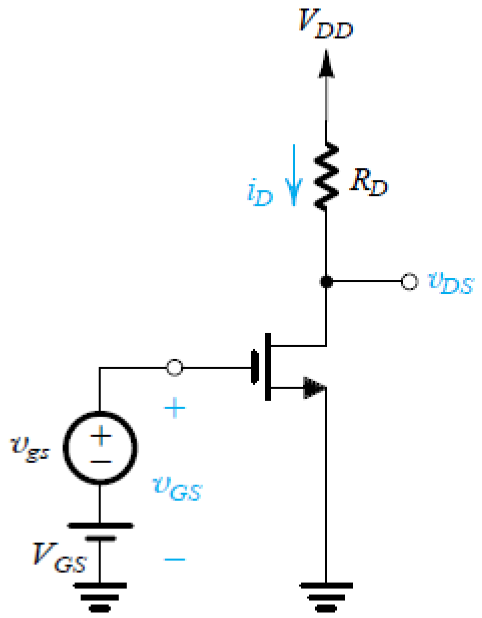
Small-Signal Operation and Models:



Rekha Kulkarni ECE

- linear amplification can be obtained by biasing the MOSFET to operate in the saturation region and by keeping the input signal small.
- The dc bias current *ID can be found by setting the signal vas to zero; thus,*

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

- *Dc voltage at drain*
- *To Ensure saturation* $V_{DS} = V_{DD} - R_D I_D$ *e must have*

$$V_{DS} > V_{OV}$$

The Signal Current in the Drain Terminal:

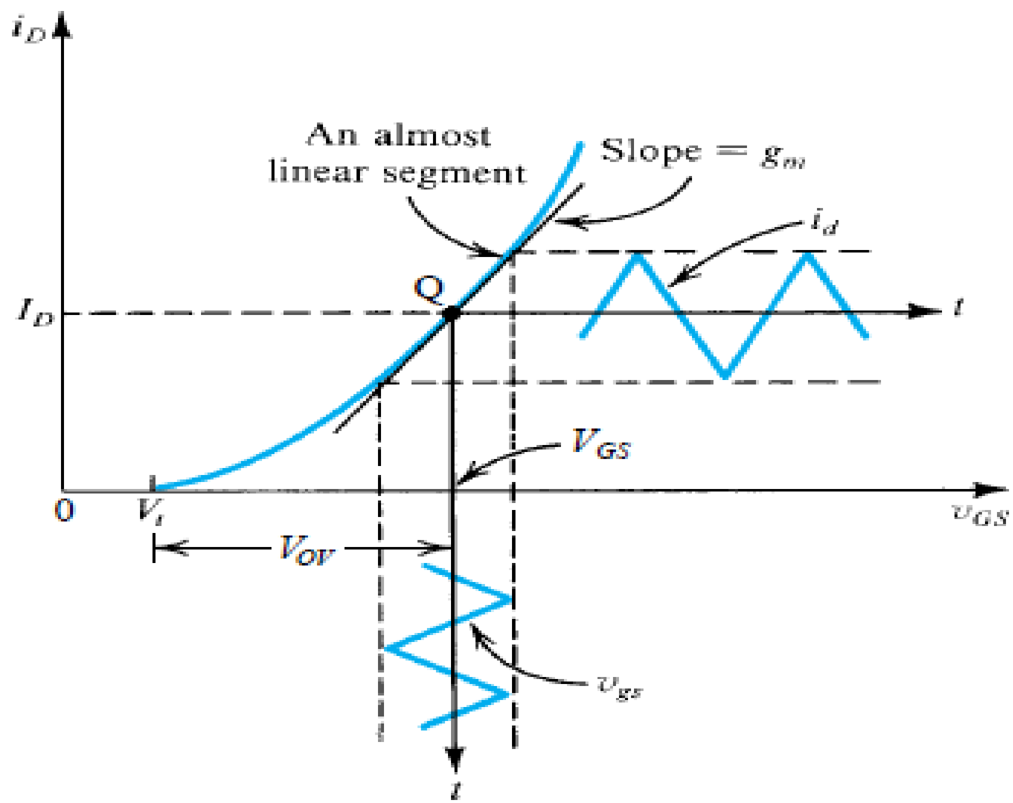
$$i_D = \frac{1}{2}k_n(V_{GS} + v_{gs} - V_t)^2$$

$$= \frac{1}{2}k_n(V_{GS} - V_t)^2 + k_n(V_{GS} - V_t)v_{gs} + \frac{1}{2}k_n v_{gs}^2$$

The parameter that relates *id and vgs is the MOSFET transconductance gm*

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

Fig: Small-signal operation of the MOSFET amplifier.



