

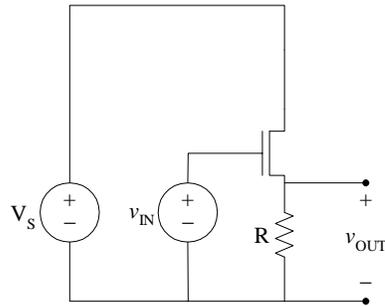
Massachusetts Institute of Technology  
Department of Electrical Engineering and Computer Science

6.002 – Circuits & Electronics  
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Problem Set #5

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**Exercise 5.1:** This problem studies the MOSFET amplifier shown below. A saturation-region model for the MOSFET is also given below. Assuming that the MOSFET operates in its saturation region, 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.

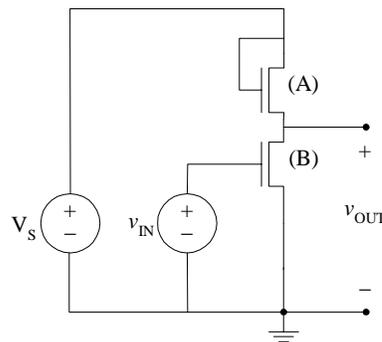


Saturation:

$$0 \leq (v_{GS} - V_T) \leq v_{DS}$$

$$i_D = K(v_{GS} - V_T)^2/2$$

**Exercise 5.2:** A “linear” MOSFET amplifier may be constructed using two MOSFETs as shown below. Note that the transconductances  $K_A$  and  $K_B$ , and the threshold voltages  $V_{TA}$  and  $V_{TB}$ , of the two MOSFETs 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.



Saturation:

$$0 \leq (v_{GSA} - V_{TA}) \leq v_{DSA}$$

$$i_{DA} = K_A(v_{GSA} - V_{TA})^2/2$$

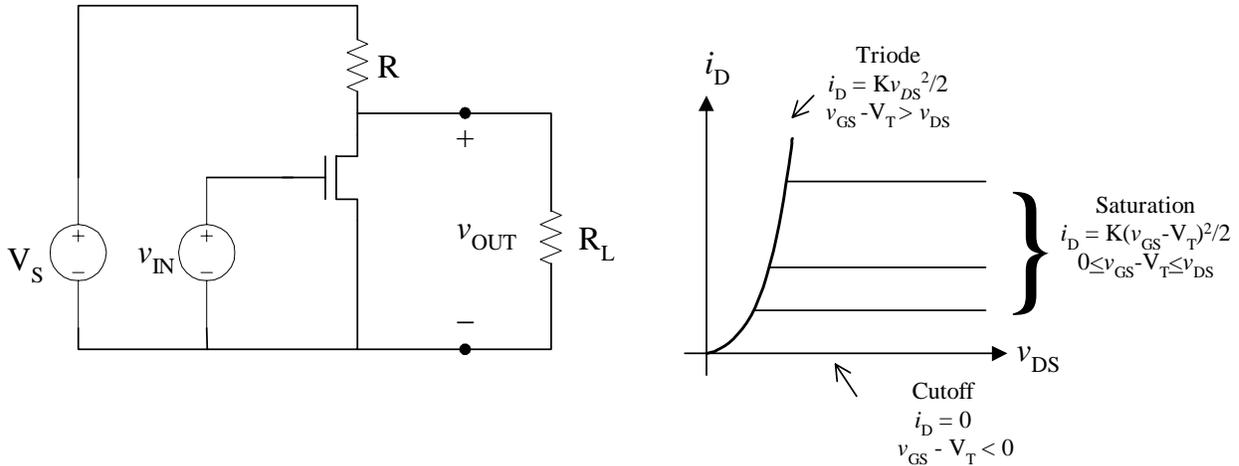
$$0 \leq (v_{GSB} - V_{TB}) \leq v_{DSB}$$

$$i_{DB} = K_B(v_{GSB} - V_{TB})^2/2$$

**Problem 5.1:** So far we have studied MOSFET amplifiers that have no load. That is, the current circulating through the output port of each amplifier was zero. For example, in Problem 4.3 the current out of the first amplifier and into the second amplifier was zero because  $i_G = 0$  for the second MOSFET. In this problem, which studies the amplifier shown below, the output current is no longer zero. The load below is a resistor that does draw current from the amplifier. Hint, in analyzing this amplifier, consider the use of both Thevenin equivalence and load line analysis to simplify the problem. Also, review your solution to Problem 4.3.

