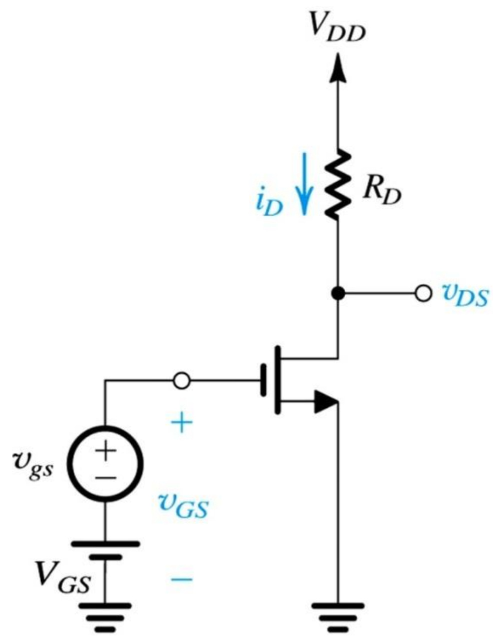
Small - signal operation and models of MOSFETs

The DC Bias Point



(a)

- DC Bias current I_D is found as:

$$I_D = \frac{1}{2} k_n' \frac{W}{L} (V_{GS} - V_t)^2$$

- DC voltage at drain, V_{DS} or V_D :

$$V_D = V_{DD} - R_D I_D$$

- To ensure saturation:

$$V_D > V_{GS} - V_t$$

Signal current in the drain terminal

- Instantaneous gate – to – source voltage, with V_{gs} applied is

$$v_{GS} = V_{GS} + v_{gs}$$

- Resulting total instantaneous drain current, i_D :

$$\begin{aligned} i_D &= \frac{1}{2}k_n'\frac{W}{L}(V_{GS} + v_{gs} - V_t)^2 \\ &= \frac{1}{2}k_n'\frac{W}{L}(V_{GS} - V_t)^2 + k_n'\frac{W}{L}(V_{GS} - V_t)v_{gs} + \frac{1}{2}k_n'\frac{W}{L}v_{gs}^2 \end{aligned}$$

The first term on the right-hand side of above equation can be recognized as the dc bias currentJD ,The second term represents a current component that is directly proportional to the input signal Vgs. The third term is a current component that is proportional to the square of the input signal. This last component is undesirable because it represents nonlinear distortion. To reduce the nonlinear

$$\frac{1}{2}k_n'\frac{W}{L}v_{gs}^2 \ll k_n'\frac{W}{L}(V_{GS}-V_t)v_{gs}$$

$$v_{gs} \ll 2(V_{GS}-V_t)$$

$$v_{gs} \ll 2V_{OV}$$

$$i_D \simeq I_D + i_d$$

$$i_d = k_n'\frac{W}{L}(V_{GS}-V_t)v_{gs}$$

- Thus, defining *transconductance* g_m *:*

$$g_m \equiv \frac{i_d}{v_{gs}} = k_n' \frac{W}{L}(V_{GS} - V_t)$$

$$g_m = k_n' \frac{W}{L} V_{OV}$$

$$g_m \equiv \left. \frac{\partial i_D}{\partial v_{GS}} \right|_{v_{GS} = V_{GS}}$$

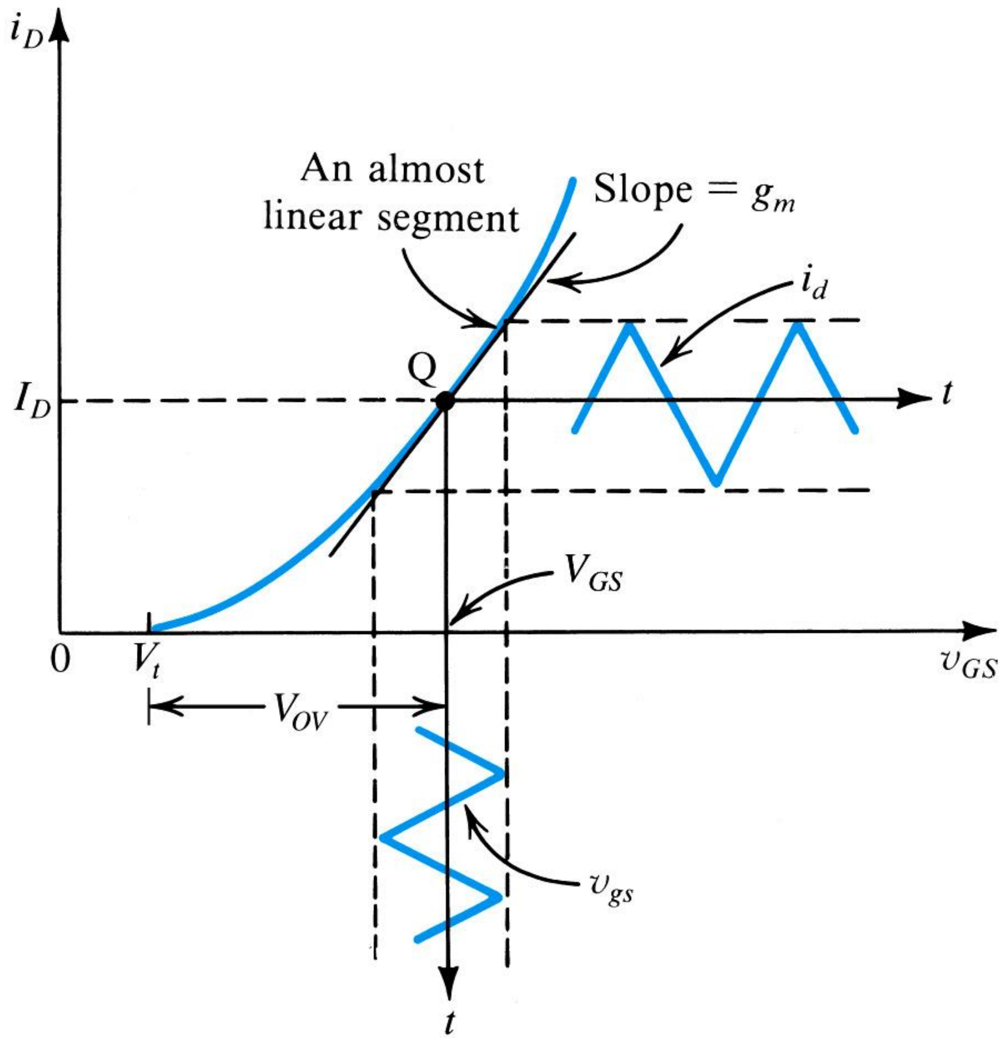


Figure 5.35 Small-signal operation of the MOSFET amplifier.

The Voltage Gain

- From the previous circuit diagram, the total instantaneous drain voltage v_D is:

$$v_D = V_{DD} - R_D i_D$$

- Under small signal condition:

$$v_D = V_{DD} - R_D(I_D + i_d)$$

$$v_D = V_D - R_D i_d$$

- The signal component of this is –

$$v_d = -i_d R_D = -g_m v_{gs} R_D$$

- This gives the voltage gain Av as:

$$A_v \equiv \frac{v_d}{v_{gs}} = -g_m R_D$$

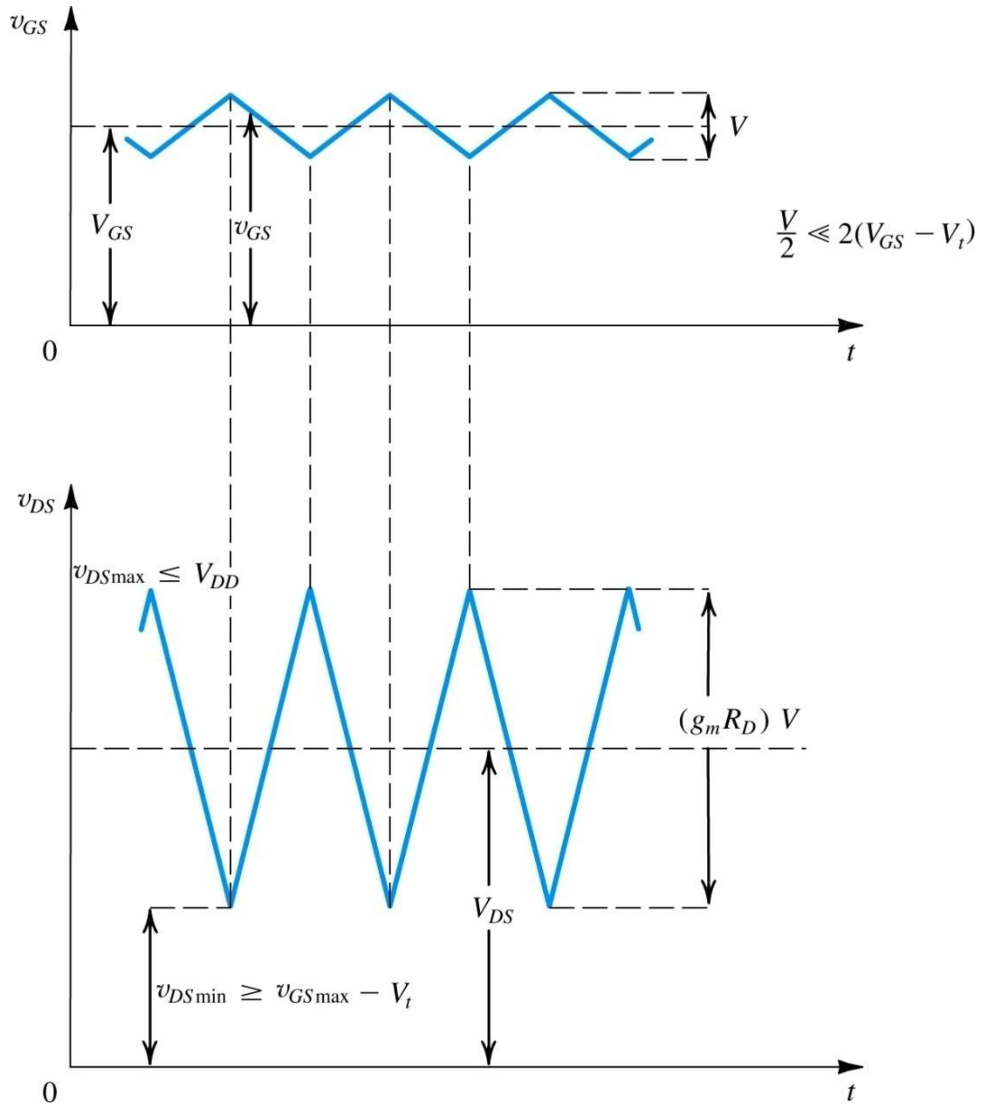
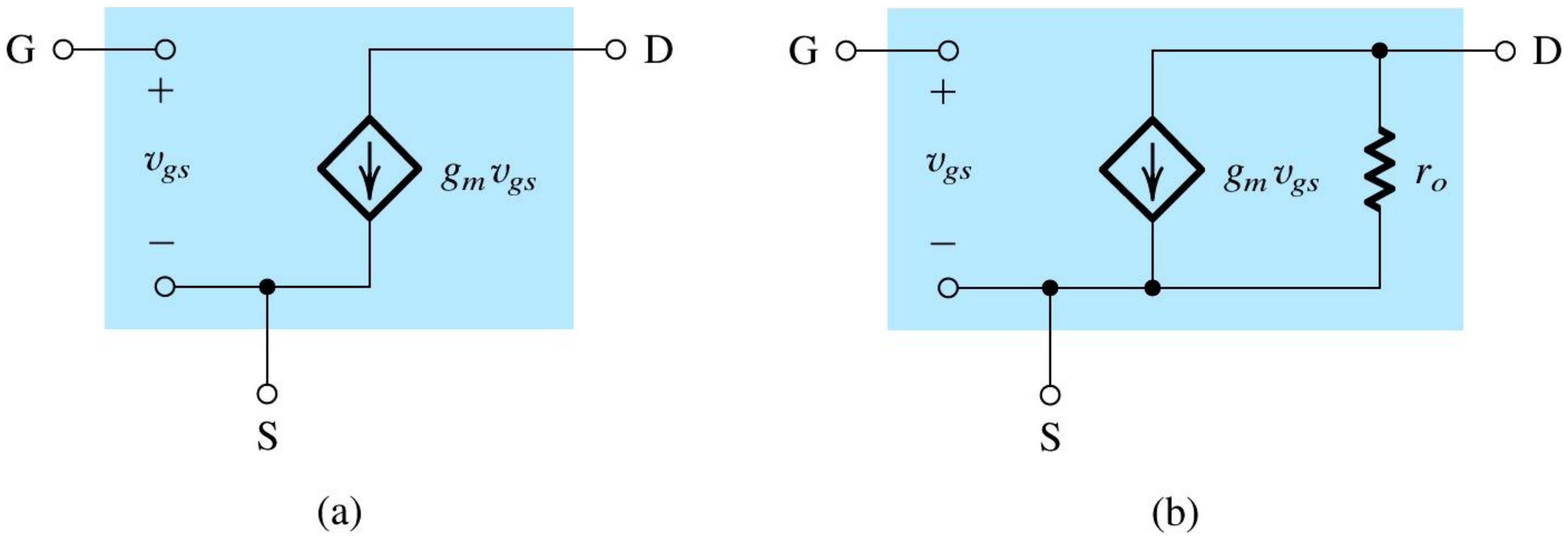


