Shunt-Series Amplifiers:Practical Case

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Contents

The feedback current amplifier in Fig 0.1 utilizes two identical NMOS transistor sized so that at $I_{D1} = 0.2mA$, they operate at $V_{OV} = 0.2V$. Both the devices have $V_t = 0.5V$ and $V_A = 10V$.

a) If I_S has zero DC component, show that both Q_1 and Q_2 are, operating at $I_D = 0.2mA$. What is DC voltage at the input?
b)Find g_m and r_o for each Q_1 and Q_2.
c) Find the open loop circuit and the value of R_i, G and R_o.
d) Find the value of H.
e) Find GH and T
f)Find R_{in} and R_{out}.

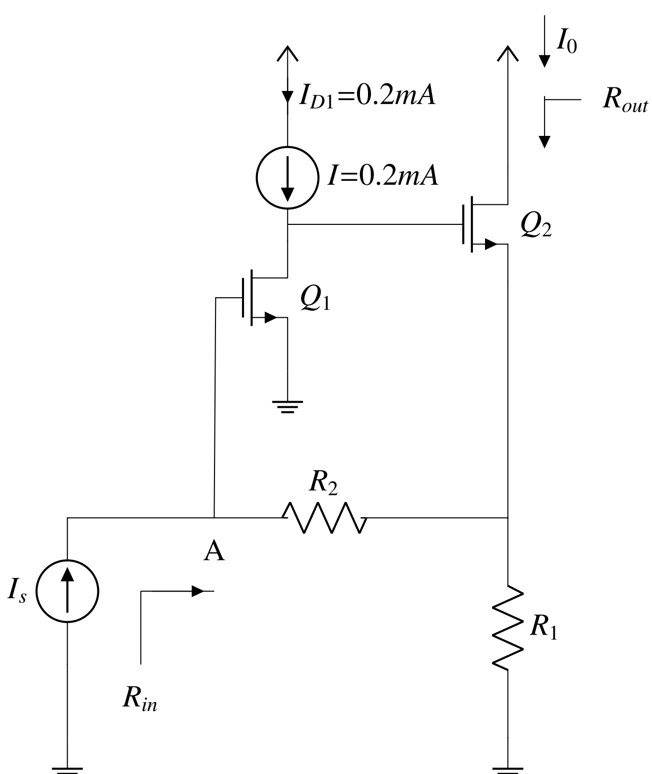

Fig. 0.1: Problem Figure

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Parameter	Value
R_1	$3.5k\Omega$
R_2	$14k\Omega$
I_{D1}	$0.2mA$
V_{OV}	$0.2V$
V_t	$0.5V$
V_A	$10V$

TABLE 0: Given Parameters

1. a)DC analysis of circuit.
Solution: Given that I_s has zero DC component, it can be neglected in DC analysis of the circuit. The current does not enter the Gate terminal of any mosfet. Thus the DC current flow looks like shown in Fig 1.2
Given $V_{OV} = 0.2V$ and $V_t = 0.5V$, for Q1-

$$V_{GS1} = V_{OV} + V_t = 0.7V \tag{1.1}$$
$$\implies V_{G1} = V_{GS1} = 0.7V \tag{1.2}$$

$$\text{The DC voltage } V_{G1} = V_{S2} \tag{1.3}$$
$$\text{by ohms law, } I_{D2} = \frac{V_{S2}}{R1} = \frac{0.7V}{3.5k\Omega} \tag{1.4}$$
$$\implies I_{D2} = 0.2mA \tag{1.5}$$

