

YOUR NAME _____

*Department of Electrical Engineering and Computer Science
Massachusetts Institute of Technology*

6.012 Electronic Devices and Circuits

Exam No. 2

Notes:

1. The parts of this exam are largely independent of each other. Thus, if you can not work one part, you should go on to the next one, and keep working through the exam, coming back to any parts you skipped at the end.
2. Unless otherwise indicated, assume room temperature and that kT/q is 0.025 V. You may also approximate $[(kT/q) \ln 10]$ as 0.06 V.
3. Open book; 6.012 text and any other notes permitted.
4. All of your answers and any relevant work must appear on these pages. Any additional paper you hand in will not be graded.
5. Make reasonable approximations and assumptions. State and justify any such assumptions and approximations you do make.
6. Be careful to include the correct units with your answers when appropriate.
7. Be certain that you have all eight (8) pages of this exam booklet and make certain that you write your name at the top of this page in the space provided.

6.012 Staff Use Only	PROBLEM 1 _____
	PROBLEM 2 _____
	PROBLEM 3 _____
	TOTAL

Problem 1 (30points)

The questions of this problem require that you give some of your answers as written statements. Keep your answers brief and to the point (twenty-five words or less should suffice).

- (a) You have a bipolar junction transistor with a forward current gain, β_F , of 200 which you want to bias so that it is in its forward active region and has an incremental input resistance, r_i , of 5,000 Ohms. At what level should you set the quiescent collector current, and why?

$$I_C = \text{_____} \text{ A, because}$$

- (b) Explain why having a large reverse beta, β_R , in a Si bipolar junction transistor is, or is not, consistent with having a large Early voltage (that is, a small base width modulation effect).

Is consistent, Is not consistent, _____ because:

- (c) Why is it easier to get small base and emitter defects in an npn bipolar junction transistor (BJT) than it is in a pnp BJT?

- (d) An n-channel Si MOSFET and a p-channel Si MOSFET have identical dimensions and doping levels and each is biased to have a drain current 1 mA in magnitude.. Which device, if any, has the larger small signal transconductance, g_m , at this bias point, and why?

n-channel, p-channel, _____ because:

Problem 1 continues on the next page

1 continued

(e) Where do (most of) the carriers in the inversion layer (channel) of an MOS field effect transistor (MOSFET) come from when its gate voltage is suddenly increased from a value which is below threshold, to one which is above threshold?

(f) Suppose that you desperately need to have a bipolar junction transistor and all that you have available is an n-channel, depletion-mode MOSFET.

(i) Which terminal (source, gate, drain, or substrate) would you select to be the emitter, which to be the base, and which to be the collector:

Emitter: _____

Base: _____

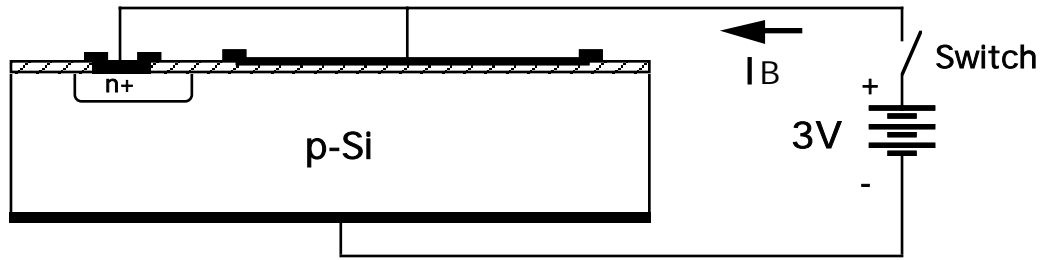
Collector: _____

(ii) Discuss briefly how good a transistor this MOSFET will make, pointing out at least one way it is similar to, or differs from, a well designed BJT.

End of Problem 1

Problem 2 (30 points)

Consider the MOS capacitor and p-n junction diode combination illustrated below. The two devices are separated sufficiently that their depletion regions do not interact. The MOS capacitor has an oxide capacitance, C_{ox} , of 0.2 pF; a flat-band voltage, V_{FB} , of - 0.5 V; and a threshold voltage, V_T , of 1.0 V. The reverse saturation current of the diode, I_S , is 10^{-9} A. The area of the MOS capacitor is 5 times as large as the area of the p-n junction. The battery is an ideal 3 V voltage source, and the switch is either open or closed, as specified in the questions.



