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 (21506)
Midterm Exam #1 ✐ 16 March 2009 ◷ 9.30-11.30

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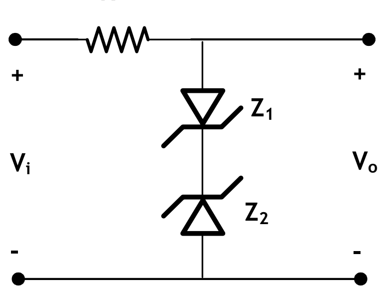
1. Assume you have a diode made of n- and p-typed doped silicon with the following specific resistances: ρ_n = 0,5 Ωcm, ρ_p = 0,75 Ωcm. You know n_i = 1,5 10^{10} /cm^3, q = 1,602 10^{-19} C, ε_r = 12, ε_o = 8,85 10^{-12} F/m, V_T = 25,2 mV. Also D_n = 36 cm^2/s, D_p = 16 cm^2/s, τ_n= τ_p = 0,8 µsec.

   a. Find the barrier potential. (10 points)

   b. For a junction area of 0,1 mm^2, calculate the current through your diode when it is forward biased at 0,7 V. (10 points)

   c. Calculate the junction capacitance when your diode is reverse biased at 5 V. (10 points)

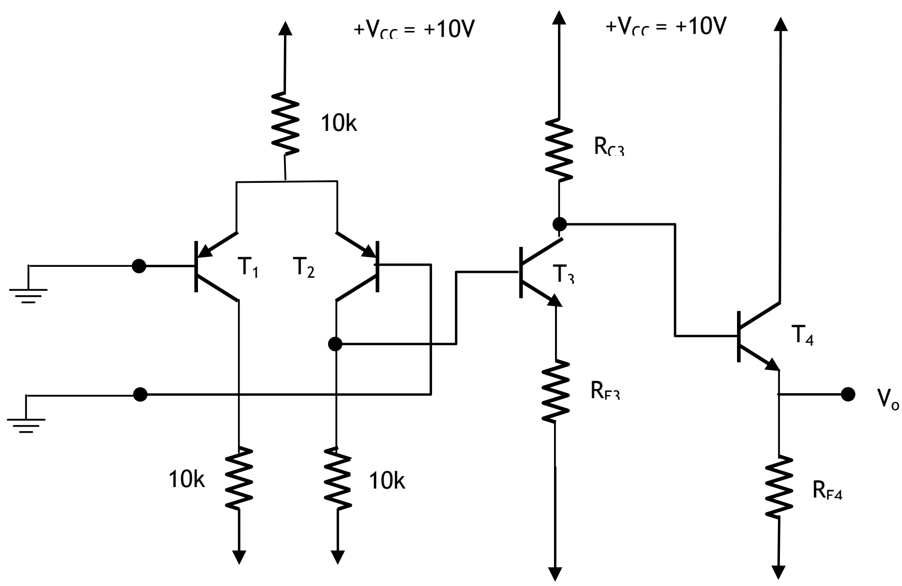


2. The two Zener diodes on the right are identical with V_Z = 6,8 V. V_D = 0,7 V when Zener diodes are forward biased. Study and sketch the output voltage V_o as a function of time when the input voltage V_i is (a) a square, (b) triangular wave with peak values of -10V and +10V. (15 points)
   What happens when one of the Zener diodes is taken out? Sketch the output voltage as a function of time with only (a) Z_1 (Z_2 shorted) (b) Z_2 (Z_1 shorted) present. (15 points)

3. Study the multi-stage amplifier circuit below at DC. For h_{FE} = 250, V_T = 25 mV, $|V_{BE}|$ = 0,6 V,

   a. Calculate R_{C3}, R_{E3} and R_{E4}, such that, I_{C3} = 0,8 mA, I_{C4} = 1 mA and V_0 = 0V. (30 points)

   b. Design a BJT based current mirror that will provide the current provided by the 10k resistor connected to the common emitters of the differential stage. (10 points)



GOOD LUCK!

