Chapter 7: FET Amplifiers Switching and Circuits

The Common-Source Amplifier

In a common-source (CS) amplifier, the input signal is applied to the gate and the output signal is taken from the drain. The amplifier has higher input resistance and lower gain than the equivalent CE amplifier.

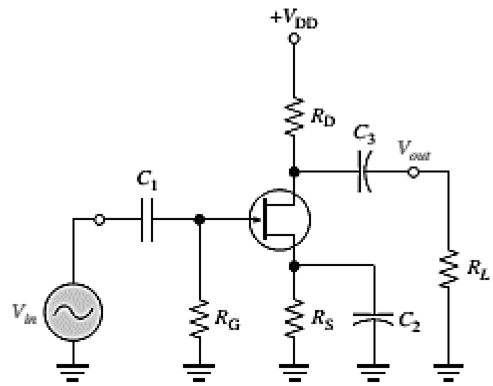


Figure 1: JFET common-source amplifier.

The ac voltage gain of this circuit is V_{out}=V_{in}, where V_{in}=V_{gs} and V_{out}=V_{ds}. The voltage gain expression is, therefore,

$$A_v = \frac{V_{ds}}{V_{gs}}$$

From the equivalent circuit, $V_{ds}=I_dR_d$

and from the definition of transconductance, $g_m=I_d/V_{gs}$,
Substituting the two preceding expressions into the equation for voltage gain yields

$$\mathbf{A_v=g_m R_d}$$

You can estimate what the transfer characteristic looks like from values on the specification sheet, but keep in mind that large variations are common with JFETs.

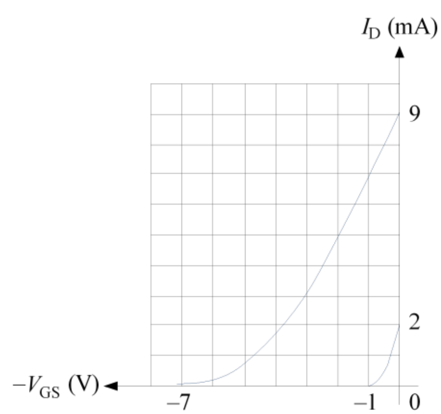
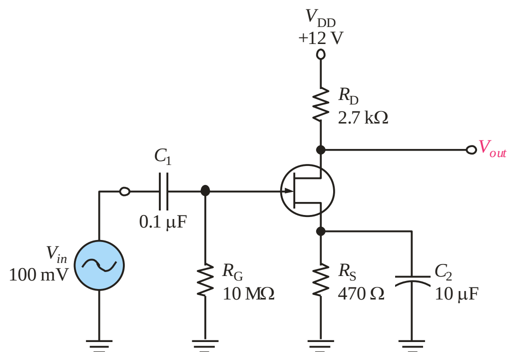


Figure 2

To analyze the CS amplifier, you need to start with dc values. It is useful to estimate I_D based on typical values; specific circuits will vary from this estimate. The gain is reduced when a load is connected to the amplifier because the total ac drain resistance (R_d) is reduced

Example: Determine the drain current for a typical 2N5458 JFET amplifier which shown in the following Figure.

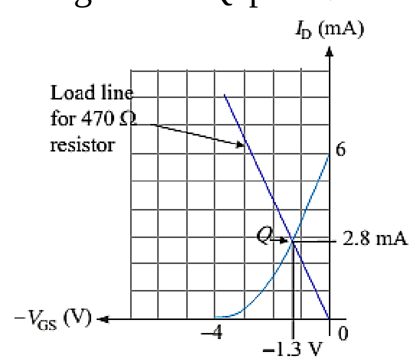


Solution: From the specification sheet, the typical I_{DSS} = 6.0 mA and $V_{GS(off)}$ = -4 V. These values can be plotted along with the load line to obtain a graphical solution. A graphical solution is illustrated. On the transconductance curve, plot the load line for the source resistor. Then read the current and voltage at the *Q*-point.