- **The Voltage Gain:** The total instantaneous drain voltage *vDS is expressed as*

$$v_{DS} = V_{DD} - R_D i_D$$

- Under the small-signal condition, we have

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

- which can be rewritten as

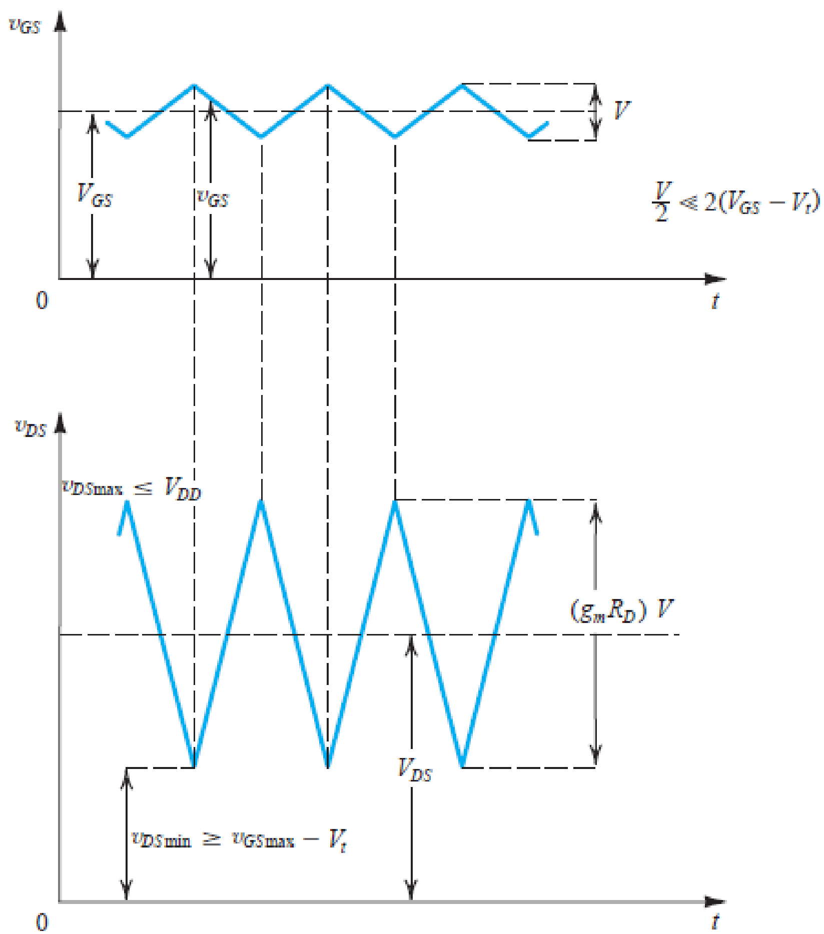
$$v_{DS} = V_{DS} - R_D i_d$$

- Thus the signal component of the drain voltage is $v_{ds} = -i_d R_D = -g_m v_{gs} R_D$

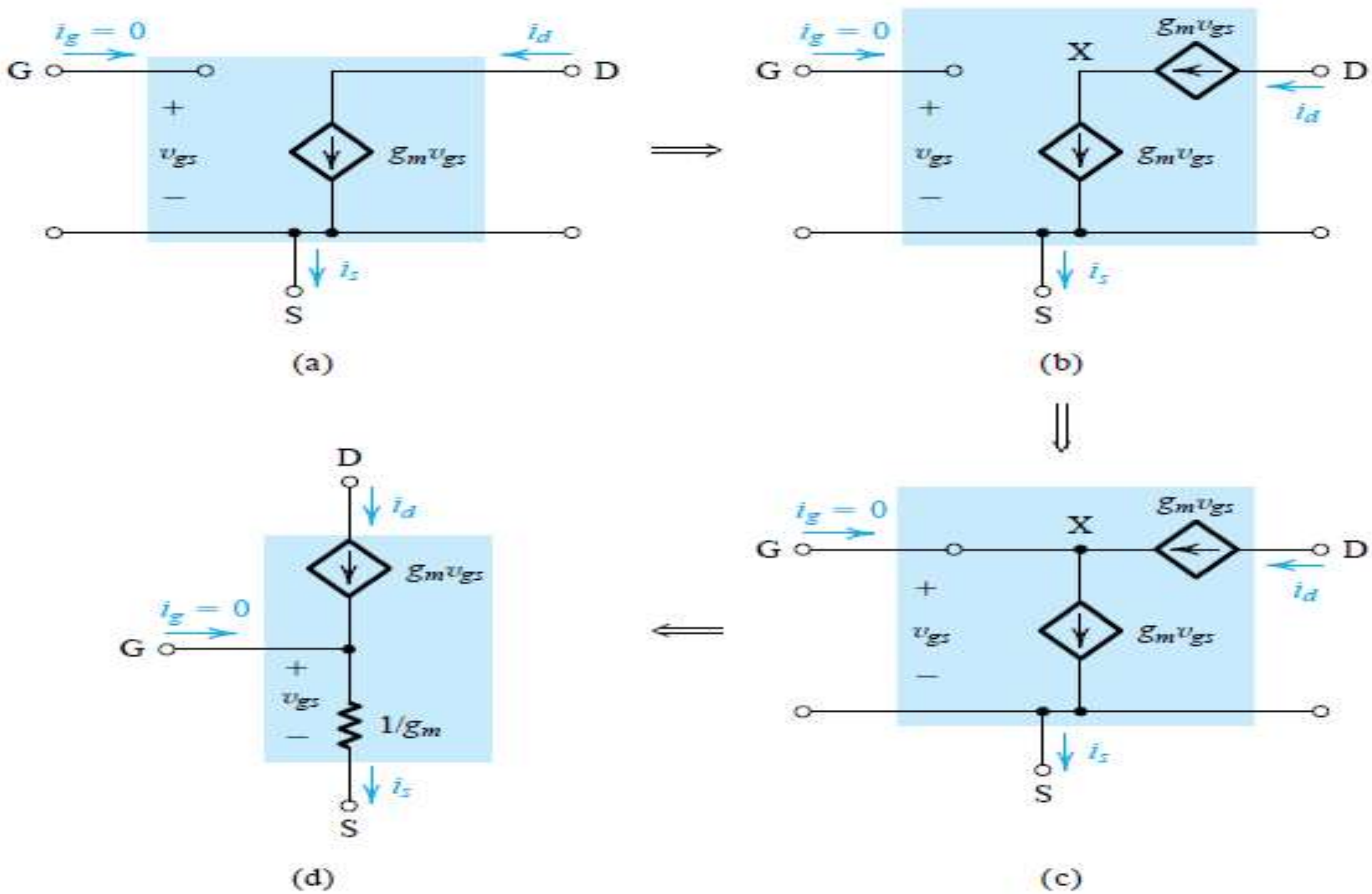
- which indicates that the voltage gain is given by