Clearly $I_{D1} = 0.2mA$.
DC voltage at input = $V_{G1} = 0.7V$
2. Verify the DC values I_{D2} and V_{G1}.
Solution: Simulate the circuit, Fig 1.2, using spice. Observe the DC operating point values. Fig 2.3 shows that I_{D2} is close to 0.2mA and V_{G1} is close to 0.7V. You can find the netlist for the simulated circuit here:

spice/ee18btech11038_dc.cir

You can find the python script used to generate the output here:

spice/ee18btech11038_dc.py

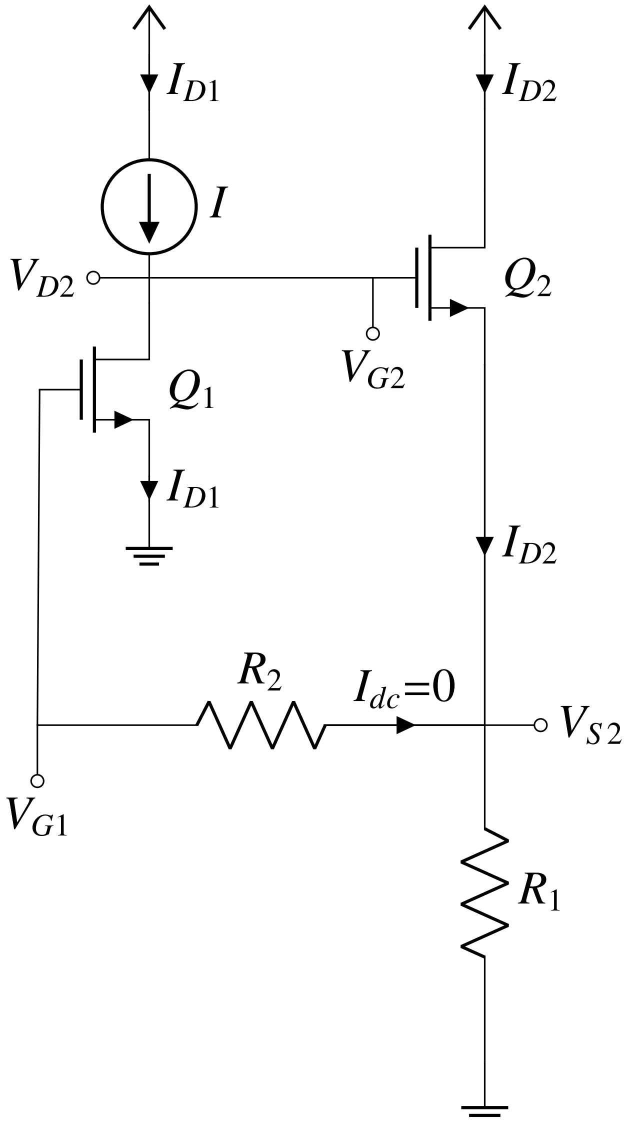

Fig. 1.2: DC Analysis Circuit

3. To find g_m and r_o
Solution: We know,

$$\text{transconductance, } g_m = \frac{2I_D}{V_{OV}} \tag{3.1}$$

therefore-

$$g_{m1} = g_{m2} = \frac{(2)(0.2)(10^-3)}{0.2} \tag{3.2}$$

$$\implies 2mA/V \tag{3.3}$$

r_o is given by,

$$r_0 = \frac{V_A}{I_D} \tag{3.4}$$

$$\implies r_{o1} = r_{o2} = 50k\Omega \tag{3.5}$$

4. c) To find open loop circuit.

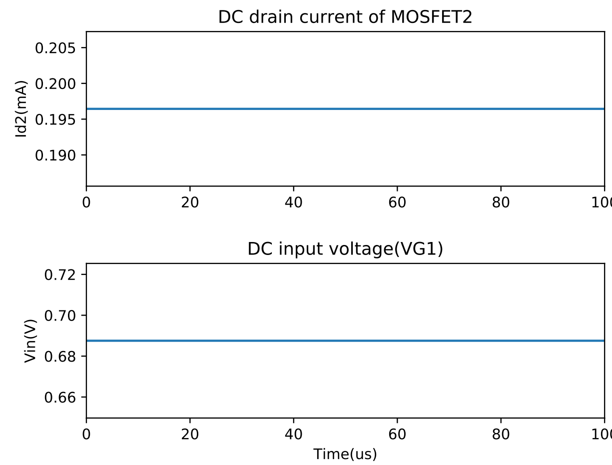

Fig. 2.3: Simulation for Verifying DC operating point

Solution: The general open loop circuit for a current(series-shunt) amplifier is shown in Fig 4.4.