I_D = 2.8 mA and V_{GS} = -1.3 V

Alternatively, you can obtain I_D using Equation

$$I_D = I_{DSS}\left(1 - \frac{I_D R_S}{V_{GS(off)}}\right)^2$$



Example: Assume I_{DSS} is 6.0 mA, $V_{GS(off)}$ is -4 V, and V_{GS} = -1.3 V as found previously. What is the expected gain?

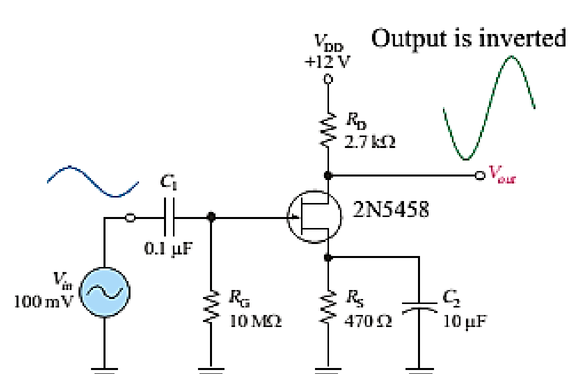
Solution:

$$g_{m0} = \frac{2I_{DSS}}{|V_{GS(off)}|} = \frac{2(6.0\text{ mA})}{4\text{ V}} = 3.0\text{ mS}$$

$$g_m = g_{m0}\left(1 - \frac{V_{GS}}{V_{GS(off)}}\right)$$

$$= 3.0\text{ mS}\left(1 - \frac{-1.3\text{ V}}{-4.0\text{ V}}\right)$$

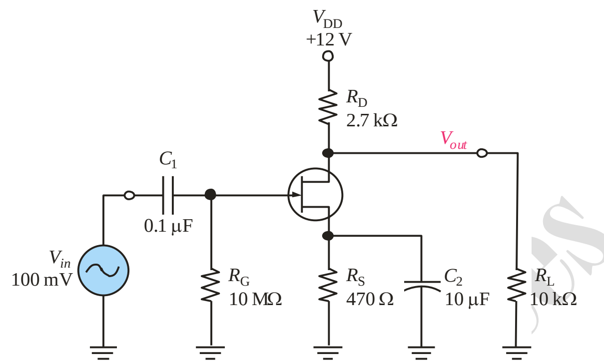
2.02 mS



$A_v = g_m R_D$ = (2.02 mS)(2.7 kΩ) = 5.45

Example: How does the addition of the 10kΩ load affect the gain?

Solution:



$$R_d = \frac{R_D R_L}{R_D + R_L}$$

$$= \frac{(2.7\ \text{k}\Omega)(10\ \text{k}\Omega)}{2.7\ \text{k}\Omega + 10\ \text{k}\Omega}$$

$$= 2.13\ \text{k}\Omega$$

$$A_v = g_m R_d = (2.02\ \text{mS})(2.13\ \text{k}\Omega) = 4.29$$

D-MOSFET Amplifier Operation

In operation, the D-MOSFET has the unique property in that it can be operated with zero bias, allowing the signal to swing above and below ground. This means that it can operate in either D-mode or E-mode.