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

Separating the DC Analysis and the Signal Analysis

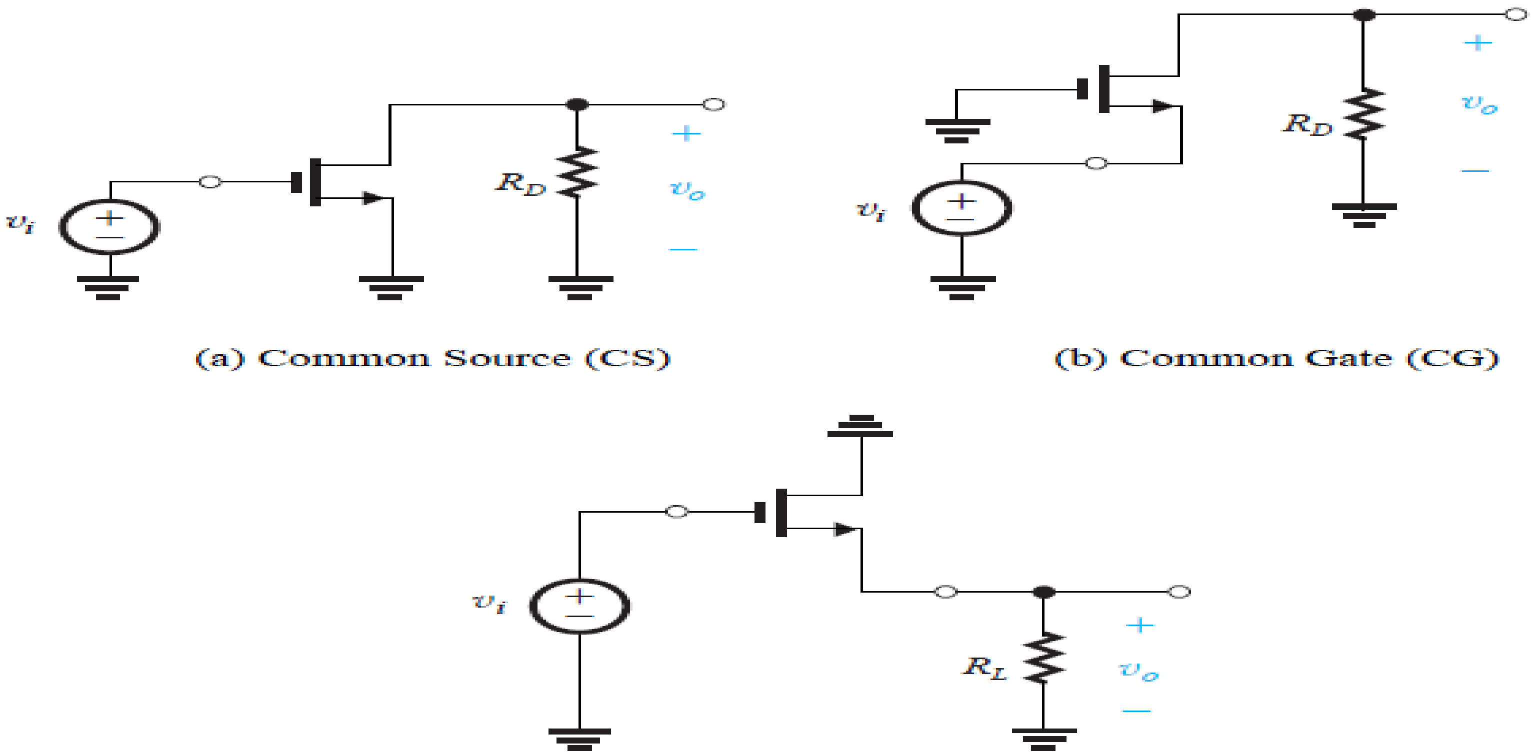


Small-Signal Equivalent-Circuit Models



Basic MOSFET Amplifier Configurations

- The Three Basic Configurations

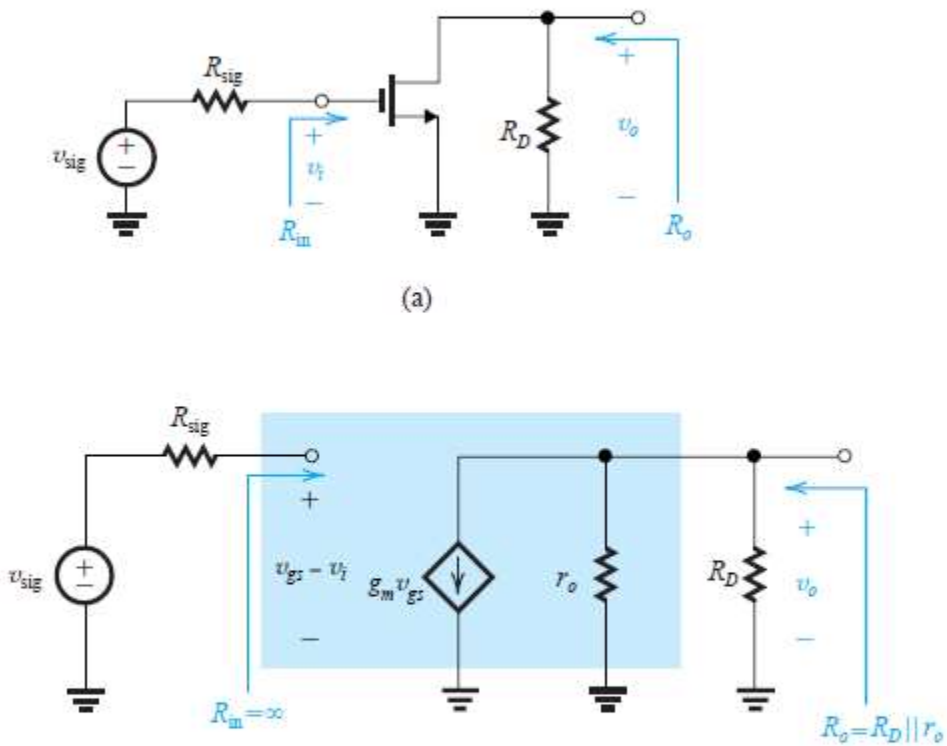


(a) Common Source (CS)

(b) Common Gate (CG)

(c) Common Drain (CD)

The Common-Source (CS) Amplifier:



(a)

(b)

Characteristic Parameters of the CS Amplifier

Replacing the MOSFET with its hybrid- model

The input resistance Rin is obviously infinite,

$R_{in} = \infty$

