CHAPTER 15

TONE COMPENSATION AND TONE CONTROL

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SECTION 1 : INTRODUCTION

(i) The purpose of tone compensation (ii) Tone control (iii) General considerations (iv) Distortion due to tone control (v) Calculations involving decibels per octave (vi) Attenuation expressed as a time constant (vii) The elements of tone control filters (viii) Fundamental circuit incorporating R and C (ix) Damping of tuned circuits (x) Tolerances.

(i) The purpose of tone compensation

An " ideal " audio frequency amplifier is one having a response which is linear and level (i.e. " flat ") over the whole a-f range. An amplifier which has a drooping characteristic at the extremes of its frequency range may be made practically flat by the incorporation of a suitable degree of bass and treble boosting. This device is adopted in studio amplifiers where rigid tolerances are imposed on the frequency response of each amplifier or unit, and also in video and wide-band amplifiers where the frequency range is so great that conventional a-f designs are unsatisfactory.

(Refs. 35, 38, 53 are typical.)

Studio microphones and pickups are " equalized " by a suitable filter to give a flat response. Thus any input source may be connected to any amplifier or amplifiers, and the overall result will be flat, since each unit in the chain is flat.

A different approach is usually adopted in complete units such as home gramophones where the whole is always used as one unit, and where we are only concerned with the overall performance.

In such a case it is possible to vary the frequency response of the amplifier so as to compensate for certain components such as pickups or loudspeakers which do not have a flat response.

All these are examples of tone compensation, the purpose of which is to give a flat overall frequency characteristic.

(ii) Tone control

A tone control is a variable filter (or one in which at least one element is adjustable) by means of which the user may vary the frequency response of an amplifier to suit his own taste.

Tonal balance is covered in Chapter 14 Sect. 4(ii).

(iii) General considerations

It is usual to regard the middle range of audio frequencies from say 500 to 2000 c/s as the " body " of musical reproduction, with 1000 c/s as the reference frequency.

Thus a lower or higher frequency is said to be attenuated if it is reproduced at a lower level than 1000 c/s or boosted if it is at a higher level than 1000 c/s.

An equalizer for a pickup or microphone is usually placed either between the source and the first amplifier valve or, if this is at a low level, between the first and second amplifier valves.

All sources of input voltage should have a frequency range which is more limited than the range which the amplifier and loudspeaker are capable of handling without noticeable distortion. In other words, no voltage should be applied to the input terminals of the amplifier which has a frequency lower than the low frequency limit of the amplifier and loudspeaker or a frequency higher than the high frequency limit of the amplifier and loudspeaker. If this does not hold, it is highly desirable to limit the frequency range of the input voltage, either at one or both ends of the range as required, by means of a suitable filter (see Sects. 3 and 6 below), inserted before the input terminals of the main amplifier. If there is a pre-amplifier followed by a main amplifier, the filter may be inserted between the two.

If a tone control is to be fitted to an amplifier, its position is of considerable importance, the only exception being when the amplifier has low distortion at all frequencies with a loudspeaker load. In an amplifier using a pentode or beam power amplifier without negative feedback, it is desirable to fit a r.c. filter across the primary of the output transformer. This may be fixed, with a supplementary tone control elsewhere, or it may form the tone control itself. In most amplifiers it is desirable to connect a small capacitance (say 0.001 μF for a 5000 ohm load) directly from the plate of the output valve to earth, or from the plate of each output valve in the case of push-pull operation. This assists in by-passing any radio or ultrasonic audio-frequencies which may be present, without having much effect on the frequency response. Its capacitance might be increased with advantage if some attenuation of the highest frequencies is permissible.

In a typical radio receiver without negative feedback, the tone control may be in the plate circuit of the power valve, in the coupling circuit between the first a-f amplifier valve and the power valve, or in the grid circuit of the first a-f valve.

If an amplifier incorporates negative feedback, the tone control may be incorporated in the feedback network (see Sect. 9 below) or else should be connected to a part of the amplifier which is external to the feedback loop.

Tone controls may be continuously variable or stepped. The more complicated types are stepped but, like a studio attenuator, the steps may be made barely perceptible.

(iv) Distortion due to tone control

Tone control frequently has a pronounced effect on the effective distortion due to stages in the amplifier preceding the tone control filter. **Treble attenuation** results in a reduction in the amplitude of harmonics compared with that of the fundamental—that is a reduction in the harmonic distortion—provided that the predominant harmonics are within the attenuation range. In general, intermodulation distortion is also reduced by treble attenuation, subject to the same limitation.

On the other hand, any form of **treble boosting** will increase *the effective distortion* at any frequency so long as the harmonics are accentuated by the treble boosting with respect to the fundamental ; the same also applies to intermodulation distortion. This is one of the reasons why treble boosting is not widely used, or is limited to a very slight rate of boosting.

If an amplifier naturally has some treble attenuation, and is equalized by the correct amount of treble boosting, the distortion will be the same as though the amplifier had a naturally flat characteristic. However, in the case of a radio receiver, effectively having a treble attenuation through side-band cutting, the distortion at the output terminals will be greater than that at the second detector if treble boosting is used, even if the a-f amplifier distortion could be zero.

Bass boosting gives a reduction in harmonic distortion provided that the fundamental frequency is amplified more than the harmonics, which condition holds over a limited frequency range.

Bass attenuation gives increased distortion over a limited frequency range where the harmonics are amplified more than the fundamental.

References to distortion : 3, 61.

(v) Calculations involving decibels per octave

The rate of attenuation, or of boosting, is usually given in the form of so many decibels per octave. For example, a simple shunt condenser across a resistive network produces an ultimate treble attenuation of 6 db/octave—see Chapter 4 Sect. 8(ii) and Fig. 4.38. Ultimate attenuation is normally in multiples of 6 db/octave—e.g. 6, 12, 18 and 24 db/octave. Actual values of attenuation may differ from the ultimate values, particularly in the range from 0 to 7 db.

In some cases the frequencies at which readings are taken do not conveniently cover an exact number of octaves. In such a case the following procedure may be adopted.

(A) To convert db/specified frequency ratio to db/octave

Frequency ratio	Multiply db/specified frequency ratio by factor
1.2 : 1	6.02 to give db/octave
1.25 : 1	3.10 „ „ „
1.33 : 1	2.43 „ „ „
1.5 : 1	1.71 „ „ „
2 : 1	1.00 „ „ „
3 : 1	0.63 „ „ „
4 : 1	0.50 „ „ „
5 : 1	0.43 „ „ „
6 : 1	0.39 „ „ „
7 : 1	0.36 „ „ „
8 : 1	0.33 „ „ „
10 : 1	0.30 „ „ „

Example—A change of 0.7 db occurs with an increase of frequency from 1000 to 1250 c/s. What is the rate of change in db/octave?

Rate of change = 0.7 × 3.10 = 2.17 db/octave.

Note. A table relating frequency ratio, octaves and decades is given on page 368.

(B) To convert db/octave to db/specified frequency ratio

Frequency ratio	Multiply db/octave by factor	
1.2 : 1	0.263	to give db/specified frequency ratio
1.25 : 1	0.322	,, ,, ,, ,,
1.33 : 1	0.412	,, ,, ,, ,,
1.5 : 1	0.585	,, ,, ,, ,,
2 : 1	1.00	,, ,, ,, ,,
3 : 1	1.59	,, ,, ,, ,,
4 : 1	2.00	,, ,, ,, ,,
5 : 1	2.33	,, ,, ,, ,,
6 : 1	2.59	,, ,, ,, ,,
7 : 1	2.81	,, ,, ,, ,,
8 : 1	3.00	,, ,, ,, ,,
10 : 1	3.33	,, ,, ,, ,,

Example—What is the change in level for a frequency ratio of 1.5 to 1 when the rate of change is 6 db per octave?

Change in level $= 0.585 \times 6 = 3.51$ db.

(vi) Attenuation expressed as a time constant

In F-M receiver design it is common practice to express the degree of pre-emphasis (treble boosting) in the transmitter as a time constant of so many microseconds, and the degree of de-emphasis (treble attenuation) in the receiver in the same form. The two methods are fundamentally related because the time constant in seconds is equal to RC where R is the resistance in ohms and C is the capacitance in farads. In the general case

attenuation in db $= -10 \log_{10} (1 + \omega^2 T^2)$

where $\omega = 2\pi f$

$T = CR$ = time constant in seconds

and R = total effective resistance of supply network.

In the particular case where $T = 75$ microseconds and f is expressed in Kc/s, this becomes

attenuation in db $= -10 \log_{10} (1 + 0.222 f^2)$.

A de-emphasis curve for a time constant of 75 microseconds is given in Fig. 15.1. This curve, like all other curves of this class, has an ultimate rate of attenuation of 6 db/octave.

FIG. 15. 1

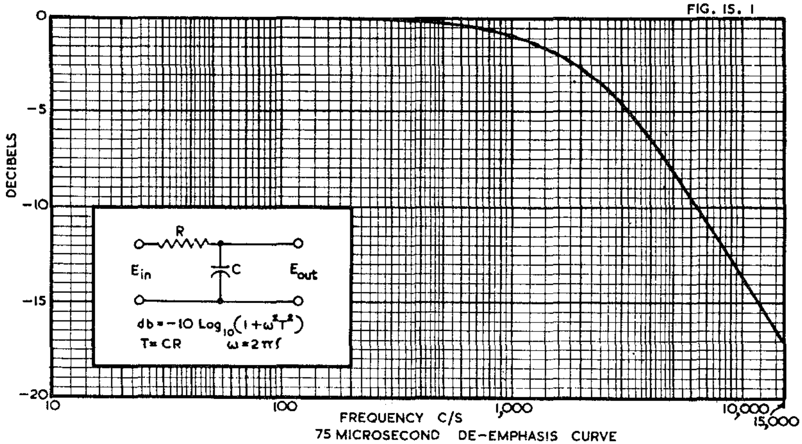

Fig. 15.1. *De-emphasis curve with time constant of* 75 *microseconds, as used in F-M receivers.*

(vii) The elements of tone control filters

Tone control filters are networks including at least two of the basic elements—resistance, capacitance and inductance. In adjustable tone controls it is simplest to use the resistance as the variable element, since continuously variable resistors are available. To vary capacitance or inductance values, it is necessary to use separate components or tappings, with a step switch.

In radio receivers and home amplifiers it is usual, wherever possible, to avoid using inductors for tone control purposes. This is firstly because inductors are generally more expensive than condensers, and secondly inductors are very prone to pick up hum unless elaborate and often expensive precautions are taken. An additional reason is that inductors with the desired values of inductance and tolerances are not usually stock lines.

The inductance of an inductor with any form of iron core is not constant, but is affected by the applied alternating voltage, the frequency, and by any direct current.

When a composition " potentiometer " is used with the moving arm in the grid return circuit of a valve, there will be additional noise caused by the movement of the arm. In such a case, the subsequent amplifier gain should be low.

(viii) Fundamental circuit incorporating *R* and *C*

The circuit shown in Fig. 15.2 may be used for the purpose of obtaining many forms of tone compensation. The values of the six components may be varied as desired to provide bass boosting or attenuation as well as treble boosting or attenuation, It is to be understood that the choice of values extends from zero to infinity, this being equivalent to the optional short-circuiting or open-circuiting of any one or more resistors or condensers. This form of filter is intended for use with a constant input voltage (E_i). This holds approximately when a triode valve is used.

FIG. 15.2

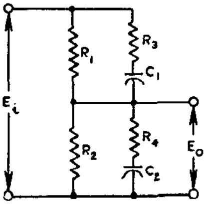

Fig. 15.2. Fundamental circuit incorporating R and C for use with a constant input voltage.

(ix) Damping of tuned circuits

When tuned circuits are used for purposes of tone control, the damping should be sufficient to reduce the " overshoot " to a small value when a unit step (pulse) input is applied to the amplifier. This overshoot may be reduced to a small value if Q does not exceed 0.7. Under no circumstances should Q exceed 1.0 by more than a small margin. Insufficient damping results in distortion of transients.

(x) Tolerances

In all cases where a tone control, tone compensating network or filter is required to have specified frequency response characteristics, the elements of the network must be specified within narrow tolerances, and should preferably also be tested after delivery by the component manufacturer. Even in cases where the response characteristic is not specified, the effect of normal tolerances with capacitors, resistors and inductors is to cause a wide " spread " of response characteristics since the tolerances are sometimes cumulative.

When a single item of equipment is being built, it is important to check either the values of the critical components or the overall response characteristic, or preferably both.

SECTION 2 : BASS BOOSTING

(i) General remarks (ii) Circuits not involving resonance or negative feedback (iii) Methods incorporating resonant circuits (iv) Circuits involving feedback (v) Regeneration due to negative resistance characteristic.

(i) General remarks

Bass boosting, either for tone compensation or tone control, implies that the gain of the amplifier at 1000 c/s must be reduced sufficiently to permit the full gain to be available for amplifying bass frequencies. For example, if the maximum amplifier gain is 56 times (35 dbvg*), and a maximum bass boost of 15 db is required, then the gain at 1000 c/s cannot be more than 20 dbvg*.

Bass boosting for tone control purposes may be used to provide better tonal balance at acoustical levels lower than the original sound, and is generally controlled manually—for automatic control see Section 10. Bass boosting increases the power output from the power valve and loudspeaker at low audio frequencies, and therefore tends to cause overloading if used at maximum volume ; this effect does not occur at lower volume levels. When using bass boosting, the apparent loudness at which overloading occurs is less than that without bass boosting. For this reason, bass boosting should be used with discretion except in amplifiers having ample reserve of power.

For general tone control purposes in typical radio receivers and amplifiers, a bass boost variable from zero to + 6 db is a good compromise. This involves, at maximum bass boosting, four times the power without bass boosting. Any increase beyond 6 db would involve a careful analysis of the whole design.

The bass boost should reach its maximum value at some suitable frequency, say 75 c/s, and should fall fairly rapidly below this frequency. There should be zero boost or even attenuation at the minimum frequency which the amplifier and loudspeaker are capable of handling without distortion.

Bass boosting should not extend appreciably above a frequency of 250 c/s at maximum volume, or the male voice will sound unnatural. When the boosting is only used at lower levels this limitation does not hold.

Some of these limitations are removed by the use of automatic frequency-compensated tone control (Sect. 10).

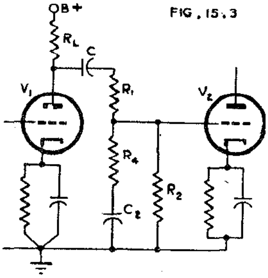

Fig. 15.3. *Conventional bass boosting circuit (plate shunt compensation).*

(ii) Circuits not involving resonance or negative feedback

(A) Conventional bass boosting circuit (Fig. 15.3)

(also known as plate shunt compensation)

The bass boosting is due to the increasing impedance of C_2 as the frequency is lowered. It is assumed here that the reactance of C is negligibly small compared with R_4 ; in practice the value of C may be selected to give attenuation below a specified frequency. R_2 should be at least 20 times R_4 and preferably higher. The top limit is the maximum grid circuit resistance permitted for V_2 ; if V_2 is a resistance coupled stage, see Chapter 12 Sect. 2(iii)E and Sect. 2(iv) for triodes, or Sect. 3(iv) and Sect. 3(v) for pentodes. If V_2 is a power valve, R_2 will usually be limited to 0.5 megohm for cathode bias.

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*Decibels of voltage gain—see Chapter 19 Sect. 1(vi)A.

The resistor R_1 is intended to reduce distortion through low a.c. load impedances connected to the plate circuit of V_1; it may be omitted if the stage is operating at a low level or if R_4 is not less than twice the plate resistance of V_1. A suitable value is not less than $2r_p$ in the case of a triode or not less than $2R_L$ in the case of a pentode. The resistor R_1 also has the effect of decreasing the gain at high frequencies more than at low frequencies, thereby increasing the ratio of gains at low and high frequencies.

It may be shown that

$$\text{Gain at high frequencies} = \frac{\mu}{(1 + r_p/R_L)(1 + R_1/R') + r_p/R'} \qquad (1)$$

where $R' = R_2R_4/(R_2 + R_4)$

$$\text{Gain at zero frequency} = \frac{\mu}{(1 + r_p/R_L)(1 + R_1/R_2) + r_p/R_2} \qquad (2)$$

$$B = \text{ratio of gains} = 1 + \frac{R_2}{R_4}\left\{\frac{(1/r_p + 1/R_L)R_1 + 1 - R_4/R_2}{(1/r_p + 1/R_L)(R_1 + R_2) + 1}\right\} \qquad (3)$$

As a sufficiently close approximation, R_4/R_2 may be taken to have a value as indicated below:

Boost	6	10	15	20	db
R_4/R_2	0.1	0.05	0.02	0.01	approx.

Using this approximation, we may determine the value of R_4 to provide any desired ratio of gains, that is the bass boost expressed as a ratio (B):

$$R_4 \approx \frac{R_2}{B - 1}\left\{\frac{(1/r_p + 1/R_L)R_1 + 1 - R_4/R_2}{(1/r_p + 1/R_L)(R_1 + R_2) + 1}\right\} \qquad (4)$$

where B = ratio of amplification at zero frequency to amplification at high frequencies.

