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:____

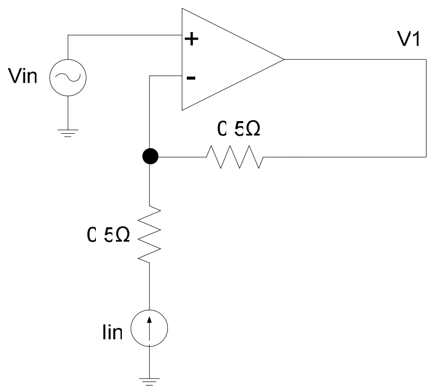
First Name: ____

Student ID: _________________________Discussion Session: _______________

Signature: ____

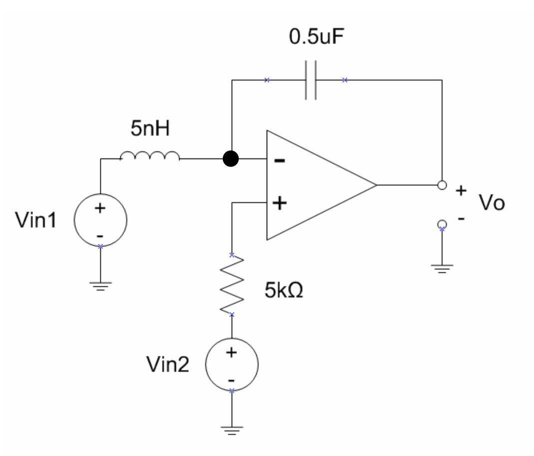
Score:	
Problem 1 (30 pts) Op Amp Circuit	
Problem 2 (40 pts): Diode Circuit	
Problem 3 (30 pts): Semiconductor Physics	
Total	

1. [30 points] Op. Amp. Circuit
a) [8 pts] Find V1 in terms of Vin and Iin.



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

b) [12 pts] Find V0 in terms of Vin1, Vin2, and ω. Use complex impedances. Assume Vin1 and Vin2 are AC signals.

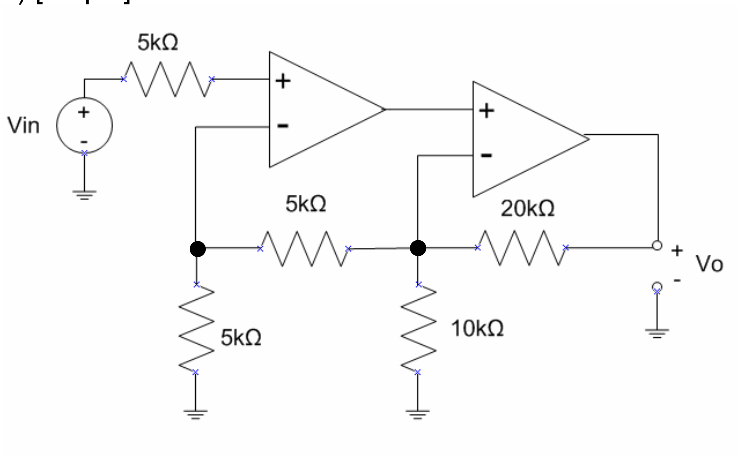


Since no current flows into the (+) terminal:
$V_+ = V_{in2}$
By the summing point constraint:
$V_- = V_{in2}$
By KCL:

$$V_0 = V_{in2} - \frac{Z_C}{Z_L}\left(V_{in1} - V_{in2}\right), Z_C = \frac{1}{j\omega 0.5\mu F}, Z_L = j\omega 5nH$$

$$V_0 = V_{in2} + \frac{1}{\omega^2 (0.5\mu F)(5nH)}\left(V_{in1} - V_{in2}\right)$$

c) [10 pts] Find Vo in terms of Vin.



