DC Amplifier

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A DC amplifier has an open loop gain of 1000 and two poles, a dominant one at 1kHz and a high frequency one whose location can be controlled. It is required to connect this amplifier in a negative feedback loop that provides a DC closed loop gain of 10 and a maximally flat response.

1. Find the required value of H.
   Solution: Table 1 summarises the given information. The open loop gain can be expressed as

$$G(s) = \frac{G_0}{\left(1 + \frac{s}{p_1}\right)\left(1 + \frac{s}{p_2}\right)} \tag{1.1}$$

$$\implies G(0) = G_0 \tag{1.2}$$

The closed loop gain

$$T(s) = \frac{G(s)}{1 + G(s)H} \tag{1.3}$$

$$\implies T(0) = \frac{G_0}{1 + G_0 H} \tag{1.4}$$

Substituting from Table 1,

$$\frac{1000}{1 + 1000H} = 10 \tag{1.5}$$

$$\implies H = 0.099 \tag{1.6}$$

Parameter	Value
dc open loop gain G_0	1000
dominant pole p_1	1000Hz
insignificant pole	p_2
dc closed loop gain $T(0)$	10

TABLE 1: 1

$$G_0 = 1000 \tag{1.7}$$

$$\text{Therefore.,} G(s) = \frac{1000}{(1 + \frac{s}{p_1})(1 + \frac{s}{p_2})} \tag{1.8}$$

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2. Find p_2.
   Solution: From (1.3) and (1.1),

$$T(s) = \frac{p_1 p_2 G_0}{s^2 + (p_1 + p_2)s + (HG_0 + 1)p_1 p_2} \tag{2.1}$$

$$= \frac{K\omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2} \tag{2.2}$$

$$\omega_n = \sqrt{(HG_0 + 1)p_1 p_2}$$

$$\implies \zeta = \frac{p_1 + p_2}{2\sqrt{(HG_0 + 1)p_1 p_2}} \tag{2.3}$$

using the standard forumulation for a second order system. Also, for maximally flat response, the quality factor

$$Q = \frac{1}{2\zeta} = \frac{1}{\sqrt{2}} \tag{2.4}$$

$$\implies \zeta = \sqrt{2} \tag{2.5}$$

$$\implies \frac{p_1 + p_2}{2\sqrt{(HG_0 + 1)p_1 p_2}} = \sqrt{2} \tag{2.6}$$

$$\implies \sqrt{\frac{p_1}{p_2}} + \sqrt{\frac{p_2}{p_1}} = 2\sqrt{2(HG_0 + 1)} \tag{2.7}$$

The above equation is of the form

$$x + \frac{1}{x} = 2a \tag{2.8}$$

$$\implies x = a \pm \sqrt{a^2 - 1} \tag{2.9}$$

Substituting

$$x = \sqrt{\frac{p_2}{p_1}} \tag{2.10}$$

$$a = \sqrt{2(HG_0 + 1)}, \tag{2.11}$$

$$p_2 = p_1 \left\{\sqrt{2\left(HG_0 + 1\right)} \pm \sqrt{2\left(HG_0 + 1\right) - 1}\right\}^2 \tag{2.12}$$

The following code computes the values

```
codes/ee18btech11005/ee18btech11005_1.py
```

3. Obtain $G(s)$ and $T(s)$
Solution: Substituting the value of p_2 in (1.1) and (2.1),

$$G(s) = \frac{1000}{(1+\frac{s}{2\pi 10^3})(1+\frac{s}{1.244x10^6})} \tag{3.1}$$

$$T(s) = \frac{10}{0.128x10^{-11}s^2 + 1.599x10^{-6}s + 1} \tag{3.2}$$

4. Verify from the Bode plot of above closed loop transfer function that it has maximally flat response.
Solution: The following code generates the bode plot of the transfer function in Fig. 4.

```
codes/ee18btech11005/ee18btech11005_2.py
```

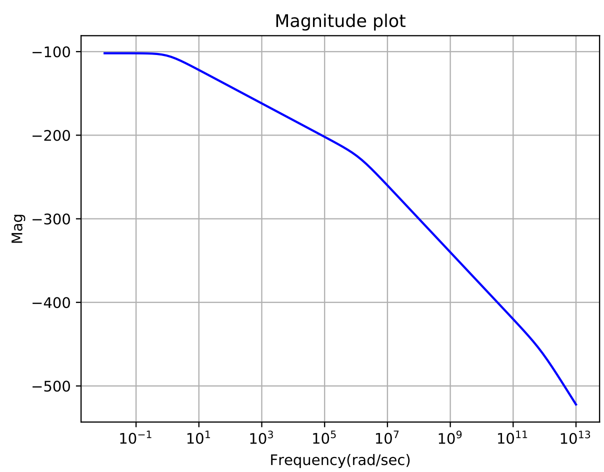

Fig. 4

5. Find the step response of $T(s)$
Solution: The following code generates the desired response of in Fig. 5.

```
codes/ee18btech11005/ee18btech11005_3.py
```

6. Design a circuit that represents the above transfer function.
Solution: The circuit can be designed using an operational amplifiers having negative feedback.Consider the circuit shown in figure.6:1.Assume the gain of all the amplifiers are large.And assume no zero state response.Take the parameters in s-domain.
For the first amplifier.., Applying KCL at

