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! Cell phones are not allowed and should be placed on the front desk before the exam.***

EHB222E INTRODUCTION TO ELECTRONICS (20936)
Midterm Exam #1 ✐ 18 March 2019 ⌛ 9:30-11:30

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EEF 5105

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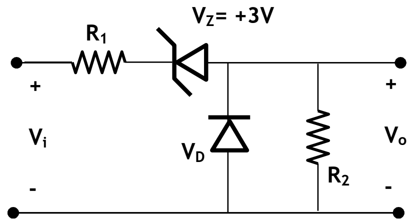
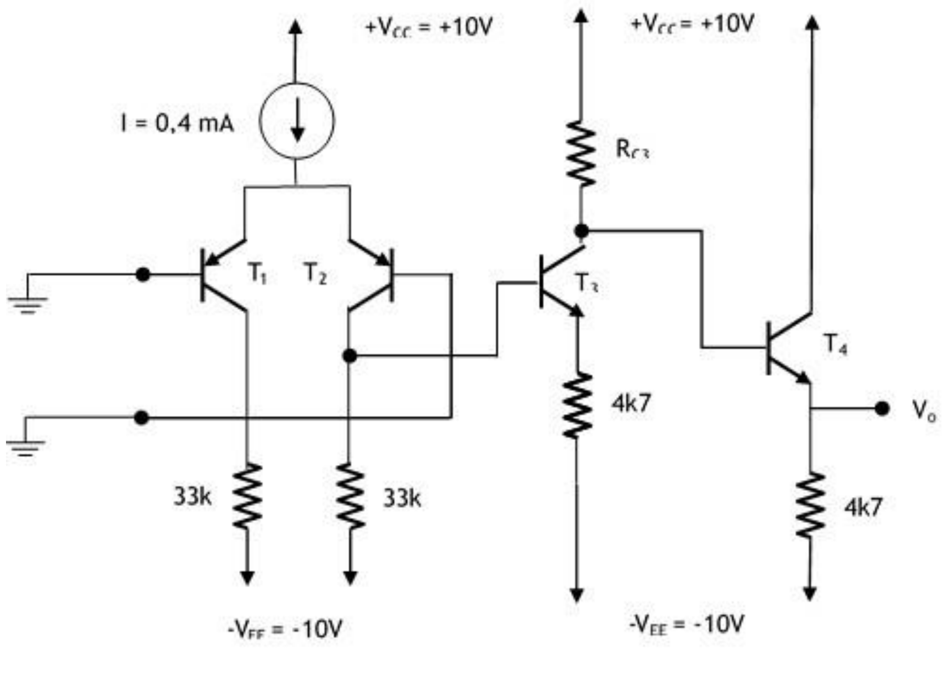
1. Assume you are to create a diode using n- and p-typed doped silicon with the following doping parameters: $N_D = 3\ 10^{17}\ /cm^3$, and $N_A = 10^{15}\ /cm^3$.
   a. Find the barrier voltage and saturation current for a junction area of 0,1 mm^2. (6 points)
   b. Calculate the specific conductivities of n- and p-type doped silicon. (6 points)
   c. Determine the depletion zone width in unbiased state, when the junction is reverse biased at 3,5 V and when it is forward biased at 0,35 V. (9 points)
   d. Calculate the junction capacitances for the cases in (c). (9 points)

   $L_n = 10\ \mu m$, $L_p = 5\ \mu m$, $\mu_n = 1400\ cm^2/Vs$, $\mu_p = 500\ cm^2/Vs$. $n_i = 1.5\ 10^{10}\ 1/cm^3$, $q = 1.602\ 10^{-19}$ C, $\varepsilon_r = 12$, $\varepsilon_o = 8.85\ 10^{-12}$ F/m, $V_T = 25$ mV.

2. Consider the circuit on the left. Study and plot the output voltage V_o as a function of the input voltage V_i over the range -10V to +10V. You may assume the diodes are ideal, i.e., $V_D = 0$ V when they are forward biased. (30 points)



3. Study DC characteristics of the 3-stage BJT amplifier circuit with **$|V_{BE}|$ = 0,6 V**, **h_{FE} = 200** for all four transistors. **Do not neglect base currents.**
   a. Design a current source that will provide **0,4 mA biasing current** to the differential stage. (10 points)
   b. Choose **R_{C3}** such that, T_3 is in active mode (30 points)



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SOLUTIONS:

1. Using Einstein Equation , i.e., $D_{p/n} = V_T \cdot \mu_{p/n}$, we find D_p = 12,5 cm²/s and D_n = 35 cm²/s.

   a. $V_B = V_T \cdot \ln\left(\dfrac{N_A \cdot N_D}{n_i^2}\right)$=698 mV; $I_o = A \cdot q \cdot n_i^2 \cdot \left[\dfrac{D_p}{L_p N_D} + \dfrac{D_n}{L_n N_A}\right]$ = 1,26 pA

   b. $\sigma_p = q \cdot \left(\dfrac{n_i^2}{N_A}\mu_n + N_A \mu_p\right) \cong q N_A \mu_p$ = 0,08 /(Ω cm)