The output voltage vo is found by multiplying the current (gmvgs) by the total resistance between the output node and ground,

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

The open-circuit voltage gain

$A_{vo} \equiv v_o/v_i$ can be obtained as

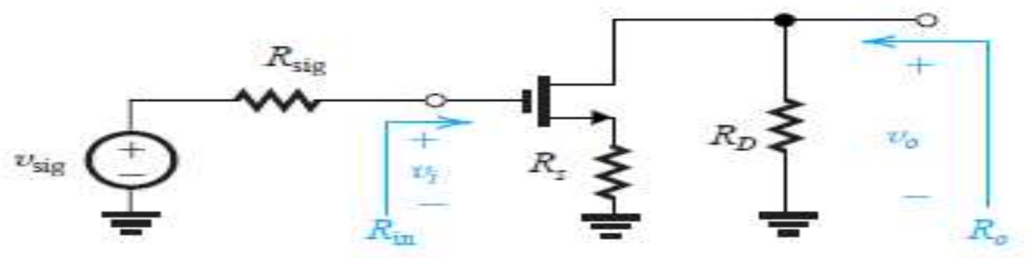
$A_{vo} = -g_m (R_D \| r_o)\, R_D$.

$A_v = -g_m (R_D \| r_o \| R_L)$ This expression together with the fact that $v_i = v_{sig}$,

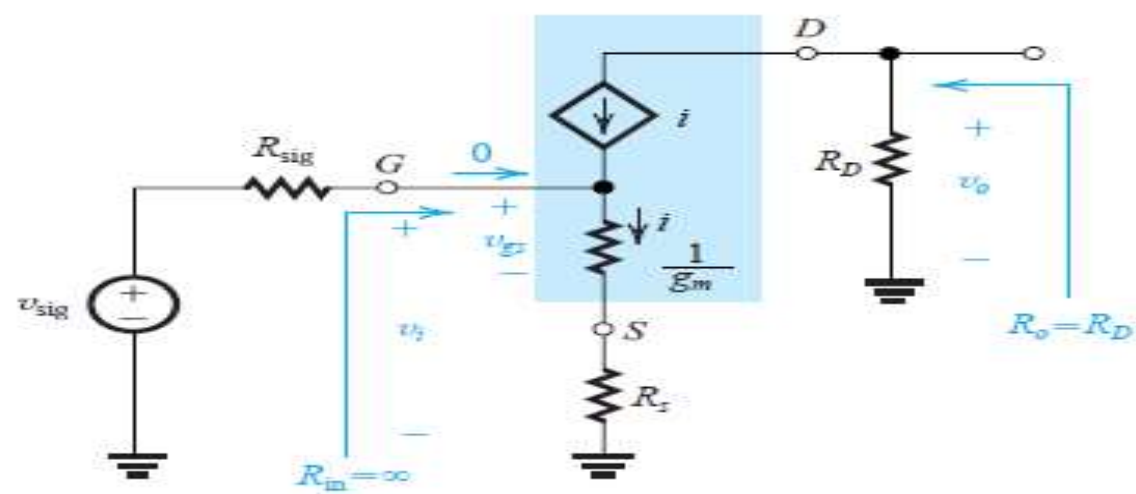
provides the overall voltage gain,

$G_v = A_v = -g_m (R_D \| r_o \| R_L)$

The Common-Source Amplifier with a Source Resistance



(a)



