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 (12482)
Final Exam ✐ 9 January 2013 ⌛ 12.00-14.00

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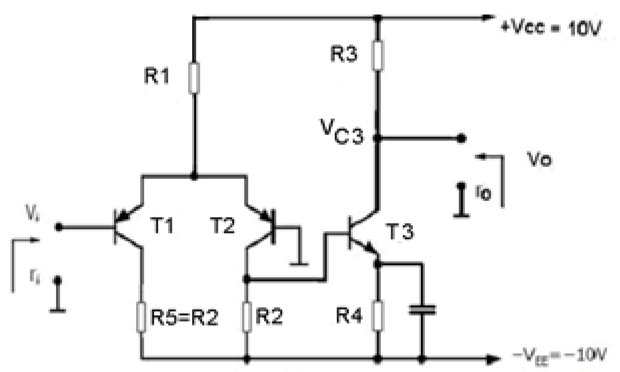
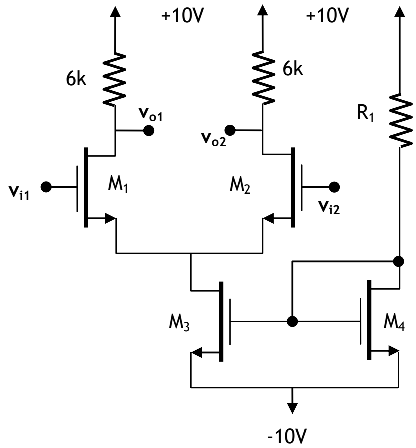
1. For the BJTs shown below left $h_{fe} = \beta_F = 250$, $|V_{BE}| = 0{,}6V$ and $V_A = \infty$. For $V_i = 0V$ determine resistor values and $CMRR$ such that $V_{C3} = 0$ V, $r_i = 62k$, $r_o = 10k$ and $|v_o/v_i| = 6400$. Recall $R_1 >> r_{e2}$ and $V_T = 25$ mV (30 points).





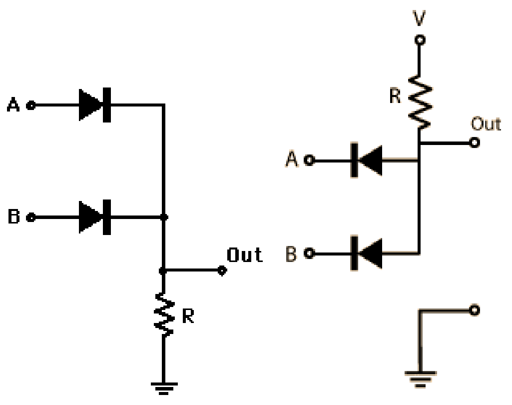
2. Looking at the NMOS differential amplifier above right, for $V_{tN} = 0{,}8\ V$, $K_N = \frac{\beta}{2} = \frac{1}{2}\mu_n\, C_{ox}\frac{W}{L} = 0{,}4\ mA/V^2$
   a. Design an NMOS current source satisfying $I_{DQ1} + I_{DQ2} = I_{DQ3} = 1\ mA$
   b. Find DC values of both outputs and <u>check</u> if all MOS are in saturation.
   c. Find common mode gain of the circuit for $V_A = \infty$.
   d. Find $K_{d1} = \frac{v_{01}}{V_{i1} - V_{i2}}$ and $K_{d2} = \frac{v_{02}}{V_{i1} - V_{i2}}$ and $CMRR$ (30 points).

3. Design a circuit that will realize the function $y = x_1 - x_2 - x_3$ using ONE single OPAMP only. (20 points)

4. Look at the circuits below (V = 5V) and complete the look-up table for both. Which logic functions do these circuits realize if $\boxed{0\text{ V} \equiv \text{logic O}}$ and $\boxed{V_{out} \geq 4\text{ V} \equiv \text{logic 1}}$? Assume $V_D = 0{,}6$ V.

