OPAMP Compensation

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The op amp in the circuit of Fig. 0 has an open-loop gain of 10^5 and a single-pole rolloff with ω_{3dB} = 10 rad/s. The circuit parameters are given in Table 0

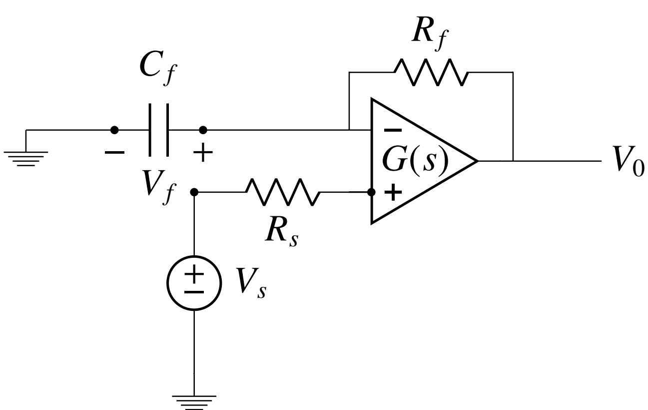

Fig. 0

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

TABLE 0

(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.

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1. Find $G(s)$.
Solution:
$$G(s) = \frac{10^5}{1 + \frac{s}{10}} \tag{1.1}$$
2. Find $H(s)$ by drawing the equivalent circuit.
Solution: From Fig. 2
$$H(s) = \frac{V_f}{V_o} = \frac{\frac{1}{sC_f}}{R_f + \frac{1}{sC_f}} = \frac{1}{1 + \frac{s}{P_{21}}} \tag{2.1}$$

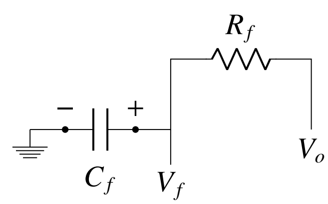

Fig. 2: Feedback loop

3. Sketch a Bode plot for the loop gain.
Solution: From Table 0,
$$P_{21} = \frac{1}{R_f C_f} = 1000 \tag{3.1}$$
The loop gain,
$$L(s) = G(s)H(s) = \frac{10^5}{\left(1 + \frac{s}{10}\right)\left(1 + \frac{s}{1000}\right)} \tag{3.2}$$
The amplitude and phase plots are available in Fig. 3.3 and Fig. 3.4 .
4. 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. 3.3 which is approximately 3×10^4. More precise value can be obtained by solving for ω in,
$$\frac{10^5}{\sqrt{1 + \frac{w_1^2}{P_1^2}}\sqrt{1 + \frac{w_1^2}{P_2^2}}} = 1 \tag{4.1}$$

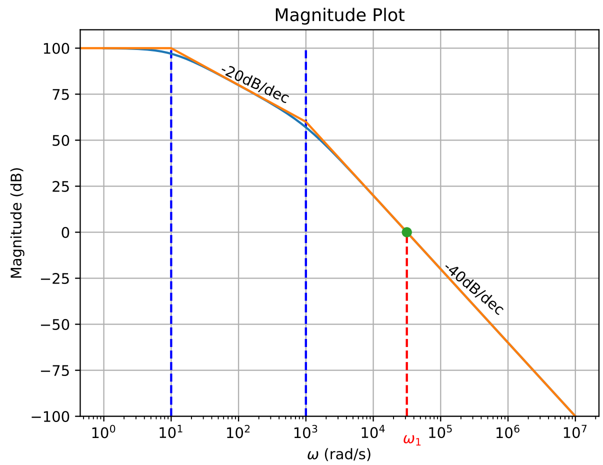

Fig. 3.3: Magnitude plot

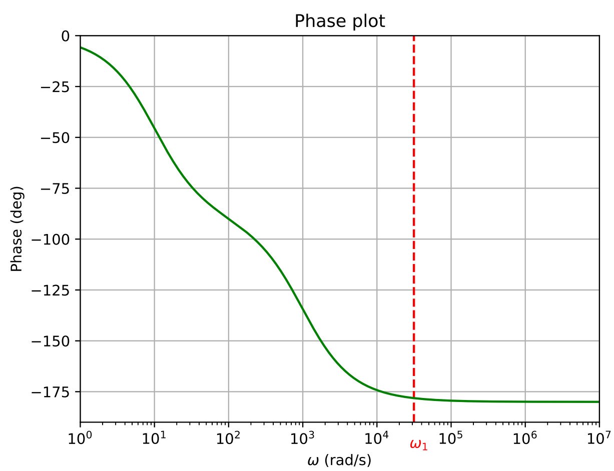

Fig. 3.4: Phase plot

Thus,

$$\omega_1 = 3.15 \times 10^4 rad/s \tag{4.2}$$

The phase margin visibly from the Fig. 3.4 is very small.

$$PM = 180^\circ - \tan^{-1}\left(\frac{\omega_1}{10}\right) - \tan^{-1}\left(\frac{\omega_1}{1000}\right) = 1.84^\circ \tag{4.3}$$

