IMPORTANT: Besides your calculator and the sheets you use for calculations you are only allowed to have an A4 sized "copy sheet" during this exam. Notes, problems and alike are not permitted. Please submit your "copy sheet" along with your solutions. You may get your "copy sheet" back after your solutions have been graded. *Do not forget to write down units and convert units carefully!*

ELE222E INTRODUCTION TO ELECTRONICS (21727)
Midterm Exam #1 ✐ 20 March 2005 ⌚ 10.00-12.00
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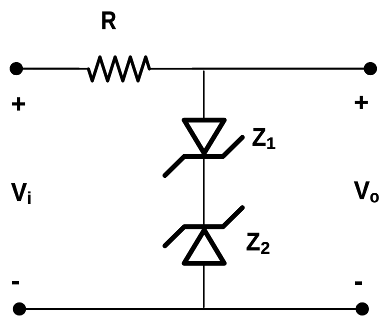
1. Assume you have a diode made of n- and p-typed doped silicon with the following specific resistances: ρ_n = 0.1 Ωcm, ρ_p = 1 Ωcm. You know n_i = 1.5 10^{10} /cm^3, q = 1.602 10^{-19} C, ε_r = 12, ε_o = 8.85 10^{-12} F/m, V_T = 25.2 mV. Also D_n = 36 cm^2/s, D_p = 16 cm^2/s, τ_n= τ_p = 1 μsec.

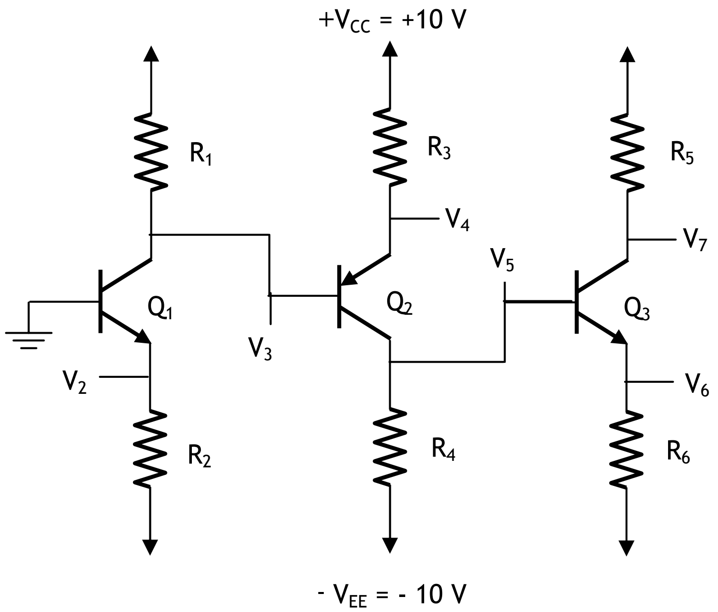
   a. Find the barrier potential. (15 points)

   b. For a junction area of 1 mm^2, calculate the current through your diode when it is forward biased at 0.6 V. (10 points)

   c. Calculate the junction capacitance when your diode is reverse biased at 10V. (10 points)



2. The two Zener diodes on the right are identical with V_Z = 6.8 V. Remember: V_D = 0.7 V when the Zener diodes are forward biased. Study and sketch the output voltage V_o as a function of the input voltage V_i in the range from -10V to +10V. (15 points)
   What happens when one of the Zener diodes is taken out? Sketch the output voltage as a function of the input voltage with only (a) Z_1 (b) Z_2 present. (15 points)



3. Study the 3-stage amplifier circuit on the left at DC. For $|V_{BE}|$ = 0.6 V

   a. Calculate the resistor values for h_{FE} = ß = ∞ ,I_{C1} = I_{C2} = 2 mA, and I_{C3} = 4 mA, such that, V_3 = 0 V, V_5 = -4 V and V_7 = 2 V (15 points).

   b. With the resistor values you found above, calculate V_3, V_4, V_5, V_6, and V_7 for h_{FE} = ß = 100. (20 points)

GOOD LUCK!