Typical values of resistors are given below:

	General case	Valve type 6J5	Valve type 6AV6
Plate resistance	r_p	7 700*	62 500*ohms
R_L	5 r_p	50 000	220 000 ohms
R_1	2 r_p	20 000	120 000 ohms
R_2	20 r_p	500 000	1 000 000 ohms
R_4 for 6 db boost	2.4 r_p	25 000	140 000 ohms
R_4 for 10 db boost	1.1 r_p	11 600	67 000 ohms
R_4 for 15 db boost	0.53 r_p	5 500	30 000 ohms
Gain at high frequencies:			
6 db boost	0.36 μ	7.6	30 times
10 db boost	0.22 μ	4.7	19 times
15 db boost	0.13 μ	2.6	10 times

A typical example incorporating a pentode is Fig. 15.37A (Sect. 8).

The procedure in design is

(1) to determine the desired total bass boost in db from high frequencies to zero frequency.
(2) to select a suitable valve type.
(3) to assume suitable values for R_L, R_1 and R_2.
(4) to calculate the value of R_4 to give the desired boost, using eqn. (4).
(5) to determine a suitable value for C (this may be done by following Chapter 12 Sect. 2(ii), assuming $R_1 + R_2$ to be the effective value of R_{g2}).
(6) to determine the value of C_2 to give the required position of the boosting curve on the frequency characteristic, as described below.

Frequency characteristics

The shape of the frequency characteristic is determined solely by the amount of the total boost in db (Fig. 15.4). It is convenient to consider the frequency at which each characteristic reaches half the total boost in decibels, and to call this the " half-

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*As normal Class A_1 amplifier. Higher values are to be anticipated for resistance-coupled conditions.

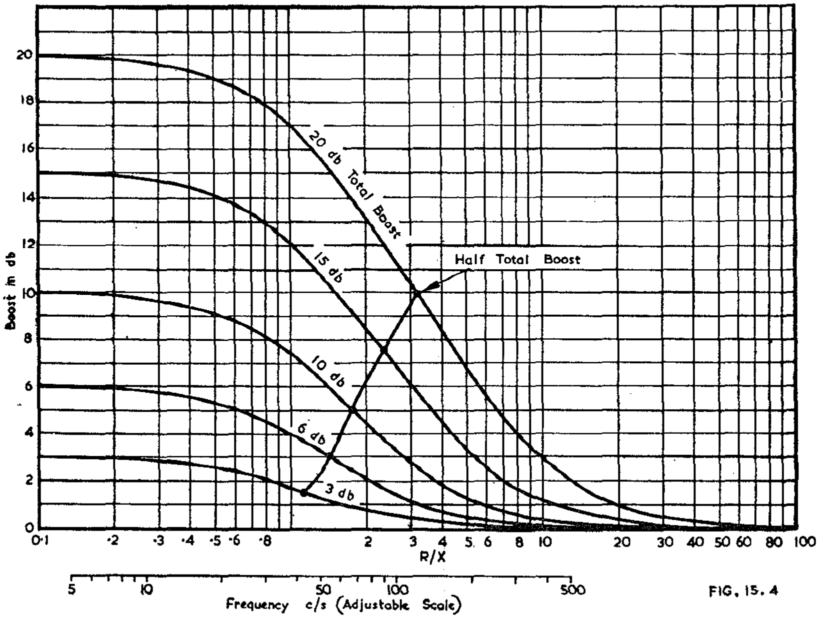


FIG. 15.4

Fig. 15.4. Bass boosting frequency characteristics. These are quite general and may be applied to any r.c. boosting provided that the value of the total boost in db is known. See text for value R/X (Ref. 10).

boost point." It will be seen that the frequency of the " half boost point " (f_0) increases as the total boost increases.

Total boost	20	15	10	6	3	db
Half-boost	10	7.5	5	3	1.5	db
Boost ratio (B)	10	5.62	3.16	2.0	1.41	
R/X for half-boost*	3.16	2.37	1.78	1.41	1.19	
C_2†	$3.16/\omega R$	$2.37/\omega R$	$1.78/\omega R$	$1.41/\omega R$	$1.19/\omega R$	F

* $(R/X) = \sqrt{B}$ at half-boost point.
† $C_2 = 1/(\omega X) = (R/X)/(\omega R)$ and $\omega = 2\pi f_0$
where $R = [r_p R_L/(r_p + R_L)] + R_1 + R_4$ (Fig. 15.3)
and f_0 = frequency at half-boost point.

The slope of the frequency characteristic at the half-boost point, which is very nearly the point of maximum slope, is approximately :

Total boost	20	15	10	6	3	db
Slope at half-boost point	4.9	4.1	3.0	2.0	1.0	db/octave

If a tangent is drawn to the curve at the half-boost point, it will be seen that the slope of the frequency characteristic does not fall off to any appreciable extent from the half-boost point to the three-quarters boost point (i.e. 75% of the total boost in db). The falling off in slope does not cause a difference of more than 1 db between the curve and the tangent up to 90% of the total boost in db, the reading of 90% being taken on the tangent.

This circuit may be applied to continuously variable bass boosting by using a variable resistor in place of R_4, but this has the effect of varying the amplifier gain at the middle audio frequencies and hence varying the apparent loudness. One possible alternative which avoids this defect, is to put a high variable resistor (say 0.5 megohm logarithmic taper) across C_2. This method gives a variation in total boost without much change in level of the middle frequencies, but the shapes of the frequency characteristics are not the most desirable for tone control purposes—Fig. 15.5 ; see also (D) below.

Several values of C_2 may be selected by means of a tapping switch, leaving the total boost unchanged, but this merely moves the frequency characteristic horizontally and is not satisfactory, on its own, for tone control purposes.

FIG. 15.5

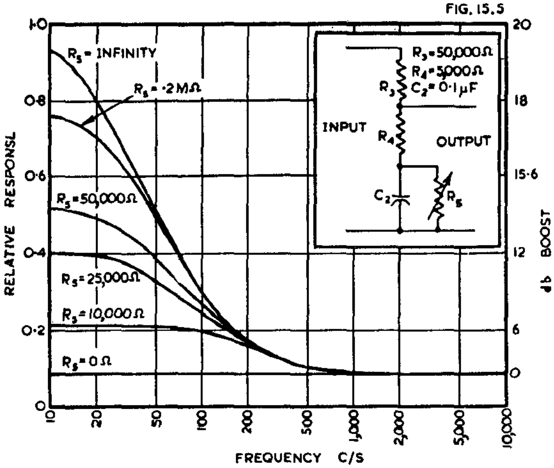


Fig. 15.5. *Frequency characteristics with conventional bass boosting circuit, having variable resistor across* C_2 (*Ref.* 9).

A modification which has some advantages is shown in Fig. 15.6. Here R_2 has been moved from the grid circuit of V_2 to reduce the shunting effect on R_4 and C_2. The total grid circuit resistance of V_2 is $(R_1 + R_2)$. Ref. 11.

References to conventional bass boosting circuit—9, 10, 11, 20, 23, 38, 51, 55.

(B) Plate series compensation (Fig. 15.7)

This is a simple method of providing a fixed amount of bass boosting which uses the plate decoupling circuit. It is generally limited to use with r.c.c. pentodes. With the values of components shown, the frequency response curves for two values of C are given in Fig. 15.8.

References to plate series compensation : 38, 52, 53.

FIG. 15.6

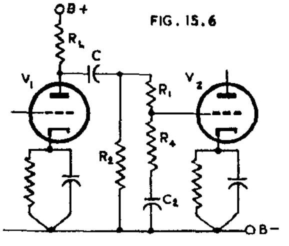


Fig. 15.6. *Modified form of Fig.* 15.3.

FIG. 15.7

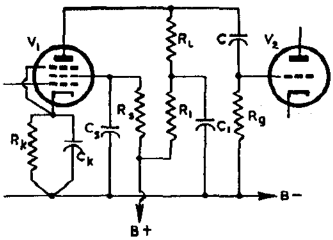


Fig. 15.7. *Bass boosting—plate series compensation.*

(C) Grid series compensation

This is the same in principle as plate series compensation (Fig. 15.7) except that C_1 is taken to a tapping point on R_g instead of on R_L. This is often preferred in wide-band amplifiers as C_1 will be smaller for the same frequency characteristic than with plate series compensation.

Reference to grid series compensation : 38.

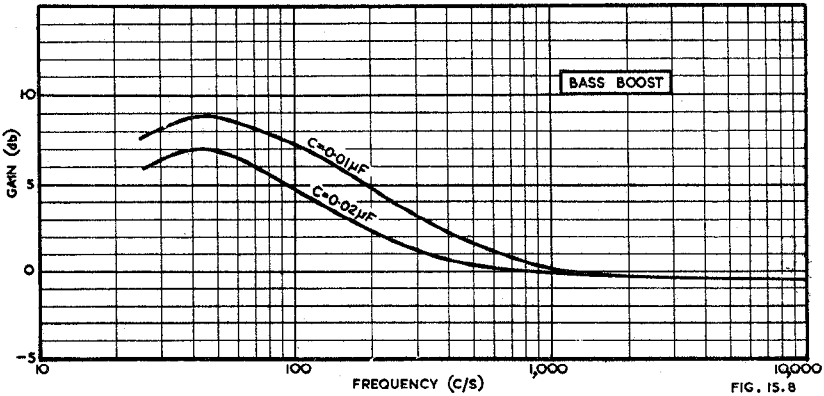


FIG. 15.8

Fig. 15.8. *Frequency characteristics with the circuit of Fig.* 15.7, $V_1 = 6J7$, $R_L = 0.05\ M\Omega$, $R_1 = 0.2\ M\Omega$, $R_k = 2000\ \Omega$, $C_k = 25\ \mu F$, $R_s = 1.5\ M\Omega$, $C_s = 0.1\ \mu F$, $C = 0.02\ \mu F$, $R_g = 1\ M\Omega$.

(D) Improved variable bass boost

A method for obtaining continuously variable bass boost having improved shape of the frequency characteristics, is incorporated in the bass and treble boost circuit of Sect. 8(x)K and Figs. 15.55 and 15.56A.

(iii) Methods incorporating resonant circuits

Resonant circuits give greater flexibility than those incorporating only capacitance and resistance. They are limited, however, to values of Q not greater than 1 (Ref. 54) and preferably not greater than 0.7—see Sect. 1(ix).

(A) Parallel resonant circuits

A parallel resonant circuit, which may be connected in the plate circuit of a r.c.c. pentode (Fig. 15.9) provides boosting in the vicinity of its resonant frequency, with maximum boost at its resonant frequency. For bass boosting the resonant frequency is often between 50 and 120 c/s, although higher and lower frequencies are sometimes adopted.

The inductor L_1 has to carry the greater part of the plate current of V_1 (several milliamperes in a typical case) and should have a butt joint or air-gap to reduce the effect of the plate current on the inductance.

FIG. 15.9

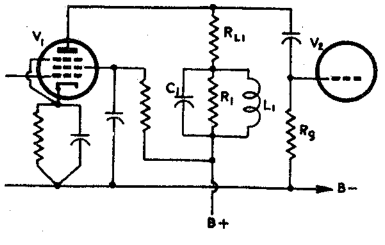


FIG. 15.10

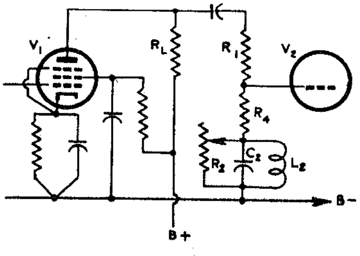


Fig. 15.9. *Bass boosting with parallel resonant tuned circuit in plate circuit.*
Fig. 15.10. *Bass boosting with parallel resonant tuned circuit in grid circuit.*

In all circuits of this type, it is advisable to select a high L/C ratio in order to give the highest gain for a fixed amount of boosting.

$$Q = \omega_0 C R_s \qquad (5)$$

For the limiting value of $Q = 1$,

$$R_s \ngtr 1/\omega_0 C \qquad (6)$$

where R_s = equivalent total shunt resistance in ohms
$\omega_0 = 2\pi f_0$
f_0 = frequency of resonance in c/s
$LC\omega_0^2 = 1$
L = inductance in henrys
and C = capacitance in farads.

Typical values for a resonant frequency of 70 c/s are : $L_1 = 51.5$ H, $C_1 = 0.1\ \mu$F, $R_1 = 22\,000\ \Omega$, $R_{L1} = 3\,900\ \Omega$, $R_g = 0.47$ MΩ, total bass boost 15 db at 70 c/s, $Q = 0.93$. The exact value of R_1 will be influenced by the winding resistance of L_1—the value given above is on the assumption that the winding resistance is zero.

An alternative arrangement which has the advantage of avoiding direct current flow through the inductor is Fig. 15.10—this has the resonant circuit in the grid circuit of V_2. As a result, it is possible to use a higher value of L and to shunt the tuned circuit by a variable resistor as a control. Typical values for $f_0 = 70$ c/s are : $R_L = 0.1$ MΩ, $R_1 = 50\,000\ \Omega$, $R_4 = 50\,000\ \Omega$, $L_2 = 250$ H, $C_2 = 0.02\ \mu$F, and $R_2 = 0.5$ MΩ maximum. In this case the winding resistance of L_2 must be taken into account.

Let r_2 = winding (series) resistance of L_2
R_e = equivalent shunt resistance corresponding to r_2
then $R_e = L_2/C_2 r_2$ (7)

The total shunting on the tuned circuit is therefore R_e in parallel with R_s in parallel with $(R_L + R_1 + R_4)$.

If r_2 is 10 000 ohms*, then
$R_e = 250/(0.02 \times 10^{-6} \times 10\,000) = 1.25$ megohms
$R_s = 0.5$ megohm (max.)
$(R_L + R_1 + R_4) = 100\,000 + 50\,000 + 50\,000 = 0.2$ megohm.

$$\text{Then } \frac{1}{R} = \frac{1}{1.25\ \text{M}\Omega} + \frac{1}{0.5\ \text{M}\Omega} + \frac{1}{0.2\ \text{M}\Omega}$$

Thus $R = 0.13$ megohm = total shunting resistance
and $Q = 1.15$ at maximum setting of R_2 and would normally be below 1.0.

(B) Series resonant circuits

A series resonant circuit has a low impedance at the resonant frequency and a gradually increasing impedance at frequencies off resonance. These are used in combined bass and treble controls (Sect. 8) and in circuits incorporating negative feedback (Sect. 9).

(C) Transformer primary resonance

When parallel feed is used with an a-f transformer, the coupling capacitance C may be made to resonate with the primary inductance of the transformer. By this means a limited degree of bass boosting is provided. See Chapter 12 Sect. 4(xii) and Fig. 12.24. The Q should not exceed unity.

The same principle holds when an inductor (choke) is used in the grid circuit, with parallel feed.

References to methods incorporating resonant circuits : 51, 54.

(iv) Circuits involving feedback

(A) Amplifiers with feedback over several stages

This is dealt with in Section 9.

(B) Negative current feedback

Negative current feedback may be applied by omitting the cathode capacitor on the power amplifier valve. This increases the output resistance and provides a close approach to a constant current source for the loudspeaker. It has the effects of peaking the loudspeaker at the bass resonant frequency, reducing the damping on the

---

*This value is typical for a silicon steel core. Very much lower values are typical for mu-metal cores.

loudspeaker, and decreasing the stage gain. This device is usually avoided on account of its short-comings.

(C) Conventional circuits with decreased negative feedback at bass frequencies

One very popular circuit is Fig. 7.33 [Chapter 7 Sect. 2(vi)] which gives feedback over two stages—this has been adapted to provide bass boosting in Fig. 15.11 (Ref. 58). As explained in Chapter 7, this circuit inherently tends to give a slight degree of bass boosting—the boosting is continuously variable from 1.3 db to 12 db using 1000 c/s as the reference frequency, Fig. 15.12. As a modification, the feedback may be taken from the secondary of the transformer—it is advisable to check experimentally to see that the phase rotation due to the transformer does not adversely affect the frequency characteristics.

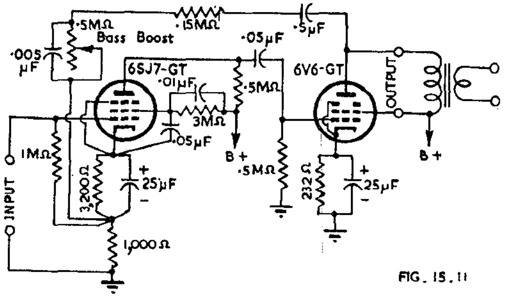


FIG. 15.11

Fig. 15.11. Two stage amplifier with negative feedback over both stages providing bass-boost tone control (typical application).

