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.

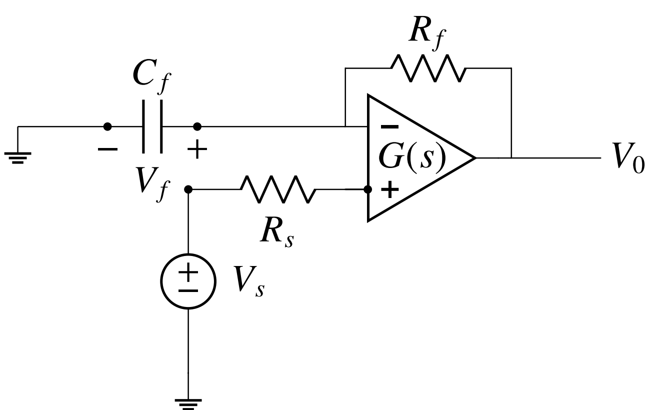

Fig. 1.1

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

TABLE 1

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.

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

Using voltage division on Fig. 1.1 we obtain,

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

$$\implies H(s) = \frac{1}{1 + \frac{s}{P_{21}}} \tag{2.3}$$

where,

$$P_{21} = \frac{1}{R_f C_f} = 1000 \tag{2.4}$$

The loop gain is,

$$GH(s) = \frac{10^5}{(1 + \frac{s}{10})(1 + \frac{s}{1000})} \tag{2.5}$$

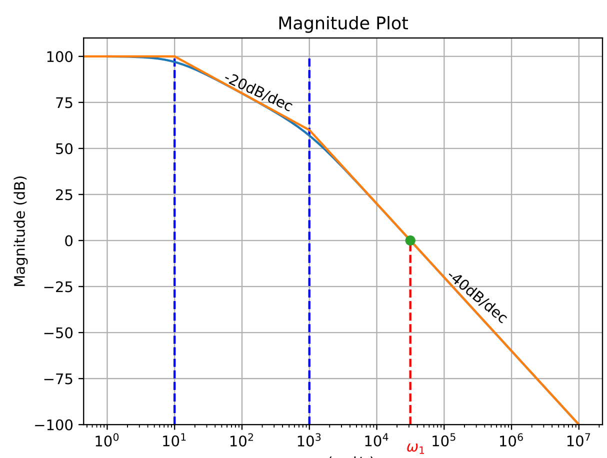

Fig. 2.2: Magnitude plot

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. 2.2 which is approximately 3×10^4. More precise value can be obtained by solving for ω in,

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

*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.

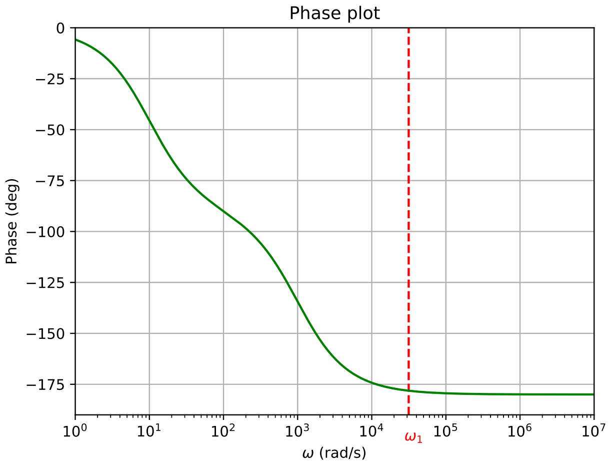

Fig. 2.3: Phase plot

Thus,

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

The phase margin visibly from the Fig. 2.3 is very small.

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

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 (2.3) 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,