(b)

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

$$v_o = -i\ R_D$$

$$i = \frac{v_i}{1/g_m + R_s} = \left(\frac{g_m}{1 + g_m R_s}\right) v_i$$

The amplifier input, as follows

$$A_{vo} = \frac{v_o}{v_i} = -\frac{R_D}{1/g_m + R_s}$$

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

Thus, the voltage gain A_{vo} can be found as

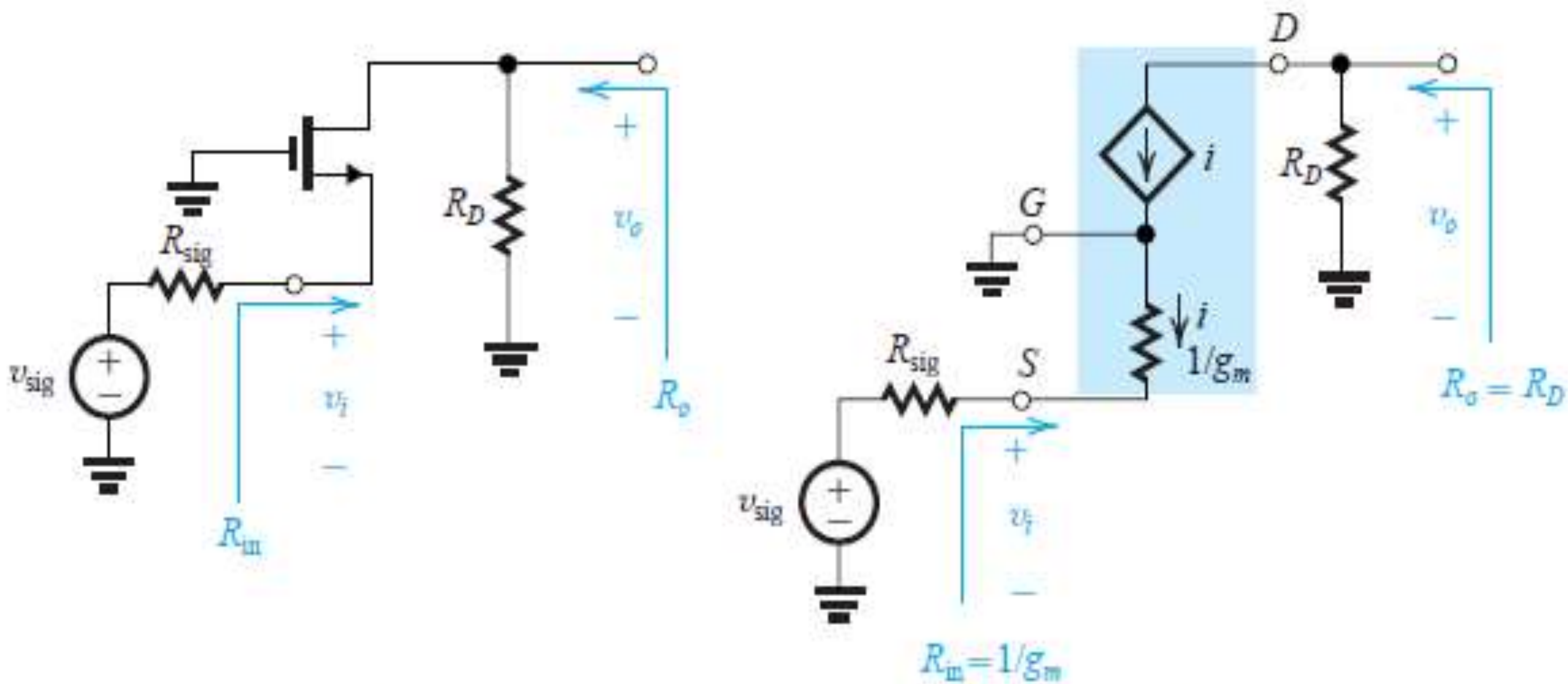
$$A_{vo} = \frac{v_o}{v_i} = -\frac{R_D}{1/g_m + R_s}$$

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

The above equation that including the resistance R_S reduces the voltage gain by the factor $(1 + g_m R_s)$.

The voltage gain between gate and drain is equal to the ratio of the total resistance in the drain (R_D) to the total resistance in the source $(1/g_m + R_s)$.