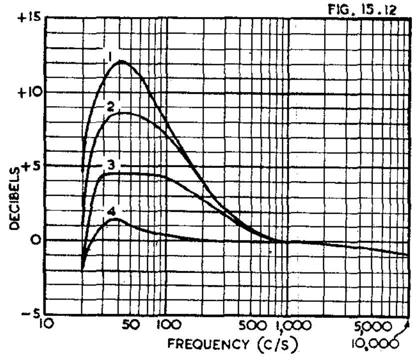


FIG. 15.12

Fig. 15.12. Frequency characteristics of amplifier in Fig. 15.11. Condition (1) tone control max. resistance (2) three quarters max. (3) half max. (4) one quarter max. resistance. The curves have been superimposed to coincide at 1000 c/s.

Another possible circuit is Fig. 15.13 (Ref. 36) in which the feedback is taken from the plate to the grid through C and R_2. The response is given by

$$(1 - \alpha)(1 + j\omega_0/\omega) \qquad (8)$$

where $\omega_0 = \alpha/[CR_2(1 - \alpha)]$

and α = proportion added to the original signal by the setting of VR_1.

Typical values are : $R_1 = R_2 = 1\ M\Omega$, $R = 0.22\ M\Omega$, $C = 200\ \mu\mu F$, giving $\omega_0/2\pi = 250$ c/s when $\alpha = 0.25$. The resistance of VR_1 and VR_2 should be high, preferably with VR_2 greater than VR_1 and $R_3 = VR_1$.

Still another possible circuit is Fig. 15.14A in which feedback is taken from the cathode of the second stage to a resistor at the earthy end of the volume control feeding the grid of the first stage (Ref. 65). It is stated that this gives 10 db of negative feedback at middle and high frequencies and 3 db of positive feedback at low frequencies, equivalent to 13 db bass boost.

FIG. 15.13

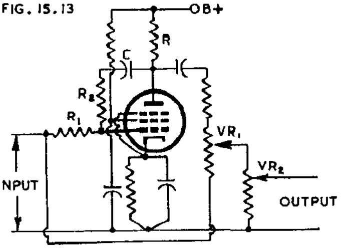


FIG. 15.14A

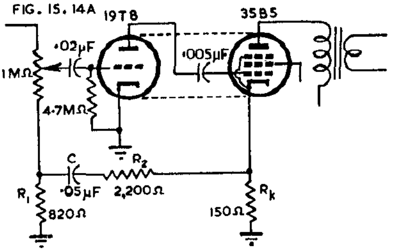


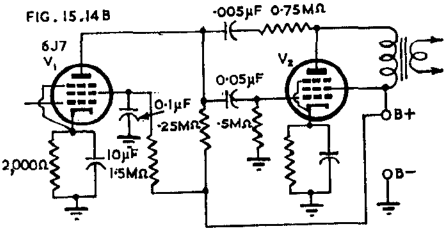
Fig. 15.13. *Single stage amplifier giving bass boosting with adjustable frequency characteristic* (*Ref.* 36).

Fig. 15.14A. *Two stage amplifier giving* 13 *db effective bass boost* (*Ref.* 65).

In Fig. 15.14B a capacitance is inserted in the feedback network from the plate of V_2 to the plate of V_1, with r.c. coupling between the stages. This capacitance provides a fixed amount of bass boosting which is generally limited to about 6 db maximum (Ref. 68).

Fig. 15.14B. *Amplifier with* 0.005 *μF condenser in feedback network to provide bass boosting.* V_2 *is a power amplifier valve* (*Ref.* 68).

FIG. 15.14B



A circuit using an inductor in the feedback network is Fig. 15.54—this may be used for bass boosting only by omitting C_2 and R_4.

A particularly interesting circuit is Fig. 15.15 which incorporates a parallel-T network in the feedback loop (Ref. 57). In the figure the parallel-T network is tuned to 80 c/s, but it may be tuned to any other desired frequency. The frequency characteristic is shown in Fig. 15.16.

There have been many other applications of negative feedback to provide bass boosting which have appeared in articles and patents, too numerous to give in detail. Some are given in the References (Sect. 15).

See also Sects. 4, 8, 9, 10 of this chapter, and Chapter 17, Sect. 5.

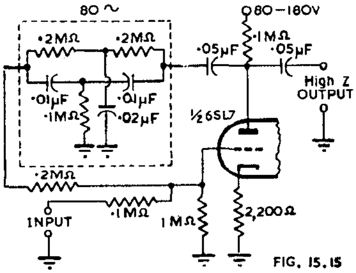


FIG. 15.15

FIG. 15.16

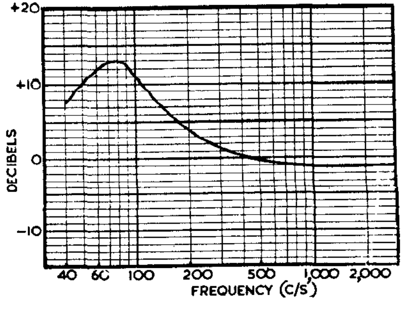


Fig. 15.15. *Single stage amplifier incorporating a parallel-T network in the feedback loop* (*Ref.* 57).

Fig. 15.16. *Frequency characteristics of circuit shown in Fig.* 15.15 (*Ref.* 57).

FIG. 15.17

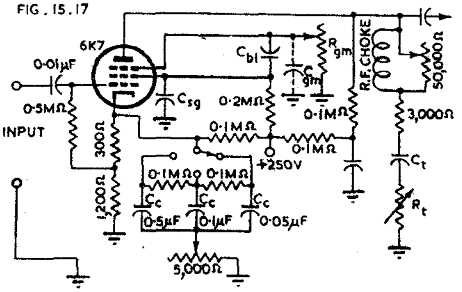


Fig. 15.17. Circuit providing bass boosting due to a negative resistance characteristic of the valve (Ref. 2).

(v) Regeneration due to negative resistance characteristic

A circuit which has interesting possibilities is Fig. 15.17 (Ref. 2). It is capable of very high degrees of bass boosting in the bass without having any appreciable effect at frequencies above 300 c/s (Figs. 15, 18A and B). Since the circuit depends on the negative resistance characteristics of valves, it is subject to larger variations than usual between valves, and is not recommended for quantity production without careful investigation in conjunction with the valve manufacturer.

The frequency of the peak response is determined largely by the values of C_{sg} and C_{gm}. The greater the capacitance of C_t, the sharper will be the bend of the knee of the response curve and the lower the gain between 100 and 500 c/s. Coupling condenser C_{bl} may be considered as regulating the amount of coupling between C_{sg} and C_{gm} with some effect on the shape of the lower end of the curve.

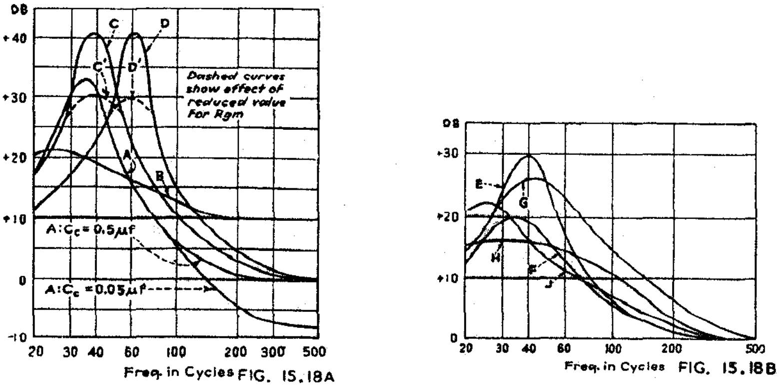


FIG. 15.18A

FIG. 15.18B

Curve	C_{sg}	C_{bl}	C_{gm}	C_t	R_{gm}	R_t
	μF	μF	μF	μF	*ohms*	*ohms*
A	0.45	0.1	—	0.1	100 000	7 000
B	0.45	0.1	—	0.1	100 000	100 000
C	0.45	0.1	—	0.2	100 000	7 000
D	0.25	0.02	—	0.2	100 000	7 000
E	0.25	0.1	0.05	0.2	40 000	7 000
F	0.25	0.02	0.05	0.2	100 000	7 000
G	0.45	0.1	—	0.1	100 000	7 000
H	0.45	0.02	—	0.1	100 000	7 000
J	0.25	0.1	0.05	0.1	100 000	7 000

Fig. 15.18 (A *and* B). *Bass boosting characteristics produced by circuit of Fig.* 15.17 (*Ref.* 2).

SECTION 3 : BASS ATTENUATION

(i) General remarks (ii) Bass attenuation by grid coupling condensers (iii) Bass attenuation by cathode resistor by-passing (iv) Bass attenuation by screen by-passing (v) Bass attenuation by reactance shunting (vi) Bass attenuation by negative feedback (vii) Bass attenuation by Parallel-T network (viii) Bass attenuation using Constant k filters (ix) Bass attenuation using M-derived filters.

(i) General remarks

It is desirable for any amplifier to have bass attenuation, although the frequency at which attenuation commences, and the rate of attenuation, should be carefully determined during the design.

Shortwave receivers are often fitted with about 6 db/octave attenuation below about 150 c/s. In multi-band receivers the attenuation may be incorporated only on the bands where it is desired. A preferable arrangement is to incorporate a choice of two or three bass cut-off frequencies, say 150, 250 and 400 c/s—this is usually only practicable in communication type receivers. This extreme attenuation is only usable under bad conditions for barely intelligible speech. A slight degree of attenuation is helpful in eliminating acoustical feedback to gang condensers and valves and other minor receiver troubles, as well as giving better listening under average shortwave conditions.

Conventional table and mantel model receivers may have an ultimate attenuation of 12 db/octave below say 100 and 150 c/s respectively. Conventional consoles may have a similar attenuation below 80 c/s, but this may be extended down to say 60 c/s in the case of those having loud-speakers capable of handling the lower frequencies. Fidelity amplifiers should have an ultimate attenuation of 18 db/octave below the lowest frequency which the loudspeaker and output transformer can handle at maximum power output without distortion. Fidelity amplifiers incorporating negative feedback should connect the filter prior to the main amplifier input terminals.

(ii) Bass attenuation by grid coupling condensers

Every grid coupling condenser introduces some bass attenuation, and it is a matter of good design to select a value to provide the best overall performance of the equipment. The choice of a capacitance to give a known attenuation at a certain frequency is covered in Chapter 12 Sect. 2(ii) and Fig. 12.9A. Each coupling condenser gives an ultimate 6 db/octave attenuation. If it is desired to eliminate low frequency interference or to reduce hum, the coupling condensers may be designed to have identical frequency characteristics, thus giving 12 or 18 db/octave attenuation for 2 or 3 stages respectively. Even if the grid resistors differ in resistance, the frequency characteristics may be made the same by maintaining the same value of time constant RC. This method does not apply to the design of feedback amplifiers (see Chapter 7 Sect. 3).

Communication receivers are usually fitted with a switch giving the choice of 2 or 3 bass attenuation characteristics—this may operate by changing the value of grid coupling condenser, or by any other convenient means.

Typical attenuation/frequency characteristics for 1, 2, and 3 stages having identical time constants are given by curves 1, 2 and 3 in Fig. 15.19.

(iii) Bass attenuation by cathode resistor by-passing

The attenuation/frequency characteristics of a resistance-coupled triode with by-passed cathode resistor are given in Chapter 12 Sect. 2(iii) and Fig. 12.3A for a typical case. These frequency characteristics differ from those for grid coupling condensers in that they are limited to a maximum attenuation which is usually less than 10 db, typical values for r.c. triodes being from 3.7 to 8 db (Chapter 12). Frequency characteristics for a typical r.c.c. pentode with by-passed cathode resistor are given in Fig. 12.12, the total attenuation being nearly 8 db in this example.

The shape of a typical attenuation/frequency characteristic is illustrated by Curve 4 in Fig. 15.19.

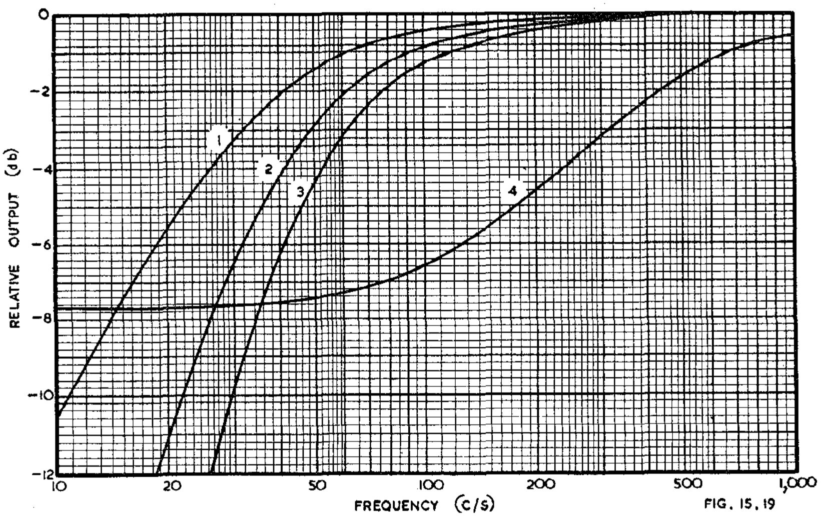


FIG. 15.19

Fig. 15.19. Bass attenuation versus frequency characteristics : (1) Single grid coupling condenser ($R = 1$ megohm, $C = 0.005$ μF) ; (2) Two stages each with identical values of time constant RC ; (3) Three stages each with identical values of time constant ; (4) R.c.c. pentode with by-passed cathode resistor (6J7, $R_L = 0.25$ MΩ, $R_k = 2000$ Ω, $C_k = 0.5$ μF) and screen adequately by-passed.

(iv) Bass attenuation by screen by-passing

The attenuation/frequency characteristics of a r.c.c. pentode with a by-passed screen are given in Chapter 12 Sect. 3(iii) and Fig. 12.11A. These characteristics have the same general form as those for cathode resistor by-passing, with a maximum attenuation which is a function of the series screen resistor—with a high resistance series resistor a typical maximum attenuation is 24 db (see Chapter 12). Although the screen by-pass condenser could be used as a step type tone-control, the use of a low capacitance by-pass generally necessitates additional screen filtering for the elimination of hum.

It is possible to design an amplifier so that all grid coupling condensers, cathode and screen by-pass condensers have the same attenuation (say 2 db each) at the same frequency. In such a case, particularly if there are two or more stages, the rate of change of attenuation becomes quite high, although the cathode and screen by-passing tends to introduce steps in the characteristic. However, care is necessary with tolerances—see Sect. 1(x).

(v) Reactance shunting

Any inductance, whether a-f transformer or output transformer, causes ultimate 6 db/octave attenuation below a certain frequency. If the amplifier is to provide good fidelity, it is advisable to design so that this frequency is below the lower frequency limit of the whole amplifier. In other cases, the cut-off frequencies may be made to coincide for more rapid attenuation—however see Sect. 1(x).

If a transformer primary is resonated with the coupling capacitance, in the case of parallel-feed, the ultimate rate of attenuation below the resonant frequency is 12 db/octave.

Owing to the wide tolerances in inductance normally occurring in quantity production, and to the variation caused by the d.c. and signal currents, it is not considered good practice to use the transformer primary resonance for tone control purposes ; a further contributory factor is the increased valve distortion caused by a low impedance load—see Chapter 12 Sect. 4(xii).

If it is desired to vary the cut-off frequency of an a-f transformer with parallel feed, a variable resistor may be inserted to adjust the equivalent source impedance (R_1 in Fig. 15.20). The low frequency attenuation (Ref. 51) is

$$\text{attenuation in db} = 10 \log_{10} [1 + (R/X_1)^2] \qquad (1)$$

where $R = R_1 + [r_p R_L/(r_p + R_L)]$

$X_1 = \omega L_1$

and L_1 = primary inductance in henrys.

(vi) Bass attenuation by negative feedback

A network may be inserted in the feedback loop which reduces the feedback voltage at middle and high audio frequencies, thus effectively giving bass attenuation (Fig. 15.21, Ref. 23). Condenser C_2 is merely for blocking the d.c. path, while R_1, R_2 and C_1 form a voltage divider across the output voltage of V_2. The voltage drop across R_2 and C_1 is applied across R_3, thus applying the feedback voltage between V_1 cathode and earth.

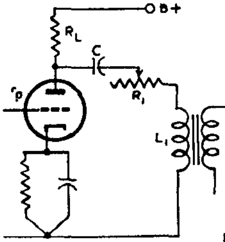


FIG. 15.20

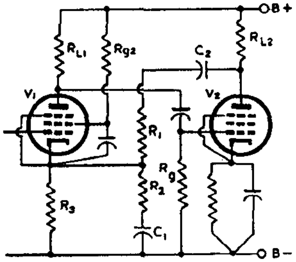


FIG. 15.21

Fig. 15.20. Amplifier, giving variable low-frequency cut-off using a-f transformer and parallel feed.

Fig. 15.21. Amplifier providing bass attenuation by negative feedback (Ref. 23).

(vii) Bass attenuation by Parallel-T network

The parallel-T network—Chapter 4 Sect. 8(iii)—may be used to provide infinite attenuation at one frequency. An example of its application is Fig. 15.22 and the frequency characteristic is given in Fig. 15.23. In its simple form the attenuation is severe even at frequencies five times the frequency giving infinite attenuation. One suggested way of providing a more level characteristic is to incorporate bass boosting around 200 c/s (Ref. 59).

