EE 462: Laboratory Assignment 8
Small Signal Models: The MOSFET Common Source Amplifier

by
Dr. A.V. Radun
Dr. K.D. Donohue (10/20/03)
Department of Electrical and Computer Engineering
University of Kentucky
Lexington, KY 40506

Laboratory # 9 Pre-lab due at lab sessions October 28, 29 and 30.
Lab due at lab sessions November 4, 5, and 6.

I. Instructional Objectives
• Estimate small-signal MOSFET model parameters from measurements
• Analyze circuit using the small-signal transistor model

See 6.1, 7.3.3, and 7.4.3 in Horenstein

II. Background

Lab 7 established the quiescent operating point of (biased) a common source amplifier employing an N-channel MOSFET. The common source amplifier is general-purpose amplifier with a good negative voltage gain, but poor high frequency characteristics. The N-channel MOSFET based common source amplifier may be used as a voltage amplifier by connecting an input signal to the gate of the transistor, and connecting a load to the drain. To ensure the input signal and output load do not upset the amplifier’s bias, these connections are capacitively coupled. This means a capacitor is connected in series with the signal source and load, providing an open circuit during DC operation in order to prevent the source and load from changing the circuit’s quiescent operating point. These capacitor values are chosen so that they behave as an effective short-circuit for the AC signal components and thus that they do not significantly effect the AC signal losses. The circuit used for this lab is shown in Fig. 1, and the small-signal model of the MOSFET used in this circuit is shown in Fig. 2, where \( r_{dl} \) and \( r_{in} \) are the MOSFET’s output resistance and input resistances, respectively.
The parameters for the small signal model are given by:

\[
g_m = \frac{\Delta I_D}{\Delta V_{GS}} \bigg|_{V_{gs}=V_{gsQ}} = 2K \left(V_{gsQ} - V_r\right) = 2\sqrt{K \cdot I_{DQ}}
\]  

(1)

where \(K\) is the notation used in Horenstein, or

\[
g_m = \frac{\Delta I_D}{\Delta V_{GS}} \bigg|_{V_{gs}=V_{gsQ}} = Kp \left(V_{gsQ} - V_r\right) = \sqrt{2Kp \cdot I_{DQ}}
\]  

(2)

where \(Kp\) is the notation used in SPICE. Let \(g_m\) denote the MOSFET’s transconductance. Two other circuits useful for this lab in measuring the total amplifier's input and output resistances are given in Figs. 3 and 4 below.

Relationship for input resistance in terms of measured quantities from the circuit in Fig. 3:

\[
R_{in} = \frac{V_{in}}{I_{in}} = \frac{V_{inpp}}{I_{inpp}} = \frac{V_{in}}{I_{inrms}} = \frac{V_2}{I_{inpp}} = \frac{V_2}{V_1 - V_2} = \frac{V_2 R_{sense}}{V_1 - V_2}
\]  

(4)
Amplifier

VDD

Vin

Amplifier

VDD

Vin

Ishort

Vshort

Rshort

Fig. 4 Circuit for measuring $R_{out}$.

Relationship for input resistance in terms of measured quantities from the circuit in Fig. 4:

$$R_{in} = R_{th} = \frac{V_{open}}{I_{short}} = \frac{V_{open}}{I_{short}} = \frac{V_{open}}{V_{short}} = \frac{V_{open}}{V_{short}} \frac{V_{open}}{V_{short}} \frac{V_{open}}{V_{short}} \frac{V_{open}}{V_{short}} (4)$$

Note that two separate tests are required to measure the input and output resistances.

### III. Pre-Laboratory Exercise

For the pre-lab assignments assume $r_d$ and $r_i$ to be infinite. In addition, assume that $R_{sin} = 1 \, \text{kΩ}$, $R_D = 1 \, \text{kΩ}$, $R_s = 100 \, \text{Ω}$, $R_L = 1 \, \text{kΩ}$, $K = K_p / 2 = 0.1125 \, \text{A/V}^2$, $V_{tr} = 2.1 \, \text{V}$, (or you can use the values you measured in the previous labs) $I_{R1} = I_{R2} = 1.475 \, \text{mA}$, and $V_{DD} = 15 \, \text{V}$. In general the capacitor values should be large to minimize the AC voltage drops for the frequencies considered. Value of $C_s$ will be computed in pre-lab and $C_{in}$ and $C_{out}$ can be set to the value of $C_s$ or greater.

