Electronic Devices

Final Term
Lecture - 09

Reference book:

Electronic Devices and Circuit Theory (Chapter-8)

Robert L. Boylestad and L. Nashelsky , (11th Edition)

OBJECTIVES

- Become acquainted with the small-signal ac model for a JFET and MOSFET.
- Be able to perform a small-signal ac analysis of a variety of JFET and MOSFET configurations.
- Begin to appreciate the design sequence applied to FET configurations.
- Understand the effects of a source resistor and load resistor on the input impedance, output impedance and overall gain.
- Be able to analyze cascaded configurations with FETs and/or BJT amplifiers.

Introduction

- Field-effect transistor amplifiers provide an excellent voltage gain with the added feature of a high input impedance.

JFET Small-Signal Model

- The ac analysis of a JFET Configuration requires that a small-signal ac model for the JFET be developed.
- ***The gate-to-source voltage controls the drain-to-source (channel) current of a JFET.***
- The *change* in drain current that will result from a *change* in gate-to-source voltage can be determined using the transconductance factor g_m in the following manner:

$$\Delta I_D = g_m \Delta V_{GS}$$

$$g_m = \frac{\Delta I_D}{\Delta V_{GS}}$$

Graphical Determination of g_m

If we now examine the transfer characteristics of Fig. 8.1, we find that g_m is actually the slope of the characteristics at the point of operation. That is,

$$\boxed{g_m = m = \frac{\Delta y}{\Delta x} = \frac{\Delta I_D}{\Delta V_{GS}}} \qquad \textbf{(8.3)}$$

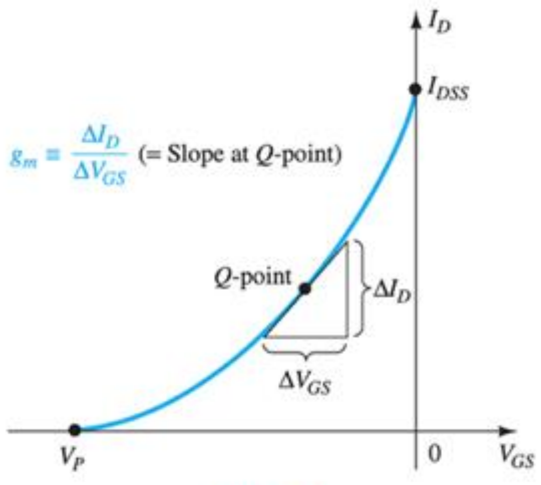

FIG. 8.1
Definition of g_m using transfer characteristic.

Example:

EXAMPLE 8.1 Determine the magnitude of g_m for a JFET with $I_{DSS} = 8$ mA and $V_P = -4$ V at the following dc bias points:

a. $V_{GS} = -0.5$ V.
b. $V_{GS} = -1.5$ V.
c. $V_{GS} = -2.5$ V.

Solution: The transfer characteristics are generated as Fig. 8.2 using the procedure defined in Chapter 7. Each operating point is then identified and a tangent line is drawn at each point to best reflect the slope of the transfer curve in this region. An appropriate increment is then chosen for V_{GS} to reflect a variation to either side of each Q-point. Equation (8.2) is then applied to determine g_m.

a. $$g_m = \frac{\Delta I_D}{\Delta V_{GS}} \cong \frac{2.1\text{ mA}}{0.6\text{ V}} = \mathbf{3.5\ mS}$$

b. $$g_m = \frac{\Delta I_D}{\Delta V_{GS}} \cong \frac{1.8\text{ mA}}{0.7\text{ V}} \cong \mathbf{2.57\ mS}$$

c. $$g_m = \frac{\Delta I_D}{\Delta V_{GS}} = \frac{1.5\text{ mA}}{1.0\text{ V}} = \mathbf{1.5\ mS}$$

Note the decrease in g_m as V_{GS} approaches V_P.

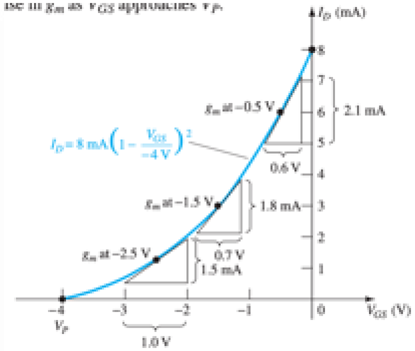

FIG. 8.2
Calculating g_m at various bias points.

Mathematical Definition of g_m

The derivative of a function at a point is equal to the slope of the tangent line drawn at that point.