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

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

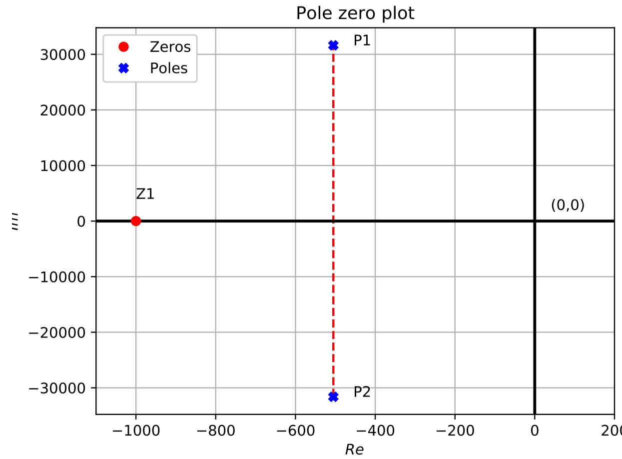

Fig. 4.4: Pole zero plot

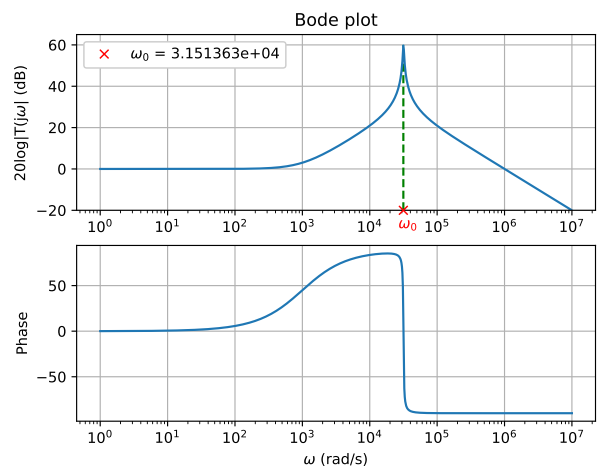

Fig. 4.5: Closed loop bode plot

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

5. Closed loop unit step response.
Solution:
From (4.4) Unit step response is,

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

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

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

which is analogous to circuit in fig. 5.6.

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

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

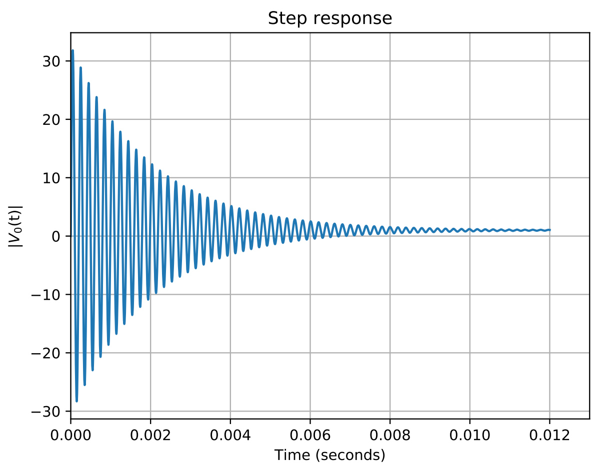

Fig. 5.6: Unit step response

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

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

of which data is stored in

```
codes/ee18btech11028/spice/ee18btech11028_sim.dat
```

which is plotted using python code in,

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

Simulation result,

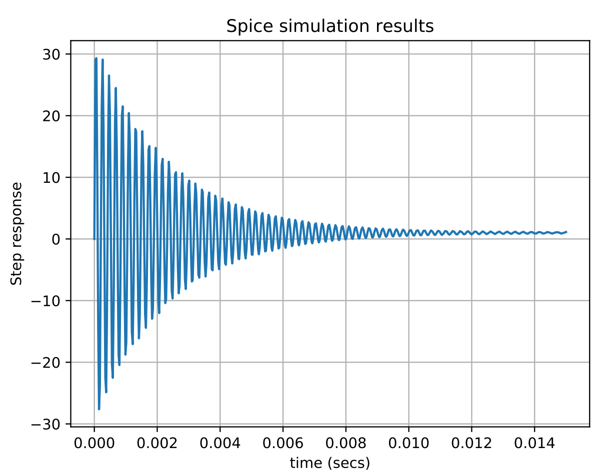

Fig. 6.7: spice simulation step response

There is very minute difference in amplitude of the initial response of the circuit due to non-ideal nature of the circuit componenets.

7. Circuit level schematic of op-amp used for simulation,

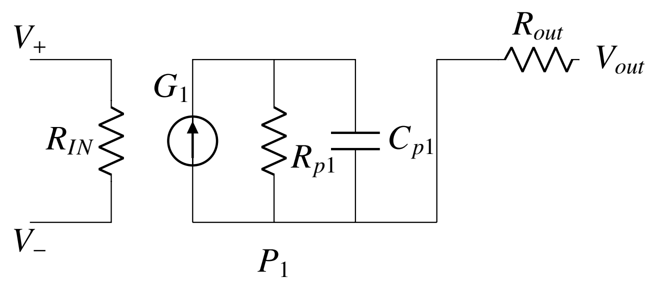

Fig. 7.8

Since we need a 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.

$$R_{p1} = 1000\Omega \tag{7.1}$$

$$C_{p1} = \frac{1}{2\pi f_{p1} R_{p1}} \tag{7.2}$$

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

TABLE 7

8. The following python code plots Fig. 2.2, Fig. 2.3, Fig. 4.4, Fig. 4.5 and Fig. 5.6.

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