MASSACHVSETTS INSTITVTE OF TECHNOLOGY
Department of Electrical Engineering and Computer Science

6.002 – Electronic Circuits
Fall 2001

Lab 1: Thevenin/Norton Equivalents & MOSFET Inverting Amplifiers

Introduction

The first part of the lab explores the characterization of a network by its Thevenin and Norton equivalents. The second part explores the static input-output relation of an inverting MOSFET amplifier. You should complete the pre-lab exercises in your lab notebook before coming to lab. Then, carry out the in-lab exercises between October 1 and October 5. After completing the in-lab exercises, have a TA check your work and sign your lab notebook. Finally, complete the post-lab exercises in your lab notebook, and turn in your lab notebook during recitation on Friday October 12.

Bring in your favorite CD for In-Lab Exercise 1-6; it is meant to be a fun experiment and its results will not be needed for the post-lab exercises.

Pre-Lab Exercises

Pre-Lab Exercises 1-1 and 1-2 explore the characterization of a network by its Thevenin and Norton equivalents. Pre-Lab Exercises 1-3 and 1-4 explore the static input-output relation of an inverting MOSFET amplifier.

(1-1) Determine the Thevenin and Norton equivalents of the network shown in Figure 1 as viewed at its port.

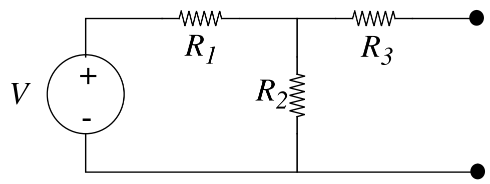

Figure 1: source-resistor network for Pre-Lab Exercises 1-1 and 1-2.

(1-2) Evaluate the Thevenin and Norton equivalents of the network for the following values: $V = 5$ V; $R_1 = 50\ \Omega$; $R_2 = 2.2\ \text{k}\Omega$; $R_3 = 1.5\ \text{k}\Omega$.

(1-3) Consider the inverting MOSFET amplifier shown in Figure 2. Write an expression for v_{O} as a function of v_{I} for $0 \leq v_{\text{I}} \leq v_{\text{O}} + V_{\text{T}}$. Also, sketch and clearly label the form of v_{O} as a function of v_{I} over the same range.

(1-4) Write an expression for the small-signal gain of the MOSFET amplifier shown in Figure 2 assuming that its MOSFET is biased into saturated operation.

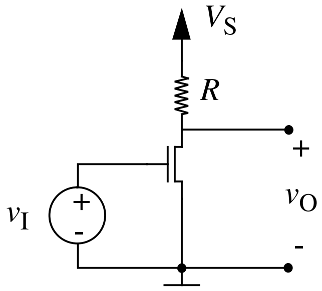

Figure 2: inverting MOSFET amplifier for Pre-Lab Exercises 1-3 and 1-4.

In-Lab Exercises

In-Lab Exercises 1-1 through 1-3 explore the characterization of a network by its Thevenin and Norton equivalents. In-Lab exercises 1-4 through 1-6 explore the input-output relation of an inverting MOSFET amplifier.

(1-1) Construct the network shown in Figure 3. However, before connecting the signal generator to the remainder of the network, set its output voltage to a constant 5 V, and check this output with the multimeter. Note that the network is the same as that shown in Figure 1, with the function generator serving as both the voltage source and resistor R_1.

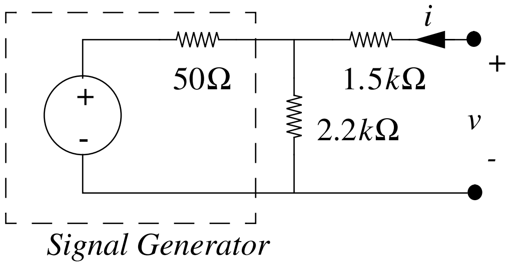

Figure 3: experimental source-resistor network.

(1-2) Measure the open-circuit voltage and short-circuit current of the network with the multimeter. Note that the multimeter is itself a near open circuit when used as a voltmeter, and a near short circuit when used as an ammeter. Therefore, the direct connection of the multimeter across the port implements the proper measurement in both cases. Your results from Pre-Lab Exercise 1-2 should show that both measurements are within the safe range for the multimeter.

(1-3) Connect a resistor across the port of the network and measure the port voltage v with the multimeter. Do so for resistors having resistances of 560 Ω, 1 kΩ and 2.2 kΩ.