FIG. 15.22

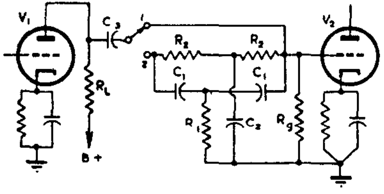


FIG. 15.23

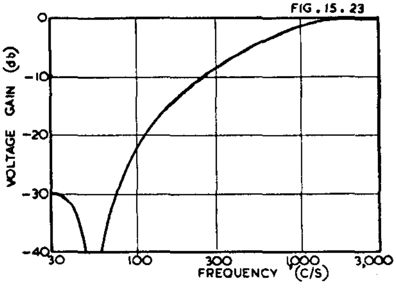


Fig. 15.22. Amplifier providing bass attenuation by Parallel-T network (Ref. 59).
Fig. 15.23. Frequency characteristics of amplifier Fig. 15.22 when V_1 = typical r.c.c. pentode, $C_1 = 0.001\ \mu F$, $C_2 = 0.004\ \mu F$, $C_3 = 0.02\ \mu F$, $R_1 = R_2 = 2\ M\Omega$, $R_L = 0.2\ M\Omega$, $R_g = 0.5\ M\Omega$. The frequency for infinite attenuation is 56 c/s. Switch position (1) Fidelity (2) Bass attenuation (Ref. 59).

(viii) Bass attenuation using Constant *k* filters

If it is desired to achieve a rapid rate of attenuation and a sharp cut-off, it is necessary to use some form of correctly designed filter incorporating both inductors and capacitors. The constant *k* filter [Chapter 4 Sect. 8(vii)] in its simplest form only incorporates 2 condensers and 1 inductor. An example of its incorporation in an amplifier is Fig. 15.24 (Ref. 60). This filter is fairly non-critical as regards the inductance of L, a 2 : 1 variation still giving a reasonable characteristic with, of course, a change in cut-off frequency. The frequency characteristic obtained with balanced loading is Fig. 15.25 Curve 1 ; when the source impedance is 50 000 ohms and load 0.5 megohm the frequency characteristic is curve 2, showing the typical rise above 0 db due to unbalanced conditions ; curve 3 shows the effect of increasing the resistance of the inductor L.

If sharper attenuation is required, two or more filter sections may be incorporated.

FIG. 15.25

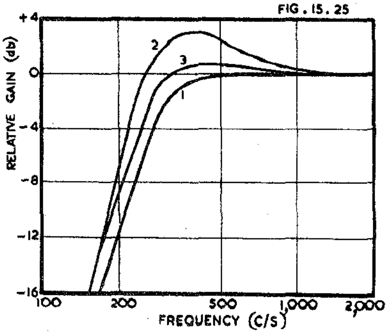


FIG. 15.24

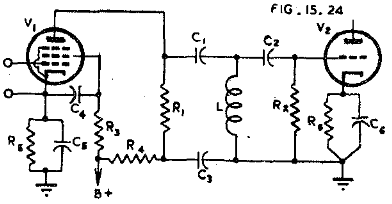
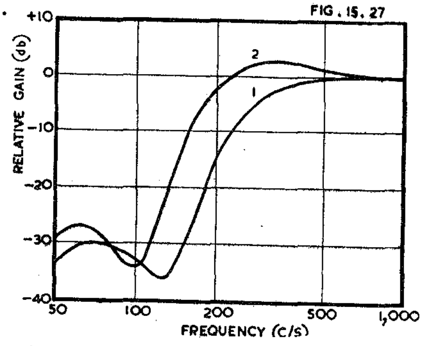


Fig. 15.24. *Amplifier providing bass attenuation by constant k filter (Ref.* 60).
Fig. 15.25. *Frequency characteristics of amplifier Fig.* 15.24 *when* V_1 = *typical r.c.c. pentode,* $C_1 = C_2 = 0.002\ \mu F \pm 5\%$, $C_3 = 1\ \mu F$, $L = 70\ H$ *with* $Q = 6$; *Curve* (1) $R_1 = R_2 = 0.25\ M\Omega$; *Curve* (2) $R_1 = 50\,000\ \Omega$, $R_2 = 0.5\ M\Omega$ *(unbalanced)* ; *Curve* (3) *as Curve* 2 *with additional resistance in inductor to give* $Q = 3$ *(Ref.* 60).

(ix) Bass attenuation using M-derived filters

One T section of an M-derived filter may be used to provide a more rapid attenuation than that of a Constant *k* filter—see Chapter 4 Sect. 8(viii). The filter itself is shown in Fig. 15.26 and the frequency characteristics for balanced and unbalanced impedances in Fig. 15.27. Here, also, a considerable tolerance is permissible with the value of L and in the degree of mismatching. With mismatching, the value of R may be taken as $\sqrt{R_1R_2}$ (Ref. 60).

FIG. 15.27



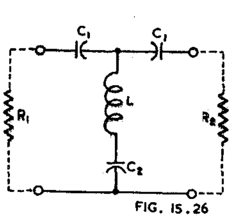


FIG. 15.26

Fig. 15.26. *One T section of a series M-derived filter.*
Fig. 15.27. *Frequency characteristics of filter Fig.* 15.26 ; *Curve* (1) $R_1 = R_2 = 0.25\ M\Omega$, $C_1 = 0.0023\ \mu F$, $C_2 = 0.024\ \mu F$, $L = 74\ H$; *Curve* (2) $R_1 = 50\,000\ \Omega$, $R_2 = 0.5\ M\Omega$ *(unbalanced)*, $C_1 = 0.0058\ \mu F$, $C_2 = 0.035\ \mu F$, $L = 73\ H$ *(Ref.* 60).

SECTION 4 : COMBINED BASS TONE CONTROLS

(i) Stepped controls (ii) Continuously variable controls.

(i) Stepped controls

A typical stepped control (Fig. 15.28) has 2 positions giving bass boost, 1 giving " flat " response, and 2 giving bass attenuation. The values of capacitance may be selected to give the desired frequency characteristics.

See also Sect. 8 for combined bass and treble tone controls, particularly Figs. 15.37A, 15.37B, 15.39, 15.40.

References 17, 50, 54, 55, 64.

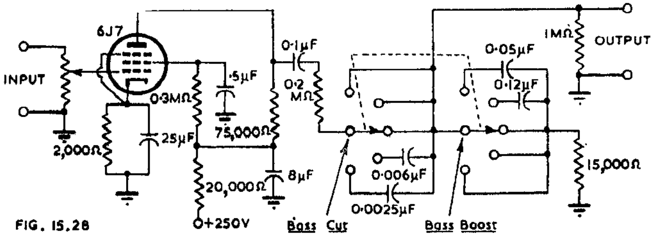


Fig. 15.28. *Step-control giving bass boosting and bass attenuation.*

(ii) Continuously variable controls

Circuits providing only bass boosting or attenuation with a single continuously variable control are not widely used.

SECTION 5 : TREBLE BOOSTING

(i) General remarks (ii) Circuits not involving resonance or negative feedback (iii) Methods incorporating resonant circuits (iv) Circuits involving feedback.

(i) General remarks

Treble boosting, mainly on account of the increased distortion which it causes, is usually avoided altogether or else used only for the purpose of equalizing an unavoidable attenuation in the amplifier at the maximum frequency limit.

The subject of distortion has been covered in Section 1(iv).

(ii) Circuits not involving resonance or negative feedback

(A) Conventional treble boosting circuit (Fig. 15.29)

This is an adaptation of the fundamental circuit Fig. 15.2. It may be shown that

$$\text{Gain at low frequencies} = \frac{\mu R R_2}{(R_1 + R_2)(R + r_p) + R r_p} \qquad (1)$$

$$\text{Gain at very high frequencies} = \frac{\mu R'}{R' + r_p} \qquad (2)$$

where $R = R_L(R_1 + R_2)/(R_L + R_1 + R_2)$

and $R' = R_2 R_L/(R_2 + R_L)$.

Then B = ratio of amplification at very high frequencies to amplification at low frequencies

$$= 1 + \frac{R_1}{R_2 + R''} \qquad (3)$$

where $R'' = r_p R_L/(r_p + R_L)$.

We may determine the value of R_1 for any desired value of B from the equation

$$R_1 = (B - 1)(R_2 + R'') \tag{4}$$

In the case of pentodes, R'' approximates to R_L.

The frequency characteristics for treble boosting have been plotted (Ref. 51 Fig. 9.18 ; also Refs. 9,55) but for most purposes it is sufficient to work on the " half-boost " points as for bass boosting, the curves being approximately symmetrical S curves about these points. The values of R/X for the half-boost point are identical to those for bass boosting, and not the inverse as might be expected.

Total boost	20	15	10	6	3	db
Half boost	10	7.5	5	3	1.5	db
Boost ratio (B)	10	5.62	3.16	2.0	1.41	
(R_1/X_1) for half boost*	3.16	2.37	1.78	1.41	1.19	
C_1†	$3.16/\omega R_1$	$2.37/\omega R_1$	$1.78/\omega R_1$	$1.41/\omega R_1$	$1.19/\omega R_1$	F

*$(R_1/X_1) = \sqrt{B}$ at half boost point. $X_1 = 1/\omega C_1$

†$C_1 = 1/\omega X_1 = (R_1/X_1)/\omega R_1$ $\omega = 2\pi f_0$

where R_1 and C_1 are as shown in Fig. 15.29
and f_0 = frequency at half-boost point.

A variable control may be achieved in various ways (Ref. 9) :

(a) Varying C_1—This can only be done in steps. The result is to change the frequency of the half-boost point (see table).

(b) Varying R_1—This varies the amplification for middle frequencies, and is unsatisfactory for tone control purposes.

(c) Adding a variable resistor in series with C_1—This is fairly effective but the shapes of the frequency characteristics are not ideal for tone control. It is used in a slightly modified form in the combined bass and treble boost circuit of Fig. 15.46.

References to conventional treble boosting circuit : 9, 17, 48, 51, 55.

FIG. 15.29

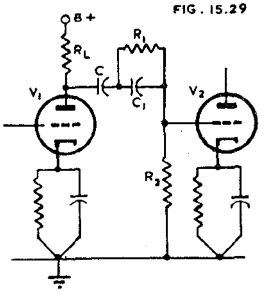


Fig. 15.29. *Conventional treble boosting circuit.*

FIG. 15.30

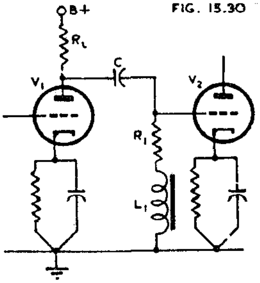


Fig. 15.30. *Treble boosting with inductance in grid circuit.*

(B) Using inductance in grid circuit (Fig. 15.30)

This gives the same shape of frequency characteristics as the conventional treble boosting circuit. The same expressions may be used except that in this case

$X_1 = \omega L_1$ and $B = R/R_1$

where $R = [r_p R_L/(r_p + R_L)] + R_1$.

If R_1 is made variable, it has a very pronounced effect on the gain at middle frequencies. A preferred method of tone control is to use a step switch and tappings on the inductance (see Sect. 8 and Fig. 15.40).

References 17, 51.

(C) Correction for side-band cutting

The methods which may be used for the equalization of side-band cutting in a receiver are described in Refs. 3 and 62.

(iii) Methods incorporating resonant circuits

Resonant circuits are rarely used for treble boosting tone control since there are other preferable methods which give the required performance (Ref. 17).

(iv) Circuits involving feedback

(A) Cathode resistor by-passing

If a suitable small capacitance is used as a by-pass condenser across any cathode resistor, a limited degree of treble boosting will be achieved. In the case of resistance-coupled amplifiers the maximum boost is not more than 6 or 8 db. Greater boosting may be achieved by increasing the cathode resistor and returning the grid resistor to a suitable tapping point in the cathode circuit.

(B) Network in feedback loop

The same method may be used as for bass attenuation—see Sect. 3(vi) and Fig. 15.21.

SECTION 6 : TREBLE ATTENUATION

(i) General remarks (ii) Attenuation by shunt capacitance (iii) Treble attenuation by filter networks (iv) Treble attenuation in negative feedback amplifiers.

(i) General remarks

Every amplifier should have a maximum frequency of response, beyond which attenuation should be at a rate of not less than a nominal 12 db per octave for conventional amplifiers or 18 db per octave for fidelity amplifiers. This attenuation may be partly prior to the input terminals of the main amplifier or in the early stages of the amplifier, and partly (at least 6 db/octave) at the output end.

Because the simplest methods of treble attenuation have a gradual commencement, there tends to occur a rounding of the response curve which may be appreciable at the maximum frequency of response. It is suggested that 2 db attenuation at this frequency is a reasonable compromise, or even higher attenuation for other than fidelity amplifiers, but where an amplifier must be designed within narrow tolerances it is generally necessary to use one of the more elaborate methods of attenuation.

In the case of amplifiers incorporating negative feedback, the filter to provide the attenuation must be outside the feedback loop.

(ii) Attenuation by shunt capacitance

The theory has been covered in Chapter 4 Sect. 8(ii) under the heading " r.c. low-pass filter " with the circuit of Fig. 4.37 ; the attenuation characteristic is given in Chapter 4 eqn. (4) and plotted in Fig. 4.38.

FIG. 15.31

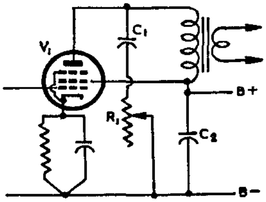


Fig. 15.31. Typical " tone control " used in radio receivers. In a typical case C_1 = 0.05 μF, R_1 = 50 000Ω (max.), V_1 = power pentode with load resistance about 5000 *ohms.*

This forms part of the usual " tone-control " in many radio receivers of the less expensive class, as illustrated in Fig. 15.31. The control is in the form of a variable resistance in series with the capacitance which limits its attenuation. A suitable maximum value for the resistance is 10 times the load resistance. In some cases a fixed capacitance only is used—typical values are from 0.005 to 0.02 μF for a loudspeaker load resistance of 5000 ohms. In this application the " effective resistance " for the calculation of the attenuation will be the loudspeaker impedance in parallel with the output resistance (R_0) of the amplifier.

Tone control by shunt capacitance, when used with discrimination, is fairly satisfactory with a flat amplifier operating from an equalized source. It is far from satisfactory in selective radio receivers in which the high audio frequencies are already heavily attenuated; this effect is minimized when variable selectivity i-f amplifiers are used. One reason for the popularity of shunt capacitance tone control is that the intermodulation frequencies produced by the distortion in the pentode or beam power amplifier valve are much reduced, and listening thereby made less fatiguing. If methods are taken to reduce the distortion, e.g. by negative feedback, the tone control may preferably take the form of bass boosting.

In order to achieve the desired treble attenuation, a shunt capacitance may be placed across the source (radio receiver, pickup or microphone), from any grid to earth, from any plate to earth or across the output terminals of the amplifier. In each case the effective resistance (R in eqn. 4 of Chapter 4 and Fig. 4.38) is the resultant a.c. resistance between the points across which the shunt capacitance is connected. In the case of a r.c.c. pentode it is approximately the load resistance in parallel with the following grid resistor, and it does not make any appreciable difference whether the capacitance is shunted across the plate load resistor or the following grid resistor, owing to the coupling through the grid coupling condenser. Even if no shunt condenser is added, the output capacitance of the valve plus the dynamic* input capacitance of the following valve plus wiring capacitances provide appreciable treble attenuation—see Chapter 12 Sect. 2(xi). The effect on treble attenuation may be reduced by reducing the plate load resistance; it may be increased by increasing the plate load resistance or by adding shunt capacitance. A typical r.c.c. pentode followed by a similar stage has only slight attenuation at 10 000 c/s when the load resistance is less than 0.25 megohm. In the case of a r.c.c. triode the effective resistance is the plate resistance of the valve (under r.c.c. conditions) in parallel with the load resistance and the following grid resistance.

In the general case the effective resistance is given by

$$R = R_s + R_L' r_p/(R_L' + r_p) \qquad (1)$$

where R_s = resistance in series with C as part of the tone control,
$R_L' = R_L R_g/(R_L + R_g)$
R_L = load resistance
R_g = following grid resistance
and r_p = plate resistance of valve.

With a high-mu triode such as type 6SQ7 the effective input capacitance is of the order of 100 $\mu\mu$F. If this capacitance is shunted across an effective resistance of 0.5 megohm, the attenuation is about 10 db at 10 000 c/s.

The **total attenuation** at any frequency will be the attenuation at that frequency prior to the amplifier plus the sum of the attenuations of the stages in the amplifier at that frequency plus the attenuation by the shunt capacitance at that frequency, all expressed in db. It is not sufficient to assume an attenuation of 6 db/octave from each stage in the amplifier unless all the stages have the same cut-off frequency. In the general case it is necessary, for design purposes, to calculate the attenuation of each stage or filter for convenient frequencies, e.g. 10 000, 14 000, 20 000, 28 000, 40 000 c/s and then to add the values in db to determine the overall attenuation characteristic. The latter will, eventually, almost reach a slope of 6 db/octave per stage or per shunt capacitance, but the knee of the curve will be very rounded unless the cut-off frequencies are identical.

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*Under operating conditions, including the " Miller Effect " capacitance from the plate.

(iii) Treble attenuation by filter networks

(A) Constant *k* low-pass filter

An approximate Constant *k* low-pass Π section filter to provide a nominal treble attenuation of 24 db/octave with the choice of several cut-off frequencies is shown in Fig. 15.32. This is intended to be connected between a pickup or microphone pre-amplifier and the main amplifier. For theory see Chapter 4 Sect. 8(vii) and Fig. 4.49. In reality only C_2 has been calculated to give a constant *k* filter for the correct terminating impedances, and C_1 and C_3 have been calculated merely to give the desired cut-off frequencies leaving L unchanged. Thus it is only a constant *k* filter on tapping 3 and a sufficiently close approximation on the other tappings. A considerable degree of mismatching is permissible between R_1 and R_2 provided that $\sqrt{R_1R_2} = 0.1$ megohm.

The calculation of the constant *k* filter is based on the expressions :

$L/C = R^2$ (see Fig. 4.49C for symbols)

$f_0 = 1/\pi\sqrt{LC}$ where f_0 = cut-off frequency.

FIG. 15.32

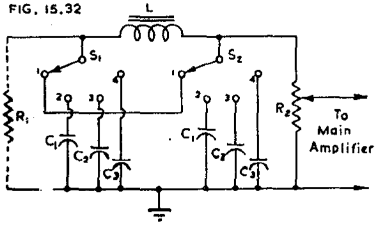

Fig. 15.32. Approximate constant k low-pass Π section filter. R_1 = source impedance. When $R_1 = R_2 = 0.1\ M\Omega$, $L = 5\ H$, $C_1 = 0.0001$, $C_2 = 0.0002$ and $C_3 = 0.0004\ \mu F$, the cut-off frequencies will be (1) *none* (2) 10 000 *c/s* (3) 7000 *c/s* (4) 5000 *c/s.*

(B) M-derived filters

One T section of an M-derived filter may also be used for treble attenuation. See remarks for bass attenuation.

(C) Parallel-T network

The parallel-T network—Chapter 4 Sect. 8(iii)—may be used to provide infinite attenuation at one frequency but the rate of attenuation begins very gradually. One improvement is described in Chapter 17 Sect. 5(iv) Figs. 17.24B and 24C (Ref. 57). See also Sect. 11(iv).

(iv) Treble attenuation in negative feedback amplifiers

A network may be inserted in the feedback loop to reduce the feedback voltage at low and middle audio frequencies, thus effectively giving treble attenuation. The circuit is effectively the same as for bass boosting (Fig. 15.11) except that the capacitance is selected to give the required frequency characteristics. See also Ref. 23, Fig. 9.

There have been many negative feedback circuits which give a measure of tone control among which are—

(A) Fig. 15.33. This circuit incorporates a very small condenser C (of the order of 10 to 100 $\mu\mu$F) to provide some negative feedback at the higher audio frequencies without seriously affecting the gain at 400 c/s. This is only fully effective when no plate by-pass capacitor is used.

FIG. 15.33

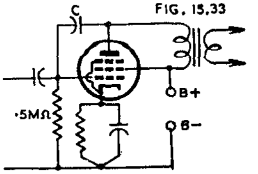

FIG. 15.34

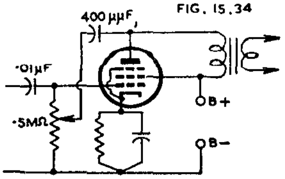

Fig. 15.33. *Power amplifier valve with small condenser C giving negative feedback at high audio frequencies (treble attenuation).*

Fig. 15.34. *Power amplifier valve with variable negative feedback at high audio frequencies (treble attenuation).*

(B) Fig. 15.34 is a development of Fig. 15.33 to provide continuously variable tone control. The feedback condenser is larger and a potentiometer is used in the grid circuit to control the tone. At maximum treble cut it gives an attenuation of 28 db at 20 000 c/s (Ref. 39).

FIG. 15.35A

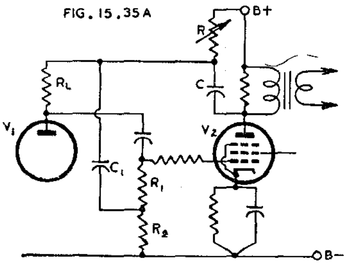

FIG. 15.35B

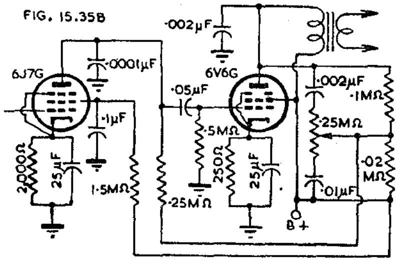

Fig. 15.35A. *Amplifier with variable treble attenuation due to negative feedback.*
Fig. 15.35B. *Amplifier with negative feedback providing treble attenuation or treble boosting* (*Ref.* 67).

(C) Fig. 15.35A is a further variation in which R and C form a potential divider across the output from V_2. At increasing frequencies a larger negative feedback voltage is applied, the amount being limited by the variable resistance R. C_1 is a blocking condenser (Ref. 63).

(D) For feedback over more than one stage, see Sect. 9.

SECTION 7 : COMBINED TREBLE TONE CONTROLS

Treble controls giving a choice of treble boosting or treble attenuation without also incorporating bass boosting or attenuation are comparatively rare. Attention is directed to Sect. 8 and Figs. 15.37A, 15.37B, 15.39, 15.40, 15.46.

One example in this class is Fig. 15.35B which provides continuously-variable tone control from treble boost to treble attenuation by means of a resistor-capacitor network in the feedback circuit (Ref. 67).

SECTION 8 : COMBINED BASS AND TREBLE TONE CONTROLS

(*i*) *Stepped controls—general* (*ii*) *Quality switch* (*iii*) *Universal step-type tone control not using inductors* (*iv*) *Universal step-type tone control using inductors* (*v*) *Fixed bass and treble boosting* (*vi*) *Step-type tone control using negative feedback* (*vii*) *Continuously-variable controls—general* (*viii*) *Single control continuously-variable tone controls* (*ix*) *Ganged continuously-variable tone controls* (*x*) *Dual control continuously-variable tone controls.*

(i) Stepped controls—general

Stepped controls are capable of better performance than continuously variable controls, partly because it is possible to vary two or more component values simultaneously and partly because the attenuation at middle frequencies may be adjusted so as to avoid an apparent change in volume as the control is moved. For most radio purposes it is sufficient to have two control knobs, one controlling the bass and the other the treble, with five positions on each—one " flat," two boosting and two attenuating with alternative degrees of each.

(ii) Quality switch

An alternative arrangement which is very effective with the non-technical public is to select suitable values for each type of listening conditions. For example, one manufacturer* has brought out a model with an 11 position tone control as under :

1. for distant stations, extremely noisy—maximum sensitivity (10% feedback), bass normal, treble attenuation severe to counteract static and noise.
2. for distant stations, noisy—maximum sensitivity, bass normal, treble attenuation less severe.
3. for distant stations, less noisy—maximum sensitivity, bass normal, treble attenuation still less.
4. for distant stations, still less noisy—maximum sensitivity, bass normal, treble attenuation slight.
5. for distant stations, slight noise—maximum sensitivity, bass normal, no treble attenuation.
6. for local stations with good fidelity at low volume—reduced sensitivity (25% feedback), bass boost, treble boost.
7. for fidelity at medium volume—slight treble boost, less bass boost.
8. for fidelity at normal volume—no treble boost, no bass boost.
9. for fidelity at normal volume but reducing needle scratch—slight treble attenuation, no bass boost.
10. as (9) but increased treble attenuation.
11. as (10) but increased treble attenuation.

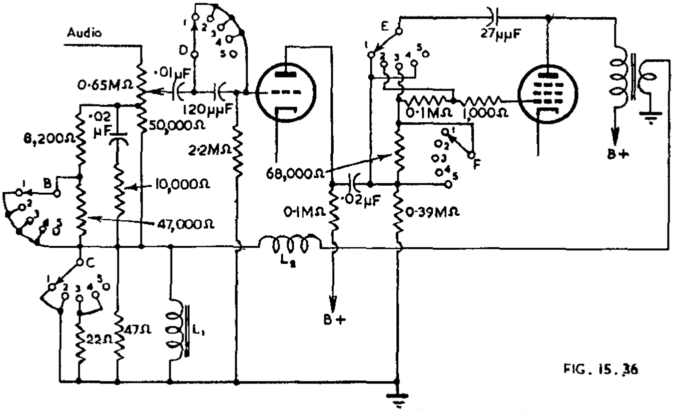

FIG. 15.36

Fig. 15.36. *One form of Quality Switch* (*Ref.* 33).

An alternative form using a 5 position switch is shown in Fig. 15.36 (Ref. 33). The switch positions are

1. heavy bass attenuation and very limited treble attenuation for very distant reception, no feedback.
2. normal bass, heavy treble attenuation, no feedback.
3. bass attenuation, medium treble attenuation, half feedback.
4. normal bass, slight treble attenuation, half feedback.
   Note : Positions 1 to 4 inclusive are for use with narrow i-f bandwidth.
5. normal bass, no treble attenuation, maximum feedback, wide i-f bandwidth, for fidelity reception of local stations.

At low settings of the tapped volume control the capacitance in series with the inductance provide a dip at middle high frequencies, thus effectively giving bass and treble boost.

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*Columbus Radio (Radio Corporation of New Zealand Limited).

(iii) Universal step-type tone control not using inductors

A simple form is shown in Fig. 15.37A where treble boost is obtained by cathode by-passing (C_1), treble attenuation by shunt capacitance (C_4), bass attenuation by grid coupling condenser (C_3), and bass boosting by the conventional method (C_5). Each of these may have two or three values—C_1 may be 0.01, 0.02, 0.03 μF ; C_3 may be 0.0025, 0.006 μF ; C_4 may be 0.002, 0.005 μF ; C_5 may be 0.02, 0.05, 0.1 μF.

FIG. 15.37A

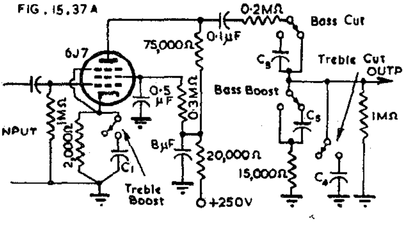


Fig. 15.37A. *Simple universal tone control not using inductors.*

FIG. 15.37B

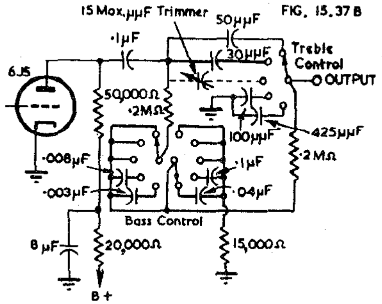


Fig. 15.37B. *Step-type tone control not using inductors (Ref.* 70).

An improved form is given in Fig. 15.37B and its frequency characteristics in Fig. 15.37C (Ref. 70). The 15 $\mu\mu$F max. trimmer capacitor is for the purpose of compensating in the " flat " position for the loss of high audio frequencies caused by stray shunt and Miller Effect capacitances when the following stage is a triode.

Increased rate of boosting and attenuation is obtainable by connecting two or more r.c. filters in cascade. A step of 6 db/octave (nominal) is too great for a flexible tone control, so that networks giving reduced rates of boosting and attenuation may be devised (Fig. 15.38). These may be combined to give any desired steps. A very comprehensive example is Fig. 15.39 (Ref. 50) which uses two six-pole 11 position control switches. Its overall gain is zero db at 500 c/s at any setting of the control switches.

FIG. 15.37C

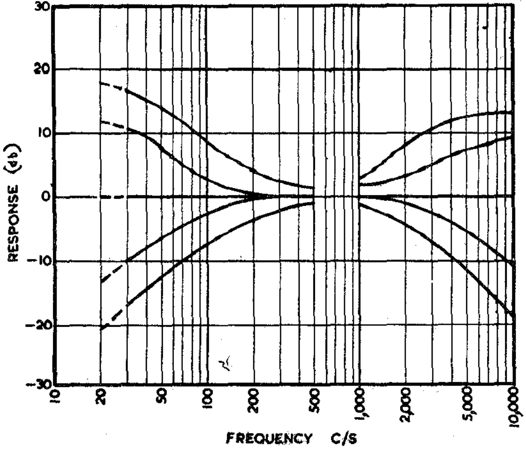
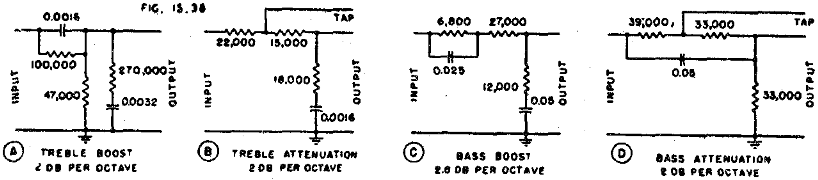


Fig. 15.37C. *Frequency response characteristics of the circuit of Fig.* 15.37B (*Ref.* 70).

FIG. 15.38



Ⓐ TREBLE BOOST 2 DB PER OCTAVE

Ⓑ TREBLE ATTENUATION 2 DB PER OCTAVE

Ⓒ BASS BOOST 2.8 DB PER OCTAVE

Ⓓ BASS ATTENUATION 2 DB PER OCTAVE

Fig. 15.38. *Networks giving selected values of decibels per octave for boosting and attenuation (Ref.* 50).

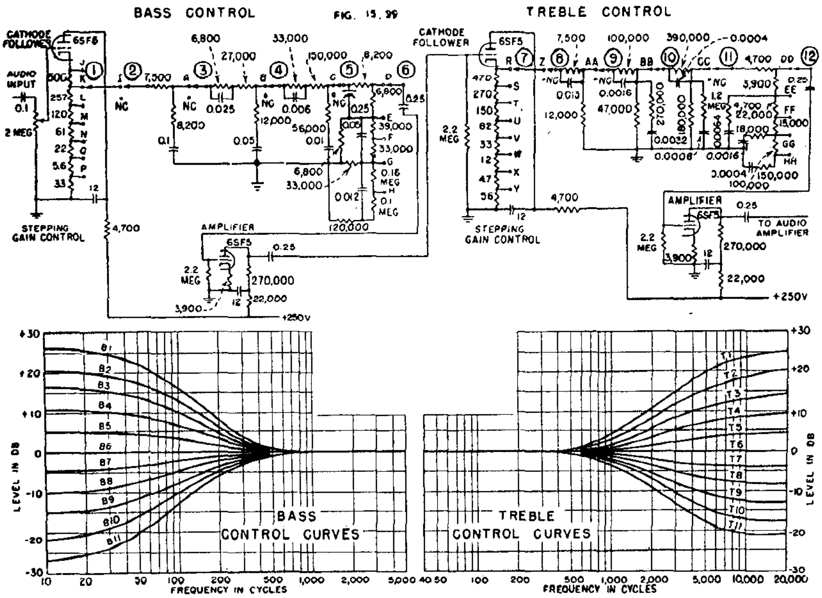


Fig. 15.39. *Step-type tone control system not using inductors (Ref.* 50).

RESP.			*CONTACT.*			
CURVE.	7	8	9	10	11	12
*T*1	*R*	*Z*	*AA*	*BB*	*NC*	*CC*
*T*2	*S*	*NC*	*Z*	*BB*	*NC*	*CC*
*T*3	*T*	*Z*	*AA*	*NC*	*NC*	*BB*
*T*4	*U*	*NC*	*Z*	*NC*	*NC*	*BB*
*T*5	*V*	*Z*	*NC*	*NC*	*NC*	*AA*
*T*6	*Y*	*NC*	*NC*	*NC*	*NC*	*Z*
*T*7	*X*	*NC*	*NC*	*NC*	*Z*	*DD*
*T*8	*X*	*NC*	*NC*	*NC*	*Z*	*EE*
*T*9	*X*	*NC*	*NC*	*NC*	*Z*	*FF*
*T*10	*X*	*NC*	*NC*	*NC*	*Z*	*GG*
*T*11	*W*	*NC*	*NC*	*NC*	*Z*	*HH*

RESP.			*CONTACT*			
CURVE.	1	2	3	4	5	6
*B*1	*J*	I	A	*B*	*NC*	C
*B*2	*K*	*NC*	*I*	*B*	*NC*	*C*
*B*3	*L*	*I*	*A*	*NC*	*NC*	*B*
*B*4	*M*	*NC*	*I*	*NC*	*NC*	*B*
*B*5	*N*	*I*	*NC*	*NC*	*NC*	*A*
*B*6	*P*	*NC*	*NC*	*NC*	*NC*	*I*
*B*7	*P*	*NC*	*NC*	*NC*	*I*	*D*
*B*8	*P*	*NC*	*NC*	*NC*	*I*	*E*
*B*9	*P*	*NC*	*NC*	*NC*	*I*	*F*
*B*10	*P*	*NC*	*NC*	*NC*	*I*	*G*
*B*11	*Q*	*NC*	*NC*	*NC*	*I*	*H*

(iv) Universal step-type tone control using inductors

The treble boosting circuit of Fig. 15.30 may be used, combined with treble attenuation by shunt capacitance and conventional bass boosting and attenuation.

