tb} = \frac{R^2}{R_1(R + R_2)}. \quad (14)$$

With the valves $R_1 = \alpha R$, $R_2 = (1 - \alpha)R$ one readily obtains

$$\alpha = 1 - \sqrt{1 - \frac{1}{K_{tb}}}. \quad (15)$$

This equation is not applicable to the treble attenuation, this case can be dealt with by simply interchanging impedances Z_1 and Z_2. This means that in (15) K_{ta} is substituted for $1/K_{tb}$, where K_{ta} is the attenuation required.

Eqs. (13) and (15) allow the determination of the circuit component valves. Fig. 9 shows the circuit diagram of the complete treble control, R is equal to 250 kilohms. The critical frequencies are 900, 1900 and 2900 cps, and attenuation and boost can be varied in 3-db steps. Figs. 10 and 11 show the complete set of curves for two critical frequencies, 900 and 2900 cps.



Components Values

$R_1=470$ kΩ	$R_{17}=16$ kΩ	$R_{33}=5,1$ kΩ
$R_2=680$ Ω	$R_{18}=11$ kΩ	$R_{34}=11$ kΩ
$R_3=100$ kΩ	$R_{19}=11$ kΩ	$R_{35}=100$ kΩ
$R_4=220$ kΩ	$R_{20}=5,1$ kΩ	$R_{36}=680$ Ω
$R_5=11$ kΩ	$R_{21}=6,8$ kΩ	
$R_6=16$ kΩ	$R_{22}=10$ kΩ	$C_1=2,2$ nF
$R_7=22$ kΩ	$R_{23}=16$ kΩ	$C_2=0,47$ μF
$R_8=33$ kΩ	$R_{24}=27$ kΩ	$C_3=220$ pF
$R_9=47$ kΩ	$R_{25}=39$ kΩ	$C_4=330$ pF
$R_{10}=75$ kΩ	$R_{26}=130$ kΩ	$C_5=680$ pF
$R_{11}=110$ kΩ	$R_{27}=130$ kΩ	$C_6=0,47$ μF
$R_{12}=110$ kΩ	$R_{28}=39$ kΩ	$C_7=100$ μF
$R_{13}=75$ kΩ	$R_{29}=27$ kΩ	
$R_{14}=47$ kΩ	$R_{30}=16$ kΩ	$T_1=\frac{1}{2}$ ECC 83
$R_{15}=33$ kΩ	$R_{31}=10$ kΩ	$T_2=\frac{1}{2}$ ECC 83
$R_{16}=22$ kΩ	$R_{32}=6,8$ kΩ	

Fig. 9—Complete diagram of the treble control.

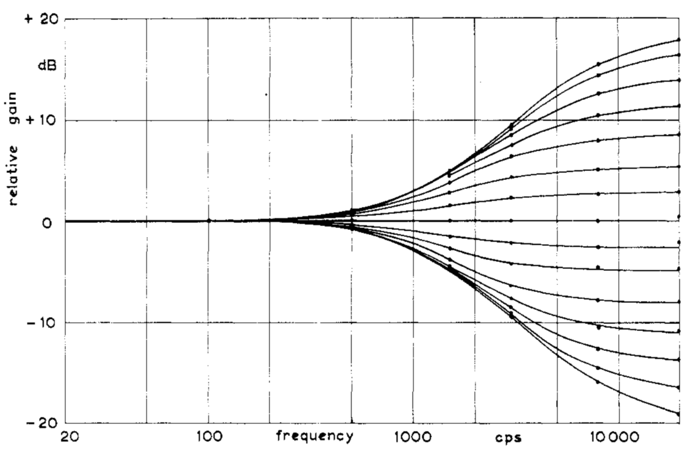


Fig. 10—Treble response curves. Critical frequency is 900 cps.

