Lab 6: MOSFET Amplifiers

Objectives

The objective of this lab is to study common-source (CS) amplifier, the MOSFET counterpart of the CE amplifier you studied in Lab 4 and Lab 5. We will learn small-signal parameters of MOSFET. We will also study CS amplifier with source degeneration.

Introduction

For this lab we will be using the 2N7000 MOSFET. A model for this MOSFET can be obtained at the following website: www.fairchildsemi.com/models/PSPICE/Discrete/MOSFET.html

1. Small-signal parameters of MOSFET

We will use the CS configuration in Fig. 6-1 to measure the small-signal parameters of the MOSFET to be used in this lab. The MOSFET remains in saturation region in order to provide a large voltage gain (similar to biasing the BJT in FAR). To accomplish this, you need to adjust the gate voltage V_G such that the drain voltage resides in the middle of the linear region of the transfer function of the amplifier.

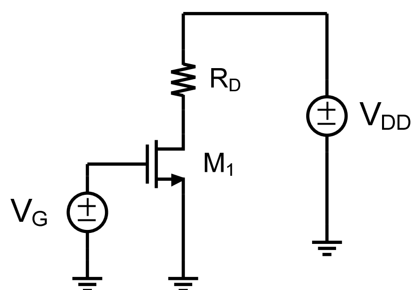

Figure 6-1: Measuring small-signal MOSFET parameters

- g_m: Transconductance, defined as

$$g_m = \frac{\partial I_D}{\partial V_{GS}}\bigg|_{V_{DS}=constant} \quad (6\text{-}1)$$

  This parameter is found by measuring the ratio of the incremental changes in drain current and gate-source voltage by slightly varying the gate voltage from the operating point. You will need to vary V_{DD} to make sure that V_{DS} is constant in your measurement.

- r_o: Output resistance, or drain-source resistance, defined as

$$r_o = \frac{\partial V_{DS}}{\partial I_D}\bigg|_{V_{GS}=constant} \quad (6\text{-}2)$$

  This parameter is found by measuring the ratio of the incremental changes in drain-source voltage and drain current by slightly varying V_{DD}.

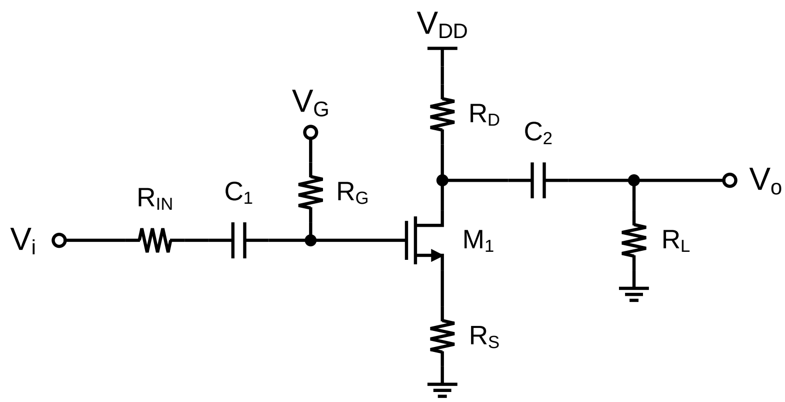

Figure 6-2: CS MOSFET amplifier with source degeneration

2. Common-source amplifier with source degeneration

We will perform DC and AC analyses for the CS amplifier shown in Fig. 6-2.

DC Analysis

To ensure that the circuit functions as an amplifier, we need to first make sure that the MOSFET is biased properly in the saturation region. This is accomplished with the resistor R_G in Fig. 6-2. To analyze the operating point of the MOSFET, we can overlay the I-V characteristic of the MOSFET-R_S combo (I_D vs. V_D not V_{DS}) with the load line of R_D. To obtain maximum output swing, the transistor is often biased at the Q (quiescent) bias point in the middle of the linear region of the transfer function. This usually leads to a drain voltage around $V_{DD}/2$.

The drain current of the MOSFET at the Q point can be determined by solving

$$I_D = \frac{1}{2}k'\left(V_G - I_D R_S - V_{TH}\right)^2 \qquad (6\text{-}3)$$

where V_{TH} is the threshold voltage of the MOSFET and k' is a device parameter.

AC Analysis

AC analysis refers to the small-signal linear analysis of the amplifier equivalent circuit shown in Fig. 6-3. Note that here the MOSFET symbol has been replaced by an equivalent model. Similar to the CE amplifier in Lab 5, we are interested in the mid-band gain of the CS amplifier. To determine this gain, we recognize C_1 and C_2 as the AC-coupling capacitors, while C_{gs} and C_{gd} are inherent capacitance of the MOSFET that will lead to high-frequency roll-offs of the amplifier gain. Since the mid-band gain is independent of frequency, we can short all AC-coupling capacitors (C_1 and C_2) and open all high-frequency capacitors (C_{gs} and C_{gd}) in the equivalent circuit and obtain the mid-band equivalent circuit shown in Fig. 6-4.