A typical example is Fig. 15.40 (Ref. 64 ; see also Refs. 17, 54, 55). The nominal slope is 6 db/octave for all positions, but the capacitances and inductances may be selected to give any desired frequencies for the commencement of attenuation or

FIG. 15.40

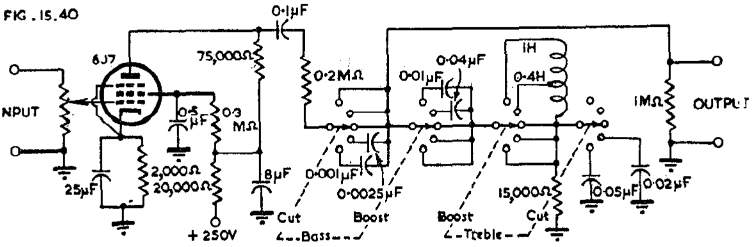


Fig. 15.40. *Universal step-type tone control using inductors.*

boosting. The inductor may be wound with an air-core as under : Former diameter ¾ in. Length between cheeks ¾ in. Winding wire 40 S.W.G. (or 36 A.W.G) SSE. Total turns 6740, tapped at 4520 turns. Layer wound. Total radial depth of winding say 0.6 in.

One defect of this method of treble boosting is the tendency for the inductor to pick up hum.

(v) Fixed bass and treble boosting

When it is desired to incorporate a fixed amount of bass and treble boosting, as for example equalizing the response of a pair of headphones, the circuit of Fig. 15.41 may be used. For headphone equalizing (Ref. 7) suitable values are $C_1 = 0.0003$, $C_2 = 0.015$ μF, $R_1 = R_4 = 0.1$ MΩ, $R_5 = 0$ For bass and treble boost for tone control suitable values are (Ref. 25) :—$C_1 = C_2 = 0.0002$ μF, $R_1 = 0.2$ MΩ, $R_4 = 0.3$ MΩ, $R_5 = 0$, giving 16 db bass boost (20 c/s) and 7 db treble boost (10 000 c/s) relative to 1000 c/s. If $R_5 = 50\,000$ ohms, other values being unchanged, the bass boost is 16 db and treble boost 12 db.

(vi) Step type tone control using negative feedback

Circuits providing universal step-type tone control using negative feedback are described in Sect. 9 (Fig. 15.58A).

(vii) Continuously-variable controls—general

Continuously-variable controls are in two groups, those which have one control knob and those which have two or more. A single control knob is obviously limited in its capabilities—for example it may be used to provide bass boosting when turned in one direction from the centre point, or treble boosting in the other direction, with flat response at the centre point. On the other hand, with two control knobs it is possible to make any desired combination of bass and treble characteristics.

FIG. 15.41

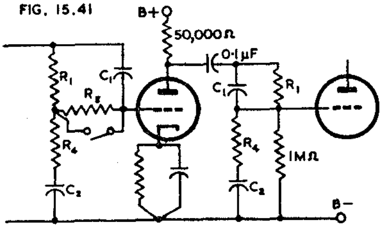


Fig. 15.41. *Circuit giving fixed bass and treble boosting* (*Ref.* 7).

FIG. 15.42

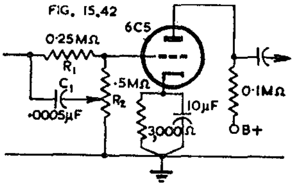


Fig. 15.42. *Single control continuously variable tone control* (*Ref.* 22).

(viii) Single-control continuously variable tone controls

(A) A typical example is Fig. 15.42 (Ref. 22). When C_1 goes to the grid end of potentiometer R_2, the bass is attenuated by the grid coupling condenser C_1, limited by R_1. When C_1 goes to the earthed of R_2, the treble is attenuated by the shunt capacitance of C_1.

FIG. 15.43

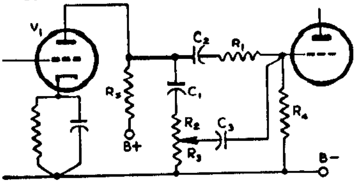


Fig. 15.43. *More elaborate single control continuously variable tone control. Typical values are :* V_1 = *pentode,* $R_1 = 5\ M\Omega$, $R_2 + R_3 = 0.25\ M\Omega$, $R_4 = 0.3\ M\Omega$, $C_1 = 0.0001\ \mu F$, $C_2 = 0.05\ \mu F$, $C_3 = 0.001\ \mu F$ (*Ref.* 62).

(B) Another example is Fig. 15.43 (Ref. 62) which is capable of giving treble boost 18 db at 10 000 c/s and bass attenuation 6 db at 50 c/s in one extreme position ; bass boost 4 db and treble attenuation 21 db in the other extreme.

(C) An interesting circuit which gives simultaneous bass and treble boosting, linear response, or simultaneous bass and treble attenuation is Fig. 15.43A (Ref. 86). The

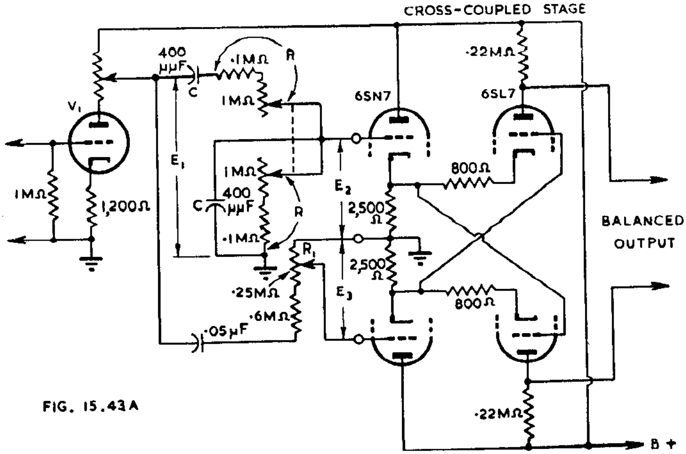


FIG. 15.43A

Fig. 15.43A. *Tone control circuit using cross coupled input stage (Ref.* 86).

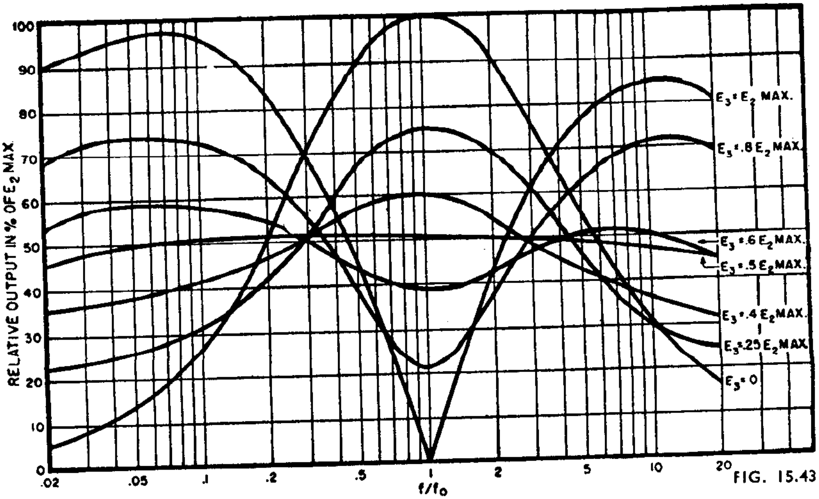


FIG. 15.43B

Fig. 15.43B. *Frequency response characteristics of circuit of Fig.* 15.43A, *the value of* R_1 *being varied (Ref.* 86).

two twin triodes form the " cross-coupled phase inverter "—see Chapter 12 Sect. 6(viii)—which is here used to amplify the difference between the input voltages to the 6SN7 grids. The frequency response curves are shown in Fig. 15.43B for different values of R_1. The maximum output and the point of zero phase shift occur at $f/f_0 = 1$, where $f_0 = 1/2\pi RC$. The frequency of the peak in the curve may be determined by choice of R and C ; in the circuit shown, this frequency is adjustable from 360 to 4000 c/s by means of a dual 1 MΩ potentiometer. A choice of $f_0 = 600$ to 800 c/s is pleasing in many cases.

(ix) Ganged continuously-variable tone controls

Two or more controls may be ganged and operated by a single knob. One control may be the tone control and the other a control of gain so that the apparent output level is held approximately constant at all settings.

(x) Dual control continuously-variable tone controls

(A) Simple duo-control circuit, Fig. 15.44A (Ref. 22)

This filter incorporates resistors and condensers only, and R_3 controls the bass and R_4 the treble. A filter having a similar function is also described in Ref. 31.

A slight modification of this circuit is Fig. 15.44B which gives either bass or treble boosting (Ref. 41).

FIG. 15.44A

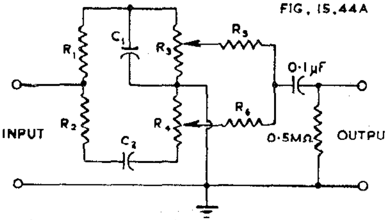


FIG. 15.44 B

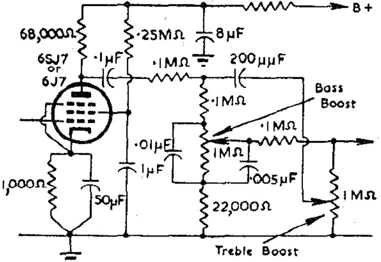


Fig. 15.44A. *Simple duo-control circuit giving individual control of bass and treble. Typical values are :* $R_1 = 0.25$ *MΩ ;* $R_2 = R_3 = 0.5$ *MΩ ;* $R_4 = 0.25$ *MΩ ;* $R_5 = R_6 = 0.5$ *MΩ ;* $C_1 = 0.01$ *μF ;* $C_2 = 0.001$ *μF (Ref.* 22).

Fig. 15.44B. *Simple tone control giving bass and treble boosting (Ref.* 41).

(B) Duo-control circuit incorporating *L* and *C* (Fig. 15.45, Ref. 26)

In this filter, R_1 controls the bass and R_3 the treble. Hum may be troublesome on account of L.

(C) Cutler duo-control circuit (Fig. 15.46, Ref. 26)

This filter may only be used to feed into the grid of an amplifier valve ; R_4 controls the bass boost and R_3 the treble boost. The maximum boost is 17 db at 40 c/s and 15 db at 10 000 c/s, relative to 1000 c/s, with the values shown.

FIG. 15.45

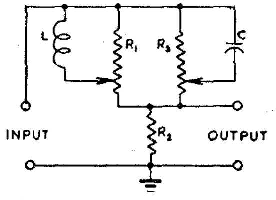


FIG. 15.46

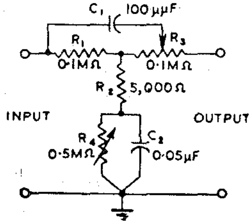


Fig. 15.45. *Duo-control circuit incorporating L and C (Ref.* 26).

Fig. 15.46. *Cutler duo-control circuit (Ref.* 26).

(D) Paraphase bass-treble tone control (Figs. 15.47A, Ref. 56)

This is an outstandingly flexible circuit which may be designed for any cross-over frequency—400 c/s in Fig. 15.47A and the curves in Fig. 15.47B. The design procedure is :

1. Choose a cross-over frequency f_c.
2. Choose $R \geqq 10R_L$ where R_L = generator impedance.
3. Make $C = 1/(2\pi f_c R)$.
4. Make $K = 10$; then $KR = 10R$ and $C/K = C/10$.

Example : Choose $f_c = 400$ c/s. Say generator impedance = 1000 ohms, then select

$R = 82\,000$ ohms, from which

$C = 1/(2\pi \times 400 \times 82\,000) = 0.005\ \mu F$; $C/K = 0.0005\ \mu F$.

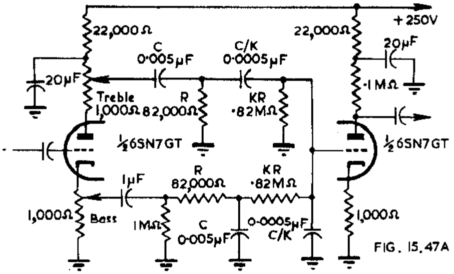


Fig. 15.47A. *Paraphase bass-treble tone control* (*Ref.* 56).

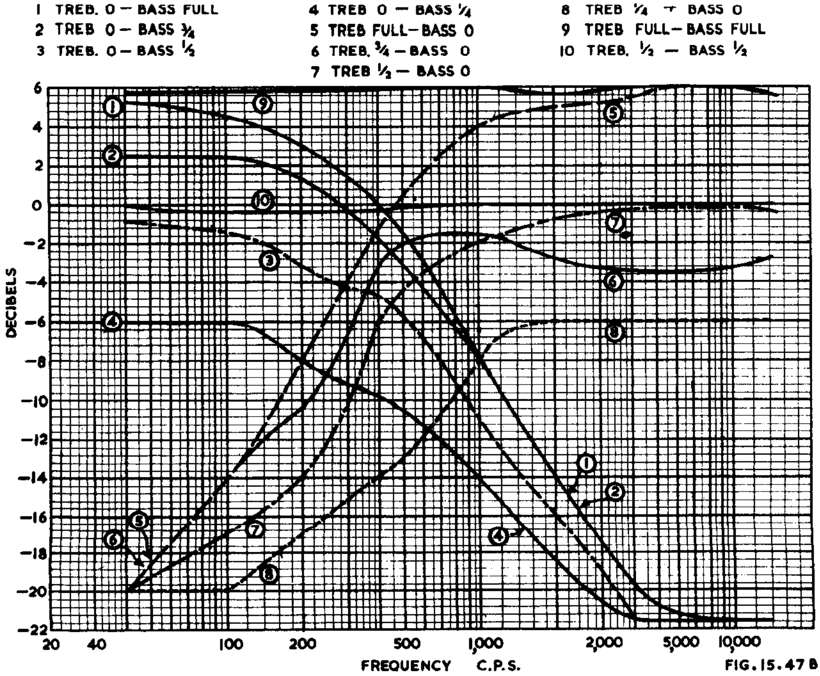


Fig. 15.47B. *Frequency characteristics of paraphase bass-treble tone control* (*Fig.* 15.47A) (*Ref.* 56).

(E) Two-stage bass and treble tone control (Fig. 15.48, Ref. 41)

This employs a twin triode with the treble boost control in the coupling from V_1 to V_2 and the bass boost control in the coupling from the plate of V_2 to the following stage.

(F) Simple two channel amplifier (Fig. 15.49, Ref. 22)

Owing to the separate amplifier valves, this circuit does not require the series resistors R_5 and R_6 used in Fig. 15.44 and has thereby less attenuation in the filter network.

FIG. 15.48

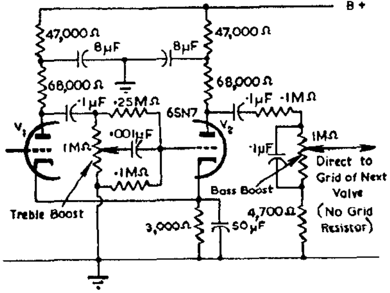


Fig. 15.48. *Two-stage bass and treble tone control* (*Ref.* 41).

FIG. 15.49

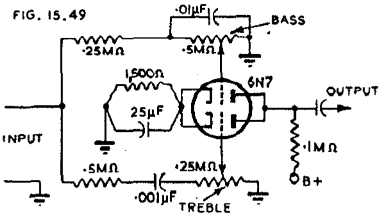


Fig. 15.49. *Simple two channel amplifier* (*Ref.* 22).

(G) Wide-range two-channel amplifier (Fig. 15.50, Ref. 31)

In this circuit V_1 is an amplifying valve common to both channels, V_2 is a bass amplifier only, while V_3 is a twin triode having one grid fed from the bass amplifier and the other from V_1 through a filter network which only passes the higher frequencies. However two plates of V_3 are approximately equal in amplitude for all frequencies, owing to the common cathode coupling, and opposite in phase, so that the output may be applied directly to a push-pull power output stage. The bass amplifier V_2 is a true bass booster, so that it is not necessary to attenuate all except bass frequencies. The two controls provide (1) flat response (2) independent treble boost (3) independent bass boost equal to the gain of V_2. If it is desired to add treble attenuation, the filter circuit of Fig. 15.51 may be used. This gives a flat response when the moving arm of the potentiometer is at the centre tap.

