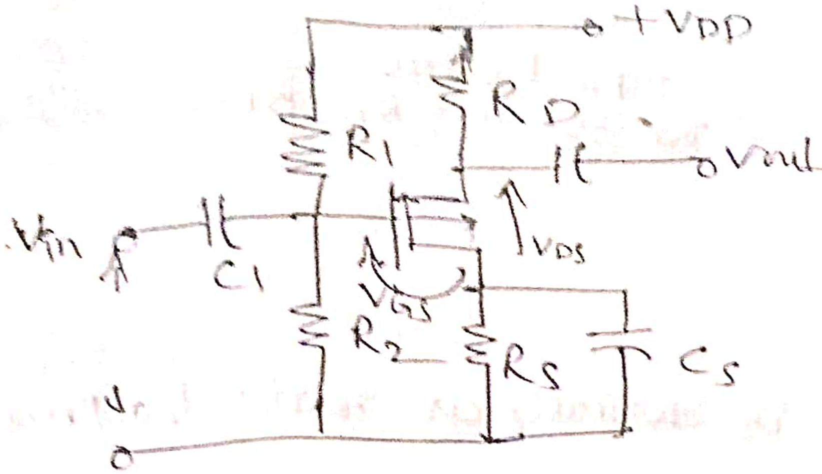
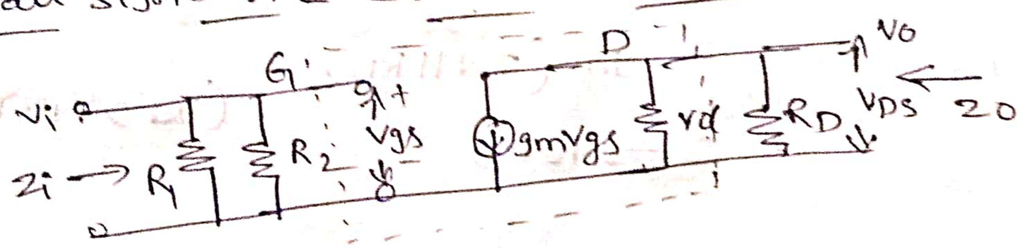
Small signal Analysis of common source amplifier



The AC equivalent model of voltage devider bias circuit of MOSFET can be obtained by all capacitors and biasing sources are shorting.

Replace the MOSFET with small signal equivalent model

Small signal AC equivalent model of MOSFET :-



Input impedance :(Z_i)

Input impedance is measured at the input terminal. Then

$$Z_i = R_1 \| R_2 = R_G$$

output impedance (Z_o) :- output impedance is measured at the output terminal with input voltage $V_i = 0$ ie all independent sources are becomes zero short ckt that is

From the fig.

When $V_i = 0$, $V_{gs} = 0$ then dependent source $g_m V_{gs}$ is open ckt then

$$Z_o = r_d \| R_D$$

normally $r_d >> R_D$. Typical values ($r_d = 35k\Omega$ & $R_D = 5k\Omega$)

Hence $\boxed{Z_o = R_D}$

<u>Voltage gain</u>:- It is defined as ratio of output voltage to the input voltage.

$$A_V = \frac{V_o}{V_i} = \frac{V_{ds}}{V_{gs}}$$

$$V_{ds} = V_o = -I_d (r_d \| R_D)$$

$$\because i_d = g_m v_{gs}$$

$$V_o = -g_m v_{gs} (r_d \| R_D)$$

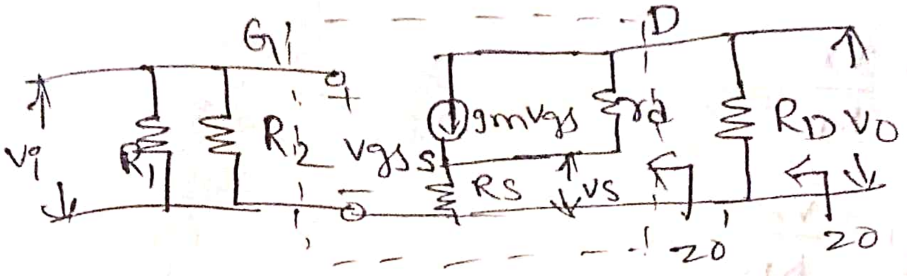
$$V_i = V_{gs}$$

$$A_V = \frac{V_o}{V_i} = \frac{-g_m V_{gs} (r_d \| R_D)}{V_{gs}}$$

$$= -g_m (r_d \| R_D)$$

$$= -g_m R_D \quad (r_d >> R_D)$$

Small signal Analysis of common source amplifier using unbypassed Rs:



Input impedance:-

Input impedance is measured at input terminal

$Z_i = R_1 \| R_2$
$= R_G$

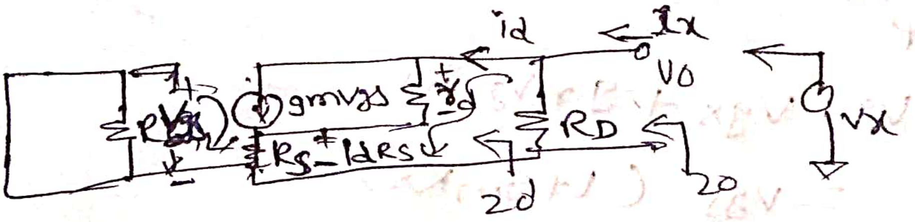
Output impedance:-

output impedance is measured at output terminal ie $V_i = 0$.

when independent sources becomes zero when $V_i = 0$ R_1 & R_2 are also short ckted. Then

$Z_0 = Z_0' \| R_D$

$Z_0' = \frac{V_{out}}{I_d} = \frac{V_x}{i_x}$ at $V_i = 0$



$R_{out} = \frac{V_x}{I_x}\Big|_{V_{in}=0}$

write at input side KVL $V_{gs} + i_d R_s = 0$

$V_{gs} = -i_d R_s$

write KVL at Drain to source

Voltage drop across R_D is $V_x = r_d(i_d - g_m V_{gs}) + i_d R_s$ current flows through r_d

$= r_d(i_d + g_m i_d R_s) + i_d R_s$

$$V_x = i_d(r_0 + g_m r_0 R_s) + i_d R_s$$

$$Z_0' = R_{out}' = \frac{V_x}{i_d} = r_d + R_s + g_m r_d R_s = r_d + R_s(1 + g_m r_d)$$

from fig

$$i_x = i_d + \frac{V_x}{R_D}$$

$$i_x = \frac{V_x}{R_{out}'} + \frac{V_x}{R_D}$$

$$= \frac{V_x}{i_x} = \frac{1}{R_{out}'} + \frac{1}{R_D} = R_{out}' \parallel R_D$$

$$= Z_0' \parallel R_D$$

$$Z_0 = \left[r_d + R_s(1 + g_m r_d)\right] \parallel R_D$$

Av : voltage gain :-

$$A_v = \frac{V_{ds}}{V_{gs}} = \frac{V_o}{V_{in}}$$

$$\cancel{V_{ds}} = \cancel{V_o} = \cancel{-i_d(R_D \parallel r_d)}$$

$$V_o = -g_m V_{gs} R_D$$

writing KVL equation from input around gate-source loop

$$V_i = V_{gs} + g_m V_{gs} R_s$$

$$= V_{gs}(1 + g_m R_s)$$

$$V_{gs} = \frac{V_i}{1 + g_m R_s}$$

$$A_v = \frac{V_o}{V_i} = \frac{-g_m V_{gs} R_D}{V_{gs}(1 + g_m R_S)}$$

$$A_v = \frac{-g_m R_D}{1 + g_m R_s}$$

∴ $g_m >>$ very large

$$\boxed{A_v \simeq \frac{-R_D}{R_S}}$$

U 4.10 ... for Exercise

−5 V

Figure 4.29 Figure for Exercise TYU4.11

4.4 THE COMMON-DRAIN (SOURCE-FOLLOWER) AMPLIFIER

Objective: • Analyze the common-drain (source-follower) amplifier and become familiar with the general characteristics of this circuit.

The second type of MOSFET amplifier to be considered is the **common-drain circuit.** An example of this circuit configuration is shown in Figure 4.30. As seen in the figure, the output signal is taken off the source

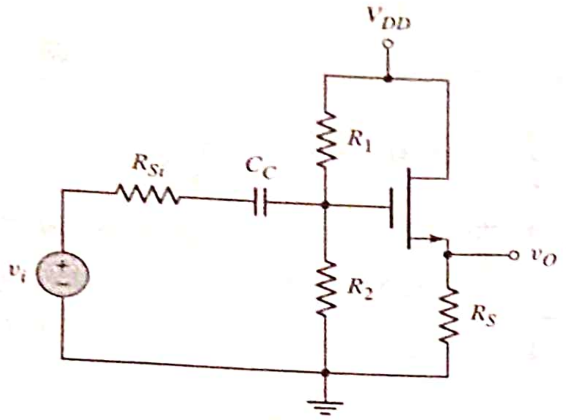


Figure 4.30 NMOS source-follower or common-drain amplifier

with respect to ground and the drain is connected directly to V_{DD}. Since V_{DD} becomes signal ground in the ac equivalent circuit, we have the name common drain. The more common name is **source follower.** The reason for this name will become apparent as we proceed through the analysis.

