EE 331 Exam 1 Spring 2012 Solutions Mean=60.1, Median=59, σ=13.3

Problem 1: Version B

a) In N region,

$$L_p = \sqrt{D_p \tau_{p_n}}$$

$$\mu_p|_{N_T=10^{16}\,\mathrm{cm}^{-3}} = 400\mathrm{cm}^2/\mathrm{Vs}$$

$$D_p = \frac{\mu_p kT}{q} = 400\mathrm{cm}^2/\mathrm{Vs} \times 0.0259\mathrm{V} = 10.4\ \mathrm{cm}^2/\mathrm{s}$$

$$L_p = \sqrt{D_p \tau_{p_n}} = \sqrt{10.4 \times 200 \times 10^{-6}} = 0.0456\ \mathrm{cm} = 456\ \mu\mathrm{m} > W_n' = 100\ \mu\mathrm{m}$$

So, N side is short base as well.

b) As p side is short base, n side is short base,

$$\mu_n|_{N_T=4\times10^{18}\,\mathrm{cm}^{-3}} = 155\mathrm{cm}^2/\mathrm{Vs} \qquad D_n = \frac{\mu_n kT}{q} = 155\mathrm{cm}^2/\mathrm{Vs} \times 0.0259\mathrm{V} = 4.0\ \mathrm{cm}^2/\mathrm{s}$$

$$I_s = qAn_i^2\left(\frac{D_p}{N_D W_n'} + \frac{D_n}{N_A W_p'}\right) =$$

$$1.6\times10^{-19}C \times 2\times10^{-5}\mathrm{cm}^2 \times 10^{20}\mathrm{cm}^{-6}\left(\frac{10.4\mathrm{cm}^2/\mathrm{s}}{10^{16}\mathrm{cm}^{-3}\times100\times10^{-4}\mathrm{cm}} + \frac{4.0\mathrm{cm}^2/\mathrm{s}}{4\times10^{18}\mathrm{cm}^{-3}\times100\times10^{-7}\mathrm{cm}}\right)$$

$= 6.5\times10^{-17}$ A

c) Resistance of the undepleted n-region:

$$R_n = \rho_n W_n' / A$$

$$\rho_n = \frac{1}{N_D q \mu_n}$$

$$\mu_n|_{N_T=10^{16}} = 1240\ \mathrm{cm}^2/\mathrm{s}$$

$$R_n = 252\ \Omega$$

d) I-V relationship of pn junction is

$$I = I_s\left(e^{\frac{V}{V_T}} - 1\right)$$

Voltage drop in pn junction is

$$V_j \approx V_T \ln\left(\frac{I}{I_s}\right) = 0.0259\ln\left(\frac{10^{-3}}{6.5\times10^{-17}}\right) = 0.79\ \mathrm{V}$$

Voltage drop in neutral n region is:

$$V_n = R_n I = 252\times10^{-3} = 0.25\mathrm{V}$$

Total voltage drop is:

$$V = V_j + V_n = 0.79 + 0.25 = 1.04\mathrm{V}$$

Problem 1, Version A

a)

$$L_p = \sqrt{D_p \tau_{p_n}} = \sqrt{10.4 \times 2 \times 10^{-6}} = 0.00456 \text{ cm} = 45.6 \mu\text{m} << W_n'$$

So, N side is long base.

b) As the P side is short base, N side is long base,

$$I_s = qAn_i^2 \left(\frac{D_p}{N_D L_p} + \frac{D_n}{N_A W_p'} \right) =$$

$$1.6 \times 10^{-19} \text{C} \times 2 \times 10^{-5} \text{cm}^2 \times 10^{20} \text{cm}^{-6} \left(\frac{10.4 \text{cm}^2/\text{s}}{10^{16} \text{cm}^{-3} \times 45.6 \times 10^{-4} \text{cm}} + \frac{4.0 \text{cm}^2/\text{s}}{2 \times 10^{18} \text{cm}^{-3} \times 100 \times 10^{-7} \text{cm}} \right)$$

$= 1.37 \times 10^{-16}$ A

c)

$$R_n = \rho_n W_n' / A$$

$$\rho_n = \frac{1}{N_D q \mu_n}$$

$$\mu_n |_{N_T = 10^{16}} = 1240 \text{ cm}^2/\text{s}$$

$$R_n = 1260\ \Omega$$

d) I-V relationship of pn junction is

$$I = I_s \left(e^{\frac{V}{V_T}} - 1 \right)$$

Voltage drop in pn junction is

$$V_j \approx V_T \ln\left(\frac{I}{I_s} \right) = 0.0259 \ln\left(\frac{10^{-3}}{1.37 \times 10^{-16}} \right) = 0.77 \text{ V}$$

Voltage drop in neutral n region is:

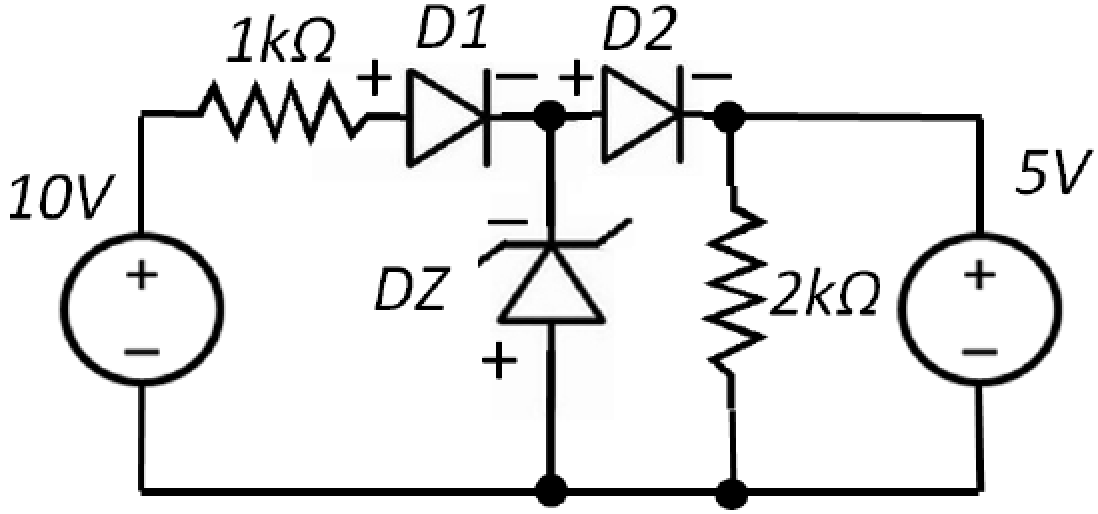
$$V_n = R_n I = 1260 \times 10^{-3} = 1.26 \text{V}$$

Total voltage is:

$$V = V_j + V_n = 0.77 + 1.26 = 2.03 \text{ V}$$

2. In the circuit below, use the constant voltage diode model for D1 and D2 with a threshold (turn-on) voltage of V_{on}= (0.7 V for A, 0.8 V for B). The reverse breakdown voltage of the Zener diode (DZ) is -5V and the series resistance is 250Ω. (30)

a) Assume that D1 is on, D2 is off and DZ is in reverse breakdown. Calculate the voltage across and current through each diode.
b) Check each of the assumptions made in (a). Which mode is each diode actually in (on, off, breakdown)?



Solution:

a) [12 pts] D2 is off, so $i_{D2} = 0$

D1 is on (V_{D1}=V_{on}), DZ is in reverse breakdown, and they are in series, so

$$i_{D1} = -i_{DZ} = \frac{10 + V_{DZ} - V_{on}}{1\ k\Omega + R_{DZ}} = \frac{4.3\text{ V}}{1250\ \Omega} = 3.44\text{ mA for A } \left[\frac{4.2\text{ V}}{1250\ \Omega} = 3.36\text{ mA for B}\right]$$

$$V_{DZ} = -5\text{ V} + i_{DZ}R_{DZ} = -5.86\text{ V } [-5.84\text{ V for B}]$$

b) [18 pts] $V_{D1} = V_{on}$ and $i_{D1} > 0$, so D1 is on.

$V_{D2} = (10\text{V} - (1\text{k}\Omega \times i_{D1}) - V_{on} - 5\text{V}) = 10 - 3.44 - 0.7 - 5 = 0.86\text{V}$ [0.84 for B]

This is greater than V_{on}, so assumption of D2 off is wrong; D2 is actually on.

