6.002 – Circuits & Electronics
Fall 2007

Homework #6
Issued 10/16/2007 – Due 10/24/2007

Reading: Sections 7.6-7.7, and Sections 8.1-8.2. Review Section 4.5

Exercise 6.1: Consider the MOSFET amplifier shown in Figure 1. Assume that the MOSFET operates in its saturation region and its threshold voltage is $V_T = 0$.

a) Derive the relationship between the output voltage v_O and the input voltage v_I.
b) Derive the range of valid input voltages. Under the saturation discipline, valid input voltages are those that keep the amplifier operating in saturation region. Determine the corresponding range of output voltage v_O and output current i_D.
c) Suppose we have an AC input signal v_i, how would you choose the input DC bias V_I (operation point) for the amplifier so that it allows a maximum peak-to-peak voltage range for v_o? What is the corresponding output operating point (V_O and I_D)?
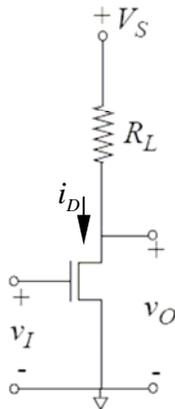
Figure 1: A common source MOSFET amplifier   Figure 2: Amplifier Dual power supplies layout
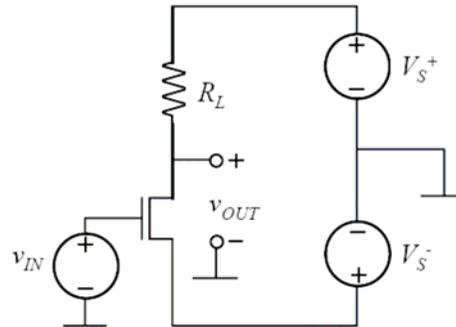
Exercise 6.2: Consider a two-terminal device formed by a MOSFET with its gate tied to its drain. The MOSFET is characterized by parameters V_T and K, and its drain-to-source voltage and drain current are denoted as v_R and i_R, respectively.

a) Write the v_R-i_R relation from this device operating under the saturation discipline.
b) Develop a small-signal model between v_r and i_r for this device about a dc operation point $v_R = V_R > V_T$. That is, determine di_R / dv_R evaluated at V_R.

Problem 6.1: In many amplifiers we use dual power supplies so we can obtain a 0V offset at the output, that is, the DC operating point at the output is 0V. An example is shown in Figure 2. For this problem, use $V_S^+ = +1.5V$, $V_S^- = -1.5V$, and MOSFET parameters $K = 1mA/V^2$ and $V_T = 0.5V$. Assume that MOSFET works in saturation region, then:

a) Find the value of R_L such that $v_{OUT} = 0V$ when $v_{IN} = 0V$.

b) As v_{IN} is increased, the output voltage v_{OUT} decreases. For the value of R_L found in part a), find the minimum output voltage v_{OUT} such that the MOSFET will obey the saturation discipline.

Problem 6.2: Consider the circuit illustrated in Figure 3. Assume that the MOSFET operates in its saturation region, and is characterized by the parameters V_T and K.

a) Draw the equivalent circuit by replacing the MOSFET by its equivalent SCS (switch-current source) model, i.e., a voltage controlled current source.

b) Determine the output operating point voltage V_O and operating point current I_D in terms of an input operating point voltage V_I.

c) Assuming an input bias point voltage V_I, draw the small-signal model. Determine the small-signal gain v_o/v_i.
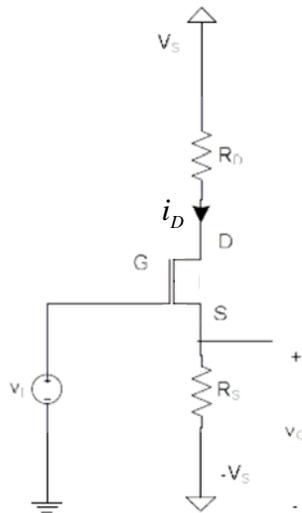
Figure 3. A common source MOSFET amplifier with source degeneration.

Problem 6.3: This problem uses WebLab to predict and then verify the input-output relation of the circuit shown below. The circuit can function either as a digital inverter or an analog amplifier. To study the circuit, this problem is divided into four parts. The first part uses WebLab to measure the MOSFET characteristics, that is, the relation between v_{DS} and i_D for various values of v_{GS}. The second part applies a load-line analysis to the measurements to

