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 #2 ✎ 29 April 2019 ⌛ 9:30-11:30
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EEF 5105

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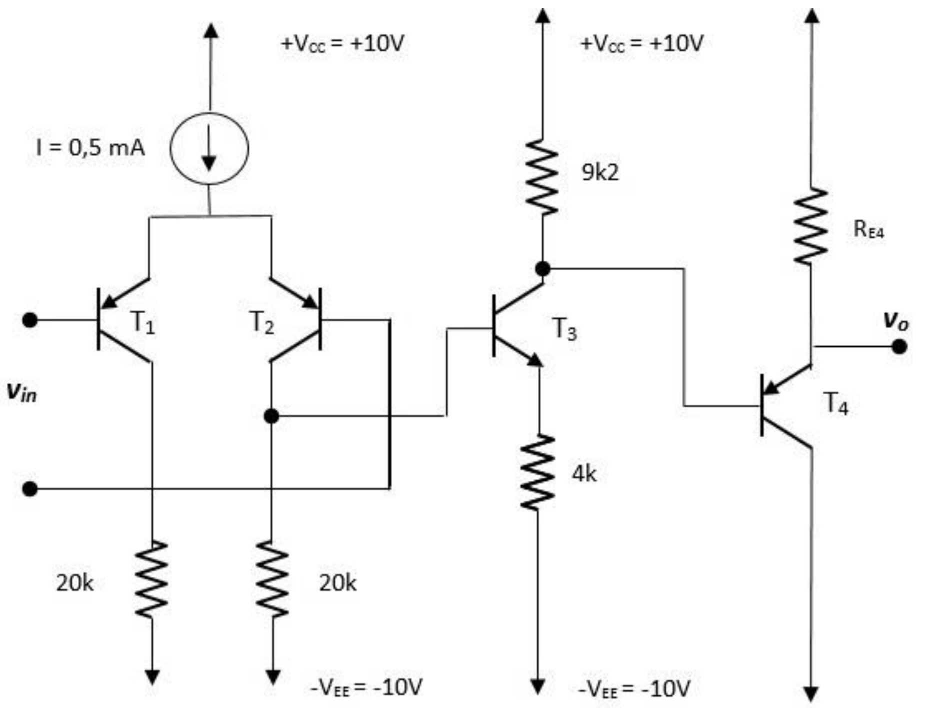
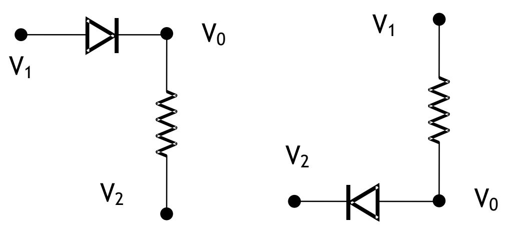
1. What is a semi-conductor? Compare and contrast conductors and semi-conductors. (10 points)
2. Assuming $|V_{BE}| = 0{,}6$ V, $h_{fe} = h_{FE} = 100$, $h_{oe} = h_{re} = 0$ analyze the three-stage BJT amplifier shown below:



   a. Design a current source that will provide **0,5 mA biasing current** to the differential stage. (10 points)
   b. Find $\mathbf{R_{E4}}$ for $\mathbf{V_o}$ = 0 V. If you cannot find I_{C3} you may assume I_{C3} = 1 mA. (20 points)
   c. Find the **overall gain** and the **output resistance**. (20 points)
   d. Find the **overall gain** when the circuit is powered by a source having an internal resistance of 1k and the load resistance is 1 k. (10 points)
   e. Calculate **CMRR**. (10 points)

3. Assuming V_D = 0 V when diodes are forward biased, find the input/output table for the circuits shown using a table like shown below. (30 points)



↓V₂/V₁→	0V	5V
0V	?	?
5V	?	?

GOOD LUCK

SOLUTIONS:

1. Conductors are elements whose valance electrons can easily move from the valance band over to the conduction band. Valance electrons of semiconductors have to overcome the gap energy barrier to move into the conduction band. Electrons are the only charged carriers in conductors. In semiconductors there are positively charged holes in addition to electrons that are charged carriers. There are at least 10 orders of magnitude difference in charged carriers conductors having much more electrons.

