4.7 Single stage MOSFET Amplifiers

1. Common Source (CS) Amplifier :

A Common Source amplifier has the source terminal connected between the input and output. Input is applied between Gate –Source terminals and output is measured between the Drain-Source terminals. Any proper biasing method is used. Consider a CS amplifier with Constant current source biasing as shown below:

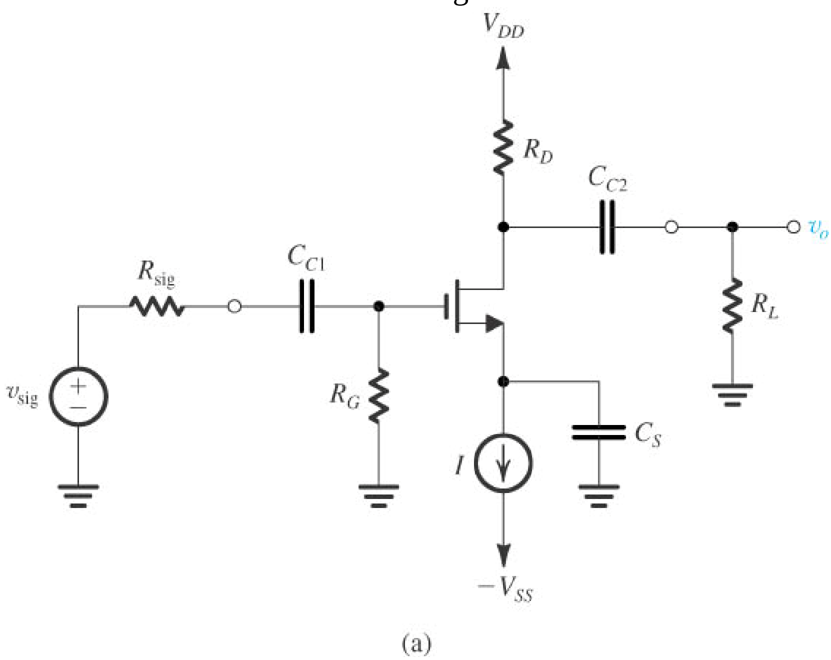

Figure 4.43 (a) Common-source amplifier

The ac equivalent circuit can be obtained by replacing the MOSFET with its small signal hybrid-π model and writing the remaining components between the respective terminals of the MOSFET in the model as shown below:

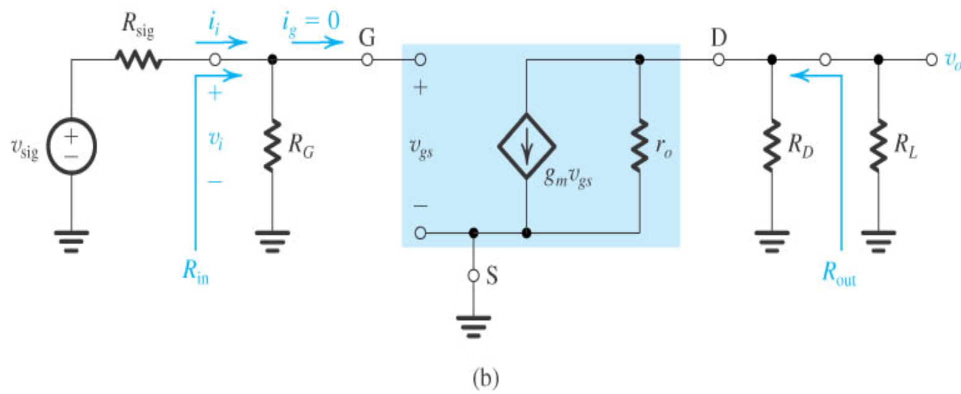

Figure 4.43 (b) Equivalent circuit of the amplifier for small-signal analysis.

Now, the electro-mathematical analysis of the CS amplifier for the voltage gain (Av), Input impedance (Zin) and Output impedance (Zout) is as shown below:

$$R_{in} = R_G$$

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

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

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

Generally a Common Source amplifier will have a source resistance to improve the stability of the bias point. But this resistance also causes negative feedback and hence the voltage gain will be lesser than in a CS amplifier without source resistance.