SOLUTIONS

1. Using Einstein relationship $V_T = \frac{D_n}{\mu_n} = \frac{D_p}{\mu_p} \Rightarrow \underline{\underline{\mu_n = 1430cm^2/Vs}}; \underline{\underline{\mu_p = 634cm^2/Vs}}$

a.

$$\sigma_p = \frac{1}{\rho_P} = q\mu_p N_A \Rightarrow \underline{\underline{N_A = 9{,}85 \cdot 10^{15}/cm^3}}$$

$$\sigma_n = \frac{1}{\rho_n} = q\mu_n N_D \Rightarrow \underline{\underline{N_D = 4{,}36 \cdot 10^{16}/cm^3}}$$

$$V_B = V_T \cdot \ln\left(\frac{N_A \cdot N_D}{n_i^2}\right) = \underline{\underline{714mV}}$$

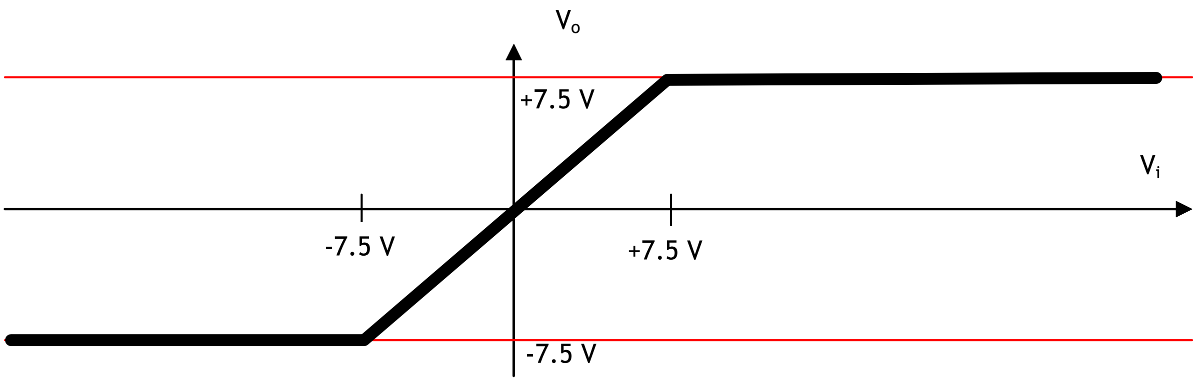
b. Using $L_n = \sqrt{\tau_n D_n}; L_p = \sqrt{\tau_p D_p} \Rightarrow \underline{\underline{L_n = 60\mu m}}; \underline{\underline{L_p = 40\mu m}}$

$$I_o(V = 0{,}6V) = A \cdot q \cdot n_i^2 \cdot \left[\frac{D_p}{L_p N_D} + \frac{D_n}{L_n N_A}\right]\left(e^{V/V_T} - 1\right) = \underline{\underline{0{,}533mA = 533\mu A}}$$

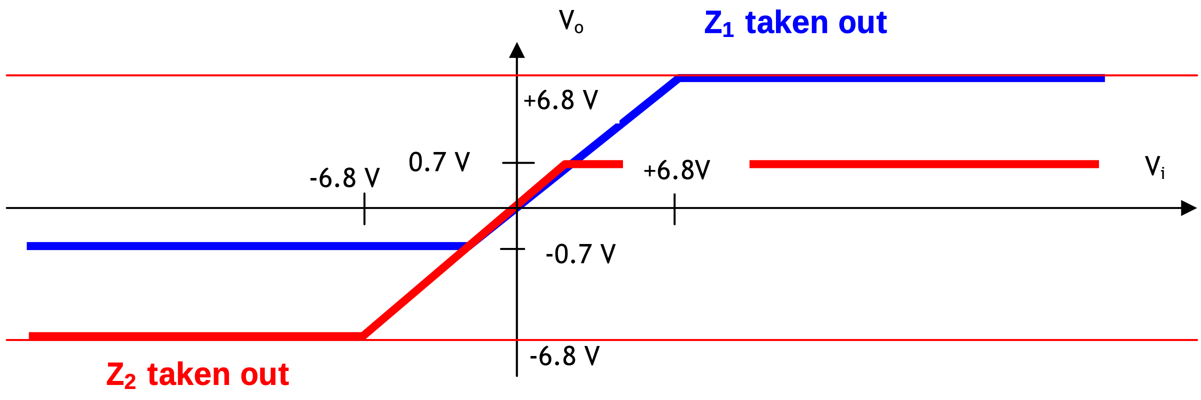
c. Using $w_{dep}(V = 10V) = \sqrt{\frac{2 \cdot \varepsilon_o \varepsilon_r}{q}(V_B + V)\left(\frac{1}{N_A} + \frac{1}{N_D}\right)} = \underline{\underline{1{,}24\mu m}}$, thus

$$C(V_{reverse} = 10V) = \varepsilon_o \cdot \varepsilon_r \frac{A}{w} = \underline{\underline{8{,}58pF}}$$