4.4.1 Small-Signal Voltage Gain

The dc analysis of the circuit is exactly the same as we have already seen, so we will concentrate on the small-signal analysis. The small-signal equivalent circuit, assuming the coupling capacitor acts as a short circuit, is shown in Figure 4.31(a). The drain is at signal ground, and the small-signal resistance r_o of the transistor is in parallel with the dependent current source. Figure 4.31(b) is the same equivalent circuit, but with all signal grounds at a common point. We are again neglecting the body effect. The output voltage is

$$V_o = (g_m V_{gs})(R_S \| r_o) \tag{4.30}$$

Writing a KVL equation from input to output results in the following:

$$V_{in} = V_{gs} + V_o = V_{gs} + g_m V_{gs}(R_S \| r_o) \tag{4.31(a)}$$

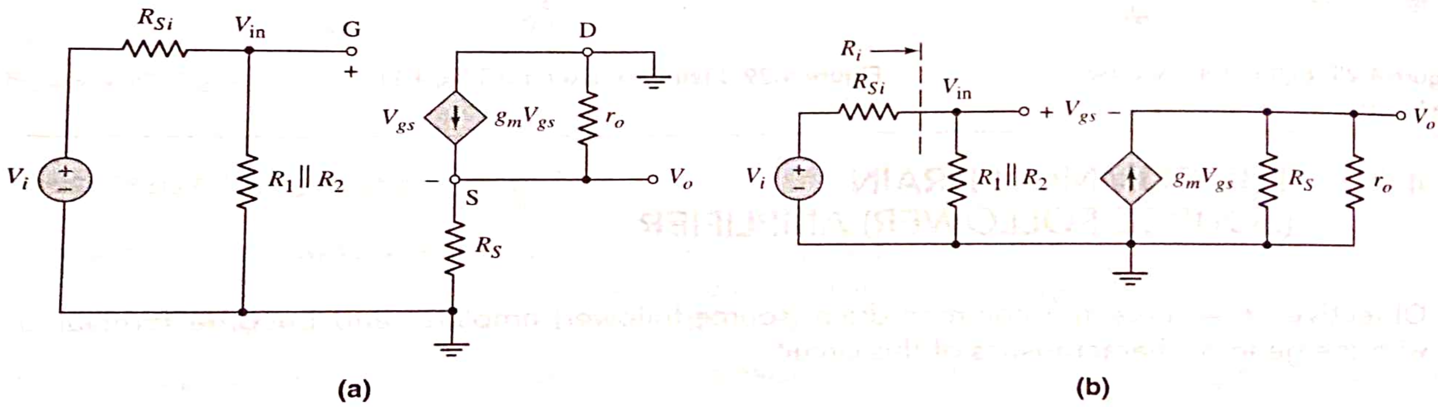


Figure 4.31 (a) Small-signal equivalent circuit of NMOS source follower and (b) small-signal equivalent circuit of NMOS source follower with all signal grounds at a common point

Therefore, the gate-to-source voltage is

$$V_{gs} = \frac{V_{in}}{1 + g_m(R_S \| r_o)} = \left[\frac{\frac{1}{g_m}}{\frac{1}{g_m} + (R_S \| r_o)} \right] \cdot V_{in} \tag{4.31(b)}$$

Equation (4.31(b)) is written in the form of a voltage-divider equation, in which the gate-to-source of the NMOS device looks like a resistance with a value of $1/g_m$. More accurately, the effective resistance looking into the source terminal (ignoring r_o) is $1/g_m$. The voltage V_{in} is related to the source input voltage V_i by

$$V_{in} = \left(\frac{R_i}{R_i + R_{Si}} \right) \cdot V_i \tag{4.32}$$

where $R_i = R_1 \| R_2$ is the input resistance to the amplifier.

Substituting Equations (4.31(b)) and (4.32) into (4.30), we have the small-signal voltage gain:

$$A_v = \frac{V_o}{V_i} = \frac{g_m(R_S \| r_o)}{1 + g_m(R_S \| r_o)} \cdot \left(\frac{R_i}{R_i + R_{Si}} \right) \tag{4.33(a)}$$

or

$$A_v = \frac{R_S \| r_o}{\frac{1}{g_m} + R_S \| r_o} \cdot \left(\frac{R_i}{R_i + R_{Si}} \right) \tag{4.33(b)}$$

which again is written in the form of a voltage-divider equation. An inspection of Equation 4.33(b) shows that the magnitude of the voltage gain is always less than unity.