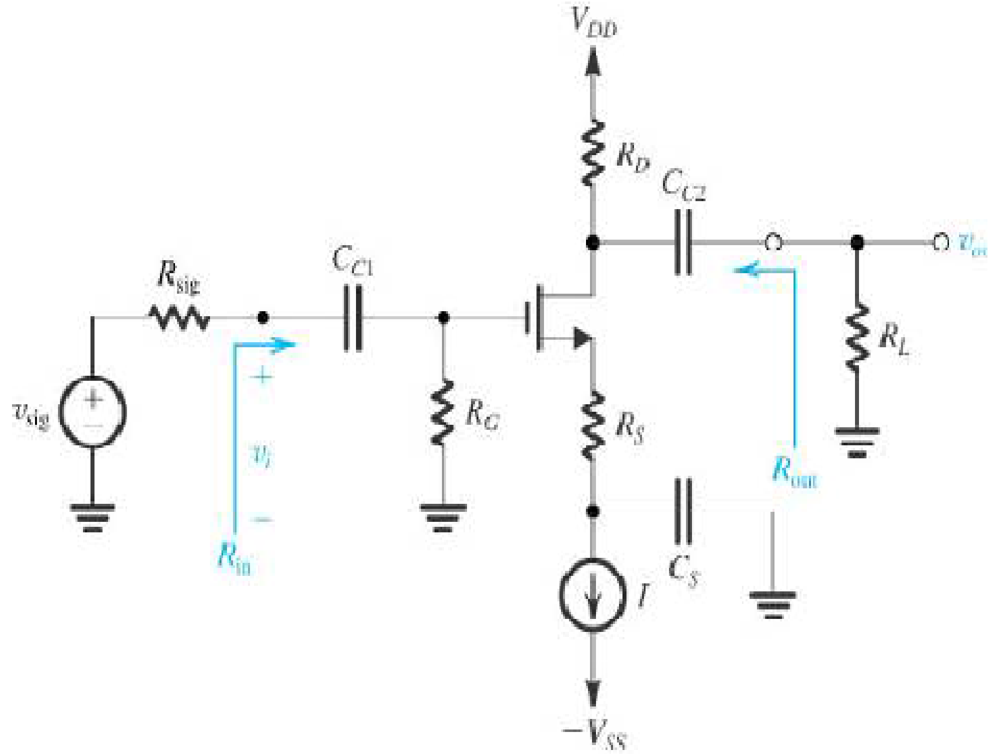

Figure 4.44 (a) Common-source amplifier with a resistance R_S in the source lead.
The small signal equivalent circuit with ro neglected is as shown below:

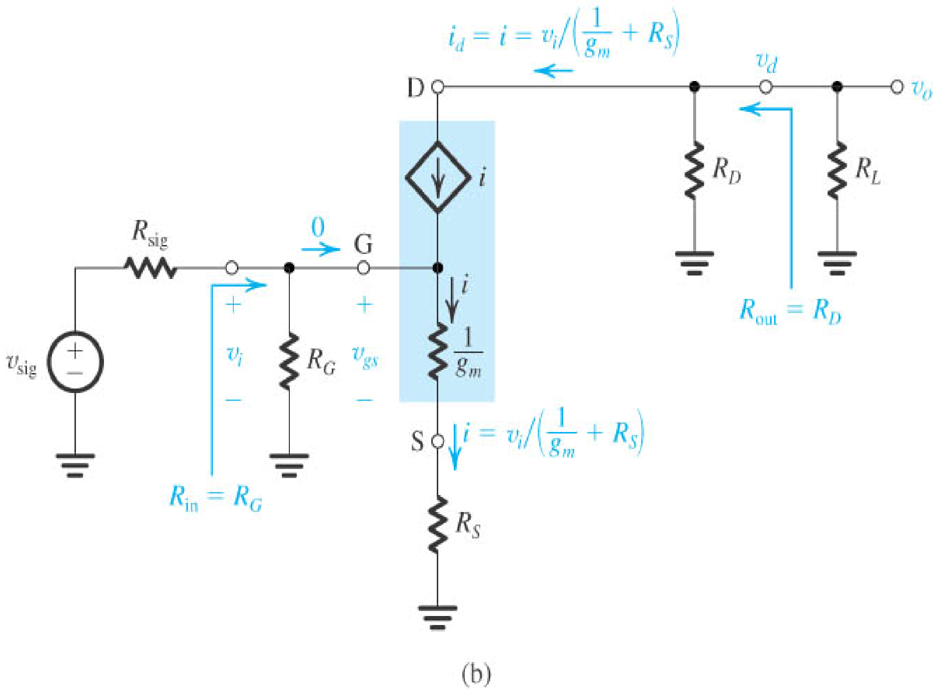

Figure 4.44 Small signal equivalent model of Common Source amplifier with R_s

From the figure we can see that as in the case of the CS amplifier,

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

$$V_i = V_{sig}\frac{R_G}{R_G + R_{sig}}$$

But, here unlike the previous CS circuit, v_{gs} is only a fraction of v_i .It can be determined from the voltage divider composed of $1/g_m$ and R_s that appears across the amplifier input as follows:

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

Hence v_{gs} can be controlled by R_S.
The current i_d is equal to the current I flowing in the source lead, thus

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

Thus including R_S reduces i_d by the factor $(1 + g_m R_S)$.
The output is now found from

$v_O = -i_d(R_D||R_L)$

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

$A_v = -\dfrac{g_m(R_D||R_L)}{\frac{1}{g_m}+R_S}$ and setting R_L as ∞ gives

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

The overall voltage gain G_v is,

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

This shows that gain is reduced by a factor $(1 + g_m R_S)$ than in the previous CS amplifier without R_S.This factor is called the "amount of feedback" and that it determines both the magnitude of performance improvement and as a tradeoff, the reduction in gain. Since this R_S was used to improve the stability under dc conditions, by reducing the variability of I_D, for ac operation it has a similar action (reducing i_d), it is called "**Source degeneration resistance**".

Another useful interpretation of the gain expression is that the gain from gate to drain is simply the ratio of the total resistance in the drain, $(R_D||R_L)$ to the total resistance in the source, $[\frac{1}{g_m} + R_S]$

Common Gate Amplifier [CG amplifier]

By applying a signal ground on the MOSFET gate terminal, a circuit configuration aptly named Common Gate or grounded gate amplifier is obtained. The input is applied between source and Gate and the Output is measured between the Drain and Gate. Since both the dc and ac voltages at the gate are zero, the gate terminal can be directly grounded as shown.

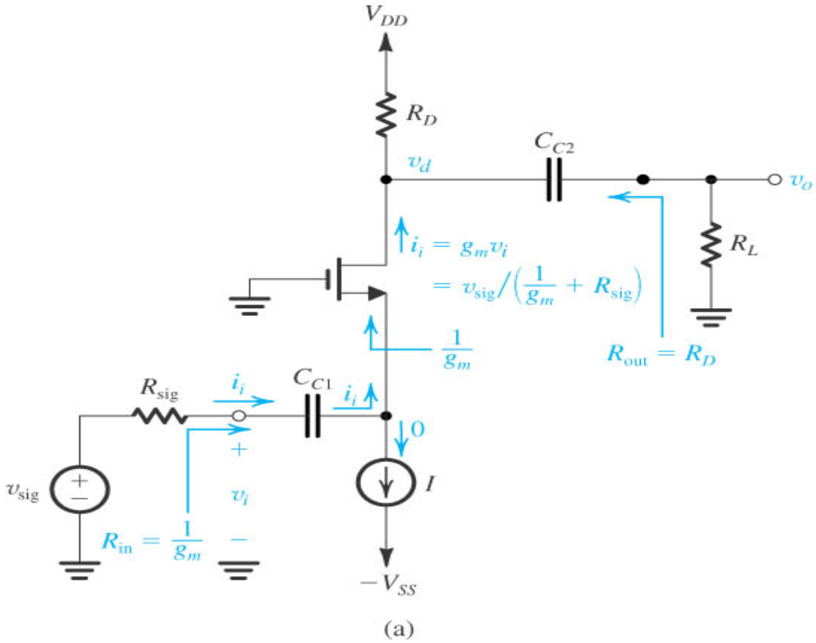

Figure 4.45 (a) A common-gate amplifier based on the circuit of Fig. 4.42.

The small signal equivalent circuit of the Common Gate Amplifier is as shown below. For simpler analysis we have used the T-model without considering the effect of r_o.

