EE 462: Laboratory Assignment 6
Small Signal Models: The MOSFET Common Source Amplifier

by
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I. Instructional Objectives

- Estimate small-signal MOSFET model parameters from measurements
- Analyze circuit using the small-signal transistor model
- Measure and Analyze amplifier distortion with transfer characteristic

See 6.1, 7.3.3, and 7.4.3 in Horenstein

II. Background

The previous lab established the quiescent operating point of a common source amplifier employing an N-channel MOSFET. The common source amplifier is a general-purpose amplifier with good negative voltage gain, but poor high frequency characteristics. The N-channel MOSFET 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 modify 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 for the DC operation. The blocking capacitor prevents 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 do not significantly affect 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_d and r_{in} are the MOSFET's output resistance and input resistances, respectively.

Recall that in saturation region:

$$I_D = \frac{K_p}{2}\left(V_{GS} - V_{tr}\right)^2 \qquad (1)$$

The parameters for the small signal model are given by (take partial derivatives of Eq. (1)):

$$g_m = \hat{i}_D / \hat{v}_{GS} = \left.\frac{\partial I_D(V_{GS})}{\partial V_{GS}}\right|_{V_{GS}=V_{GSQ}} = 2K\left(V_{GSQ} - V_{tr}\right) = 2\sqrt{K \cdot I_{DQ}} \qquad (2)$$

where K is the notation used in Horenstein, or

$$g_m = \hat{i}_D / \hat{v}_{GS} = \left.\frac{\partial I_D(V_{GS})}{\partial V_{GS}}\right|_{V_{GS}=V_{GSQ}} = Kp\left(V_{GSQ} - V_{tr}\right) = \sqrt{2Kp \cdot I_{DQ}} \qquad (3)$$

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.

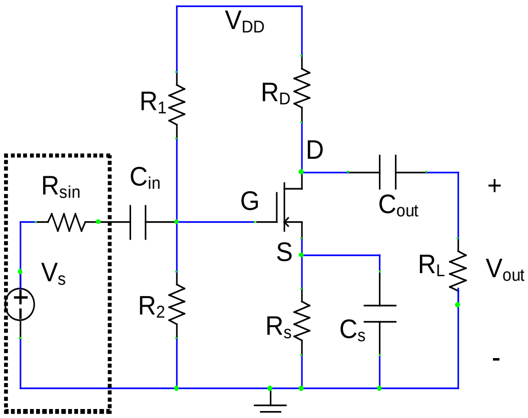

Fig. 1. N-channel MOSFET common source amplifier

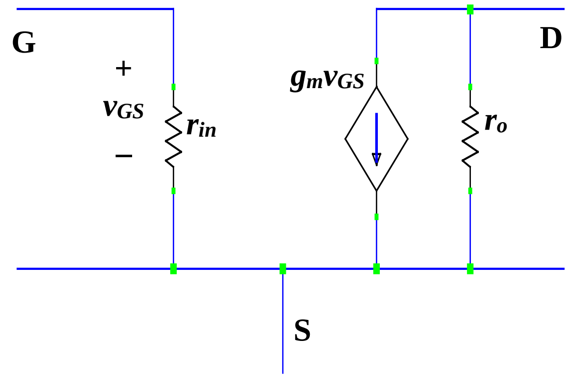

Fig. 2. Small-signal MOSFET model

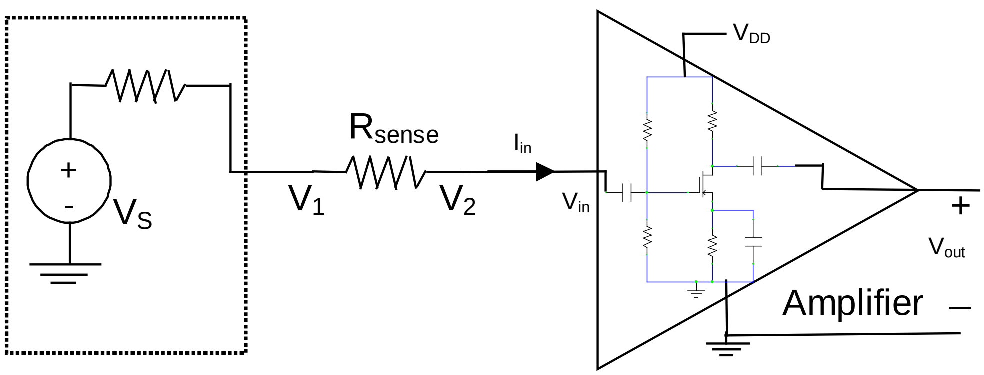

Fig. 3. Circuit for measuring R_{in}.