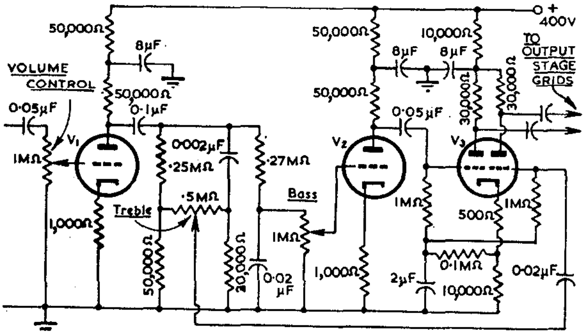


FIG. 15.50

Fig. 15.50. *Wide-range two-channel amplifier* (*Ref.* 31).

(H) Resonant plate loading (Fig. 15.52, Refs. 26, 54)

Two parallel tuned circuits, one of which may be tuned to 50-80 c/s and the other to 6000-8000 c/s (or any other desired frequencies) are connected in series with the

FIG. 15.51

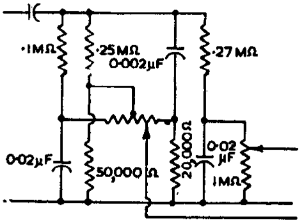


FIG. 15.52

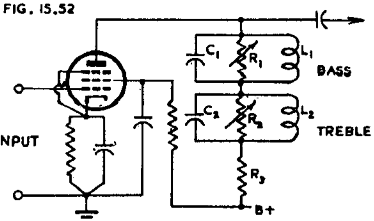


Fig. 15.51. *Modification to Fig.* 15.50 *to provide treble attenuation* (*Ref.* 31).
Fig. 15.52. *Resonant plate loading to provide bass and treble boost* (*Refs.* 26, 54).

plate load resistance R_3. Control of the bass is given by R_1 and of the treble by R_2. The Q of each of these circuits should not exceed 1—see Sect. 1(ix).

(I) Negative feedback incorporating *L* and *C* in cathode circuit (Fig. 15.53, Ref. 26)

Feedback provides degeneration across R_1 and R_2, which determines the gain at middle frequencies. With L and C connected directly across R_1 and R_2, the feedback is decreased at low and high frequencies respectively and the stage gain is consequently greater at these frequencies. L may require shielding to reduce hum pickup.

FIG. 15.54

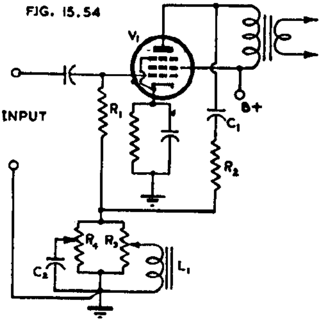


FIG. 15.53

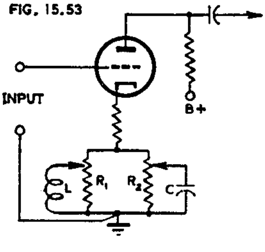


Fig. 15.53. *Bass and treble boosting due to negative feedback incorporating L and C in cathode circuit* (*Ref.* 26).
Fig. 15.54. *Bass and treble boosting due to negative feedbaok incorporating L and C* (*Ref.* 15).

(J) Negative feedback incorporating *L* and *C* (Fig. 15.54, Ref. 15)

V_1 is a power amplifier valve with L_1 and C_2 and their control potentiometers in the feedback network. L_1 may have an inductance of about 10 henrys and C_2 may be 0.002 μF ; $R_3 = R_4$ may be 0.1 megohm.

(K) Patchett tone control (Fig. 15.55, Ref. 9)

This circuit has been developed to provide continuously-variable independent bass and treble boost without variation of the middle frequencies and at the same time with frequency characteristics which are close to the ideal for tone control purposes. V_1 is a phase splitter and develops equal voltages across its plate and cathode load resistances. The former feeds directly through an isolating resistor to the output ; the latter feeds the bass and treble filters and potentiometers which in turn feed the grids of the twin triode V_2 whose plates are connected to the output. The output voltage at middle frequencies is about one third of the input voltage. An input of 2.5 volts r.m.s. may be applied with negligible distortion. V_1 may be type 6C5 or 6J5 ; V_2 may be type 6N7 or other twin triode.

FIG. 15.55

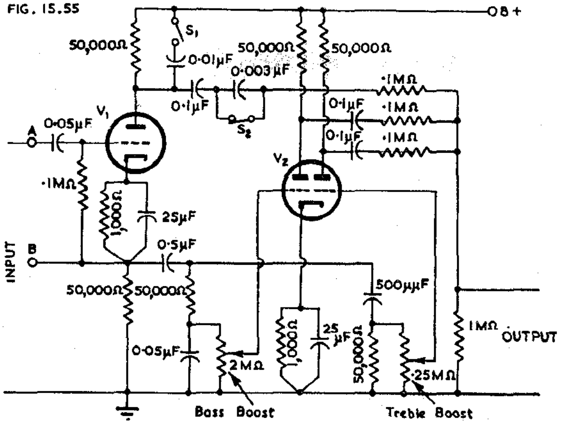


Fig. 15.55. *Patchett tone control circuit* (*Ref.* 9).

FIG. 15.56A

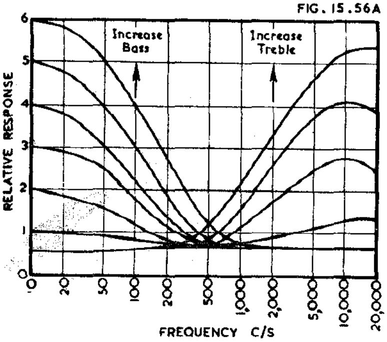


FIG. 15.56B

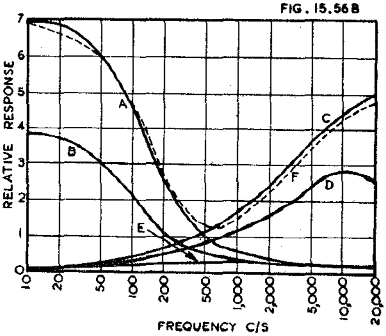


Fig. 15.56A. *Response characteristics of Patchett tone control circuit with* S_1 *open and* S_2 *closed, and other control at minimum* (*Ref.* 9).

Fig. 15.56B. *Response characteristics of Patchett tone control circuit with* S_1 *closed and* S_2 *open* (*Ref.* 9).

Curve A Max. bass, min. treble	*Curve D Min. bass, ½ max. treble*
,, *B ½ Max. bass, min. treble*	,, *E Min. bass, min. treble*
,, *C Min. bass, max. treble*	,, *F Max. bass, max. treble*

Fig. 15.56A shows the response characteristics without provision for bass or treble attenuation ; Fig. 15.56B shows the response with bass and treble attenuation.

If desired, step switches may be arranged to give a wider choice of frequency characteristics by changing the values of the filter condensers.

(L) Two-stage universal tone control (Fig. 15.57A, Ref. 77)

This is a very effective arrangement incorporating a twin triode, which gives entirely independent control of both bass and treble with control extending over a wide range of boosting and attenuation in each case (Fig. 15.57B). The overall gain of the amplifier of Fig. 15.57A at 800 c/s is only slight.

FIG. 15.57A

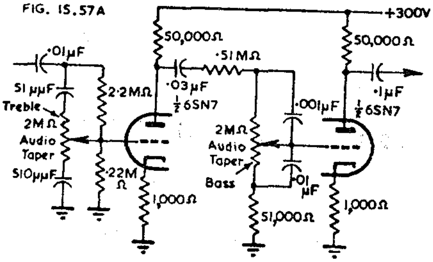


Fig. 15.57A. *Two stage universal tone control* (*Ref.* 77).

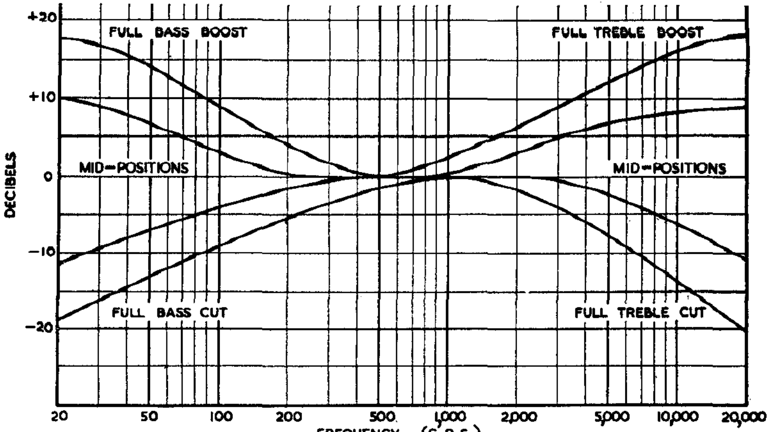


FIG. 15.57B

Fig. 15.57B. *Response characteristics of Fig.* 15.57A (*Ref.* 77).

SECTION 9 : FEEDBACK TO PROVIDE TONE CONTROL

(*i*) *Introduction* (*ii*) *Amplifiers with feedback providing tone control* (*iii*) *Whistle filters using feedback.*

(i) Introduction

Simple feedback circuits to give tone control have been described above (Figs. 15.11, 13, 14A, 14B, 15, 35B). See also Ref. 80. Tone control may be achieved by incorporating a suitable frequency selective network in the feedback loop, but this involves the question of stability if the feedback is over 2 or more stages—in this case the design should be based on Chapter 7 Sect. 3.

The general principles have been covered very fully in the literature e.g. Refs. 16, 19 (see also References Chapter 7).

In any amplifier in which negative feedback tone control is to be used, maximum freedom in other aspects of the design is desirable. For example it should be possible to alter the feedback factor, and a variation in the feedback over the a-f range should be acceptable. It is also desirable not to be limited to a specified value of output resistance. The feedback should preferably be applied over a small number of stages.

In the case of fidelity amplifiers, there should be sufficient negative feedback at the bass resonant frequency of the loudspeaker to give adequate damping.

Most tone-control amplifiers are only stable for values of β up to a limiting value. One good experimental test is to determine the maximum of β before instability occurs. The working value of β should be less than this limiting value by a comfortable margin (say 8 to 10 db) to allow for all variable factors and for tolerances in the various components.

(ii) Amplifiers with feedback providing tone control

(A) Dual Control continuously variable bass and treble tone control

A simple but effective circuit is shown in Fig. 15.57C and its frequency characteristics in Fig. 15.57D (Ref. 91). Figs. 15.57C and 15.57D will be found on page 1483. The mid-frequency gain is approximately unity, and the output is 4 V r.m.s. (or 1 V r.m.s. with low gain valve) with not more than 0.1% total harmonic distortion up to 5000 c/s. An Americanized form is given in Ref. 98.

A more elaborate circuit is given in Ref. 84.

(B) Dual control step-type bass and treble tone control

Fig. 15.58A (Ref. 42).

This is an example of a well designed amplifier with feedback taken from the secondary of the output transformer over three amplifying stages, having *RC* networks in the feedback loop to provide bass and/or treble boosting. V_1 is a Schmitt type phase inverter—Chapter 12 Sect. 6(vi)A—V_2 is a similar stage but operating with push-pull input, V_3 and V_4 are push-pull beam power amplifiers. The total voltage gain from the first grid to push-pull output load is 87.7 dbvg, giving full output with a peak input to the first grid of 17 mV without feedback or 0.14 V with feedback ($\beta = -0.0066$). The maximum bass boost is 26 db, and treble boost 11.7 db. The treble boost operates at a low impedance level where the effect of stray capacitances is negligible, while the bass boost, which is less sensitive in this respect, operates at a high impedance level.

V_1 and V_2 are type ECC32 (approx. 6N7) while V_3 and V_4 are type KT61 (high slope output tetrode). T_1 is a miniature screened line-to-grid transformer to match 25-600 ohms on input. T_2 is an output transformer with 22 : 1 turns ratio to match 10 000 ohms plate-to-plate to 20 ohms voice coil. Total primary inductance not less than 60 henrys.

(C) Modified " straight " feedback amplifier to provide bass boosting

In many cases a " straight " feedback amplifier may have a capacitive impedance added to the feedback loop to provide bass boosting. This decreases the feedback at bass frequencies, thereby causing the amplifier to lose some of the advantages of feedback ; the arrangement is less desirable than a special circuit such as Fig. 15.58A which has been specially designed for tone control.

For example, a capacitor of 0.1 μF may be inserted in series with the 5000 ohm resistor in the feedback circuit in Fig. 7.44 (as in Ref. 69) ; alternatively a switch giving a choice of several values of capacitance may be used.

FIG. 15.58A

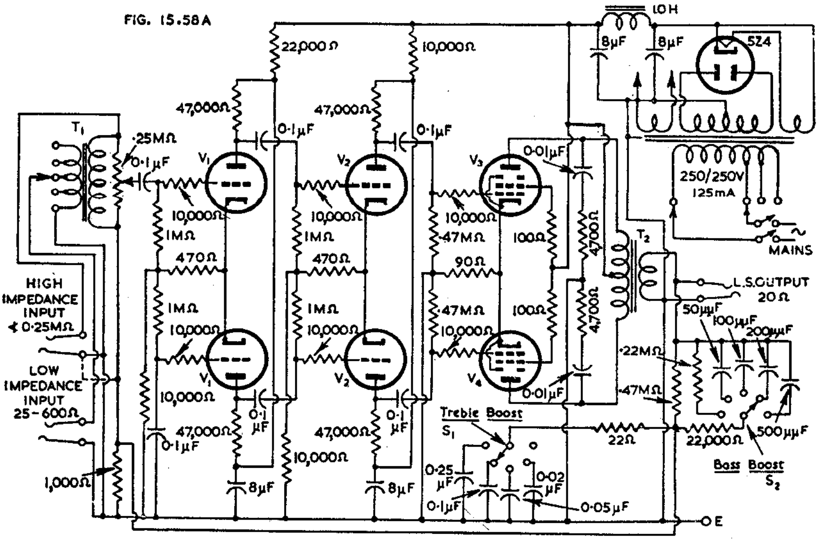


Fig. 15.58A. High gain amplifier with overall feedback giving bass and treble boosting (Ref. 42).

(D) The use of feedback to provide special attenuation characteristics at low or high frequencies

If an amplifier is designed with a falling low frequency characteristic, possibly due (in part) to economy in the output transformer design, and negative feedback is applied over the amplifier, its response can readily be made flat or, owing to a phase shift caused by coupling capacitors and by the inductance of the output transformer, the response may rise at those frequencies where it fell without feedback.

If in such an amplifier one of the grid coupling capacitors (included in portion of the amplifier covered by the feedback loop) is replaced by one of smaller capacitance, the feedback will tend to counteract the attenuation produced by this capacitor. The response will be more or less flat down to a certain frequency below which the attenuation will be rapid.

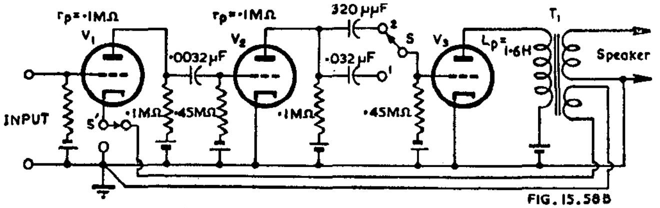


FIG. 15.58B

Fig. 15.58B. *Use of feedback to provide special attenuation characteristics at low frequencies. The total effective resistance across T_1 primary is taken as* 1000 *ohms. Switch S_1 normal ; S_2 tone control (low frequency attenuation). Switch S′ controls feedback.*

Some practical response characteristics are described below, based on a theoretical analysis of Fig. 15.58B (after E. Watkinson) :

(a) **To provide rapid low frequency attenuation below a specified frequency** f_0 (Curves are in Fig. 15.58C)

1. Design the amplifier so that the response without feedback and without tone control is only slightly down at f_0, say − 6 db (100 c/s in Curve *A*).

2. Design the tone control to provide a total attenuation, without feedback, of about 3 db at 10 f_0 (Curve *D*).

3. Apply sufficient negative feedback to flatten the response over the desired frequency range (Curve *C*). In the example, 20 db of feedback is used, and the combined effect is to give an attenuation of 18 db in the octave from 100 to 50 c/s.

(b) To provide optional bass boosting

If now the tone control is switched out of circuit, there will be bass boosting as the result of phase shift in the amplifier (Curve *B*).

Thus by a single switch *S* it is possible to change from curve *C* to curve *B*, using only one additional component.

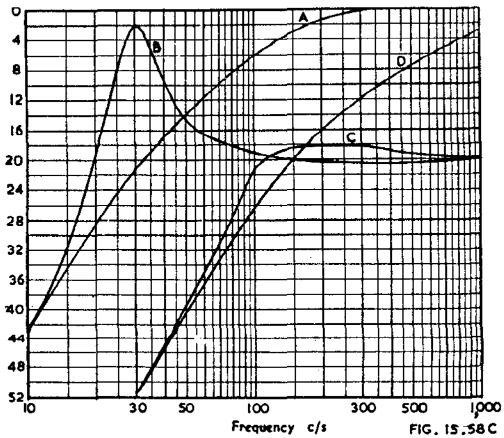


FIG. 15.58C

Fig. 15.58C. *Frequency characteristics of circuit of Fig.* 15.58B. (*A*) *No feedback, no tone control*; (*B*) *feedback without tone control*; (*C*) *feedback with tone control*; (*D*) *no feedback, with tone control.*

(c) To provide high frequency attenuation or boosting

The same principles apply to the high frequency end of the range.

