OPAMP Compensation

Surya Prakash *

An op amp with open-loop voltage gain of 10^4 and poles at $10^6, 10^7$and10^8 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,

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

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

*The author is with the Department of Electrical Engineering, Indian Institute of Technology, Hyderabad 502285 India. All content in this manual is released under GNU GPL. Free and open source.

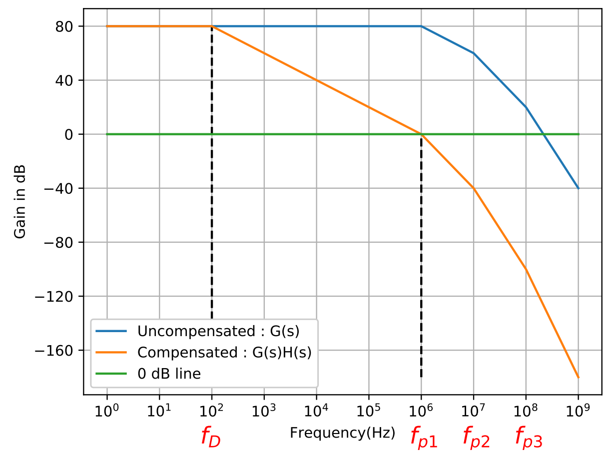

Fig. 2: Bode Plot using asymptotic approximations

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

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

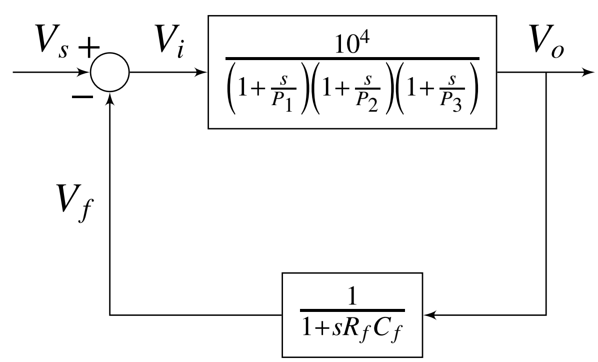

Fig. 3: Block Diagram

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

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

5. Find R_f and C_f.

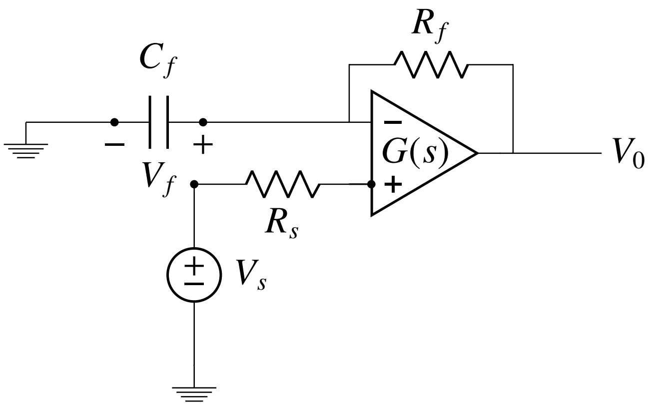

Fig. 4

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. 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

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

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

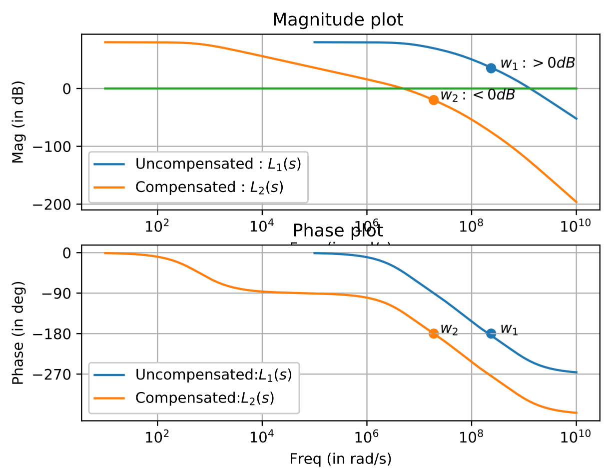

Fig. 6: Bode Plots for verificaition

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 Bode plot of $T(s)$ is avaiable 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 code provides instructions about the simulation.

```
codes/ee18btech11026/spice/README.md
```

The following netlist simulates the unity feedback system.

```
codes/ee18btech11026/spice/buffer_fb.net
```

