# Shunt-Series Amplifiers:Practical Case

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The feedback current amplifier in Fig 6 utilizes two identical NMOS transistor sized so that at $I_D = 0.2mA$, they operate at $V_{OV} = 0.2V$. Both the devices have $V_t = 0.5V$ and $V_A = 10V$.

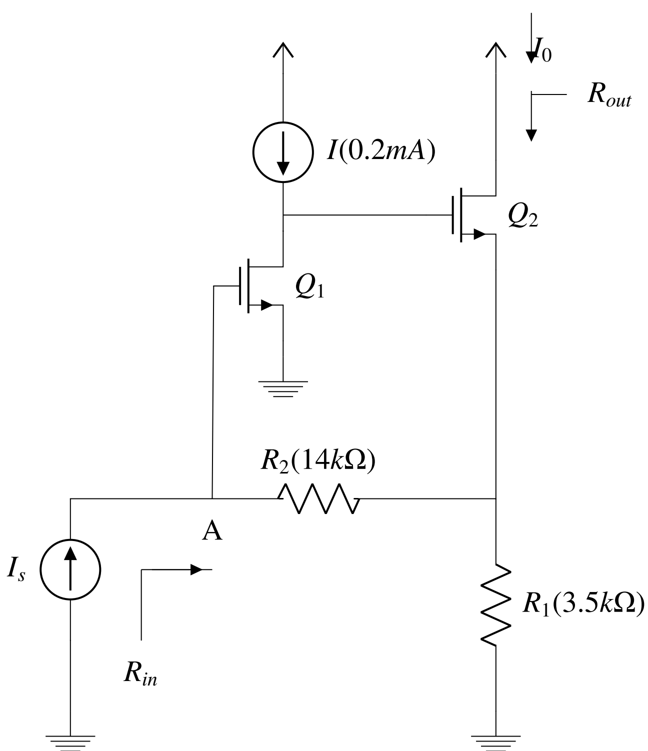


Fig. 0: Problem Figure

1) 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?
2) Find $g_m$ and $r_o$ for each $Q_1$ and $Q_2$.
3) Find the open loop circuit and the value of $R_i$, $G$ and $R_o$.
4) Find the value of $H$.
5) Find $GH$ and $T$
6) Find $R_{in}$ and $R_{out}$.

1. Find $V_{g_1} = V_A$
**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 looks like shown in Fig 1

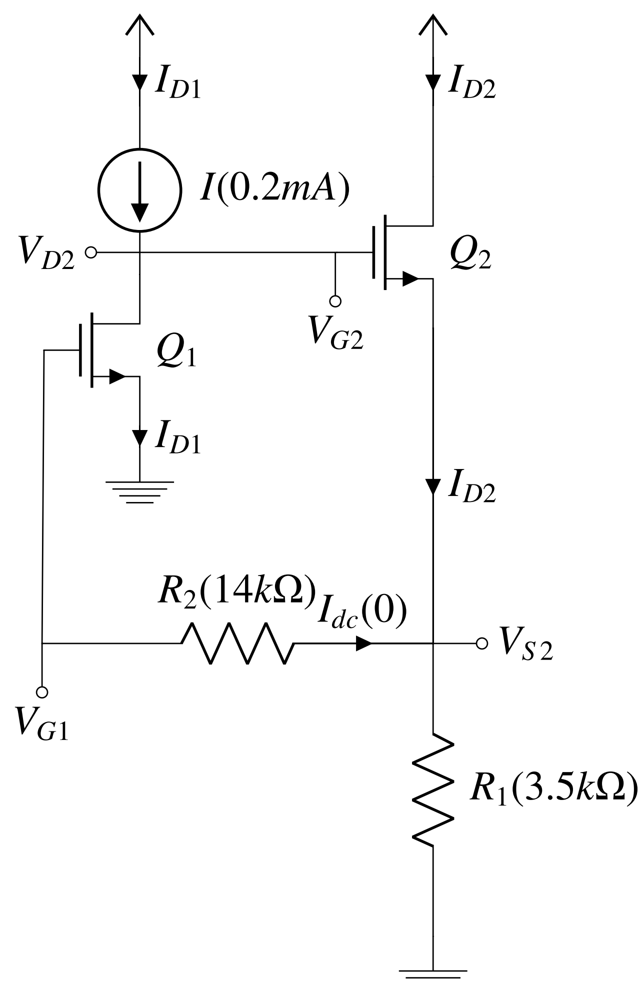


Fig. 1: DC Analysis Circuit

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Given $V_{OV} = 0.2V$ and $V_t = 0.5V$, for Q1-