A↓\B→	0 V	5 V
0 V		
5 V		

A↓\B→	0 V	5 V
0 V		
5 V		



(20 points)

GOOD LUCK

SOLUTIONS: PROBLEM 1:

$$V_{C3} = V_{CC} - R_{C3} I_{C3} = 0V \Rightarrow I_{C3} = \frac{V_{CC}}{R_{C3}} = \frac{10V}{10k} = \underline{\underline{1mA}}$$

$r_o = r_{o3} = R_{C3} = 10k \Rightarrow R_3 = \underline{\underline{10k}}$ also

$$\Rightarrow r_{e3} = \frac{V_T}{I_{C3}} = \frac{25mV}{1mA} = \underline{\underline{25\,\Omega}}$$

$$r_i = r_{i1/2} = 2h_{fe} r_{e1/2} = 62k \Rightarrow r_{e1/2} = \frac{62k}{2h_{fe}} = \frac{62k}{2 \cdot 250} = \underline{\underline{128\,\Omega}}$$

Since $r_{e1/2} = \frac{V_T}{I_{C1/2}} \Rightarrow I_{C1/2} = \frac{V_T}{r_{e1/2}} = \frac{25mV}{128\,\Omega} = \underline{\underline{195\,\mu A}}$

$$V_{CC} - V_{EB} = 2I_{E1/2} \cdot R_1 \Rightarrow R_1 = \frac{V_{CC} - V_{EB}}{2I_{E1/2}} = \frac{V_{CC} - V_{EB}}{2\frac{h_{fe}+1}{h_{fe}} I_{C1/2}} = \frac{10V - 0{,}6V}{2\frac{250+1}{250} 0{,}195\,mA} \cong \underline{\underline{24k}}$$

Now $|A_v| = \left|\frac{v_o}{v_i}\right| = \left| -\frac{R_{C3}}{r_{e3}} \cdot \frac{R_{C2} \parallel r_{i3}}{2r_{e1/2}} \right| = 6400$ Thus $R_2 \parallel r_{i3} = \frac{6400}{\left(\frac{R_{C3}}{r_{e3}}\right)} 2r_{e1/2} = \frac{6400}{\left(\frac{10k}{25\,\Omega}\right)} 2 \cdot 128\,\Omega = 4k096$

with $r_{i3} = h_{fe} r_{e3} = 250 \cdot 25\Omega = \underline{\underline{6k25}} \Rightarrow R_2 \parallel r_{i3} = 4k096 = R_2 \parallel 6k25 \Rightarrow R_2 = \underline{\underline{11k8}}$

Since $-R_2(I_{C2} - I_{B3}) + V_{BE} + I_{E3}R_4 = 0$ that is $-R_2(I_{C2} - I_{B3}) + V_{BE} + (h_{fe}+1)I_{B3}R_4 = 0$

Inserting the values we know $R_4 = \frac{R_2(I_{C2} - I_{B3}) - V_{BE}}{(h_{fe}+1)I_{B3}} = \frac{11k8(195\,\mu A - \frac{1mA}{250})}{251 \cdot \frac{1mA}{250}} = \underline{\underline{2k26}}$

$$CMRR = 20\log_{10}\left|\frac{2R_E + r_{e1/2}}{r_{e1/2}}\right| = 20\log_{10}\left|\frac{2R_1 + r_{e1/2}}{r_{e1/2}}\right| = 20\log_{10}\left|\frac{2 * 24k + 128\,\Omega}{128\,\Omega}\right| = \underline{\underline{51{,}5dB}}$$

PROBLEM 2

$V_{GS3} = \pm\sqrt{\frac{I_{D3}}{K_3}} + V_{t3}$ →→→ $V_{GS3} = \pm\sqrt{\frac{1mA}{0{,}4mA/V^2}} + 0{,}8V = \pm 1{,}58 + 0{,}8 = \begin{cases} -0{,}78V \\ 2{,}38V \end{cases}$, →→→ proper solution comes as $V_{GS3} = \underline{\underline{2{,}38V}}$

On the other hand $R_1 = \frac{+10V - (-10V) - V_{GS4}}{I_{DQ4}} = \frac{10V + 10V - 2{,}87V}{1mA} = \underline{\underline{17k62}}$

Since M_1 & M_2 are indetical $V_{o1} = V_{o2} = +10V - 6k \cdot I_{D1/2} = +10V - 6k \cdot 0{,}5mA = \underline{\underline{7V}}$ →→→

