

FIGURE 2.14.10 Fletcher-Munson Curves (USA). (Courtesy, Acoustical Society of America)

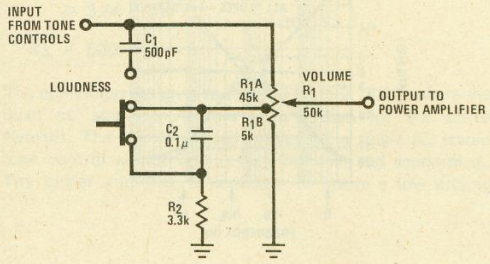


FIGURE 2.14.11 Loudness Control

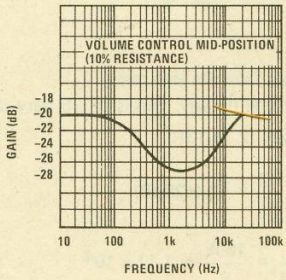


FIGURE 2.14.12 Loudness Control Frequency Response

The most common active tone control circuit is the so-called "Americanized" version of the Baxandall (1952)[2] negative feedback tone controls. A complete bass and treble active tone control circuit is given in Figure 2.14.13a. At very low frequencies the impedance of the capacitors is large enough that they may be considered open circuits, and the gain is controlled by the bass pot, being equal to Equations (2.14.13) and (2.14.14) at the extreme ends of travel.

$$A_{VB} = \frac{R_1 + R_2}{R_1} \quad \text{(max bass boost)} \qquad (2.14.13)$$

$$\frac{1}{A_{VB}} = \frac{R_1}{R_1 + R_2} \quad \text{(max bass cut)} \qquad (2.14.14)$$

At very high frequencies the impedance of the capacitors is small enough that they may be considered short circuits, and the gain is controlled by the treble pot, being equal to Equations (2.14.15) and (2.14.16) at the extreme ends of travel.

$$A_{VT} = \frac{R_3 + R_1 + 2R_5}{R_3} \quad \text{(max treble boost)} \qquad (2.14.15)$$

$$\frac{1}{A_{VT}} = \frac{R_3}{R_3 + R_1 + 2R_5} \quad \text{(max treble cut)} \qquad (2.14.16)$$

Equations (2.14.15) and (2.14.16) are best understood by recognizing that the bass circuit at high frequencies forms a wye-connected load across the treble circuit. By doing a wye-delta transformation (see Appendix A3), the effective loading resistor is found to be $(R_1 + 2R_5)$ which is in parallel with $(R_3 + R_4)$ and dominates the expression. (See Figure 2.14.13b.) This defines a constraint upon R_4 which is expressed as Equation (2.14.17).

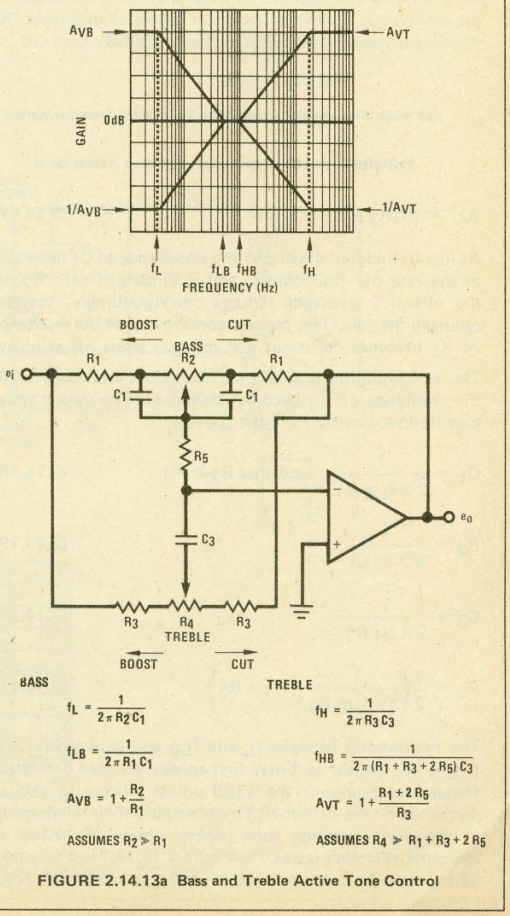
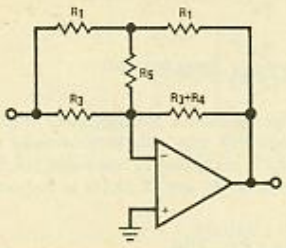
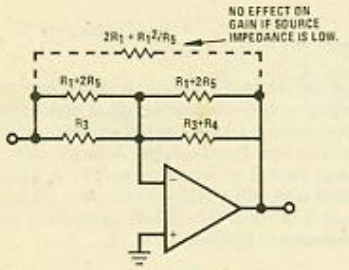