2. For ***V_o = 0 V*** $V_{B4} = V_{BE4} = -0{,}6V = V_{C3} = V_{CC} - R_{C3}(I_{C3} - I_{B4}) = 10V - 10k \cdot (I_{C3} - I_{B4})$ We know $I_{C1} = I_{C2} \cong \underline{\underline{0{,}25mA}}$. From the loop 20k – T_3 – 4k, $-20k(I_{C2} - I_{B3}) + V_{BE3} + 4k \cdot I_{E3} = 0$

$\Rightarrow I_{C3} = h_{FE}\dfrac{20k \cdot I_{C2} - V_{BE3}}{(h_{FE}+1)4k + 20k}$ and $I_{C3} = \underline{\underline{1{,}04mA}}$.

Insert those values into $V_{B4} = V_{BE4} = -0{,}6V = 10V - 10k \cdot (I_{C3} - I_{B4})$ you find $I_{C4} = \underline{\underline{2mA}}$.

$V_o = V_{CC} - R_{E4}I_{E4} = 10V - R_{E4}(h_{FE}+1)I_{B4} = 0V$ and thus $R_{E4} = \dfrac{10V}{(h_{FE}+1)I_{B4}} = \underline{\underline{4k95}}$

$$r_{e1} = r_{e2} = \frac{V_T}{0{,}25mA} = \underline{\underline{100\Omega}}; r_{e3} = \frac{V_T}{1{,}04mA} = \underline{\underline{24\Omega}}; r_{e4} = \frac{V_T}{2mA} = \underline{\underline{12{,}5\Omega}}$$

$$A_v = \frac{v_o}{v_{in}} = \frac{v_o}{v_{b4}} \cdot \frac{v_{b4}}{v_{b3}} \cdot \frac{v_{b3}}{v_{in}} = +\frac{R_{e4}}{r_{e4} + R_{e4}} \cdot \left[-\frac{R_{C3} \parallel r_{i4}}{r_{e3} + R_{e3}}\right] \cdot \left[-\frac{R_{C2} \parallel r_{i3}}{2r_{e1}}\right] \text{ with}$$

$$r_{i3} = h_{fe}(r_{e3} + R_{e3}) = 100(24 + 4k) = \underline{\underline{402k4}}; r_{i4} = h_{fe}(r_{e4} + R_{e4}) = 100(12{,}5 + 4k95) = \underline{\underline{496k25}}$$

$$A_v = \frac{v_o}{v_{in}} = \frac{4k95}{12{,}5 + 4k95} \cdot \left[-\frac{10k \parallel 496k25}{24 + 4k}\right] \cdot \left[-\frac{20k \parallel 402k4}{2 \cdot 100}\right] = 0{,}997 \cdot (-2{,}436)(-95{,}265) \cong \underline{\underline{231{,}5}}$$

$$r_o = r_{e4} + \frac{R_{g4}}{h_{fe}} = r_{e4} + \frac{R_{C3}}{h_{fe}} = 12{,}5 + \frac{10k}{100} = \underline{\underline{112{,}5\Omega}}$$

With 1k load and source resistors $\dfrac{v_o}{v_{b4}} = \dfrac{R_{e4} \parallel 1k}{r_{e4} + R_{e4} \parallel 1k}$ and thus

$$A_v^* = \frac{v_o}{v_{in}} = \frac{v_o}{v_{b4}} \cdot \frac{v_{b4}}{v_{b3}} \cdot \frac{v_{b3}}{v_{in}} = 0{,}985 \cdot (-2{,}436) \cdot (-95{,}265) = \underline{\underline{228{,}63}}.$$

$$A_{total} = \frac{v_o}{v_g} = \frac{r_i}{r_i + R_g} \cdot \frac{R_{e4} \parallel 1k}{r_{e4} + R_{e4} \parallel 1k} \cdot \left[-\frac{R_{C3} \parallel r_{i4}}{r_{e3} + R_{e3}}\right] \cdot \left[-\frac{R_{C2} \parallel r_{i3}}{2r_{e1}}\right] = \frac{20k}{20k + 1k} \cdot 228{,}63 = \underline{\underline{217{,}74}}$$

Since there is no emitter resistor in the differential stage CMRR → ∞

3. Diodes will be assumed short circuit when forward biased. Thus as long as **$V_1>V_2$** the output will follow the input. When **$V_1<V_2$ or $V_1=V_2$** diodes are open circuit.

↓V_2/V_1→	0V	5V
0V	0V	5V
5V	5V	5V

↓V_2/V_1→	0V	5V
0V	0V	0V
5V	0V	5V

Thus the first circuit is a LOGIC OR gate whereas the second one is a LOGIC AND gate.