$V_{GS1} = V_{GS2} = \pm\sqrt{\dfrac{I_{D1/2}}{K_{1/2}}} + V_t = \pm\sqrt{\dfrac{0{,}5mA}{0{,}4mA/V^2}} + 0{,}8V = \pm 1{,}12V + 0{,}8V = \begin{cases} 1{,}92V \\ -0{,}32V \end{cases}$, →→→ proper solution comes as $V_{GS1/2} = \underline{\underline{1{,}92V}}$

Now, for $v_{i1} = v_{i2} = 0V$ $V_{DS1/2} = V_{o1/2} - V_{S1/2} = V_{o1/2} - (V_{G1/2} - V_{GS1/2}) = 7V + (0 - 1{,}92V) = 8{,}92V$ which satisfies $V_{DS1/2} \geq V_{GS1/2} - V_t$ thus $8{,}92V \geq 1{,}92V - 0{,}8V \Leftrightarrow 8{,}92V \geq 1{,}12V$, →→→ M_1 & M_2 are both in saturation. On the other hand, $V_{S1/2} = (V_{G1/2} - V_{GS1/2}) = -1{,}92V = V_{D3}$ →→→

$V_{DS3} \geq V_{GS3} - V_t$ thus $V_{D3} - (-10V) \geq V_{GS3} - V_t$ or

$-1{,}92V - (-10V) \geq 2{,}38V - 0{,}8V \Leftrightarrow 8{,}08V \geq 1{,}58V$ →→→ M_3 is also in saturation.

At AC recall differential circuit analysis for BJT where $v_{e1/2} = \dfrac{v_{i1} + v_{i2}}{2 + \dfrac{r_{e1/2}}{R_E}}$. Think in terms of MOS this will be

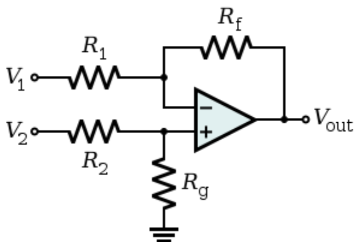
$v_{S1/2} = \dfrac{v_{i1} + v_{i2}}{2 + \dfrac{1}{g_{m1/2} R_S}}$ Alternatively, $A_{v-common} = -\dfrac{R_C}{2R_E + r_e}$ becomes

$$A_{v-common} = -\frac{R_D}{2R_S + 1/g_{m1/2}} = -\frac{g_{m1/2} R_D}{2 g_{m1/2} R_S + 1} \text{ with } R_S = R_{o3} = \frac{V_A}{I_{D3}} \to \infty$$

$g_{m1/2} = 2\sqrt{K_n I_{D1/2}} = \underline{\underline{0{,}894\ mA/V}}$ $\Rightarrow A_{v-common} = -\dfrac{g_{m1/2} R_D}{2 g_{m1/2} R_S + 1} \to 0$

With similar analogies $K_{d1} = \dfrac{-g_{m1/2} R_D}{2} = \underline{\underline{-2{,}68}}$ and $K_{d2} = \dfrac{g_{m1/2} R_D}{2} = \underline{\underline{2{,}68}}$

→→→ $CMRR = 20 \cdot \log_{10} \left| \dfrac{2 g_{m1/2} R_{o3} + 1}{2} \right| \to \infty$



PROBLEM 3. You can easily do this yourself like in the picture here!!!!!!!

PROBLEM 4.

A↓\B→	**0 V**	**5 V**
0 V	**0 V**	**4,4 V**
5 V	**4,4 V**	**4,4 V**

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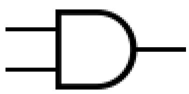
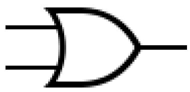
A↓\B→	**logic 0**	**logic 1**
logic 0	**logic 0**	**logic 1**
logic 1	**logic 1**	**logic 1**



A↓\B→	**0 V**	**5 V**
0 V	**0,6 V**	**0,6 V**
5 V	**0,6 V**	**5 V**

>>>>>>>>

A↓\B→	**logic 0**	**logic 1**
logic 0	**logic 0**	**logic 0**
logic 1	**logic 0**	**logic 1**



Also look at http://hyperphysics.phy-astr.gsu.edu/hbase/electronic/diodgate.html or http://www.eng.utah.edu/~cs6710/handouts/AppendixB/appendixB.doc2.html