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:

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

where the gain and poles are listd 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,

$$f_D = \frac{f_{P1}}{10^4} \tag{2.1}$$

$$\implies f_D = 10^2 Hz \tag{2.2}$$

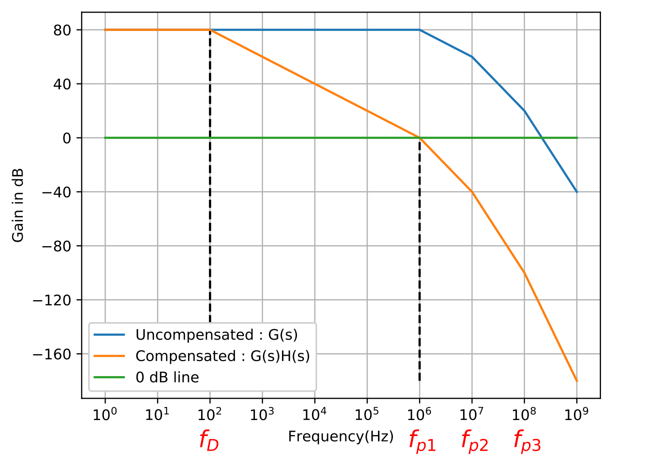

Fig. 2: Bode Plot using asymptotic approximations

3. Draw the block diagram for the stabilized circuit.
Solution: See Fig. 3, where

$$P_D = \frac{1}{R_f C_f} \tag{3.1}$$

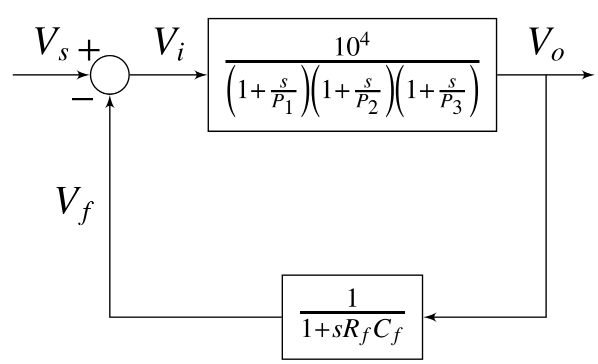

Fig. 3: Block Diagram

4. Design the OPAMP circuit for Fig. 3.
Solution: See Fig. 4.

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

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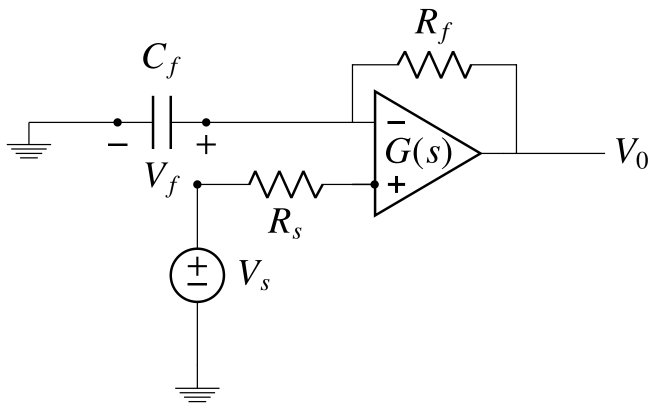

Fig. 4

5. Find R_f and C_f.
Solution:

$$\because P_D = 2\pi f_D, \tag{5.1}$$

$$C_f = \frac{1}{2\pi R_f f_D} \tag{5.2}$$

Choosing

$$R_f = R_s = 1M\Omega, C_f = 1.59nF \tag{5.3}$$

Table 5 summarizes this.