EXAMPLE 4.8

Objective: Calculate the small-signal voltage gain of the source-follower circuit in Figure 4.30.

Assume the circuit parameters are $V_{DD} = 12$ V, $R_1 = 162$ kΩ, $R_2 = 463$ kΩ, and $R_S = 0.75$ kΩ, and the transistor parameters are $V_{TN} = 1.5$ V, $K_n = 4$ mA/V^2, and $\lambda = 0.01$ V^{-1}. Also assume $R_{Si} = 4$ kΩ.

Solution: The dc analysis results are $I_{DQ} = 7.97$ mA and $V_{GSQ} = 2.91$ V. The small-signal transconductance is therefore

$$g_m = 2K_n(V_{GSQ} - V_{TN}) = 2(4)(2.91 - 1.5) = 11.3 \text{ mA/V}$$

and the small-signal transistor resistance is

$$r_o \cong [\lambda I_{DQ}]^{-1} = [(0.01)(7.97)]^{-1} = 12.5 \text{ k}\Omega$$

The amplifier input resistance is

$$R_i = R_1 \| R_2 = 162 \| 463 = 120 \text{ k}\Omega$$

The small-signal voltage gain then becomes

$$A_v = \frac{g_m(R_S \| r_o)}{1 + g_m(R_S \| r_o)} \cdot \frac{R_i}{R_i + R_{Si}}$$

$$= \frac{(11.3)(0.75 \| 12.5)}{1 + (11.3)(0.75 \| 12.5)} \cdot \frac{120}{120 + 4} = +0.860$$

4.5.1 Small-Signal Voltage and Current Gains

In the common-gate configuration, the input signal is applied to the source terminal and the gate is at signal ground. The common-gate configuration shown in Figure 4.36 is biased with a constant-current source I_Q. The gate resistor R_G prevents the buildup of static charge on the gate terminal, and the capacitor C_G ensures that the gate is at signal ground. The coupling capacitor C_{C1} couples the signal to the source, and coupling capacitor C_{C2} couples the output voltage to load resistance R_L.

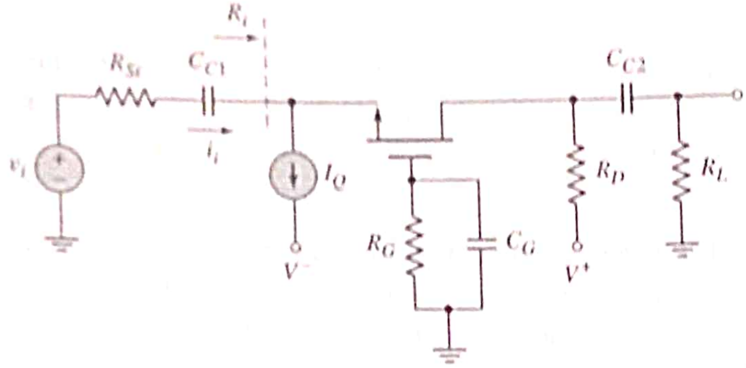


Figure 4.36 Common-gate circuit

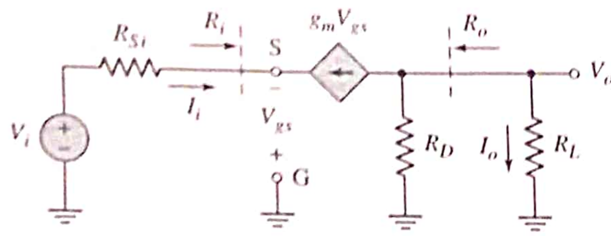


Figure 4.37 Small-signal equivalent circuit of common-gate amplifier

The small-signal equivalent circuit is shown in Figure 4.37. The small-signal transistor resistance assumed to be infinite. Since the source is the input terminal, the small-signal equivalent circuit shown i ure 4.37 may appear to be different from those considered previously. However, to sketch the equi circuit, we can use the same technique as used previously. Sketch in the three terminals of the transisto the source at the input for this case. Then draw in the transistor equivalent circuit between the three ter and then sketch in the remaining circuit elements around the transistor.