5. 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:

$$T(s) = \frac{G(s)}{1 + G(s)H(s)} \tag{5.1}$$

$$\tag{5.2}$$

From (2.1) and (1.1) we have,

$$\implies T(s) = \frac{10^6(s+1000)}{s^2 + 1010s + 10^4 + 10^9} \tag{5.3}$$

$$\tag{5.4}$$

Zeros of closed loop transfer function,

$$Z_1 = -1000 \tag{5.5}$$

Similarly for poles,

$$s^2 + 1010s + 10^4 + 10^9 = 0 \tag{5.6}$$

$$\implies P_1, P_2 = -505 \pm j31618.9 \tag{5.7}$$

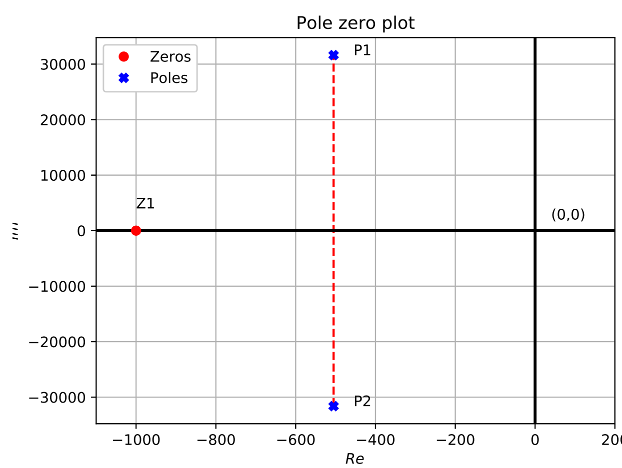

Fig. 5: Pole zero plot

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

6. Closed loop unit step response.
Solution:
From (5.4) Unit step response is,

$$Y_\gamma(s) = \frac{T(s)}{s} \tag{6.1}$$

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

$$\lim_{t\to\infty} V_o(t) = \lim_{s\to 0} sY_\gamma(s) \approx 1 \tag{6.2}$$

which is analogous to plot in fig. 6.

7. The following python code plots Fig. 3.3, Fig. 3.4, Fig. 5, Fig. 5 and Fig. 6.

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

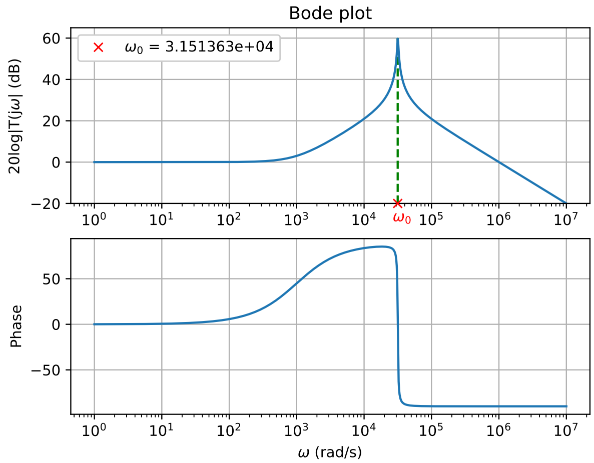

Fig. 5: Closed loop bode plot

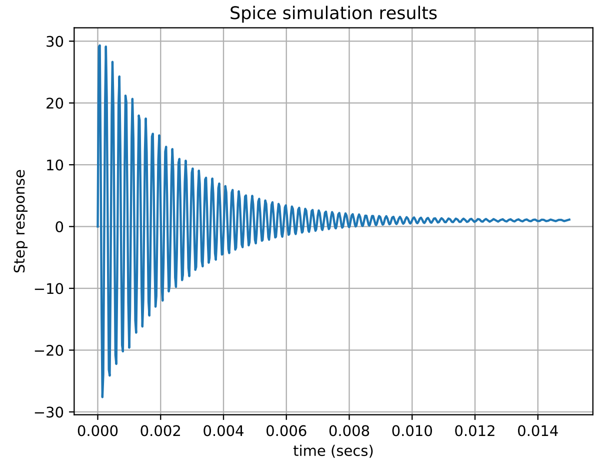

Fig. 8: spice simulation step response

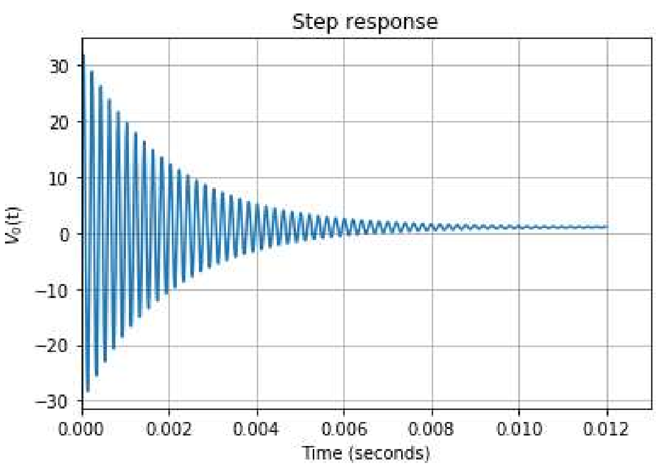

Fig. 6: Unit step response

8. 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. 0

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

which is plotted using python code in,

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

As can be noticed in fig. 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.

9. Circuit level schematic of op-amp used for simulation, is in fig. 9 Since we need a single pole

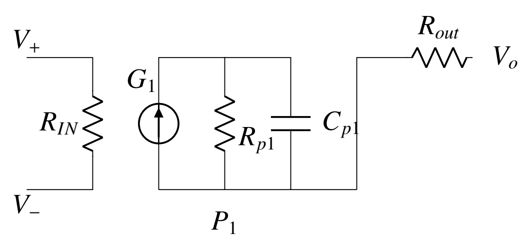

Fig. 9

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

$$R_{p1} = 1000\Omega \tag{9.1}$$

$$C_{p1} = \frac{1}{2\pi f_{p1} R_{p1}} \tag{9.2}$$

The values corresponding to the components used for op-amp are given in table 9.

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

TABLE 9