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

TABLE 5

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

$$L(s) = G(s)H(s)$$

$$= \frac{10^4}{(1 + sR_fC_f)(1 + \frac{s}{P_1})(1 + \frac{s}{P_2})(1 + \frac{s}{P_3})} \tag{6.1}$$

The closed loop gain

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

Let

$$\angle L(\jmath\omega_{180}) = -180^\circ \tag{6.3}$$

Then, for stability,

$$\left|L(\jmath\omega_{180})\right| < 1 \tag{6.4}$$

For the uncompensated System

$$L_1(s) = G(s) \tag{6.5}$$

and

$$L_2(s) = G(s)H(s) \tag{6.6}$$

for the compensated system . The following code plots Figs. 2 and 6.

```
codes/ee18btech11026/ee18btech11026_1.py
```

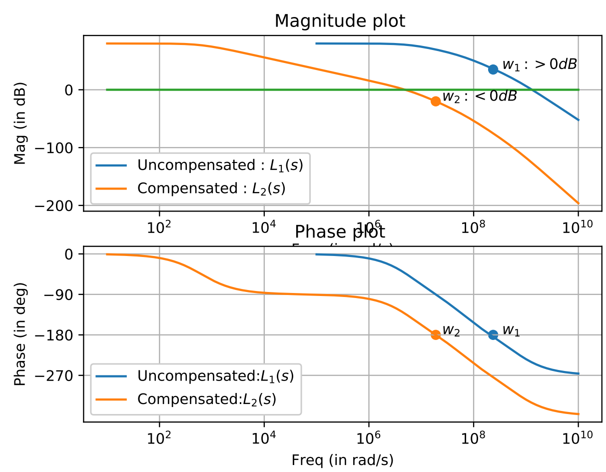

Fig. 6: Bode Plots for verificaition

From Fig. 6,

$$\left|L_1(\jmath\omega_{180})\right| > 1 \tag{6.7}$$

$$\implies L_1 \text{ is unstable} \tag{6.8}$$

$$\left|L_2(\jmath\omega_{180})\right| < 1 \tag{6.9}$$

$$\implies L_2 \text{ is stable} \tag{6.10}$$

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

7. Describe the functionality of the feedback circuit.
Solution: The following code plots the Bode plot of $T(s)$ in Fig. 7.

```
codes/ee18btech11026/time_res.py
```

It can be seen that the feedback circuits acts as a DC buffer. It also behaves like a band pass filter and amplifies the frequencies lying between 0.1 MHz to 10 MHz.

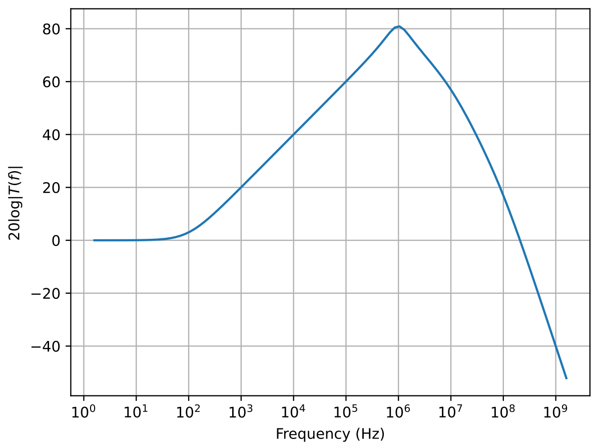

Fig. 7: Bode Plots of T(s)

8. Simulate the circuit using ngspice.
Solution: Fig. 8.1 shows how the circuit is actually implemented in spice using the parameters in Table 8

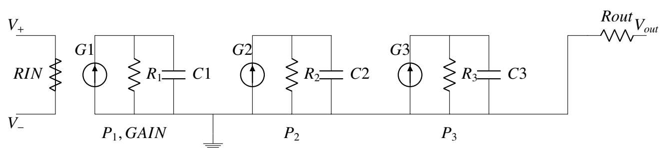

Fig. 8.1: Circuit resembling G(s)

The following code provides instructions about the spice simulation.

codes/ee18btech11026/spice/README.md

The following netlist simulates the uncompensated unity feedback system (buffer) for a DC input.

