Shunt-Series Amplifiers:Practical Case

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The feedback current amplifier in Fig 0 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 $V_A = 10V$.

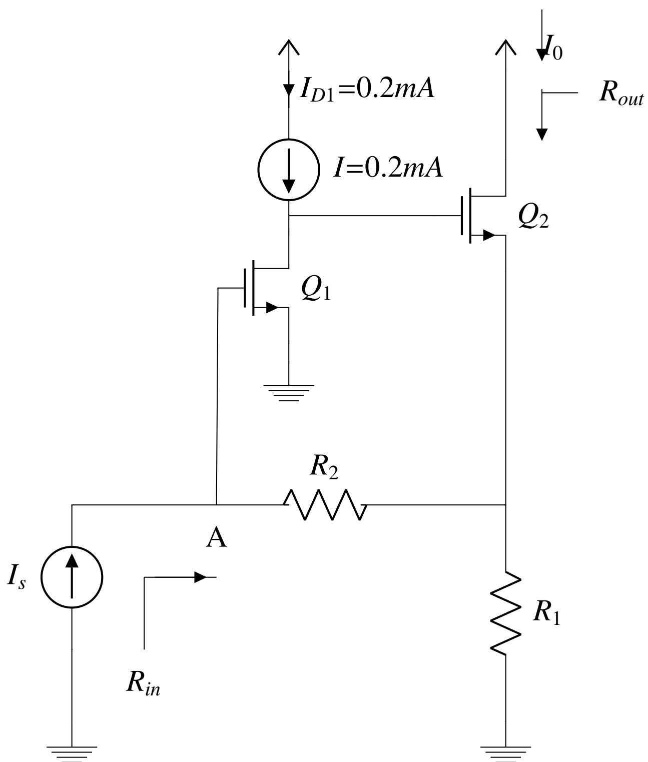

Fig. 0: Problem Figure

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

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(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}.

1. Find the DC voltage at the node A.
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 is as shown in Fig 1.2

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

2. Show that the drain current for $Q2$ is $I_{D_2} = 0.2$mA.
Solution:

$$\because I_s = 0 \text{ and} \tag{2.1}$$
$$I_{G1} = 0, \tag{2.2}$$

no current passes through R_2 and

$$\because I_s = 0 \text{ and} \tag{2.3}$$
$$V_{S2} = V_A = 0.7 \tag{2.4}$$
$$\implies I_{D2} = \frac{V_{S2}}{R1} \tag{2.5}$$
$$I_{D2} = 0.2mA \tag{2.6}$$

