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.***

ELE222E INTRODUCTION TO ELECTRONICS (21071)
Midterm Exam #1 ✐ 25 March 2013 ⌛ 9.30-11.30

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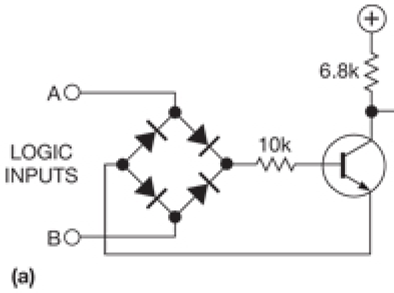
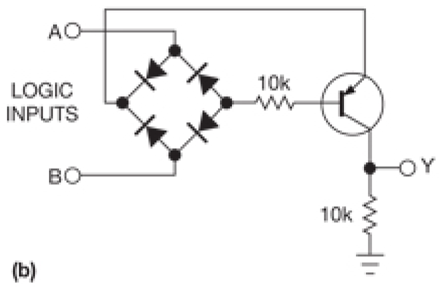
1. You have a diode with the following doping properties: $\mathbf{N_D} = 10^{18}$ /cm^3 , and $\mathbf{N_A} = 10^{15}$ /cm^3. Other important parameters to consider are $\mathbf{n_i}$ = 1,5 10^{10} /cm^3, $\mathbf{q}$ = 1,602 10^{-19} C, $\boldsymbol{\varepsilon_r}$ = 12, μ_n = 1600 cm^2/Vs, μ_p = 400 cm^2/Vs, $\boldsymbol{\varepsilon_o}$ = 8,85 10^{-12} F/m, $\mathbf{V_T}$ = 25 mV. (35 points)
   a. Find majority and minority carrier concentrations in n- and p-type doped silicon. (6 points)
   b. Find the barrier voltage. (5 points)
   c. Calculate the specific conductivities of n- and p-type doped silicon. (2x3 points)
   d. Determine the depletion zone width. How large is the depletion zone in n- and p-typed doped silicon around the junction? (7 points)
   e. What is the maximum value of the electrical field in unbiased state? (6 points)
   f. Calculate the junction capacitance for a junction area of 1 mm^2. (5 points)

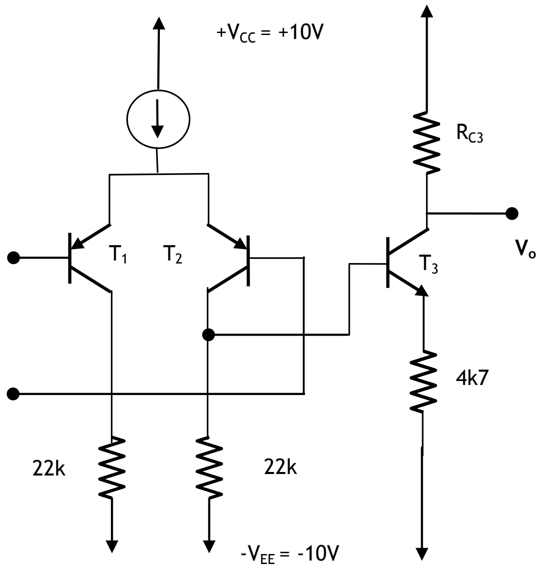
2. Look at the circuits below and complete look-up tables (like the one shown) for both (a) and (b). Assuming $\boxed{\text{logic 0} \equiv \text{low voltage; such as 0 V}}$ and $\boxed{\text{logic 1} \equiv \text{high voltage ; such as 5 V}}$ Which logic functions do these circuits realize? You need to analyze states for **A < B**, **A > B**, and **A = B** with V_D = 0,6 V, V_+ = 5V. (30 points)





A↓\B→	Logic 0	Logic 1
Logic 0		
Logic 1		

3. Study DC characteristics of the 2-stage BJT amplifier circuit shown on the right with $|\mathbf{V_{BE}}|$ = 0,6 V, and $\mathbf{h_{FE}}$ = 200 for all three transistors. (35 points)



a. Design a current source that will provide 0,4 mA biasing current to the differential stage. (10 points)

b. Choose $\mathbf{R_{C3}}$ such that $\mathbf{V_o}$ = 0V. <u>Do NOT neglect</u> base currents. (25 points)

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SOLUTIONS:

1. Using the given parameters

a.

region	Majority carriers	Mainority carriers
n-type	$n_n = N_D = 10^{18}$ /cm^3	$p_n = n_i^2/N_D = 225$ /cm^3
p-ype	$p_p = N_A = 10^{15}$ /cm^3	$n_p = n_i^2/N_A = 2{,}25\ 10^5$/cm^3

b. $V_B = -V_T \cdot \ln\left(\dfrac{n_i^2}{N_A \cdot N_D}\right) = \underline{\underline{728mV}}$

c. $\sigma_n = q\mu_n N_D = 256/\Omega\cdot cm; \sigma_p = q\mu_p N_A = 0{,}06/\Omega\cdot cm$

d. Since $x_n N_D = x_p N_A$ and $N_D/N_A = 1000 \Rightarrow w \cong x_p$, that is $x_p/x_n = 1000 \Rightarrow w \cong x_p$

$$w = \sqrt{\frac{2\cdot\varepsilon_o\cdot\varepsilon_r\cdot V_B}{q}\left[\frac{1}{N_D}+\frac{1}{N_A}\right]} = \underline{\underline{0{,}98\mu m}} \Rightarrow x_p \cong \underline{\underline{0{,}98\mu m}} \Rightarrow x_n = x_p/1000 = \underline{\underline{0{,}98nm}}$$

e. We need to find the electrical field at the junction $V_p(x) = \dfrac{q\cdot N_A}{2\cdot\varepsilon_o\cdot\varepsilon_r}x^2 - \dfrac{q\cdot N_A}{\varepsilon_o\cdot\varepsilon_r}x_p\cdot x$. Thus,

$$E(x) = -\frac{dV(x)}{dx} = \frac{q\cdot N_A}{\varepsilon_o\cdot\varepsilon_r}x - \frac{q\cdot N_A}{\varepsilon_o\cdot\varepsilon_r}x_p \Rightarrow E(x=0) = \underline{\underline{14{,}8kV/cm}}$$