SOLUTIONS

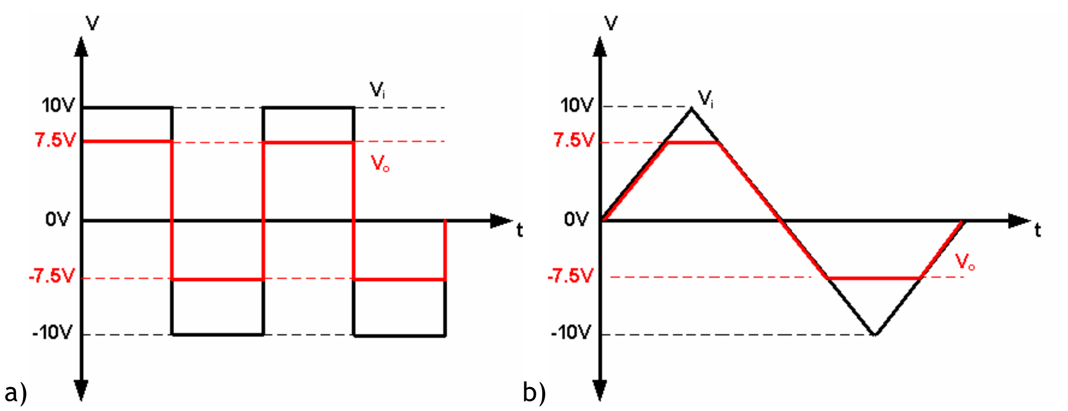
1. Using Einstein relationship $V_T = \frac{D_n}{\mu_n} = \frac{D_p}{\mu_p} \Rightarrow \underline{\underline{\mu_n = 1430cm^2/Vs}}; \underline{\underline{\mu_p = 634cm^2/Vs}}$

   a. $$\sigma_p = \frac{1}{\rho_P} = q\mu_p N_A \Rightarrow \underline{\underline{N_A = 1{,}31 \cdot 10^{16}/cm^3}}$$
   $$\sigma_n = \frac{1}{\rho_n} = q\mu_n N_D \Rightarrow \underline{\underline{N_D = 8{,}75 \cdot 10^{15}/cm^3}}$$
   $$V_B = V_T \cdot \ln\left(\frac{N_A \cdot N_D}{n_i^2}\right) = \underline{\underline{680mV}}$$

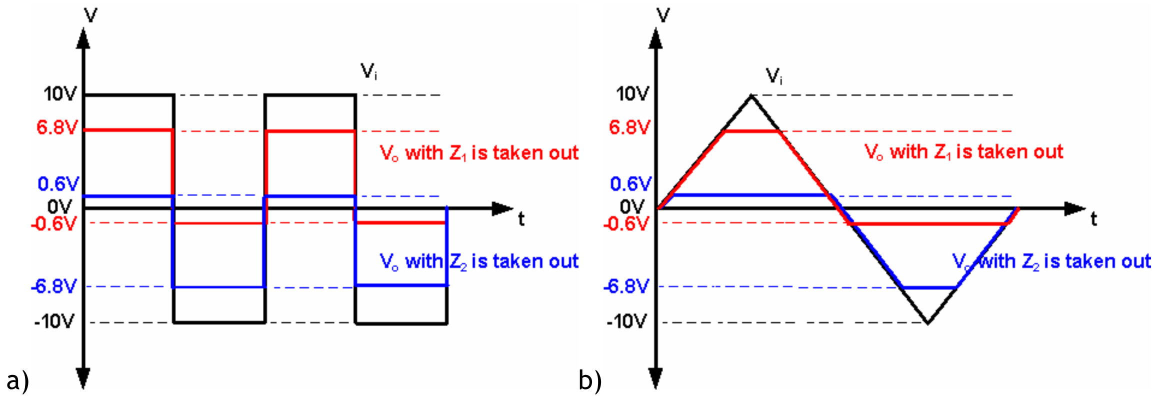
   b. Using $L_n = \sqrt{\tau_n D_n}; L_p = \sqrt{\tau_p D_p} \Rightarrow \underline{\underline{L_n = 53{,}7\mu m}}; \underline{\underline{L_p = 35{,}8\mu m}}$
   $$I_D(V = 0{,}7V) = A \cdot q \cdot n_i^2 \cdot \left[\frac{D_p}{L_p N_D} + \frac{D_n}{L_n N_A}\right]\left(e^{V/V_T} - 1\right) = \underline{\underline{41mA}}$$

   c. Using $w_{dep}(V_{reverse} = 5V) = \sqrt{\frac{2 \cdot \varepsilon_o \varepsilon_r}{q}(V_B + V)\left(\frac{1}{N_A} + \frac{1}{N_D}\right)} = \underline{\underline{1{,}2\mu m}}$, thus
   $$C(V_{reverse} = 5V) = \varepsilon_o \cdot \varepsilon_r \frac{A}{w} = \underline{\underline{8{,}87\,pF}}$$