3. Find g_m and r_o.

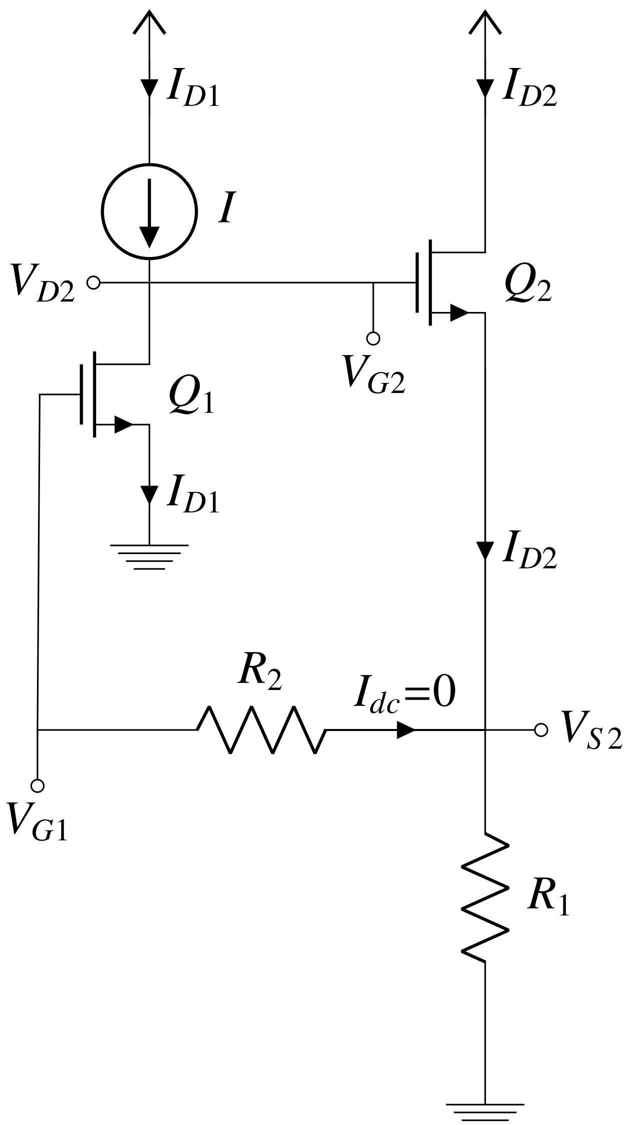

Fig. 1.2: DC Analysis Circuit

Solution:

$$g_m = \frac{2I_D}{V_{OV}} \tag{3.1}$$
$$= 2\,mA/V \tag{3.2}$$

and

$$r_0 = \frac{V_A}{I_D} \tag{3.3}$$
$$= 50k\Omega \tag{3.4}$$

4. Find H.
   Solution: With port1 shorted in Fig. 4.3,

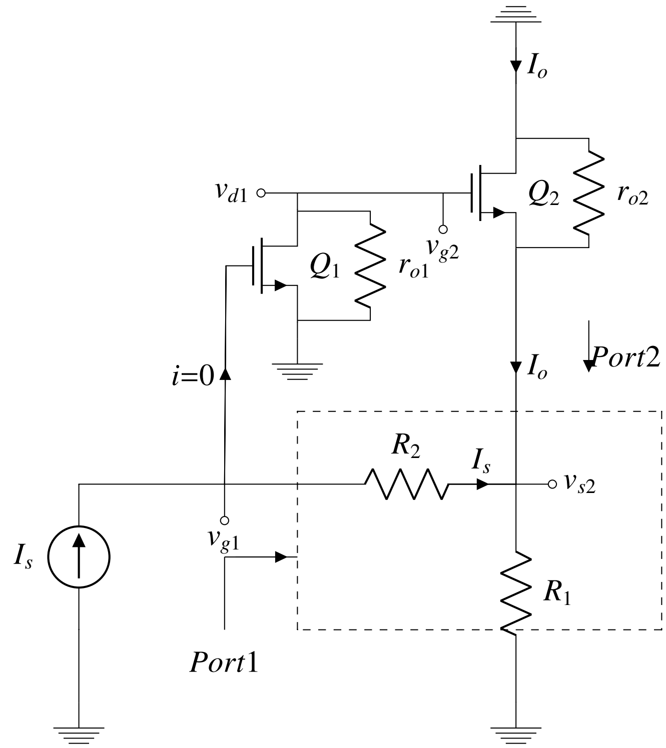

Fig. 4.3: Small Circuit Model

$$H = \frac{I_f}{I_0}, \tag{4.1}$$
$$= \frac{R_1}{R_1 + R_2} \tag{4.2}$$

5. Sketch the open loop circuit model.
   Solution: See Fig. 5.4.

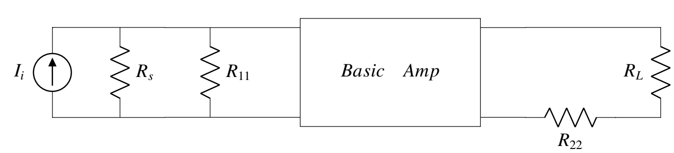

Fig. 5.4: General open loop circuit

6. Find R_{11} and R_{22} in Fig. 5.4.
   Solution: See Fig. 4.3. For a shunt-series amplifier, R_{11} is the resistance looking into the feedback circuit from port 1 while port 2 is open circuited.

$$R_{11} = R_1 + R_2 \tag{6.1}$$

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

$$R_{22} = R_1 || R_2 \tag{6.2}$$

7. Find G using Fig. 7.5

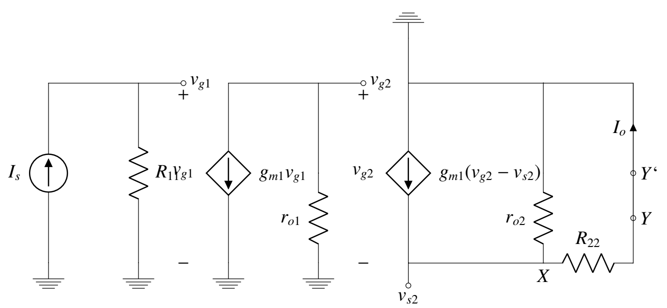

Fig. 7.5: Open loop circuit

Solution: See Table 7 for the description of various parameters. Assum $R_L = 0$ and $R_s = \infty$.

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 7: Resistances

From Fig. 7.5,

$$v_{g1} = I_s R_{11} \tag{7.1}$$

$$v_{g2} = -g_{m1} v_{g1} r_{o1} \tag{7.2}$$

$$I_o = g_{m2}(v_{g2} - v_{s2}) \frac{r_{o2}}{r_{o2} + R_{22}} \tag{7.3}$$

$$v_{s2} = I_o R_{22} \tag{7.4}$$

Simplifying the above,

$$G = \frac{I_o}{I_s} \tag{7.5}$$

$$\tag{7.6}$$

$$= \frac{-g_{m1} g_{m2} r_{o1}(R_1 + R_2)}{g_{m2}(R_1||R_2) + \frac{R_1||R_2}{r_{o2}||R_1||R_2}} \tag{7.7}$$

8. Find the input resistance for G.
Solution: From Fig 7.5,

$$R_i = R_{11} = R_1 + R_2 \tag{8.1}$$

9. Find the output resistance for G.
Solution: See Fig. 9.6 obtained by breaking Fig 7.5, at YY' and setting the input to zero. Then

$$v_{gs2} = -R_{22} I_x \tag{9.1}$$

$$I_x = \frac{v_x + v_{gs2}}{r_{o2}} + g_{m2} v_{gs2} \tag{9.2}$$

$$\implies \frac{v_x}{I_x} = r_{o2} + R_{22} + g_{m2} r_{o2} R_{22} \tag{9.3}$$

$$\tag{9.4}$$

$$\text{or, } R_o = r_{o2} + R_1||R_2 + g_{m2} r_{o2}(R_1||R_2) \tag{9.5}$$

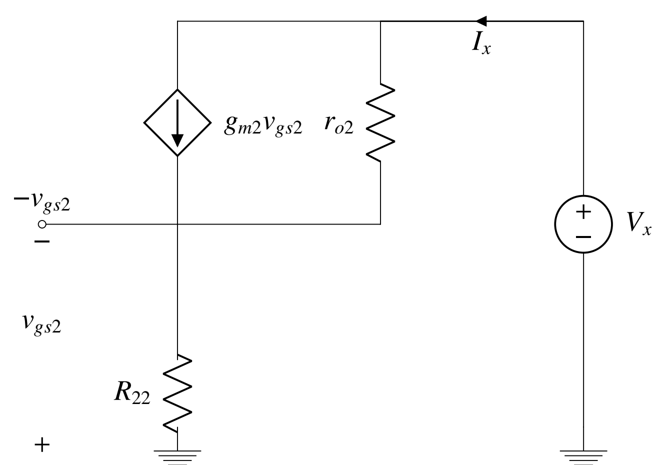

Fig. 9.6: Output Circuit

10. Find the closed-loop gain T.
Solution:

$$T = \frac{G}{1 + GH} \tag{10.1}$$

$$= \frac{-g_{m1} g_{m2} r_{o1}(R_1 + R_2)}{g_{m2}(R_1||R_2) + \frac{R_1||R_2}{r_{o2}||R_1||R_2} + g_{m1} g_{m2} r_{o1} R_1} \tag{10.2}$$

11. Find R_{in} and R_{out} for T.
Solution: Since $R_L = 0$ and $R_s = \infty$,

$$R_{in} = R_{if} = \frac{R_i}{1 + GH} \tag{11.1}$$

$$R_{out} = R_{of} = (1 + GH)R_o \tag{11.2}$$

12. Find the numerical values for all the above.
Solution: See 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

13. Verify T using spice.