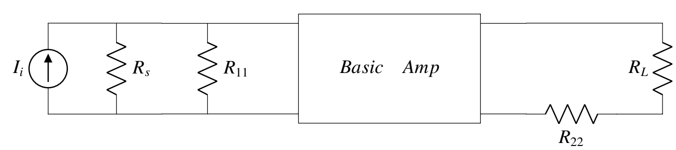

Fig. 4.4: General open loop circuit

Resistance	Description
R_{in}	Total Input Resistance
R_{out}	Total Ouput Resistance
r_{o1}	Output resistance of MOSFET1
r_{o2}	Output resistance of MOSFET2
R_i	Input resistance of Open Loop
R_o	Output resistance of Open Loop
R_{if}	Input resistance of Feedback
R_{of}	Output resistance of Feedback
R_s	Resistance of Current Source
R_L	Output Load Resistance
R_{11}	Input load resist. (due feedback)
R_{22}	Output load resist. (due feedback)

TABLE 4: Resistances

For our problem, the small circuit model is shown in Fig 4.5. All the different resistances are summarized in Table 4

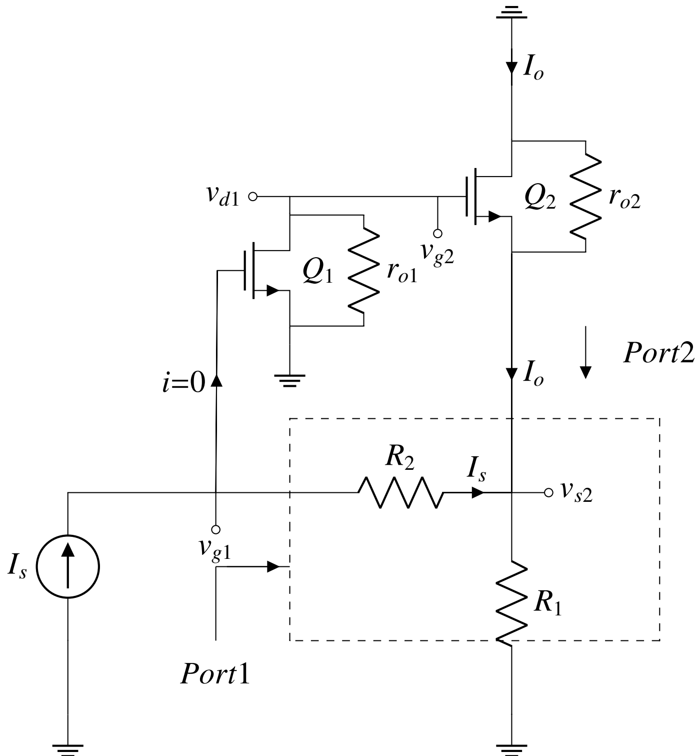

Fig. 4.5: Small Circuit Model

For a shunt-series amplifier, R_{11} is the resistance looking into the feedback circuit from port 1 while port 2 is open circuited.

$$R_{11} = R_1 + R_2 \tag{4.1}$$

R_{22} is the resistance looking into the feedback circuit from port 2 while port 1 is short circuited.

$$R_{22} = R_1 || R_2 \tag{4.2}$$

Also for our problem, $R_L = 0$ and $R_s = \infty$.Open loop circuit for our problem is shown in Fig 4.6.