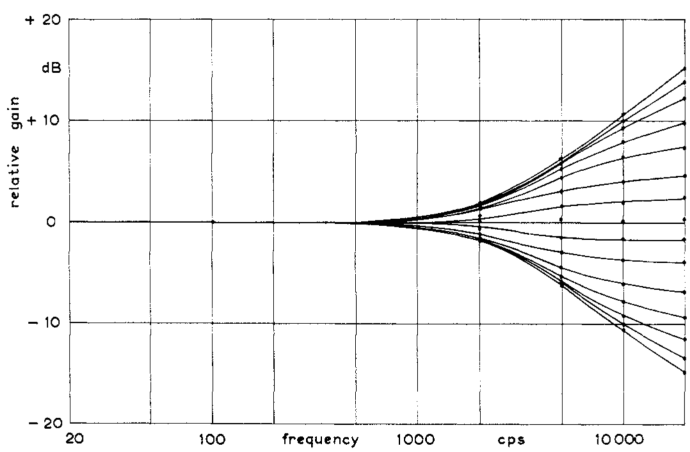


Fig. 11—Treble response curves. Critical frequency is 2900 cps.

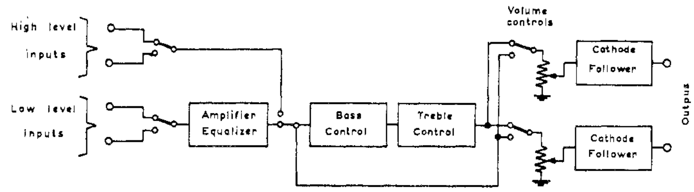
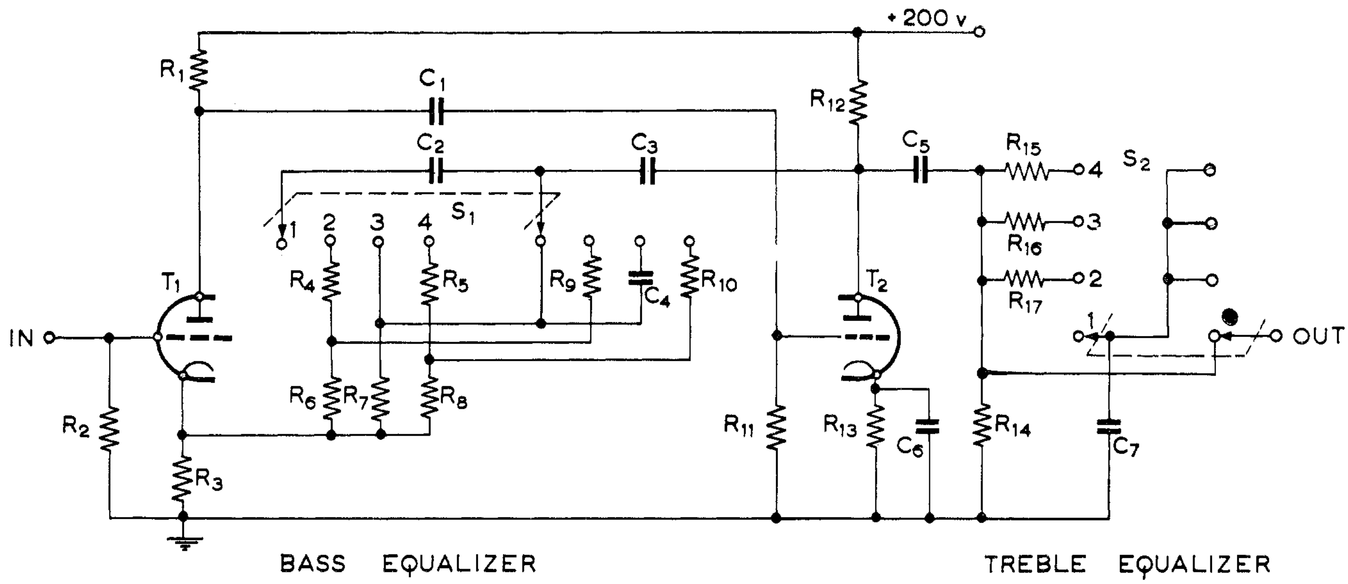


Fig. 12—Block diagram of the complete preamplifier.