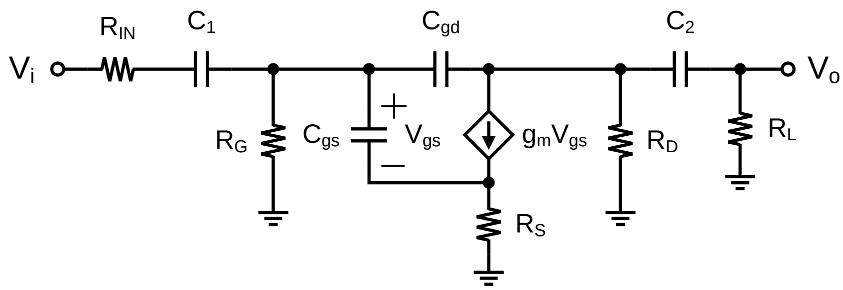

Figure 6-3: AC equivalent circuit of the amplifier in Fig. 6-2

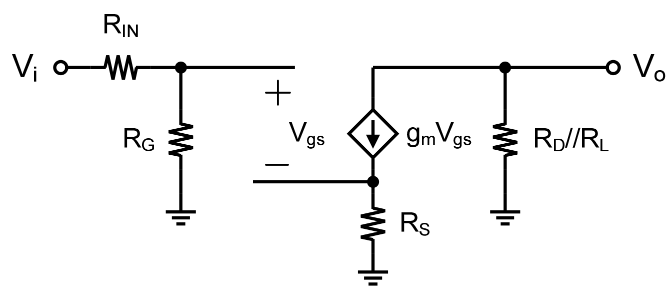

Figure 6-4: Mid-band AC equivalent circuit of the amplifier in Fig. 6-2

The mid-band gain thus can be determined as

$$A_{mid} = -\left(\frac{R_G}{R_{IN} + R_G}\right)\frac{g_m}{1 + g_m R_S}\left(R_D // R_L\right) \tag{6-4}$$

Here we assume that $r_o >> R_D$ and R_L. If $g_m R_S >> 1$, Eq. (6-4) can be simplified as

$$A_{mid} \approx -\left(\frac{R_G}{R_{IN} + R_G}\right)\frac{1}{R_S}\left(R_D // R_L\right) \tag{6-5}$$

Preparation

1. Simulate in PSpice the circuit in Fig. 6-1. Set V_{DD} to 10V and R_D to 1k.
    - Determine the gate bias V_G to set the drain voltage to roughly $V_{DD}/2$.
    - Determine I_D, g_m, and r_o of the MOSFET at the operating point above.
    - Obtain the large-signal transfer function of the CS amplifier.
    - Determine the small-signal (AC) gain of the amplifier at the operating point above.
2. Simulate in PSpice the circuit in Fig. 6-2. Set V_{DD} = 10V, $R_G = R_{IN} = R_S$ = 1k, $R_D = R_L$ = 20k, and $C_1 = C_2$ = 22uF.
    - Determine the gate bias V_G to set the drain voltage to roughly $V_{DD}/2$.
    - Determine I_D, g_m, and r_o of the MOSFET at the operating point above. Does $g_m R_S >> 1$ hold? What is the effective transconductance of the MOSFET with degeneration?

- Obtain the large-signal transfer function of the amplifier.
- Determine the small-signal (AC) gain of the amplifier at the operating point above.

Procedure

1. For the circuit in Fig. 6-1:

- Set V_{DD} to 10V and R_D to 1k. Find the value of V_G to set the drain voltage to $V_{DD}/2$.
- Measure the small-signal parameters g_m and r_o of the MOSFET at the operating point above according to the description in the introduction.
- Use the function generator as the input source, and set it up as follows
    - Waveform: sinusoidal
    - Offset: the V_G you found
    - Amplitude: 0.1V
    - Frequency: 1kHz
- Use the oscilloscope to view the input and output waveforms. Record the small-signal (AC) voltage gain.
- Increase the amplitude of the function generator until you see the output clipped at the top and bottom of the sine wave. Then use the XY display mode of the oscilloscope, and set the input signal to Channel 1 and the output signal to Channel 2. What you will see here is the transfer function of the CS amplifier. Use the cursors to measure the maximum as well as the minimum output voltages.

2. For the circuit in Fig. 6-2:

- Build the circuit. Set V_{DD} = 10V, $R_G = R_{IN} = R_S$ = 1k, $R_D = R_L$ = 20k, and $C_1 = C_2$ = 22uF. Choose V_G such that the MOSFET is in saturation and the output voltage is close to $V_{DD}/2$.
- Set the input signal to sine wave at 100 kHz with an amplitude of 0.1V, and measure the gain of the amplifier. If the gain is too large, tune down the amplitude of your sine-wave generator to avoid saturating your amplifier.
- Use *freqlog.vi* to obtain the Bode plot for the gain. Record the mid-band gain and mark the high and low frequency end points for the mid-band region.

Lab 6 Report Instructions

Besides the general guidelines, report the following for this lab:

Common Source (Fig. 6-1)

1. Sketch (by hand, PSpice or any drawing program) the circuit.
2. Plot Vout vs. Vin curve (transfer function), show the range of the linear gain region (Vin,min, Vout,max) and (Vout,min, Vout,max) and AC gain computed from the slope.
3. Show Vin,middle and Vout,middle in linear region.
4. Show AC gain obtained from oscilloscope readings, and the DC values of the Vout and Iout. Compare the measured gain to your simulation result.
5. Show the Vin value to achieve Vout clipping. Explain why clipping occurred at this value.

Common Source with Source Degeneration (Fig. 6-2)

1. Sketch (by hand, PSpice or any drawing program) the circuit.
2. Show the input and output waveforms of the amplifier.
3. Show the Bode plots you measured for the amplifier and clearly mark the high and low frequency end points and the mid-band gain.
4. Compare the measured mid-band gain to your hand calculation as well as simulation results.