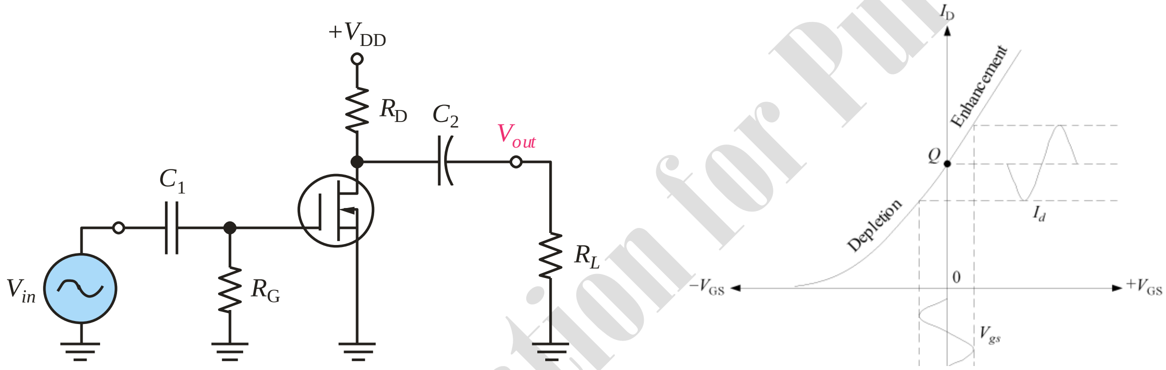


Figure 3: (a) Zero-biased D-MOSFET common-source amplifier. (b) Depletion-enhancement operation D-MOSFET shown on transfer characteristic curve.

E-MOSFET Amplifier Operation

The E-MOSFET is a normally off device. The *n*-channel device is biased on by making the gate positive with respect to the source. A voltage-divider biased E-MOSFET amplifier is shown in Figure 4.

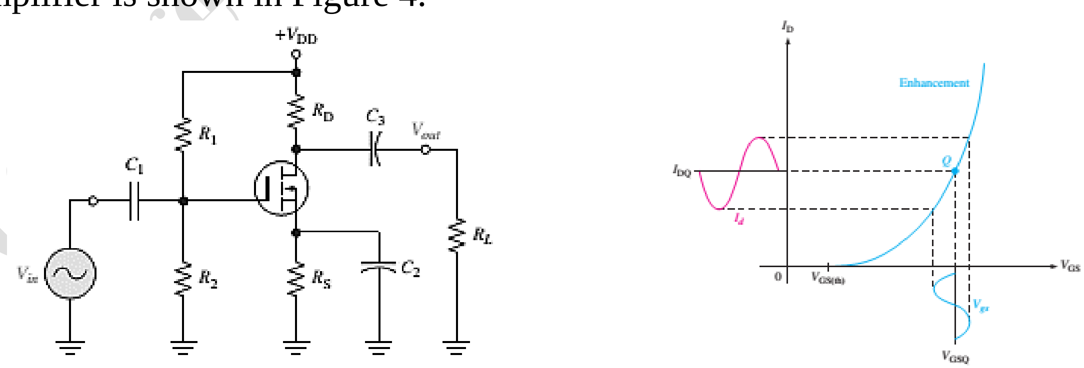


Figure 4: (a) Common-source E-MOSFET amplifier with voltage-divider bias. (b) E-MOSFET (*n*-channel) operation shown on transfer characteristic curve.

The Common-Drain (CD) Amplifier

In a CD amplifier, the input signal is applied to the gate and the output signal is taken from the source. There is no drain resistor, because it is *common* to the input and output signals.

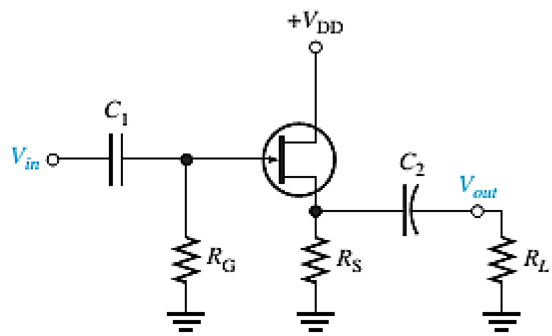


Figure 5: JFET common-drain amplifier (source-follower).

The voltage gain is given by the equation

$$A_v = \frac{g_m R_S}{1 + g_m R_S}$$

The voltage gain is always slightly < 1. If $g_m R_s$>>1, then a good approximation is $A_v \cong 1$.

Common-Gate Amplifier Operation

A self-biased common-gate amplifier is shown in Figure 6. The gate is connected directly to ground. The input signal is applied at the source terminal through C_1. The output is coupled through C_2 from the drain terminal.