Components Values

$R_1=100$ kΩ	$R_{15}=200$ kΩ
$R_2=39$ kΩ	$R_{16}=120$ kΩ
$R_3=1,5$ kΩ	$R_{17}=90$ kΩ
$R_4=24$ kΩ	
$R_5=22$ kΩ	$C_1=220$ nF
$R_6=5,1$ kΩ	$C_2=10$ nF
$R_7=30$ kΩ	$C_3=3$ μF
$R_8=10$ kΩ	$C_4=2,5$ nF
$R_9=270$ kΩ	$C_5=47$ nF
$R_{10}=150$ kΩ	$C_6=100$ μF
$R_{11}=0,47$ MΩ	$C_7=500$ pF
$R_{12}=100$ kΩ	
$R_{13}=1,5$ kΩ	$T_1=\frac{1}{2}$ ECC 83
$R_{14}=1$ MΩ	$T_2=\frac{1}{2}$ ECC 83

Fig. 13—Circuit diagram of the amplifier-equalizer.
Bass equalizer: position 1: flat
position 2, 3 and 4: see Fig. 14
Treble equalizer: position 1: flat
position 2, 3 and 4: see Fig. 15.

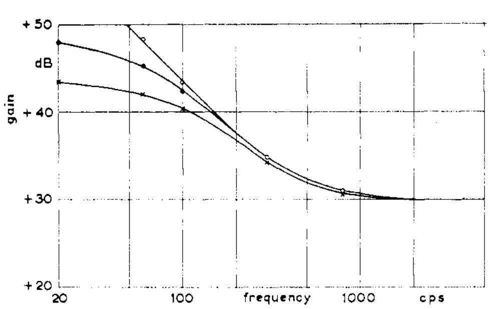


Fig. 14—Bass equalization curves: × position 2 (Fig. 13)
○ position 3
● position 4.

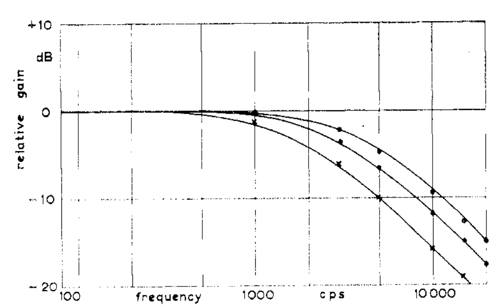


Fig. 15—Treble equalization curves: ○ position 2 (Fig. 13)
● position 3
× position 4.

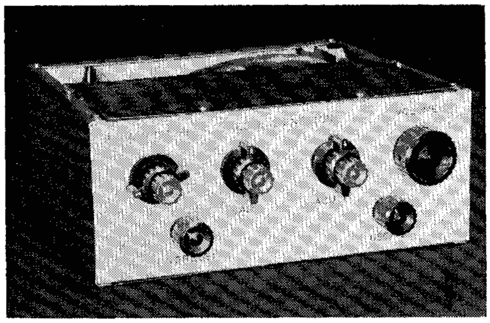


Fig. 16—Over-all view of the preamplifier.
(Construction I.E.N.g.f.)

The Complete Preamplifier

The tone controls previously described were included in a preamplifier for musical reproduction, the block diagram of which is shown in Fig. 12. There are two inputs for low-level signals (gain 30 db), two "flat" inputs for high-level signals (0-db gain) and two separate outputs. The tone controls can be bypassed independently for both outputs.

The functions of amplification and equalization of low-level signals are performed by a double triode plate-to-cathode-feedback stage, the diagram of which is shown in Fig. 13. The equalization curves have been chosen according to current data, and, in order to achieve more flexibility, it was decided to control independentely the bass and treble equalization.

Bass boost is obtained with RC networks placed in the feedback loop. These networks employ as few capacitors as possible in order to minimize switching transients. The curves obtained are shown in Fig. 14; mid-frequency gain is 30 db.

Treble equalization is obtained through RC networks at the output of the second triode, the equalization curves are shown in Fig. 15.

Distortion, measured with a one-volt output which is five times the maximum signal required by the power amplifier, is less than 0.1 per cent with any setting of the various controls. Noise is more than 80 db below the maximum output level (200 mv).

Conclusions

The independent selection of attenuation or boost and critical frequency in the low- and high-frequency ranges of the acoustic spectrum gives a great flexibility to this tone control circuit. These features are obtained with structurally simple networks; however, owing to the large number of possibilities offered and to the accuracy given by the selection of attenuation and boost in discrete steps, the number of components is rather large but in any case not larger than for similar equipments. If a continuous variation of attenuation or boost is preferred, it seems possible to reduce substantially the number of components: the use of potentiometers in this circuit is now under consideration.

Acknowledgment

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