

# Feedback Voltage Amplifier

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**Abstract**—This manual is an introduction to control systems in feedback circuits. Links to sample Python codes are available in the text.

Download python codes using

svn co <https://github.com/gadepall/school/trunk/control/feedback/codes>

1 FEEDBACK VOLTAGE AMPLIFIER: SERIES-SHUNT

2 FEEDBACK CURRENT AMPLIFIER: SHUNT-SERIES

## 2.1 Ideal Case

2.1. The feedback current amplifier in fig.2.1a can be thought of as a super CG transistor. Note that rather than connecting the gate of  $Q_2$  to signal ground, an amplifier is placed between source and gate.

the resulting circuit to that in Fig.2.1a to find  $I_o$  and  $R_{out}$ ?

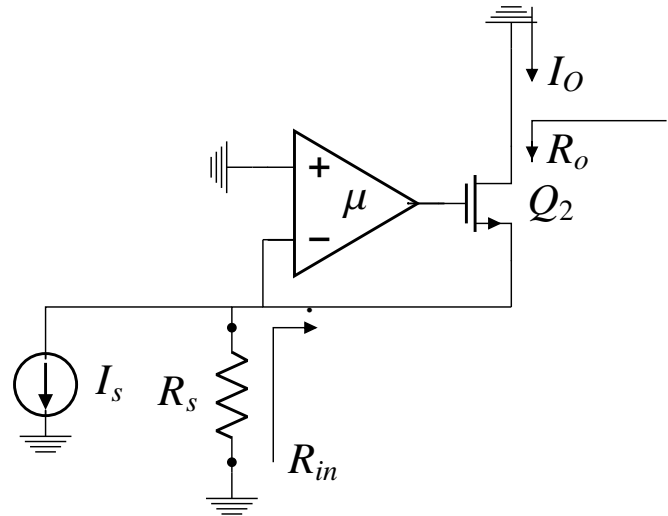


Fig. 2.1: a

(a) If  $\mu$  is very large, what is the signal voltage at the input terminal? What is the input resistance? What is the current gain  $I_o/I_s$ ?

(b) For finite  $\mu$  but assuming that the input resistance of the amplifier  $g$  is very large, find the 'G' circuit and derive expressions for  $G$ ,  $R_i$ , and  $R_o$ ?

(c) What is the value of  $H$ ?

(d) Find  $GH$  and  $T$ . If  $\mu$  is large, what is the value of  $T$ ?

(e) Find  $R_{in}$  and  $R_{out}$  assuming the loop gain is large?

(f) The super CG transistor can be utilized in the cascode configuration shown in Fig.2.1b, where  $V_G$  is a dc bias voltage. Replacing  $Q_1$  by its small-signal model, use the analogy of

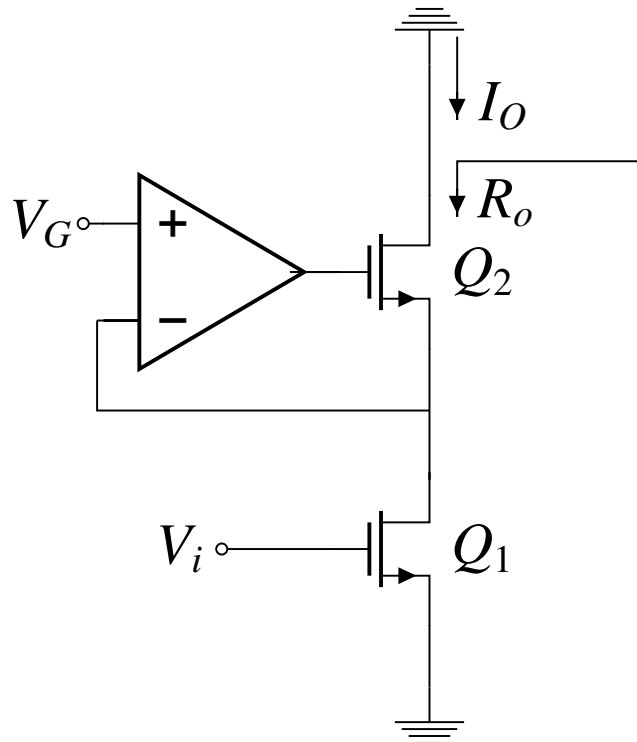


Fig. 2.1: b

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Parameter	Value
input resistance(large $\mu$ )	0
output resistance(large $\mu$ )	$\infty$
Input voltage	$-I_s R_s$
input resistance(finite $\mu$ )	$R_s$
output resistance(finite $\mu$ )	$r_o$
source resistance	$R_s$
feedback factor H	1
Open Loop Gain, G	$\mu g_m R_s$ A/A
Closed Loop Gain, T	1 A/A

TABLE 2.1: parameter's table for fig.2.1a

Parameter	Value
output resistance(large $\mu$ )	$\mu g_{m2} R_s R_o$
Input voltage	$I_s / g_{m1}$
output current $I_o$	$g_{m1} V_i$
feedback factor H	1
Open Loop Gain, G	$\mu g_{m2} R_s$ A/A
Closed Loop Gain, T	1 A/A

TABLE 2.1: parameter's table for fig.2.1b

- 2.2. (a) If  $\mu$  is very large, what is the signal voltage at the input terminal? What is the input resistance? What is the current gain  $I_o/I_s$ ?

