OPAMP Compensation

Kuntal Kokate *
ee18btech11028@iith.ac.in

1. The op amp in the circuit of Fig. 1.1 has an open-loop gain of 10^5 and a single-pole rolloff with $\omega_{3dB} = 10$ rad/s.

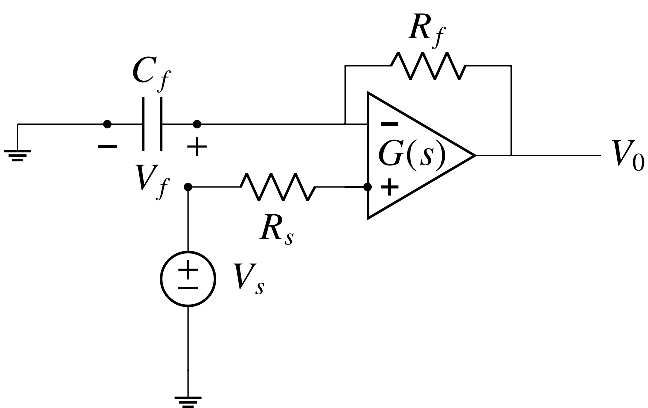

Fig. 1.1

Parameters	Value
C_f	0.01μF
R_s	$100k\Omega$
R_f	$100k\Omega$
P_{11}	10 rad/sec

TABLE 1

   (a)Sketch a Bode plot for the loop gain. (b) Find the frequency at which $|GH| = 1$, and find the corresponding phase margin. (c)Find the closed-loop transfer function, including its zero and poles. Sketch a pole-zero plot. Sketch the magnitude of the transfer function versus frequency, and label the important parameters on your sketch. (d) Find the unit step response of the system.

2. Sketch a Bode plot for the loop gain.
   Solution: Op-amp in our question has an open loop gain characterised by a single pole P_{11} from table 1 i.e.

$$G(s) = \frac{10^5}{1 + \frac{s}{P_{11}}} \tag{2.1}$$

   Also, feedback gain from Fig. 2.2,

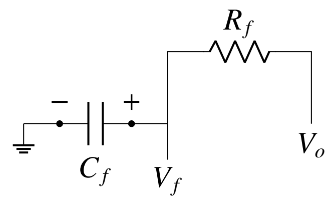

Fig. 2.2: Feedback loop

$$H(s) = \frac{V_f}{V_o} = \frac{\frac{1}{sC_f}}{R_f + \frac{1}{sC_f}} = \frac{1}{1 + \frac{s}{P_{21}}} \tag{2.2}$$

   where,

$$P_{21} = \frac{1}{R_f C_f} = 1000 \tag{2.3}$$

   The loop gain is,

$$GH(s) = \frac{10^5}{\left(1 + \frac{s}{10}\right)\left(1 + \frac{s}{1000}\right)} \tag{2.4}$$

   Corresponding plots are in Fig. 2.3 and Fig. 2.4 .

3. Find the frequency at which $|GH| = 1$, and find the corresponding phase margin.
   Solution: Value of ω for unity magnitude can be obtained from Fig. 2.3 which is approximately 3×10^4. More precise value can be obtained by solving for ω in,

$$\frac{10^5}{\sqrt{1 + \frac{w_1^2}{P_1^2}}\sqrt{1 + \frac{w_1^2}{P_2^2}}} = 1 \tag{3.1}$$

   Thus,

$$\omega_1 = 3.15 \times 10^4 rad/s \tag{3.2}$$

*The author is with the Department of Electrical Engineering, Indian Institute of Technology, Hyderabad 502285 India.