FIGURE 2.14.13a Bass and Treble Active Tone Control



(a) High Frequency Max Treble Boost Equivalent Circuit



$$A_V = \frac{(R_1 + 2R_5)(R_3 + R_4)}{(R_1 + 2R_5)R_3} \approx \frac{R_3 + R_1 + 2R_5}{R_3}$$

IF $R_4 \geq R_1 + R_3 + 2R_5$

(b) High Frequency Circuit After Wye-Delta Transformation

FIGURE 2.14.13b Development of Max Treble Gain

$$R_4 \geq 10(R_3 + R_1 + 2R_5) \qquad (2.14.17)$$

At low-to-middle frequencies the impedance of C_1 decreases at the rate of –6dB/octave, and is in parallel with R_2, so the effective resistance reduces correspondingly, thereby reducing the gain. This process continues until the resistance of R_1 becomes dominant and the gain levels off at unity.

The action of the treble circuit is similar and stops when the resistance of R_3 becomes dominant. The design equations follow directly from the above.

$$C_1 = \frac{1}{2\pi f_{LB} R_1} \quad \text{assumes } R_2 \gg R_1 \qquad (2.14.18)$$

$$R_2 = \frac{1}{2\pi f_L C_1} \qquad (2.14.19)$$

$$C_3 = \frac{1}{2\pi f_H R_3} \qquad (2.14.20)$$

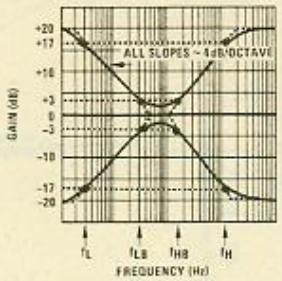
$$R_5 = \frac{1}{2}\left(\frac{1}{2\pi f_{HB} C_3} - R_1 - R_3\right) \qquad (2.14.21)$$

The relationship between f_L and f_{LB} and between f_H and f_{HB} is not as clear as it may first appear. As used here these frequencies represent the ±3dB points relative to gain at midband and the extremes. To understand their relationship in the most common tone control design of ±20dB at extremes, reference is made to Figure 2.14.14. Here it is seen what shape the frequency response will actually have. Note that the flat (or midband) gain is not unity but approximately ±2dB. This is due to the close proximity of the poles and zeros of the transfer function. Another effect of this close proximity is that the slopes of the curves are not the expected ±6dB/octave, but actually are closer to ±4dB/octave. Knowing that f_L and f_{LB} are 14dB apart in magnitude, and the slope of the response is 4dB/octave, it is possible to relate the two. This relationship is given as Equation (2.14.22).

$$\frac{f_{LB}}{f_L} = \frac{f_H}{f_{HB}} \approx 10 \qquad (2.14.22)$$

Example 2.14.2

Design a bass and treble active tone control circuit having ±20dB gain with low frequency upper 3dB corner at 30Hz and high frequency upper 3dB corner at 10kHz.



$$\frac{f_{LB}}{f_L} = \frac{f_H}{f_{HB}} = 10$$

FIGURE 2.14.14 Relationship Between Frequency Breakpoints of Active Tone Control Circuit

Solution

BASS DESIGN:

1. Select R_2 = 100k (linear). This is an arbitrary choice.
2. From Equation (2.14.13):

$$A_{VB} = 1 + \frac{R_2}{R_1} = 10\ (+20\text{dB})$$

$$R_1 = \frac{R_2}{10 - 1} = \frac{100k}{9} = 1.11 \times 10^4$$

$$R_1 = 11k$$

3. Given f_L = 30Hz and from Equations (2.14.22) and (2.14.18):

$$f_{LB} = 10 f_L = 300\text{Hz}$$

$$C_1 = \frac{1}{2\pi f_{LB} R_1} = \frac{1}{(2\pi)(300)(11k)} = 4.82 \times 10^{-8}$$

$$C_1 = 0.05\mu F$$

TREBLE DESIGN:

4. Let $R_5 = R_1$ = 11k. This also is an arbitrary choice.

5. From Equation (2.14.15):

$$A_{VT} = 1 + \frac{R_1 + 2R_5}{R_3} = 10 \ (+20\text{dB})$$

$$R_3 = \frac{R_1 + 2R_5}{10 - 1} = \frac{11k + 2(11k)}{9} = 3.67 \times 10^3$$

$$R_3 = 3.6k$$

6. Given $f_H = 10\text{kHz}$ and from Equation (2.14.20):

$$C_3 = \frac{1}{2\pi f_H R_3} = \frac{1}{(2\pi)(10\text{kHz})(3.6k)} = 4.42 \times 10^{-9}$$

$$C_3 = 0.005\mu F$$

7. From Equation (2.14.17):

$$R_4 \geqslant 10(R_3 + R_1 + 2R_5)$$

$$\geqslant 10(3.6k + 11k + 22k)$$

$$\geqslant 3.66 \times 10^5$$

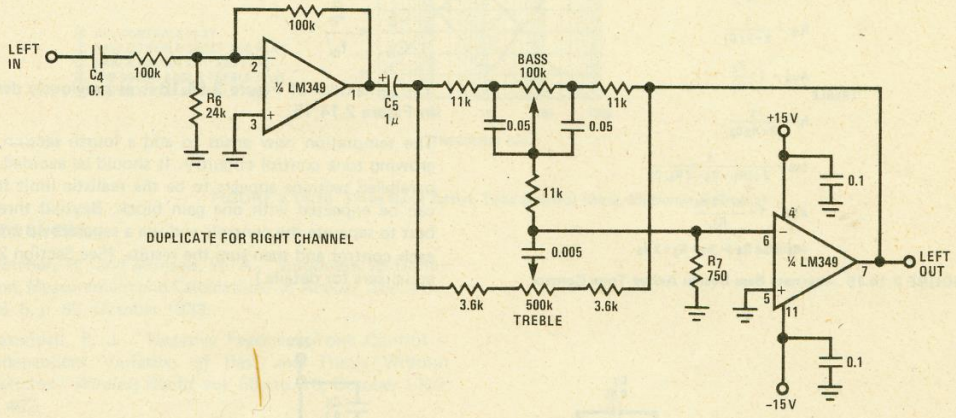
$$R_4 = 500k$$

The completed design is shown in Figure 2.14.15, where the quad op amp LM349 has been chosen for the active element. The use of a quad makes for a single IC, stereo tone control circuit that is very compact and economical. The buffer amplifier is necessary to insure a low driving impedance for the tone control circuit and creates a high input impedance (100kΩ) for the source. The LM349 was chosen for its fast slew rate (2.5V/μs), allowing undistorted, full-swing performance out to > 25kHz. Measured THD was typically 0.05% @ 0dBm (0.77V) across the audio band. Resistors R_6 and R_7 were added to insure stability at unity gain since the LM349 is internally compensated for positive gains of five or greater. R_6 and R_7 act as input voltage dividers at high frequencies such that the actual input-to-output gain is never less than five (four if used inverting). Coupling capacitors C_4 and C_6 serve to block DC and establish low-frequency roll-off of the system; they may be omitted for direct-coupled designs.

2.14.8 Alternate Active Bass Control

Figure 2.14.16 shows an alternate design for bass control, offering the advantage of one less capacitor while retaining identical performance to that shown in Figure 2.14.13. The development of Figure 2.14.16 follows immediately from Figure 2.14.13 once it is recognized that at the extreme wiper positions one of the C_1 capacitors is shorted out and the other bridges R_2.