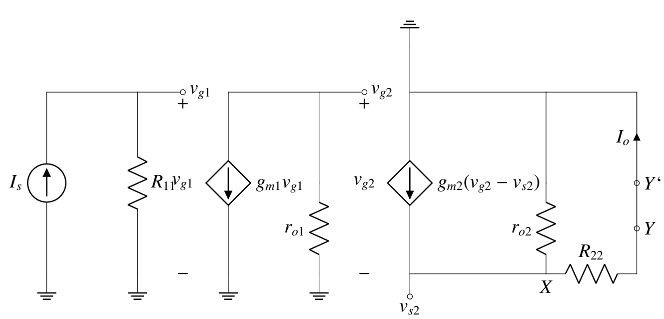

Fig. 4.6: Open loop circuit

From the open loop circuit, Fig 4.6, we have-

$$v_{g1} = I_s R_{11} = I_s(R_1 + R_2) \tag{4.3}$$

$$v_{g2} = -g_{m1} v_{g1} r_{o1} \tag{4.4}$$

$$\implies g_{m1} r_{o1}(R_1 + R_2) I_s \tag{4.5}$$

KCL at node X yields -

$$g_{m2}(v_{g2} - v_{s2}) = \frac{v_{s2}}{r_{02}||R_{22}} \tag{4.6}$$

$$\tag{4.7}$$

$$\implies g_{m2} v_{g2} = (g_{m2} + \frac{1}{r_{o2}||R_{22}}) v_{s2} \tag{4.8}$$

$$\tag{4.9}$$

$$\implies v_{s2} = \frac{v_{g2} g_{m2}}{g_{m2} + \frac{1}{r_{02}||R_{22}}} \tag{4.10}$$

$$\tag{4.11}$$

therefore,

$$I_o = \frac{v_{s2}}{R_{22}} \tag{4.12}$$

$$\implies \frac{v_{g2} g_{m2}}{g_{m2}(R_1 + R_2) + \frac{R_1||R_2}{r_{o2}||R_1||R_2}} \tag{4.13}$$

Substituting v_{g2} from 4.4,

$$I_o = \frac{-g_{m1} g_{m2} r_{o1}(R_1 + R_2) I_s}{g_{m2}(R_1||R_2) + \frac{R_1||R_2}{r_{o2}||R_1||R_2}} \tag{4.14}$$

Thus, open loop gain G-

$$G = \frac{I_o}{I_s} \tag{4.15}$$

$$\implies \frac{-g_{m1} g_{m2} r_{o1}(R_1 + R_2)}{g_{m2}(R_1||R_2) + \frac{R_1||R_2}{r_{o2}||R_1||R_2}} \tag{4.16}$$

5. Verify the open loop gain value(G).
Solution: Simulate the circuit, Fig 4.6, using spice. Pass small signal as input I_s and observe the output. Fig 5.7 shows that $G = -525.76$ which is closed to that obtained in Table 12. You can find the netlist for the simulated circuit here:

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spice/ee18btech11038_olgain.cir
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You can find the python script used to generate the output here:

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spice/ee18btech11038_olgain.py
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6. c)Input Resistance for Open loop
Solution: Input resistance of the Open loop,

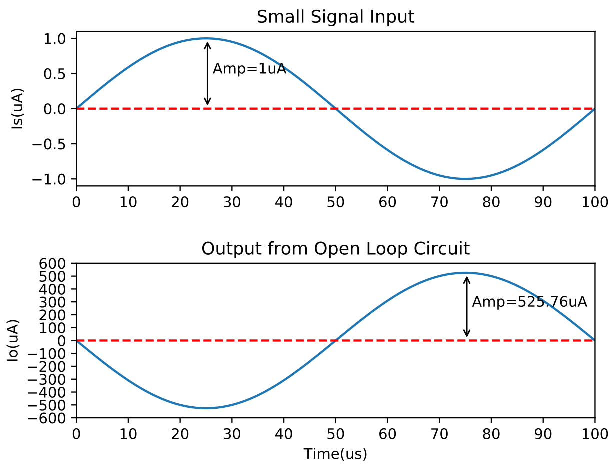

Fig. 5.7: Simulation for Open loop gain

R_i, see Fig 4.6, clearly is-

$$R_i = R_1 + R_2 \tag{6.1}$$

7. c) To find Output Resistance of Open loop, R_o
Solution: See Fig 7.8 which is the output circuit obtained by breaking the open loop circuit, Fig 4.6, at YY‘ and setting the input to zero. R_o is the resistance looking into YY‘.

