3.6
MULTIPLE-FEEDBACK FILTERS

Multiple-feedback filters utilize more than one feedback path. Unlike their *KRC* counterparts, which configure the op amp for a *finite* gain K, multiple-feedback filters exploit the full open-loop gain and are also referred to as *infinite-gain filters*. Together with *KRC* filters, they are the most popular single-op-amp realizations of the second-order responses.

Band-Pass Filters

In the circuit of Fig. 3.30, also called the *Delyiannis-Friend* filter, named after its inventors, the op amp acts as a differentiator with respect to V_1, so we write

$$V_o = -sR_2C_2V_1$$

Summing currents at node V_1,

$$\frac{V_i - V_1}{R_1} + \frac{V_o - V_1}{1/sC_1} + \frac{0 - V_1}{1/sC_2} = 0$$

Eliminating V_1, letting $s \to j\omega$, and rearranging,

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$$H(j\omega) = \frac{V_o}{V_i} = \frac{-j\omega R_2C_2}{1 - \omega^2 R_1R_2C_1C_2 + j\omega R_1(C_1 + C_2)}$$

To put this function in the standard form $H(j\omega) = H_{0\text{BP}}H_{\text{BP}}(j\omega)$, we impose $\omega^2 R_1R_2C_1C_2 = (\omega/\omega_0)^2$ to get

$$\omega_0 = \frac{1}{\sqrt{R_1R_2C_1C_2}} \tag{3.70a}$$

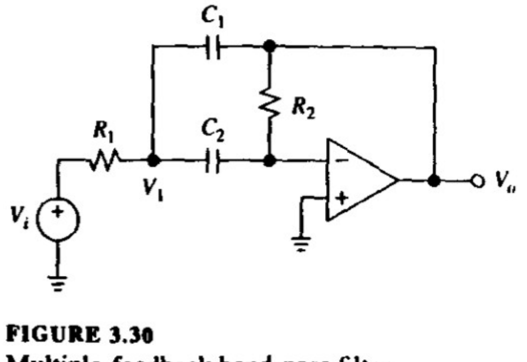

FIGURE 3.30
Multiple-feedback band-pass filter.

and $j\omega R_1(C_1 + C_2) = (j\omega/\omega_0)/Q$ to get

$$Q = \frac{\sqrt{R_2/R_1}}{\sqrt{C_1/C_2} + \sqrt{C_2/C_1}} \tag{3.70b}$$

Finally, we impose $-j\omega R_2 C_2 = H_{0BP} \times (j\omega/\omega_0)/Q$ to get

$$H_{0BP} = \frac{-R_2/R_1}{1 + C_1/C_2} \tag{3.70c}$$

Clearly, this filter is of the inverting type. It is customary to impose $C_1 = C_2 = C$, after which the above expressions simplify to

$$\omega_0 = \frac{1}{\sqrt{R_1 R_2} C} \qquad Q = 0.5\sqrt{R_2/R_1} \qquad H_{0BP} = -2Q^2 \tag{3.71}$$

The corresponding design equations are

$$R_1 = 1/2\omega_0 QC \qquad R_2 = 2Q/\omega_0 C \tag{3.72}$$

Denoting resonance-gain magnitude as $H_0 = |H_{0BP}|$ for simplicity, we observe that it increases quadratically with Q. If we want $H_0 < 2Q^2$, we must replace R_1 with a voltage divider in the manner of Example 3.9. The design equations are then