Common-Gate (CG) Amplifier:



(a) (b)

Fig: (a) **Common-gate (CG) amplifier without bias. (b) Equivalent circuit of the CG amplifier with the MOSFET replaced with its T model.** The amplifier is fed with a signal source characterized by *vsig and Rsig. Since Rsig appears in series with the source, it is more convenient to represent the transistor with the T model than with the model and is shown in fig.(b). This circuit is excluding the resistor ro.*

From the equivalent circuit the input resistance is given by

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

Thus the CG amplifier has a low input resistance.
To determine the voltage gain A_{vo}, we write at the drain node

$$v_o = -iR_D$$

The source current i from the circuit is

$$i = -\frac{v_i}{1/g_m}$$

The voltage gain is

$$A_{vo} \equiv \frac{v_o}{v_i} = g_m R_D$$

The output resistance of the CG equivalent circuit is

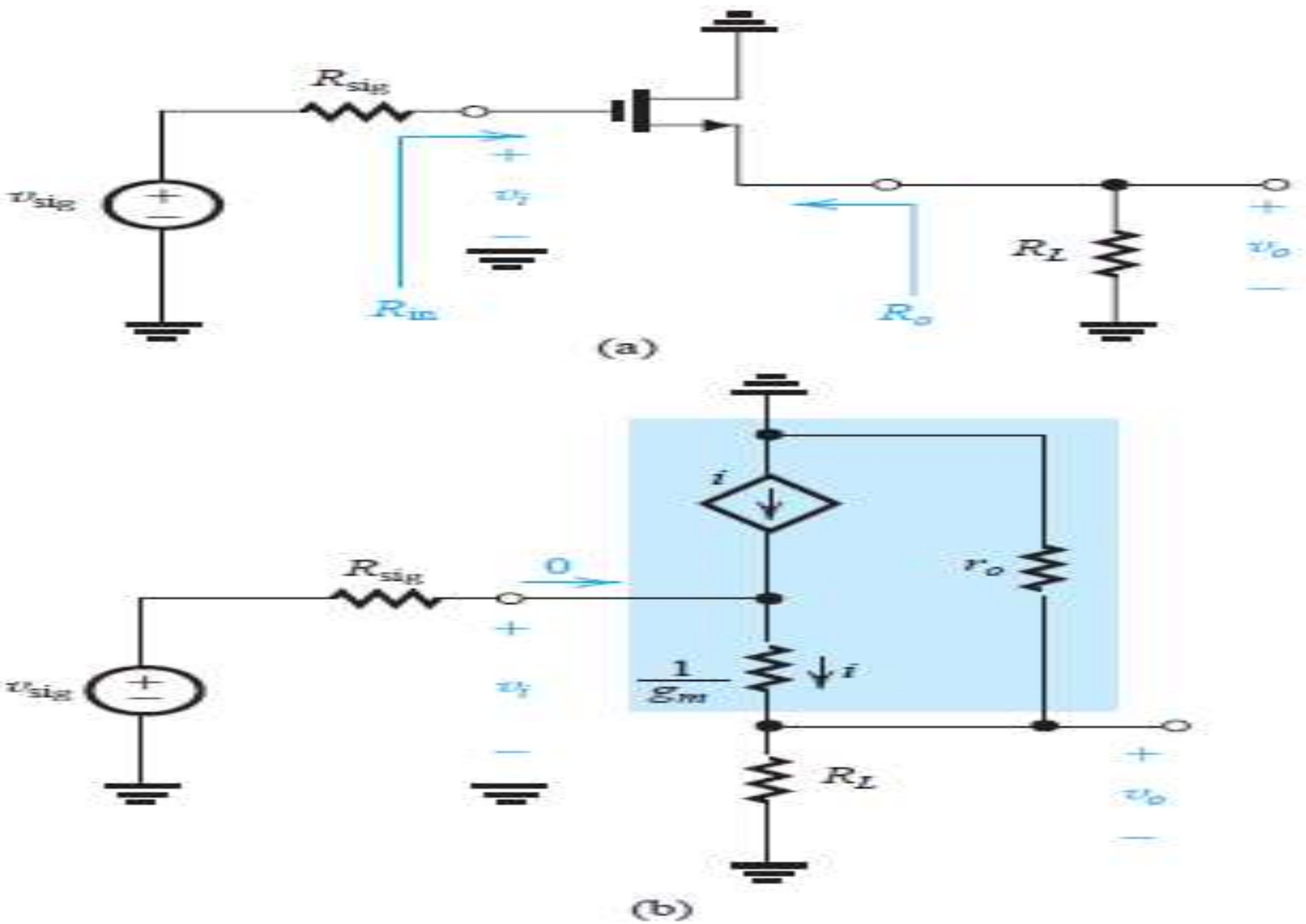
$$R_o = R_D$$

The low input resistance of the CG amplifier can cause the input signal to be severely attenuated.

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

Because of its low input resistance, the CG amplifier alone has very limited application.

The Common-Drain Amplifier or Source Follower



The source follower is fed with a signal generator (v_{sig}, R_{sig}) and has a load resistance R_L connected between the source terminal and ground. We shall assume that R_L includes both the actual load and any other resistance that may be present between the source terminal and ground (e.g., for biasing purposes).

