

# OPAMP Compensation

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An op amp with open-loop voltage gain of  $10^4$  and poles at  $10^6$ ,  $10^7$  and  $10^8$  Hz is to be compensated by the addition of a fourth dominant pole to operate stably with unity feedback ( $|H| = 1$ ). What is the frequency of the required dominant pole? The compensation network placed in the negative feedback path of the op amp. The dc bias conditions are such that a  $1M\Omega$  resistor can be tolerated in series with each of the negative and positive input terminals. What capacitor is required between the negative input and ground to implement the required fourth pole?

1. Find  $G(s)$  for the OPAMP.

**Solution:**

$$G(s) = \frac{G_0}{\left(1 + \frac{s}{P_1}\right)\left(1 + \frac{s}{P_2}\right)\left(1 + \frac{s}{P_3}\right)} \quad (1.1)$$

where the gain and poles are listed in Table 1.

Parameters	Value
$P_1$	$2\pi 10^6$ rad/sec
$P_2$	$2\pi 10^7$ rad/sec
$P_3$	$2\pi 10^8$ rad/sec
$G_0$	$10^4$

TABLE 1

2. Find the 4th dominant pole  $P_D$  that will stabilize the system.

**Solution:** Let the pole frequency be  $f_D$ . The 4 pole system will be stable if the gain begins to rolloff from 80dB at a -20 dB/dec rate from  $f_D$  and continues until  $f_{P1}$  where it cuts 0dB line. From Fig. 2,

$$f_D = \frac{f_{P1}}{10^4} \quad (2.1)$$

$$\Rightarrow f_D = 10^2 \text{ Hz} \quad (2.2)$$

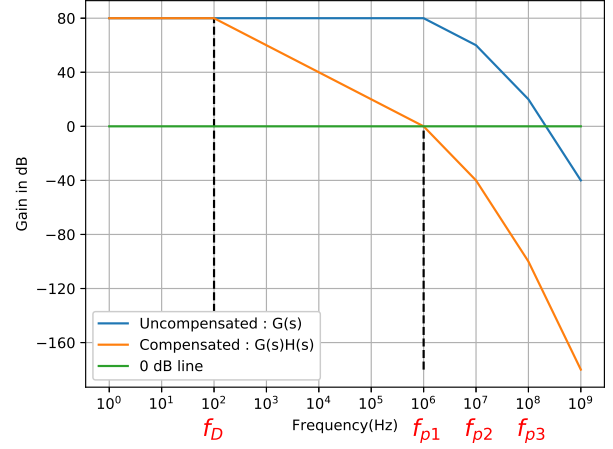


Fig. 2: Bode Plot using asymptotic approximations

3. Draw the block diagram for the stabilized circuit.

**Solution:** See Fig. 3, where

$$P_D = \frac{1}{R_f C_f} \quad (3.1)$$

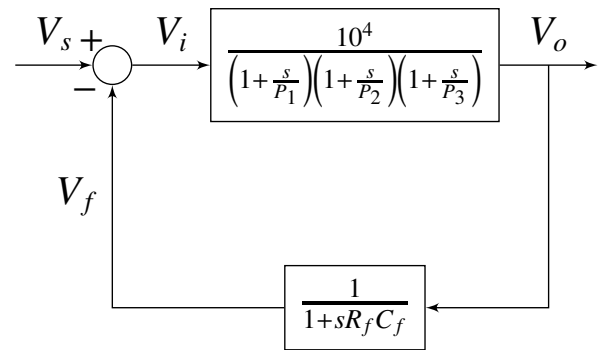


Fig. 3: Block Diagram

4. Design the OPAMP circuit for Fig. 3.

**Solution:** See Fig. 4.

$$H(s) = \frac{V_f}{V_0} = \frac{1}{1 + sR_f C_f} \quad (4.1)$$

5. Find  $R_f$  and  $C_f$ .

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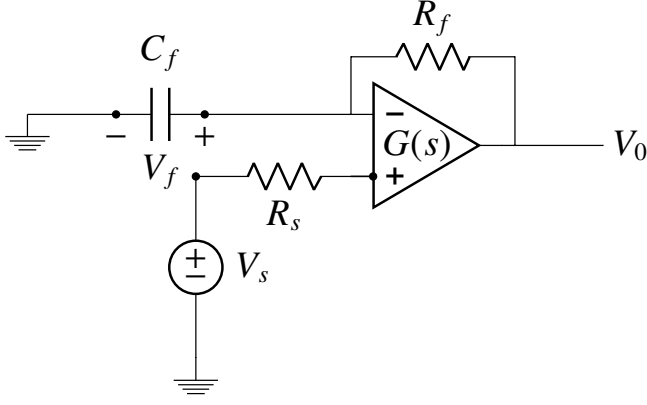


Fig. 4

**Solution:**

$$\therefore P_D = 2\pi f_D, \quad (5.1)$$

$$C_f = \frac{1}{2\pi R_f f_D} \quad (5.2)$$

Choosing

$$R_f = R_s = 1M\Omega, C_f = 1.59nF \quad (5.3)$$

Table 5 summarizes this.