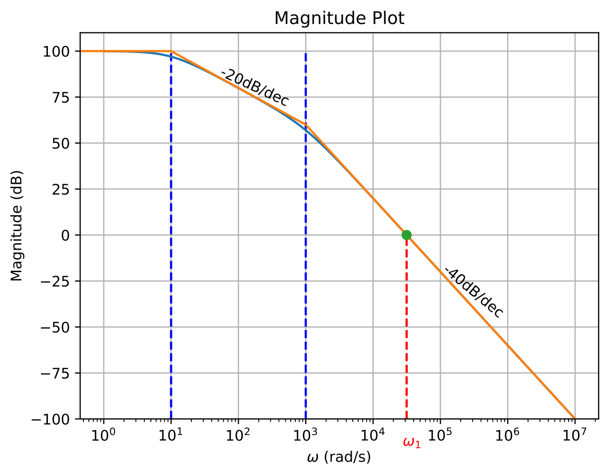

Fig. 2.3: Magnitude plot

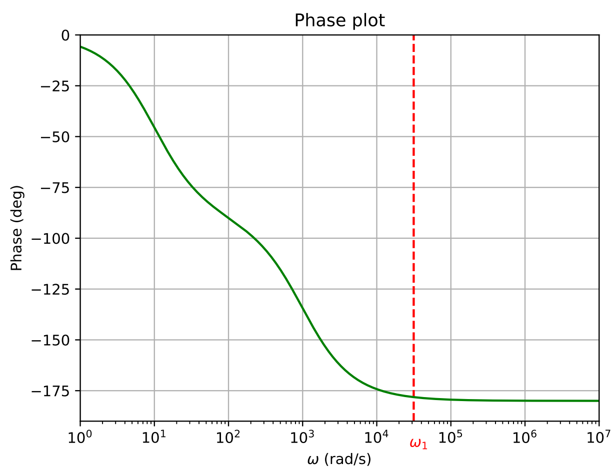

Fig. 2.4: Phase plot

The phase margin visibly from the Fig. 2.4 is very small.

$$PM = 180^\circ - \tan^{-1}\left(\frac{\omega_1}{10}\right) - \tan^{-1}\left(\frac{\omega_1}{1000}\right) = 1.84^\circ \tag{3.3}$$

4. Find the closed-loop transfer function, including its zero and poles. Sketch a pole-zero plot. Sketch the magnitude of the transfer function versus frequency, and label the important parameters on your sketch.
Solution:

$$T(s) = \frac{G(s)}{1 + G(s)H(s)} \tag{4.1}$$

$$\tag{4.2}$$

From (2.2) and (2.1) we have,

$$\implies T(s) = \frac{10^6(s + 1000)}{s^2 + 1010s + 10^4 + 10^9} \tag{4.3}$$

$$\tag{4.4}$$

Zeros of closed loop transfer function,

$$Z_1 = -1000 \tag{4.5}$$

Similarly for poles,

$$s^2 + 1010s + 10^4 + 10^9 = 0 \tag{4.6}$$

$$\implies P_1, P_2 = -505 \pm j31618.9 \tag{4.7}$$

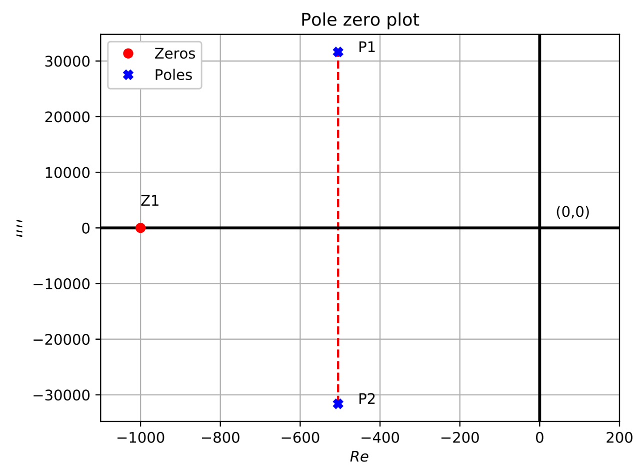

Fig. 4.5: Pole zero plot

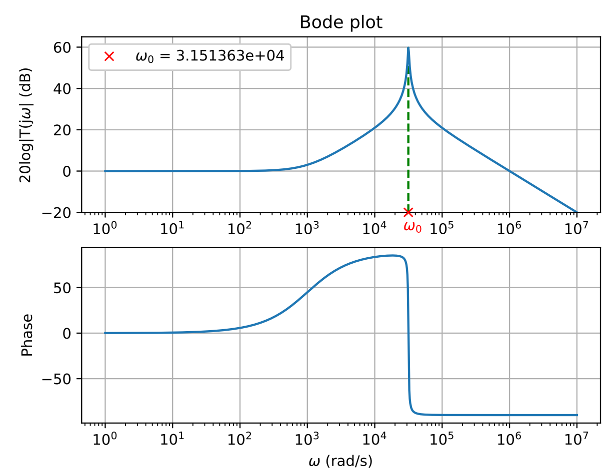

Fig. 4.6: Closed loop bode plot

Poles are at $\omega_0 = 3.16 \times 10^4$

5. Closed loop unit step response.
Solution:

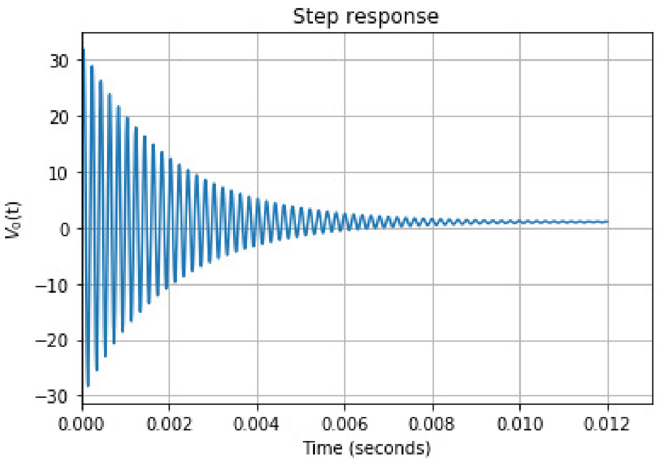

Fig. 5.7: Unit step response

From (4.4) Unit step response is,

$$Y_\gamma(s) = \frac{T(s)}{s} \tag{5.1}$$

We can calculate the steady state output voltage using Final value theorem,

$$\lim_{t\to\infty} V_o(t) = \lim_{s\to 0} sY_\gamma(s) \approx 1 \tag{5.2}$$

which is analogous to plot in fig. 5.7.

6. The following python code plots Fig. 2.3, Fig. 2.4, Fig. 4.5, Fig. 4.6 and Fig. 5.7.

```
codes/ee18btech11028/ee18btech11028_2.py
```

7. Simulate the circuit in Ngspice.
Solution: Following readme provides instructions about the simulation

```
codes/ee18btech11028/spice/README.md
```

The following netlist simulates the closed loop unit step response for circuit in fig. 1.1

```
codes/ee18btech11028/spice/step_response.
    net
```

which is plotted using python code in,

```
codes/ee18btech11028/spice/step.py
```

As can be noticed in fig. 7.8 there is very minute difference in amplitude of the initial response of the circuit due to non-ideal nature of the circuit components. But rest of the response is identical including the steady state output voltage of 1.

8. Circuit level schematic of op-amp used for simulation, is in fig. 8.9 Since we need a

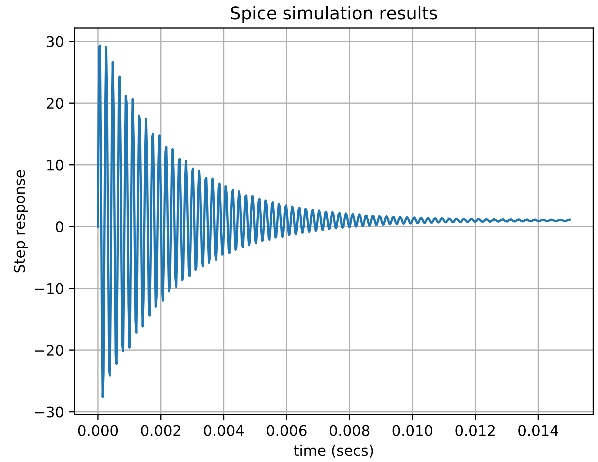

Fig. 7.8: spice simulation step response

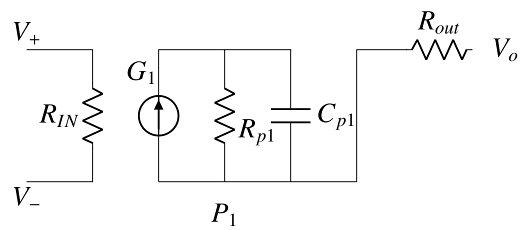

Fig. 8.9

single pole op-amp having $\omega_{3db} = 10 rad/s$ ($f_{p1} = \frac{10}{2\pi} Hz$), we choose a R_{p1} appropriately and calculate the value of C_{p1} according to our single pole roll off frequency.

$$R_{p1} = 1000\Omega \tag{8.1}$$

$$C_{p1} = \frac{1}{2\pi f_{p1} R_{p1}} \tag{8.2}$$

The values corresponding to the components used for op-amp are given in table 8.

Parameters	**Value**
R_{IN}	$100M\Omega$
R_{p1}	1000Ω
C_{p1}	100μF
G_1	$100k$
R_{out}	10Ω

TABLE 8