Neglecting r_o and obtain the simplified equivalent circuit shown in Fig.(c).

$$R_{in} = \infty$$

A_v is obtained from the voltage divider

$$A_v \equiv \frac{v_o}{v_i} = \frac{R_L}{R_L + 1/g_m}$$

Setting $R_L = \infty$ we obtain

$$A_{vo} = 1$$

The output resistance R_o is found by setting $v_i = 0$ (i.e., by grounding the gate). Now looking back into the output terminal, excluding R_L, we simply see $1/g_m$, thus

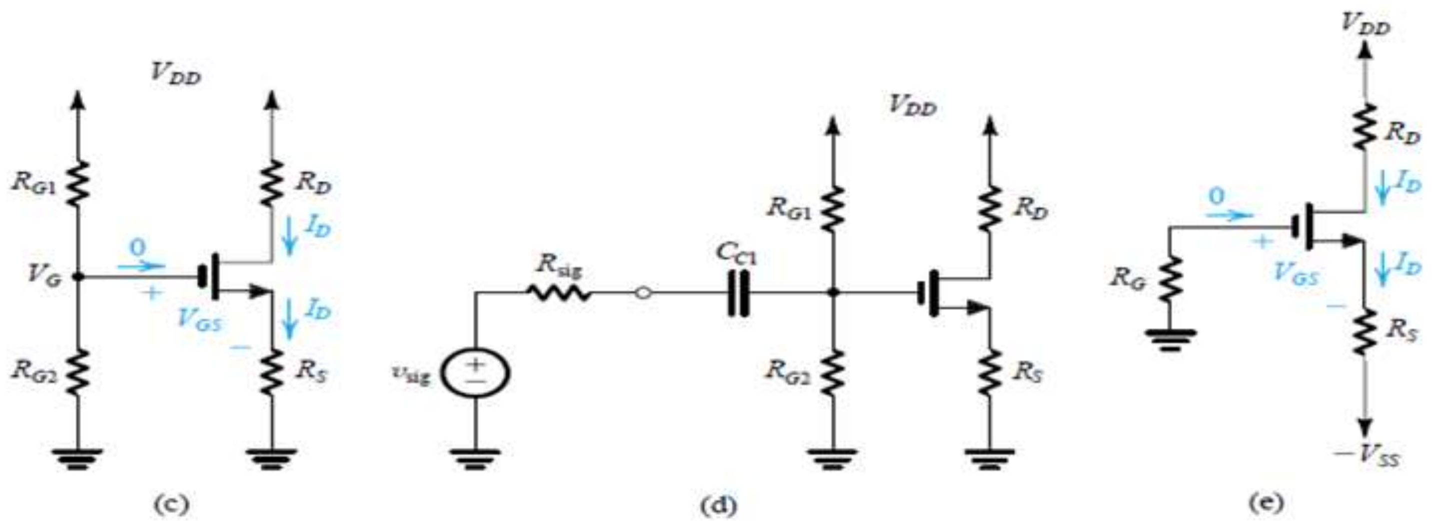
$$R_o = 1/g_m$$

Finally, because of the infinite R_{in}, $v_i = v_{sig}$, and the overall voltage gain is

$$G_v = A_v = \frac{R_L}{R_L + 1/g_m}$$

G_v will be lower than unity.

