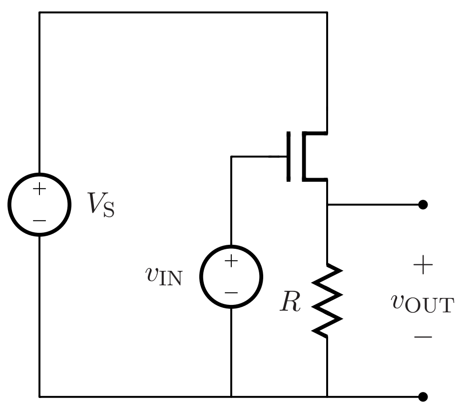
Massachusetts Institute of Technology
Department of Electrical Engineering and Computer Science

6.002 – Circuits & Electronics
Spring 2008

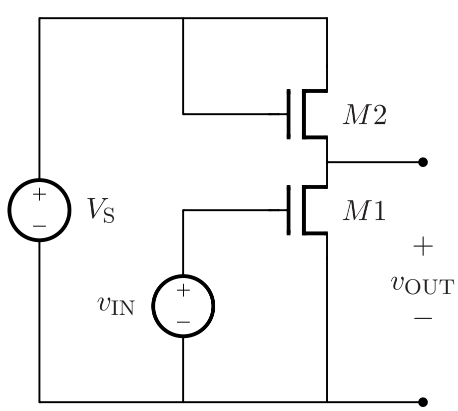
Problem Set #5

Issued 3/5/08 – Due 3/12/08

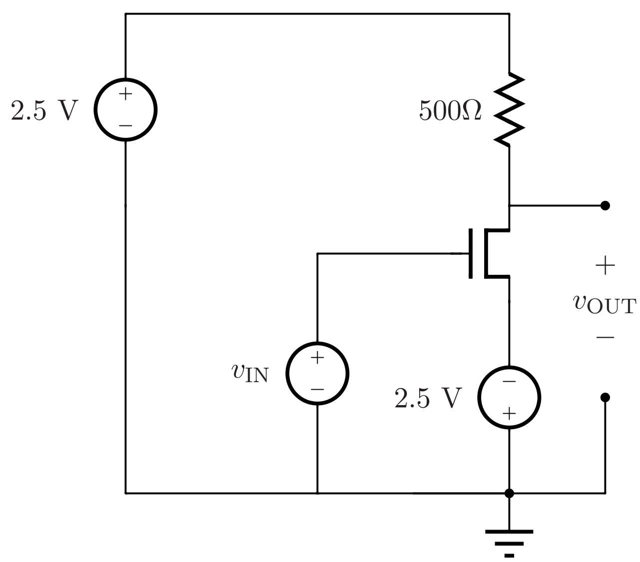
Exercise 5.1 (1 Point): This problem studies the MOSFET amplifier shown below. Assuming that the MOSFET operates in its saturation region, defined by $i_{\text{D}} = 0.5K(v_{\text{GS}} - V_{\text{T}})^2$ and $0 \leq v_{\text{GS}} - V_{\text{T}} \leq v_{\text{DS}}$, determine v_{OUT} as a function of v_{IN}. Also, determine the range of v_{IN}, and the corresponding range of v_{OUT}, over which the MOSFET operates in its saturation region.



Exercise 5.2 (1 Point): A more linear MOSFET amplifier can be constructed using two MOSFETs as shown below. Note that the parameters K_1 and K_2, and the threshold voltages V_{T1} and V_{T2}, of the two MOSFETs M1 and M2 are different. Assuming that both MOSFETs operate in their saturation regions, determine v_{OUT} as a function of v_{IN}. Also, determine the range of v_{IN} and the corresponding range of v_{OUT} over which both MOSFETs operate in their saturation region.



Problem 5.1 (2 Points): This problem makes use of the ELVIS iLab to study the small-signal characteristics of a common-source MOSFET-resistor amplifier. The amplifier is shown below. The transistor is the 2N7000 MOSFET that you have characterized in previous homework. Suitable parameters for this transistor are $K = 0.14$ A/V^2 and $V_T = 1.4$ V. The resistor has a nominal value of 500 Ω. Notice that in this amplifier, the top power supply is set to +2.5 V, and the bottom power supply is set to −2.5 V, both with respect to ground. This is to allow an optimum bias point at the output that is right around 0 V with respect to ground. In this problem, you will measure the transfer characteristics of the amplifier and the small-signal voltage gain, and compare the voltage gain to a prediction based on the models developed in class.



(A) The transfer characteristics of this amplifier can be obtained by sweeping the input voltage between −2.5 V and 2.5 V. To do so, apply a sine wave at the input with a frequency of 100 Hz, an amplitude of 2.5 V and an offset of 0 V. At the output, appropriately configure the oscilloscope to see at least one full period of the output signal with good resolution. To graph the transfer characteristics, graph v_{OUT} against v_{IN}. Print a screen shot of the canvas showing the transfer characteristics.

