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 (21454)
Midterm Exam #2 ✎ 5 May 2014 ⌛ 9.30-11.30
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EEF 2104 and 5201

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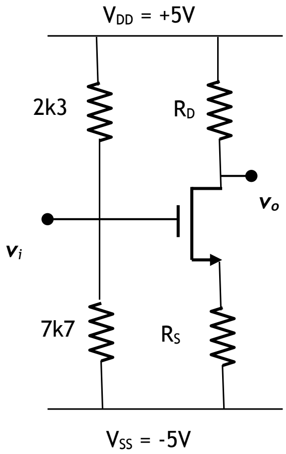
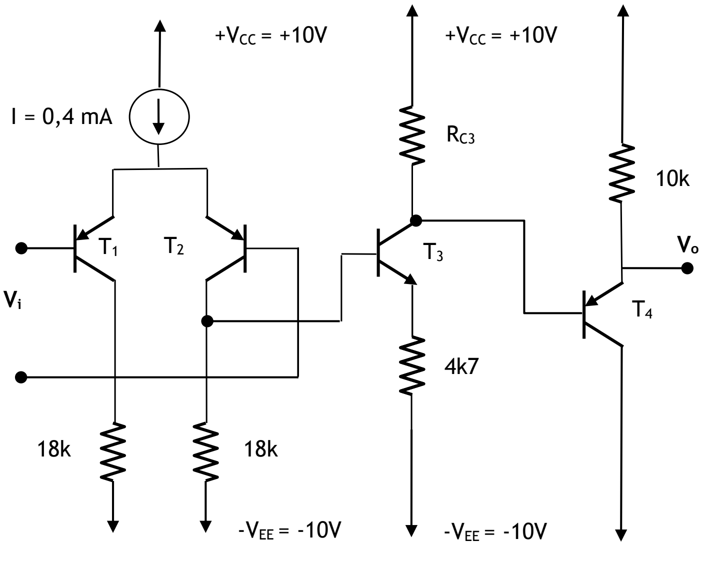
1. You remember the MOS transistor shown on the circuit to the left from your first exam. The NMOS properties are **V_T = 2 V, V_A = ∞**, $\mu_n C_{ox}\left(\frac{W}{L}\right) = 2mA/V^2$
   a. Find the missing resistor values for the NMOS to operate in saturation with **I_D = 1 mA** . (10 points).
   b. Calculate **input** and **output resistances**, gain **v_o/v_i** and **v_o/v_s** when the circuit is fed capacitively (i.e., using a capacitor to ensure that biasing conditions are not affected) with a source having an internal resistance of **1 k**. (30 points).
   c. How can you increase the gain *<u>without changing biasing conditions</u>*? Calculate the increased gain **v_o/v_i** and **v_o/v_s** (10 points).



2. You also know the 3-stage BJT amplifier circuit from your first exam. **|V_{BE}| = 0,6 V, h_{FE} = h_{fe} = 200, h_{re} = 0, h_{oe} = 0,** for all four transistors. **Do NOT neglect base currents.**
   a. Determine the value of the emitter resistor that will provide **0,4 mA biasing current** to the differential stage. (5 points)
   b. Choose **R_{C3}** such that, waveform distortion at the output V_o is minimum and symmetrical, i.e., **V_o = 0V**? (10 points)
   c. Find the **input** and **output resistances**, the gain **v_o/v_i** and **CMRR**. **V_T = 25 mV.** (35 points)



GOOD LUCK

SOLUTIONS:

1. The MOS design looks very simple BUT as you know from your first exam, many make mistakes. 2k3 and 7k7 resistors divide the 10 V voltage difference, such that $V_G = -5V + 7{,}7V = 2{,}7V$.

   From the given properties it is obvious that $V_{GS} - V_t = 1V$.

   Since we are working with NMOS $V_{GS} = 3V \Rightarrow V_S = V_G - V_{GS} = -0{,}3\ V \Rightarrow$

$$R_S = \frac{V_S - V_{SS}}{I_D} = \frac{-0{,}3V - (-5V)}{1mA} = \underline{\underline{4k7}}$$

   For the NMOS to operate in saturation $V_{DS} = V_{GS} - V_t = 1V \Rightarrow V_D = V_S + 1V = -0{,}3 + 1 = 0{,}7\ V$

$$R_D = \frac{V_{DD} - V_D}{I_D} = \frac{5V - 0{,}7V}{1mA} = \underline{\underline{4k3}}$$

$$Gain = \frac{v_o}{v_i} = \frac{-R_D}{1/g_m + R_S} \text{ with } g_m = \mu_n C_{ox}\frac{W}{L}(V_{GS} - V_{tn}) = 2(3-2) = \underline{\underline{2mA/V}} = \frac{1}{\underline{\underline{500\Omega}}}$$

   Thus $\dfrac{v_o}{v_i} = \dfrac{-R_D}{1/g_m + R_S} = \dfrac{-4k3}{500\Omega + 4k7} = \underline{\underline{-0{,}826}}$

   Realize $r_i = \dfrac{v_i}{i_i} \to \infty$ for the NMOS, thus $r_i^* = 2k3 \parallel 7k7 = \underline{\underline{1k77}}$, also $r_o = R_D = \underline{\underline{4k3}}$

   Since $\dfrac{v_s}{v_i} = \dfrac{r_i^*}{R_{in} + r_i^*} = \dfrac{1k77}{1k + 1k77} = 0{,}639$, $\dfrac{v_o}{v_s} = \dfrac{v_o}{v_i} \cdot \dfrac{v_i}{v_s} = \underline{\underline{-0{,}528}}$

   To increase gain R_s should be shorted at AC using a bridging capacitor resulting in

$$\frac{v_o}{v_i} = \frac{R_D}{1/g_m} = \frac{-4k3}{1/2mA/V} = \frac{-4k3}{500} = \underline{\underline{-8{,}6}} \text{ and } \frac{v_o}{v_s} = \frac{v_o}{v_i} \cdot \frac{v_i}{v_s} \cong \underline{\underline{-5{,}5}}$$

2. DC characteristics are to be studied.

   a. $R_E = \dfrac{V_{CC} - V_E}{I} = \dfrac{10V - 0{,}6V}{0{,}4mA} = \underline{\underline{23k5}}$

   b. <u>Without neglecting</u> the base currents of the differential (the very first) stage, for V_i = 0 V

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

$$-(I_{C2} - I_{B3})18k + V_{BE3} + (h_{FE}+1)I_{B3}4k7 = 0$$

$$I_{C3} = h_{FE}\frac{18k * I_{C2} - V_{BE3}}{(h_{FE}+1)4k7 + 18k} = 200\frac{18k * 0{,}199mA - 0{,}6V}{(200+1)4k7 + 18k} = \underline{\underline{0{,}62mA}}$$

That the output voltage is in the middle of the power supply range (+10 V and -10 V), V_o = 0 V

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

$$(I_{C3}-I_{B4})R_{C3}=10V+V_{EB4} \Rightarrow R_{C3}=\frac{10V+V_{EB4}}{I_{C3}-I_{B4}}=\underline{\underline{17k25}}$$

Now the gain is $\dfrac{v_o}{v_i}=\dfrac{v_o}{v_{b3}}\cdot\dfrac{v_{b4}}{v_{b3}}\cdot\dfrac{v_{b3}}{v_i}=\dfrac{10k}{10k+r_{e4}}\cdot\dfrac{-R_{C3}\parallel r_{i4}}{4k7+r_{e3}}\cdot\dfrac{18k\parallel r_{i3}}{2r_{e1/2}}$ with

$$r_i=r_{i1/2}=2h_{fe}r_{e1/2}=2\cdot 200\cdot\frac{25mV}{0{,}199mA}=\underline{\underline{50k25}};$$

$$r_{e1/2}=\underline{\underline{125{,}6\Omega}}$$

$$r_{e3}=\frac{25mV}{0{,}62mA}=40{,}3\Omega;$$

$$r_{e4}=\frac{25mV}{1mA}=25\Omega$$

$$r_{i3}=h_{fe}(r_{e3}+4k7)=948k$$

$$r_{i4}=h_{fe}(r_{e4}+10k)=2M$$

Resulting in $\dfrac{v_o}{v_i}=\dfrac{10k}{10k+r_{e4}}\cdot\dfrac{-17k25\parallel r_{i4}}{4k7+r_{e3}}\cdot\dfrac{18k\parallel r_{i3}}{2r_{e1/2}}=0{,}997\cdot(-3{,}608)\cdot 70{,}307\cong\underline{\underline{-253}}$

$$CMRR=20\log_{10}\left|\frac{2R_E+r_{e1/2}}{r_{e1/2}}\right|=20\log_{10}\left|\frac{2\cdot 23k5+125{,}6}{125{,}6}\right|=\underline{\underline{51{,}5dB}}$$