VOLTAGE DIVIDER BIAS OF MOSFET

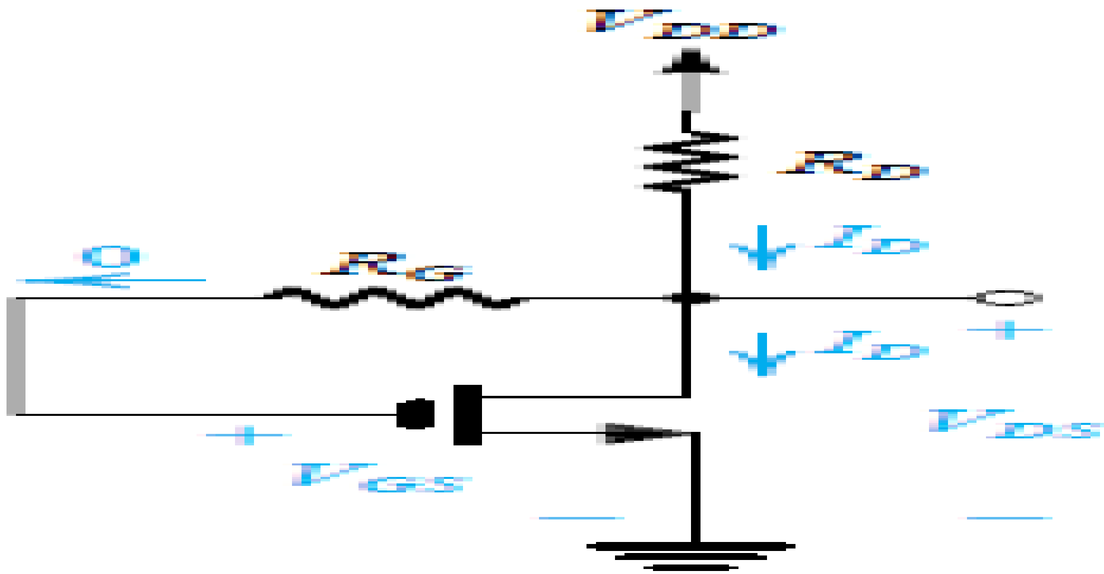


$$I_D = \frac{1}{2} k_n (V_{GS} - V_t)^2 =$$

$$V_G = V_{GS} + R_S I_D$$

VDS=VDD-IDRD

SELF BIAS OF MOSFET



From the circuit

$$V_{GS} = V_{DS} = V_{DD} - R_D I_D$$

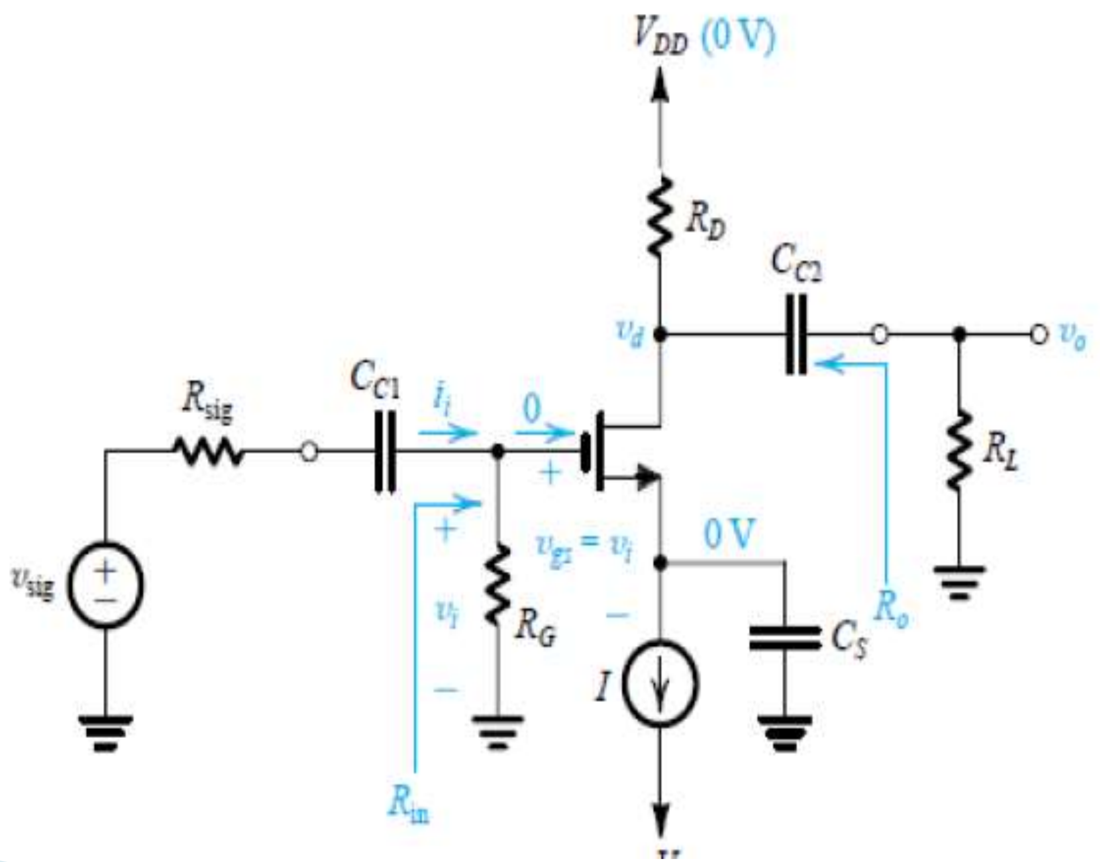
This equation can be rewritten as

$$V_{DD} = V_{GS} + R_D I_D$$

This circuit can be utilized as an amplifier by applying the input voltage signal to the gate via a coupling capacitor so as not to disturb the dc bias conditions already established. The amplified output signal at the drain can be coupled to another part of the circuit, again via a capacitor.

The Common-Source (CS) Amplifier:

A common-source amplifier is shown in the following figure.



- Here to establish a **signal ground, or an ac ground as it is sometimes called, at the source, we have connected a large capacitor,** *CS, between the source and ground. CS is called a bypass capacitor. In order not to disturb the dc bias current and voltages, the signal to be amplified, shown as voltage source vsig with an internal resistance Rsig, is connected to the gate through a large capacitor CC1. Capacitor CC1, known as a coupling capacitor, and is required to act as a perfect short circuit at all signal frequencies of interest while blocking dc. The voltage signal resulting at the drain is coupled to the load resistance RL via another coupling capacitor CC2. We shall assume that CC2 acts as a perfect short circuit at all signal frequencies of interest and thus that the output voltage vo = vd. Note that RL can be either an actual load resistor, to which the amplifier is required to provide its output voltage signal, or it can be the input resistance of another amplifier stage in cases where more than one stage of amplification is needed. To determine the terminal characteristics of the CS amplifier—that is, its input resistance, voltage gain, and output resistance—we replace the MOSFET with its small-signal model. The resulting circuit*

To keep R_{in} high, a large value of R_G (in the megohm range) is usually selected. The finite R_{in} will affect the overall voltage gain G_v which becomes

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