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

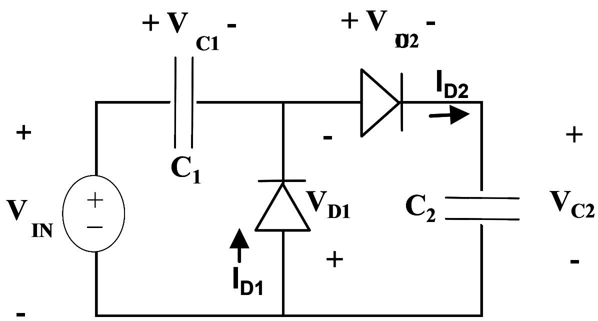
Since no current flows into the (-,2) terminal:
$V_{-,2} = V_O[5k\Omega/(5k\Omega+20k\Omega)]$
$V_O = 5V_{-,2} = 5(2V_{-,1}) = 10V_{in}$

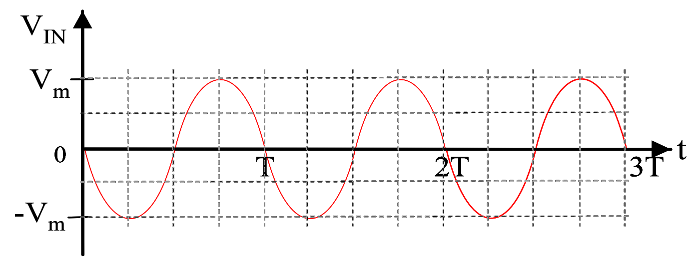
2. [40 points] Diode Circuit:
Given the following circuit and input. Assume C1 >> C2. Use the Ideal Diode model:

If $V_D < 0$, then the diode is OFF and does not pass current ($I_D=0$)
If $I_D >= 0$, 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.

$V_{IN}(t) = -V_m sin(2\pi t/T)$ for t>0,
and
$V_{C1}(t=0^-)= V_{C2}(t=0^-)=0$.





(a) (20 pts) **For the time period** $0 \le t \le \frac{T}{4}$
Is Diode 1 on or off? *On, Vin is -, so Diode 1 is turned on, charging C1*

V_{D1}=? *0V (on, Ideal)*

V_{C1}=? *Vin(t) , Diode 1 on grounds the node above the diode, (Vc1 = Vin – 0)*

I_{D1}=? $C_1 \frac{2\pi}{T} V_m \cos\left(\frac{2\pi t}{T}\right)$, Id1 enters negative reference of C1, $I_{D1} = -C_1 \frac{dV_{C1}}{dt}$

If this was done in the frequency domain, $I = -\frac{V_{in}}{\left(\frac{1}{j\omega C_1}\right)}$

Is Diode 2 on or off? On, node between diodes is ground (0V), Vc2 is 0V above the ground

V_{D2}=? *0V (on, Ideal)*

V_{C2}=? 0V (ground on both sides of C2)

I_{D2}=? 0 A, no current flows through capacitor, all current is through D1 and C1

(b) (20 pts) **For the period** $\frac{T}{4} \le t \le \frac{3T}{4}$

Is Diode 1 on or off? *Off, Voltage begins decreasing on + reference of diode. (At t = T/4, treat VC1+ node as ground, Voltage on both sides of diode is +Vm. This magnitude begins decreasing, shutting off diode, since VD+ < VD-)*

V_{D1}=? *-Vin + Vc1, KVL requires Vin – Vc1 + Vd1 = 0*

V_{C1}=? *-Vm,* (If you assume that C1 >> C2, the same current through both will charge C2 without significantly discharging C1)

I_{D1}=? 0A, Diode off

Is Diode 2 on or off? on

V_{D2}=? *0V (on, Ideal)*

V_{C2}=? *Vin + Vm (KVL: Vin – Vc1 – Vd2 – Vc2 = 0)*

I_{D2}=? $-C_2 \frac{2\pi}{T} V_m \cos\left(\frac{2\pi t}{T}\right),\ I_{D2} = C_2 \frac{dV_{C2}}{dt}$

In the frequency domain, $I = \frac{V_{in}}{\left(\frac{1}{j\omega C_2}\right)}$

3. [30 points] Semiconductor Physics
Suppose two doped blocks of silicon, one with an N-dopant concentration of 5×10^{18} cm^{-3}, and the other with a P-dopant concentration of 1×10^{17} 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?