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

$$\text{The DC voltage } V_{G2} = V_{S2} \tag{1.3}$$
$$\text{by ohms law, } I_{D2} = \frac{V_{S2}}{R1} = \frac{0.7V}{3.5k\Omega} \tag{1.4}$$
$$\implies I_{D2} = 0.2mA \tag{1.5}$$

Clearly $I_{D1} = 0.2mA$.
DC voltage at input = $V_{G1} = 0.7V$

2. To find $g_m$ and $r_o$
**Solution:** We know,

$$\text{transconductance, } g_m = \frac{2I_D}{V_{OV}} \tag{2.1}$$

therefore-

$$g_{m1} = g_{m2} = \frac{(2)(0.2)(10^-3)}{0.2} \tag{2.2}$$
$$\implies 2mA/V \tag{2.3}$$

$r_o$ is given by,

$$r_0 = \frac{V_A}{I_D} \tag{2.4}$$
$$\implies r_{o1} = r_{o2} = 50k\Omega \tag{2.5}$$

3. c) To find open loop circuit.
**Solution:** The general open loop circuit for a current(series-shunt) amplifier is shown in Fig 3.

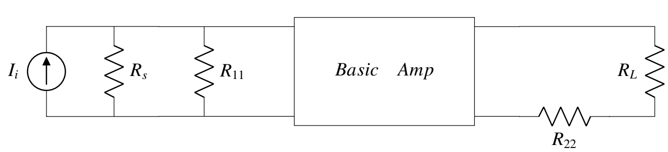


Fig. 3: General open loop circuit

For our problem, the small circuit model is shown in Fig 3. All the different resistances are summarized in Table 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.

$$R_{11} = R_1 + R_2 \tag{3.1}$$

$R_{22}$ is the resistance looking into the feedback circuit from port 2 while port 1 is short cir-

| **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 3: Resistances

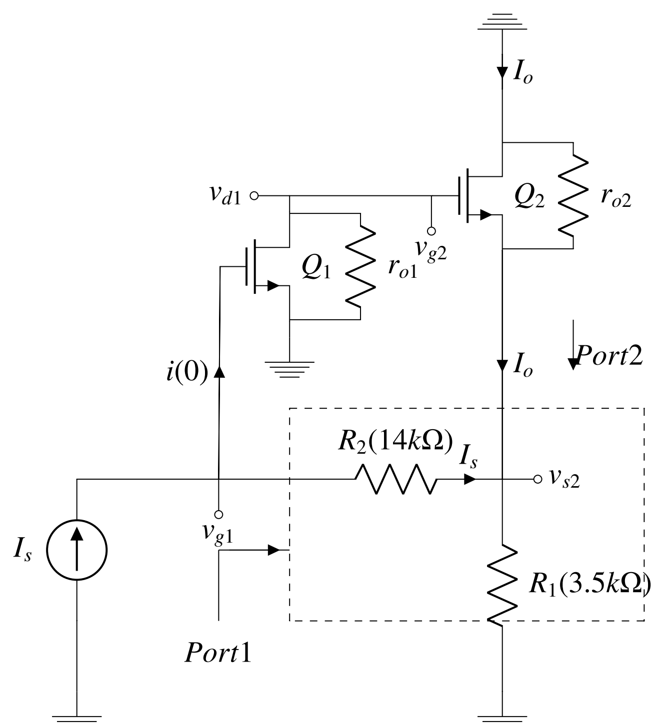


Fig. 3: Small Circuit Model

cuited.

$$R_{22} = R_1 || R_2 \tag{3.2}$$

Also for our problem, $R_L = 0$ and $R_s = \infty$.Open loop circuit for our problem is shown in Fig 3.

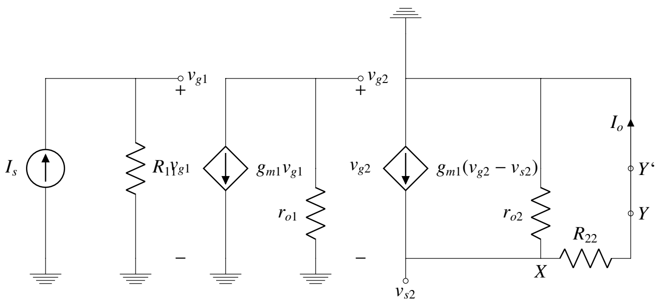


Fig. 3: Open loop circuit

From the open loop circuit, Fig 3, we have-

$$v_{g1} = I_s R_{11} = I_s(R_1 + R_2) \tag{3.3}$$

$$v_{g2} = -g_{m1} v_{g1} r_{o1} \tag{3.4}$$

$$\implies g_{m1} r_{o1}(R_1 + R_2) I_s \tag{3.5}$$

KCL at node X yields -

$$g_{m2}(v_{g2} - v_{s2}) = \frac{v_{s2}}{r_{02}||R_{22}} \tag{3.6}$$

$$\tag{3.7}$$

$$\implies g_{m2} v_{g2} = (g_{m2} + \frac{1}{r_{o2}||R_{22}}) v_{s2} \tag{3.8}$$

$$\tag{3.9}$$

$$\implies v_{s2} = \frac{v_{g2} g_{m2}}{g_{m2} + \frac{1}{r_{02}||R_{22}}} \tag{3.10}$$

$$\tag{3.11}$$

therefore,

$$I_o = \frac{v_{s2}}{R_{22}} \tag{3.12}$$

$$\implies \frac{v_{g2} g_{m2}}{g_{m2}(R_1 + R_2) + \frac{R_1||R_2}{r_{o2}||R_1||R_2}} \tag{3.13}$$

Substituting $v_{g2}$ from 3.4,

$$I_o = \frac{-g_{m1} g_{m2} r_{o1}(R_1 + R_2) I_s}{g_{m2}(R_1||R_2) + \frac{R_1||R_2}{r_{o2}||R_1||R_2}} \tag{3.14}$$

Thus, open loop gain G-

$$G = \frac{I_o}{I_s} \tag{3.15}$$

$$\implies \frac{-g_{m1} g_{m2} r_{o1}(R_1 + R_2)}{g_{m2}(R_1||R_2) + \frac{R_1||R_2}{r_{o2}||R_1||R_2}} \tag{3.16}$$

4. c)Input Resistance for Open loop
**Solution:** Input resistance of the Open loop, $R_i$, see Fig 3, clearly is-

$$R_i = R_1 + R_2 \tag{4.1}$$

5. c) To find Output Resistance of Open loop, $R_o$
**Solution:** See Fig 5 which is the output circuit obtained by breaking the open loop circuit, Fig 3, at YY' and setting the input to zero. $R_o$ is the resistance looking into YY'.

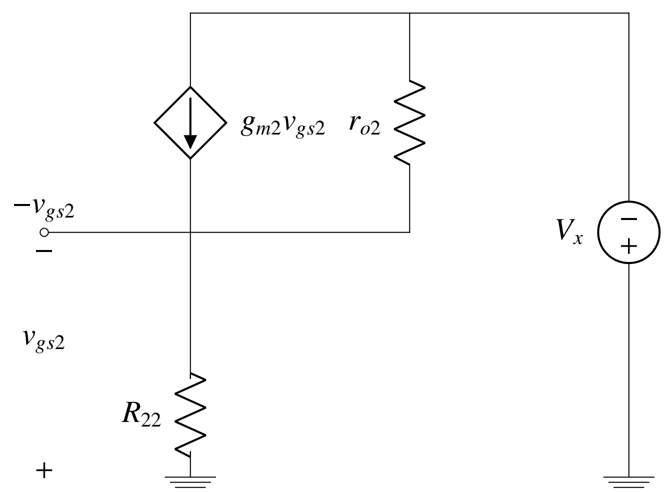


Fig. 5: Output Circuit

The current source can be changed into an equivalent voltage source, and the circuit obtained is Fig 5.
From circuit Fig 5, we have,

