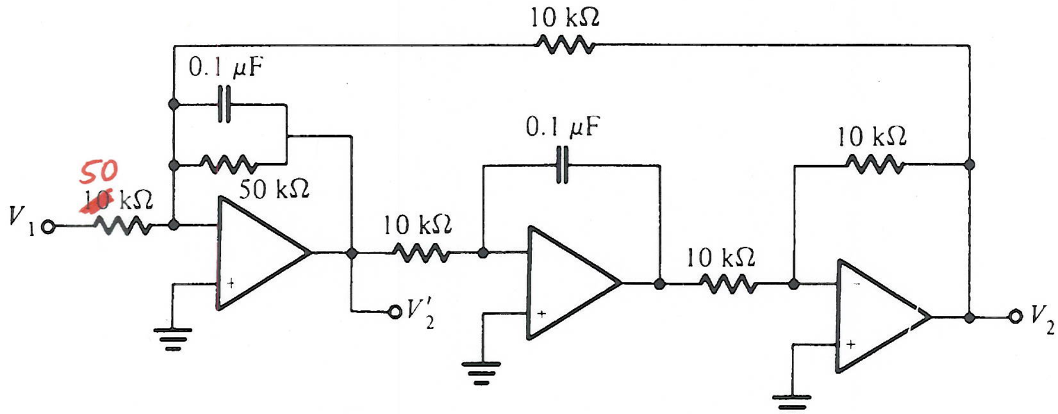

FIGURE 5.21

5.4 The FOUR-OP-AMP BIQUAD CIRCUIT

The addition of a fourth op amp to the biquad circuit gives it versatility in the kinds of filtering it can provide. Since it is common to manufacture op amps with four units on a chip—the *quad op amp*—the fourth unit is available to the designer. We use the extra op amp to add voltages taken from the biquad circuit. In terms of the quantities in Fig. 5.22 we see that

$$V_2'' = -(V_2' + V_1) \tag{5.60}$$

Dividing by V_1, we have a new transfer function:

$$\frac{V_2''}{V_1} = -\left(\frac{V_2'}{V_1} + \frac{V_1}{V_1}\right) \tag{5.61}$$

If we merge the circuit of Fig. 5.22 with that for the biquad circuit given in Fig. 5.9, the result is the circuit of Fig. 5.23. If we substitute Eq. (5.31) for V_2'/V_1 into the last equation, there results

$$\frac{V_2''}{V_1} = -\frac{(-1/R_3C_1)s}{s^2 + (1/R_1C_1)s + 1/R_2R_4C_1C_2} + \frac{s^2 + (1/R_1C_1)s + 1/R_2R_4C_1C_2}{s^2 + (1/R_1C_1)s + 1/R_2R_4C_1C_2} \tag{5.62}$$

Combining the two equations gives us

$$\frac{V_2''}{V_1} = -\frac{s^2 + (1/R_1C_1 - 1/R_3C_1)s + 1/R_2R_4C_1C_2}{s^2 + (1/R_1C_1)s + 1/R_2R_4C_1C_2} \tag{5.63}$$

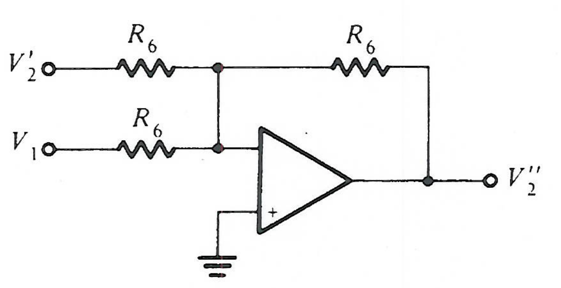

FIGURE 5.22

5.8 (a) For the circuit shown in Fig. P5.8, show that with $K = 1 + (R_7/R_6)$,

$$\frac{V_2}{V_1} = K\frac{R_4}{R_5}\,\frac{s^2 + R_5/R_1R_2R_4C_1C_2}{s^2 + (1/R_2C_{\cancel{4}\,2})s + K/R_2R_3C_1C_2}$$

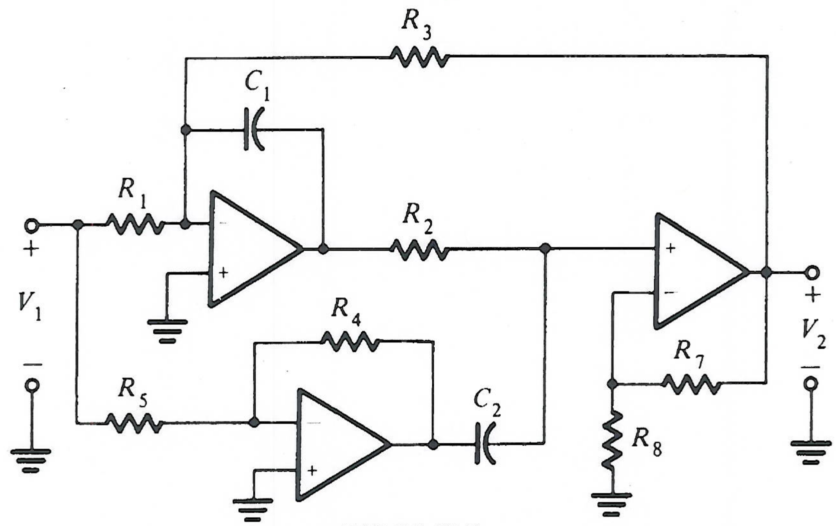

FIGURE P5.8

(b) Devise a tuning algorithm for the circuit to meet Q, ω_0, ω_z, and gain specifications.

(c) Devise a design algorithm for the circuit to match the specifications given in (b).

5.9 The circuit shown in Fig. P5.9 is a generalization of that given in Fig. 5.23. We wish to use it to study the lowpass notch and highpass notch filters illustrated by Fig. 12.39, and also the gain-equalizer filter illustrated by Fig. 5.32. Let $R_2 = R_4 = R_5 = R_7 = R_{10} = R$, $C_1 = C_2 = C$, $R_1 = QR$, and $R_9 = R/K$.

(a) Show that $\omega_0 = 1/RC$ and

$$\frac{V_2}{V_1} = -K\frac{s^2 + (1/Q - R/KR_3)\,\omega_0 s + (1 \pm R^2/KR_3R_8)\omega_0^2}{s^2 + (\omega_0/Q)\,s + \omega_0^2}$$

where $\pm$ is $-$ when Sw_1 is closed, $+$ when Sw_2 is closed. Let the denominator of this equation be $D(s)$ and $V_2/V_1 = T$.

Find the values for R_3, R_8, and the switch positions that will provide the following values of $T(s)$:

(b) $T = \dfrac{s^2 + \omega_z^2}{D}$ $\qquad \omega_z < \omega_0$,

(c) $T = \dfrac{s^2 + \omega_z^2}{D}$ $\qquad \omega_z > \omega_0$

(d) $T = \dfrac{s^2 + (\omega_0/Q_z)s + \omega_0^2}{D}$

5.10 Using the results of Problem 5.9, design a so-called "universal filter" for which $Q = 5$ and $f_0 = 10$ kHz. The preferred value of C is 0.01 μF. Devise a switching arrangement so that you may obtain bandpass, lowpass, highpass, and allpass, characteristics.