

Electronic Devices

Final Term Lecture - 09

Reference book:

Electronic Devices and Circuit Theory (Chapter-8)

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



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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,

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

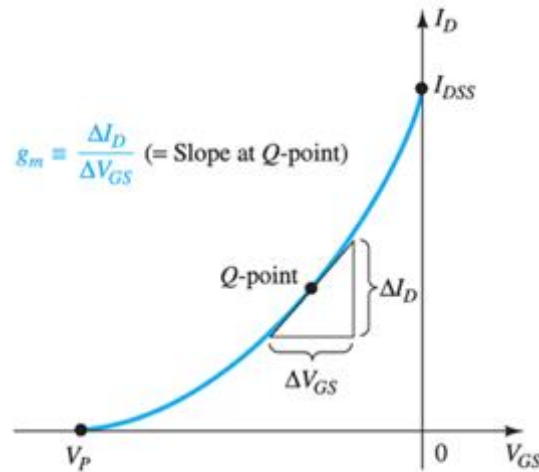


FIG. 8.1

Definition of g_m using transfer characteristic.

Example:

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

- $V_{GS} = -0.5 \text{ V}$.
- $V_{GS} = -1.5 \text{ V}$.
- $V_{GS} = -2.5 \text{ V}$.

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 .

$$\begin{aligned} \text{a. } g_m &= \frac{\Delta I_D}{\Delta V_{GS}} \cong \frac{2.1 \text{ mA}}{0.6 \text{ V}} = 3.5 \text{ mS} \\ \text{b. } g_m &= \frac{\Delta I_D}{\Delta V_{GS}} \cong \frac{1.8 \text{ mA}}{0.7 \text{ V}} \cong 2.57 \text{ mS} \\ \text{c. } g_m &= \frac{\Delta I_D}{\Delta V_{GS}} = \frac{1.5 \text{ mA}}{1.0 \text{ V}} = 1.5 \text{ mS} \end{aligned}$$

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

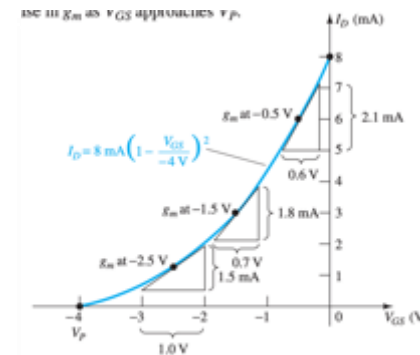


FIG. 8.2
Calculating g_m at various bias points.

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:

$$\begin{aligned} g_m &= \left. \frac{dI_D}{dV_{GS}} \right|_{Q\text{-pt.}} = \frac{d}{dV_{GS}} \left[I_{DSS} \left(1 - \frac{V_{GS}}{V_P} \right)^2 \right] \\ &= I_{DSS} \frac{d}{dV_{GS}} \left(1 - \frac{V_{GS}}{V_P} \right)^2 = 2I_{DSS} \left[1 - \frac{V_{GS}}{V_P} \right] \frac{d}{dV_{GS}} \left(1 - \frac{V_{GS}}{V_P} \right) \\ &= 2I_{DSS} \left[1 - \frac{V_{GS}}{V_P} \right] \left[\frac{d}{dV_{GS}} (1) - \frac{1}{V_P} \frac{dV_{GS}}{dV_{GS}} \right] = 2I_{DSS} \left[1 - \frac{V_{GS}}{V_P} \right] \left[0 - \frac{1}{V_P} \right] \end{aligned}$$

and

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

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

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

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

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



Example

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

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

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

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

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

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

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

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



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.

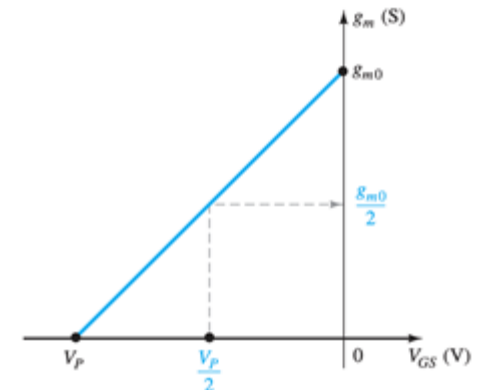


FIG. 8.3
Plot of g_m versus V_{GS}



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.

