Feedback current amplifier

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The feedback current amplifier in Fig. 1.1 utilizes an op amp with an input differential resistance R_{id}, an open-loop gain μ , and an output resistance r_o. The output current I_o that is delivered to the load resistance R_L is sensed by the feedback network composed of the two resistances R_M and R_F and a fraction I_f, is fed back to the amplifier input node. Find expressions for $G = \frac{I_o}{I_i}$, $H = \frac{I_f}{I_o}$ and $T = \frac{I_o}{I_s}$, assuming that the feedback causes the voltage at the input node to be near ground. If the loop gain is large, what does the closed-loop current gain become? State precisely the condition under which this is obtained. For $\mu = 10^4$ V/V, R_{id} = 1 MΩ, r_o = 100 Ω, R_L = 10 kΩ , R_M = 100 Ω , and R_F = 10 kΩ, find G, H, and T.

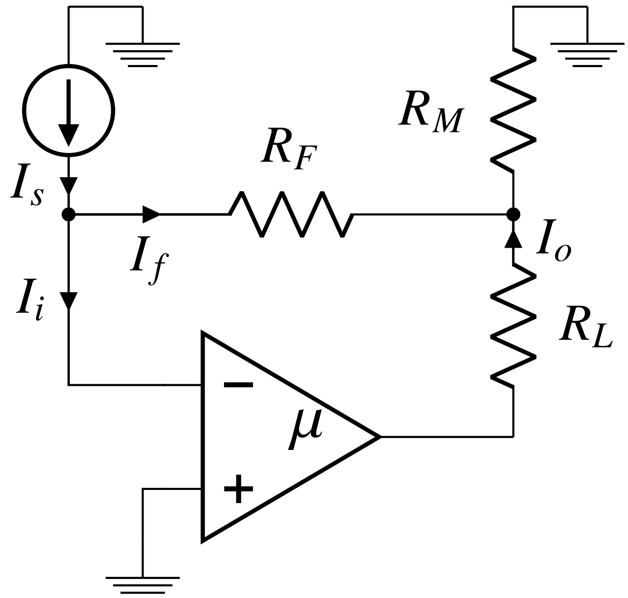

Fig. 1.1

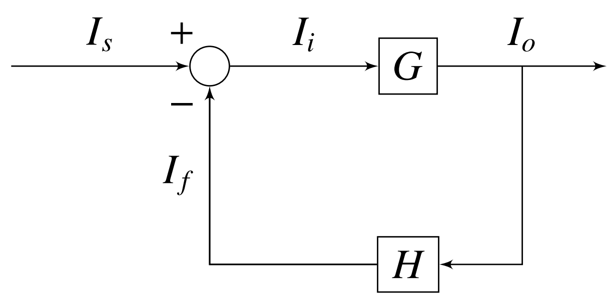

Fig. 1.2

1. Fig. 1.1 shows a feedback current amplifier. Draw the equivalent control system.
   Solution: See fig 1.2

2. Refer table 2 for the parameters and draw the small signal equivalent model of the fig 1.1
   Solution: See fig 2

Component	Description
R_{id}	Input Resistance of Op Amp
R_{out}	Output Resistance of Op Amp
I_s	Input Current
I_o	Output Current
R_M, R_F	Feedback Resistances
R_L	Load Resistance

TABLE 2

3. Given G (open-loop gain), H (feedback gain) and T (closed-loop gain) as

$$G = \frac{I_o}{I_i} \tag{3.1}$$

$$H = \frac{I_f}{I_o} \tag{3.2}$$

$$T = \frac{I_o}{I_s} \tag{3.3}$$

Find G and H as a function of the resistances.
Solution: Refer fig. 2,

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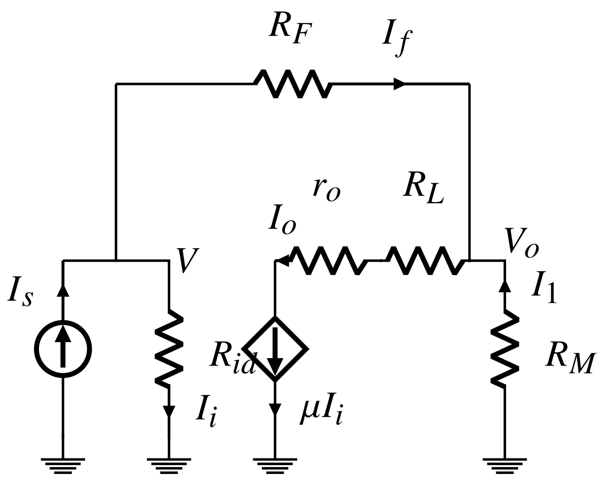

Fig. 2

We get,

$$I_o = \mu I_i \tag{3.4}$$

$$\implies G = \frac{I_o}{I_i} = \mu \tag{3.5}$$

Using nodal analysis, we get,

$$I_s = I_f + I_i \tag{3.6}$$

And,

$$I_o = I_1 + I_f \tag{3.7}$$

$$\implies \mu i_i = I_1 + I_f \tag{3.8}$$

Also,

$$V_o = -I_f R_F \tag{3.9}$$

$$V = I_i R_i \tag{3.10}$$

$$V - V_o = I_f R_F \tag{3.11}$$

Using above equations,

$$I_i R_{id} + I_1 R_M = I_f R_F \tag{3.12}$$

Therefore, from eq. 3.8 and eq. 3.12, we get,

$$I_i \frac{R_{id}}{R_M} + \mu I_i - I_f = I_f \frac{R_F}{R_M} \tag{3.13}$$

$$\implies \frac{I_f}{I_i} = \frac{\frac{R_{id}}{R_M} + \mu}{1 + \frac{R_F}{R_M}} \tag{3.14}$$

So,

$$H = \frac{I_f}{I_o} = \frac{I_f}{\mu I_i} \tag{3.15}$$

$$\implies H = \frac{1}{\mu}\left(\frac{\frac{R_{id}}{R_M} + \mu}{1 + \frac{R_F}{R_M}}\right) \tag{3.16}$$

Now using eq. 3.6 and eq. 3.16, we get,

$$I_s = \left(\frac{\frac{R_{id}}{R_M} + \mu}{1 + \frac{R_F}{R_M}} + 1\right) I_i \tag{3.17}$$

So,

$$T = \frac{I_o}{I_s} = \frac{\mu I_i}{I_s} \tag{3.18}$$

$$\implies T = \mu\left(\frac{1 + \frac{R_F}{R_M}}{\mu + 1 + \frac{R_{id}}{R_M} + \frac{R_F}{R_M}}\right) \tag{3.19}$$

4. What will be closed-loop gain(T) if $\mu \to \infty$
   Solution: From eq. 3.19 we get,

$$T = \mu\left(\frac{1 + \frac{R_F}{R_M}}{\mu + 1 + \frac{R_{id}}{R_M} + \frac{R_F}{R_M}}\right) \tag{4.1}$$

$$T = \frac{1 + \frac{R_F}{R_M}}{1 + \frac{1}{\mu} + \frac{R_{id}}{\mu R_M} + \frac{R_F}{\mu R_M}} \tag{4.2}$$

   Applying the limit, we get,

$$\implies T = 1 + \frac{R_F}{R_M} \tag{4.3}$$

5. Refer table 5 and find G, H and T
   Solution: Using eqs. 3.5, 3.16 and 3.19

Component	Value
μ	10^4
R_{id}	$1\ M\Omega$
r_o	$100\ \Omega$
R_L	$10\ \mathrm{k}\Omega$
R_M	$100\ \Omega$
R_F	$10\ \mathrm{k}\Omega$

