Feedback Circuits

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A dc amplifier having a single-pole response with pole frequency 10Hz and unity-gain frequency of 1MHz is operated in a loop whose frequency-independent feedback factor is 0.01. Find the low-frequency gain, the 3-dB frequency, and the unity-gain frequency of the closed-loop amplifier. By what factor does the pole shift?

1. Find $G(s)$.
Solution: The open-loop gain of the amplifier can be expressed as

$$G(s) = \frac{G_0}{1 + \frac{s}{\omega_p}} = \frac{G_0}{1 + \frac{s}{2\pi 10}} \tag{1.1}$$

Let $f_0 = 1$ MHz.

$$\because \left|G(\jmath\omega_0)\right| = 1, \tag{1.2}$$
$$\implies |G_0| = \left|1 + \jmath\frac{2\pi.10^6}{2\pi.10}\right| \tag{1.3}$$
$$\text{or, } G_0 \approx 10^5 \tag{1.4}$$

Thus,

$$G(s) = \frac{10^5}{1 + \frac{s}{2\pi 10}} \tag{1.5}$$

2. Given that $H = 0.01$, find $T(s)$.
Solution: From (1.5),

$$T(s) = \frac{G(s)}{1 + G(s)H(s)} \tag{2.1}$$
$$= \frac{99.90}{1 + \frac{s}{2\pi 10010}} \tag{2.2}$$

The block diagram is shown in Fig. 2.

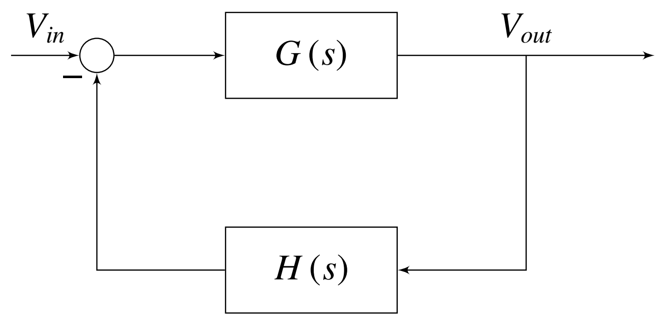

Fig. 2

Block diagram representation of the amplifier

3. Find the low frequency gain $T(0)$.
Solution: From (2.2)

$$T(0) = 99.900 \tag{3.1}$$

4. Find the 3-dB frequency of the closed loop amplifier.
Solution: From (2.2)

$$f_{3dB} = 10.01kHz \tag{4.1}$$

5. Find the unity gain frequency of the closed loop amplifier
Solution:

$$\left|T(\jmath\omega_1)\right| = 1 \tag{5.1}$$
$$\implies 99.90 = \left|1 + \frac{\jmath\omega}{2\pi 10010}\right| \tag{5.2}$$
$$\text{or, } f_1 = 999.94kHz \tag{5.3}$$

upon substitution from (2.2) and some algebra.

6. By what factor does the pole shift?
Solution: From (1.5) and (2.2), the ratio of the poles is

$$\frac{2\pi \times 10010}{2\pi \times 10} = 1001 \tag{6.1}$$

7. Tabulate the DC Gain, Bandwidth and Gain bandwidth product for $G(s)$ and $T(s)$.
Solution: See Table 7
$\therefore$, by using feedback we can get desired Gain of an amplifier while maintaining constant Gain Bandwidth product(for a first-order op-amp).
8. Design the circuit for H.

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	$G(s)$	$T(s)$
Gain	10^5	99.9
Band-width	20π	$20\pi.1001$
Gain band-width product	$2\pi.10^6$	$2\pi.10^6$