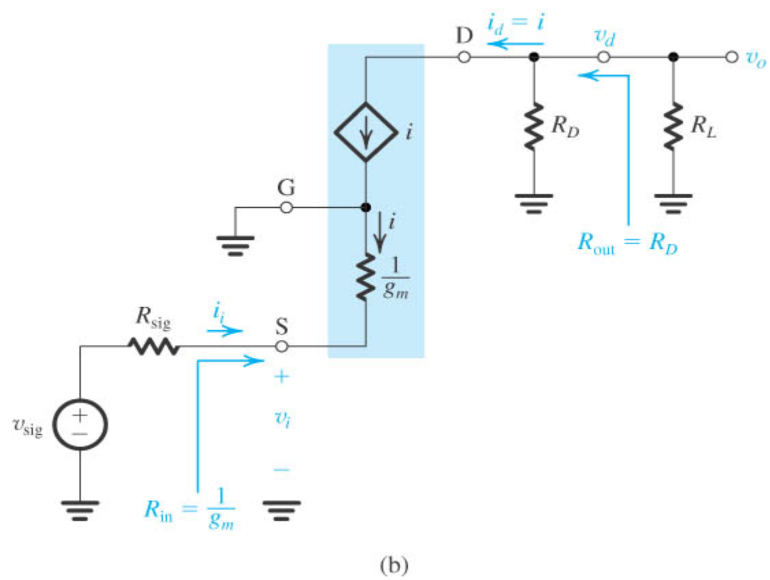

Figure 4.45 (b) A small-signal equivalent circuit of the amplifier in (a).

Analysis:

The input resistance is given as

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

Since g_m is of the order of 1mA/V, the input resistance of the CG amplifier is relatively low (of the order of 1kΏ) than in the CS amplifier.

$$V_i = V_{sig} \frac{R_{in}}{R_{in} + R_{sig}}$$

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

The loss of signal strength in coupling the signal to input of the CG amplifier is due to the low value of R_{in}.

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

The current i_i is given by,

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

And the drain current id is

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

Thus the output voltage can be found as

$$v_O = v_d - i_d(R_D||R_L) = g_m(R_D||R_L)$$

Resulting in voltage gained

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

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:

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

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,

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

Note:

- The CG amplifier is non inverting
- The input resistance of CG amplifier is very low.
- Voltage gain is smaller than that of a CS amplifier by factor (1+gmRsig) which is due to low R_{in}.
- This circuit also acts like a Unity gain current amplifier or a Current follower
- This is most commonly used in the Cascode amplifier.

Common Drain Amplifier (CD amplifier)

The signal ground is established at the drain terminal, input is given between the Gate and Drain terminals and Output is measured between the Source and Drain terminals as shown below:

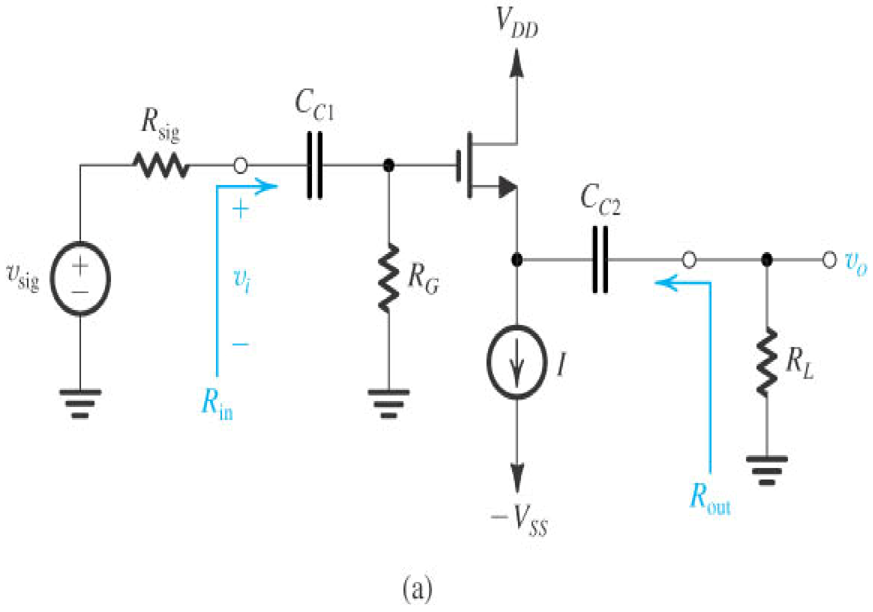

Figure 4.46 (a) A common-drain or source-follower amplifier.