(a) The switch has been open for a long time, and the diode and MOS capacitor are at thermal equilibrium. What is the condition of the oxide-semiconductor interface? Explain your answer.

Accumulated Depleted Inverted, because

(b) The switch is now closed and the system is allowed to come to a steady state. What values will the following quantities have?

(i) The current from the battery, I_B .

$I_B = \underline{\hspace{2cm}}$ Amps

(ii) The total inversion layer charge in the MOS capacitor, Q_N .

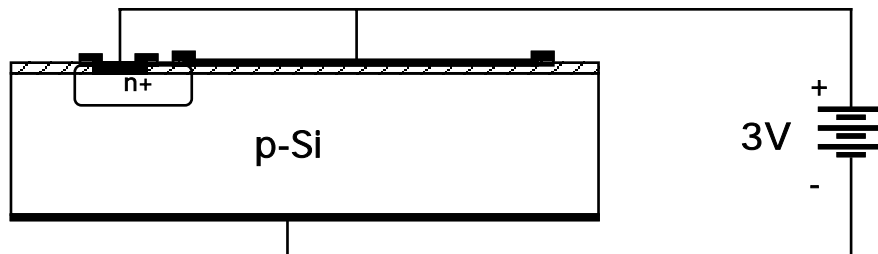
$Q_N = \underline{\hspace{2cm}}$ Coul

Problem 2 continues on the next page

Problem 2 continued

Now consider the situation where the devices are not separated but rather are interacting as they are in a MOSFET.

- (c) Suppose first that the p-n diode and MOS capacitor are both biased to 3 V, as they were before and as illustrated below.

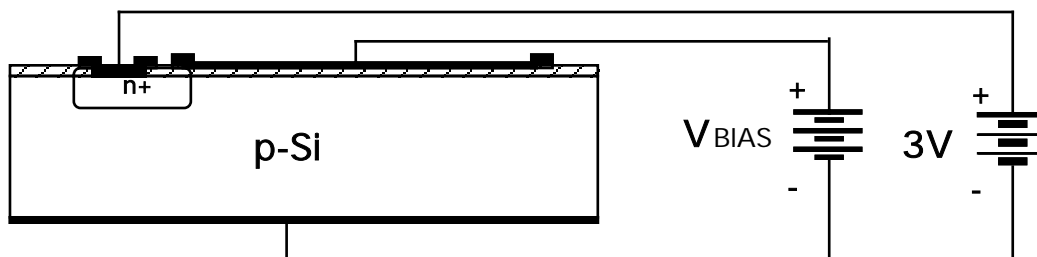


Is there now an inversion layer under the MOS capacitor? If you answer "yes", calculate Q_N in this situation; if you answer "no", explain why Q_N is zero.

Yes, and $Q_N =$ _____ Coul.

No, $Q_N = 0$ because:

- (d) Suppose now that the p-n diode is reverse biased to 3 V, and the MOS capacitor is biased separately, as illustrated below.



- (i) If the MOS capacitor is biased in accumulation, what is I_B ?

$I_B =$ _____ Amps, because

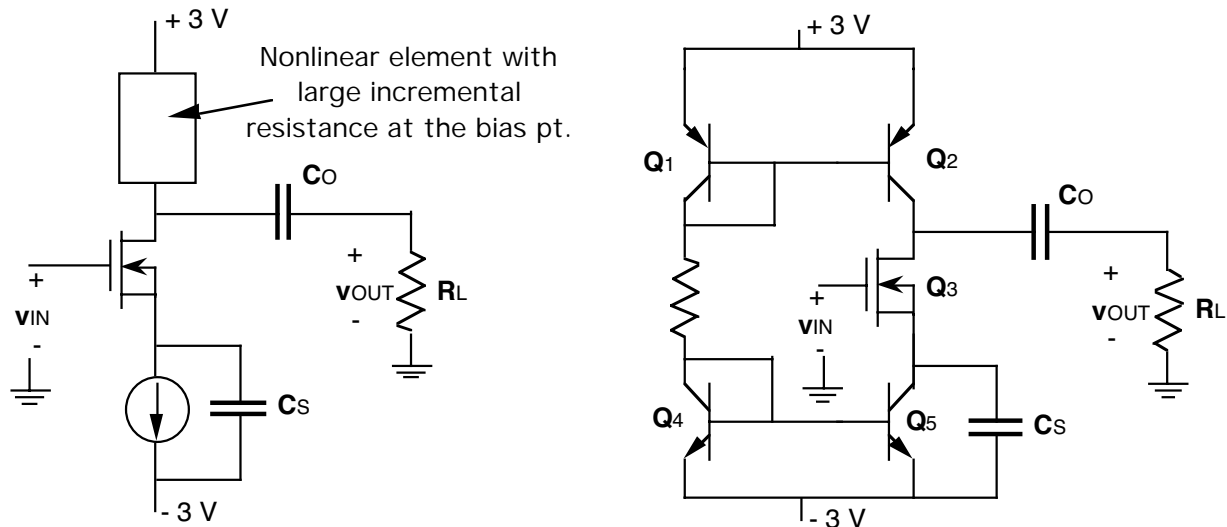
- (ii) If the MOS capacitor is biased in inversion, what is I_B ?