2. As long as $|V_i| \geq V_D + V_Z = 7.5V$ both Zeners will be conducting (one az a Zener diode the other as an ordinary diode) and will limit the output at 7.5 V. However, for $V_i < 7.5V$, Z_1 cannot work as a Zener diode and Z_2 cannot work as a regular diode. Likewise, for $V_i > -7.5V$, Z_2 cannot work as a Zener diode and Z_1 cannot work as a regular diode. Thus for $|V_i| < 7.5V$, one of the diodes is not conducting. As a result the output will follow the input. This is visualized in the following graph:



On the other hand, when one of the diodes are taken out, the limiter circuit functions differently. The remaining Zener diode functions either as a Zener diode or as an ordinary diode as shown below:



3. The 3-stage amplifier circuit has two npn and one pnp type BJT. Thus $V_{BE1} = V_{BE2} = 0.6$ V and $V_{BE2} = -0.6$ V. Taking $h_{FE} = \beta = \infty$ we can neglect base currents. **All $I_{Ci} = I_{Ei}$**

   a. $I_{C1} = 2$ mA and $V_3 = 0$ V

   $$\rightarrow \underline{\underline{R_1}} = \frac{+10V - V_3}{I_{C1}} = \frac{10V}{2mA} \underline{\underline{= 5k}}.$$

   Furthermore the base of Q_1 is grounded

   $$\rightarrow \underline{\underline{V_2}} = 0V - V_{BE1} \underline{\underline{= -0,6\ V}} \text{ and } \underline{\underline{R_2}} = \frac{V_2 - (-10V)}{I_{E1}} = \frac{-0,6V + 10V}{2mA} \underline{\underline{= 4k7}}.$$

   $I_{C2} = 2$ mA and $V_3 = 0$ V

   $$\rightarrow \underline{\underline{V_4}} = V_3 - V_{BE2} \underline{\underline{= 0,6\ V}} \text{ and } \underline{\underline{R_3}} = \frac{+10V - V_4}{I_{E2}} = \frac{9,4V}{2mA} \underline{\underline{= 4k7}}.$$

   $I_{C2} = 2$ mA and $V_5 = -4$ V

   $$\rightarrow \underline{\underline{R_4}} = \frac{V_5 - (-10V)}{I_{C2}} = \frac{6V}{2mA} \underline{\underline{= 3k}}.$$

   $V_7 = 2$ V and $I_{C3} = 4$ mA

   $$\rightarrow \underline{\underline{R_5}} = \frac{+10V - V_7}{I_{C3}} = \frac{8V}{4mA} \underline{\underline{= 2k}}$$

   $V_5 = -4$ V and $I_{C3} = 4$ mA, $\underline{\underline{V_6}} = V_5 - 0,6\ V \underline{\underline{= -4,6\ V}}$

   $$\rightarrow \underline{\underline{R_6}} = \frac{V_6 - (-10V)}{I_{E3}} = \frac{5,4V}{4mA} \underline{\underline{= 1k35}}.$$

   b. For $h_{FE} = \beta = 100$ $I_{C1} = I_{C2} = 2$ mA, $I_{C3} = 4$ mA, $\underline{\underline{I_{B1} = I_{B2} = 0,02\ mA}}$ and $\underline{\underline{I_{B3} = 0,04\ mA}}$.

   $$\underline{\underline{V_3}} = 10V - R_1\left[I_{C1} - I_{B2}\right] = 10V - 5 \cdot 10^3 * 2,02 \cdot 10^{-3} V \underline{\underline{= 0,1V}}$$

$$\underline{\underline{V_4}} = V_3 - V_{BE2} = 0{,}1V - (-0{,}6V) \underline{\underline{= 0{,}7V}}$$

$$\underline{\underline{V_5}} = (-10V) + R_4\left[I_{C2} - I_{B3}\right] = -10 + 3\cdot 10^3 * 1{,}96\cdot 10^{-3} \underline{\underline{= -4{,}12V}}$$

$$\underline{\underline{V_6}} = V_5 \; - V_{BE3} = -4{,}12 - 0{,}6 \underline{\underline{= -4{,}72V}}$$

$$\underline{\underline{V_7}} = 10V - R_5 I_{C3} = 10V - 2\cdot 10^3 * 4\cdot 10^{-3} V \underline{\underline{= 2V}}$$

We see hereby that voltages are very close to voltages given in (a). We could also have solved this part by finding all currents from scratch.