The modifications necessary for application with the LM387 are shown in Figure 2.14.17 for a supply voltage of 24V. Resistors R_4 and R_5 are added to supply negative input bias as discussed in Section 2.8. The feedback coupling capacitor C_0 is necessary to block DC voltages from being fed back into the tone control circuitry and upsetting the DC bias, also to insure quiet pot operation since there are no DC level changes occurring across the capacitors, which



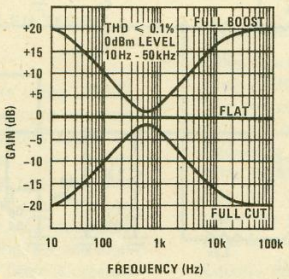


FIGURE 2.14.15 Typical Active Bass & Treble Tone Control with Buffer

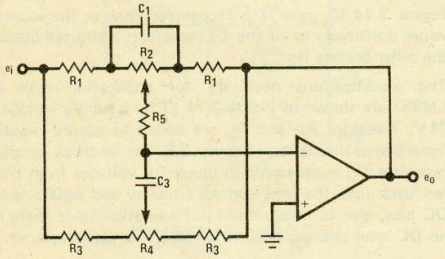
would cause "scratchiness." The R_7-C_3 network creates the input attenuation at high frequencies for stability.

For other supply voltages R_4 is recalculated as before, leaving R_5 equal to 240kΩ. It is not necessary to change R_7 since its value is dictated by the high frequency equivalent impedance seen by the inverting input (equals 33kΩ).

2.14.9 Midrange Control

The addition of a midrange control which acts to boost or cut the midrange frequencies in a manner similar to the bass and treble controls offers greater flexibility in tone control.

The midrange control circuitry appears in Figure 2.14.18. It is seen that the control is a merging together of the bass and treble controls, incorporating the bass bridging capacitor and the treble slider capacitor to form a combined network. If the bass control is, in fact, a low pass filter, and the treble control a high pass filter, then the midrange is a combination of both, i.e., a bandpass filter.



BASS

$$f_L = \frac{1}{2\pi R_2 C_1}$$

$$f_{LB} = \frac{1}{2\pi R_1 C_1}$$

$$A_{VB} = 1 + \frac{R_2}{R_1}$$

TREBLE

$$f_H = \frac{1}{2\pi R_3 C_3}$$

$$f_{HB} = \frac{1}{2\pi (R_1 + R_3 + 2R_5) C_3}$$

$$A_{VT} = 1 + \frac{R_1 + 2R_5}{R_3}$$

ASSUMES $R_4 \gg R_1 + R_3 + 2R_5$

FIGURE 2.14.16 Alternate Bass Design Active Tone Control

While the additional circuitry appears simple enough, the resultant mathematics and design equations are not. In the bass and treble design of Figure 2.14.13 it is possible to include the loading effects of the bass control upon the treble circuit, make some convenient design rules, and obtain useful equations. (The treble control offers negligible load to the bass circuit.) This is possible, primarily because the frequencies of interest are far enough apart so as not to interfere with one another. Such is not the case with the midrange included. Any two of the controls appreciably loads the third. The equations that result from a detailed analysis of Figure 2.14.18 become so complex that they are useless for design. So, as is true with much of real-world engineering, design is accomplished by empirical (i.e., trial-and-error) methods. The circuit of Figure 2.14.18 gives the performance shown by the frequency plot, and should be optimum for most applications. For those who feel a change is necessary, the following guidelines should make it easier.

1. To increase (or decrease) midrange gain, decrease (increase) R_6. This will also shift the midrange center frequency higher (lower). (This change has minimal effect upon bass and treble controls.)
2. To move the midrange center frequency (while preserving gain, and with negligible change in bass and treble performance), change both C_4 and C_5. Maintain the relationship that $C_5 \approx 5C_4$. Increasing (decreasing) C_5 will decrease (increase) the center frequency. The amount of shift is approximately equal to the inverse ratio of the new capacitor to the old one. For example, if the original capacitor is C_5 and the original center frequency is f_o, and the new capacitor is C_5' with the new frequency being f_o', then

$$\frac{C_5'}{C_5} \approx \frac{f_o}{f_o'}$$

The remainder of Figure 2.14.18 is as previously described in Figure 2.14.15.

The temptation now arises to add a fourth section to the growing tone control circuitry. It should be avoided. Three paralleled sections appears to be the realistic limit to what can be expected with one gain block. Beyond three, it is best to separate the controls and use a separate op amp with each control and then sum the results. (See Section 2.17 on equalizers for details.)