Figure 5.36 Total instantaneous voltages v_{GS} and v_{DS} for the circuit in Fig. 5.34.

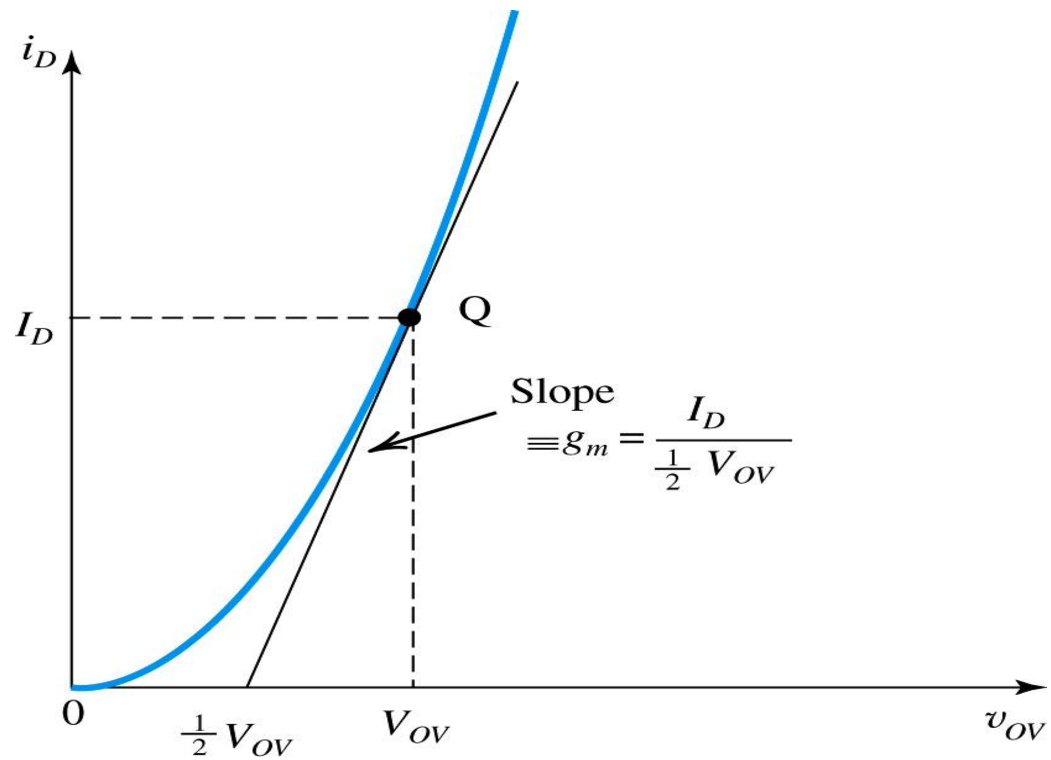
Separating dc analysis and the signal analysis

- The analysis and design can be simplified by separating dc or bias calculations from small-signal calculations.
- That is, once a stable dc operating point has been established, all dc quantities are calculated.
- We then perform signal analysis ignoring dc quantities.

Small signal equivalent circuit models



Small-signal models for the MOSFET: **(a)** neglecting the dependence of i_D on v_{DS} in saturation (the channel-length modulation effect); and **(b)** including the effect of channel-length modulation, modeled by output resistance $r_o = |V_A| / I_D$.



The slope of the tangent at the bias point Q intersects the v_{OV} axis at $\frac{1}{2}V_{OV}$. Thus, $g_m = I_D / (\frac{1}{2}V_{OV})$.

Transconductance g_m

$$g_m = k_n'(W/L)(V_{GS} - V_t) = k_n'(W/L)V_{OV}$$

$$g_m = \sqrt{2k_n'}\sqrt{W/L}\sqrt{I_D}$$

$$g_m = \frac{2I_D}{V_{GS} - V_t} = \frac{2I_D}{V_{OV}}$$

Another useful expression for g_m can be obtained by substituting for $(V_{GS} - V_t)$ in Eq. (4.69) by $\sqrt{2I_D/(k_n'(W/L))}$ [from Eq. (4.53)]:

$$g_m = \sqrt{2k_n'}\sqrt{W/L}\sqrt{I_D} \tag{4.70}$$

This expression shows that

1. For a given MOSFET, g_m is proportional to the square root of the dc bias current.
2. At a given bias current, g_m is proportional to $\sqrt{W/L}$.

In contrast, the transconductance of the bipolar junction transistor (BJT) studied in Chapter 5 is proportional to the bias current and is independent of the physical size and geometry of the device.

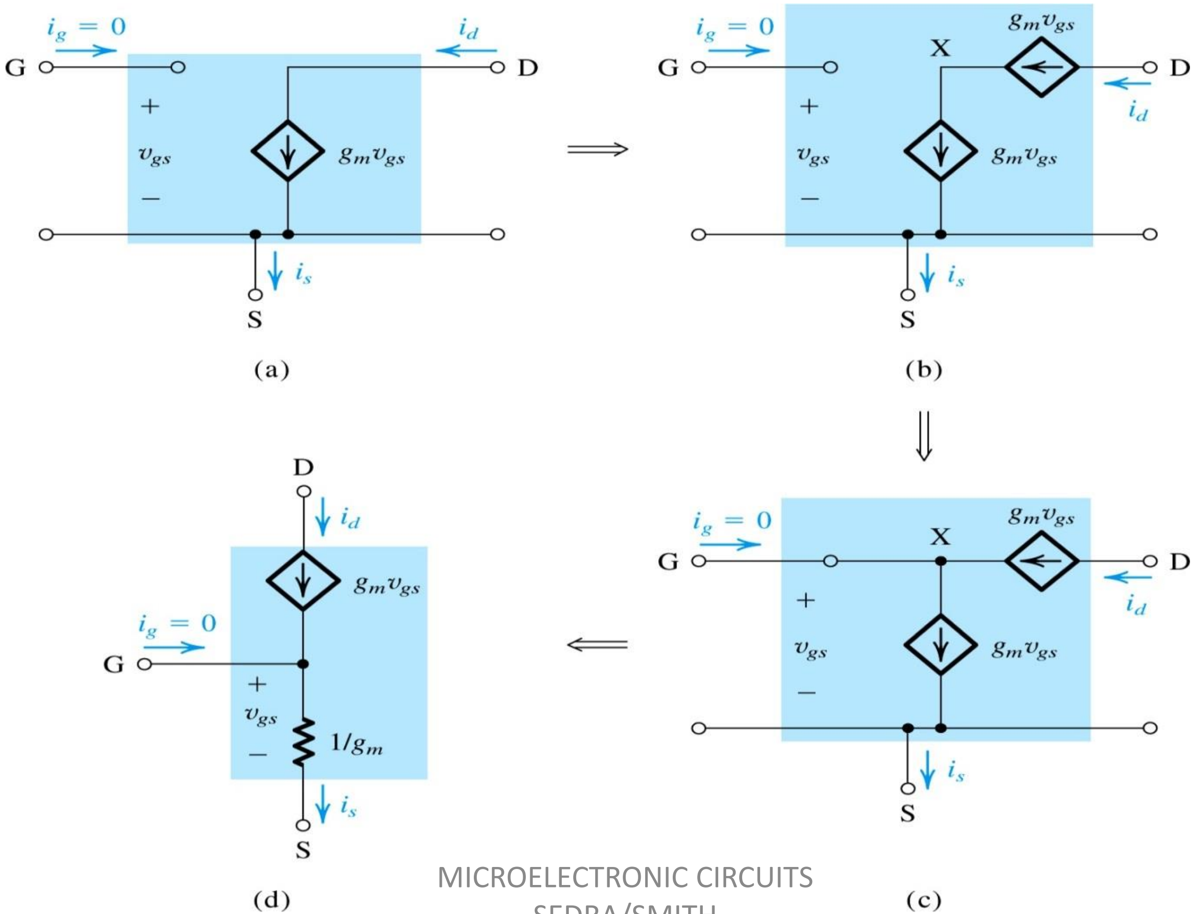
To gain some insight into the values of g_m obtained in MOSFETs consider an integrated-circuit device operating at $I_D = 0.5$ mA and having $k_n' = 120\ \mu A/V^2$. Equation (4.70) shows that for $W/L = 1$, $g_m = 0.35$ mA/V, whereas a device for which $W/L = 100$ has $g_m =$ 3.5 mA/V. In contrast, a BJT operating at a collector current of 0.5 mA has $g_m = 20$ mA/V.

