Operational Amplifier Compensation (cont.) 13

Note: All references to Figures and Equations whose numbers are *not* preceded by an "S" refer to the textbook.

Solution 13.1 (P13.10)

With minor-loop compensation, including the capacitive loading,

$$a(s) \simeq \frac{K}{Y_c(s)(10^{-6}s + 1)} \tag{S13.1}$$

The desired open-loop transfer function is

$$a(s) \simeq \frac{2 \times 10^{11}(5 \times 10^{-6}s + 1)}{s^2} \tag{S13.2}$$

Equating the above two expressions allows us to solve for $Y_c(s)$ as

$$Y_c(s) = \frac{Ks^2}{2 \times 10^{11}(5 \times 10^{-6}s + 1)(10^{-6}s + 1)} \tag{S13.3}$$

This is a second-order transfer function; thus, we can realize it with two energy storage elements. We choose to use two capacitors.

At high frequencies $(|s| \gg 10^6)$,
$Y_c(s) = \frac{K}{2 \times 10^{11}(5 \times 10^{-6})(10^{-6})} = 2 \times 10^{-4}$. That is, at high frequencies the network is resistive, with $R = 5\ \text{k}\Omega$. Thus, the compensating network is of the form shown in Figure S13.1, consisting of a second-order network yet to be determined, in series with a 5 kΩ resistor. Further, the two-port network must appear as a short circuit at high frequencies.

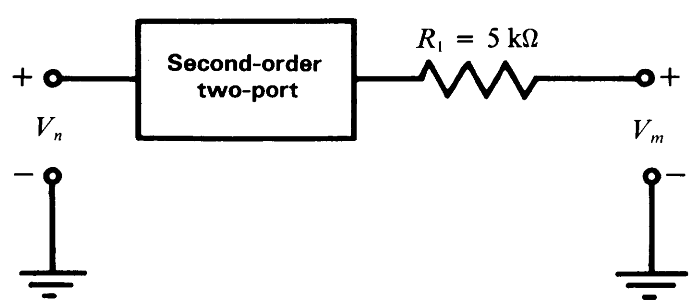
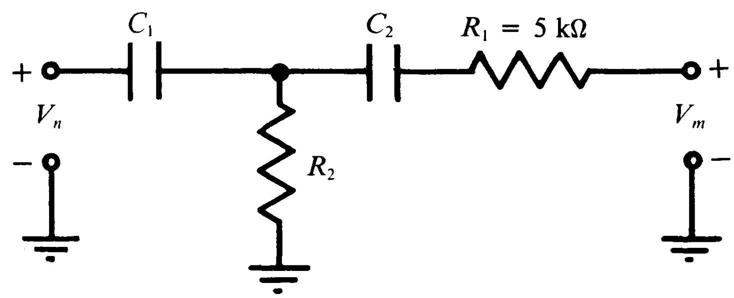


Figure S13.1 Compensating network for Problem 13.1 (P13.10).

Using the above discussion for guidance, we pick the compensating network topology shown in Figure S13.2.

Figure S13.2 Compensating network for Problem 13.1 (P13.10).



This network has a short-circuit transfer admittance of

$$Y(s) = \frac{R_2C_1C_2s^2}{R_1R_2C_1C_2s^2 + [R_1C_2 + R_2(C_1 + C_2)]s + 1} \qquad \textbf{(S13.4)}$$

Now, we can solve for element values by equating S13.4 and S13.3. Because we've already found the value of $R_1 = 5\ \text{k}\Omega$, this gives only two independent equations, that is,

$$R_2C_1C_2 = 10^{-15} \qquad \textbf{(S13.5)}$$

$$R_1C_2 + R_2(C_1 + C_2) = 6 \times 10^{-6} \qquad \textbf{(S13.6)}$$

These two equations are in three unknowns, implying an extraneous degree of freedom. This degree of freedom is eliminated by choosing $R_2 = 1\text{k}\Omega$. (There is no real solution if $R_1 = R_2$.) Even with this constraint, as the equations are quadratic in form, there are still two sets of solutions. They are

Solution A	*Solution B*
$C_1 = 1269$ pF	$C_1 = 4719$ pF
$C_2 = 788$ pF	$C_2 = 212$ pF

Either solution set is acceptable. There are also many other parameter sets that will yield the same transfer admittance, as well as other possible network topologies.