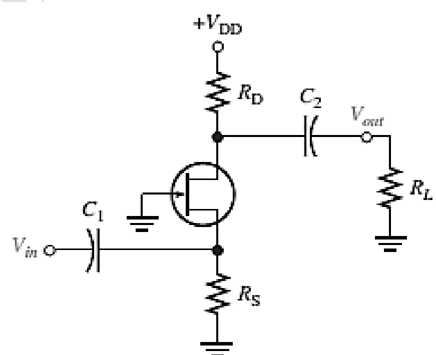


Figure 6: JFET common-gate amplifier.

The Class-D Amplifier

MOSFETs are useful as class-D amplifiers, which are very efficient because they operate as switching amplifiers. They use pulse- width modulation (PWM), a process in which the input signal is converted to a series of pulses. The pulse width varies proportionally to the amplitude of the input signal.

The modulated signal is amplified by class-B complementary MOSFET transistors. The output is filtered by a low-pass filter to recover the original signal and remove the higher modulation frequency. PWM is also useful in control applications such as motor controllers. MOSFETs are widely used in these applications because of fast switching time and low on-state resistance.

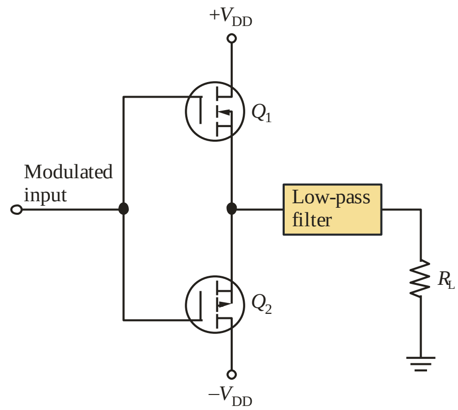


Figure 7: Complementary MOSFETs operating as switches to amplify power.

MOSFET Switching Operation

MOSFETs are also used as analog switches to connect or disconnect an analog signal. Analog switches are available in IC form. The configuration shown allows signals to be passed in either direction. Advantages of MOSFETs are that they have relatively low on-state resistance and they can be used at high frequencies, such as found in video applications. A basic n-channel MOSFET analog switch is shown in Figure 8. The signal at the drain is connected to the source when the MOSFET is turned on by a positive V_{GS} and is disconnected when V_{GS} is 0, as indicated.

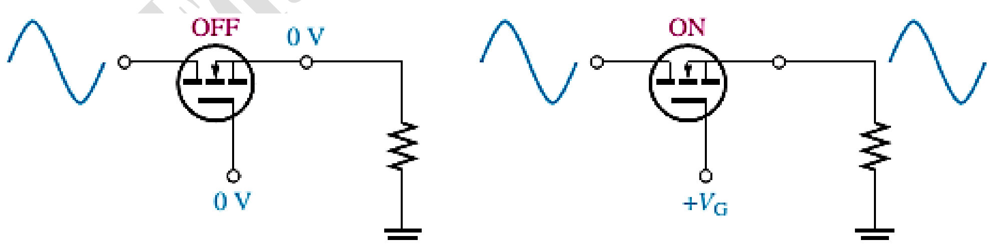
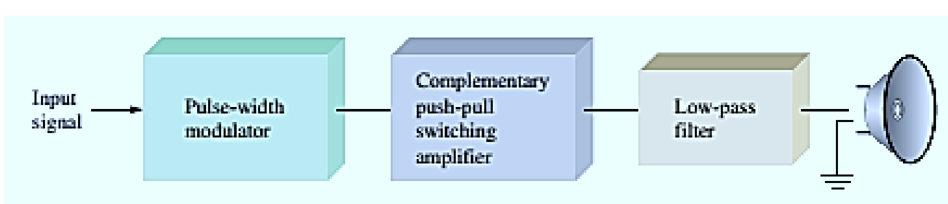


Figure 9: Operation of an *n*-channel MOSFET analog switch.



Basic class D audio amplifier