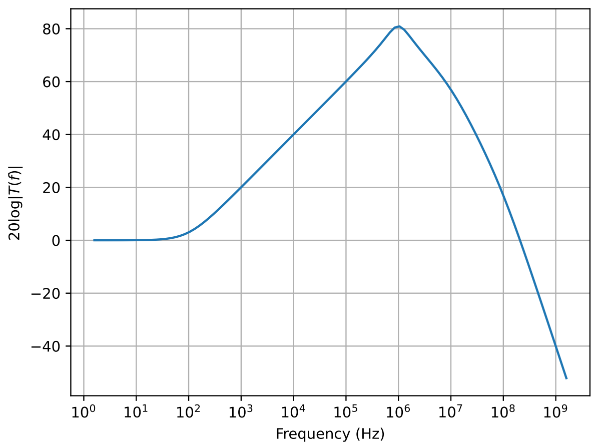

Fig. 7: Bode Plots of T(s)

The step response in spice is plotted using the following code in Fig. 8

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

We can observe that the step response shoots up to a very large value(10^{293}).This was a consequence for the initial system being unstable.

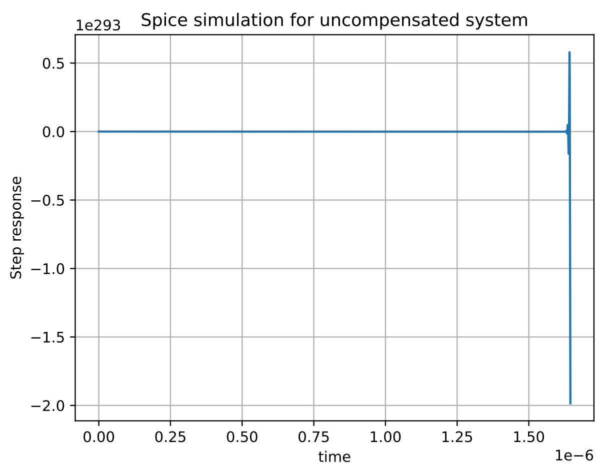

Fig. 8: Step response of Uncompensated System

The following netlist simulates the compensated system.

```
codes/ee18btech11026/spice/rc_bf.net
```

The step response in spice is plotted using the following code in Fig. 8

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

Here we can observe that the system has a transient response and it eventually goes to 1.

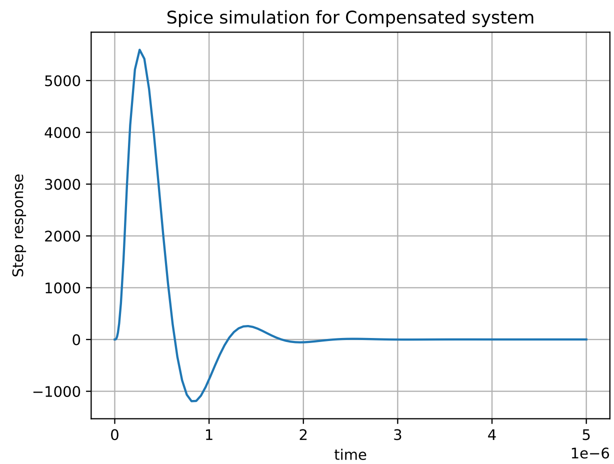

Fig. 8: Step response of Compensated System

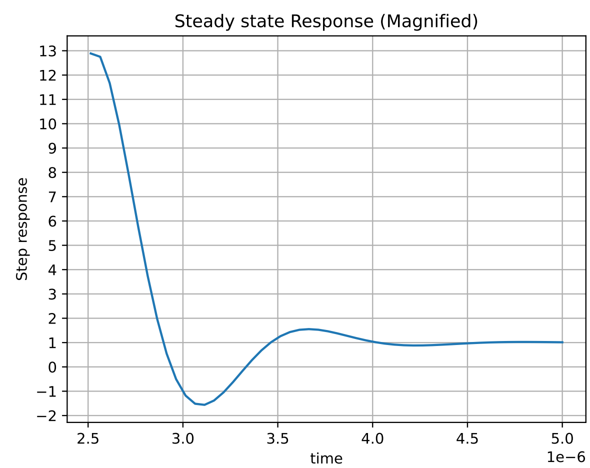

Fig. 8: Magnified Plot focussing on steady state

Fig. 8 shows how the circuit is actually implemented in spice using the parameters in Table 8

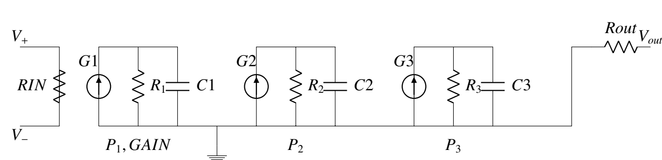

Fig. 8: Circuit resembling G(s)

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

TABLE 8