EECS 40, Fall 2006  
Prof. Chang-Hasnain  
Midterm #3  

November 29, 2006  
Total Time Allotted: 50 minutes  
Total Points: 100 pts  

1. This is a closed book exam. However, you are allowed to bring one page (8.5" x 11"), single-sided notes PLUS your 1-page notes from midterm 1 and 2.  
2. No electronic devices, i.e. calculators, cell phones, computers, etc.  
3. Slide rules are allowed.  
4. SHOW all the steps on the exam. **Answers without steps will be given only a small percentage of credits.** Partial credits will be given if you have proper steps but no final answers.  
5. **Remember to put down units.** Points will be taken off for answers without units.  

Last (Family) Name:_____________________________________________________  

First Name:_____________________________________________________________  

Student ID:___________________________Discussion Session:_________________

Signature:________________________________________________________________

<table>
<thead>
<tr>
<th>Score:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Problem 1 (30 pts)</td>
<td></td>
</tr>
<tr>
<td>Op Amp Circuit</td>
<td></td>
</tr>
<tr>
<td>Problem 2 (40 pts):</td>
<td></td>
</tr>
<tr>
<td>Diode Circuit</td>
<td></td>
</tr>
<tr>
<td>Problem 3 (30 pts):</td>
<td></td>
</tr>
<tr>
<td>Semiconductor Physics</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
</tr>
</tbody>
</table>
   a) [8 pts] Find $V_1$ in terms of $V_{in}$ and $I_{in}$.

   By the summing point constraint:
   $V_c = V_+ = V_{in}$
   By Ohm’s Law:
   $V_1 = V_{in} - I_{in}(0.5\Omega)$

   b) [12 pts] Find $V_0$ in terms of $V_{in1}$, $V_{in2}$, and $\omega$. Use complex impedances. Assume $V_{in1}$ and $V_{in2}$ are AC signals.

   Since no current flows into the (+) terminal:
   $V_+ = V_{in2}$
   By the summing point constraint:
   $V_c = V_{in2}$
   By KCL:
   $V_0 = V_{in2} - \frac{Z_C}{Z_L}(V_{in1} - V_{in2})$, $Z_C = \frac{1}{j\omega 0.5 \mu F}$, $Z_L = j\omega 5nH$

   
   $V_0 = V_{in2} + \frac{1}{\omega^2(0.5 \mu F)(5nH)}(V_{in1} - V_{in2})$
c) [10 pts] Find $V_o$ in terms of $V_{in}$.

Since no current flows into the $(+,1)$ terminal:

$V_{+,1} = V_{in}$

By the summing point constraint:

$V_{-,1} = V_{in}$

Since no current flows into the $(-,1)$ terminal:

$V_{-,2} = 2(V_{-,1})$ by voltage divider across 2 resistors

Since no current flows into the $(-,2)$ terminal:

$V_{-,2} = V_o[5kΩ/(5kΩ+20kΩ)]$

$V_o = 5V_{-,2} = 5(2V_{-,1}) = 10V_{in}$
2. [40 points] Diode Circuit:
Given the following circuit and input. Assume C1 >> C2. Use the Ideal Diode model:

If \( V_D < 0 \), then the diode is OFF and does not pass current (\( I_D = 0 \))
If \( I_D \geq 0 \), then the diode is ON and \( V_D = 0 \)

\( V_D \) is the voltage drop across the diode and \( I_D \) is current through the diode.

\[
V_{in}(t) = -V_m \sin(2\pi t/T) \text{ for } t > 0,
\]
and
\[
V_{C1}(t=0^+) = V_{C2}(t=0^+) = 0.
\]

(a) (20 pts) For the time period \( 0 \leq t \leq \frac{T}{4} \)

Is Diode 1 on or off? On, \( V_{in} \) is -, so Diode 1 is turned on, charging \( C_1 \)

\( V_{D1} =? \quad 0V \text{ (on, Ideal)} \)

\( V_{C1} =? \quad V_{in} \), Diode 1 on grounds the node above the diode, \( (V_{C1} = V_{in} - 0) \)

\( I_{D1} =? \quad C_1 \frac{2\pi}{T} V_m \cos\left(\frac{2\pi t}{T}\right), \text{ \( I_{D1}\) enters negative reference of \( C1 \), \( I_{D1} = -C_1 \frac{dV_{C1}}{dt}\) } \)