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

$$R_{in} \approx \frac{V_{in}}{I_{in}} \approx \frac{V_{inrms}}{I_{inrms}} \approx \frac{V_{inp}}{I_{inp}} \approx \frac{V_{inpp}}{I_{inpp}} \approx \frac{V_{2pp}}{\frac{(V_1 - V_2)_{pp}}{R_{sense}}} = \frac{V_{2pp} R_{sense}}{(V_1 - V_2)_{pp}} \quad (4)$$

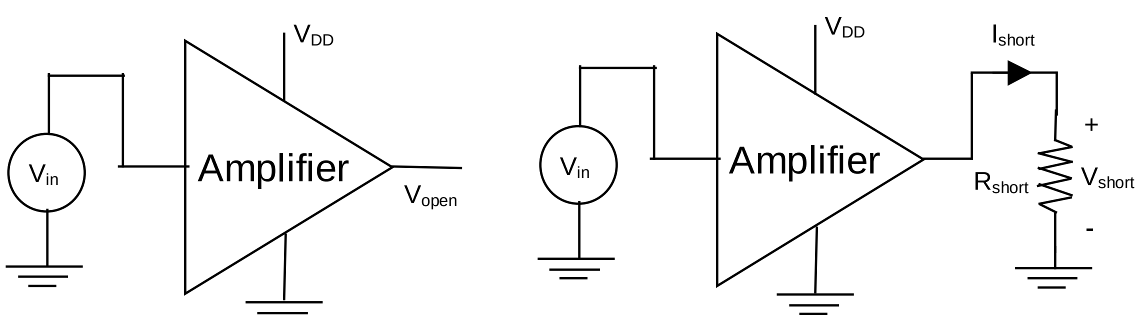

Fig. 4. Circuit for measuring R_{out}.

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

$$R_{out} = R_{th} \approx \frac{V_{open}}{I_{short}} \approx \frac{V_{openp}}{I_{shortp}} \approx \frac{V_{openrms}}{I_{shortrms}} \approx \frac{V_{openpp}}{I_{shortpp}} \approx \frac{V_{openpp}}{\frac{V_{shortpp}}{R_{short}}} = \frac{V_{openpp} R_{short}}{V_{shortpp}} \tag{5}$$

Note that V_{short} is not really a voltage over a short but the drop over a sensing resistor to measure current. Two separate tests are required to measure the input and output resistances. The sensing resistor (R_{short}) is used to make a current measurement that emulates a short circuit (through the DC blocking capacitor). If R_{short} is much smaller than the output resistance it should not affect the measurement significantly and Eq. (5) can be used directly. If R_{short} is significant with respect to R_{out}, then a relationship analogous to Eq. (5) should be derived to account for interaction between R_{out} and R_{short}, which results in:

$$Rout = \frac{(Vopen - Vshort)Rshort}{Vshort} \tag{6}$$

Note, if V_{short} is small with respect to V_{open} Eq. (6) reduces to Eq. (5).

III. Pre-Laboratory Exercise

For the pre-lab assignments assume r_d and r_{in} in the small signal model to be infinite. In addition, assume that R_{sin} = 50 Ω (internal source resistance), Let R_1 , R_2 , R_D , and R_s be what you used in your last lab where you biased the transistor amplifier. Let R_L = 1kΩ, and V_{DD} = 12 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.