$I_B =$ _____ Amps, because

End of Problem 2

Problem 3 (40 points)

This question concerns the common source amplifier stage illustrated two different ways below. The schematic on the left omits the details of the current source used to bias the stage and the non-linear element (another current source) used as the collector load. The circuit schematic on the right presents the full circuit.



In this circuit, Q_1 and Q_2 are identical pnp BJTs with $\beta_F = 50$, $|V_A| = 20\text{ V}$, and $I_{ES} = 10^{-13}\text{ A}$; Q_3 is an n-channel MOSFET with $K = 0.5\text{ mA/V}^2$, $V_T = 0.5\text{ V}$, and $|V_A| = 10\text{ V}$; and Q_4 and Q_5 are identical npn BJTs with $\beta_F = 150$, $|V_A| = 50\text{ V}$, and $I_{ES} = 10^{-13}\text{ A}$. The BJTs are in saturation when the base-collector junction is forward biased 0.4 V , or more (i.e., when V_{CE} is less than 0.2 V for an npn, or greater than -0.2 V for a pnp); and $|V_{BE}| = 0.6\text{ V}$ when the BJTs are in their forward active regions.

- (a) What is the quiescent value of the gate-to-source voltage, V_{GS} , on the MOSFET, Q_3 ? Notice from the circuit on the left that the quiescent drain current in Q_3 is 1 mA .

$$V_{GS} = \underline{\hspace{2cm}} \text{ V}$$

- (b) What is the approximate value of R (in the right-hand representation)? Notice that the quiescent drain current in Q_3 is 1 mA . You may neglect the BJT base currents for purposes of this calculation.

$$R = \underline{\hspace{2cm}} \text{ Ohms}$$

Problem 3 continues on the next page

Problem 3 continued

- (c) The input signal, v_{IN} , has a DC level, V_{IN} , and a signal component, v_{in} . If V_{IN} is too positive, the circuit will not function properly; the same is true if V_{IN} is too negative. [Note: If you were not able to answer Part (b) and find you need that result to get a numerical answer for this question, leave your answers in terms of V_{GS} .]
- (i) What is the positive bound on V_{IN} , and what happens if V_{IN} exceeds this value?

$$V_{INmax} = \text{_____} \text{ V, because}$$

- (ii) What is the negative bound on V_{IN} , and what happens if V_{IN} is below this value?

$$V_{INmin} = \text{_____} \text{ V, because}$$

- (d) What is the quiescent (DC) power dissipation in this circuit?

$$P = \text{_____} \text{ Watts}$$

Problem 3 continues on the next page.

Problem 3 continued

(e) This part of the problem concerns the small signal behavior of this amplifier.

(i) In the space provided below, draw a small signal linear equivalent circuit for this circuit valid for operation in the mid-band frequency range. Indicate on your sketch the values of all of the elements in your circuit.

(ii) What is the small-signal, mid-band voltage gain, $A_v (= v_{out}/v_{in})$, of this circuit? Notice that the load resistor, R_L , is 10^5 Ohms.

$$A_v = \underline{\hspace{2cm}}$$

(iii) Is it possible to increase the voltage gain, A_v , by changing the bias current? If yes, indicate whether I_{BIAS} should be increased or decreased? If no, explain why not.

Yes, by increasing the bias current decreasing the bias current

because

No, because

End of Problem 3

End of Exam