codes/ee18btech11026/spice/buffer_fb.net

The following code plots the output of the uncompensated (buffer) generated by the above netlist in Fig. 8.2

```
codes/ee18btech11026/spice/
    ee18btech11026_buffer.py
```

We can observe that the step response shoots up to a very large value(10^{293}). This shows that the uncompensated buffer is unstable.
The following netlist simulates the compensated system.

codes/ee18btech11026/spice/rc_bf.net

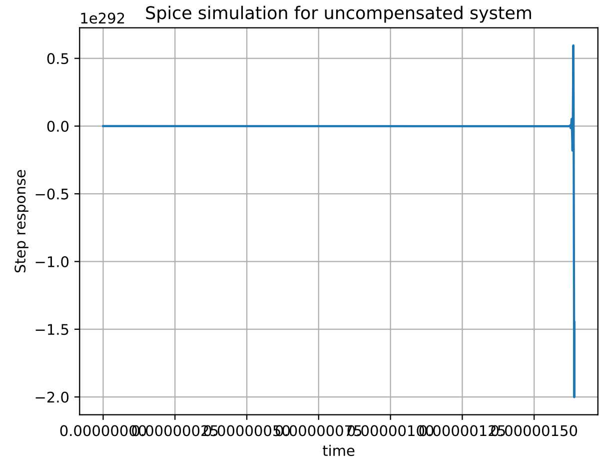

Fig. 8.2: Step response of Uncompensated System

The step response in spice is plotted using the following code in Fig. 8.3

```
codes/ee18btech11026/spice/
    ee18btech11026_rc_fb.py
```

The maginified output is available in Fig. . Here we can observe that the system has a transient response and it eventually goes to 1. Thus, the feedback H stabilizes the system.

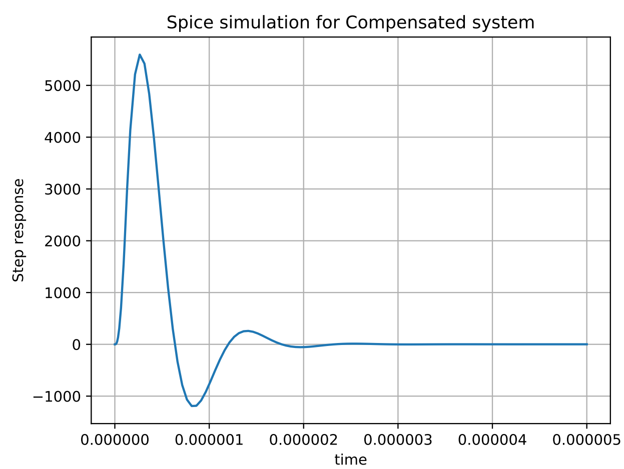

Fig. 8.3: Step response of Compensated System

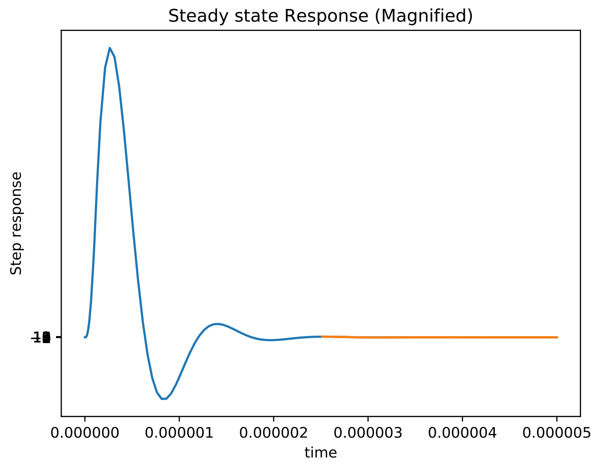

Fig. 8.4: Magnified Plot focussing on steady state

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}	100Ω
R_f	$1M\Omega$
C_f	$1.59nF$
R_s	$1M\Omega$

TABLE 8