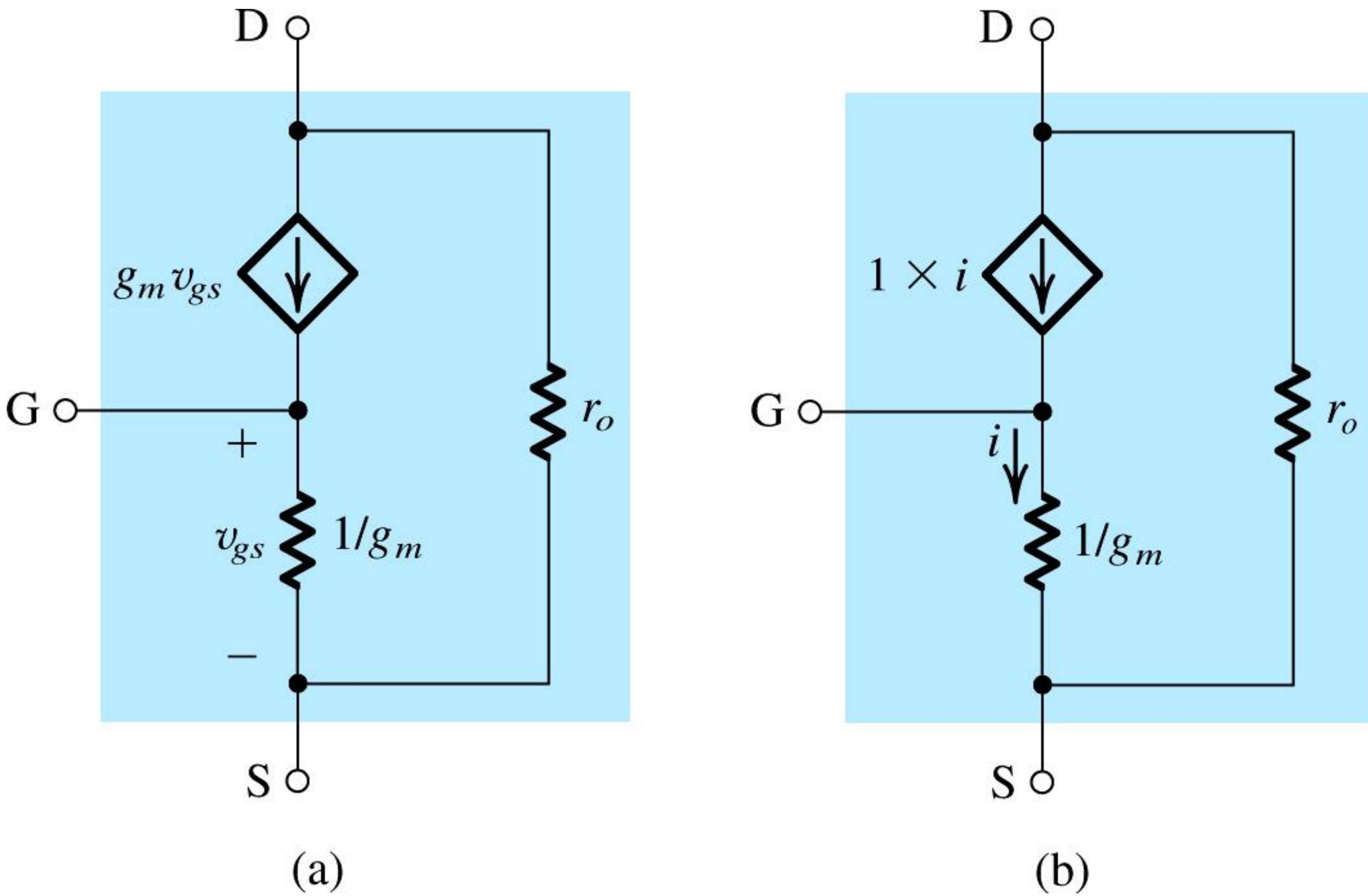
Yet another useful expression for g_m of the MOSFET can be obtained by substituting for $k_n'(W/L)$ in Eq. (4.69) by $2I_D/(V_{GS} - V_t)^2$:

$$g_m = \frac{2I_D}{V_{GS} - V_t} = \frac{2I_D}{V_{OV}} \tag{4.71}$$

T equivalent circuit model

Development of T Equivalent Model

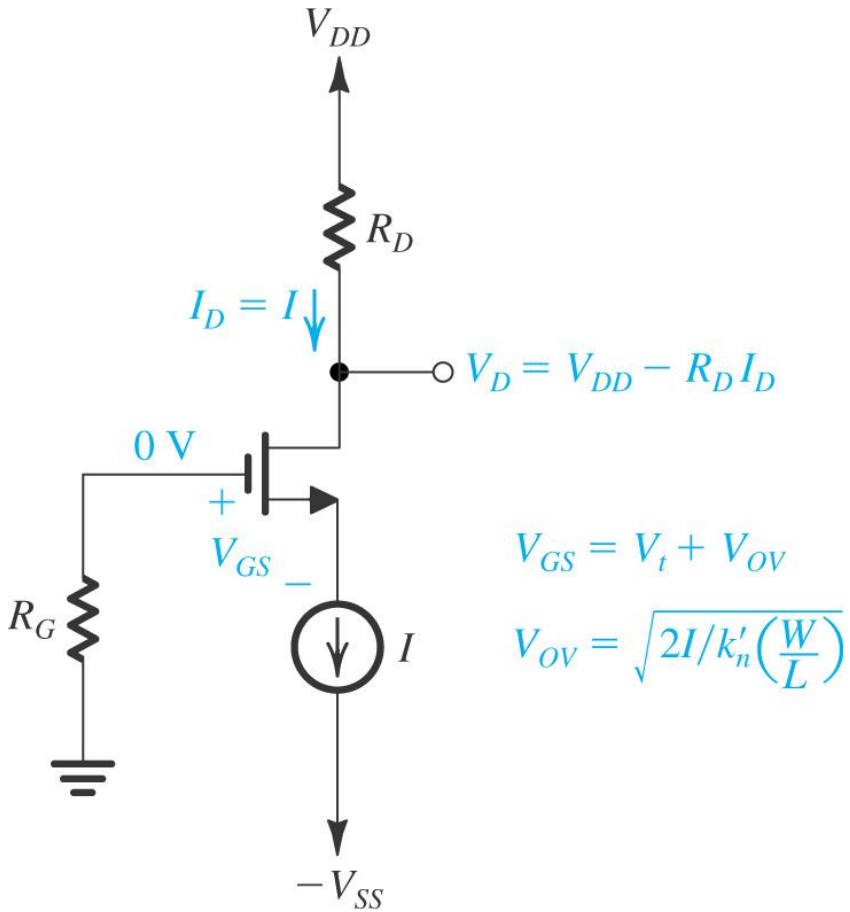




(a) The T model of the MOSFET augmented with the drain-to-source resistance r_o. (b) An alternative representation of the T model.

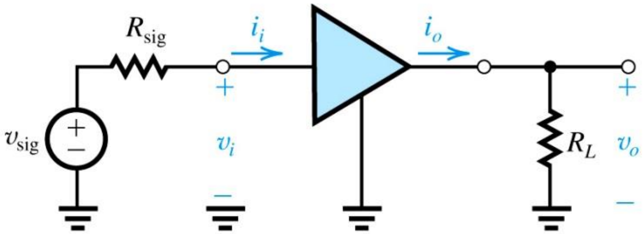
Single stage MOS amplifiers

The basic structure



Basic structure of the circuit used to realize single-stage, discrete-circuit MOS amplifier configurations.

Characterizing amplifiers



(a)

An amplifier fed with a voltage signal v_{sig} having a source resistance R_{sig} and feeding a load resistance R_L

Definitions

- Input resistance with no load

$$R_i \equiv \left.\frac{v_i}{i_i}\right|_{R_L=\infty}$$

- Input resistance

$$R_{in} \equiv \frac{v_i}{i_i}$$

- Open circuit voltage gain

$$A_{vo} \equiv \left.\frac{v_o}{v_i}\right|_{R_L=\infty}$$

- Voltage gain

$$A_v \equiv \frac{v_o}{v_i}$$

- Short circuit current gain

$$A_{is} \equiv \left.\frac{i_o}{i_i}\right|_{R_L=0}$$

- Current gain

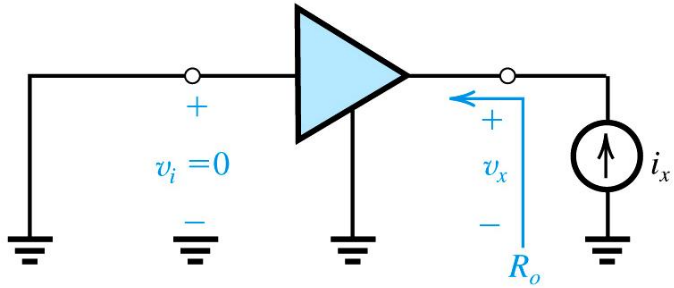
$$A_i \equiv \frac{i_o}{i_i}$$

- Short circuit trans conductance

$$G_m \equiv \left.\frac{i_o}{v_i}\right|_{R_L=0}$$

- Output resistance of amplifier proper

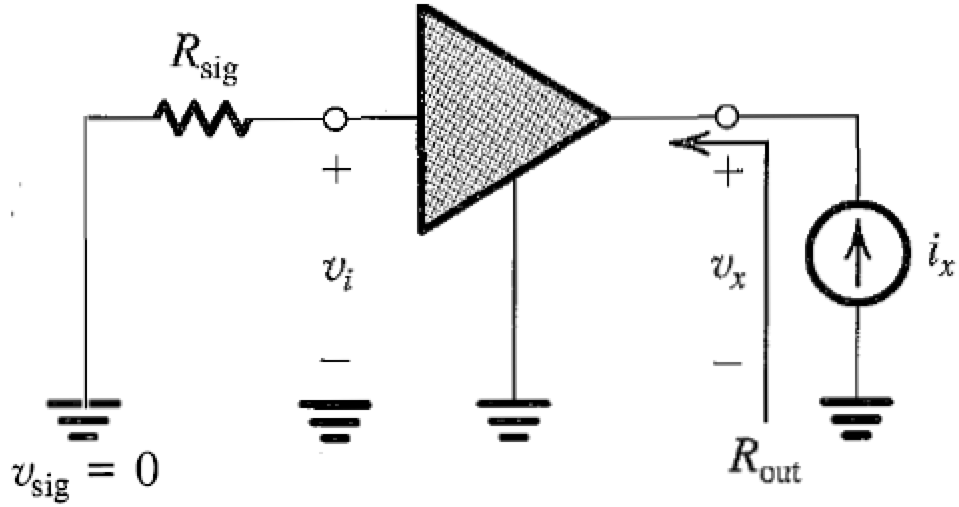
$$R_o \equiv \left.\frac{v_x}{i_x}\right|_{v_i=0}$$



(b) Determining the amplifier output resistance

- Output resistance

$$R_{\text{out}} \equiv \left.\frac{v_x}{i_x}\right|_{v_{\text{sig}}=0}$$



(c)