   $\sigma_n = q \cdot \left(N_D \mu_n + \dfrac{n_i^2}{N_D}\mu_p\right) \cong q N_D \mu_n$ = 67,3 /(Ω cm)

   c. unbiased $w_{dep} = \sqrt{\dfrac{2 \cdot \varepsilon_o \cdot \varepsilon_r \cdot V_B}{q}\left(\dfrac{1}{N_A} + \dfrac{1}{N_D}\right)}$ =0,96 µm

   with reverse bias at 3,5 V, $w_{dep} = \sqrt{\dfrac{2 \cdot \varepsilon_o \cdot \varepsilon_r \cdot (V_B + V_{bias})}{q}\left(\dfrac{1}{N_A} + \dfrac{1}{N_D}\right)}$ = 2,36 µm

   with forward bias at 0,35 V, $w_{dep} = \sqrt{\dfrac{2 \cdot \varepsilon_o \cdot \varepsilon_r \cdot (V_B - V_{bias})}{q}\left(\dfrac{1}{N_A} + \dfrac{1}{N_D}\right)}$ = 0,68 µm

   Thus, $C = \varepsilon_o \cdot \varepsilon_r \dfrac{A}{w} = \begin{cases} \underline{\underline{11{,}02\,pF}}, unbiased \\ \underline{\underline{4{,}49\,pF}}, reverse @ 3{,}5V \\ \underline{\underline{15{,}61\,pF}}, forward @ 0{,}35V \end{cases}$

2. This circuit has to be analyzed in three parts. The plot is placed at the bottom.

   a. **-10 V < V_{in} < 0 V**: Both the regular diode and the Zener diode are forward biased. If we assume they are ideal, they effectively create electrical shorts. That is,

      i. R_1 is directly connected to R_2
      ii. both ends of R_2 are shorted
      iii. V_o = 0 V

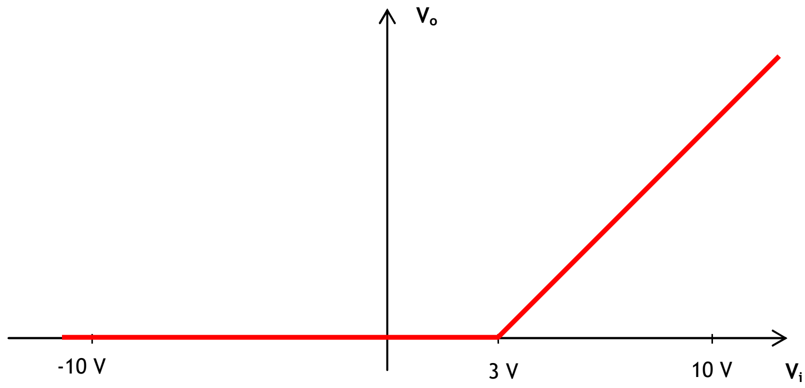
   b. **+3 V < V_{in} < +10 V**: Both the regular diode and the Zener diode are reverse biased.

      i. the Zener diode is in the Zener zone and 3 V drops across it.
      ii. the regular diode is in cut off.
      iii. current flows over R_1, the Zener diode and R_2.and is $I = \dfrac{V_i - V_Z}{R_1 + R_2}$
      iv. $V_o = R_2 I$. If this current changes linearly, then V_o changes linearly.

c. **0 V < V_{in} < +3 V**: Both the regular diode and the Zener diode are reverse biased, yet, the Zener diode is <u>not</u> in Zener zone.

   i. no current flows over R_1, the Zener diode, the regular diode and R_2.

   ii. $V_o = 0$ V.



3. DC characteristics are to be studied.

   a. You do your own design!

   b. <u>Without neglecting</u> the base currents of the differential (the very first) stage, for $V_i = 0$ V

$$I_{C1} = I_{C2} = \frac{h_{FE}}{h_{FE}+1} \cdot \frac{I_{ref}}{2} = \frac{200}{200+1} \cdot \frac{0{,}4mA}{2} \Rightarrow I_{C1} = I_{C2} = \underline{\underline{0{,}199mA}}$$

$$-(I_{C2} - I_{B3})33k + V_{BE3} + (h_{FE}+1)I_{B3}4k7 = 0$$

$$I_{C3} = h_{FE}\frac{33k * I_{C2} - V_{BE3}}{(h_{FE}+1)4k7 + 33k} = 200\frac{33k * 0{,}199mA - 0{,}6V}{(200+1)4k7 + 33k} = \underline{\underline{1{,}2mA}}$$

Now we need to find the base voltage of T_3. $V_{B3} = -10V + (I_{C2} - I_{B3})33k = \underline{\underline{-3{,}63V}}$

For T_3 to be in active mode $V_{B3} \le V_{C3}$. I take $V_{C3} = -3{,}5V > -3{,}63V$. Thus

$$V_{C3} = V_{B4} = -10V + 4k7 \cdot I_{E4} + V_{BE4} = -10V + 4k7 \cdot I_{B4}(h_{FE}+1) + 0{,}6V = -3{,}5V$$

$$\Rightarrow I_{C4} = h_{FE} \cdot I_{B4} = h_{FE}\frac{10V - 3{,}5V - 0{,}6V}{4k7 \cdot (h_{FE}+1)} = \underline{\underline{1{,}2mA}}$$

For T_3 to be in active mode

$$V_{C3} = -3{,}5V = 10V - R_{C3}(I_{C3} + I_{B4}) \Rightarrow R_{C3} \le \frac{10V - 3{,}5V}{(I_{C3} + I_{B4})} = \underline{\underline{5k35}}$$