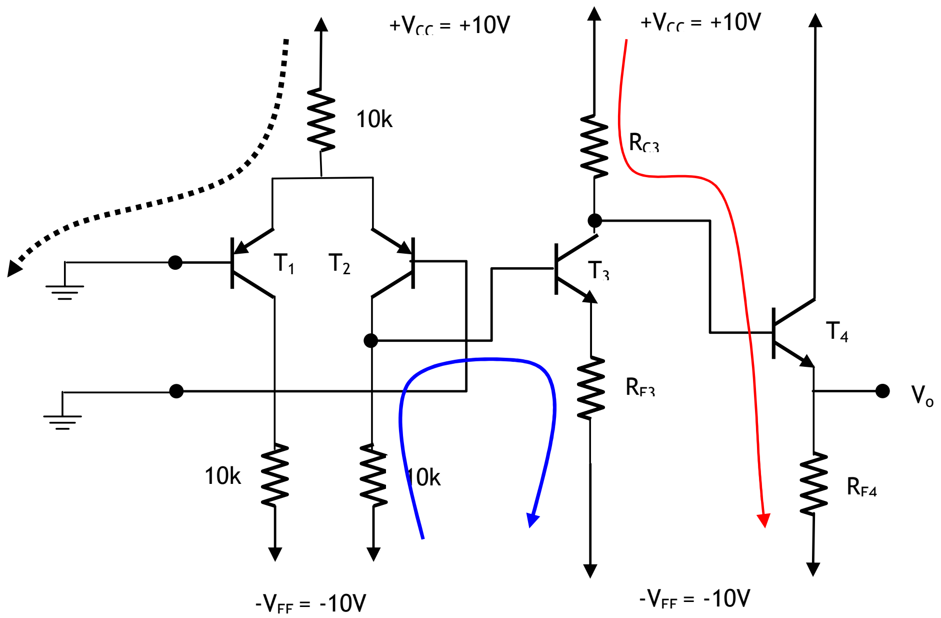
2. As long as $|V_i| \geq V_D + V_Z = 7.5V$ both Zeners will be conducting (one as a Zener diode the other as an ordinary diode) and will limit the output at 7.5 V. However, for $V_i < 7.5V$, Z_1 cannot work as a Zener diode and Z_2 cannot work as a regular diode. Likewise, for $V_i > -7.5V$, Z_2 cannot 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 graphs:



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 can be analyzed using the loops and lines shown below.



Using the dotted line $V_{CC} - 0V = R_E\left(I_{E1} + I_{E2}\right) + V_{EB1} = R_E \cdot 2I_{E1} + V_{EB1}$

$$I_{E1} = I_{E2} = \frac{V_{CC} - V_{EB1}}{2R_E} = \frac{10V + V_{BE1}}{20k} = \frac{10V - 0{,}6V}{20k} = \frac{9{,}4V}{20k} = \underline{\underline{0{,}47mA}}$$

Since $I_{E1} = I_{E2} = I_{E1,2}$, $I_{C1,2} = \dfrac{h_{FE}}{h_{FE}+1} I_{E1,2} = \underline{\underline{0{,}465mA \cong I_{E1,2}}}$.

Using the blue loop $-(I_{C2} - I_{B3})10k + V_{BE3} + (1 + h_{FE3})I_{B3}R_{E3} = 0$ and inserting value for the base current of T$_3$, i.e., $I_{C3} = 0{,}8mA \Rightarrow I_{B3} = \dfrac{I_{C3}}{h_{FE}} = \dfrac{0{,}8m}{250} = \underline{\underline{3{,}2\mu A}}$,

$$R_{E3} = \frac{(I_{C2} - I_{B3})R_{C2} - V_{BE3}}{(1 + h_{FE})I_{B3}} = \frac{(0{,}465mA - 3{,}2\mu A)10k - 0{,}6V}{(1 + 250)3{,}2\mu A} = \underline{\underline{5k}}$$

Using the red line and taking into account that V_0 = 0V and $I_{C4} = 1mA \Rightarrow I_{B3} = \frac{I_{C4}}{h_{FE}} = \frac{1m}{250} = \underline{\underline{4\mu A}}$

$$V_{B4} = V_{CC} - R_{C3}(I_{C3} + I_{B4}) = +10V - R_{C3}(0{,}8mA + 4\mu A) = V_{BE4} = 0{,}6V$$

$R_{C3} = \frac{V_{CC} - V_{BE4}}{I_{C3} + I_{B4}} = \frac{10V - 0{,}6V}{0{,}8mA + 4\mu A} = \underline{\underline{11k7}}$ and since $(h_{FE4} + 1)I_{B4}R_{E4} = 10V$,

$$R_{E4} = \frac{0V - (-V_{EE})}{(h_{FE} + 1)I_{B4}} = \frac{10V}{(250 + 1)4\mu A} = \underline{\underline{10k}}$$

<u>BJT based current mirror design:</u>

$I_{ref} = 2I_{E1} = 2I_{E2}$ = 0,94 mA.

On the right is my design. NOTE that the collector of T_6 is connected to the common emitters of the differential stage. At DC $V_{E1} = V_{E2}$ = 0,6 V, that means, V_{C6} = 0,6 V. This voltage should keep T_6 in active mode! Does it?

V_{B6} = 9,4 V. For BC junction to be reverse biased,

$V_{C6} \leq V_{B6}$ - 0,6 V that is $V_{C6} \leq$ 8,8 V.

V_{C6} = 0,6 V < 8,8 V and THUS this condition is satisfied.