(1-4) This exercise measures the static input-output relation of the MOSFET amplifier shown in Figure 2. To begin, construct the amplifier as shown in Figure 4, and connect the signal generator and oscilloscope as shown. Next, set the signal generator to produce a 1-kHz sine wave with a peak-to-peak amplitude of 3 V and an offset of 1.5 V. Thus, the signal generator will produce a biased sine wave between 0 V and 3 V. Set the oscilloscope to operate in its X-Y mode with an X-axis (Channel #1) sensitivity of 500 mV per division and a Y-axis (Channel #2) sensitivity of 1 V per division. You should now see the input-output relation

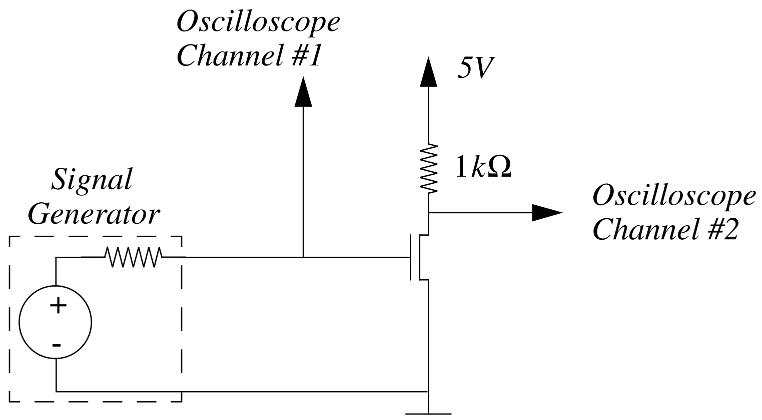

Figure 4: measuring the static input-output relation of the MOSFET amplifier shown in Figure 2.

displayed on the oscilloscope. Finally, compare the displayed relation to that sketched in Pre-Lab Exercise 1-3.

Record the following data. First, record the value of v_I above which v_O just begins to fall. This is the threshold voltage V_T of the MOSFET; see the sketch from Pre-Lab Exercise 1-3. Second, record the values of v_I which correspond to v_O values of 5 V, 4 V, 3 V, 2 V and 1 V. Alternatively, you may find it easier and much more accurate to use the signal generator as a programmable v_I source and measure v_O with a multimeter.

(1-5) This exercise measures the small-signal gain of the amplifier shown in Figure 2 when its output bias voltage is 2 V. To begin, construct Circuit #1 shown in Figure 5. Adjust the potentiometer until $v_O = 2$ V as measured by the multimeter. Next, connect the signal generator and the oscilloscope as shown in Circuit #2. Set the signal generator to zero and re-adjust the potentiometer so that $v_O = 2$ V. Then, set the signal generator to produce an unbiased 1-kHz sine wave with a peak-to-peak amplitude of 100 mV. Measure the amplitude of both v_i and v_o, which are the sinusoidal components of v_I and v_O, respectively; use AC coupling in Channel #1 of the oscilloscope to accurately measure v_i. The ratio of the amplitudes is the small-signal gain. Retain this circuit for the next exercise.

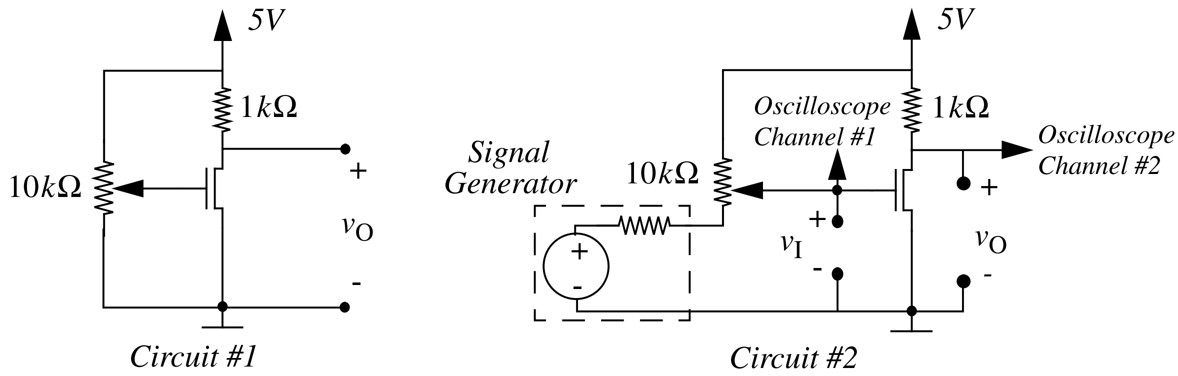

Figure 5: measuring the small-signal gain of the MOSFET amplifier.