$$v_{gs2} = -I_x R_{22} \tag{5.1}$$

$$v_x + g_{m2} v_{gs2} r_{o2} = I_x(r_{o2} + R_{22}) \tag{5.2}$$

On subtituting 5.1 in 5.2 and simplifying, we get,

$$\frac{v_x}{I_x} = r_{o2} + R_{22} + g_{m2} r_{o2} R_{22} \tag{5.3}$$

$$\implies R_o = r_{o2} + R_1||R_2 + g_{m2} r_{o2}(R_1||R_2) \tag{5.4}$$

6. d) To find feedback gain, $H$
**Solution:** We know,

$$H = \frac{I_f}{I_0}, \text{port1 shorted} \tag{6.1}$$

$$\tag{6.2}$$

Therefore,

$$H = \frac{-R_1}{R_1 + R_2} \tag{6.3}$$

7. e) To find closed-loop gain T

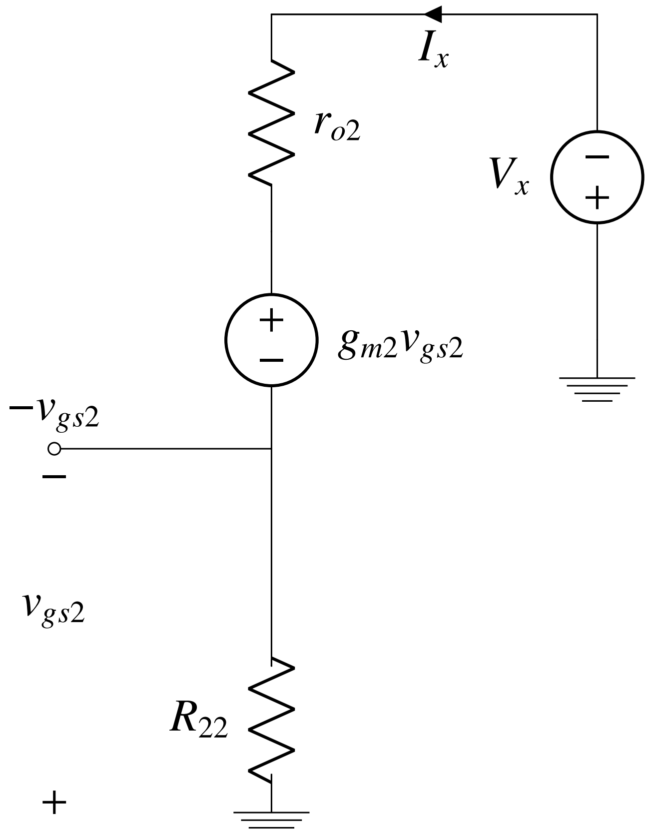


Fig. 5: Simplified Output Circuit

**Solution:**

$$GH = \frac{g_{m1}g_{m2}r_{o1}R_1}{g_{m2}(R_1||R_2) + \frac{R_1||R_2}{r_{o2}||R_1||R_2}} \tag{7.1}$$

We know,

$$T = \frac{G}{1+GH} \tag{7.2}$$

$$\tag{7.3}$$

$$\implies \frac{-g_{m1}g_{m2}r_{o1}(R_1+R_2)}{g_{m2}(R_1||R_2) + \frac{R_1||R_2}{r_{o2}||R_1||R_2} + g_{m1}g_{m2}r_{o1}R_1} \tag{7.4}$$

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

$$R_{in} = R_{if} = \frac{R_i}{1+GH} \tag{8.1}$$

and,

$$R_{out} = R_{of} = (1+GH)R_o \tag{8.2}$$

Refer 4.1 for $R_i$ and 5.4 for $R_o$. Expressions are large for $R_{out}$ and $R_{in}$. Numerical values are calculated in Table 8.

| Parameter | Value |
|---|---|
| $R_1$ | $3.5k\Omega$ |
| $R_2$ | $14k\Omega$ |
| $g_{m1}$ | $2mA/V$ |
| $g_{m2}$ | $2mA/V$ |
| $r_{o1}$ | $50k\Omega$ |
| $r_{o2}$ | $50k\Omega$ |
| $R_s$ | $\infty$ |
| $R_L$ | 0 |
| $A$ | $-526.3$ |
| $R_i$ | $17.5k\Omega$ |
| $R_o$ | $332.8k\Omega$ |
| $\beta$ | $-0.2$ |
| $A\beta$ | 105.26 |
| $A_f$ | $-4.95$ |
| $R_{in}$ | $164\Omega$ |
| $R_{out}$ | $35.3M\Omega$ |

TABLE 8: Numerical Values