

Feedback Transconductance Amplifier

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Consider a feedback transconductance amplifier as shown in the figure. It utilizes an op amp with open-loop gain μ , very large resistance, and an NMOS transistor Q . The amplifier delivers its output current to R_L . The feedback network, composed of resistor R , senses the equal current in the source terminal of Q and delivers a proportional voltage V_f to the negative input terminal of the op amp.

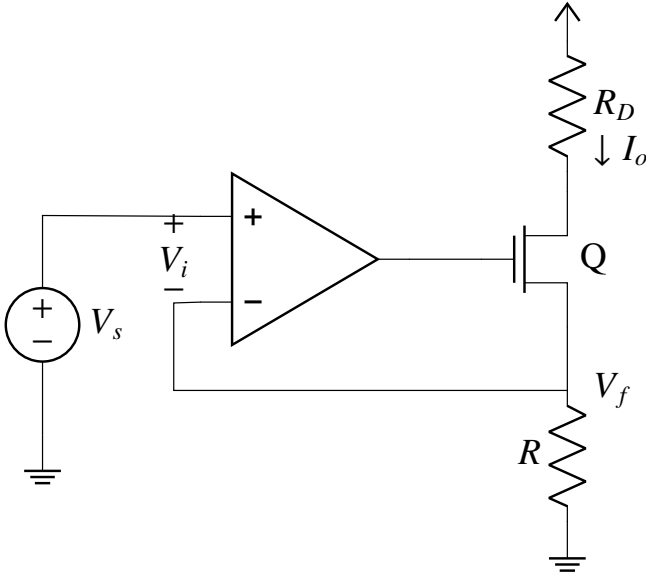


Fig. 0

1. Show that the feedback is negative.
2. Open the feedback loop by breaking the connection of R to the negative input of the op amp and grounding the negative input terminal. Find an expression for $G \equiv \frac{I_o}{V_i}$
3. Find an expression for $H \equiv \frac{V_f}{I_o}$
4. Find an expression for $T \equiv \frac{I_o}{V_s}$
5. What is the condition to obtain $I_o \approx \frac{V_s}{R}$

1. Show that the feedback is negative.

Solution: Suppose if source voltage V_s increases, then V_G increases
Since,

$$I_o = \frac{1}{2} \mu_n C_{ox} \frac{W}{L} (V_{GS} - V_{TH})^2 \quad (1.1)$$

$$I_o = \frac{1}{2} \mu_n C_{ox} \frac{W}{L} (V_G - V_f - V_{TH})^2 \quad (1.2)$$

which thereby increases I_o

Now, since I_o is increasing,

$V_f (= I_o R)$ increases.

and V_f is feedback to negative terminal of the amplifier.

Hence, the system is in negative feedback.

2. Find an expression for $G \equiv \frac{I_o}{V_i}$

Solution: Applying small signal analysis, we get the resultant circuit as follows

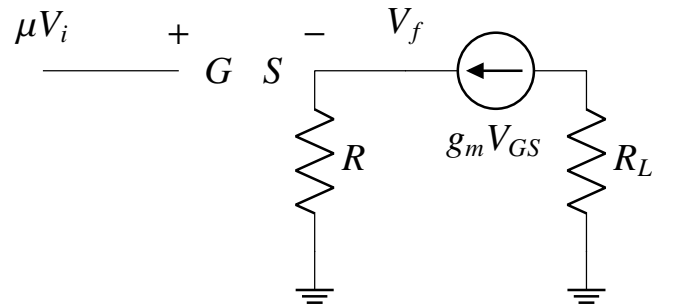


Fig. 2

$$V_f = I_o R \quad (2.1)$$

and

$$I_o = g_m (\mu V_i - V_f) \quad (2.2)$$

$$= g_m (\mu V_i - I_o R) \quad (2.3)$$

$$\Rightarrow (1 + g_m R) I_o = g_m \mu V_i \quad (2.4)$$

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Therefore,

$$G \equiv \frac{I_o}{V_i} = \frac{g_m \mu}{1 + g_m R} \quad (2.5)$$

3. Find an expression for $H \equiv \frac{V_f}{I_o}$

Solution: From the circuit diagram, Fig: 0

$$V_f = I_o R \quad (3.1)$$

Therefore,

$$H \equiv \frac{V_f}{I_o} = R \quad (3.2)$$

4. Find an expression for $T \equiv \frac{I_o}{V_s}$

Solution: Applying small signal analysis, we get the resultant circuit as follows

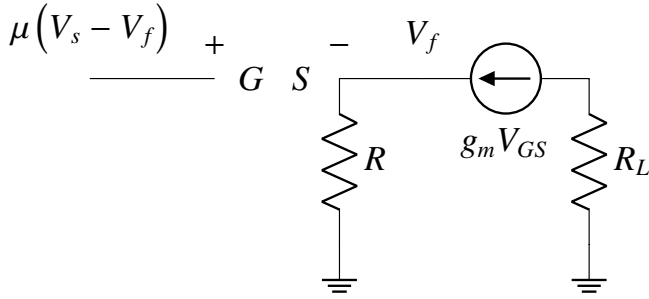


Fig. 4

$$I_o = g_m V_{GS} \quad (4.1)$$

$$= g_m (\mu (V_s - V_f) - V_f) \quad (4.2)$$

$$= g_m (\mu V_s - (\mu + 1) V_f) \quad (4.3)$$

$$= g_m \mu V_s - g_m (\mu + 1) I_o R \quad (4.4)$$

$$\Rightarrow (1 + g_m (\mu + 1) R) I_o = g_m \mu V_s \quad (4.5)$$

$$(4.6)$$

Therefore,

$$T \equiv \frac{I_o}{V_s} = \frac{g_m \mu}{1 + g_m (\mu + 1) R} \quad (4.7)$$

5. What is the condition to obtain $I_o \approx \frac{V_s}{R}$

Solution: From the circuit diagram, Fig: 0

$$I_o = \frac{1}{2} \mu_n C_{ox} \frac{W}{L} (V_{GS} - V_{TH})^2 \quad (5.1)$$

$$I_o = \frac{1}{2} \mu_n C_{ox} \frac{W}{L} (V_G - V_f - V_{TH})^2 \quad (5.2)$$

and

$$V_f = I_o R \quad (5.3)$$

$$\Rightarrow I_o = \frac{1}{2} \mu_n C_{ox} \frac{W}{L} (\mu V_s - (\mu + 1) I_o R - V_{TH})^2 \quad (5.4)$$

If

$$I_o \ll \frac{\mu_n C_{ox} W}{2L} \quad (5.5)$$

and

$$\mu \gg 1 \quad (5.6)$$

From equation (5.4), we get

$$\sqrt{\frac{2I_o}{\mu_n C_{ox} \frac{W}{L}}} \ll \mu V_s - (\mu + 1) I_o R \quad (5.7)$$

$$(5.8)$$

then,

$$\mu V_s \approx (\mu + 1) I_o R - V_{TH} \quad (5.9)$$

which can be approximated to

$$V_s \approx I_o R \quad (5.10)$$

Thus, $\mu \gg 1$ and $I_o \ll \frac{\mu_n C_{ox} W}{2L}$ are the conditions to obtain $V_s \approx I_o R$