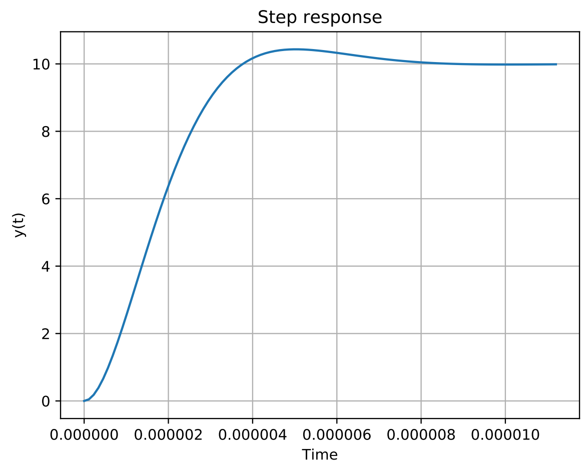

Fig. 5

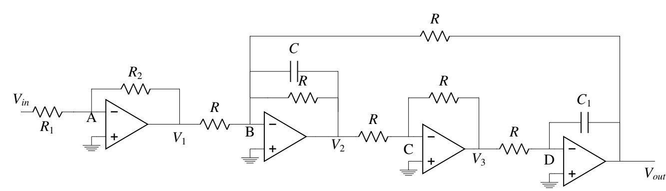

Fig. 6: 1

node A., Since, the opamp has large gain, potential at node A is assumed to be zero due to virtual short at node A.

$$\frac{0 - V_{in}(s)}{R_1} + \frac{0 - V_1(s)}{R_2} = 0 \tag{6.1}$$

$$\frac{V_{in}(s)}{R_1} = \frac{V_1(s)}{R_2} \tag{6.2}$$

$$\implies V_{in} = -\frac{V_1(s)R_1}{R_2} \tag{6.3}$$

For the second amplifier.., Applying KCL at node B.., Similarly potential at node B is zero.

$$\frac{-V_1(s)}{R} + \frac{-V_2(s)}{R} - sCV_2(s) + \frac{-V_{out}(s)}{R} = 0 \tag{6.4}$$

$$\frac{-V_1(s)}{R} + \frac{-V_2(s)}{R} - sCV_2(s) = \frac{V_{out}(s)}{R} \tag{6.5}$$

$$\frac{-V_1(s)}{R} = V_2(s)\left[sC + \frac{1}{R}\right] + \frac{Vout(s)}{R} \tag{6.6}$$

For the third amplifier.., Potential at node C is zero(Due to high gain of amplifier).Applying

KCL at node C.

$$\frac{-V_2(s)}{R} + \frac{-V_3(s)}{R} = 0 \tag{6.7}$$

$$\implies V_2(s) = -V_3(s) \tag{6.8}$$

For the Fourth amplifier., Potential at node D is zero.Applying KCL at node D.

$$\frac{-V_3(s)}{R} + sC_1(-V_{out}(s)) = 0 \tag{6.9}$$

$$V_3(s) = -sC_1RV_{out}(s) \tag{6.10}$$

From equation.6.10 and equation. 6.8..,

$$V_2(s) = sC_1RV_{out}(s) \tag{6.11}$$

Substituting the equation.6.6 and equation.6.11,

$$\frac{-V_1(s)}{R} = (s^2C_1CR + sC_1)V_{out}(s) + \frac{V_{out}(s)}{R} \tag{6.12}$$

$$V_1(s) = -(s^2C_1CR^2 + sC_1R + 1)V_{out}(s) \tag{6.13}$$

from equation.6.3 and equation.6.13.

$$V_1(s) = \frac{R_1}{R_2}(s^2C_1CR^2 + sC_1R + 1)V_{out}(s) \tag{6.14}$$

$$\frac{V_{out}(s)}{V_{in}(s)} = \frac{R_2}{R_1(s^2C_1CR^2 + sC_1R + 1)} \tag{6.15}$$

Comparing equation.3.3 and equation.6.15

$$\frac{R_2}{R_1} = 10 \tag{6.16}$$

$$C_1CR^2 = 0.128x10^{-11} \tag{6.17}$$

$$C_1R = 1.599x10^{-6}F \tag{6.18}$$

$$\text{Let.,}R = 1000\Omega \tag{6.19}$$

$$\implies C_1 = 1.599x10^{-9} \tag{6.20}$$

$$\text{and.,}C_1CR^2 = 0.128x10^{-11} \tag{6.21}$$

$$\implies C = 0.8005x10^{-9}F \tag{6.22}$$

$$\text{Let..,}R_1 = 100\Omega \tag{6.23}$$

$$\implies R_2 = 1000\Omega \tag{6.24}$$

From Table.6:1. The Final circuit is shown in figure.6

Parameter	**Value**
R_1	100 Ω
R_2	1000 Ω
R	1000 Ω
C	0.8005 nF
C_1	1.599 nF

TABLE 6: 1

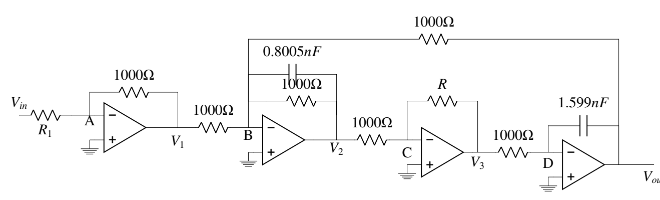

Fig. 6: 1