(iii) Whistle filters using feedback

See Figs. 17.24A and 17.24B incorporating a parallel-T network and feedback—also Section 11(iv) of this chapter.

SECTION 10: AUTOMATIC FREQUENCY-COMPENSATED VOLUME CONTROL

(i) Introduction (ii) Methods incorporating a tapped potentiometer (iii) Methods incorporating step-type controls (iv) Method incorporating inverse volume expansion with multi-channel amplifier.

(i) Introduction

Owing to the special characteristics of the human ear, it is necessary for bass boosting and (to a less extent) treble boosting to be applied to music or speech when reproduced at a lower level than the original sound, if it is desired to retain the full tonal qualities of the original. Provision is therefore often made in the better quality receivers and amplifiers for this to be done automatically as the volume control is adjusted. For this to be fully effective, the volume with the volume control at its maximum setting should be the same as that of the original sound—a condition which it is rarely possible to fulfil in radio reception. One possible way of achieving an approach to the true condition would be to fit two auxiliary volume controls—one with settings for say (1) speech (2) orchestral and (3) solo instrument, and the other to be adjusted to bring the reading on some form of level indicator to a predetermined value. The first of these auxiliary controls is necessary because the various original sounds differ in level, the second control to provide for imperfect a.v.c. in the receiver and variations in percentage modulation between stations. These complications are not likely to be popular. However the intelligent listener should have a second volume control which may be pre-set to give a desired output level for maximum volume—this is particularly important in reproduction from records.

In practice, some form of automatic frequency-compensated volume control is found beneficial, in spite of its technical imperfections. One reason for this popularity is that it permits a considerable degree of bass boosting to be used at low volume but not at maximum volume-control setting. It is therefore more fool-proof than manually-operated bass boosting, and less likely to cause overloading of the power amplifier.

(ii) Methods incorporating a tapped potentiometer

A typical application is Fig. 15.59 in which L and C form a series resonant circuit tuned to about 1000 c/s, while R is a limiting resistance to reduce the by-passing at middle frequencies. The tapping point is usually about one fifth of the total resistance, being equivalent to about 14 db below maximum. With this method it is impossible to obtain theoretically correct compensation.

If treble boosting is not desired, L may be omitted leaving C and R to provide bass boosting.

References 71, 72, 89.

FIG. 15.59

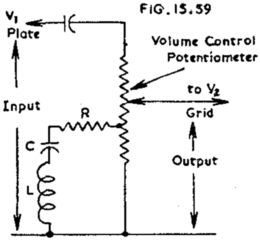


Fig. 15.59. Tone-compensated volume control with tapped potentiometer.

A more satisfactory result over a wider range of volume levels can be obtained by using a volume control with two tappings (e.g. at one sixth and one third of the resistance) as in Ref. 88.

A more elaborate type of continuously-variable control has been described (Ref. 79) but requires a special volume control.

Another more elaborate type (Ref. 82) uses three ganged volume controls which are not tapped.

FIG. 15.60

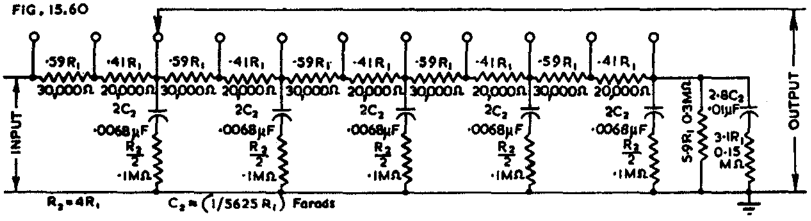


Fig. 15.60. *Step-type tone-compensated volume control for bass correction only (Ref.* 43).

(iii) Methods incorporating step-type controls

All the simpler systems with step-type controls neglect the treble boosting, which is only of secondary importance, but they are capable of a fairly close approach to the ideal for the lower frequencies. One design is shown in Fig. 15.60 (Ref. 43) which uses five 6 db filter sections each divided into two parts, thus giving 11 steps with a total range of 30 db. This is for use with an amplifier having low output resistance (less than 10 000 ohms). The numerical values shown in the figure are for $R_1 =$ 50 000 ohms.

See also Ref. 78 for a design mounted on a single switch assembly, with a greater number of positions.

(iv) Method incorporating inverse volume expansion with multi-channel amplifier (Ref. 21)

In Fig. 15.61 there are three amplifier channels. The centre one is essentially flat over the whole a-f range. The upper (high-pass) and lower (low-pass) amplifiers may be adjusted to give zero output at any selected output level (generally the maximum) and at any lower level there will be bass and treble boosting which is a function of the output level. Each of the boosting amplifiers is brought to zero output at the desired output level by adjusting three potentiometers (R_1, R_2, R_3 in the bass-boost amplifier). Under these conditions the output voltages of V_7 and V_8 are equal but opposite in phase, hence giving a combined output which is zero.

SECTION 11 : WHISTLE FILTERS

(*i*) *Resonant circuit filters* (*ii*) *Narrow band rejection filter* (*iii*) *Crystal filters* (*iv*) *Parallel-T network* (*v*) *Filters incorporating L and C.*

A whistle filter is one which is sharply tuned to eliminate a particular frequency, usually 9 or 10 Kc/s, with the least possible effect on adjacent frequencies.

The same principles may also be applied to the elimination of scratch from a pickup when this is peaked, but in this case the maximum attenuation is adjusted to occur at the frequency of pickup resonance.

(i) Resonant circuit filters (Ref. 15 62)

The ratio of normal gain (A_n) to gain (A_r) at the resonant frequency of L_1C_1 is

FIG. 15.61

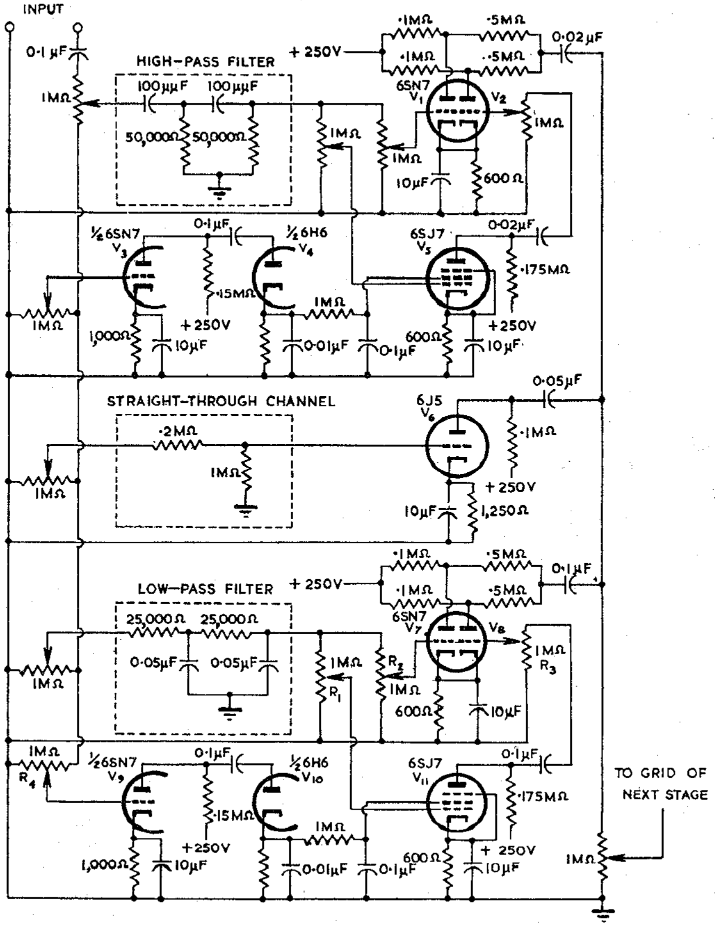


Fig. 15.61. *Inverse volume-expansion circuit with 3 channel amplifier for automatic frequency-compensated volume control* (*Ref.* 21).

given by

$$A_n/A_r = (R' + R_1)/R_1$$

where $R' = r_p R_L'/(r_p + R_L')$
and $R_L' = R_L R_g/(R_L + R_g)$.

For effective filtering, the maximum attenuation may have to be 20 db or more. The sharpness of the attenuation curve depends upon the Q of the tuned circuit, where $Q = \omega_r L_1/R_1$. A value of $Q = 10$ is probably the highest practicable value, and under these conditions the filter will have a minimum attenuation of 4 db over a bandwidth of 0.64 f_r or a minimum attenuation of 8 db over a bandwidth of 0.38 f_r where f_r is the frequency of resonance. This is equivalent to an attenuation of at

FIG. 15.62

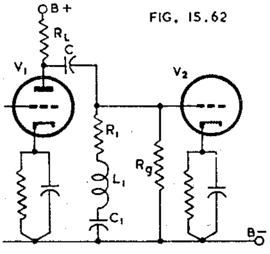


Fig. 15.62. *Whistle filter using resonant circuit.*

least 8 db over a frequency range from approximately 8000 to 12 000 c/s when f_r = 10 000 c/s. Thus the filter cuts such a serious hole in the amplifier frequency characteristics that it is not a satisfactory solution. It is reasonably satisfactory for a maximum attenuation of 6 db, but this may not be sufficient to eliminate the whistle.

For theory and curves see Refs. 17, 51, pp. 52-54.

(ii) Narrow band rejection filter

A more complicated and more effective circuit is Fig. 15.62A (Ref. 81) which, when tuned to 9000 c/s, gives an attenuation of 2 db at 8000 c/s, over 40 db at 9000 c/s, 8 db at 10 000 c/s and 5 db at 20 000 c/s relatively to the level at low frequencies. The frequency of resonance may be changed either by adjusting the inductance of L_1, or by varying the capacitance of both C_1 and C_2. The attenuation at low frequencies (insertion loss) is 2 db.

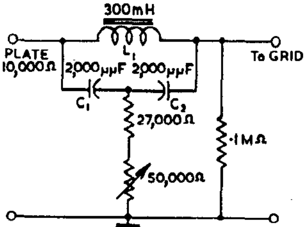


FIG. 15.62A

Fig. 15.62A. *Narrow-band rejection filter* (*Ref.* 81).

A narrow band rejection filter is described in Ref. 75 which has the disadvantage of reducing the maximum a-f power output. An improved form for application to a linear reflex detector is Fig. 15.63 in which an attenuation of more than 40 db is obtained at 9000 c/s while the attenuation is only 3 db at 8400 c/s. The principle may also be applied to a cathode-loaded amplifier by omitting C_1 and providing the correct bias for amplification.

The resonant circuit LC_3 is tuned approximately to the whistle frequency, a vernier control for C_3 being desirable. The value of C_1 should be such that its reactance is very much smaller than R_1 at the lowest signal frequency and should be very much larger than R_1 at 9000 c/s. The value of C_2 should be such that its reactance is approximately equal to $R_2 + R_3$ at the low frequency limit of the amplifier, say 50 c/s. If its reactance is higher, a slight amount of bass boosting will occur. The potentiometer R_2R_3 is adjusted to give zero output at the whistle frequency (Ref. 74).

An elaboration of this principle, using two valves, is given in Ref. 83.

FIG. 15.63

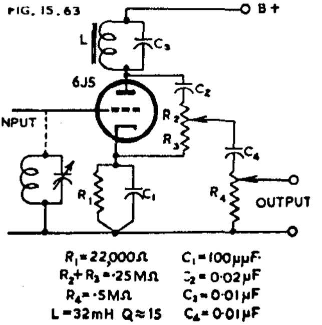


Fig. 15.63. *Narrow-band rejection filter for* 9 *Kc/s* (*Ref.* 74).

(iii) Crystal filters

A crystal filter is one of the few really satisfactory methods of eliminating a whistle, but the cost precludes its use in all except the most expensive communication receivers.

(iv) Parallel-T network

See also Sect. 6(iii)C.

The circuit of Fig. 4.40 may be inserted between two r.c.c. stages with a load resistance of say 0.25 megohm and following grid resistor say 1 megohm. Suitable values for a 10 000 c/s whistle filter are :—$C_1 = C_2 = 0.0001\ \mu$F, $C_0 = 0.0002\ \mu$F, $R_1 = R_2 = 160\,000$ ohms, $R_0 = 80\,000$ ohms.

A special application of the parallel-T network is described in Chapter 17 Sect. 5 and Figs. 17.24B and 24C where an attenuation of 34 db at 10 000 c/s with almost flat response up to 6 Kc/s is obtained by means of a parallel-T feedback loop which gives minimum feedback at 6 Kc/s, together with a parallel-T filter across the output of the amplifier to give the desired attenuation at 10 Kc/s (Ref. 57).

The parallel-T network is also used in the equalizer circuit of Fig. 17.35B and in the filter unit of Fig. 17.35C.

The frequency of maximum attenuation may be varied by varying one element in each of the component T's (see Ref. 85).

(v) Filters incorporating *L* and *C*

Constant *k* and M-derived filters may be used to attenuate a very narrow band of frequencies, but the cost precludes their general use.

SECTION 12 : OTHER METHODS OF TONE CONTROL

(*i*) *Multiple-channel amplifiers* (*ii*) *Synthetic bass.*

(i) Multiple-channel amplifiers

With a three-channel amplifier, or one having more than three channels, it is possible to exercise a certain amount of tone control by controlling the volume of the bass and treble amplifiers. For this to be satisfactory for tone control, the cross-over frequencies should be :

Bass—not higher than 200 c/s.
Treble—not lower than 3000 c/s.

In each case the cross-over network may produce an attenuation of 6 or 12 db/octave nominal.

An amplifier in this class is described in Ref. 5. See also Sect. 10(iv) and Ref. 21.

(ii) Synthetic bass

In small receivers, in which the loudspeaker is incapable of reproducing the bass at all adequately, a device is sometimes used to introduce distortion of the bass frequencies. The fundamental bass frequency is heavily attenuated to avoid overloading, but the harmonics are reproduced and provide " synthetic bass." One such circuit is Fig. 15.64 (Ref. 73, based on Sonora Model RCU-208). Positive feedback at low frequencies is applied from the cathode of the second valve to the cathode of the first by means of the network R_3, R_2, R_1 and C_1.

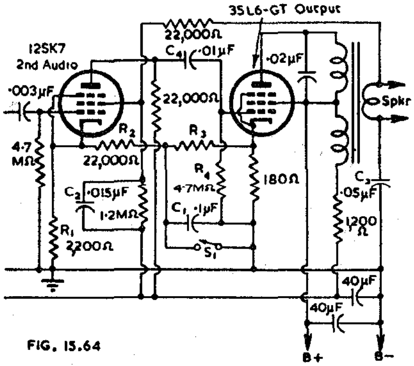


FIG. 15.64

Fig. 15.64. *Amplifier providing synthetic bass* (*Ref.* 73).

Another circuit (Ref. 87) has a supplementary channel with a distorting valve (triode 6SF5) functioning effectively only below about 100 c/s. Grid distortion is produced through zero bias operation. A plate load resistor of 0.5 MΩ is used, and the plate coupled to the grid of the output pentode. It is stated that the loudspeaker bass resonance should preferably be less than 60 c/s, and that the results sound unnatural to the ear on music when the loudspeaker resonance is about 150 c/s.

The principles of synthetic bass are given in Chapter 14 Sect. 3(viii).

SECTION 13 : THE LISTENER AND TONE CONTROL

Tone control is a controversial subject with very strong conflicting views held by many competent authorities. It is the author's opinion that, in view of the differences of opinion, it is only reasonable to provide the listener with some degree of tone control to permit him to derive the maximum degree of satisfaction while listening. This freedom of choice should not be unlimited, otherwise some listeners will become lost in the possible variations.

1. The cheapest type of set will probably be fitted with a fixed shunt capacitance tone control.
2. Sets which are somewhat higher-priced will be fitted with a single control. This may cover any one of the following :
    - (a) Variable resistance and fixed shunt capacitance (this has obvious shortcomings).
    - (b) Bass boosting only (this is quite satisfactory in its class provided that the bass boosting is limited to about 6 db total).
    - (c) Continuously-variable control giving, say, bass boosting in one direction and treble boosting in the other.
    - (d) Step-type control in the form of a " quality switch."
3. The most elaborate radio receivers and amplifiers may be fitted with two controls, one for bass and the other for treble. In addition, many equipments in this class will be fitted with automatic frequency-compensated volume control, thereby limiting the degree of manual bass boosting which is necessary (say 6 db maximum).

Anything which can be done to assist the listener to obtain the best results with the least trouble is to be commended.

SECTION 14 : EQUALIZER NETWORKS

Equalizer networks for pickups are covered in Chapter 17 Sect. 5 while those for microphones are covered in Chapter 18 Sect. 1(xii).

An example of a universal equalizer is given in Ref. 49

A helpful general article on design is Ref. 92. See also Ref. 102.

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Additional references will be found in the Supplement commencing on page 1475.