Solution 13.2 (P13.11)

As described in Section 13.3.4, the feedback network of a differentiator adds a loop-transmission pole. The solution is to apply minor-loop compensation to create an open-loop zero that will partially offset the negative phase shift of the pole in the vicinity of crossover. From Equation 13.45, with a series $R_c - C_c$ compensating network,

$$a(s) \simeq \frac{K(R_cC_cs + 1)}{C_cs} \qquad \textbf{(S13.7)}$$

The pole resulting from the feedback network is at $s = -1/RC = -10\ \text{sec}^{-1}$. Thus, the approximate loop transmission is

$$L(s) \simeq -\frac{K(R_cC_cs + 1)}{C_cs(0.1s + 1)} \qquad \textbf{(S13.8)}$$

Crossover is specified at 10^4 rad/sec. To achieve 60° of phase margin, we set the zero at $\omega_z = 5.8 \times 10^3$ rad/sec. Thus, $R_cC_c = 1/\omega_z = 1.7 \times 10^{-4}$ sec. (Because no phase margin requirement is specified in the problem, other solutions are also acceptable.) Now, we can use C_c to set $\omega_c = 10^4$ rad/sec by requiring that $|L(j10^4)| = 1$. Because crossover occurs well above the pole at 10 rad/sec, the resulting equation is

$$|L(j\omega)|\Big|_{\omega=10^4} \simeq \left|\frac{K(1.7 \times 10^{-4}j\omega + 1)}{0.1\ C_c\omega^2}\right|\Bigg|_{\omega=10^4} = 1 \qquad \textbf{(S13.9)}$$

This is solved by $C_c = 40$ pF. Then, because $R_cC_c = 1.7 \times 10^{-4}$ sec, we find that $R_c = 4.3\ \text{M}\Omega$.

The 3 pF shunt guarantees that the compensating network is capacitive in the vicinity of minor-loop crossover. Note that this topology is slightly different than that of Figure 13.29 in the textbook. That is, for this problem, the compensating network is as shown in Figure S13.3, with 3 pF shunting the entire compensating network. With this network, the loop transmission becomes

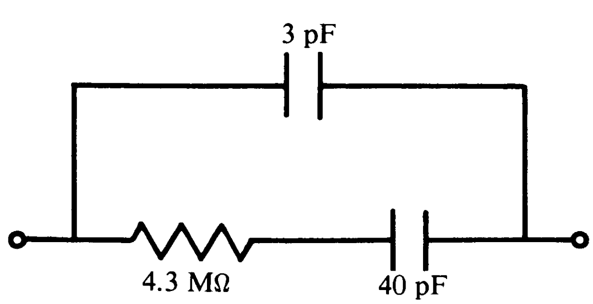


Figure S13.3 Modified compensation network for Problem 13.2 (P13.11).

$$L(s) \simeq -\frac{2 \times 10^{-4}(1.7 \times 10^{-4}s + 1)}{4.3 \times 10^{-11}s(0.1s + 1)(1.2 \times 10^{-5}s + 1)} \quad \textbf{(S13.10)}$$

There are two effects of the shunt. First the loop-transmission magnitude is lowered by about 8% across all frequencies. This is due to the additional admittance of the 3 pF cap. Secondly, a loop-transmission pole is introduced at 8.3×10^4 rad/sec. These two effects combine to reduce the loop-transmission crossover to $\omega_c = 9.3 \times 10^3$ rad/sec with a phase margin of about 51°. This will have only a minor effect on closed-loop performance.