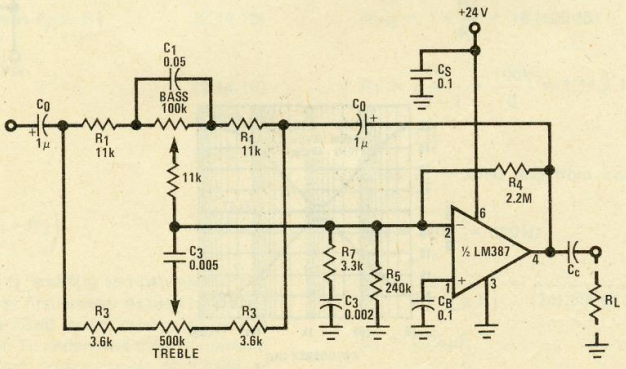
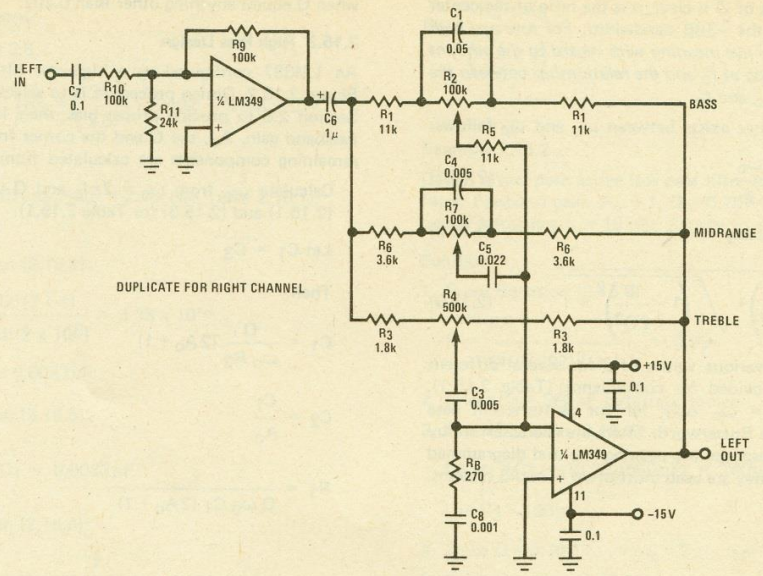


FIGURE 2.14.17 LM387 Feedback Tone Controls



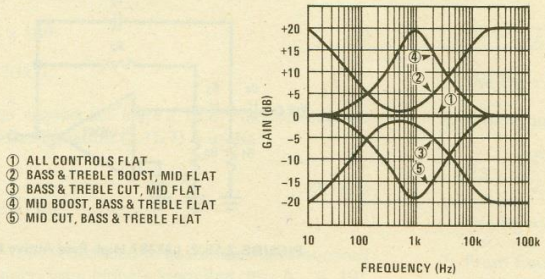


FIGURE 2.14.18 Three Band Active Tone Control (Bass, Midrange & Treble)

REFERENCES

1. Fletcher, H., and Munson, W. A., "Loudness, Its Definition, Measurement and Calculation," *J. Acoust. Soc. Am.*, vol. 5, p. 82, October 1933.
2. Baxandall, P. J., "Negative Feedback Tone Control – Independent Variation of Bass and Treble Without Switches," *Wireless World*, vol. 58, no. 10, October 1952, p. 402.

2.15 SCRATCH, RUMBLE AND SPEECH FILTERS

2.15.1 Introduction

Infinite-gain, multiple-feedback active filters using LM387 (or LM381) as the active element make simple low-cost audio filters. Two of the most popular filters found in audio equipment are SCRATCH (low pass), used to roll off excess high frequency noise appearing as hiss, ticks and pops from worn records, and RUMBLE (high pass), used to roll off low frequency noise associated with worn turntable and tape transport mechanisms. By combining low and high pass filter sections, a broadband bandpass filter is created such as that required to limit the audio bandwidth to include only speech frequencies (300 Hz-3 kHz)

2.15.2 Definition of ω_c and ω_o for 2-Pole Active Filters

When working with active filter equations, much confusion exists about the difference between the terms ω_o and ω_c. The center frequency, f_o, equals $\omega_o/2\pi$ and has meaning only for *bandpass* filters. The term ω_c and its associated frequency, f_c, is the cutoff frequency of a high or low pass filter defined as the point at which the magnitude of the response is –3dB from that of the passband (i.e., 0.707 times the passband value). Figure 2.15.1 illustrates the two cases for two-pole filters.

Equally confusing is the concept of "Q" in relation to high and low pass two-pole active filters. The design equations contain Q; therefore it must be determined before a filter