Octave Equaliser

This design could do with some modern enhancements, such as using NE5532 ic's as the op amps. I have a feeling that putting linear center tap pots instead of the ones shown in the circuit will improve the interaction between channels.
Oh, put the center tap to ground! This might improve the "woodles" on the graph at the bottom of the last page

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

For checking and trimming, use the following:

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

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

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

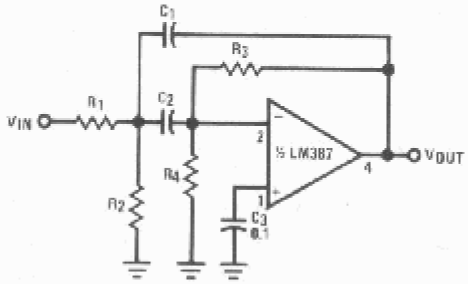

FIGURE 2.16.1 LM387 Bandpass Active Filter

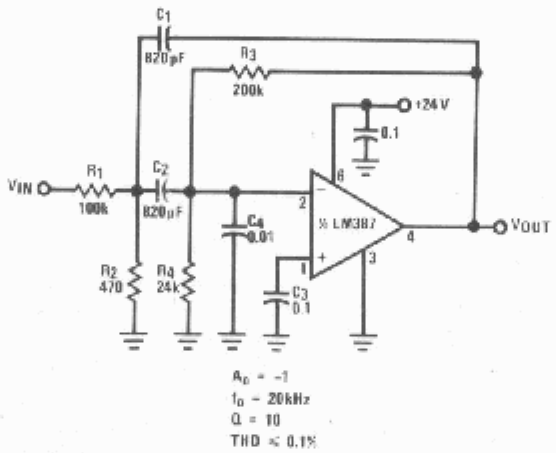

FIGURE 2.16.2 20kHz Bandpass Active Filter

Example 2.16.1

Design a two-pole active bandpass filter with a center frequency f_o = 20 kHz, midband gain A_o = 1, and a bandwidth of 2000 Hz. A single supply, V_s = 24 V, 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 = 820 pF

6. From Equation (2.16.3):

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

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

   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 0.1 μF for all designs. Input shunting capacitor C_4 is included for stability since the design gain is less than 10.

2.17 OCTAVE EQUALIZERS

2.17.1 Ten Band Octave Equalizer

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

A convenient ten band octave equalizer can be constructed based on the filter circuit shown in Figure 2.17.1 where the potentiometer R_2 can control the degree of boost or cut at the resonant frequency set by the series filter of C_2R_s and L, by varying the relative proportions of negative feedback and input signal to the amplifier section.

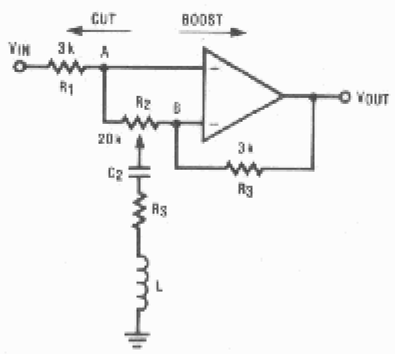

FIGURE 2.17.1 Typical Octave Equalizer Section

Assuming ideal elements, at the resonant frequency with R_2 slider set to the mid position, the amplifier is at unity gain. With the slider of R_2 moved such that C_2 is connected to the junction of R_1 and R_2, the R_sLC_2 network will attenuate the input such that

$$\frac{V_{OUT}}{V_{IN}} = \frac{R_s}{3k + R_s} \quad (2.17.1)$$

If the slider is set to the other extreme, the gain at the resonant frequency is:

$$\frac{V_{OUT}}{V_{IN}} = \frac{3k + R_s}{R_s} \quad (2.17.2)$$

In the final design, R_s is approximately 500Ω, giving a boost or attenuation factor of 7 (≅ 17dB). However, other filter sections of the equalizer connected between A and B will reduce this factor to about 12dB.

To avoid trying to obtain ten inductors ranging in value from 3.9H to 7.95mH for the ten octave from 32Hz to 16kHz, a simulated inductor design will be used. Consider the equivalent circuit of an inductor with associated series and parallel resistance as shown in Figure 2.12.2. The input impedance of the network is given by:

$$Z_{IN} = \frac{sLR_p}{(sL + R_p)} + R_s$$

$$= \frac{(R_p + R_s)\left(sL + \frac{R_pR_s}{R_p + R_s}\right)}{(sL + R_p)}$$

$$\therefore Z_{IN} = \frac{(R_p + R_s)\left(s + \frac{R_pR_s}{L(R_p + R_s)}\right)}{\left(s + R_p/L\right)} \quad (2.17.3)$$

