UNIVERSITY OF CALIFORNIA AT BERKELEY EECS Department

EECS 40, Fall 2007
Prof. Chang-Hasnain

Homework #9

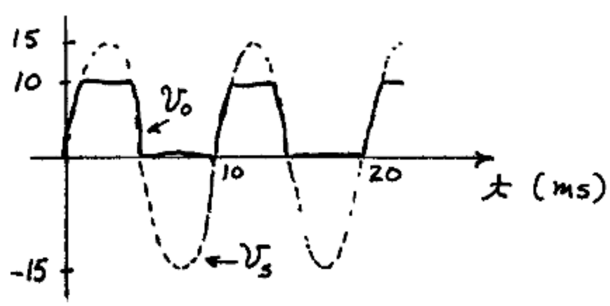
Due at 5 pm in 240 Cory on WEDNESDAY, 11/21/07
Total Points: 100

- Put (1) your name and (2) discussion section number on your homework.
- You need to put down all the derivation steps to obtain full credits of the problems. Numerical answers alone will at best receive low percentage partial credits.
- No late submission will be accepted except those with prior approval from Prof. Chang-Hasnain.
- Problems of this HW are from Hambley 4th Edition

Wave-Shaping Circuits

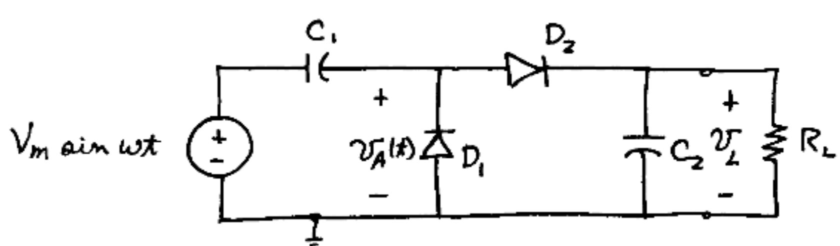
1. P10.63 (11pts)

P10.63 Refer to Figure P10.63 in the book. When the source voltage is negative, diode D_3 is on and the output $v_o(t)$ is zero. For source voltages between 0 and 10 V, none of the diodes conducts and $v_o(t) = v_s(t)$. Finally when the source voltage exceeds 10 V, D_1 is on and D_2 is in the breakdown region so the output voltage is 10 V. The waveform is:

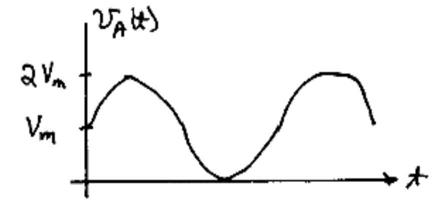


2. P10.71 (12pts)

P10.71



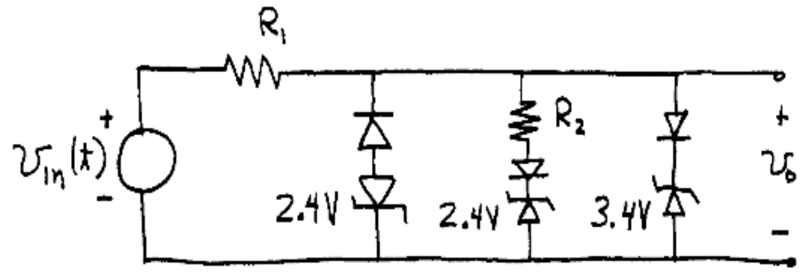
The capacitor C_1 and diode D_1 act as a clamp circuit that clamps the negative peak of $v_A(t)$ to zero. Thus, the waveform at point A is:

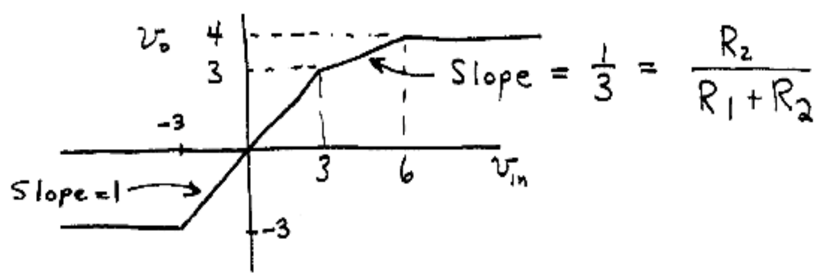


Diode D_2 and capacitor C_2 act as a half-wave peak rectifier. Thus, the voltage across R_L is the peak value of $v_A(t)$. Thus, $v_L(t) \cong 2V_m$. This is called a voltage-doubler circuit because the load voltage is twice the peak value of the ac input. The peak inverse voltage is $2V_m$ for both diodes.