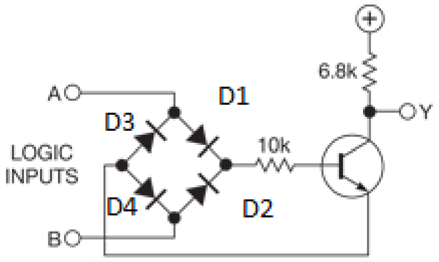
f. $C = \varepsilon_o\cdot\varepsilon_r\dfrac{A}{w} = \underline{\underline{130nF}}$

2. Lookup tables

A↓\B→	Logic 0	Logic1
Logic 0	1	0
Logic1	0	1

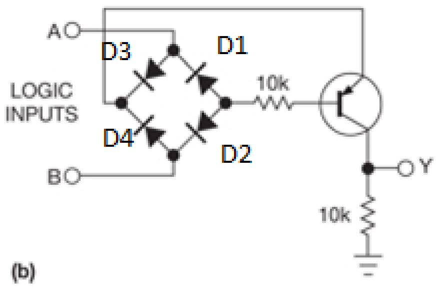
A↓\B→	Logic 0	Logic1
Logic 0	0	1
Logic1	1	0

It looks like (a) realizes an XNOR and (b) realizes an XOR functions. Let us see how this works:



(a)

With AB, 00, none of the diodes are conducting, thus, the transistor is obviously in cut off. With no collector current flowing Y = 5 V (logic 1)
Likewise with AB, 11.
With AB, 10, D1 and D4 are conducting, a base current flows. The collector is at a higher voltage than the base of the npn, thus collector current flows. The collector current initiates a voltage drop on 6k8 and Y→0 (logic 0)
With AB, 01, D2 and D3 are conducting a base current flows. The collector is at a higher voltage than the base of the npn, thus collector current flows. The collector current initiates a voltage drop on 6k8 and Y→0 (logic 0)



(b)

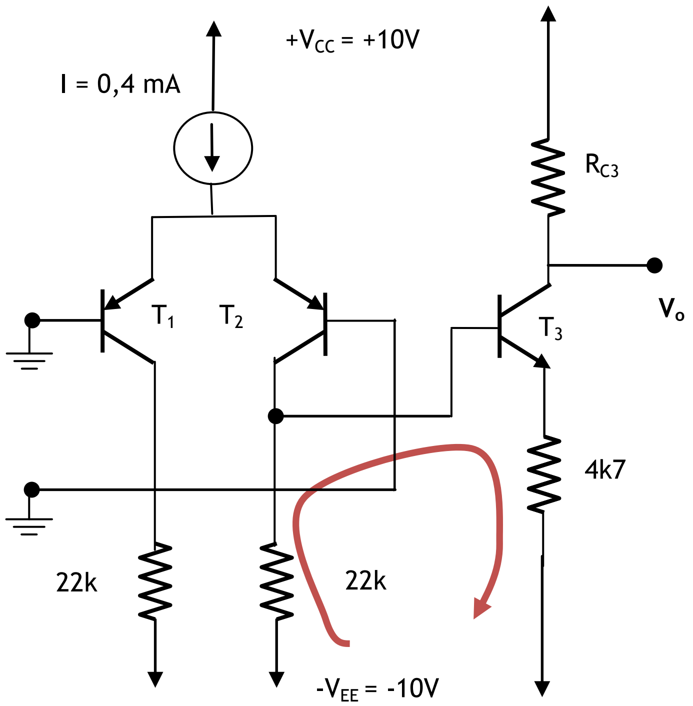
With AB, 00, none of the diodes are conducting, thus, the transistor is obviously in cut off. With no collector current flowing Y = 0 V (logic 0)
Likewise with AB, 11.
With AB, 10, D3 and D2 are conducting, a base current flows. The collector is at a lower voltage than the base of the pnp, thus collector current flows. The collector current initiates a voltage drop on 10k and Y increases (logic 1)
With AB, 01, D1 and D4 are conducting, a base current flows. The collector is at a lower voltage than the base of the pnp, thus collector current flows. The collector current initiates a voltage drop on 10k and Y increases (logic 1).

For more information look at http://jjackson.eng.ua.edu/courses/ece380/lectures/lect11-4.pdf

3. Exactly the same problem as in ELE222E INTRODUCTION TO ELECTRONICS (11245) Midterm Exam #2….
You can easily design the current mirror. So this part is left to you. Without neglecting the base currents of the differential (the very first) stage, for $V_i = 0$ V

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

Following the brown loop shown in the sketch $-(I_{C2} - I_{B3})22k + V_{BE3} + (h_{FE}+1)I_{B3}4k7 = 0$



$$I_{C3} = h_{FE}\frac{22k*I_{C2} - V_{BE3}}{(h_{FE}+1)4k7 + 22k} = 200\frac{22k*0{,}199mA - 0{,}6V}{(200+1)4k7 + 22k} = \underline{\underline{0{,}782mA}}$$

$$V_o = 0V \Rightarrow I_{C3}R_{C3} = V_{CC} = 10V \Rightarrow R_{C3} = \frac{V_{CC} - V_o}{I_{C3}} = \frac{10V}{0{,}782mA} = \underline{\underline{12k8}}$$