$$R_2 = \frac{Q}{(2Q^2 - A_o)\,\omega_o C_1} \qquad (2.16.3)$$

For checking and trimming, use the following:

$$A_o = \frac{R_3}{2R_1} \qquad (2.16.4)$$

$$f_o = \frac{1}{2\pi C_1}\sqrt{\frac{R_1 + R_2}{R_1 R_2 R_3}} \qquad (2.16.5)$$

$$Q = \frac{1}{2}\omega_o R_3 C_1 \qquad (2.16.6)$$

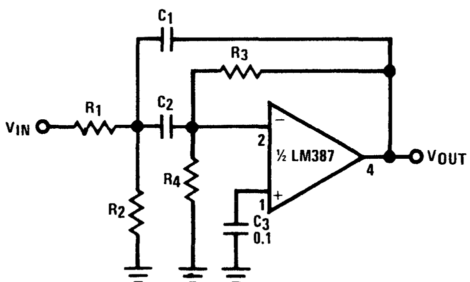

FIGURE 2.16.1 LM387 Bandpass Active Filter

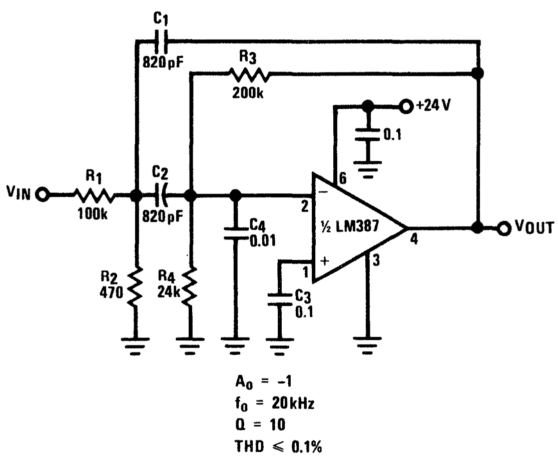

FIGURE 2.16.2 20kHz Bandpass Active Filter

Example 2.16.1

Design a two-pole active bandpass filter with a center frequency f_o = 20kHz, midband gain A_o = 1, and a bandwidth of 2000Hz. A single supply, V_s = 24V, is to be used.

Solution

1. $Q \triangleq \frac{f_o}{BW} = \frac{20\,kHz}{2000\,Hz} = 10, \quad \omega_o = 2\pi f_o$

2. Let $R_4 = 24\,k\Omega$.

3. $R_3 = \left(\frac{V_s}{2.6} - 1\right) R_4 = \left(\frac{24}{2.6} - 1\right) 24k = 1.98 \times 10^5$

   Use R_3 = 200k

4. From Equation (2.16.1):

   $$R_1 = \frac{R_3}{2A_o} = \frac{200k}{2} = 100k$$

   R_1 = 100k

5. Let $C_1 = C_2$; then, from Equation (2.16.2):

   $$C_1 = \frac{Q}{A_o \omega_o R_1} = \frac{10}{(1)(2\pi)(20k)(1 \times 10^5)} = 796\,pF$$

   Use C_1 = 820pF

6. From Equation (2.16.3):

   $$R_2 = \frac{Q}{(2Q^2 - A_o)\,\omega_o C_1}$$

   $$= \frac{10}{[(2)(10)^2 - 1]\,(2\pi)(20k)(820\,pF)} = 488\Omega$$

   Use $R_2 = 470\Omega$

The final design appears as Figure 2.16.2. Capacitor C_3 is used to AC ground the positive input and can be made equal to 0.1µF for all designs. Input shunting capacitor C_4 is included for stability since the design gain is less than 10.

2.17 OCTAVE EQUALIZER

An octave equalizer offers the user several bands of tone control, separated an octave apart in frequency with independent adjustment of each. It is designed to compensate for any unwanted amplitude-frequency or phase-frequency characteristics of an audio system.

The midrange tone control circuit described in Section 2.14 can be used separately to make a convenient ten band octave equalizer. Design equations result from a detailed analysis of Figure 2.17.1, where a typical section is shown. Resistors R_3 have been added to supply negative input DC bias currents, and to guarantee unity gain at low frequencies. This circuit is particularly suited for equalizer applications since it offers a unique combination of results depending upon the slider position of R_2. With R_2 in the flat position (i.e., centered) the circuit becomes an all-pass with unity gain; moving R_2 to full boost results in a bandpass characteristic, while positioning R_2 in full cut creates a band-reject (notch) filter.

Writing the transfer function for Figure 2.17.1 in its general form for max boost (assuming only $R_3 \gg R_1$) results in Equation (2.17.1).

$$\frac{e_o}{e_i} = -\frac{S^2 + \left[\frac{2R_1R_2C_1 + R_3(R_1 + R_2)C_2}{R_1R_2R_3C_1C_2}\right]S + \frac{2R_1 + R_2}{R_1R_2R_3C_1C_2}}{S^2 + \left[\frac{(R_1 + R_2)C_2 + 2R_2C_1 + R_3C_2}{R_2R_3C_1C_2}\right]S + \frac{2R_1 + R_2}{R_1R_2R_3C_1C_2}} \qquad (2.17.1)$$

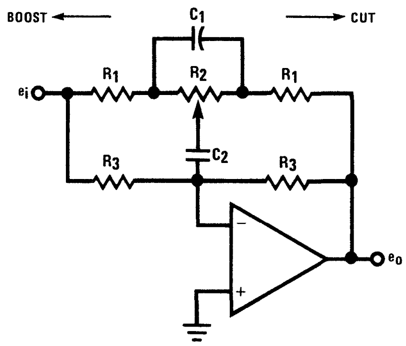

FIGURE 2.17.1 Typical Octave Equalizer Section

Equation (2.17.1) has the form of Equation (2.17.2):

$$\frac{e_o}{e_i} = -\frac{S^2 + K2\rho\,\omega_o S + \omega_o^2}{S^2 + 2\rho\,\omega_o S + \omega_o^2} \qquad (2.17.2)$$

where: $Q = \frac{1}{2\rho}$, A_o = gain @ f_o = K, $\omega_o = 2\pi f_o$

Equating coefficients yields Equations (2.17.3)-(2.17.5):

$$\omega_o = \sqrt{\frac{2R_1 + R_2}{R_1 R_2 R_3 C_1 C_2}} \qquad (2.17.3)$$

$$A_o = -\frac{2R_1R_2C_1 + R_3(R_1 + R_2)C_2}{2R_1R_2C_1 + R_1(R_2 + R_3)C_2} \qquad (2.17.4)$$

$$Q = \sqrt{\frac{2R_1 + R_2}{R_1R_2R_3C_1C_2}}\left(\frac{R_2R_3C_1C_2}{(R_1 + R_2)C_2 + 2R_2C_1 + R_3C_2}\right) \qquad (2.17.5)$$

In order to reduce these equations down to something useful, it is necessary to examine what is required of the finished equalizer in terms of performance. For normal home use, ±12dB of boost and cut is adequate, which means only a moderate amount of passband gain is necessary; and since the filters will be centered one octave apart in frequency a large Q is not necessary (Q = 1-2 works fine). What *is* desirable is for the passband ripple (when all filters are at maximum) to be less than 3dB.

Examination of Equation (2.17.5) in terms of optimizing the ratio of C_1 and C_2 in order to maximize Q shows a good choice is to let $C_1 = 10C_2$. A further design rule that is reasonable is to make $R_3 = 10R_2$, since R_3 is unnecessary for the filter section. Applying these rules to Equations (2.17.3)-(2.17.5) produces some useful results:

$$\omega_o = 2\pi f_o = \frac{1}{10R_2C_2}\sqrt{2 + \frac{R_2}{R_1}} \qquad (2.17.6)$$

$$A_o = 1 + \frac{R_2}{3R_1} \qquad (2.17.7)$$

$$Q = \sqrt{\frac{2R_1 + R_2}{9.61R_1}} \qquad (2.17.8)$$

Rewriting (2.17.7) and (2.17.8) yields:

$$R_2 = 3(A_o - 1)R_1 \qquad (2.17.9)$$

$$R_2 = (9.61Q^2 - 2)R_1 \qquad (2.17.10)$$

Combining (2.17.9) and (2.17.10) gives:

$$A_o = \left(\frac{9.61Q^2 - 2}{3}\right) + 1 \qquad (2.17.11)$$

From Equation (2.17.11) it is seen that gain and Q are intimately related and that large gains mean large Qs and vice versa. Equations (2.17.9) and (2.17.10) show that R_1 and R_2 are not independent, which means one may be arbitrarily selected and from it (knowing A_o and/or Q) the other is found.

Design

1. Select R_2 = 100k.
2. $R_3 = 10R_2 = 10(100k)$

   R_3 = 1 Meg
3. Let A_o = 12dB = 4V/V and from Equation (2.17.9):

   $$R_1 = \frac{R_2}{3(A_o - 1)} = \frac{100k}{3(4 - 1)} = 1.11 \times 10^4$$

   Use R_1 = 10k.
4. Check Q from Equation (2.17.8):

   $$Q = \sqrt{\frac{2(10k) + 100k}{(9.61)(10k)}}$$

   Q = 1.12, which is satisfactory.
5. Calculate C_2 from Equation (2.17.6) and $C_1 = 10C_2$:

   $$C_2 = \frac{1}{2\pi f_o (10R_2)}\sqrt{2 + \frac{R_2}{R_1}}$$

   $$C_2 = \frac{1}{2\pi f_o (10)(100k)}\sqrt{2 + \frac{100k}{10k}}$$

   $$C_2 = \frac{5.513 \times 10^{-7}}{f_o}$$

A table of standard values for C_1 and C_2 vs. f_o is given below:

TABLE 2.17.1

f_o (Hz)	C_1	C_2
32	0.18µF	0.018µF
64	0.1µF	0.01µF
125	0.047µF	0.0047µF
250	0.022µF	0.0022µF
500	0.012µF	0.0012µF
1k	0.0056µF	560pF
2k	0.0027µF	270pF
4k	0.0015µF	150pF
8k	680pF	68pF
16k	360pF	36pF

The complete design appears as Figure 2.17.2. While it appears complicated, it is really just repetitious. By using quad amplifier ICs, the whole thing consists of only three integrated circuits. Figure 2.17.2 is for one channel and would be duplicated for a stereo system. The input buffer amplifier guarantees a low source impedance to drive the equalizer and presents a large input impedance for the preamplifier. Resistor R_8 is necessary to stabilize the LM349 while retaining its fast slew rate (2V/μs). The output amplifier is a unity gain, inverting summer used to add each equalized octave of frequencies back together again. One aspect of the summing circuit that may appear odd is that the original signal is subtracted from the sum via R_{20}. (It is subtracted rather than added because each equalizer section inverts the signal relative to the output of the buffer and R_{20} delivers the original signal without inverting.) The reason this subtraction is necessary is in order to maintain a unity gain system. Without it the output would equal ten times the input, e.g., an input of 1V, with all pots flat, would produce 1V at each equalizer output – the sum of which is 10V. By scaling R_{20} such that the input signal is multiplied by 9 before the subtraction, the output now becomes 10V - 9V = 1V output, i.e., unity gain. The addition of R_4 to each section is for stability. Capacitor C_3 minimizes possibly large DC offset voltages from appearing at the output. If the driving source has a DC level then an input capacitor is necessary (0.1μF), and similarly, if the load has a DC level, then an output capacitor is required.

It is possible to generate just about any frequency response imaginable with this ten band octave equalizer. A few possibilities are given in Figure 2.17.3.