3. P10.74 (12pts)

P10.74 (a) A suitable circuit is:



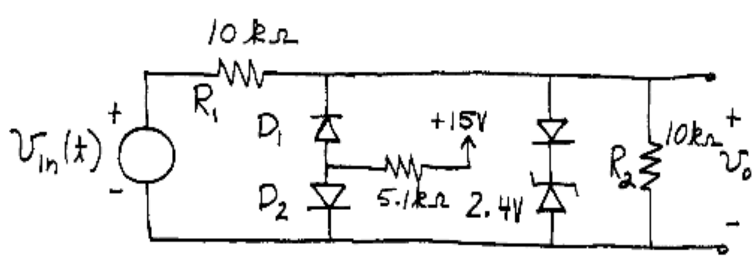


We choose the resistors R_1 and R_2 to achieve the desired slope.

$$\text{Slope} = \frac{1}{3} = \frac{R_2}{R_1 + R_2}$$

Thus, choose $R_1 = 2R_2$. For example, $R_1 = 2\ \text{k}\Omega$ and $R_2 = 1\ \text{k}\Omega$.

(b) A suitable circuit is:



Other resistor values will work, but we must make sure that D_2 remains forward biased for all values of v_{in}, including $v_{in} = -10$ V. To achieve the desired slope (i.e., the slope is 0.5) for the transfer characteristic, we must have $R_1 = R_2$.

There is not one correct answer to this problem though – there are many solutions.

4. **Doping** (17 pts)
   α. Does pure silicon conduct at room temperature? Why or why not? Does its conductance increase or decrease with temperature?

Pure silicon does conduct at room temperature. This capability is due to the nonzero likelihood that electrons are in the conduction band at temperatures greater than absolute zero. Si has an intrinsic concentration of electrons and holes of ~10^10 cm^-3 at room temperature. The higher the temperature; the higher this probability. Therefore, the conductance increases with temperature.

Regardless of this, pure silicon is a very poor conductor, hence its name semiconductor. Conductance (1/Resistance) is proportional to electron/hole concentration; so intrinsic (undoped) silicon is about 7 orders of magnitude less conductive than typical doped silicon (with a doping level of ~10^17 cm^-3).

   β. Identify the majority carrier and find the electron and hole concentrations at room temperature if Aluminum is added with a concentration of 10^14 cm^-3.

Aluminum has 3 valence electrons. Therefore, it is an acceptor and silicon doped with aluminum will be p-type. The majority carriers are holes.

$$p = N_A = 1\_10^{14}\_cm^{-3}$$
$$n = \frac{n_i^2}{N_A} = \frac{1\_10^{20}\_cm^{-3}}{1\_10^{14}} = 1\_10^{6}\_cm^{-3}$$

   χ. Identify the major carrier and find the electron and hole concentrations at room temp if instead Antimony is added at 1.1*10^14 cm^-3.

Antimony has 5 valence electrons. Hence the majority carriers are now electrons.

$$p = \frac{n_i^2}{N_D} = \frac{1\_10^{20}\_cm^{-3}}{1.1\_10^{14}} = 9\_10^{5}\_cm^{-3}$$
$$n = N_D = 1.1\_10^{14}\_cm^{-3}$$

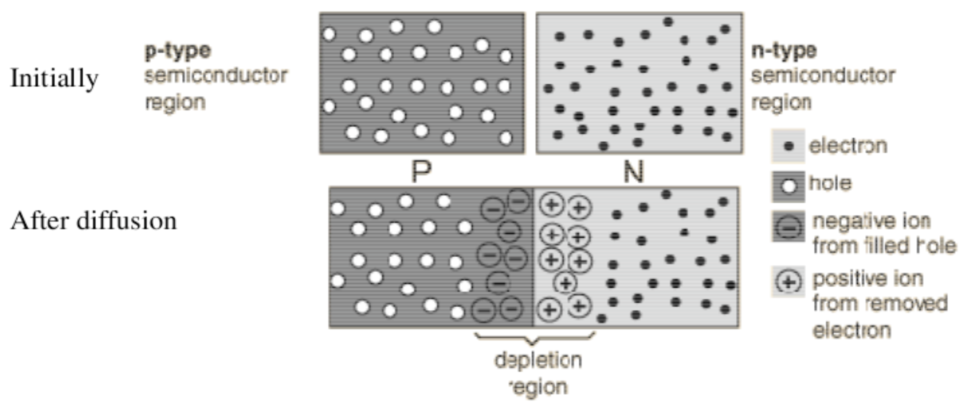
5. **PN Junction and the Depletion Approximation (26 pts)**
   a. Why do the quasi-neutral p and n regions of the PN Junction have low resistivity, while the depletion region has high resistivity?