1. Draw the DC model of the circuit. Derive and draw the DC load line equation for the circuit.
2. Set the operating point $V_{DSQ} = V_{DD} / 2$ which is approximately the intersection of the midpoint of the load line and the characteristic curves for the NMOSFET. You can draw or plot these curves knowing $K$ or $K_p$ as done in a previous lab. Since most of the operation will be in the saturation region, the following relationship is all that is needed to relate the gate voltage to the drain current:

$$I_D = K (V_{GS} - V_{tr}) = \frac{K_p}{2} (V_{GS} - V_{tr})^2 \text{ for } V_{DS} > V_{GS} - V_{tr} (3)$$

3. Find the values of $R_1$ and $R_2$ to set the operating point ($I_{DQ}, V_{DSQ}$).
4. Draw the AC or incremental model of the circuit.
5. Using the AC or incremental model, determine the small signal voltage gain ($\hat{V}_{out} / \hat{V}_{in}$) and current gain ($\hat{i}_{out} / \hat{i}_{in}$) of the circuit for $C_s = 0$. For these calculations assume $R_{sin}$ is zero and $R_L$ is infinite. Repeat the voltage gain calculation with the given values of $R_{sin}$ and $R_L$ (1 kΩ).
6. Determine the small signal voltage ($\hat{V}_{out} / \hat{V}_{in}$) and current gain ($\hat{i}_{out} / \hat{i}_{in}$) of the circuit for $C_S$ so large that it shorts out $R_S$. For this calculation you may again assume $R_{sin}$ is zero and $R_L$ is infinite. Repeat the voltage gain calculation with the given values of $R_{sin}$ and $R_L$. 


7. Determine the input resistance and the output resistance (Thévenin equivalent resistance with respect to the output terminals) of the amplifier circuit ($R_{\text{in}}$ and $R_L$ are not considered part of the amplifier circuit). Do the input and output resistances depend on $C_S$?

8. What value of $C_S$ must you choose in order to effectively short-out $R_S$? Assume the signal frequency is 10 kHz.

9. Explain a way to determine the input resistance and the output resistance of the circuit above in terms of experimental measurements (note the output resistance is the same as the Thévenin equivalent resistance)?

IV. Laboratory Exercise

1. Measure the output drain characteristics of your MOSFET on the curve tracer. Estimate the MOSFET’s threshold voltage. This was done in a previous lab; however do it again now that you are more familiar with the MOSFET.

2. Construct the circuit above using values given or calculated in the pre-lab. Make sure to connect the capacitors with the correct polarity. Make $R_{\text{in}} = 0\,\Omega$ and $R_L = 1\,\Omega$.

3. Before connecting the input signal $V_s$, measure the quiescent operating point by measuring $V_{DSQ}$ ($V_{DG}$ and $V_{SQ}$), $V_{GSQ}$ ($V_{GQ}$ and $V_{SQ}$), and $I_{DQ}$ (measure the exact value of $R_D$ and the voltage across $R_D$ or measure the exact value of $R_S$ and the voltage across $R_S$). (Discussion: How well does the quiescent operating point compare with the quiescent operating point calculated in the pre-lab? Why should it be different?)

4. With no $C_S$ ($C_S = 0$), apply a 10 KHz sine wave to the input with a value that does not push the MOSFET into cut-off or its triode region and observe the input and output signals on the scope simultaneously ($R_{\text{in}} = 0\,\Omega$ and $R_L = 1\,\Omega$). Record the waveforms. Indicate the phase between the input and output voltages? What is the small signal voltage gain. (Discussion: Compare with pre-lab values).

5. Measure the current gain of the amplifier. Use an appropriate resistor as a current sensor to measure the input current and the load resistor to measure the output current. What value of resistor did you use to measure the input current? (Discussion: Compare with pre-lab values).

6. Increase the peak value of the sine wave until the MOSFET goes into cut-off or the triode region. Explain how can you tell when the MOSFET has left the saturated region. Record the waveforms. (Discussion: Did the MOSFET enter the cutoff or the triode region of operation at the smallest input voltage? How can you tell? Why can’t you determine the small signal voltage gain and current gain of the amplifier when the amplifier has left the saturated region?)

7. Repeat 4, 5, and 6 with the $C_S$ you calculated in the pre-lab ($R_{\text{in}} = 0\,\Omega$ and $R_L = 1\,\Omega$).

8. Use the instrumentation set up of Fig. 3 to determine experimentally the input resistance of the MOSFET common emitter amplifier with the $C_S$ you calculated in the pre-lab. Record the voltage into the amplifier and the voltage proportional to the amplifier’s input current. What resistor value did you use to measure the amplifier’s input current? (Discussion: Compare the measured input resistance with your pre-lab calculated value. What is the phase relationship between the input voltage and the input current?)

9. Use the instrumentation set up of Fig. 4 to determine experimentally the output resistance of the MOSFET common emitter amplifier with the $C_S$ you calculated in the pre-lab. Record the output open circuit voltage and the voltage proportional to the output short circuit current. What resistor value did you use to measure the output short circuit current? Explain how you know that this nonzero resistor value is adequately small to short the output of the amplifier? (Discussion: Compare the measured output resistance with your calculated pre-lab value).