DC Circuit Set Up

1. Verify that your design for the bias point operation from the last prelab by substituting in the resistor values you actually used in the last lab to bias your nmos amplifier. Compute the resulting V_{GS} and V_{GG} and plot the resulting loadline equation and actual TC curve for the V_{GS} value. Use Matlab to plot the loadline and critical TC curve to indicate the intersection point (V_{DSQ} and I_{DQ}).

AC Circuit Set Up

2. Draw the AC or incremental model of the circuit.
3. 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 (no capacitor shorting out the source resistor). For these calculations assume R_{sin} is zero and R_L is infinite. Repeat the voltage gain calculation with given values of R_{sin} (50 Ω) and R_L (1 kΩ). Comment on how input resistance from the source and output load resistance affect gain.
4. Determine a value of C_S in order to effectively short-out R_s. Assume a typically signal frequency of 2 kHz.
5. Determine the small signal voltage ($\hat{v}_{out} / \hat{v}_{in}$) and current ($\hat{i}_{out} / \hat{i}_{in}$) gains of the circuit assuming C_S is large enough to effectively short 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. Compare to results in Problem 4 and comment on how the source (feedback) resistor affects the gain.

Input and Output Impedances

6. From the AC model (with C_{s} in the circuit shorting-out R_s), determine the input resistance and the output resistance (Thévenin equivalent resistance with respect to the output terminals) of the amplifier circuit (R_{sin} and R_L are NOT considered part of the amplifier circuit).

7. Repeat Problem 6 without the capacitor C_{s} shorting out R_s . In other words include R_s in the AC model and compute the input and out resistances. Comment on how R_s effects the input and output resistances

8. 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 at the output terminal).

IV. Laboratory Exercise

1. **Verify DC circuit Parameters:** After constructing the circuit you had in the previous lab, measure the quiescent points to ensure they are correct (the same as last lab).
2. **Measure AC gain and saturation limits with feedback resistor:** For $C_S = 0$, apply a 2 kHz sine wave to the input with a value that does not push the MOSFET into cutoff or its triode region and observe the input and output signals on the scope simultaneously ($R_{sin} = 0\Omega$ and $R_L = 1k\Omega$). Record the waveforms. Indicate the phase between the input and output voltages and the small-signal voltage gain. (**Discussion: Compare with pre-lab values**). 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. Be sure to include the value of resistors used to measure the currents in the procedure descriptions. (**Discussion: Compare with pre-lab values**). Increase the peak value of the input sine wave until the MOSFET goes into cut-off or the triode region. Describe how you determined when the signal went into the MOSFETs cut-off or the triode region in the procedure section. Record the output waveforms before being pushed into the cut-off or triode region and also when it has left the saturation region of operation. (**Discussion: Explain why inaccurate gain measurements will result if the measurements were made when the amplifier output is saturated?**)
3. **Measure AC gain and saturation limits without feedback resistor:** Repeat Exercise 2 with the C_S in the circuit to effectively short-out R_s for the AC component. (**Discussion: Described the impact of the feedback resistor on the amplifier gain?**)
4. **Frequency Dependent Transfer Characteristics:** Fix the input frequency at 2000 Hz and sweep its amplitude from 0 to a value that pushes the amplifier into saturation (i.e. clipped or distorted sine wave outputs). As in the frequency sweep program you will need to create a text file; however this one will contain a sequence of amplitude values. Save the output to a file and write a Matlab program to plot the input amplitudes on the x-axis and output amplitudes on the y-axis to get the amplifiers transfer characteristics. Repeat this for 20 kHz and 100 kHz. (**Discussion: Indicate why the TC curve looks as it does and comment on the differences between input frequencies.**)
5. **Measure AC input resistance:** 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 at the amplifier input and the voltage proportional to the amplifier's input current (you will need these 2 waveforms to comment on the phase relationship between the input voltages and currents). Be sure to include the resistor value used to measure the amplifier's input current in the procedure description. (**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? What does that imply about the resistance/impedance?**)
6. **Measure AC output resistance:** 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? In the procedure section explain how you can be confident that this nonzero resistor value is adequately small for an accurate estimate of the output resistance. (**Discussion: Compare the measured output resistance with your calculated pre-lab value**).