In the quasi-neutral regions, there are free electrons (n-region) and holes (p-regions) which can easily carry charge (low resistivity). In the depletion region, the free electrons from the n-region recombine with the free holes in the p-regions. Therefore, there are hardly any free carriers for the charge.

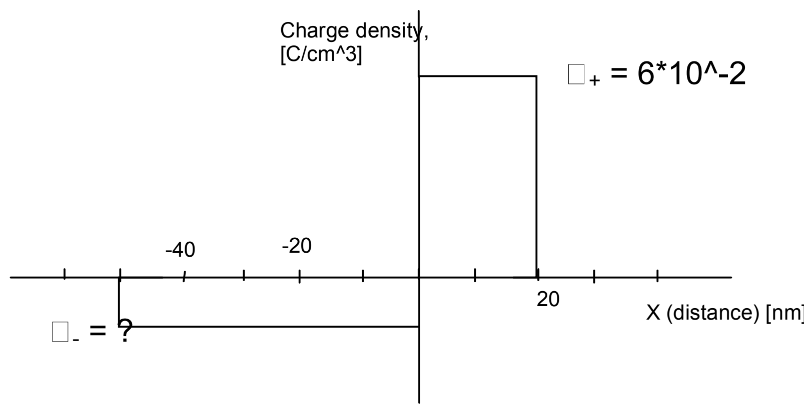
b. What is the *approximation* in the Depletion Approximation?

We assume that the charge density on both sides of the depletion region is constant (not dependent on the distance from the junction)

c. Sketch (and label charge accumulations) for the depletion region for a PN junction.



d. Now suppose you have the following charge profile for a PN junction:



Which is the P side and which is the N side? Find □-

The P side is left, the N side right.
$\_\, x_{po} = \__{+}\, x_{no}$ -> $\_\_ = 2.4\_10^{-2}$

e. Write down an expression for the electric field E(X) and plot it (call the permittivity of the material □).

$E\_x\_= \frac{-}{-} \_x\_x_{po}\_$

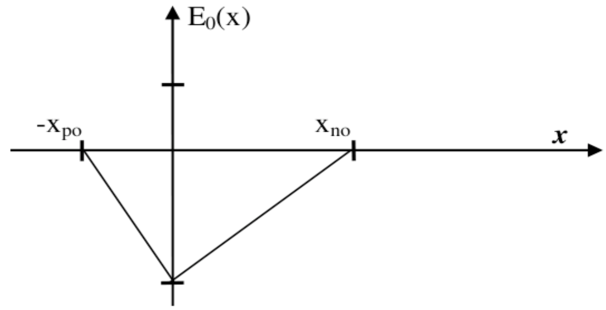
for p side

$E\_x\_= \frac{-+}{-} \_x\_x_{no}\_$

for n side

$E\_x\_=0$

anywhere else



f. Find the potential function □(X) and plot it. Note that our reference is arbitrary, so assume □(-100nm)=0V.

$\_\_x\_= \frac{--}{2\_} \_x\_x_{po}\_^{2}$

for p side

$\_\_x\_= \frac{--}{2\_} x_{po}^{2}\_ \frac{-+}{2\_} x\_2x_{no}\_x\_$

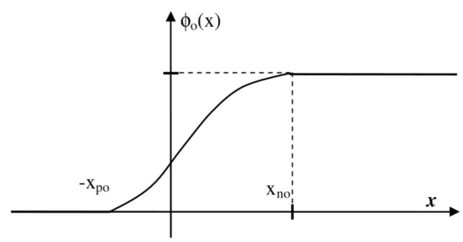
for n side

$\_\_x\_=0$

left from p side

$\_\_x\_= \frac{--}{2\_} x_{po}^{2}\_ \frac{-+}{2\_} x_{no}^{2}$

right from n side



For thought: how would you find E(X) if the charge density was not a step function, but a different shape?

Similarly to the simplified case, gauss' law is valid as well. The algebra, however, would be more difficult.

How would E(X) change if the positive charge region artificially shifted to the right by 5nm, while the negative charge region remained the same?

If the positive charge region is shifted to the right by 5nm, there was a non-charged region in the middle. In this region, The electric field does not change. Therefore there would be a plateau in the middle with constant potential □.