If we therefore take the derivative of I_D with respect to V_{GS} (differential calculus) using Shockley's equation, we can derive an equation for g_m as follows:

$$g_m = \left.\frac{dI_D}{dV_{GS}}\right|_{Q\text{-pt.}} = \frac{d}{dV_{GS}}\left[I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2\right]$$

$$= I_{DSS}\frac{d}{dV_{GS}}\left(1 - \frac{V_{GS}}{V_P}\right)^2 = 2I_{DSS}\left[1 - \frac{V_{GS}}{V_P}\right]\frac{d}{dV_{GS}}\left(1 - \frac{V_{GS}}{V_P}\right)$$

$$= 2I_{DSS}\left[1 - \frac{V_{GS}}{V_P}\right]\left[\frac{d}{dV_{GS}}(1) - \frac{1}{V_P}\frac{dV_{GS}}{dV_{GS}}\right] = 2I_{DSS}\left[1 - \frac{V_{GS}}{V_P}\right]\left[0 - \frac{1}{V_P}\right]$$

and

$$\boxed{g_m = \frac{2I_{DSS}}{|V_P|}\left[1 - \frac{V_{GS}}{V_P}\right]} \qquad \textbf{(8.4)}$$

the slope of the transfer curve is a maximum at $V_{GS} = 0$ V.

$$g_m = \frac{2I_{DSS}}{|V_P|}\left[1 - \frac{0}{V_P}\right]$$

$$\boxed{g_{m0} = \frac{2I_{DSS}}{|V_P|}}$$

$$\boxed{g_m = g_{m0}\left[1 - \frac{V_{GS}}{V_P}\right]}$$

Example

EXAMPLE 8.2 For the JFET having the transfer characteristics of Example 8.1:

a. Find the maximum value of g_m.
b. Find the value of g_m at each operating point of Example 8.1 using Eq. (8.6) and compare with the graphical results.

Solution:

a. $$g_{m0} = \frac{2I_{DSS}}{|V_P|} = \frac{2(8\text{ mA})}{4\text{ V}} = \mathbf{4\text{ mS}} \qquad \text{(maximum possible value of } g_m\text{)}$$

b. At $V_{GS} = -0.5$ V,

$$g_m = g_{m0}\left[1 - \frac{V_{GS}}{V_P}\right] = 4\text{ mS}\left[1 - \frac{-0.5\text{ V}}{-4\text{ V}}\right] = \mathbf{3.5\text{ mS}} \qquad \text{(vs. 3.5 mS graphically)}$$

At $V_{GS} = -1.5$ V,

$$g_m = g_{m0}\left[1 - \frac{V_{GS}}{V_P}\right] = 4\text{ mS}\left[1 - \frac{-1.5\text{ V}}{-4\text{ V}}\right] = \mathbf{2.5\text{ mS}} \qquad \text{(vs. 2.57 mS graphically)}$$

At $V_{GS} = -2.5$ V,

$$g_m = g_{m0}\left[1 - \frac{V_{GS}}{V_P}\right] = 4\text{ mS}\left[1 - \frac{-2.5\text{ V}}{-4\text{ V}}\right] = \mathbf{1.5\text{ mS}} \qquad \text{(vs. 1.5 mS graphically)}$$

Plotting g_m versus V_{GS}

Since the factor $\left(1 - \frac{V_{GS}}{V_P}\right)$ of Eq. (8.6) is less than 1 for any value of V_{GS} other than 0 V, the magnitude of g_m will decrease as V_{GS} approaches V_P and the ratio $\frac{V_{GS}}{V_P}$ increases in magnitude. At $V_{GS} = V_P$, $g_m = g_{m0}(1 - 1) = 0$. Equation (8.6) defines a straight line with a minimum value of 0 and a maximum value of g_m, as shown by the plot of Fig. 8.3.

In general, therefore

the maximum value of g_m occurs where $V_{GS} = 0$ V and the minimum value at $V_{GS} = V_P$. The more negative the value of V_{GS} the less the value of g_m.

Figure 8.3 also shows that when V_{GS} is one-half the pinch-off value, g_m is one-half the maximum value.

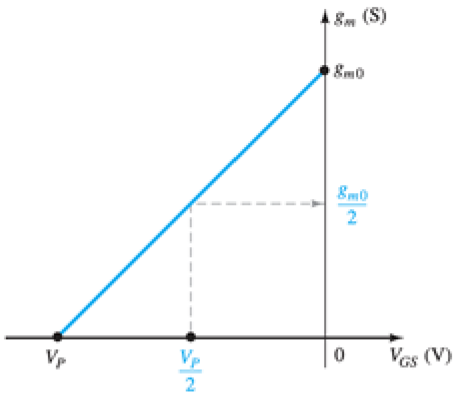

FIG. 8.3
Plot of g_m versus V_{GS}.

Example

EXAMPLE 8.3 Plot g_m versus V_{GS} for the JFET of Examples 8.1 and 8.2.

Solution: Note Fig. 8.4.