**Solution:**

Refer to the fig. 2.1a for the feedback current amplifier circuit, in this super common gate transistor is connected between the gate and source terminals of the MOSFET.

Replace the op-amp with its equivalent modal and replace the MOSFET with its small signal equivalent circuit.

with reference to the fig,2.3. For ideal op-amp, the input resistance( $R_{id}$ ) is very high (infinite). And the drain current is approximately equal to source current

$$I_D \cong I_s \quad (2.2.1)$$

The closed loop gain of op-amp is

$$T = \frac{\mu}{1 + \mu H} \quad (2.2.2)$$

for larger value of closed loop gain, open loop gain ' $\mu$ ' will be large. from fig.2.3 we can observe that input voltage is,

$$V_{in} = -R_s I_s \quad (2.2.3)$$

Since the drain current is approximately is

equal to source current, And the current flowing through resistor  $R_s$  is  $I_s$  since there is no current flowing through the negative terminal of op-amp. Therefore, it is connected that the output current  $I_o$  is flowing through the resistor  $R_s$ , then

$$I_o = I_s \quad (2.2.4)$$

$$\frac{I_o}{I_s} \equiv 1$$

therefore the current gain is,

$$\frac{I_o}{I_s} = 1 \text{ A/A} \quad (2.2.5)$$

and from fig.2.3 the input Resistance is equal to  $R_{id}$

$$R_i = R_{id} \quad (2.2.6)$$

- 2.3. (b) For finite  $\mu$  but assuming that the input resistance of the amplifier  $g$  is very large, find the 'G' circuit and derive expressions for G,  $R_i$ , and  $R_o$ ?

**Solution:**

For the finite value of  $\mu$  and the input resistance of a ideal op-amp is very high(infinite). the open loop amplifier circuit ('G' circuit) fig.2.3

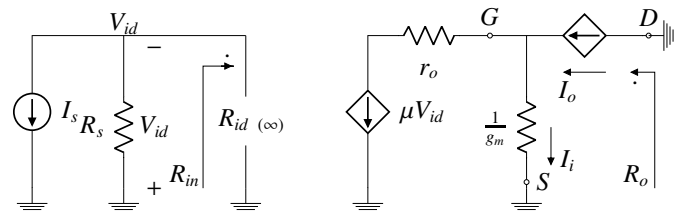


Fig. 2.3

For a ideal op-amp the output Resistance is very small, so we can neglect the resistance  $r_o$ . from fig.2.3

$$V_{id} = I_s R_s \quad (2.3.1)$$

current through resistance  $R_s$  is

$$\text{since } I_o \equiv I_s$$

$$I_o = \frac{\mu V_{id}}{\frac{1}{g_m}} \quad (2.3.2)$$

$$I_o = \mu g_m I_s R_s \quad (2.3.3)$$

Expression for current gain G is:

$$\frac{I_o}{I_s} = \mu g_m R_s \quad (2.3.4)$$

$$G = \mu g_m R_s \quad (2.3.5)$$

from the fig.2.3

$$\text{since } R_{id} = \infty$$

the input resistance:

$$R_I = R_s \quad (2.3.6)$$

the output Resistance:

$$R_o = r_o \quad (2.3.7)$$

#### 2.4. (c) What is the value of H?

**Solution:**

closed loop gain of the op-amp is:

$$T = \frac{\mu}{1 + \mu H} \quad (2.4.1)$$

$$\text{since } \mu H \gg 1$$

then

$$T = \frac{\mu}{\mu H} \quad (2.4.2)$$

for the larger value of  $\mu$

$$T \Rightarrow 1$$

the value of 'H' will be:

$$H = 1 \quad (2.4.3)$$

#### 2.5. (d) Find GH and T . If $\mu$ is large, what is the value of T ?

**Solution:**

from eq.2.3.5 and from eq.2.4.3

$$G = \mu g_m R_s, \quad H = 1$$

value of GH:

$$GH = \mu g_m R_s \quad (2.5.1)$$

closed loop gain of op-amp is:

$$T = \frac{G}{1 + GH} \quad (2.5.2)$$

substitute values of G and GH in eq.2.5.2

$$T = \frac{\mu g_m R_s}{1 + \mu g_m R_s} \quad (2.5.3)$$

for the larger value of  $\mu$

$$T \Rightarrow 1 \quad (2.5.4)$$

#### 2.6. (e) Find $R_{in}$ and $R_{out}$ assuming the loop gain is large

**Solution:**

**for a Feedback Amplifier**

$$R_{if} = \frac{R_i}{1 + GH} \quad (2.6.1)$$

Here,  $R_i = R_s$

substituting the values of GH and  $R_i$  in eq.2.6.1 we get:

$$R_{if} = \frac{R_s}{1 + \mu g_m R_s} \quad (2.6.2)$$

dividing the eq.2.6.2 with  $R_s$

$$R_{if} = \frac{1}{\frac{1}{R_s} + \mu g_m} \quad (2.6.3)$$

the eq.2.6.3 can also written like

$$R_{if} = R_s \parallel \frac{1}{\mu g_m} \quad (2.6.4)$$

$$R_{if} = R_s \parallel R_{in} \quad (2.6.5)$$

from the equations 2.6.4 and 2.6.5  $R_{in}$  can be written as:

$$R_{in} = \frac{1}{\mu g_m} \quad (2.6.6)$$

for the larger value of  $\mu$  then  $R$  will be small

$$\text{for } \mu \Rightarrow \infty$$

then  $R_{in}$  becomes:

$$R_{in} = 0 \quad (2.6.7)$$

**for a Feedback Amplifier output Resistance is:**

$$R_{out} = (1 + GH)R_o \quad (2.6.8)$$

From the figure Fig.2.3

$$R_o = \frac{1}{g_m} \quad (2.6.9)$$

substitute the values of GH and  $R_o$  in eq.2.6.8 we get:

$$R_{out} = (1 + \mu g_m R_s) \frac{1}{g_m} \quad (2.6.10)$$

$$R_{out} = \frac{1}{g_m} + \mu R_s \quad (2.6.11)$$

By observing the eq.2.6.11, for the larger value for  $\mu$  we will have larger value for  $R_{out}$

$$\mu \Rightarrow \infty$$

$$R_{out} \Rightarrow \infty \quad (2.6.12)$$

2.7. (f) The super CG transistor can be utilized in the cascode configuration shown in Fig.2.1b, where  $V_G$  is a dc bias voltage. Replacing Q1 by its small-signal model, use the analogy of the resulting circuit to that in Fig.2.1a to find  $I_o$  and  $R_{out}$ .

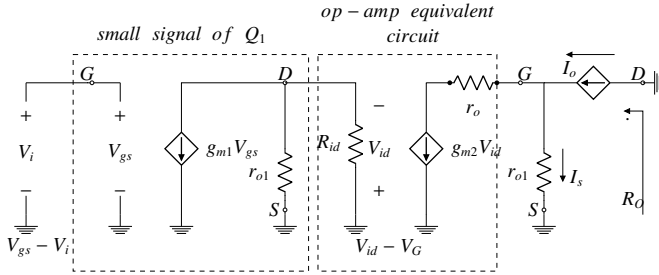


Fig. 2.7

### Solution:

Refer to the fig.2.1b for the cascode configuration in which the super CG transistor is used. the small signal equivalent circuit is shown in fig.2.7,

from the fig.2.7 clearly observed that the current  $I_s$

$$I_s = g_{m1} V_{gs} \quad (2.7.1)$$

the voltage  $V_i$  is applied at the gate terminal of the transistor  $Q_1$ , therefore the gate source voltage becomes  $V_i$ :

$$V_i = V_{gs} \quad (2.7.2)$$

from the eq.2.7.2 and eq.2.7.1

$$I_s = g_{m1} V_i \quad (2.7.3)$$

the closed loop gain of the op-amp is:

$$T = \frac{G}{1 + GH} \quad (2.7.4)$$

from the questions Q.2.3 and Q.2.4 we will get:

$$G = \mu g_{m2} R_s \quad (2.7.5)$$

$$H \Rightarrow 1 \quad (2.7.6)$$

substitute the values of H and G in eq.2.7.4

$$T = \frac{\mu g_{m2} R_s}{1 + \mu g_{m2} R_s} \quad (2.7.7)$$

$$\text{since } T = \frac{I_o}{I_s}$$

$$\frac{I_o}{I_s} = \frac{\mu g_{m2} R_s}{1 + \mu g_{m2} R_s} \quad (2.7.8)$$

$$I_o = I_s \left[ \frac{\mu g_{m2} R_s}{1 + \mu g_{m2} R_s} \right] \quad (2.7.9)$$

from eq.2.7.3 substitute the value of  $I_s$  in eq.2.7.9

$$I_o = g_{m1} V_i \left[ \frac{\mu g_{m2} R_s}{1 + \mu g_{m2} R_s} \right] \quad (2.7.10)$$

$$\text{since } \mu g_{m2} R_s \gg 1$$

$$I_o = g_{m1} V_i \left[ \frac{\mu g_{m2} R_s}{\mu g_{m2} R_s} \right] \quad (2.7.11)$$

$$I_o = g_{m1} V_i \quad (2.7.12)$$

the expression for the output current is:

$$I_o = g_{m1} V_i \quad (2.7.13)$$

the output amplifier is:

$$R_{out} = (1 + GH) R_o \quad (2.7.14)$$

from the question Q.2.5 we will get:

$$GH = \mu g_{m2} R_s \quad (2.7.15)$$

Parameter	Value
resistance( $R_s$ )	10K $\Omega$
current source( $I_s$ )	SINE(0 1 1000)
resistance( $R$ )	1 $\Omega$