Since D2 is on, $V_{DZ} = -(5\text{ V} + V_{on}) < -V_Z = -5\text{ V}$, so DZ is in still reverse breakdown.

Checking, $i_{D2} - i_{D1} = i_{DZ} = {[V_Z - (5\text{ V} + V_{on})]}/{R_{DZ}} = {-V_{on}}/{R_{DZ}} < 0.$

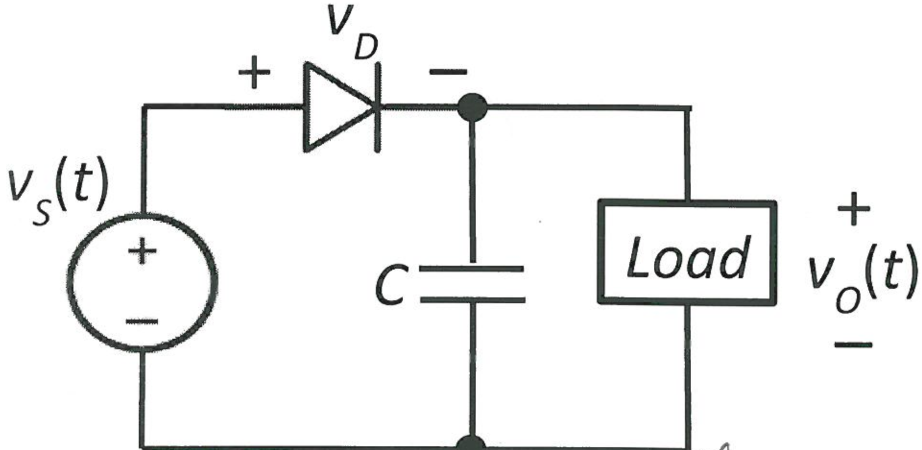
3. For the power supply circuit shown below, the rms value of v_S is 10 V, the operating frequency is 50 Hz, C = 2000 μF, and the on-voltage of the diode is 0.70 V. The load sinks up to 5 mA. State your assumptions clearly and check them if possible. (~~40~~) [30]

   (a) What is the dc output voltage V_O if the ripple voltage is small?

   (b) What is the maximum value of the ripple voltage at V_O ?

   (c) What is the minimum PIV rating for the diode?

   (d) What is the maximum current through the diode during start-up transient ($v_C = 0$)?



(a) $V_{dc} = V_p - V_{on} - \cancel{\overset{\text{small}}{\frac{V_r}{2}}} \cong V_p - V_{on} = 10\sqrt{2} - 0.7 = \underline{13.44\,V}$ [5 points]

$(10\sqrt{2} - 0.8 = \underline{13.34\,V}$ for B$)$

(b) $\frac{dV_c}{dt} = \frac{-i_c}{C} = \frac{i_D - i_{LOAD}}{C} \le \frac{-i_{LOAD}}{C} \le \frac{-5mA}{C}$ [10]

For most of cycle, diode is off, so $V_r \le \frac{+i_{LOAD}^{max}\, T}{C} = \frac{(5\times10^{-3}A)(\frac{1}{50}s)}{2\times10^{-3}F}$

$= \underline{0.05\,V}$

(c) Minimum value of $v_s(t)$ is $-V_p = -14.14V$

[5] Maximum value of $v_c(t)$ is $V_p - V_{on} = 13.44\,V$, so

PIV rating must be greater than $13.44 - (-14.14) = \underline{27.58V}$ (27.48 for B)

(d) $i_D = i_C + i_{LOAD}$ $\quad i_C = C\frac{dv_c}{dt} = C\omega V_p \cos(\omega t)$ when diode is on

For $v_c = 0$, diode turns on when $v_s = V_{on} \Rightarrow \omega t = \sin^{-1}\left(\frac{V_{on}}{V_p}\right) = 0.05$ rad

[10] $i_C = C(2\pi f)V_p\cos(0.05) = 2\times10^{-3}(2\pi)50\times14.14(1) = 8.87A$ $\quad i_D = i_c + i_{LOAD} = \underline{8.87A}$