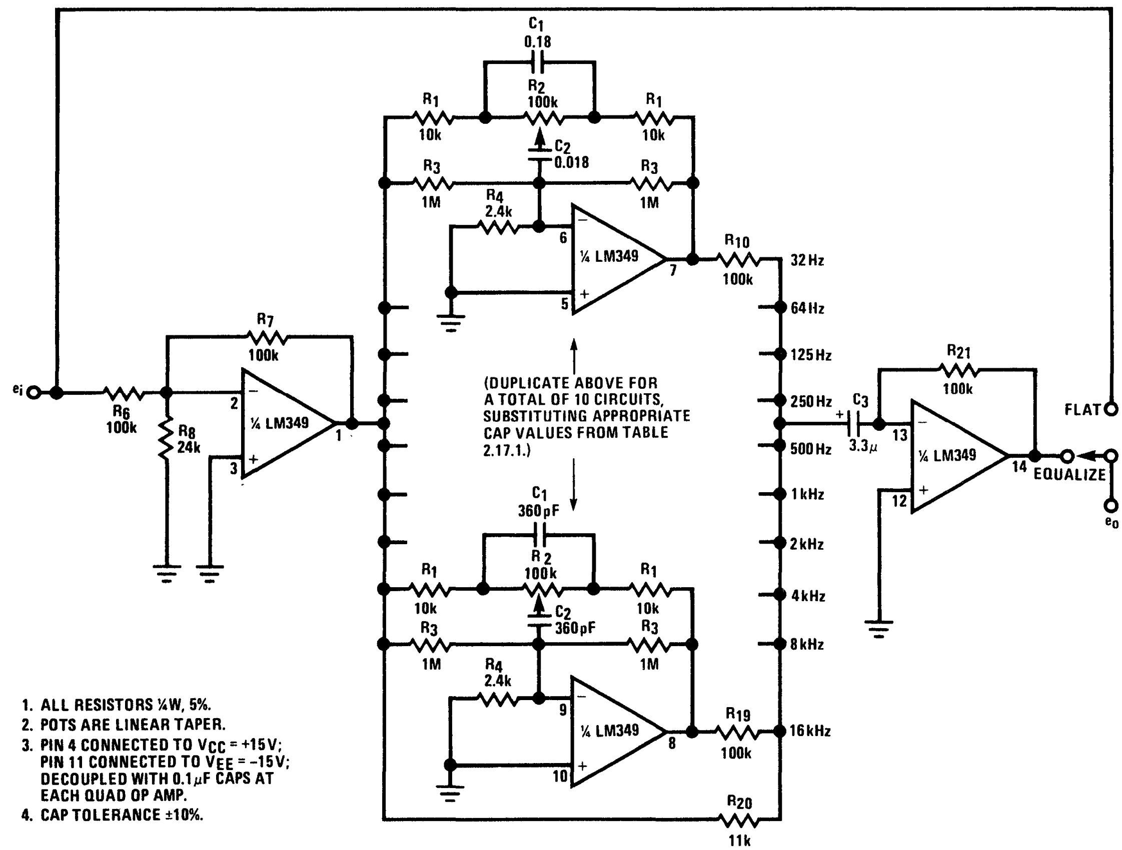

FIGURE 2.17.2 Ten Band Octave Equalizer

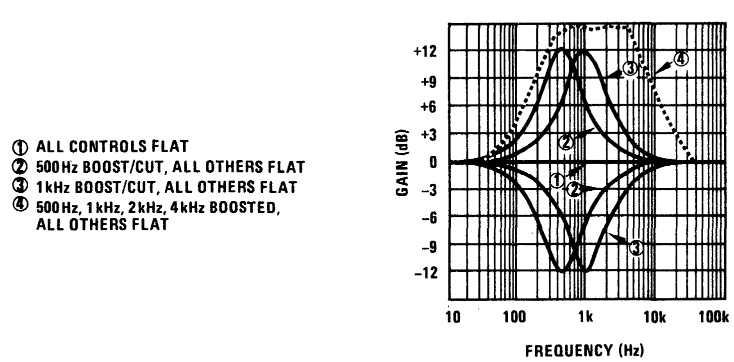

FIGURE 2.17.3 Typical Frequency Response of Equalizer