TABLE 2.8: parameter's table for fig.2.8

$$R_{out} = (1 + \mu g_{m2} R_s) R_o \quad (2.7.16)$$

$$R_{out} \equiv \mu g_{m2} R_s R_o \quad (2.7.17)$$

therefore the expression for output resistance is :

$$R_{out} = \mu g_{m2} R_s R_o \quad (2.7.18)$$

## 2.8. verify circuit by ngspice simulation.

for the circuit we found that

$$\frac{I_o}{I_s} \equiv 1 \quad (2.8.1)$$

then

$$I_s \equiv I_o \quad (2.8.2)$$

to simulate the circuit we are giving some values to  $I_s$  and  $R_s$  and to find  $I_o$  we are introducing a 1ohm resistance at drain of nmos. then ,

$$V_o = -R I_o \quad (2.8.3)$$

since the value of resistance  $R$  is 1ohm

$$I_o = -V_o \quad (2.8.4)$$

following link provides instructions for simulation

[spice/EE18BTECH11023/README](https://spice/EE18BTECH11023/README)

fig.2.8 shows the circuit implemented in spice using parameter Table.2.8

the following netlits code simulates the feedback current amplifier and generates sinusoidal output

[spice/EE18BTECH11023/ee18btech11023.net](https://spice/EE18BTECH11023/ee18btech11023.net)

And the following code plots the output of the feedback system generated by netlist code.

fig.

[spice/EE18BTECH11023/ee18btech11023.py](https://spice/EE18BTECH11023/ee18btech11023.py)

final output plot is below. here we are using

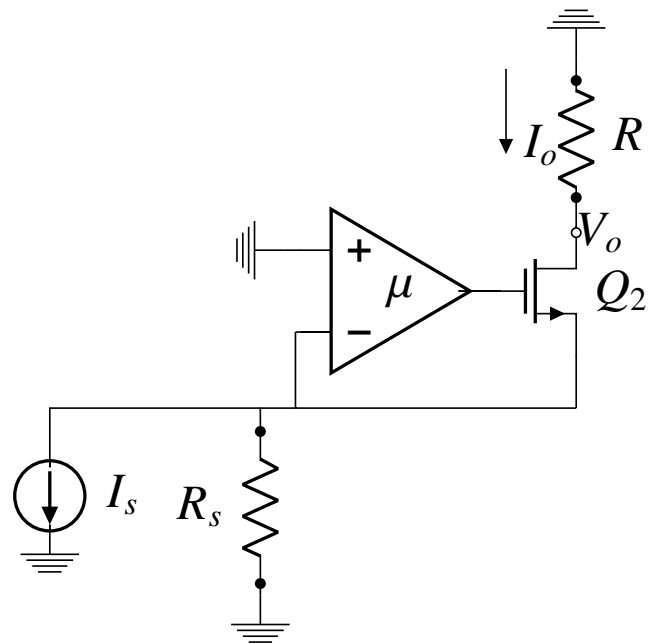


Fig. 2.8

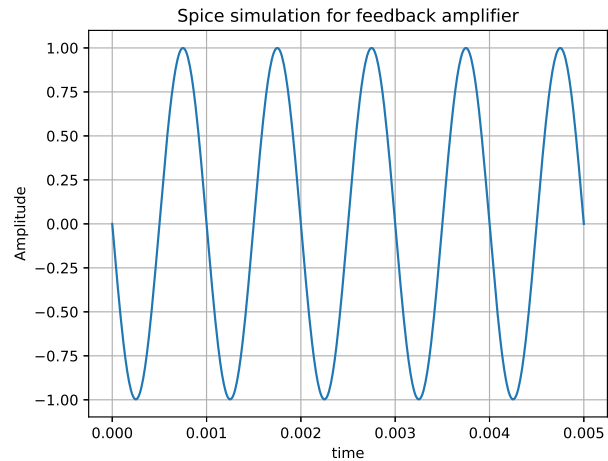


Fig. 2.8: output of feedback Amplifier

amplitude 1 for input signal.

then the output voltage will be negative of the input signal. there will be no change in amplitude in output signal.

## 2.2 Practical Case