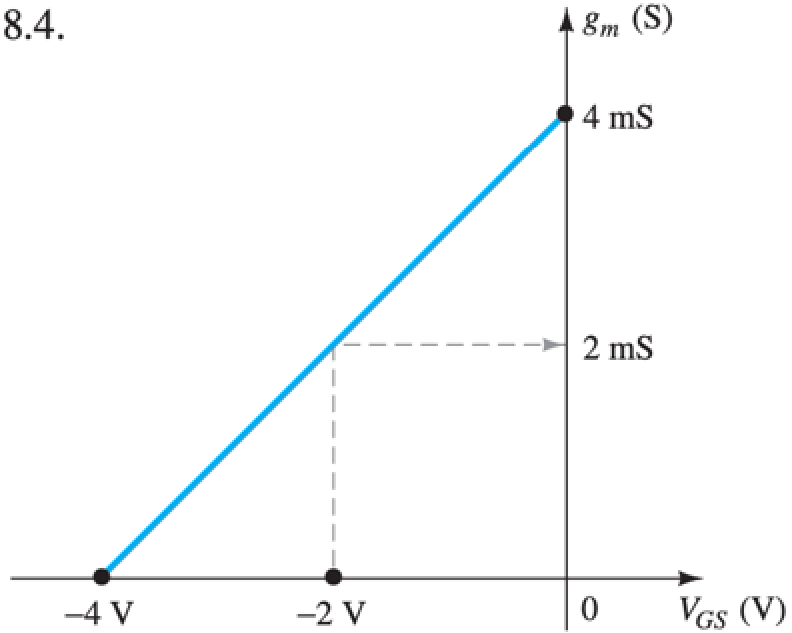

FIG. 8.4

Plot of g_m versus V_{GS} for a JFET with I_{DSS} = 8 mA and $V_P = -4$ V.

Effect of I_D on g_m

A mathematical relationship between g_m and the dc bias current I_D can be derived by noting that Shockley's equation can be written in the following form:

$$\boxed{1 - \frac{V_{GS}}{V_P} = \sqrt{\frac{I_D}{I_{DSS}}}} \tag{8.8}$$

Substituting Eq. (8.8) into Eq. (8.6) results in

$$\boxed{g_m = g_{m0}\left(1 - \frac{V_{GS}}{V_P}\right) = g_{m0}\sqrt{\frac{I_D}{I_{DSS}}}} \tag{8.9}$$

Using Eq. (8.9) to determine g_m for a few specific values of I_D, we obtain the following results:

a. If $I_D = I_{DSS}$,

$$g_m = g_{m0}\sqrt{\frac{I_{DSS}}{I_{DSS}}} = \mathbf{g_{m0}}$$

b. If $I_D = I_{DSS}/2$,

$$g_m = g_{m0}\sqrt{\frac{I_{DSS}/2}{I_{DSS}}} = \mathbf{0.707g_{m0}}$$

c. If $I_D = I_{DSS}/4$,

$$g_m = g_{m0}\sqrt{\frac{I_{DSS}/4}{I_{DSS}}} = \frac{g_{m0}}{2} = \mathbf{0.5g_{m0}}$$

Example

EXAMPLE 8.4 Plot g_m versus I_D for the JFET of Examples 8.1 through 8.3.

Solution: See Fig. 8.5.

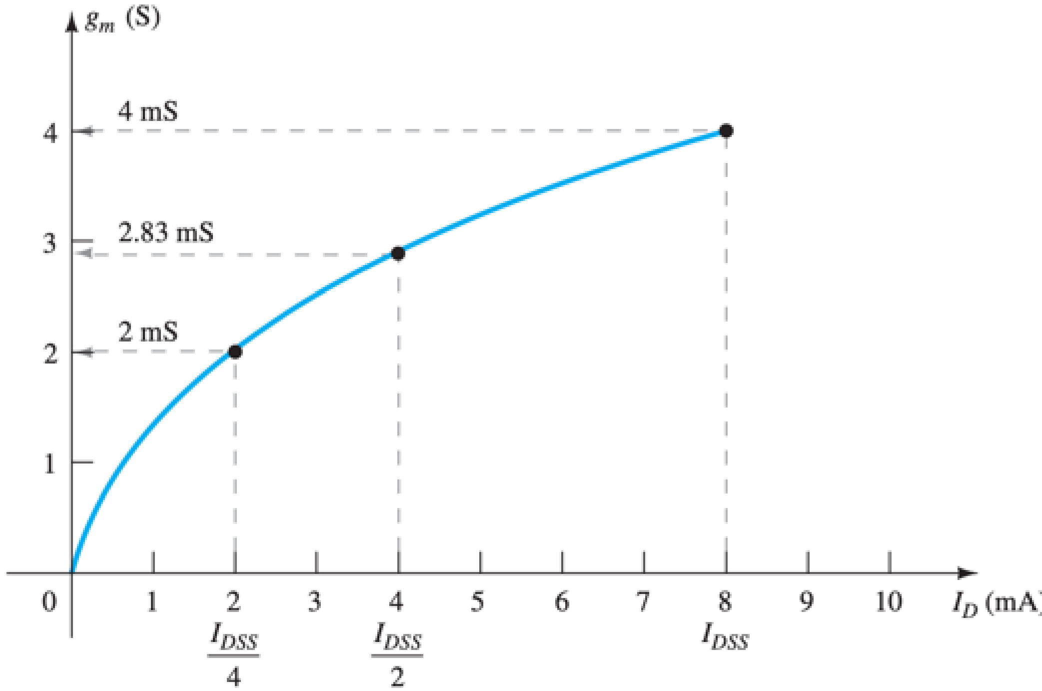

FIG. 8.5

Plot of g_m versus I_D for a JFET with $I_{DSS} = 8$ mA and $V_{GS} = -4$ V.

End of Lecture-9