If this was done in the frequency domain, \( I = -\frac{V_{in}}{j\omega C_1} \)

Is Diode 2 on or off? On, node between diodes is ground (0V), \( V_{C2} \) is 0V above the ground

\( V_{D2} =? \quad 0V \text{ (on, Ideal)} \)

\( V_{C2} =? \quad 0V \text{ (ground on both sides of } C2) \)
(b) (20 pts) For the period \( \frac{T}{4} \leq t \leq \frac{3T}{4} \)

Is Diode 1 on or off? Off, Voltage begins decreasing on + reference of diode. (At \( t = T/4 \), treat \( V_{C1}+ \) node as ground, Voltage on both sides of diode is +\( V_m \). This magnitude begins decreasing, shutting off diode, since \( V_D^+ < V_D^- \))

\[ V_{D1} =? -V_{in} + V_{c1}, \text{KVL requires } V_{in} - V_{c1} + V_{d1} = 0 \]

\[ V_{C1} =? -V_m, \text{ (If you assume that } C_1 \gg C_2, \text{ the same current through both will charge } C_2 \text{ without significantly discharging } C_1) \]

\[ I_{D1} =? 0A, \text{ Diode off} \]

Is Diode 2 on or off? on

\[ V_{D2} =? 0V \text{ (on, Ideal)} \]

\[ V_{C2} =? V_{in} + V_m \text{ (KVL: } V_{in} - V_{c1} - V_{d2} - V_{c2} = 0) \]

\[ I_{D2} =? -C_2 \frac{2\pi}{T} V_m \cos\left(\frac{2\pi}{T}\right), \quad I_{d2} = C_2 \frac{dV_{c2}}{dt} \]

In the frequency domain, \( I = \frac{V_{in}}{1/j\omega C_2} \)
3. [30 points] Semiconductor Physics

Suppose two doped blocks of silicon, one with an N-dopant concentration of 5x10^{18} \text{ cm}^{-3}, and the other with a P-dopant concentration of 1x10^{17} \text{ cm}^{-3}.

a) (5 pts) What is the concentration of majority charge carriers in N-block? What type of charge carriers is in the majority?

Answer:

5x10^{18} \text{ cm}^{-3}
Electrons

b) (5 pts) What is the concentration of majority charge carriers in P-block? What type of charge carriers is in the majority?

Answer:

1x10^{17} \text{ cm}^{-3}
Holes

c) (6 pts) Suppose the two regions are connected together to form a PN junction with the junction as x = 0, p-side on the left (x<0) and n-side on the right (x>0). Use depletion approximation and assume the depletion region in the N side is \( x \in [0, x_N] \) and P side is \( x \in [-x_P, 0] \). Plot the charge density \( \rho(x) \) over the pn junction. What is \( x_N/x_P \)?

Answer:

\( x_N/x_P = Na/Nd = 1x10^{17}/5x10^{18} = 0.02 \)
d) (7 pts) Plot electric field $E(x)$ vs. distance $x$. Assuming the $\varepsilon$ is the permittivity of the material Label your plot. Write $E_{\text{max}}$ as a function of $x_N$.

Answer:

$$E_{\text{min}} = -\frac{q N_D x_p}{\varepsilon} = -\frac{q N_D x_N}{\varepsilon}$$

\[ E(V/cm) \]

\[ \begin{array}{c}
-\mathbf{X}_P \\
\hline
\mathbf{X}_N \\
\hline
\mathbf{X}
\end{array} \]

\[ E = \frac{-q N_D x_p}{\varepsilon} = \frac{-q N_D x_N}{\varepsilon} \]

\[ E_{\text{max}} = q N_D (x_N)^2 \quad \frac{2\varepsilon}{2\varepsilon} \quad \frac{q N_A (x_P)^2}{2\varepsilon} \]

\[ V_{\text{max}} = \frac{q N_D (x_N)^2}{2\varepsilon} + \frac{q N_A (x_P)^2}{2\varepsilon} \]

\[ \text{where} \quad x_p = \frac{N_P x_N}{N_A} \]

\[ \text{so} \quad V_{\text{max}} = \frac{q N_D (x_N)^2}{2\varepsilon} \left(1 + \frac{N_P}{N_A}\right) \]

e) (7 pts) Plot electrostatic potential $V(x)$ vs. distance $x$. Assume the reference point $V=0$ at p-side $x=x_p$. Label your plot and write $V_{\text{max}}$ as a function of $x_N$.

Answer: