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!**

ELE222E INTRODUCTION TO ELECTRONICS (21403)
Midterm Exam #1 ✎ 19 March 2007 ⌚ 10.00-12.00

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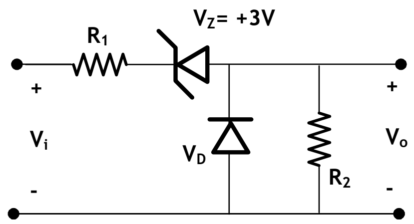
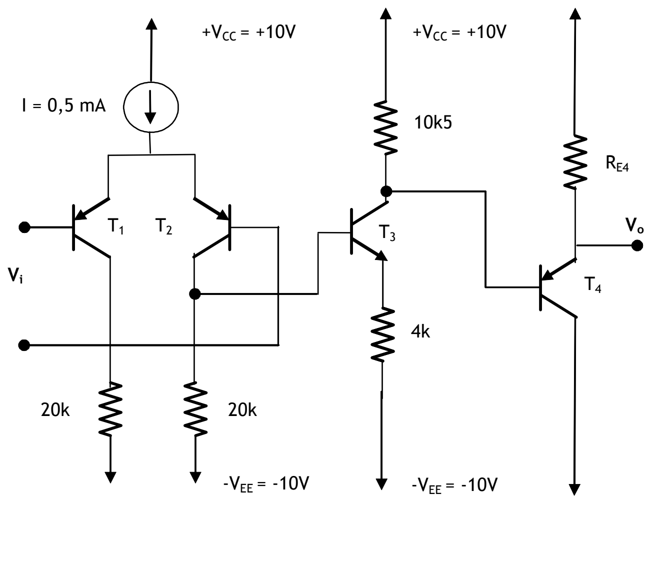
1. Assume you are to create a diode using n- and p-typed doped silicon with the following doping parameters: N_D = 5 10^{15} /cm^3 , and N_A = 10^{17} /cm^3.
   a. Find the barrier voltage and saturation current for a junction area of 0,1 mm^2. (10 points)
   b. Calculate the specific conductivities of n- and p-type doped silicon. (6 points)
   c. Determine the depletion zone width in unbiased state. (4 points)
   d. Calculate the junction capacitance when this diode is reverse biased with 2 V. (5 points)

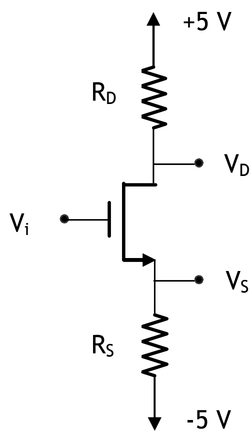
   L_n = 10 µm, L_p = 5 µm, μ_n = 1350 cm^2/Vs, μ_p = 480 cm^2/Vs. n_i = 1.5 10^{10} /cm^3, q = 1.602 10^{-19} C, ε_r = 12, ε_o = 8.85 10^{-12} F/m, V_T = 25 mV.



2. 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. (25 points)

3. 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 points)
   b. How should R_{E4} be chosen, such that, waveform distortion at the output V_o is minimum and symmetrical? If you cannot find take I_{C3} = 1 mA. (20 points)





4. The NMOS transistor on the left has the following parameters:
   V_{th} = 1,2 V, $\mu_n C_{ox}(W/L)$ = 0,16 mA/V^2.
   Determine the source and drain resistances, such that, with the gate grounded, I_D = 100 µA and V_{DS} = 4,5 V. (20 points)

GOOD LUCK!

SOLUTIONS:

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

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

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

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

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

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

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

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.

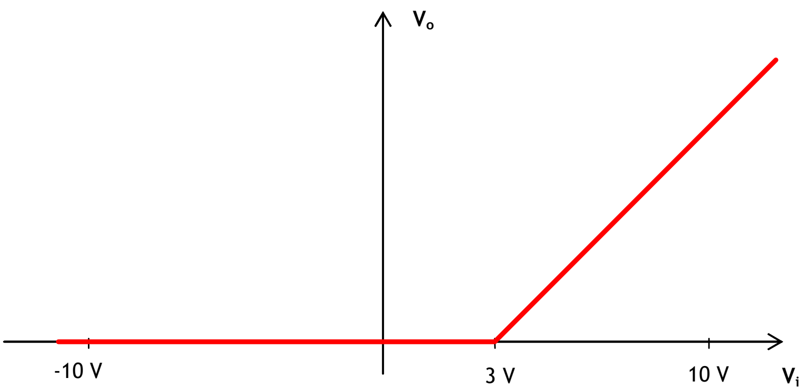
      iii. current flows over R_1, the Zener diode and R_2.and is $I = \frac{V_i - V_Z}{R_1 + R_2}$

      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 not in Zener zone.

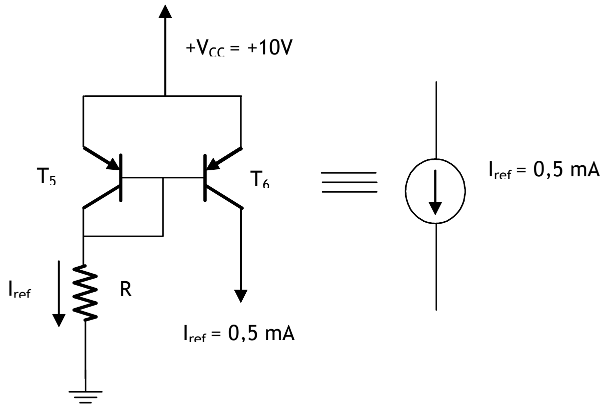
      i. no current flows over R_1, the Zener diode, the regular diode and R_2.

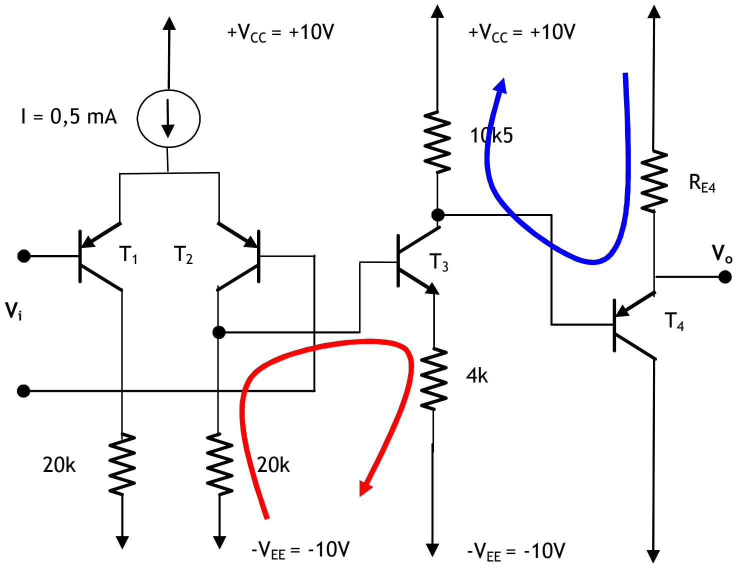
      ii. V_o = 0 V.



3. DC characteristics are to be studied.

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





<u>Without neglecting</u> the base currents of the differential stage, for $V_i = 0$

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

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

   b. Following the red loop

$$-(I_{C2} - I_{B3})20k + V_{BE3} + (h_{FE}+1)I_{B3}4k = 0$$

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

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 $(h_{FE}+1)I_{B4}R_{E4} = 10V$

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

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

4. $I_D = \frac{\mu_n C_{ox}}{2}\frac{W}{L}[V_{GS} - V_{th}]^2 \Rightarrow V_{GS} = V_{th} \pm \sqrt{\frac{I_D}{\frac{\mu_n C_{ox}}{2}\frac{W}{L}}} = 1{,}2V \pm \sqrt{\frac{0{,}1mA}{0{,}08mA/V^2}} = \begin{cases} 2{,}318V \\ 0{,}082V \end{cases}$

Since $V_{GS} \geq V_{th}$ for channel creation, $V_{GS} = \underline{\underline{2{,}318V}}$.

As $V_G = 0V \Rightarrow V_S = -2{,}318V$ thus $R_S = \frac{V_S - (-5V)}{0{,}1mA} = \underline{\underline{26k82}}$

Since $V_{DS} = 4{,}5V \Rightarrow V_D = V_S + V_{DS} = -2.318V + 4{,}5V = 2{,}182V$ and thus

$$R_D = \frac{5V - V_D}{0{,}1mA} = \frac{5V - 2{,}182V}{0{,}1mA} = \underline{\underline{28k18}}$$