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 $V_A = 10V$.

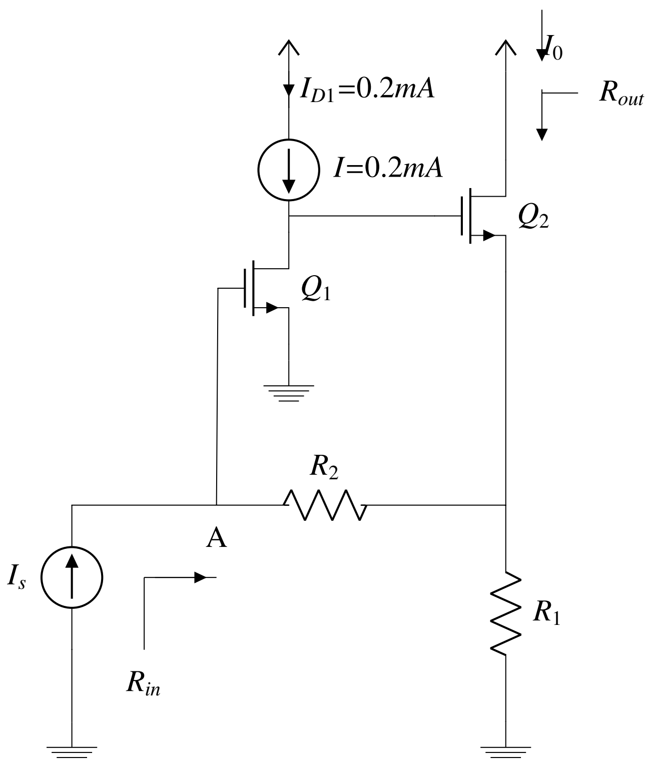

Fig. 0: Problem Figure

(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.

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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

(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 $I_{D_2} =$ 0.2mA.
Solution:

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

no current passes through R_2 and

$$\because I_s = 0 \text{ and } V_{S2} = V_A = 0.7 \tag{2.2}$$
$$\implies I_{D2} = \frac{V_{S2}}{R1} \tag{2.3}$$
$$\implies I_{D2} = 0.2mA \tag{2.4}$$