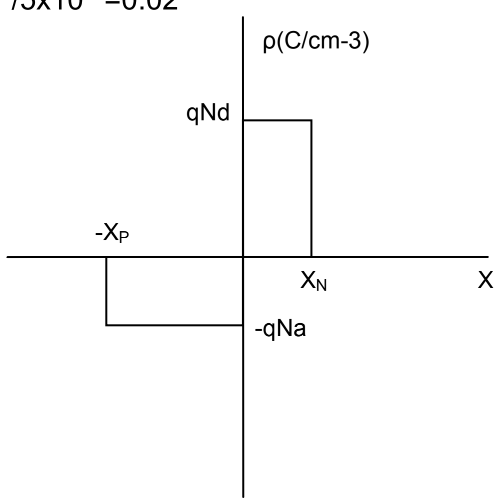
Answer:
5×10^{18} cm^{-3}
Electrons

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

Answer:
1×10^{17} cm^{-3}
Holes

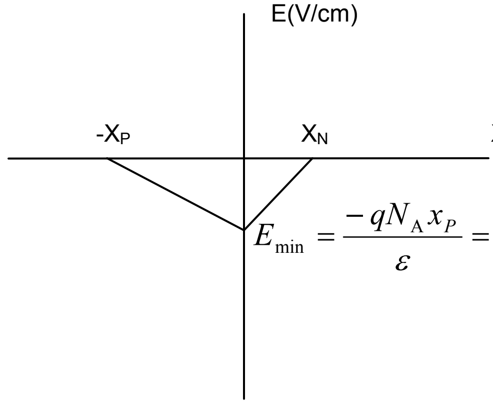
c) (6 pts) Suppose the two regions are connected together to form a PN junction with the junction as x = 0, p-side on the left (x<0) and n-side on the right (x>0). Use depletion approximation and assume the depletion region in the N side is $x \in [0, x_N]$ and P side is $x \in [-x_P, 0]$. Plot the charge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

Answer:
$x_N / x_P = Na/Nd = 1 \times 10^{17} / 5 \times 10^{18} = 0.02$



d) (7 pts) Plot electric field $E(x)$ vs. distance x. Assuming the ε is the permittivity of the material Label your plot. Write E_{max} as a function of x_N.

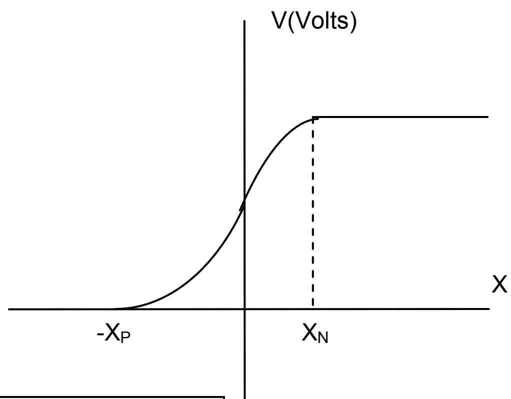
Answer:



$$E_{\min} = \frac{-qN_A x_P}{\varepsilon} = \frac{-qN_D x_N}{\varepsilon}$$

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

Answer:



$$V_{\max} = \frac{qN_D (x_N)^2}{2\varepsilon} + \frac{qN_A (x_P)^2}{2\varepsilon}$$

where

$$x_P = \frac{N_D x_N}{N_A}$$

so

$$V_{\max} = \frac{qN_D (x_N)^2}{2\varepsilon}\left(1 + \frac{N_D}{N_A}\right)$$