predict the input-output relation of the circuit. The third part uses WebLab to verify the predicted input-output relation through direct measurement. The fourth part compares the input-output relation predicted with the theoretical MOSFET model to that measured by WebLab over the cutoff and saturation ranges.
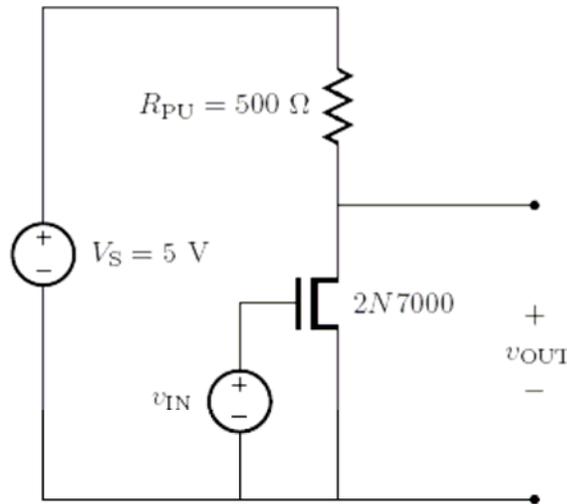
Figure 4: A NMOSFET inverter with pull up resistor.

a) Use the following procedure to measure and plot the MOSFET characteristics via WebLab. Feel free to modify the procedure as desired.

- Launch WebLab using the procedure given in Problem 1.4.
- Select Device 8 from the drop-down menu of devices.
- For all measurements, SMU2 should be grounded. To do so, select it and set MODE = COMM. Name the variables, but do not select them for downloading.
- To measure the MOSFET characteristics, SMU1 must be set to act as an open circuit. This can be done by programming it as a current source with zero current. To do so, select it and set: MODE = I; FUNCTION = CONS; VALUE = 0 A; and COMPLIANCE = 5 V. Name the variables, but do not select them for downloading.
- SMU4 must be set to sweep v_{DS} over an inner loop. To do so, select it and set: MODE = V; FUNCTION = VAR1; and COMPLIANCE = 100 mA. Set VAR1 to sweep from 0 V to 5 V in 200-mV steps. Finally, name both variables and select both for downloading. These variables are v_{DS} and i_D.
- SMU3 must be set to sweep v_{GS} over an outer loop. To do so, select it and set: MODE = V; FUNCTION = VAR2; and COMPLIANCE = 100 mA. Set VAR2 to sweep from 1.9 V to 2.5 V in 50-mV steps. Finally, name both variables, but do not select them for downloading.
- Run WebLab to measure the MOSFET characteristics.
- Plot the measured characteristics with v_{DS} on the horizontal axis over the range 0 V to 5 V, and i_D on the vertical axis over the range 0 mA to 10 mA. You can do so directly in WebLab, and then capture a screen shot for printing. Alternatively,

you can download the measurements, and then plot and print them using another program such as MatLab or Excel. Note that the measured data will not all fit within the specified graphing range.

b) On the graph produced in Part (a), plot the v_{DS}-i_D load line that is imposed by the 5-V power supply and the 500-Ω resistor in the circuit below. Using the intersections of the load line with the MOSFET characteristics, determine the values of $v_{OUT} = v_{DS}$ that correspond to the values of $v_{IN} = v_{GS}$. Make a table of the resulting input-output relation.

c) Use the following procedure to measure and plot the input-output relation of the circuit via WebLab. Feel free to modify the procedure as desired.
   - To measure the input-output relation, SMU1 must be set to the power supply voltage of 5 V. To do so, select it and set: MODE = V; FUNCTION = CONS; VALUE = 5 V; and COMPLIANCE = 100 mA.
   - SMU3 must be set to sweep $v_{IN} = v_{GS}$. To do so, select it, and set: MODE = V; FUNCTION = VAR1; and COMPLIANCE = 100 mA. Set VAR1 to sweep from 0 V to 5 V in 20-mV steps. Select the voltage for downloading. This variable is the circuit input.
   - SMU4 must be set to act as an open circuit while it measures the output v_{OUT}. To do so, select it and set MODE = I; FUNCTION = CONS; VALUE = 0 A; and COMPLIANCE = 5 V. Select the voltage for downloading. This variable is the output of the circuit.
   - SMU2 should remain grounded, as it was during the measurement of the MOSFET characteristics.
   - Run WebLab to measure the input-output relation of the circuit.
   - Plot the input-output relation of the circuit, with both variables ranging from 0 V to 5 V. You can do so directly in WebLab, and then capture a screen shot for printing. Alternatively, you can download the measurements, and then plot and print them using another program such as MatLab or Excel.

d) On the graph produced in Part (c), plot the input-output relation found in Part (b). The input-output relations found in Parts (b) and (c) should be identical.

e) Following Lectures 7 and 8, $v_{OUT} = V_S$ for $v_{IN} < V_T$ (Cutoff Operation) and $v_{OUT} = V_S - 0.5KR_{PU}(v_{IN} - V_T)^2$ for $V_T \leq v_{IN} < V_T + (\sqrt{1 + 2V_S KR_{PU}} - 1)/(KR_{PU})$ (Saturation Operation). By comparing these theoretical expressions to the input-output relation measured in Part (c), determine fitted values for K and V_T. Given these values, plot the theoretical input-output relation on the graph from Part (d) over the range of v_{IN} that corresponds to cut off and saturation operation.