- Open circuit overall voltage gain

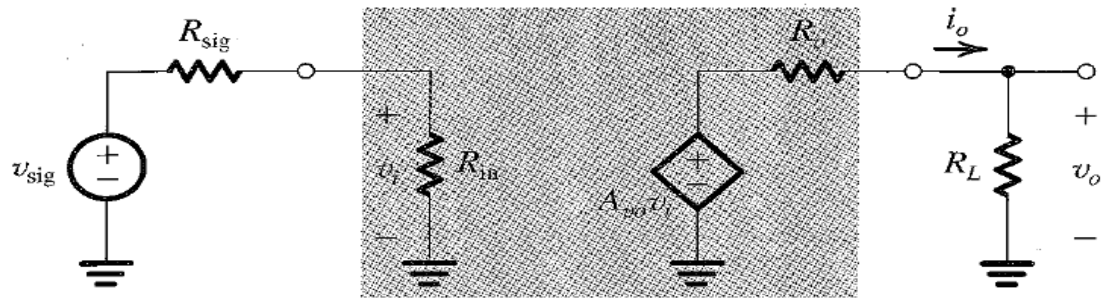
$$G_{vo} \equiv \left.\frac{v_o}{v_{sig}}\right|_{R_L=\infty}$$

- Over all voltage gain

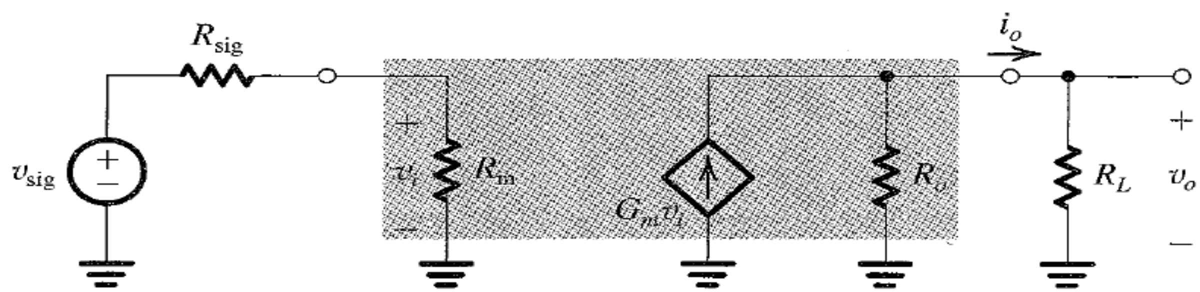
$$G_v \equiv \frac{v_o}{v_{sig}}$$

Equivalent circuits for the figures (a) , (b) and (c)

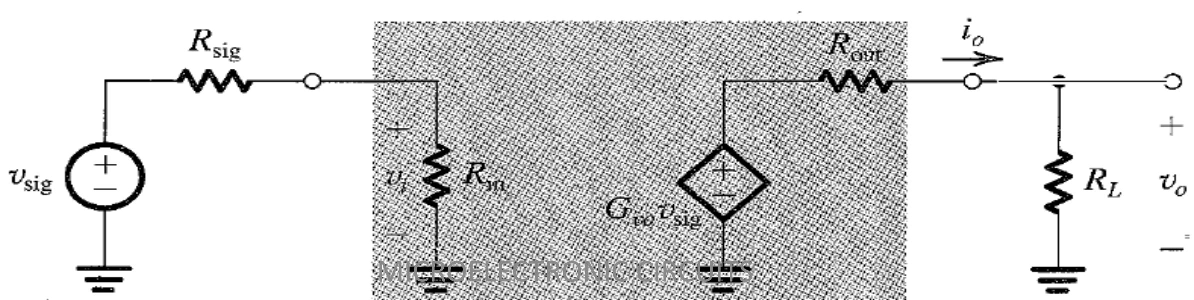
A:



B:



C:



- Relationships

- $$\frac{v_i}{v_{\text{sig}}} = \frac{R_{\text{in}}}{R_{\text{in}} + R_{\text{sig}}}$$
- $$A_v = A_{vo}\frac{R_L}{R_L + R_o}$$
- $$A_{vo} = G_m R_o$$
- $$G_v = \frac{R_{\text{in}}}{R_{\text{in}} + R_{\text{sig}}} A_{vo} \frac{R_L}{R_L + R_o}$$
- $$G_{vo} = \frac{R_i}{R_i + R_{\text{sig}}} A_{vo}$$
- $$G_v = G_{vo} \frac{R_L}{R_L + R_{\text{out}}}$$

A transistor amplifier is fed with a signal source having an open-circuit voltage v_{sig} of 10 mV and an internal resistance R_{sig} of 100 kΩ. The voltage v_i at the amplifier input and the output voltage v_o are measured both without and with a load resistance $R_L = 10$ kΩ connected to the amplifier output. The measured results are as follows:

	v_i (mV)	v_o (mV)
Without R_L	9	90
With R_L connected	8	70

Find all the amplifier parameters.

Solution

First, we use the data obtained for $R_L = \infty$ to determine

$$A_{vo} = \frac{90}{9} = 10 \text{ V/V}$$

and

$$G_{vo} = \frac{90}{10} = 9 \text{ V/V}$$

Now, since

$$G_{vo} = \frac{R_i}{R_i + R_{sig}} A_{vo}$$

$$9 = \frac{R_i}{R_i + 100} \times 10$$

which gives

$$R_i = 900 \text{ k}\Omega$$

Next, we use the data obtained when $R_L = 10 \text{ k}\Omega$ is connected to the amplifier output to determine

$$A_v = \frac{70}{8} = 8.75 \text{ V/V}$$

and

$$G_v = \frac{70}{10} = 7 \text{ V/V}$$

The values of A_v and A_{vo} can be used to determine R_o as follows:

$$A_v = A_{vo}\frac{R_L}{R_L + R_o}$$

$$8.75 = 10\frac{10}{10 + R_o}$$

which gives

$$R_o = 1.43 \text{ k}\Omega$$

Similarly, we use the values of G_v and G_{vo} to determine R_{out} from

$$G_v = G_{vo}\frac{R_L}{R_L + R_{out}}$$

$$7 = 9\frac{10}{10 + R_{out}}$$

resulting in

$$R_{out} = 2.86 \text{ k}\Omega$$

The value of R_{in} can be determined from

$$\frac{v_i}{v_{sig}} = \frac{R_{in}}{R_{in} + R_{sig}}$$

Thus,

$$\frac{8}{10} = \frac{R_{in}}{R_{in} + 100}$$

which yields

$$R_{in} = 400 \text{ k}\Omega$$

The short-circuit transconductance G_m can be found as follows:

$$G_m = \frac{A_{vo}}{R_o} = \frac{10}{1.43} = 7 \text{ mA/V}$$

and the current gain A_i can be determined as follows:

$$A_i = \frac{v_o/R_L}{v_i/R_{in}} = \frac{v_o}{v_i}\frac{R_{in}}{R_L}$$

$$= A_v\frac{R_{in}}{R_L} = 8.75 \times \frac{400}{10} = 350 \text{ A/A}$$

Finally, we determine the short-circuit current gain A_{is} as follows. From Equivalent Circuit A, the short-circuit output current is

$$i_{osc} = A_{vo}v_i/R_o \tag{5.107}$$

However, to determine v_i we need to know the value of R_{in} obtained with $R_L = 0$. Toward this end, note that from Equivalent Circuit C, the output short-circuit current can be found as

$$i_{osc} = G_{vo}v_{sig}/R_{out} \tag{5.108}$$

Now, equating the two expressions for i_{osc} and substituting for G_{vo} by

$$G_{vo} = \frac{R_i}{R_i + R_{sig}}A_{vo}$$

and for v_i from

$$v_i = v_{sig}\frac{R_{in}|_{R_L=0}}{R_{in}|_{R_L=0} + R_{sig}}$$

results in

$$R_{in}|_{R_L=0} = R_{sig}\Big/\left[\left(1 + \frac{R_{sig}}{R_i}\right)\left(\frac{R_{out}}{R_o}\right) - 1\right]$$