Once again, use a simplified model for the MOSFET as shown below. The simplification is again that the triode region of operation is compressed onto the curve  $i_D = K v_{DS}^2/2$ , which becomes a common curve of operation for  $v_{GS} - V_T > v_{DS}$ .

- (A) Determine the range of  $v_{IN}$  over which the MOSFET operates in cutoff. Also, determine  $v_{OUT}$  for this operating range.
- (B) Assuming that the MOSFET operates in its saturation region, determine  $v_{OUT}$  as a function of  $v_{IN}$ . Also, determine the range of  $v_{OUT}$  and the range of  $v_{IN}$  that correspond to the saturated operation of the MOSFET.
- (C) For values of  $v_{IN}$  that are above the range found in Part (B), the MOSFET operates in its triode region, which in the model below is compressed onto the curve  $i_D = K v_{DS}^2/2$ . Determine  $v_{OUT}$  for  $v_{IN}$  in this range of operation.



**Problem 5.2:** This problem continues to study the two-stage amplifier studied first in Problem 4.3. In this problem, let  $v_{\text{IN}} = V_{\text{IN}} + v_{\text{in}}$  and  $v_{\text{OUT}} = V_{\text{OUT}} + v_{\text{out}}$ , where  $V_{\text{IN}}$  and  $V_{\text{OUT}}$  are the large-signal components of  $v_{\text{IN}}$  and  $v_{\text{OUT}}$ , respectively, and  $v_{\text{in}}$  and  $v_{\text{out}}$  are the small-signal components of  $v_{\text{IN}}$  and  $v_{\text{OUT}}$ , 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  $v_{\text{out}}$  as a function of  $v_{\text{in}}$ . In doing so, assume that  $V_{\text{IN}}$  defines the operating point around which the small-signal model is constructed, and evaluate all small-signal model parameters in terms of  $V_{\text{IN}}$  as necessary.
- (B) Use the small-signal model to determine  $v_{\text{out}}$  as a function of  $v_{\text{in}}$ .
- (C) Compare the small-signal gain found in Part (B), defined as  $v_{\text{out}}/v_{\text{in}}$ , 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:** Consider again the amplifier described in Exercise 5.1. In this problem, let  $v_{\text{IN}} = V_{\text{IN}} + v_{\text{in}}$  and  $v_{\text{OUT}} = V_{\text{OUT}} + v_{\text{out}}$ , where  $V_{\text{IN}}$  and  $V_{\text{OUT}}$  are the large-signal components of  $v_{\text{IN}}$  and  $v_{\text{OUT}}$ , respectively, and  $v_{\text{in}}$  and  $v_{\text{out}}$  are the small-signal components of  $v_{\text{IN}}$  and  $v_{\text{OUT}}$ , respectively.

- (A) Using your result from Exercise 5.1, determine the small signal gain of the amplifier as a function of the input bias voltage  $v_{\text{IN}}$ . That is, determine  $v_{\text{out}}/v_{\text{in}} = dv_{\text{OUT}}/dv_{\text{IN}}$  evaluated at  $V_{\text{IN}}$ .
- (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  $v_{\text{out}}$  as a function of  $v_{\text{in}}$ . In doing so, assume that  $V_{\text{IN}}$  defines the operating point around which the small-signal model is constructed, and evaluate all small-signal model parameters in terms of  $V_{\text{IN}}$  as necessary.
- (C) Use the small-signal model to determine the small-signal gain  $v_{\text{out}}/v_{\text{in}}$ . 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.