Elements	Value
$R_f$	$1M\Omega$
$R_s$	$1M\Omega$
$C_f$	$1.59 \text{ nF}$

TABLE 5

6. Verify stability using Bode plots. The loop gain of the compensated system is

$$L(s) = G(s)H(s) = \frac{10^4}{(1 + sR_f C_f)(1 + \frac{s}{P_1})(1 + \frac{s}{P_2})(1 + \frac{s}{P_3})} \quad (6.1)$$

The closed loop gain

$$T(s) = \frac{G(s)}{1 + L(s)} \quad (6.2)$$

Let

$$\angle L(j\omega_{180}) = -180^\circ \quad (6.3)$$

Then, for stability,

$$|L(j\omega_{180})| < 1 \quad (6.4)$$

For the uncompensated System

$$L_1(s) = G(s) \quad (6.5)$$

and

$$L_2(s) = G(s)H(s) \quad (6.6)$$

for the compensated system

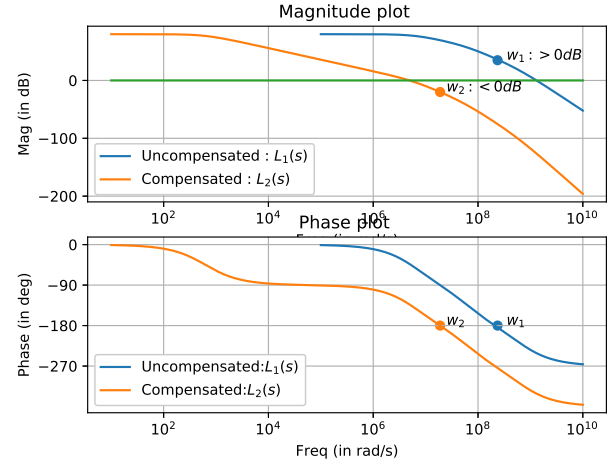


Fig. 6: Bode Plots for verification

From Fig. 6,

$$|L_1(j\omega_{180})| > 1 \quad (6.7)$$

$$\Rightarrow L_1 \text{ is unstable} \quad (6.8)$$

$$|L_2(j\omega_{180})| < 1 \quad (6.9)$$

$$\Rightarrow L_2 \text{ is stable} \quad (6.10)$$

Thus,  $H(s)$  stabilizes the unity feedback system.

7. Describe the functionality of the feedback circuit.

**Solution:** The Bode plot of  $T(s)$  is available in Fig 7. This resembles a band pass filter and amplifies the frequencies lying between 0.1 MHz to 10 MHz, while rejecting higher and lower frequencies.

8. Simulate the circuit using ngspice.

**Solution:** The following netlist simulates the unity feedback system. The step response in spice is plotted using the following code in Fig. The following netlist simulates the compensated system in Fig. Fig. 8 shows how the circuit is actually implemented in spice using the parameters in Table .

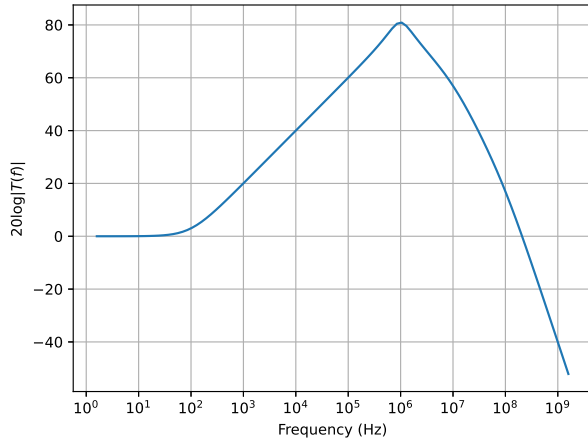


Fig. 7: Bode Plots of  $T(s)$

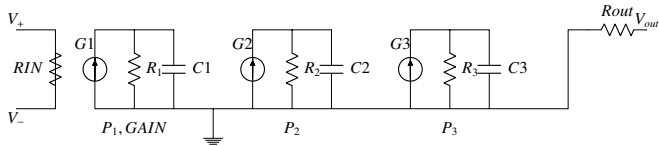


Fig. 8: Circuit resembling  $G(s)$

Elements	Value
$G_1$	$10^{-2}(V_+ - V_-)A/V$
$G_2$	$10^{-6}A/V$
$G_3$	$10^{-6}A/V$
$R_1$	$1M\Omega$
$R_2$	$1M\Omega$
$R_3$	$1M\Omega$
$C_1$	$0.159pF$
$C_2$	$0.0159pF$
$C_3$	$0.00159pF$
$R_{IN}$	$1000M\Omega$
$R_{OUT}$	$100\Omega$
$R_f$	$1M\Omega$
$C_f$	$1.59nF$
$R_s$	$1M\Omega$

TABLE 8