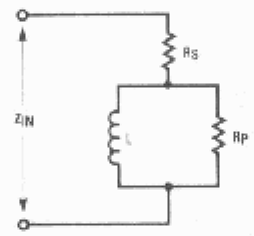

FIGURE 2.17.2 Ideal Inductor with Series and Parallel Resistances

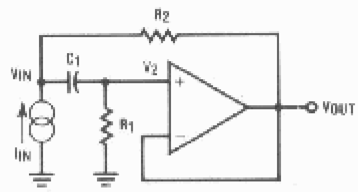

FIGURE 2.17.3 Simulated Inductor

This input impedance can be realised with the active circuit shown in Figure 2.17.3. Assuming an ideal amlifier with infinite gain and infinite input impedance,

$$V_2 - V_{OUT} = \frac{V_{IN}R_1}{(1/sC_1 + R_1)} \quad (2.17.4)$$

The input current I_{IN} is given by,

$$I_{IN} = \frac{V_{IN} - V_2}{R_2} + \frac{V_{IN}}{(1/sC_1 + R_1)} \quad (2.17.5)$$

Substituting (2.17.4) into this expression gives:

$$I_{IN} = V_{IN}\left\{\frac{1}{R_2} + \frac{sC_1}{(1 + sC_1R_1)} - \frac{R_1}{R_2\left(R_1 + \frac{1}{sC_1}\right)}\right\}$$

$$= V_{IN}\left\{\frac{1 + sC_1R_2}{R_2(sC_1R_1 + 1)}\right\}$$

Since $Z_{IN} = \frac{V_{IN}}{I_{IN}}$

$$Z_{IN} = \frac{R_2 + sC_1R_1R_2}{1 + sC_1R_2}$$

$$= \frac{R_1\left(\frac{1}{C_1R_1} + s\right)}{\left(\frac{1}{C_1R_2} + s\right)} \quad (2.17.6)$$

Equating (2.17.3) and (2.17.6)

$$\frac{(R_p + R_s)\left[s + \frac{R_pR_s}{L(R_p + R_s)}\right]}{s + R_p/L} = \frac{R_1\left(s + \frac{1}{C_1R_1}\right)}{s + \frac{1}{C_1R_2}}$$

$$\therefore R_1 = R_p + R_s \quad (2.17.7)$$

$$\frac{R_pR_s}{L(R_p + R_s)} = \frac{1}{C_1R_1}$$

$$\therefore C_1 = \frac{1}{R_pR_s} \quad (2.17.8)$$

$$\frac{R_p}{L} = \frac{1}{C_1R_2}$$

$$\therefore R_2 = \frac{L}{R_p} \times \frac{R_pR_s}{L} = R_s \quad (2.17.9)$$

From the above equations it is apparent that R_1 should be large in order to reduce the effect of R_p on the filter operation, and to allow reasonably small capacitor values for each band (since capacitors will be non-polarized). R_1 should not be too large since it will carry the bias current for the non-inverting input of the amplifier.

The choice of Q for each of the filters depends on the permissible "ripple" in the boost or cut positions and the number of filters being used. For example, if we had only two filters separated by one octave, an ideal filter Q would be 1.414 so that the −3dB response frequencies will coincide, giving the same gain as that at the band centers. For the ten band equalizer a Q of 1.7 is better, since several filters will be affecting the gain at a given frequency. This will keep the maximum ripple at full boost or cut to less than ± 2dB.

EXAMPLE 2.17.1

Design a variable (± 12dB) octave equalizer section with a Q of 1.7 and a center frequency of 2kHz.

Solution

1. Select R_1 = 68k
2. From equations (2.17.1) and (2.17.2) R_s = 470
3. $L = \frac{QR_s}{2\pi f_o} = \frac{QR_2}{2\pi f_o}$

$$\therefore L = \frac{1.7 \times 470}{2\pi \times 2 \times 10^3} = 63.6\text{mH} \quad (2.17.10)$$

4. From equation (2.17.8)

$$C_1 = \frac{L}{R_p + R_s} = \frac{L}{(R_1 - R_2)R_2}$$

$$= \frac{63.6 \times 10^{-3}}{(68 \times 10^3 - 470)470}$$

$$\therefore C_1 = 2000\text{pF}$$

5.

$$C_2 = \frac{1}{\omega_o^2 L}$$

$$= \frac{1}{(2\pi \times 2 \times 10^3)^2 63.5 \times 10^{-3}}$$

$$\therefore C_2 = 0.1\mu\text{F} \qquad (2.17.11)$$

Table 2.17.1 summarizes the component values required for the other sections of the equalizer. The final design appears in Figure 2.17.4 and uses LM348 quad op-amps. Other unity gain stable amplifiers can be used. For example, LF356 will give lower distortion at the higher frequencies. Although linear taper potentiometers can be used, these will result in very rapid action near the full boost or full cut positions. S taper potentiometers (Allen Bradley #70A1G032 R2035) will give a better response. All the capacitors used for tuning the simulated inductors (C_2) should be non-polarized mylar or polystyrene.