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

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

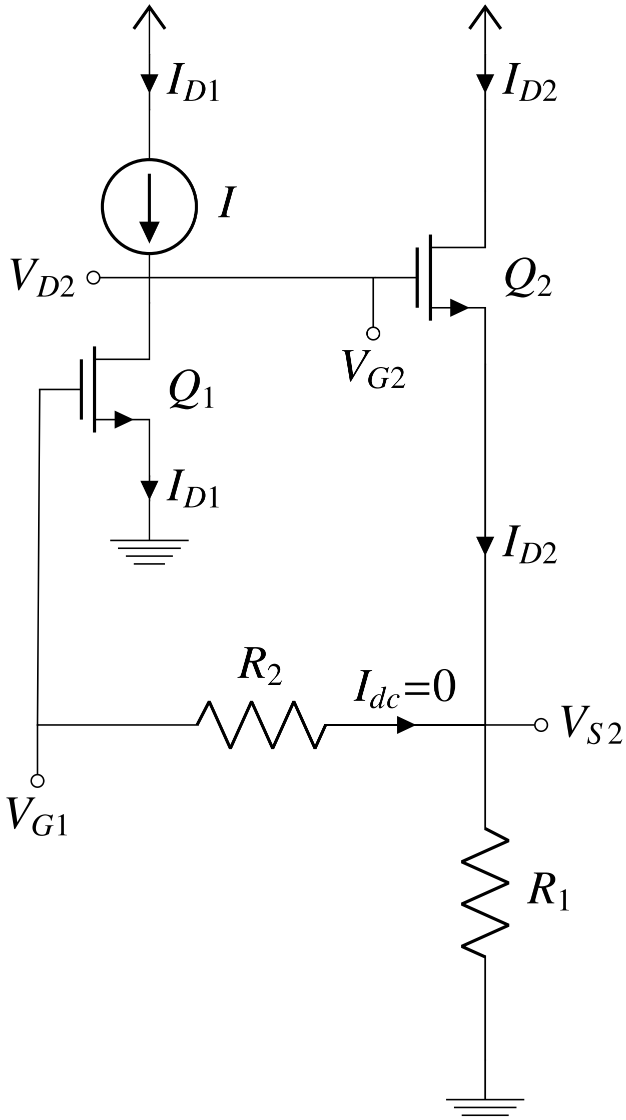

Fig. 1.2: DC Analysis Circuit

therefore-

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

$$\implies 2mA/V \quad (3.3)$$

r_o is given by,

$$r_0 = \frac{V_A}{I_D} \quad (3.4)$$

$$\implies r_{o1} = r_{o2} = 50k\Omega \quad (3.5)$$

4. c) To find open loop circuit.
Solution: The general open loop circuit for a current(series-shunt) amplifier is shown in Fig 4.3.
For our problem, the small circuit model is shown in Fig 4.4. All the different resistances are summarized in Table 4

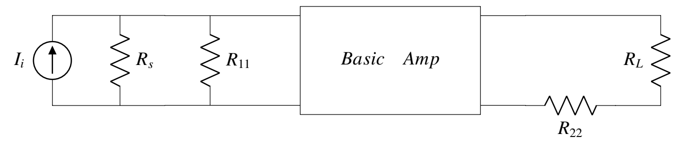

Fig. 4.3: General open loop circuit

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

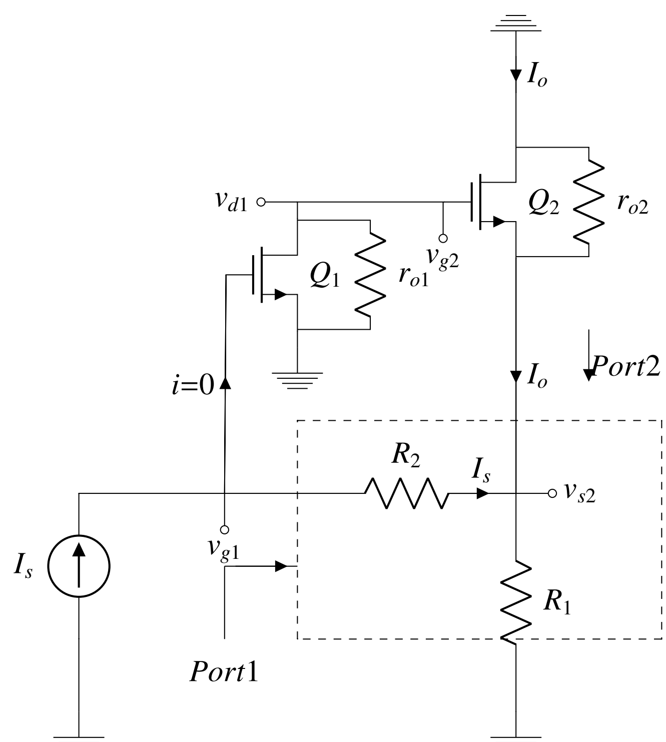

Fig. 4.4: Small Circuit Model

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 4.5.

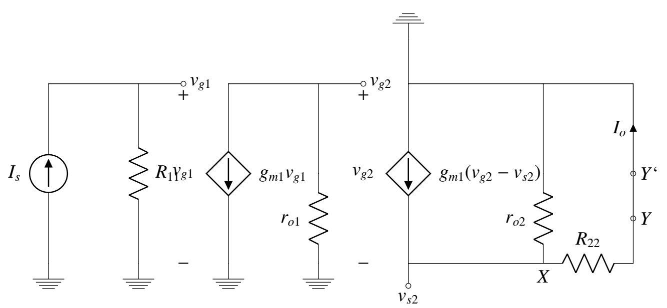

Fig. 4.5: Open loop circuit

From the open loop circuit, Fig 4.5, 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. c)Input Resistance for Open loop
Solution: Input resistance of the Open loop, R_i, see Fig 4.5, clearly is-

$$R_i = R_1 + R_2 \tag{5.1}$$

6. c) To find Output Resistance of Open loop, R_o
Solution: See Fig 6.6 which is the output circuit obtained by breaking the open loop circuit, Fig 4.5, at YY‘ and setting the input to zero. R_o is the resistance looking into YY‘.