$$= 81.8 \text{ k}\Omega$$

We now can use

$$i_{osc} = A_{vo}i_iR_{in}|_{R_L=0}/R_o$$

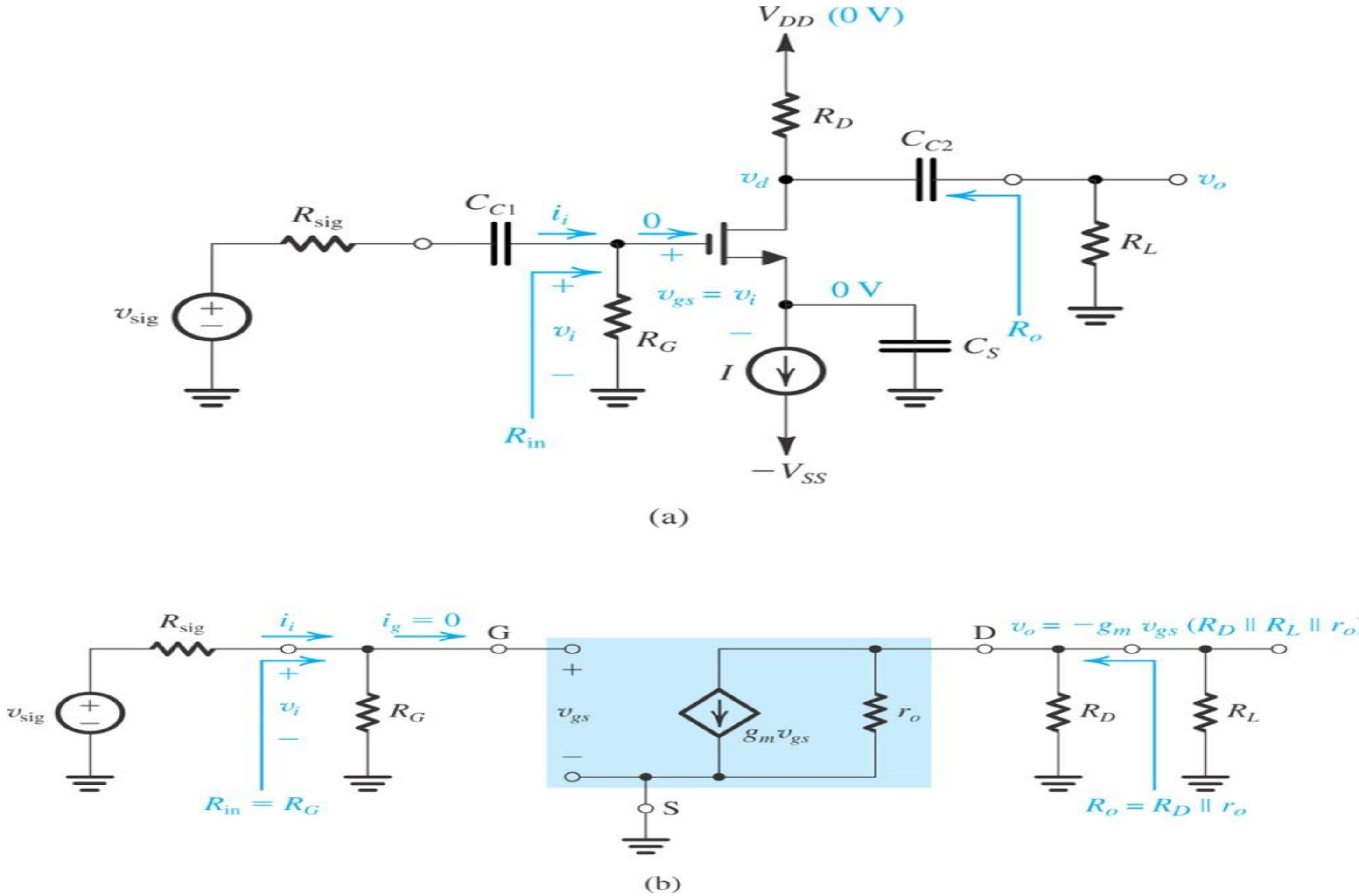
We now can use

$$i_{osc} = A_{vo} i_i R_{in}|_{R_L=0} / R_o$$

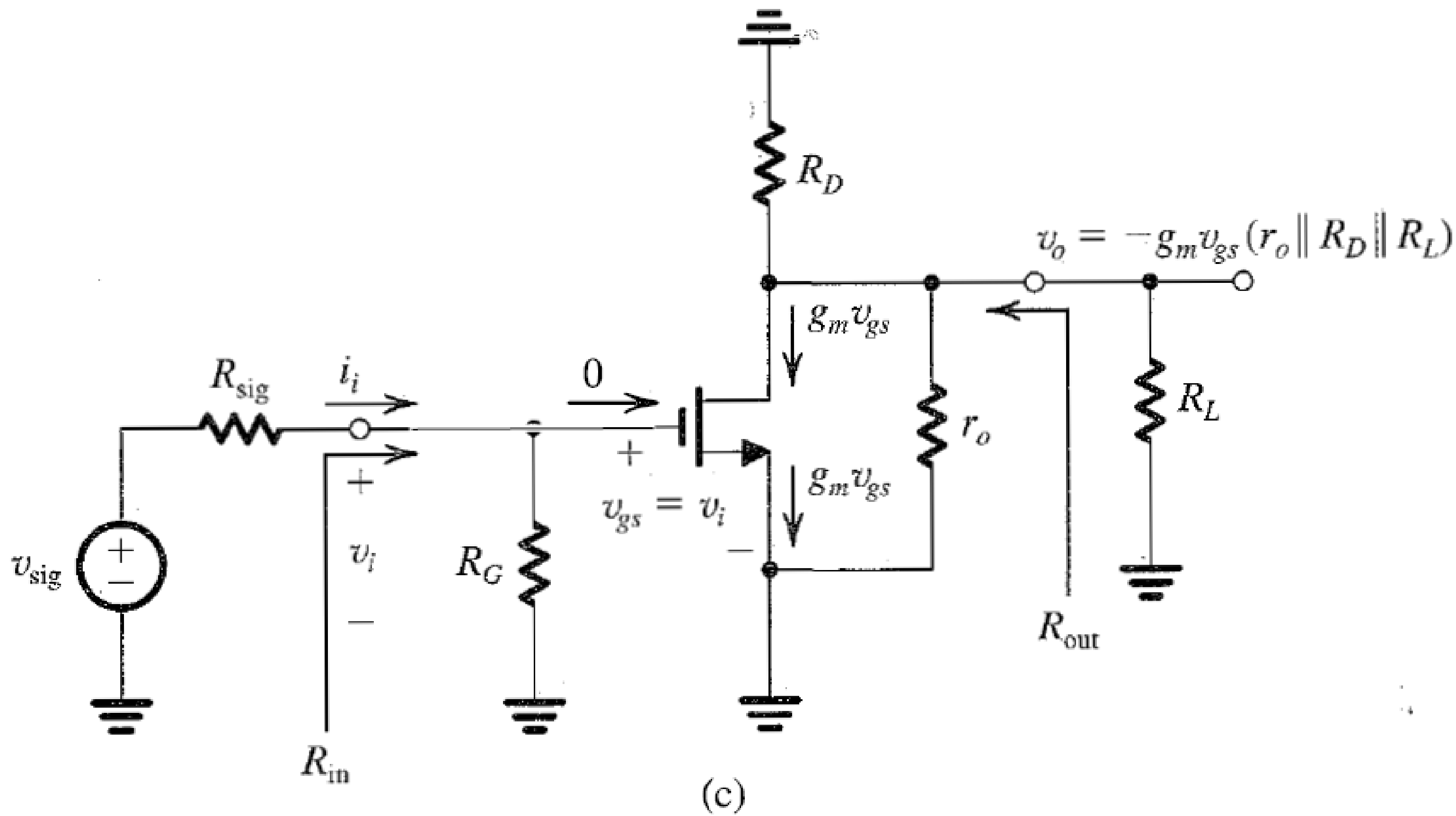
to obtain

$$A_{is} = \frac{i_{osc}}{i_i} = 10 \times 81.8 / 1.43 = 572 \text{ A/A}$$

The CS amplifier



(a) Common-source amplifier (b) Equivalent circuit of the amplifier for small-signal analysis.



(c)

(c) Small-signal analysis performed directly on the amplifier circuit with the MOSFET model implicitly utilized.

- At the input,

$$i_g = 0$$

$$R_{\text{in}} = R_G$$

$$v_i = v_{\text{sig}} \frac{R_{\text{in}}}{R_{\text{in}} + R_{\text{sig}}} = v_{\text{sig}} \frac{R_G}{R_G + R_{\text{sig}}}$$

Usually R_G is selected very large (e.g., in the MΩ range) with the result that in many applications $R_G \gg R_{\text{sig}}$ and

$$v_i \cong v_{\text{sig}}$$

Now

$$v_{gs} = v_i$$

and

$$v_o = -g_m v_{gs}(r_o \parallel R_D \parallel R_L)$$

Thus the voltage gain A_v is

$$A_v = -g_m(r_o \parallel R_D \parallel R_L)$$

and the open-circuit voltage gain A_{vo} is

$$A_{vo} = -g_m(r_o \parallel R_D)$$

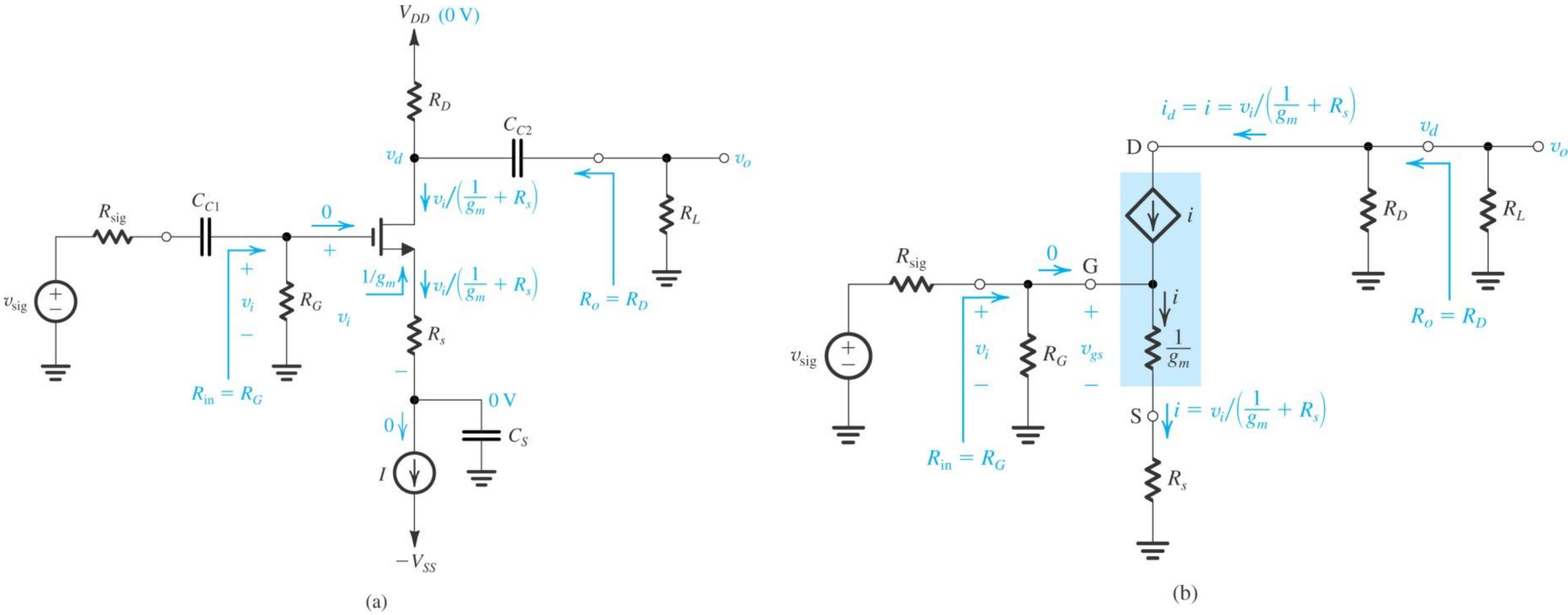
The overall voltage gain from the signal-source to the load will be

$$G_v = \frac{R_{in}}{R_{in} + R_{sig}} A_v$$

$$= -\frac{R_G}{R_G + R_{sig}} g_m(r_o \parallel R_D \parallel R_L)$$

$$R_{out} = r_o \parallel R_D$$

The CS amplifier with a source resistance



(a) Common-source amplifier with a resistance R_S in the source lead. (b) Small-signal equivalent circuit with r_o neglected.

- From the above fig, in the case of a CS amplifier,

$$R_{in} = R_i = R_G$$

$$v_i = v_{sig}\frac{R_G}{R_G + R_{sig}}$$

$$v_{gs} = v_i\frac{\frac{1}{g_m}}{\frac{1}{g_m} + R_S} = \frac{v_i}{1 + g_m R_S}$$

$$i_d = i = \frac{v_i}{\frac{1}{g_m} + R_S} = \frac{g_m v_i}{1 + g_m R_S}$$

- Output voltage

$$v_o = -i_d(R_D \parallel R_L)$$

$$= -\frac{g_m(R_D \parallel R_L)}{1 + g_m R_S} v_i$$

- Voltage gain

$$A_v = -\frac{g_m(R_D \parallel R_L)}{1 + g_m R_S}$$

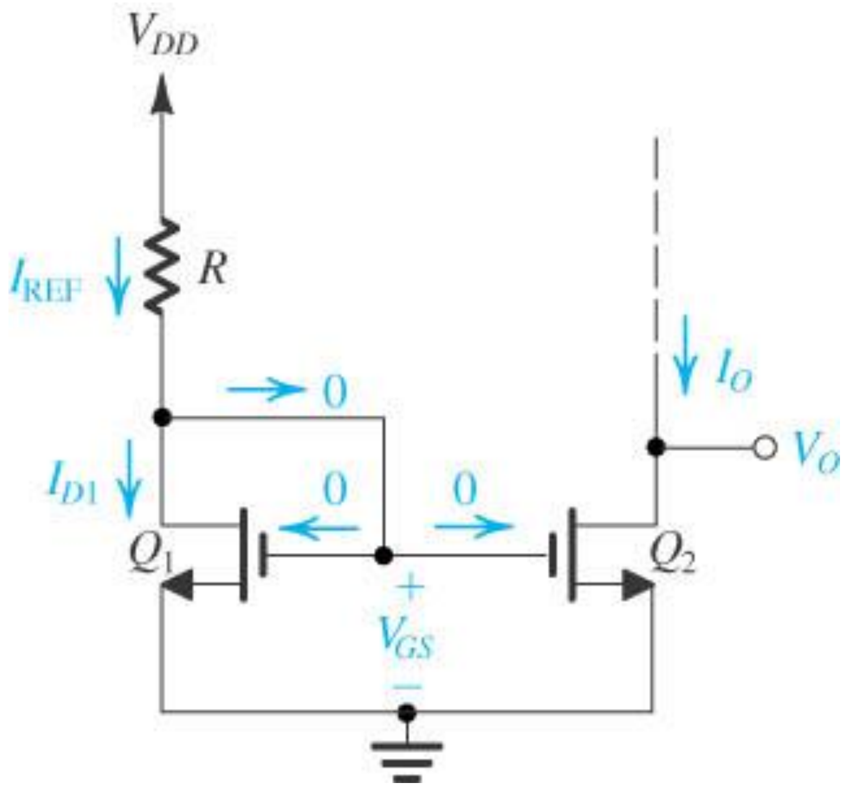
$$A_{vo} = -\frac{g_m R_D}{1 + g_m R_S}$$

- Overall voltage gain

$$G_v = -\frac{R_G}{R_G + R_{\text{sig}}} \frac{g_m(R_D \parallel R_L)}{1 + g_m R_S}$$

IC Biasing - Current sources, current mirror and current steering circuits

The basic MOSFET current source



Circuit for a basic MOSFET constant-current source.