(1-6) The experiments in this exercise will use Circuit #2 constructed in In-Lab Exercise 1-5 to explore the limits of saturation operation of the amplifier by observing clipping of an output waveform and by listening to distortion in music output. Start by adjusting the input bias with the potentiometer, and observing the variation in v_O. Now, increase the peak-to-peak amplitude of the sine wave input from the signal generator to 300 mV. Observing the output on Channel #2 of the oscilloscope, increase the input bias voltage until you see clipping on the bottom part of the output. Use DC coupling in Channel #1 of the oscilloscope to make a note of the upper excursion limit of the voltage v_I. Similarly, decrease the input bias voltage until you see clipping on the top part of the output, and make a note of the lower excursion limit of the voltage v_I. These upper and lower limits of v_I approximate the input operating limits of the amplifier.

Next, replace the signal generator with the CD player (use the headphones output). Set the CD player volume such that the peak-to-peak amplitude of the music signal v_i is approximately 300 mV. Connect the v_O signal to an amplifying speaker (leave the oscilloscope connection in place) and adjust the speaker volume to listen to the music. Vary the input bias voltage with the potentiometer and listen to the change in volume. Observing v_I on Channel #1 of the oscilloscope (using DC coupling), increase the input bias voltage till you begin to hear distortion. Is the upper excursion limit of the voltage v_I at the onset of distortion approximately the same as that measured with the sine wave input? Now, decrease the input bias voltage till you begin to hear distortion. Is the lower excursion limit of the voltage v_I at the onset of distortion approximately the same as that measured with the sine wave input?

Post-Lab Exercises

Post-Lab Exercises 1-1 through 1-3 explore the characterization of a network by its Thevenin and Norton equivalents. Post-Lab Exercises 1-4 and 1-5 explore the static input-output relation of an inverting MOSFET amplifier.

(1-1) Refer to your measurements from In-Lab Exercise 1-2; note that these measurements are the Thevenin equivalent voltage and Norton equivalent current of the network in Figure 3. From these measurements, compute the Thevenin/Norton equivalent resistance of the network. Compare the experimental Thevenin/Norton parameters to their corresponding values from Pre-Lab Exercise 1-2, and explain any discrepancies. Hint: consider measurement error and resistance variation.

(1-2) Refer to your measurements from In-Lab Exercise 1-3. For each combination of resistor and voltage measurement, calculate the corresponding port current i.

(1-3) Using the open-circuit voltage and short-circuit current measured during In-Lab Exercise 1-2, graph the i-v relation for the network. On this graph also plot the i-v data obtained by combining the voltages measured during In-Lab Exercise 1-3 and the currents calculated during Post-Lab Exercise 1-2. Explain any discrepancies between the measured i-v data and the i-v relation obtained from the Thevenin/Norton parameters.

(1-4) This exercise examines how well the MOSFET amplifier model developed during Pre-Lab Exercise 1-3 explains the input-output relation measured during In-Lab Exercise 1-4. The model contains four parameters which are required to numerically evaluate the input-output relation: V_S, R, V_T and K. From Figure 4, $V_S = 5$ V and $R = 1$ kΩ. Furthermore, V_T was measured during In-Lab Exercise 1-4. Thus, only K is unknown. Use the value of v_I

recorded for $v_{\mathrm{O}} = 1$ V to determine K. Then, use the numerical parameters and the model to graph v_{O} as a function of v_{I} for $1\ \mathrm{V} \leq v_{\mathrm{O}} \leq 5$ V. On this graph, also plot the data measured during In-Lab Exercise 1-4. How well does the model explain the data?

(1-5) From the data recorded during In-Lab Exercise 1-5, compute the small-signal gain of the amplifier for $v_{\mathrm{O}} = 2$ V. From the data recorded during In-Lab Exercise 1-4, again compute the small-signal gain by estimating the slope of the input-output relation at $v_{\mathrm{O}} = 2$ V. Finally, compute the small-signal gain from the analysis of Pre-Lab Exercise 1-4 using the parameters determined during Post-Lab Exercise 1-4. Do the three gains match well?