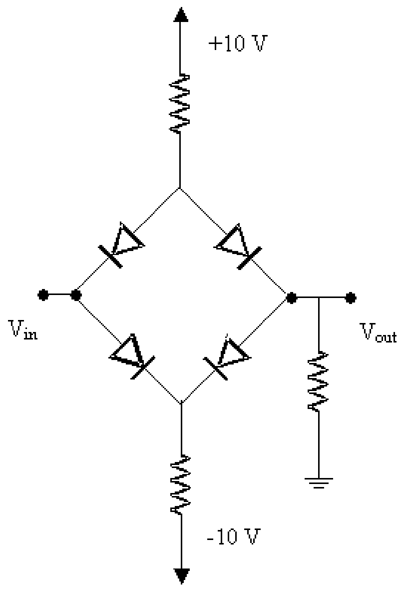
IMPORTANT: Besides your **calculator** and the sheets you use for calculations you are only allowed to have an A4 sized **"copy sheet"** during this exam. Notes, problems and alike are not permitted. **Please submit your "copy sheet" along with your solutions.** You may get your "copy sheet" back after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

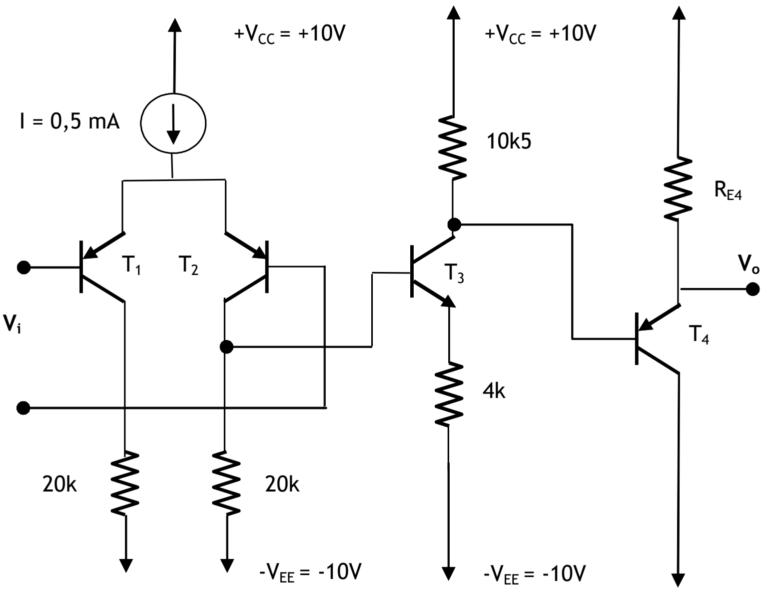
EHB222E INTRODUCTION TO ELECTRONICS (21124)
Midterm Exam #1 ✐ 19 March 2018 ⌛ 9.30-11.30
İnci ÇİLESİZ, PhD, M. Yasin ADIYAMAN
EEF 5205

---

1. Compare and contrast conductors vs. semi-conductors. State similarities and differences. (10 p BONUS!)
2. Assume you have a diode made of n- and p-typed doped silicon with the following parameters $N_D = 10^{16}$ 1/cm^3 and $N_A = 10^{17}$ 1/cm^3 . You also know $L_n = 10$ µm, $L_p = 5$ µm, $\mu_n = 1350$ cm^2/Vs, $\mu_p = 480$ 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
   a. For the dark current (I_o) to be under 100 fA how large should the junction area A be in mm^2? (10)
   b. If you cannot find A above, assume 0,5 mm^2 and calculate specific conductances of n and p type doped regions. (10)
   c. Find depletion range width and junction capaticance in unbiased state. (10 puan)
3. For the circuit shown on the right sketch V_{out} as a function of V_{in} for V_{in}: -10 V to +10 V assuming all three resistors are 10k and the voltage drop across conducting diodes are constant at 0,6 V. (30 points) HINT: Analyze the circuit first at V_{in} = 0V; then at +10 V and –10 V, and finally at values in between.



4. Study DC characteristics of the 3-stage BJT amplifier circuit with $|V_{BE}| = 0,6$ V, $h_{FE} = 100$ for all four transistors.
   a. Design a current source that will provide 0,5 mA biasing current to the differential stage. (10 p)



   b. How should R_{E4} be chosen, such that, waveform distortion at the output is symmetrical, that is, V_o = 0V? If you cannot find take I_{C3} = 1 mA. (30p)

GOOD LUCK

SOLUTIONS:

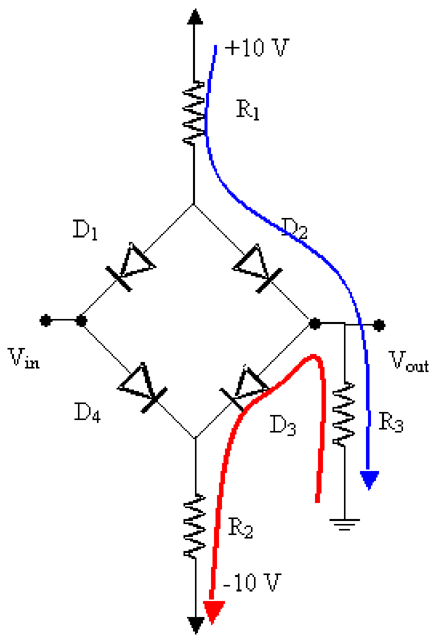
2. $D_{p/n} = V_T \cdot \mu_{p/n}$ ‘ thus D_p = 12 cm^2/s and D_n = 33.8 cm^2/s

   a. $I_o = A \cdot q \cdot n_i^2 \cdot \left[\frac{D_p}{L_p N_D} + \frac{D_n}{L_n N_A} \right]$ thus if I_o < 100 fA for A < 1,01 mm^2.
   Thus I choose A = 1 mm^2.

   b. $\sigma_p = q \cdot \left(\frac{n_i^2}{N_A} \mu_n + N_A \mu_p \right)$; $\sigma_n = q \cdot \left(N_D \mu_n + \frac{n_i^2}{N_D} \mu_p \right)$
   Thus σ_p = 7,69 1/(Ω cm) σ_n = 2,16 1/(Ω cm).

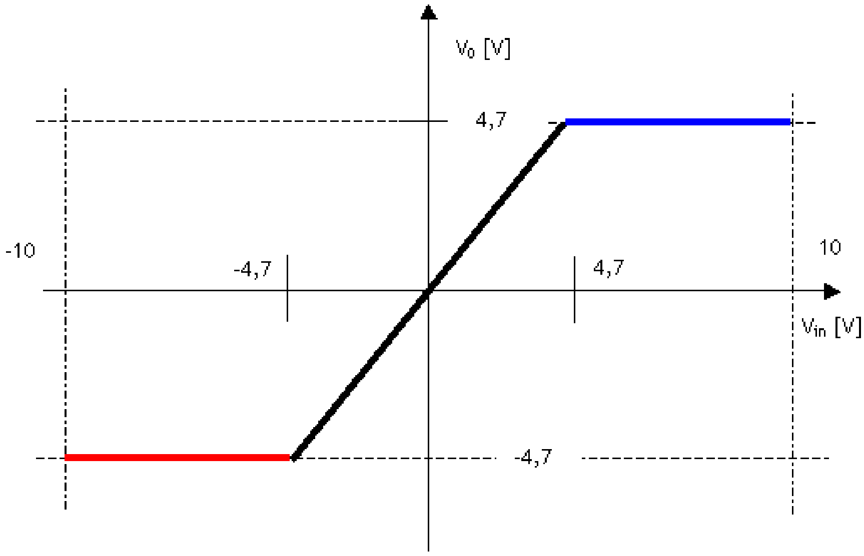
   c. $V_B = -V_T \cdot \ln \left(\frac{n_i^2}{N_A \cdot N_D} \right)$ thus V_B = 728 mV and $w = \sqrt{\frac{2 \cdot \varepsilon_o \cdot \varepsilon_r \cdot V_B}{q \cdot} \left[\frac{1}{N_A} + \frac{1}{N_D} \right]}$ thus
   w_{dep} = 3,26 µm and $C = \varepsilon_o \cdot \varepsilon_r \frac{A}{w}$ C = 326 pF

3. Assume there is no V_{in}. V_{out} = 0V because of the symmetry of the circuit, and because all diodes are conducting. This is the same as V_{in} = 0V. Now assume V_{in} = 10V. We can easily see that D_1 and D_3 are reverse biased because most of the voltage drop from +10 V to –10 V is over the resistors R_1 and R_2. In other words, the anode of D_1 is much less than +10V whereas the cathode is at +10V (reverse bias). Also, D_4 is conducting, thus, the cathode of D_3 is at 9,4V wheras the anode of D_3 is much less than +9,4V. That means current flows (a) from +10V over R_1, D_2 , and R_3 to ground (**follow blue line**), and (b) from V_{in} over D_4 and R_4 to –10V. Since only 0,6V drops on the conducting diodes 9,4V drops over the two resistors R_1 and R_3. Since R_1 and R_3 have equal values, we divide the voltage drop by 2 and this is V_{out} = 4.7V.