- For transistor Q_1 ,

$$I_{D1} = \frac{1}{2}k_n'\left(\frac{W}{L}\right)_1 (V_{GS} - V_{tn})^2$$

- Since the gate currents are zero,

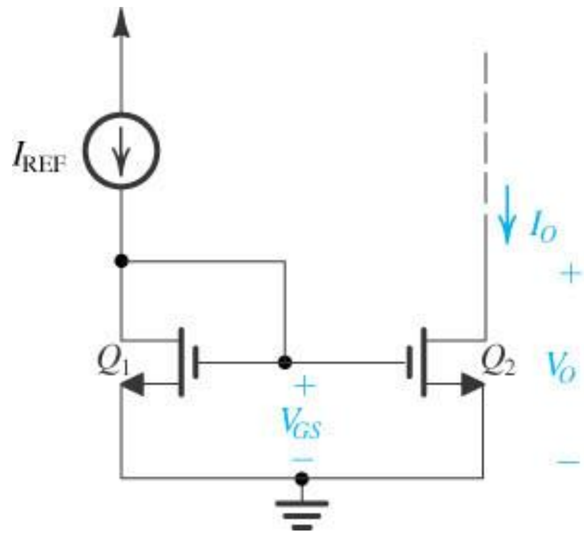
$$I_{D1} = I_{REF} = \frac{V_{DD} - V_{GS}}{R}$$

- For transistor Q_2 ,

$$I_O = I_{D2} = \frac{1}{2}k_n'\left(\frac{W}{L}\right)_2 (V_{GS} - V_{tn})^2$$

$$\frac{I_O}{I_{REF}} = \frac{(W/L)_2}{(W/L)_1}$$

Effect of V_o on I_o



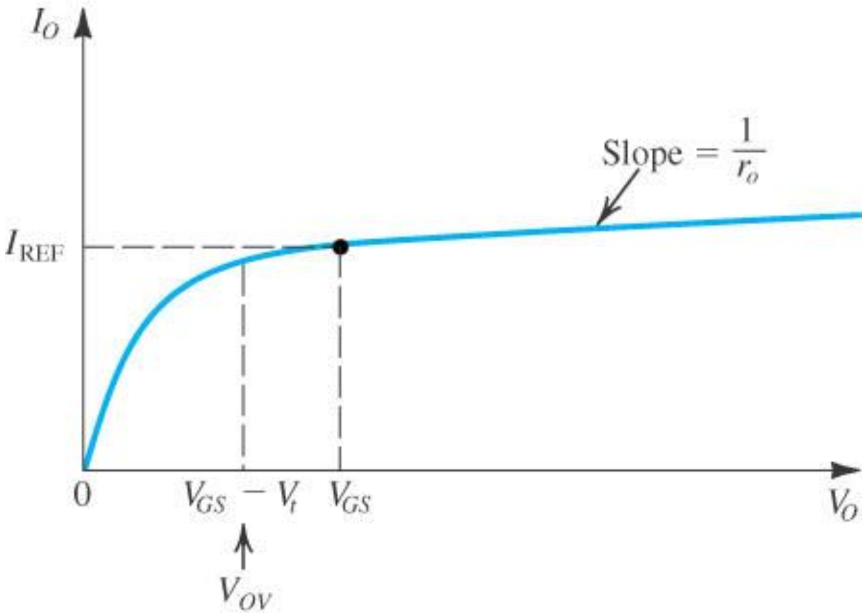
Basic MOSFET current mirror.

$$V_O \geq V_{GS} - V_t$$

$$V_O \geq V_{OV}$$

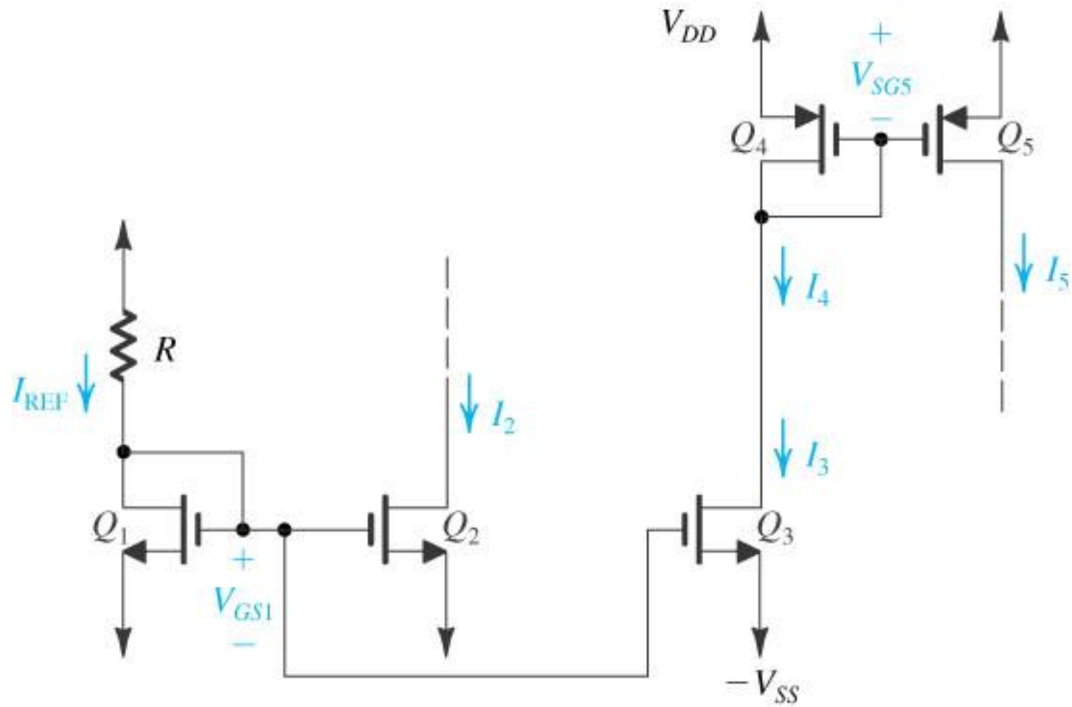
$$R_o \equiv \frac{\Delta V_O}{\Delta I_O} = r_{o2} = \frac{V_{A2}}{I_O}$$

$$I_O = \frac{(W/L)_2}{(W/L)_1} I_{\text{REF}} \left(1 + \frac{V_O - V_{GS}}{V_{A2}}\right)$$



Output characteristic of the current source and the current mirror for the case Q_2 is matched to Q_1.

MOS current steering circuits



A current-steering circuit.

$$I_2 = I_{\text{REF}} \frac{(W/L)_2}{(W/L)_1}$$

$$I_3 = I_{\text{REF}} \frac{(W/L)_3}{(W/L)_1}$$

- To ensure operation in the saturation region,

$$V_{D2}, V_{D3} \geq -V_{SS} + V_{GS1} - V_{tn}$$

$$V_{D2}, V_{D3} \geq -V_{SS} + V_{OV1}$$

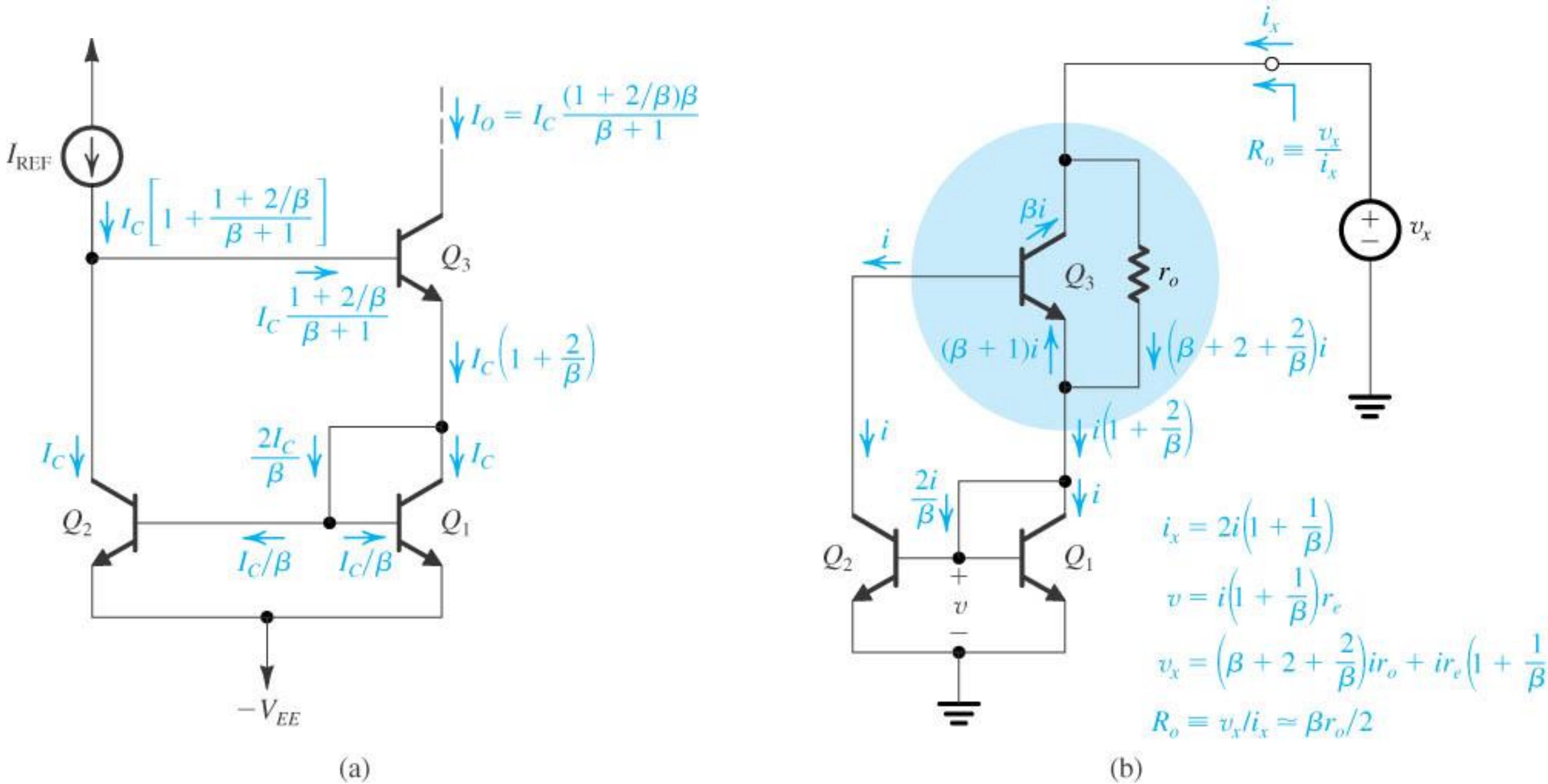
- This mirror provides,

$$I_5 = I_4 \frac{(W/L)_5}{(W/L)_4}$$

- To keep Q_5i n saturation, its drain voltage should be

$$V_{D5} \leq V_{DD} - |V_{OV5}|$$

Current mirror circuit with improved performance - The Wilson current mirror



The Wilson bipolar current mirror: **(a)** circuit showing analysis to determine the current transfer ratio; and **(b)** determining the output resistance. Note that the current i_x that enters Q_3 must equal the sum of the currents that leave it, $2i$.

