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 propotional voltage V_f to the negative input terminal of the op amp.

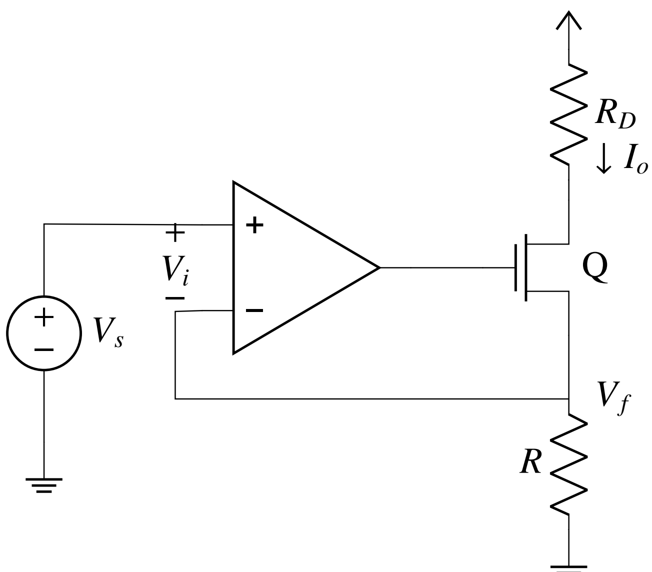

Fig. 0

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 $A \equiv \frac{I_o}{V_i}$
3. Find an expression for $\beta \equiv \frac{V_f}{I_o}$
4. Find an expression for $A_f \equiv \frac{I_o}{V_s}$
5. What is the condition to obtain $I_o \approx \frac{V_s}{R}$

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1. Show that the feedback is negative.
   Solution: Suppose if source voltage V_s increases, then V_G increases
   Since,

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

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

which thereby increases I_o

Now, since I_o is increasing,
$V_f\,(= I_oR)$ increases.
and V_f is feedback to negative terminal of the amplifier.
Hence, the system is in negative feedback.

2. Find an expression for $A \equiv \frac{I_o}{V_i}$
   Solution: Applying small signal analysis, we get the resultant circuit as follows

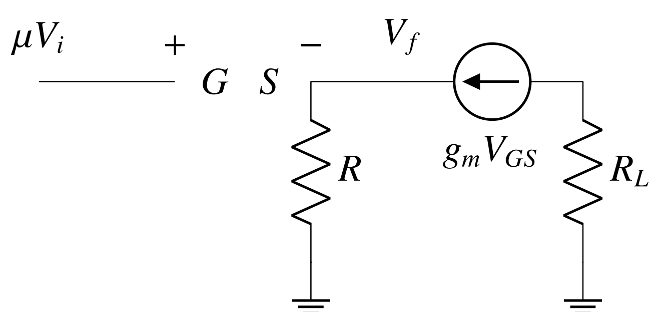

Fig. 2

$$V_f = I_oR \tag{2.1}$$

and

$$I_o = g_m\left(\mu V_i - V_f\right) \tag{2.2}$$

$$= g_m\left(\mu V_i - I_oR\right) \tag{2.3}$$

$$\implies (1 + g_mR)\,I_o = g_m\mu V_i \tag{2.4}$$

Therefore,

$$A \equiv \frac{I_o}{V_i} = \frac{g_m \mu}{1 + g_m R} \tag{2.5}$$

3. Find an expression for $\beta \equiv \frac{V_f}{I_o}$
   Solution: From the circuit diagram, Fig: 0

$$V_f = I_o R \tag{3.1}$$

Therefore,

$$\beta \equiv \frac{V_f}{I_o} = R \tag{3.2}$$

4. Find an expression for $A_f \equiv \frac{I_o}{V_s}$
   Solution: Applying small signal analysis, we get the resultant circuit as follows

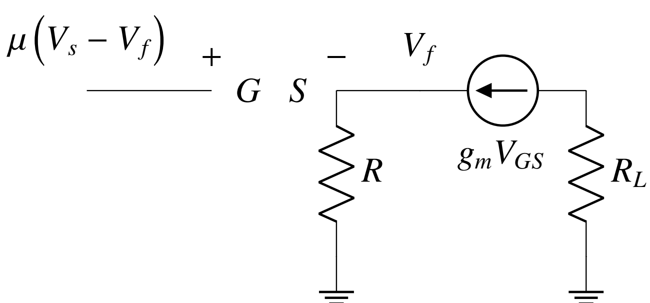

Fig. 4

$$\begin{aligned} I_o &= g_m V_{gs} &(4.1)\\ &= g_m\left(\mu\left(V_s - V_f\right) - V_f\right) &(4.2)\\ &= g_m\left(\mu V_s - (\mu+1) V_f\right) &(4.3)\\ &= g_m \mu V_s - g_m (\mu+1) I_o R &(4.4)\\ \implies (1 + g_m(\mu+1)R) I_o &= g_m \mu V_s &(4.5)\\ & &(4.6) \end{aligned}$$

Therefore,

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

5. What is the condition to obtain $I_o \approx \frac{V_s}{R}$
   Solution: From the circuit diagram, Fig: 0

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

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

and

$$V_f = I_o R \tag{5.3}$$

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

If

$$I_o << \frac{\mu_n C_{ox} W}{2L} \tag{5.5}$$

and

$$\mu >> 1 \tag{5.6}$$

From equation (5.4), we get

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

$$\tag{5.8}$$

then,

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

which can be approximated to

$$V_s \approx I_o R \tag{5.10}$$

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