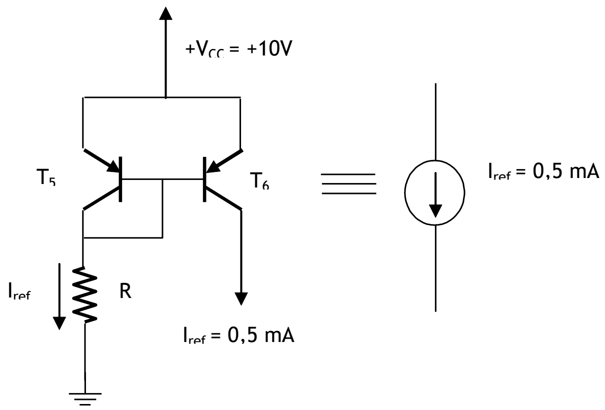
Now assume V_{in} = -10V. Similar to the observations above, D_4 and D_2 are reverse biased because most of the voltage drop from +10 V to –10 V is again over the resistors R_1 and R_2. In other words, the cathode of D_4 is much higher than -10V whereas the anode is at -10V (reverse bias again). Also, D_1 is conducting, thus, the anode of D_2 is at -9,4V wheras the cathode of D_2 is much higher than -9,4V. That means current flows (a) from the ground over R_3, D_3 , and R_2 to –10V (**follow red line**), and (b) from +10V over R_1 and D_1 to V_{in}. Since only 0,6V drops on the conducting diodes 9,4V drops over the two resistors R_2 and R_3. Since R_2 and R_3 have equal values, we divide the voltage drop by 2 and this is V_{out} = 4.7V.

Finally, we need to consider the output for 0V ≥ V_{in} ≥ -10V and 0V ≤ V_{in} ≤ +10V. One sees easily that when all the 4 diodes are conducting, the output V_{out} follows the input V_{in} because the circuit is symmetrical. When do all the 4 diodes conduct? See the sketch below….Capito????



4. DC characteristics are to be studied.

   a. See the sketch below. You should calculate the value of R, and make sure T_6 operates in active mode.

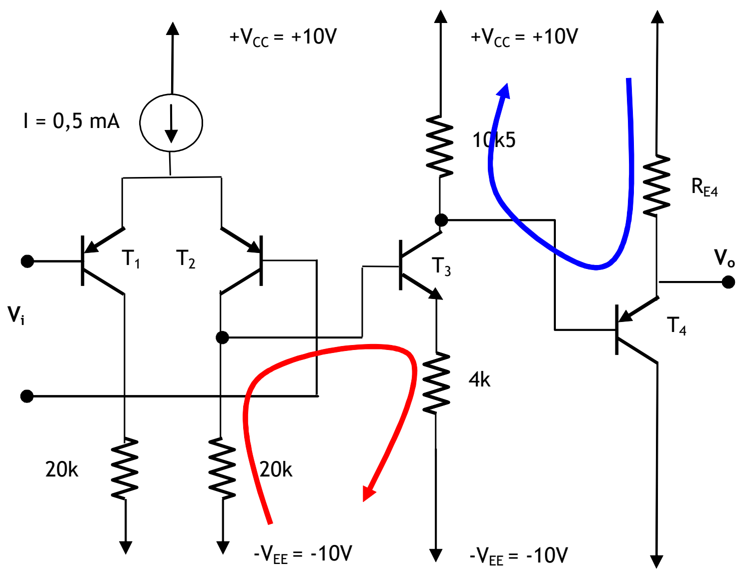


   Without neglecting the base currents of the differential stage, for $V_i = 0$

$$I_{C1} = I_{C2} = \frac{h_{FE}}{h_{FE}+1} \cdot \frac{0{,}5mA}{2}$$

$$I_{C1} = I_{C2} = 0{,}248mA$$

   b. Following the red loop $-(I_{C2} - I_{B3})20k + V_{BE3} + (h_{FE}+1)I_{B3}4k = 0$



$$I_{C3} = h_{FE}\frac{20k * I_{C2} - V_{BE3}}{(h_{FE}+1)4k + 20k} = 100\frac{20k * 0{,}248mA - 0{,}6V}{(100+1)4k + 20k} = 1{,}028mA$$

Following the blue loop and recalling that waveform distortion at the output should be minimum and symmetrical, i.e., $V_o = 0\ V$

$(h_{FE}+1)I_{B3}R_{E4}+V_{EB4}-(I_{C3}-I_{B4})10k5=0$, with $(h_{FE}+1)I_{B4}R_{E4}=10V$

$$10V+V_{EB4}-(I_{C3}-I_{B4})10k5=10V+0{,}6V-(1{,}028\,mA-I_{B4})10k5=0$$

$I_{C4}=h_{FE}\left[1{,}028mA-\dfrac{10{,}6V}{10k5}\right]=\underline{\underline{1{,}87mA}}$ and $R_{E4}=\dfrac{10V}{(h_{FE}+1)I_{B4}}=\underline{\underline{5k27}}$