Here also, it is more convenient to use the small signal T-model for analysis, but including the resistance r_o as shown below:

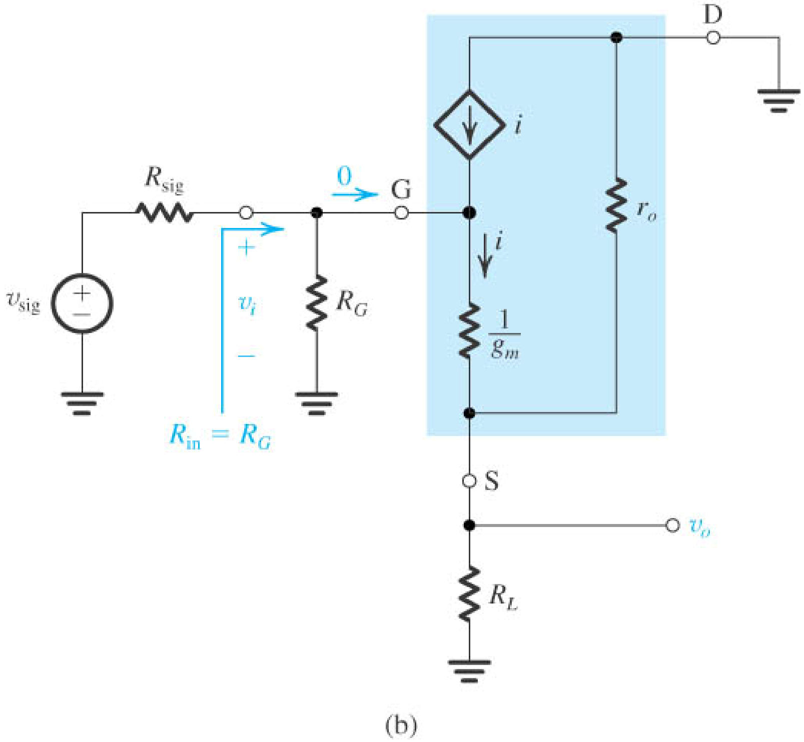

Figure 4.46 (b) Small-signal equivalent-circuit model.

Analysis:

The input resistance is given as

$R_{in} = R_G$

$V_i = V_{sig} \frac{R_{in}}{R_{in}+R_{sig}} = V_{sig} \frac{R_G}{R_G+R_{sig}}$

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

$v_i \cong v_{sig}$

$$v_O = v_i \frac{R_L \| r_o}{(R_L \| r_o) + \frac{1}{g_m}}$$

From which the voltage gain Av is obtained as

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

And the open circuit voltage gain A_{vo} as

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

Normally $r_o \gg \frac{1}{g_m}$, causing voltage gain to become nearly unity. Thus the voltage at the source follows the voltage at the gate, giving the circuit its popular name of **source follower**. In many discrete circuits $r_o \gg R_L$ which enables the equation to be approximated by,

$$A_v \cong \frac{R_L}{R_L + \dfrac{1}{g_m}}$$

The overall voltage gain Gv can be found as,

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

Which approaches unity for $R_G \gg R_{sig}$, $r_o \gg R_L$ and $r_o \gg \frac{1}{g_m}$

The circuit for determining the output resistance R_{out} is as shown in figure. Because the gate voltage is now zero, looking back into the source, we see between the source and ground a resistance $\frac{1}{g_m}$ in parallel with r_o, thus

$$R_{out} = \frac{1}{g_m} ||r_o$$

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

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

Which indicates R_{out} will be moderately low.

Note:

- In source follower, R_{in} is independent of R_L and R_{out} is independent of R_{sig}, due to zero gate current.
- Hence, it has a very high input resistance, very low output resistance and a voltage gain that is less than or close to unity.
- It is normally used as a buffer amplifier.

Summary:

- The CS amplifier is best suited for obtaining the bulk of the gain required in an amplifier. Depending on the gain required, either a single stage or a cascade of two or three stages is used.
- Including a resistor R_S in the source terminal of the CS amplifier provides a number of improvements in its performance, as it behaves like an amplifier with negative Voltage series feedback amplifier, but at the expense of reduced gain.
- The low input resistance of the CG amplifier is used as unity gain current amplifier or current follower and also in Cascode amplifier.
- The source follower finds application as a voltage buffer for connecting a high resistance source to a low resistance load and as the output stage in a multistage amplifier.