TABLE 7

Solution: See Fig. 8. For

$$R_1 = 10\Omega \tag{8.1}$$

$$R_f = 990\Omega, \tag{8.2}$$

$$H = \frac{V_f}{V_{out}} = \frac{R_1}{R_1 + R_f} \tag{8.3}$$

$$= 0.01 \tag{8.4}$$

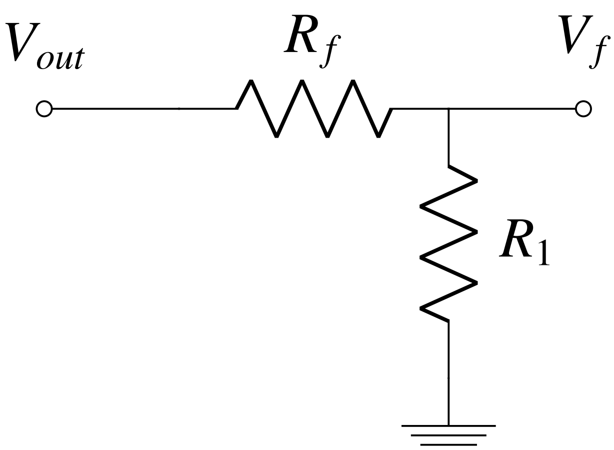

Fig. 8

9. Design the closed loop circuit for $T(s)$.
Solution: See Fig. 9. Table 9 lists the various parameters.

Circuit Element	Parameter Value
Op-amp Gain	10^5
Op-amp pole	$10Hz$
R_1	10Ω
R_f	990Ω

TABLE 9

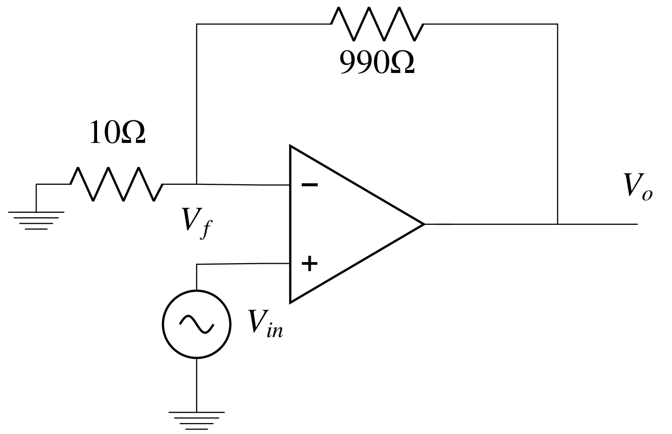

Fig. 9

10. Verify the gain of closed loop Circuit using spice
Solution: Follow the Instructions for SPICE simulation:

spice/README.md

Netlist file for simulation:

spice/ee18btech11035_spice2.net

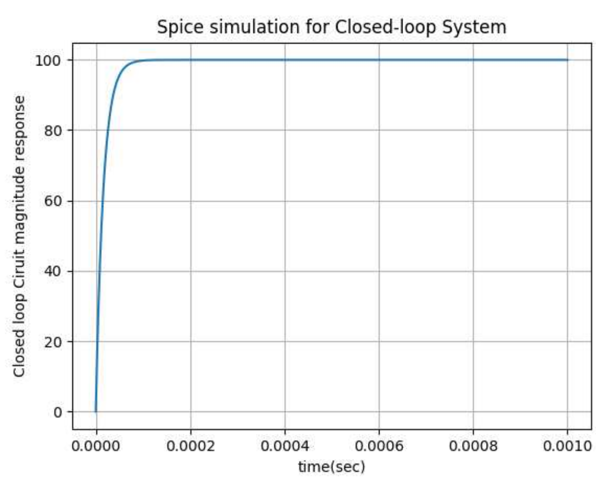

Fig. 10.1: Spice simulation of Closed-loop Transfer Function

The following python code plots the spice output in Fig. 10.1.

codes/ee18btech11035_spice2.py

The following code generates Fig. 10.2.

codes/ee18btech11035_pythonverify2.py

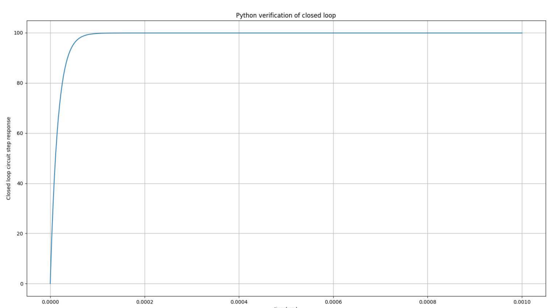

Fig. 10.2: Python verification of closed-loop Transfer Function