EECS 40 Midterm Exam II

Fall 2004

Print Name (Last,First) _______________________________________________

Sign Name_________________________________________________________

Do not begin exam until you are instructed to start.
Note that there are several versions of this exam in the room.
To get credit for a problem, make your method clear to the grader.

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Problem 1 (24 points)  General Questions
a. [1] Give a concise definition of the properties of an acceptor atom that could be used in a silicon wafer and explain what it does.

b. [1] What is the power of 50 watts in decibels referred to a reference power of 1mW (this is often referred to as dBm)?

c. [1] Identify clearly the meaning of the acronym \textit{rms}.

d. [1] What component can you use to couple a time-varying signal to an amplifier yet keep steady currents from flowing into the amplifier? ________________

e. [1] List two components that can form a circuit that acts as a frequency filter. ____________ and ____________.

f. [1] Draw a simple analog circuit that employs negative feedback (make clear where the feedback appears).

g. [5] List in the table below different devices that are essentially just semiconductor diodes, and indicate their functions:

<table>
<thead>
<tr>
<th>Table 1: Diodes</th>
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<tr>
<td><strong>Name of diode Device</strong></td>
<td><strong>Function of diode device (give distinguishing functions, being as specific as you can)</strong></td>
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Problem 1 (continued)

h. [6] FET structure. On the cross-sectional transistor view of a silicon n-channel transistor shown below, mark the p-type regions with a 1, the n-type regions with a 2, metallic or heavily conducting regions with a 3, insulating regions with a 4, regions containing dopants predominantly from Group III of the periodic table with a III, and dopants predominantly from Group V of the periodic table with a V. (If more than one label applies to a particular region use each one that applies.) Also please indicate and name on the diagram the four terminals of the device.

![FET structure diagram]

i. [7] Small-signal resistance of a pn diode

One can apply the small-signal approach to pn diodes to represent how they will behave in response to a small variation of their bias current. To see this, first

a. [3] Write the “exponential diode equation” (called the Shockley equation by your text) for the diode current, \( i_D \), as a function of the diode voltage, \( v_D \): (Note: \( q_e = 1.6 \times 10^{-19} \) C, \( k = 1.38 \times 10^{-23} \) JK\(^{-1}\).)

b. [4] Find the small-signal resistance of this diode at room temperature when the diode current is 1 mA. (Assume that the diode ideality factor or “emission factor” \( n = 1 \).) The small-signal resistance \( r \) is defined as \( r = 1/(di_D/dv_D) \). (Hint: Since the saturation current is much smaller than 1 mA, you can approximate \( i_D \) with just \( I_S \) times the exponential term.)
Problem 2 (16 points)  First-Order Transient

In the circuit below, let $v_A(t) = -1$ V for $t<0$ and $v_A(t) = 1$ V for $t>0$. $R_1 = 2000$ Ω, $R_2 = 3000$ Ω, and $C = 10$ µF.

a. [2]  Find $v_C(t = 0-)$. 

b. [2]  Find $v_C(t = 0+)$. 

c. [2]  Find the current $i_1$ at $t = 0-$. 

d. [2]  Find $i_1(t = 0+)$. 

(continued on next page)
e. [4] Find the time constant for this circuit.

d. [4] Find an expression for $v_C(t)$ for $t > 0$, and sketch it below.
Problem 3 (15 points)  Op-Amps

a.  [7] The op-amp in the circuit below is ideal except that it has a finite gain $A$. If the measured voltages indicated are found to be $v_{in} = 4.000 \, \text{V}$ and $v_{out} = 5.000 \, \text{V}$, with $R_1 = 1 \, \text{M}\Omega$ and $R_2 = 3 \, \text{k}\Omega$, what is the value of $A$?

![Circuit diagram](image)

b.  [8] For the (ideal) op-amp circuit below find $I$, $v_x/v_{in}$ and $v_{out}/v_{in}$. $R_1 = 6 \, \text{k}\Omega$, $R_2 = 6 \, \text{k}\Omega$, $R_3 = 5 \, \text{k}\Omega$, $R_4 = 3 \, \text{k}\Omega$. Assume that $v_{in} = 6 \, \text{mV}$.

![Circuit diagram](image)
Problem 4 (22 points)  Diodes

Each of the diodes in the following circuits is ideal.

a. [6] Find I and V for this circuit (R = 8 kΩ, V+ = +4 V, V- = -3 V)

b. [8] Find I and V for this circuit (R = 3 kΩ, V1 = +1 V, V2 = +3 V, V3 = -3 V) and indicate which diodes are conducting and which are not conducting.

c. [8] The voltage v_in in the circuit below is a 1 kHz, 10 V peak-to-peak sine wave. I = 2 mA, V2 = +10 V, R = 1 kΩ. Sketch the waveform resulting at v_out and indicate the values of the positive and negative peaks.
Problem 5 (23 points)  MOSFET

A set of MOSFET characteristics is shown below. Assume that $V_T = 0.5 \, \text{V}$.

![Graph of MOSFET characteristics with $V_{GS}$ values of 2.5 V, 2.0 V, 1.5 V, and 1.0 V.]

a. [3] Indicate and label the three regions of MOSFET operation:

b. [6] Write equations for $I_D (V_{DS}, V_{GS})$ for each of the three regions and the conditions under which they apply. (Express your equations in unambiguous variables: $\mu$, $C_{ox}$, W, L, ...).

Region: _________ Equation:

Region: _________ Equation:

Region: _________ Equation:

The MOSFET is put in the circuit shown below ($V_B = 1.5 \, \text{V}$, $R = 12.5 \, \text{k}\Omega$, $V_{DD} = 2.5 \, \text{V}$).
c. [2] Identify the terminals of the MOSFET.

d. [4] Draw the load line on the plot and find the Q point \((I_{DQ}, V_{DSQ})\).
\[
I_{DQ} = \underline{\hspace{2cm}} \text{A} \quad V_{DSQ} = \underline{\hspace{2cm}} \text{V}
\]

e. [4] Assume that you are considering using this circuit as an analog amplifier and are worried about distortion of the signals. For a positive excursion of \(v_{in}\) of 0.5 V how much does \(v_{out}\) change (positive or negative)? For a negative excursion of \(v_{in}\) of -0.5 V how much does \(v_{out}\) change (positive or negative)?

\[
v_{out} \text{ for positive excursion of } v_{in}: \underline{\hspace{1cm}} \text{V} \\
v_{out} \text{ for negative excursion of } v_{in}: \underline{\hspace{1cm}} \text{V}
\]
g. [4] Draw a simple two-component circuit that represents this MOSFET under the following two extreme conditions:

$V_{GS} - V_T > 0$, $V_{DS} < V_{GS} - V_T$:

```
O---
|   |
| D |
|   |      O---
     |   |
     | S |
```

$V_{GS} - V_T < 0$:

```
O---
|   |
| D |
|   |
     S
```