MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Department of Electrical Engineering and Computer Science

6.012 ELECTRONIC DEVICES AND CIRCUITS

Problem Set No. 7

Issued: October 17, 2003 **Due:** October 24, 2003

Reading Assignments:

Lecture 14 (10/21/03) - Chap. 7 (7.4.2); Chap. 8 (8.2.2, 8.2.3); Chap. 10 (10.2.2, 10.2.3)
Lecture 15 (10/23/03) - Chap. 15 (15.1, 15.2)
Lecture 16 (10/28/03) - Chap. 15 (15.2.4)
Lecture 17 (10/30/03) - Chap. 11 (11.1, 11.2)
Lecture 18 (11/4/03) - Chap. 11 (11.3 to end)

Problem 1 - This problem deals with evaluating the parameters in the gradual channel model for the MOSFET.

(a) Do Problem 10.2 in the course text, but use $N_A = 1 \times 10^{16}$ cm^{-3}, rather than 10^{17} cm^{-3}. In Part c, calculate the α factor with $v_{BS} = 0$, before finding i_D.

(b) Calculate the MOSFET α factor for a device in which N_{Ap} is 5×10^{17} cm^{-3}, and the oxide thickness is 3 nm (3×10^{-7} cm). Take ε_{ox} to be 3.5×10^{-13} F/cm and ε_{Si} to be 10^{-12} F/cm. Do this for back-to-source biases, v_{BS}, of 0, -1, and -2 V.

Problem 2 - You want to be comfortable working with depletion-mode, as well as enhancement-mode, MOSFETs, and with p-, as well as n-, channel devices. These two problems give you some practice with this. Use $\alpha = 1$ in both problems.

(a) Do Problem 10.3 in the course text. This problem has a p-channel MOSFET.

(b) Look at Figure 11.12(c) on page 351 in the course text. The transistor in this circuit is an n-channel, depletion-mode MOSFET. Calculate and plot i_D for v_{AB} between 0 and 6 Volts using the device parameters given in the figure caption. (This is curve c in part e of this figure.)

Problem 3 - In Parts (a), (b), and (c) of this problem you will use an npn bipolar junction transistor for which the Ebers-Moll parameters are $I_{ES} = 10^{-13}$ A, $I_{CS} = 2 \times 10^{-13}$ A, $\alpha_F = 0.98$, and $\alpha_R = 0.49$. Put this transistor into the circuit in Figure P8.8(a) on Page 237 of the course text. Replace the 1.1 V source on the input of this circuit with a variable voltage source, v_{IN}.

(a) Calculate and plot the voltage at the collector of the transistor as a function of v_{IN}, the input voltage, for $0 \leq v_{IN} \leq 5$ V. This plot is called the transfer characteristic for this circuit (a simple inverter or common-emitter amplifier stage).

Do not attempt to use the Ebers-Moll model, but instead use the forward active region beta model and replace the exponential diode with a piecewise linear model having a breakpoint at 0.6 V. Assume also that the minimum collector-to-emitter voltage is 0.2 V (when the BJT is saturated).

(b) With v_{IN} = 1.0 V, what would the Ebers-Moll model predict for the base-emitter voltage of the npn transistor, and what is the voltage on the collector? (Use the forward active region beta model, but unlike what was the case in Part (a), you should leave the exponential diode in the model. You will find that you have to iterate to get a solution; get an answer accurate to ten millivolts, or so.)

(c) Repeat Part (b) with v_{IN} = 2.0 V.

(d) Repeat Part (a) with the BJT in the circuit replaced with an n-channel, enhancement-mode MOSFET having a threshold voltage of 1 V, and a K-factor of 0.5 mA / V^2. Use the simple gradual channel MOSFET model derived in lecture; use $\alpha = 1$.

Problem 4 - Use weblab to do this problem. You will be looking at transistors which are easier to damage than the diode you looked at earlier so again be careful.

(a) Use the npn bipolar transistor and prepare (and submit with your solution) plots of the input and output families of characteristics as requested below. Caution: Do not let i_B exceed 40 µA or v_{CE} exceed 4 V.

(i) On linear scales, plot i_B vs v_{BE} with v_{CE} as a parameter, and plot i_C vs v_{CE} with i_B as a parameter. In both cases restrict your range to v_{BE} 0 and v_{CE} 0.

(ii) In a semilog plot present log i_B and log i_C vs v_{BE}. This is called a Gummel Plot; from it you should be able to find I_{BS} and also β_F as a function of i_C. Do this and on your solution give I_{BS} and state over what range of collector currents this transistor is most useful, i.e., has high current gain.

(b) Use the n-channel MOSFET and look at its charac-teristics in two ways. Again prepare and submit the plots requested, and give the requested parameter values. Caution: Do not let v_{GS} exceed 3 V or v_{DS} exceed 4 V.

(i) On linear scales, plot i_D vs v_{DS} with v_{GS} as a parameter and with $v_{BS} = 0$.

(ii) Plot i_D vs v_{GS}, with v_{DS} as a parameter. Use this plot to find the K-factor and the threshold voltage of this device with $v_{BS} = 0$.

Note: The dimensions and current operating levels of these two devices are quite different so the current scales on your plots will be different for the two devices.

Problem 5 - Do Problem 8.13 in the course text.