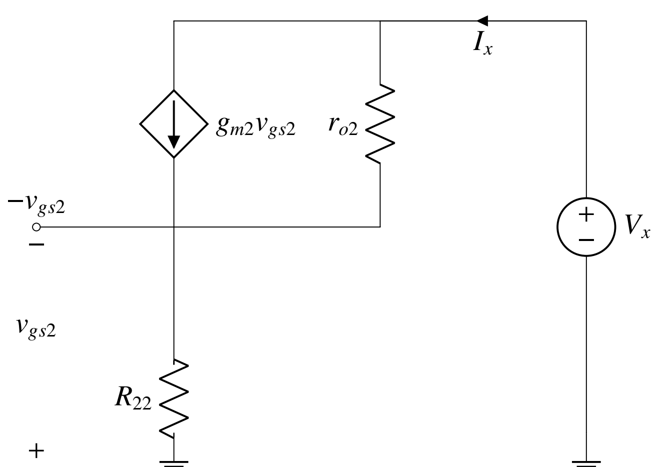

Fig. 7.8: Output Circuit

The current source can be changed into an equivalent voltage source, and the circuit obtained is Fig 7.9.
From circuit Fig 7.9, we have,

$$v_{gs2} = -I_x R_{22} \tag{7.1}$$
$$v_x + g_{m2} v_{gs2} r_{o2} = I_x (r_{o2} + R_{22}) \tag{7.2}$$

On subtituting 7.1 in 7.2 and simplifying, we

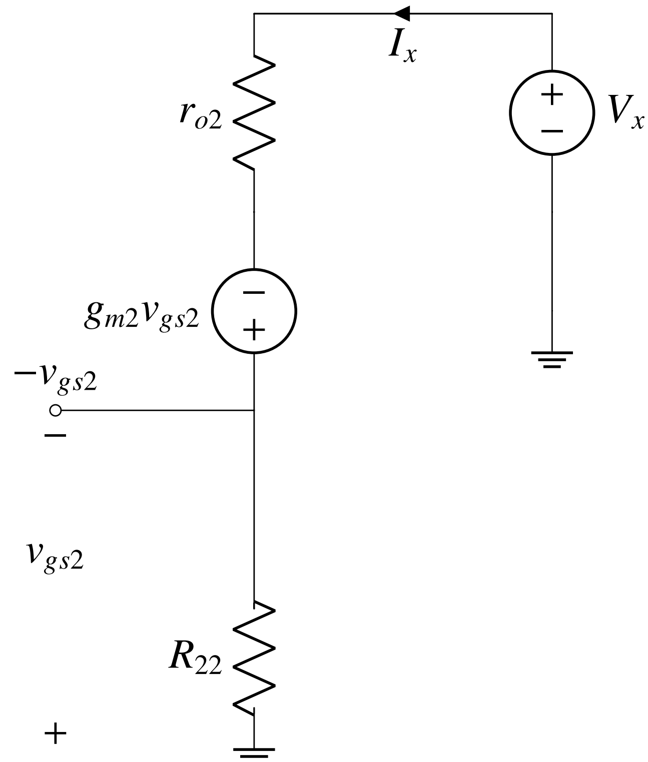

Fig. 7.9: Simplified Output Circuit

get,

$$\frac{v_x}{I_x} = r_{o2} + R_{22} + g_{m2} r_{o2} R_{22} \tag{7.3}$$
$$\implies R_o = r_{o2} + R_1 \| R_2 + g_{m2} r_{o2} (R_1 \| R_2) \tag{7.4}$$

8. Verify R_o value.
Solution: Simulate the circuit, Fig 7.8, using spice. Sweep the DC input V_x and observe output I_x. Fig 8.10 shows that $R_o = Slope = 332.79k\Omega$ which is close to that obtained in Table 12. You can find the netlist for the simulated circuit here:

spice/ee18btech11038_rout.cir

You can find the python script used to generate the output here:

spice/ee18btech11038_rout.py

9. d) To find feedback gain, H
Solution: We know,

$$H = \frac{I_f}{I_0}, \text{port1 shorted} \tag{9.1}$$
$$\tag{9.2}$$

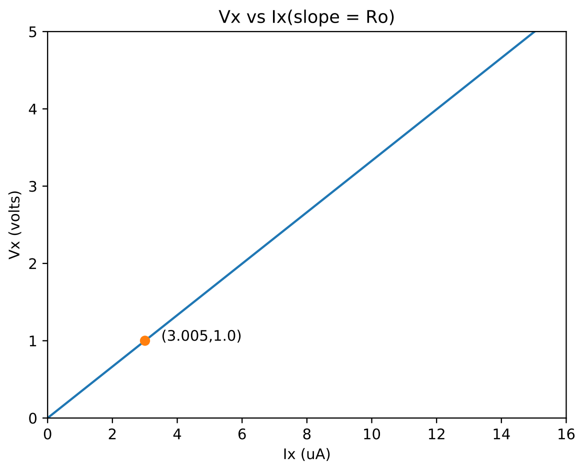

Fig. 8.10: Simulation for verifying R_o

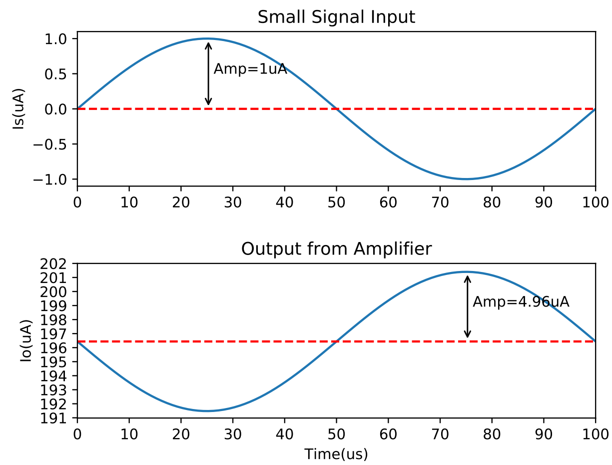

Fig. 11.11: Simulation for Closed Loop gain, T

Therefore,

$$H = \frac{-R_1}{R_1 + R_2} \tag{9.3}$$

10. e) To find closed-loop gain T
Solution:

$$GH = \frac{g_{m1}g_{m2}r_{o1}R_1}{g_{m2}(R_1\|R_2) + \frac{R_1\|R_2}{r_{o2}\|R_1\|R_2}} \tag{10.1}$$

We know,

$$T = \frac{G}{1+GH} \tag{10.2}$$

$$\tag{10.3}$$

$$\implies \frac{-g_{m1}g_{m2}r_{o1}(R_1 + R_2)}{g_{m2}(R_1\|R_2) + \frac{R_1\|R_2}{r_{o2}\|R_1\|R_2} + g_{m1}g_{m2}r_{o1}R_1} \tag{10.4}$$

11. Verify the Closed loop gain value.
Solution: Simulate the circuit, Fig 0.1, using spice. Pass small signal as input I_s and observe the output. Fig 11.11 shows that $T = -4.96$ which is close to that obtained in Table 12. You can find the netlist for the simulated circuit here:

spice/ee18btech11038_clgain.cir

You can find the python script used to generate the output here:

spice/ee18btech11038_clgain.py

12. f) To find R_{in} and R_{out}
Solution: Since $R_L = 0$ and $R_s = \infty$,

$$R_{in} = R_{if} = \frac{R_i}{1+GH} \tag{12.1}$$

and,

$$R_{out} = R_{of} = (1+GH)R_o \tag{12.2}$$

Refer 6.1 for R_i and 7.4 for R_o. Expressions are large for R_{out} and R_{in}. Numerical values are calculated in Table 12.

Parameter	**Value**
g_{m1}	$2mA/V$
g_{m2}	$2mA/V$
r_{o1}	$50k\Omega$
r_{o2}	$50k\Omega$
R_s	∞
R_L	0
G	-526.3
R_i	$17.5k\Omega$
R_o	$332.8k\Omega$
H	-0.2
GH	105.26
T	-4.95
R_{in}	164Ω
R_{out}	$35.3M\Omega$

TABLE 12: Numerical Values