Signal to noise ratio of the equalizer with the controls set "flat" is 73dB referred to a $1V_{RMS}$ input signal. THD is under 0.01% at 20kHz.

TABLE 2.17.1

fo(Hz)	C_1	C_2	R_1	R_2
32	0.12μF	4.7μF	75kΩ	560Ω
64	0.056μF	3.3μF	68kΩ	510Ω
125	0.033μF	1.5μF	62kΩ	510Ω
250	0.015μF	0.82μF	68kΩ	470Ω
500	8200pF	0.39μF	62kΩ	470Ω
1k	3900pF	0.22μF	68kΩ	470Ω
2k	2000pF	0.1μF	68kΩ	470Ω
4k	1100pF	0.056μF	62kΩ	470Ω
8k	510pF	0.022μF	68kΩ	510Ω
16k	330pF	0.012μF	51kΩ	510Ω

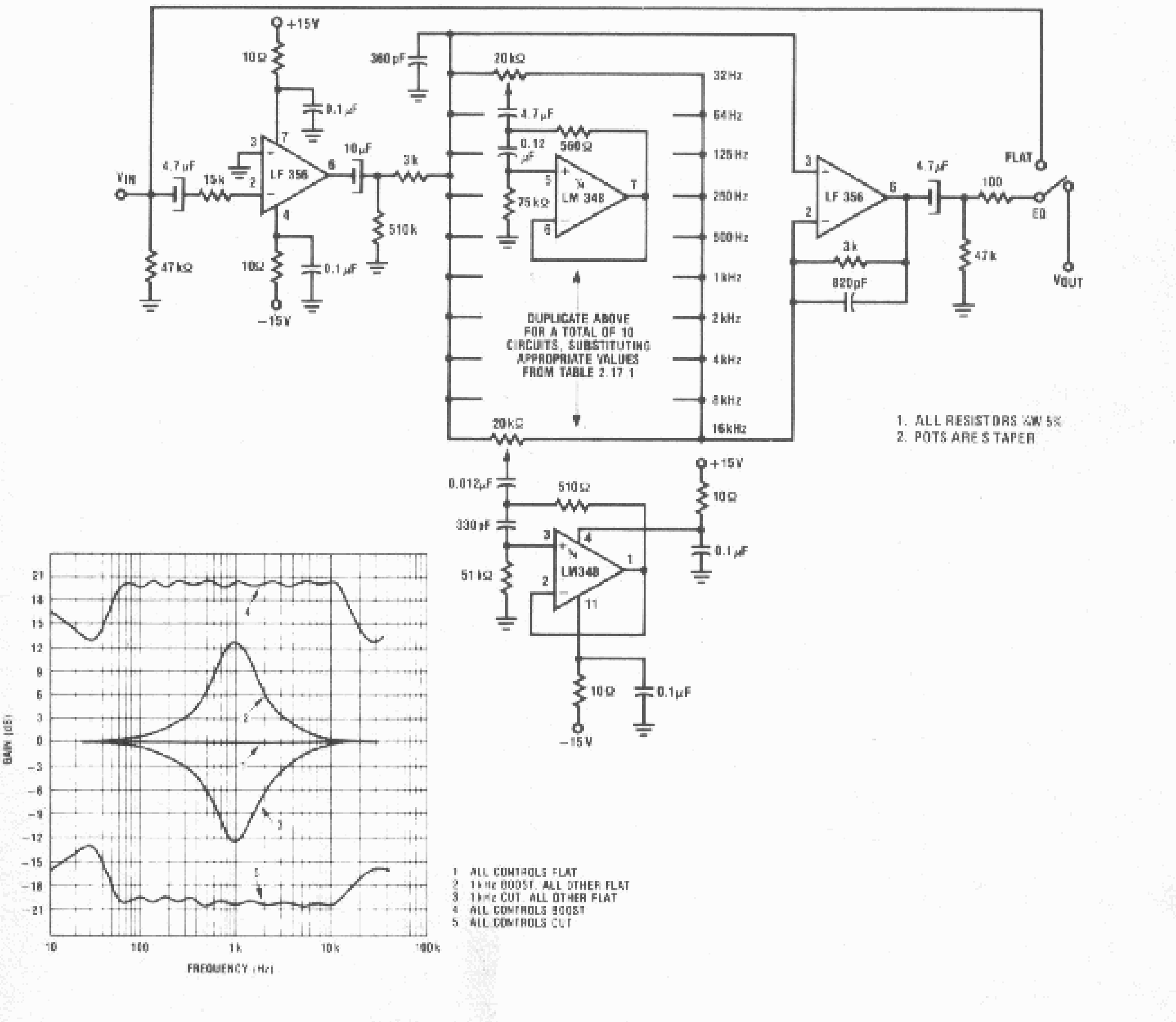

FIGURE 2.17.4 Complete Ten Band Octave Equalizer