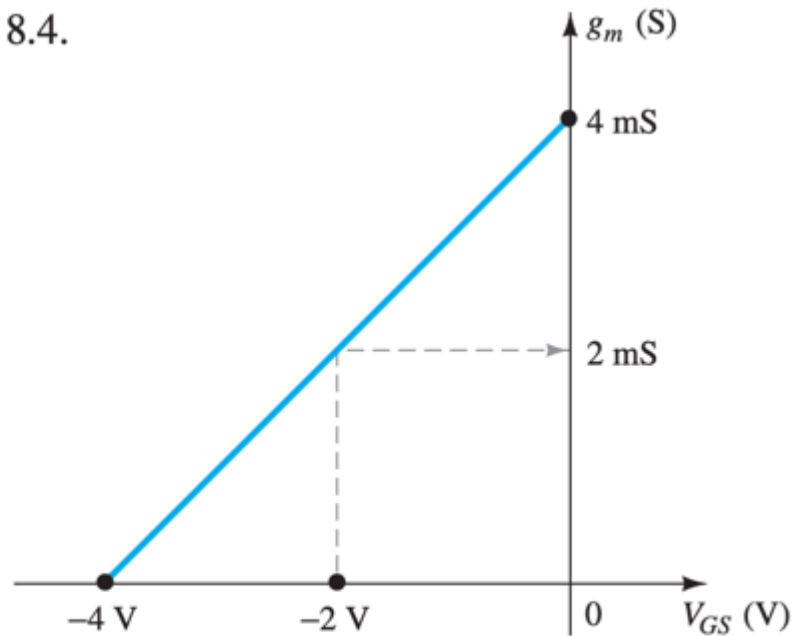


FIG. 8.4

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:

$$1 - \frac{V_{GS}}{V_P} = \sqrt{\frac{I_D}{I_{DSS}}} \quad (8.8)$$

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

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

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

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

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

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

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

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

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



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.

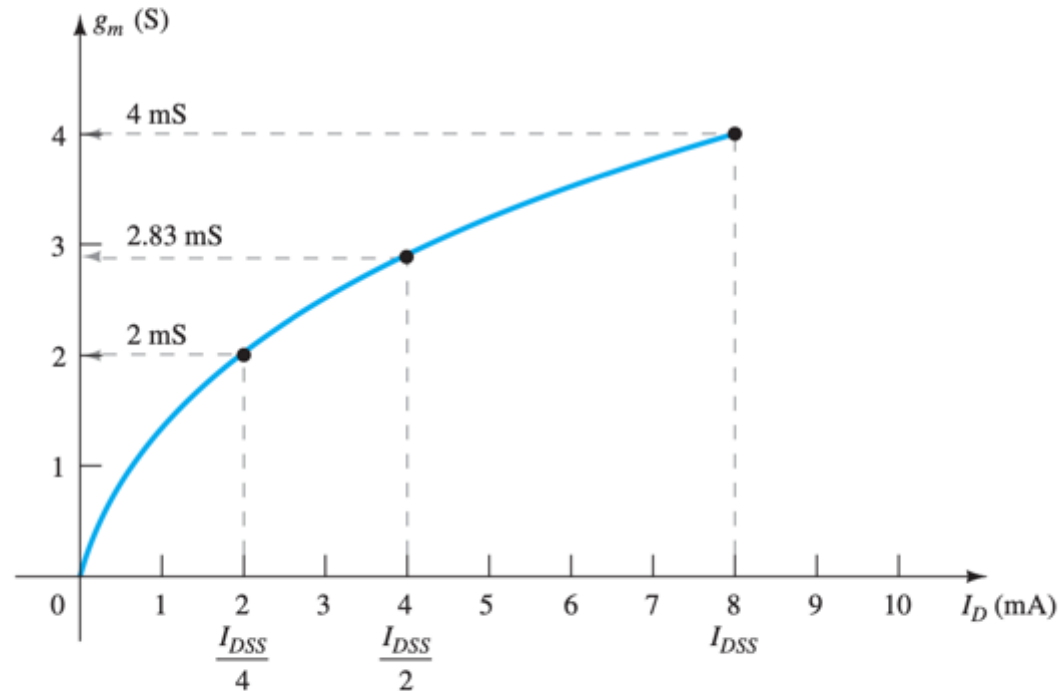


FIG. 8.5

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



End of Lecture-9