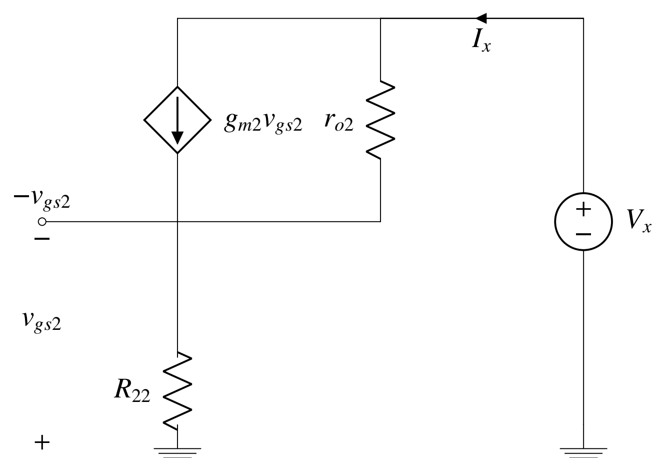

Fig. 6.6: Output Circuit

The current source can be changed into an equivalent voltage source, and the circuit obtained is Fig 6.7.
From circuit Fig 6.7, we have,

$$v_{gs2} = -I_x R_{22} \tag{6.1}$$
$$v_x + g_{m2} v_{gs2} r_{o2} = I_x(r_{o2} + R_{22}) \tag{6.2}$$

On subtituting 6.1 in 6.2 and simplifying, we get,

$$\frac{v_x}{I_x} = r_{o2} + R_{22} + g_{m2} r_{o2} R_{22} \tag{6.3}$$
$$\implies R_o = r_{o2} + R_1||R_2 + g_{m2} r_{o2}(R_1||R_2) \tag{6.4}$$

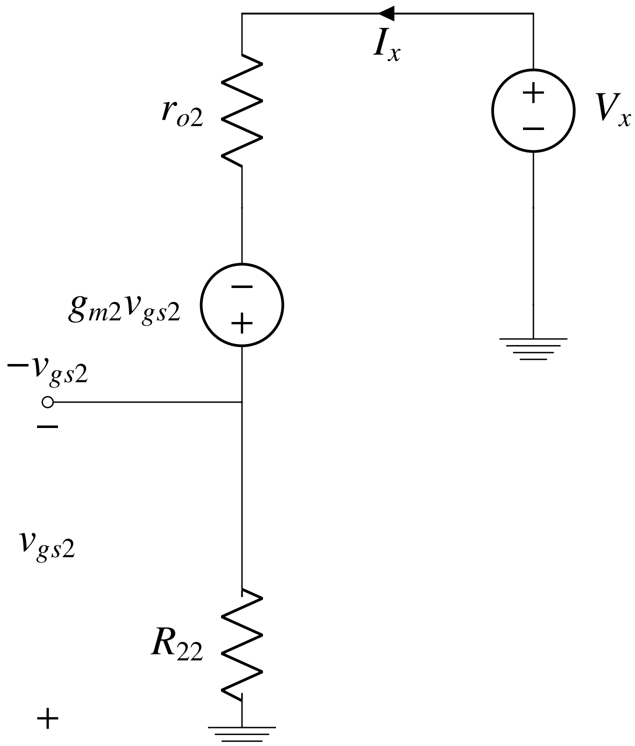

Fig. 6.7: Simplified Output Circuit

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

$$H = \frac{I_f}{I_0}, \text{port1 shorted} \tag{7.1}$$

$$\tag{7.2}$$

Therefore,

$$H = \frac{-R_1}{R_1 + R_2} \tag{7.3}$$

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

$$GH = \frac{g_{m1}g_{m2}r_{o1}R_1}{g_{m2}(R_1||R_2) + \frac{R_1||R_2}{r_{o2}||R_1||R_2}} \tag{8.1}$$

We know,

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

$$\tag{8.2}$$

$$\tag{8.3}$$

$$\implies \frac{-g_{m1}g_{m2}r_{o1}(R_1 + R_2)}{g_{m2}(R_1||R_2) + \frac{R_1||R_2}{r_{o2}||R_1||R_2} + g_{m1}g_{m2}r_{o1}R_1} \tag{8.4}$$

9. f) To find R_{in} and R_{out}

Solution: Since $R_L = 0$ and $R_s = \infty$,

$$R_{in} = R_{if} = \frac{R_i}{1 + GH} \tag{9.1}$$

and,

$$R_{out} = R_{of} = (1 + GH)R_o \tag{9.2}$$

Refer 5.1 for R_i and 6.4 for R_o. Expressions are large for R_{out} and R_{in}. Numerical values are calculated in Table 9.

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 9: Numerical Values