The output voltage is

$$V_o = -(g_m V_{gs})(R_D \| R_L)$$

Writing the KVL equation around the input, we find

$$V_i = I_i R_{Si} - V_{gs}$$

where $I_i = -g_m V_{gs}$. The gate-to-source voltage can then be written as

$$V_{gs} = \frac{-V_i}{1 + g_m R_{Si}}$$

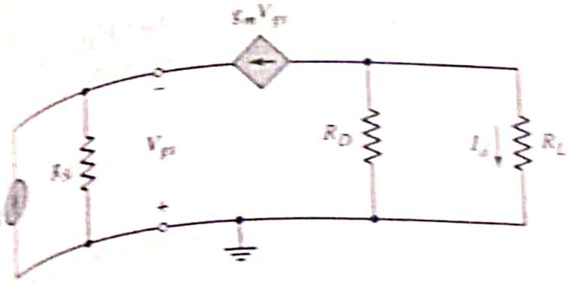


Figure 4.38 Small-signal equivalent circuit of common-gate amplifier with a Norton equivalent signal source

The small-signal voltage gain is found to be

$$A_v = \frac{V_o}{V_i} = \frac{g_m(R_D \| R_L)}{1 + g_m R_{Si}} \tag{4.41}$$

Also, since the voltage gain is positive, the output and input signals are in phase.

In many cases, the signal input to a common-gate circuit is a current. Figure 4.38 shows the small-signal equivalent common-gate circuit with a Norton equivalent circuit as the signal source. We can calculate a current gain. The output current I_o can be written

$$I_o = \left(\frac{R_D}{R_D + R_L}\right)(-g_m V_{gs}) \tag{4.42}$$

At the input we have

$$I_i + g_m V_{gs} + \frac{V_{gs}}{R_{Si}} = 0 \tag{4.43}$$

or

$$V_{gs} = -I_i\left(\frac{R_{Si}}{1 + g_m R_{Si}}\right) \tag{4.44}$$

The small-signal current gain is then

$$A_i = \frac{I_o}{I_i} = \left(\frac{R_D}{R_D + R_L}\right) \cdot \left(\frac{g_m R_{Si}}{1 + g_m R_{Si}}\right) \tag{4.45}$$

We may note that if $R_D \gg R_L$ and $g_m R_{Si} \gg 1$, then the current gain is essentially unity.

4.5.2 Input and Output Impedance

In contrast to the common-source and source-follower amplifiers, the common-gate circuit has a low input resistance because of the transistor. However, if the input signal is a current, a low input resistance is an advantage. The input resistance is defined as

$$R_i = \frac{-V_{gs}}{I_i} \tag{4.46}$$

Since $I_i = -g_m V_{gs}$, the input resistance is

$$R_i = \frac{1}{g_m} \tag{4.47}$$

This result has been obtained previously.

We can find the output resistance by setting the input signal voltage equal to zero. From Figure 4.37, we see that $V_{gs} = -g_m V_{gs} R_{Si}$, which means that $V_{gs} = 0$. Consequently, $g_m V_{gs} = 0$. The output resistance, looking back from the load resistance, is therefore

$$R_o = R_D \tag{4.48}$$

EXAMPLE 4.11

Objective: For the common-gate circuit, determine the output voltage for a given input current.

For the circuits shown in Figures 4.36 and 4.38, the circuit parameters are: $I_Q = 1$ mA, $V^+ = 5$ V, $V^- = -5$ V, $R_G = 100$ kΩ, $R_D = 4$ kΩ, and $R_L = 10$ kΩ. The transistor parameters are: $V_{TN} = 1$ V, $K_n = 1$ mA/V^2, and $\lambda = 0$. Assume the input current in Figure 4.38 is $100 \sin \omega t$ μA and assume $R_{Si} = 50$ kΩ.

Solution: The quiescent gate-to-source voltage is determined from

$$I_Q = I_{DQ} = K_n(V_{GSQ} - V_{TN})^2$$

or

$$1 = 1(V_{GSQ} - 1)^2]$$

which yields

$$V_{GSQ} = 2\,\text{V}$$

The small-signal transconductance is

$$g_m = 2K_n(V_{GSQ} - V_{TN}) = 2(1)(2-1) = 2\,\text{mA/V}$$

From Equation (4.45), we can write the output current as

$$I_o = I_i\left(\frac{R_D}{R_D + R_L}\right) \cdot \left(\frac{g_m R_{Si}}{1 + g_m R_{Si}}\right)$$

The output voltage is $V_o = I_o R_L$, so we find

$$V_o = I_i\left(\frac{R_L R_D}{R_D + R_L}\right) \cdot \left(\frac{g_m R_{Si}}{1 + g_m R_{Si}}\right)$$

$$= \left[\frac{(10)(4)}{4 + 10}\right] \cdot \left[\frac{(2)(50)}{1 + (2)(50)}\right] \cdot (0.1) \sin \omega t$$

or

$$V_o = 0.283 \sin \omega t\ \text{V}$$

Comment: As with the BJT common-base circuit, the MOSFET common-gate amplifier is useful if the input signal is a current.