TABLE 5

We get,

$$G = \mu = 10^4 \tag{5.1}$$

$$H = \frac{1}{\mu}\left(\frac{\frac{R_{id}}{R_M} + \mu}{1 + \frac{R_F}{R_M}}\right) = 1.98 \times 10^{-2} \tag{5.2}$$

$$T = \mu\left(\frac{1 + \frac{R_F}{R_M}}{\mu + 1 + \frac{R_{id}}{R_M} + \frac{R_F}{R_M}}\right) = 50.25 \tag{5.3}$$

6. Tabulate your results.
Solution: Refer table 6,

Gain	Value
G	10^4
H	9.9×10^{-3}
T	100

TABLE 6

7. Simulate the circuit 1.1 using spice simulators and plot the generated output of the gains using python script
Solution: Refer fig. 7.4, 7.5 and 7.6 for the plots.
Find the netlist of the simulated circuit here:

```
codes/ep18btech11016/spice/
    ep18btech11016.net
```

Python code used for generating the output:

```
codes/ep18betch11016/spice/
    ep18btech11016.py
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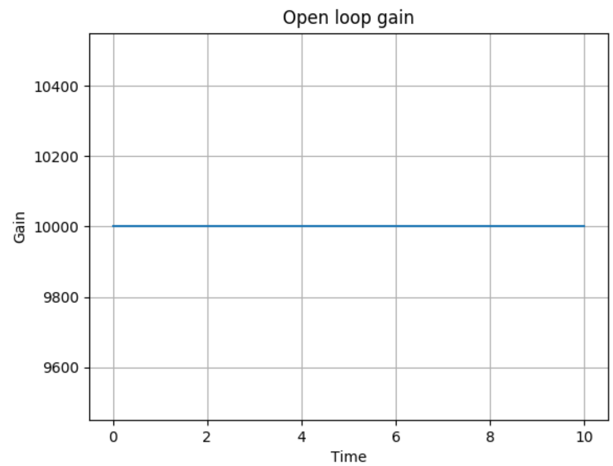

Fig. 7.4

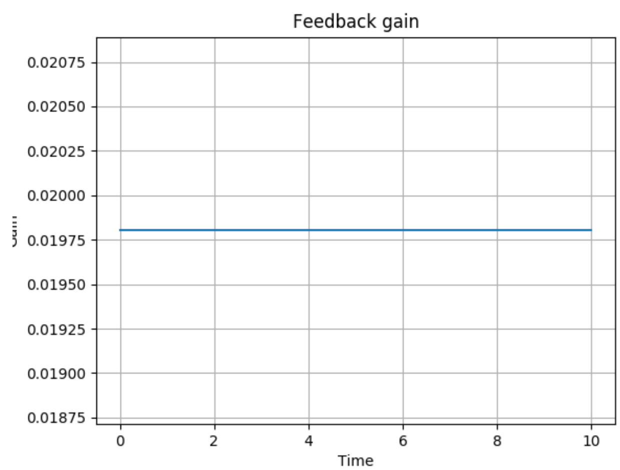

Fig. 7.5

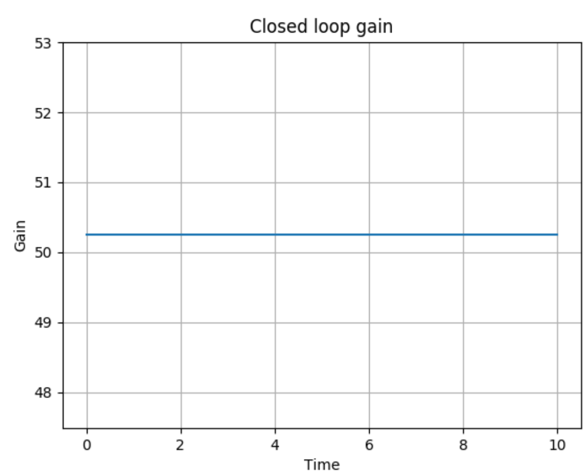

Fig. 7.6