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 (12137)
Midterm Exam #1 ✐ 24 October 2017 ⌛ 17.00-19.00

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EEF 5302-5304

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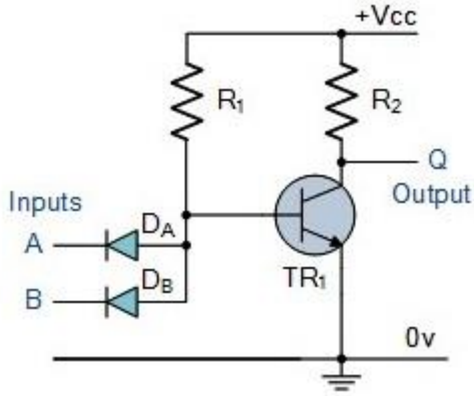
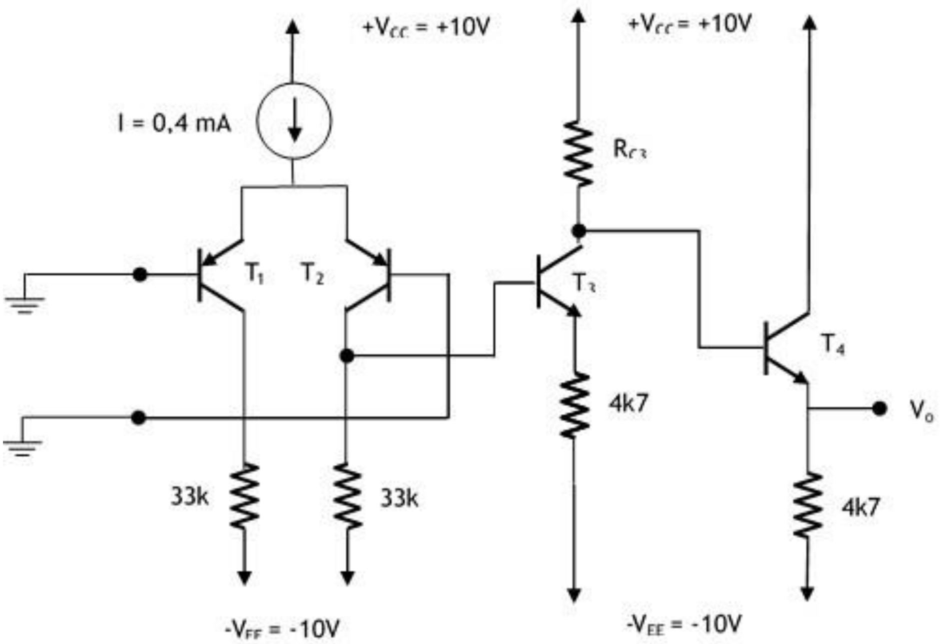
1. Assume you are to create a diode using n- and p-typed doped silicon with the following doping parameters: $N_D = 5\ 10^{15}\ /cm^3$, and $N_A = 10^{17}\ /cm^3$. (30 points)
   a. Find the barrier voltage and saturation current for a junction area of 0,1 mm^2. Calculate the specific conductivities of n- and p-type doped silicon.
   b. Determine the depletion zone width in unbiased state.
   c. Calculate the junction capacitance when this diode is reverse biased with 2 V.

   L_n = 10 µm, L_p = 5 µm, μ_n = 1350 cm^2/Vs, μ_p = 480 cm^2/Vs. 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 mV.



2. Study the logic circuit on the right and create the input output table. What function does this circuit realize? Why? (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.** (points)
   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)



BONUS: Who gave these units their names and which country are they from: mH, nF, kH, C. **Each correct answer 2,5 points! Wrong answers -2,5 each!!!!**

GOOD LUCK

SOLUTIONS:

1. Using Einstein Equation , i.e., $D_{p/n} = V_T \cdot \mu_{p/n}$, we find D_p = <u>12 cm²/s</u> and D_n = <u>33.8 cm²/s</u>.

   a. $V_B = V_T \cdot \ln\left(\frac{N_A \cdot N_D}{n_i^2}\right)$ = <u>711 mV</u>; $I_o = A \cdot q \cdot n_i^2 \cdot \left[\frac{D_p}{L_p N_D} + \frac{D_n}{L_n N_A}\right]$ = <u>185 fA</u>

   b. $\sigma_p = q \cdot \left(\frac{n_i^2}{N_A}\mu_n + N_A \mu_p\right) \cong qN_A\mu_p$ = <u>7,69 /(Ω cm)</u>

   $\sigma_n = q \cdot \left(N_D \mu_n + \frac{n_i^2}{N_D}\mu_p\right) \cong qN_D\mu_n$ = <u>1,08 /(Ω cm)</u>

   c. $w_{dep} = \sqrt{\frac{2 \cdot \varepsilon_o \cdot \varepsilon_r \cdot V_B}{q}\left(\frac{1}{N_A} + \frac{1}{N_D}\right)}$ =<u>0,44 µm</u>

   d. with reverse at 2 V, $w_{dep} = \sqrt{\frac{2 \cdot \varepsilon_o \cdot \varepsilon_r \cdot (V_B + V_{bias})}{q}\left(\frac{1}{N_A} + \frac{1}{N_D}\right)}$ = <u>0,87 µm</u>

   Thus, $C = \varepsilon_o \cdot \varepsilon_r \frac{A}{w}$ = <u>12 pF</u>

A	B	OUT
0	0	1
0	1	1
1	0	1
1	1	0

2. **It IS A NAND GATE….**

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

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