$$\frac{I_O}{I_{REF}} = \frac{I_C\left(1+\frac{2}{\beta}\right)\beta/(\beta+1)}{I_C\left[1+\left(1+\frac{2}{\beta}\right)/(\beta+1)\right]}$$

$$= \frac{\beta+2}{\beta+1+\frac{\beta+2}{\beta}} = \frac{\beta+2}{\beta+2+\frac{2}{\beta}}$$

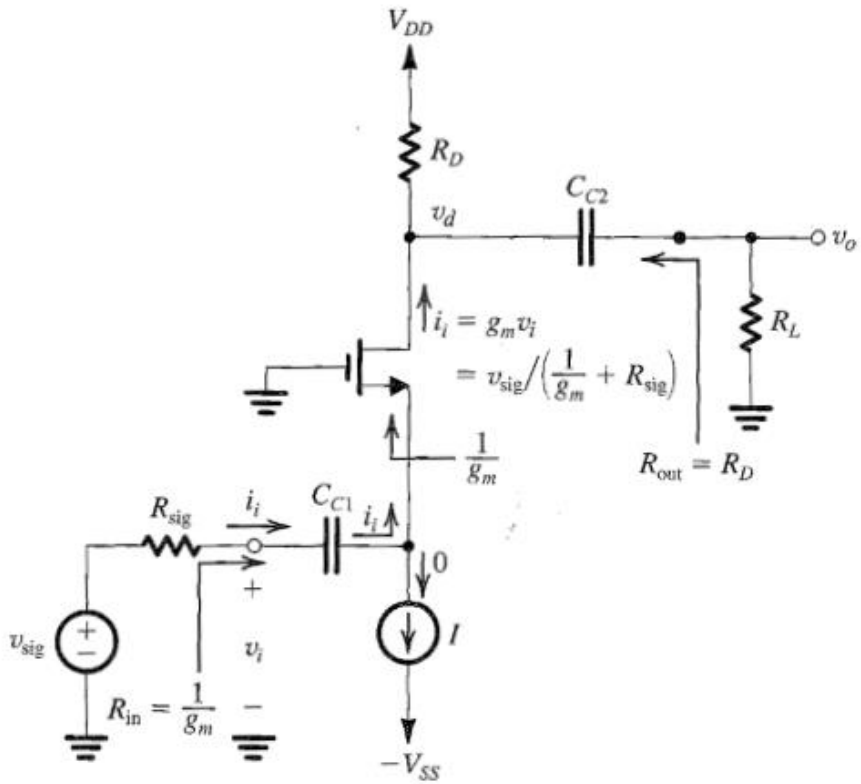
$$= \frac{1}{1+\frac{2}{\beta(\beta+2)}}$$

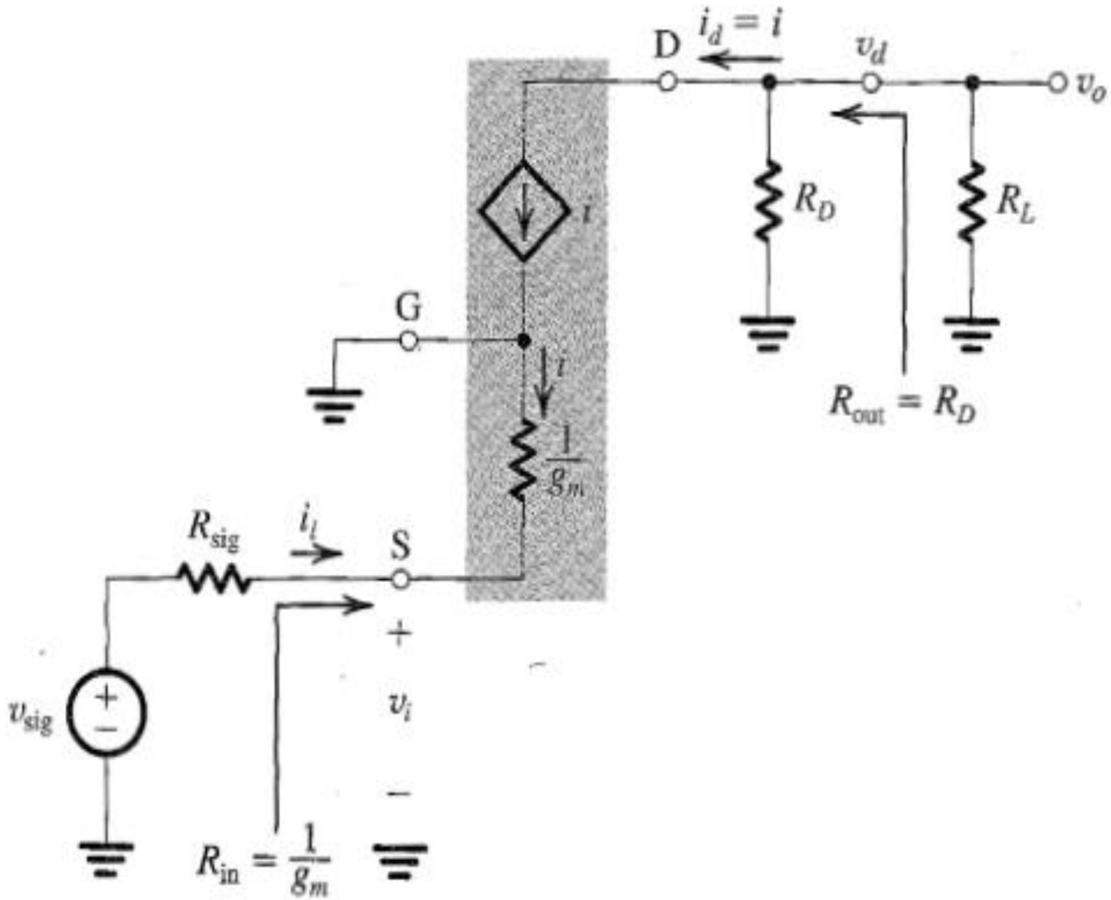
$$\cong \frac{1}{1+2/\beta^2}$$

$$R_o = \beta r_o/2$$

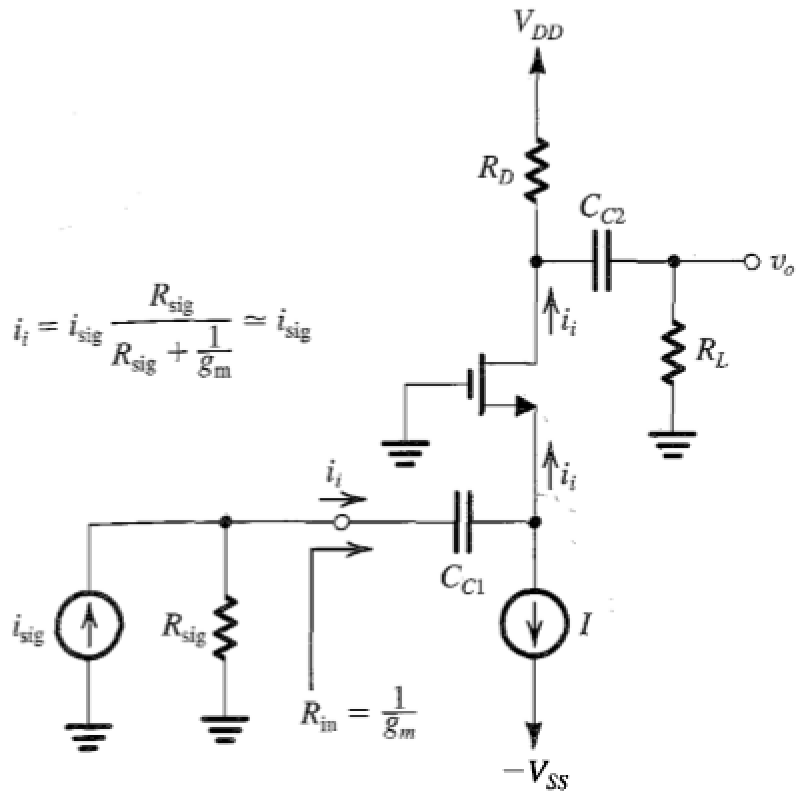
The Common-Gate (CG) Amplifier

The small-signal equivalent circuit model of the CG amplifier is shown in
Since resistor R_{sig} appears directly in series with the MOSFET source lead we have selected the T model for the transistor. Either model, of course, can be used and yields identical





- Small signal equivqlent



The common-gate amplifier fed with a current-signal input.

$$R_{\text{in}} = \frac{1}{g_m}$$

$$v_i = v_{\text{sig}} \frac{R_{\text{in}}}{R_{\text{in}} + R_{\text{sig}}}$$

$$v_i = v_{\text{sig}} \frac{\frac{1}{g_m}}{\frac{1}{g_m} + R_{\text{sig}}} = v_{\text{sig}} \frac{1}{1 + g_m R_{\text{sig}}}$$

from which we see that to keep the loss in signal strength small, the source resistance R_{sig} should be small,

$$R_{sig} \ll \frac{1}{g_m}$$

The current i_i is given by

$$i_i = \frac{v_i}{R_{in}} = \frac{v_i}{1/g_m} = g_m v_i$$

and the drain current i_d is

$$i_d = i = -i_i = -g_m v_i$$

Thus the output voltage can be found as

$$v_o = v_d = -i_d(R_D \| R_L) = g_m(R_D \| R_L)v_i$$

resulting in the voltage gain

$$A_v = g_m(R_D \| R_L)$$

from which the open-circuit voltage gain can be found as

$$A_{vo} = g_m R_D$$

The overall voltage gain can be obtained as follows:

$$G_v = \frac{R_{in}}{R_{in} + R_{sig}} A_v = \frac{\dfrac{1}{g_m}}{\dfrac{1}{g_m} + R_{sig}} A_v = \frac{A_v}{1 + g_m R_{sig}}$$

resulting in

$$G_v = \frac{g_m(R_D \| R_L)}{1 + g_m R_{sig}}$$

Finally, the output resistance is found by inspection to be

$$R_{out} = R_o = R_D$$

Comparing these expressions with those for the common-source amplifier we make the following observations:

1. Unlike the CS amplifier, which is inverting, the CG amplifier is noninverting. This, however, is seldom a significant consideration.
2. While the CS amplifier has a very high input resistance, the input resistance of the CG amplifier is low.
3. While the A_v values of both CS and CG amplifiers are nearly identical, the overall voltage gain of the CG amplifier is smaller by the factor $1 + g_m R_{sig}$ (Eq. 4.96b), which is due to the low input resistance of the CG circuit.