Using the *Tracking* feature in the bottom left corner of the client, read off the input bias voltage, V_{IN}, that results in an output bias voltage, V_{OUT}, that is close to 0 V. Give these values.

(B) Now, measure the small-signal gain at the bias point that you just determined. To do so, reduce the input amplitude to 100 mV, and apply the offset found in Part (A) such that the output is biased close to 0 V. When you do this, you will see that the instrument is not perfectly precise and that the input bias is a bit different from what you program. You will need to try different offset values until you get close enough. Once the output bias voltage is within about ±200 mV of 0 V, it is good enough. For this case, plot the waveforms of the input voltage and the output voltage versus time. Print a screen shot of this plot. Measure the amplitudes of both signals and determine the voltage gain.

(C) Next, obtain the input and output waveforms and extract the gain for other bias points. Bias the input 0.6 V below (more negative than) the bias point you selected for Part (B). Plot the input and output waveforms, print a screen shot of this plot, measure the amplitudes of both signals, and extract the voltage gain. Do the same for an input bias 0.3 V above (more positive than) the bias point you selected for Part (B). Plot and measure the same parameters. Comment on the change in voltage gain and the distortion that you observe in the output waveforms. Explain its origin in both cases.

(D) Finally, use an appropriate small-signal model to calculate the voltage gain of this amplifier for an input bias such that the biased output voltage is equal to 0 V. Use the parameters for the transistor given above. Compare what you obtain against the measurement results obtained in Part (B) above. Comment appropriately.

As always, start this problem early to avoid any last minute crunch on the system.

Problem 5.2 (2 Points): This problem continues to study the two-stage amplifier studied first in Problem 4.3. In this problem, let $v_{IN} = V_{IN} + v_{in}$ and $v_{OUT} = V_{OUT} + v_{out}$, where V_{IN} and V_{OUT} are the large-signal components of v_{IN} and v_{OUT}, respectively, and v_{in} and v_{out} are the small-signal components of v_{IN} and v_{OUT}, respectively.

(A) Assume that both MOSFETs are biased so that they operate in their saturation regions. Develop a small-signal circuit model for the amplifier that can be used to determine v_{out} as a function of v_{in}. In doing so, assume that V_{IN} defines the operating point around which the small-signal model is constructed, and evaluate all small-signal model parameters in terms of V_{IN} as necessary.

(B) Use the small-signal model to determine v_{out} as a function of v_{in}.

(C) Compare the small-signal voltage gain found in Part (B), defined as v_{out}/v_{in}, to that found in Part (F) of Problem 4.3. Explain any differences.

(D) Determine the small-signal Thevenin equivalent of the amplifier when it is viewed through its output port.

Problem 5.3 (2 Points): Consider again the amplifier described in Exercise 5.1. In this problem, let $v_{\rm IN} = V_{\rm IN} + v_{\rm in}$ and $v_{\rm OUT} = V_{\rm OUT} + v_{\rm out}$, where $V_{\rm IN}$ and $V_{\rm OUT}$ are the large-signal components of $v_{\rm IN}$ and $v_{\rm OUT}$, respectively, and $v_{\rm in}$ and $v_{\rm out}$ are the small-signal components of $v_{\rm IN}$ and $v_{\rm OUT}$, respectively.

(A) Using your result from Exercise 5.1, determine the small-signal voltage gain of the amplifier as a function of the input bias voltage $v_{\rm IN}$. That is, determine $v_{\rm out}/v_{\rm in} = dv_{\rm OUT}/dv_{\rm IN}$ evaluated at $V_{\rm IN}$.

(B) Again assume that the MOSFET is biased so that it operates in its saturation region. Develop a small-signal circuit model for the amplifier that can be used to determine $v_{\rm out}$ as a function of $v_{\rm in}$. In doing so, assume that $V_{\rm IN}$ defines the operating point around which the small-signal model is constructed, and evaluate all small-signal model parameters in terms of $V_{\rm IN}$ as necessary.

(C) Use the small-signal model to determine the small-signal voltage gain $v_{\rm out}/v_{\rm in}$. Compare this small-signal gain to that found in Part (A) and explain any differences.

(D) Determine the small-signal Thevenin equivalent of the amplifier when it is viewed through its output port.

Problem 5.4 (2 Points): Repeat Problem 5.3, for the amplifier shown in Exercise 5.2. Hint: note that for MOSFET M2, $v_{\rm GS} = v_{\rm DS}$ in this amplifier. Given this, does the small-signal model for MOSFET M2 simplify?