$R_{in} = 1/g_m$ and the current-divider rule we can find the fraction of i_{sig} that flows into the MOSFET source, i_i,

$$i_i = i_{sig}\frac{R_{sig}}{R_{sig} + R_{in}} = i_{sig}\frac{R_{sig}}{R_{sig} + \dfrac{1}{g_m}} \tag{4.98}$$

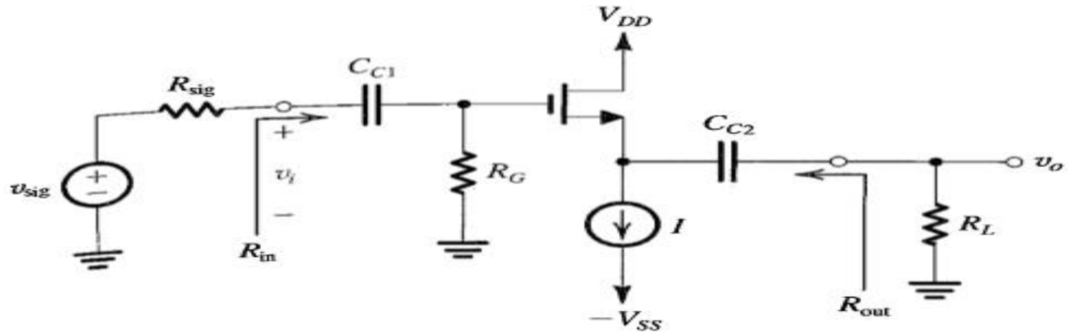
Normally, $R_{sig} \gg 1/g_m$, and

$$i_i \cong i_{sig} \tag{4.98a}$$

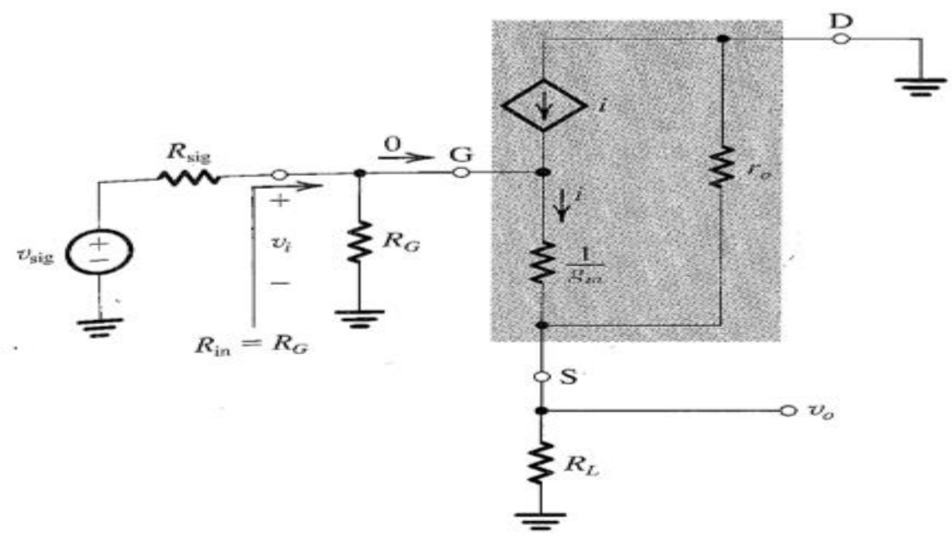
Thus we see that the circuit presents a relatively low input resistance $1/g_m$ to the input signal-current source, resulting in very little signal-current attenuation at the input. The MOSFET then reproduces this current in the drain terminal at a much higher output resistance. The circuit thus acts in effect as a **unity-gain current amplifier** or a **current follower.** This view of the operation of the common-gate amplifier has resulted in its most popular application, in a configuration known as the **cascode circuit,** which we shall study in Chapter 6.

Another area of application of the CG amplifier makes use of its superior high-frequency performance, as compared to that of the CS stage (Section 4.9). We shall study wideband

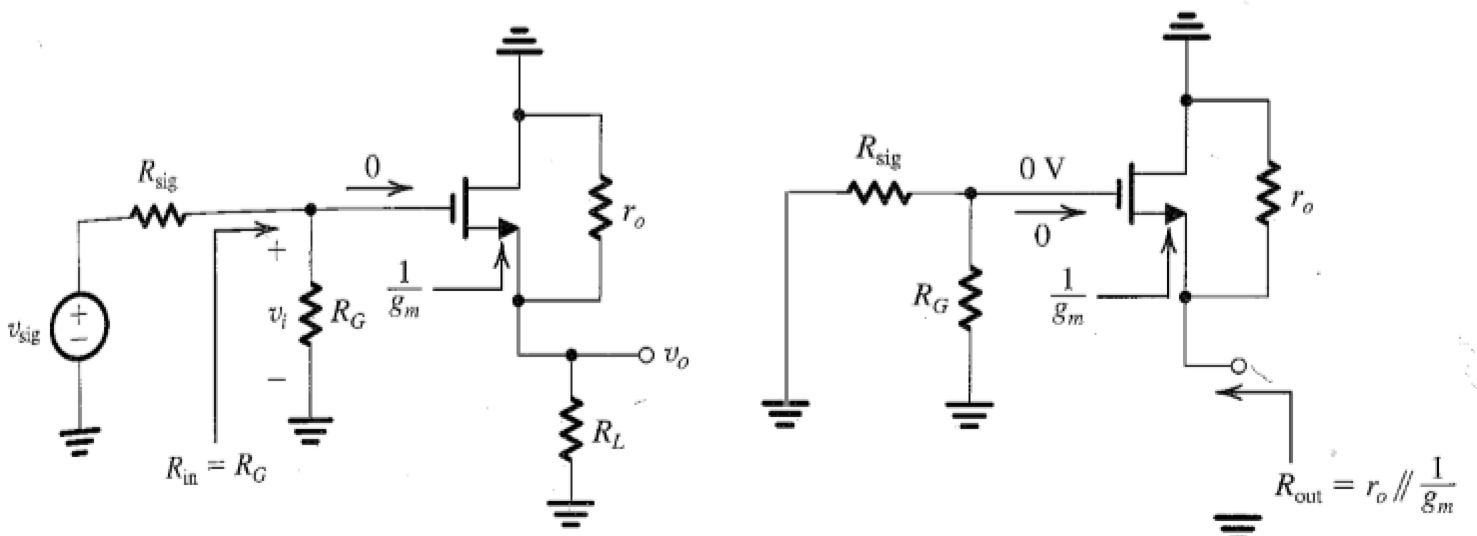
The Common-Drain or Source-Follower Amplifier



(a)



(b)



(c) (d)

FIGURE 4.46 **(a)** A common-drain or source-follower amplifier. **(b)** Small-signal equivalent-circuit model. **(c)** Small-signal analysis performed directly on the circuit. **(d)** Circuit for determining the output resistance R_{out} of the source follower.

amplifier is shown in Fig. 4.46(b). Analysis of this circuit is straightforward and proceeds as follows: The input resistance R_{in} is given by

$$R_{in} = R_G$$

Thus,

$$v_i = v_{sig}\frac{R_{in}}{R_{in}+R_{sig}} = v_{sig}\frac{R_G}{R_G+R_{sig}}$$

Usually R_G is selected to be much larger than R_{sig} with the result that

$$v_i \cong v_{sig}$$

To proceed with the analysis, it is important to note that r_o appears in effect in parallel with R_L, with the result that between the gate and ground we have a resistance $(1/g_m)$ in series with $(R_L \parallel r_o)$. The signal v_i appears across this total resistance. Thus we may use the voltage-divider rule to determine v_o as

$$v_o = v_i\frac{R_L \parallel r_o}{(R_L \parallel r_o)+\dfrac{1}{g_m}}$$

from which the voltage gain A_v is obtained as

$$A_v = \frac{R_L \parallel r_o}{(R_L \parallel r_o)+\dfrac{1}{g_m}}$$

and the open-circuit voltage gain A_{vo} as

$$A_{vo} = \frac{r_o}{r_o+\dfrac{1}{g_m}}$$

Normally $r_o \gg 1/g_m$, causing the open-circuit voltage gain from gate to source, A_{vo} in Eq. (4.103), to become nearly unity. Thus the voltage at the source follows that at the gate, giving the circuit its popular name of **source follower.** Also, in many discrete-circuit applications, $r_o \gg R_L$, which enables Eq. (4.102) to be approximated by

$$A_v \cong \frac{R_L}{R_L + \frac{1}{g_m}} \tag{4.102a}$$

The overall voltage gain G_v can be found by combining Eqs. (4.100) and (4.102), with the result that

$$G_v = \frac{R_G}{R_G + R_{sig}} \frac{R_L \| r_o}{(R_L \| r_o) + \frac{1}{g_m}} \tag{4.104}$$

which approaches unity for $R_G \gg R_{sig}$, $r_o \gg 1/g_m$, and $r_o \gg R_L$.

To emphasize the fact that it is usually faster to perform the small-signal analysis directly on the circuit diagram with the MOSFET small-signal model utilized only implicitly, we show such as analysis in Fig. 4.46(c). Once again, observe that to separate the intrinsic action of the MOSFET from the Early effect, we have extracted the output resistance r_o and shown it separately.

The circuit for determining the output resistance R_{out} is shown in Fig. 4.46(d). Because the gate voltage is now zero, looking back into the source we see between the source and ground a resistance $1/g_m$ in parallel with r_o; thus,

$$R_{out} = \frac{1}{g_m} \parallel r_o \tag{4.105}$$

Normally, $r_o \gg 1/g_m$, reducing R_{out} to

$$R_{out} \cong \frac{1}{g_m} \tag{4.106}$$

which indicates that R_{out} will be moderately low.

We observe that although the source-follower circuit has a large amount of internal feedback (as we will find out in Chapter 8), its R_{in} is independent of R_L (and thus $R_i = R_{in}$) and its R_{out} is independent of R_{sig} (and thus $R_o = R_{out}$). The reason for this, however, is the zero gate current.

In conclusion, the source follower features a very high input resistance, a relatively low output resistance, and a voltage gain that is less than but close to unity. It finds application in situations in which we need to connect a voltage-signal source that is providing a signal of reasonable magnitude but has a very high internal resistance to a much smaller load resistance—that is, as a unity-gain voltage buffer amplifier. The need for such amplifiers was discussed in Section 1.5. The source follower is also used as the output stage in a multi-stage amplifier, where its function is to equip the overall amplifier with a low output resistance, thus enabling it to supply relatively large load currents without loss of gain (i.e., with little reduction of output signal level.) The design of output stages is studied in Chapter 14.