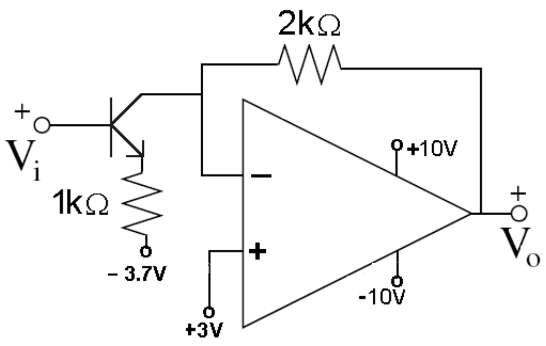
IMPORTANT: Besides your calculator and problem the sheets you are only allowed to have an A4 sized “copy sheet” during this exam. Notes, problems and alike are not permitted. Please submit your “copy sheet” along with your solutions. You may get your “copy sheet” back after your solutions have been graded. ***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 (21133-21134)

Final Exam 21 May 2012 12.00-14.00

STUDENT ID_______________NAME___________________SIGNATURE__________



PROBLEM-1

Calculate the output voltage $\mathbf{V_o}$ as a function for the input voltage $\mathbf{V_i}$ for the BJT to operate in the active zone. What are the ranges of $\mathbf{V_i}$ and $\mathbf{V_o}$? You may take $\mathbf{V_{BE} \approx 0,7\ V}$.

For the BJT to be active, (1) $V_C = 3V \geq V_B = V_i \Rightarrow 3V \geq V_i$ and (2) the current on 2k resistor should flow from right to left.

Thus, $V_o \geq 3V \Rightarrow 10V \geq V_o \geq 3V$ and $I_C = \frac{Vo - 3V}{2k} = \frac{h_{FE}}{h_{FE}+1} I_E$. On the other hand $I_E = \frac{V_i - V_{BE} - (-3{,}7V)}{1k} = \frac{V_i + 3V}{1k}$. That also means for the BJT to be active, (3) $I_E \geq 0 \Rightarrow V_i \geq -3V$.

So $3V \geq V_i \geq -3V$ and $I_C = \frac{V_o - 3V}{2k} = \frac{h_{FE}}{h_{FE}+1} \cdot \frac{V_i + 3V}{1k} \Rightarrow V_o = \frac{h_{FE}}{h_{FE}+1} \cdot 2(V_i + 3V) + 3V \cong 2V_i + 9V$ for $h_{FE} >> 1$

PROBLEM-2

For the BJT above $\mathbf{\beta_F = h_{fe} = 100}$ and $\mathbf{V_{BE} \approx 0,7\ V}$.
What is the gain $\mathbf{v_o/v_i}$ at the point of operation for $\mathbf{V_i = 0\ V}$?

$$V_i = 0V \Rightarrow V_E = -0{,}7V \Rightarrow I_E = \frac{-0{,}7 - (-3{,}7)}{1k} = 3mA$$

$$\Rightarrow I_C = \frac{h_{FE}}{h_{FE}+1} I_E = \frac{100}{101} 3mA = \underline{\underline{2{,}97mA}}$$

$$\Rightarrow r_e = \frac{V_T}{I_C} = \frac{25mV}{2{,}97mA} = \underline{\underline{8{,}42\Omega}}$$

Realize that at AC $v_c = 0V$, that means the collector is grounded for AC signals. The BJT circuit acts like a common-E circuit, Yet because the collector is at ground level, the phase of the output voltage does not change!

$$K_v = \frac{v_o}{v_i} = \frac{2k \parallel R_y}{r_e + R_e} = \frac{2k}{r_e + R_e} = \frac{2k}{8{,}42\Omega + 1k} = \underline{\underline{1{,}98}}$$

NOTE 1: You need to solve the problems in the space provided. Each problem is worth 20 points.
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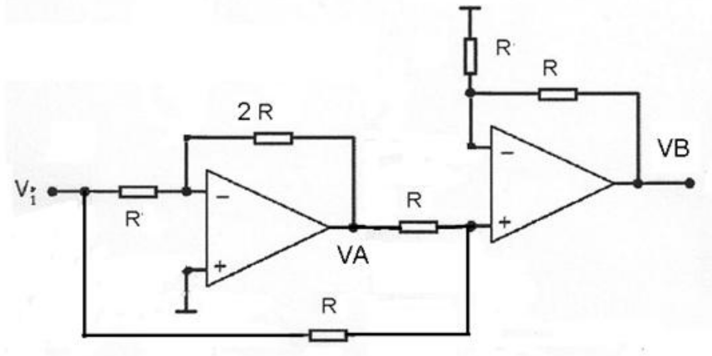
GOOD LUCK



PROBLEM-3
The OPAMPs on the left are ideal with $\mathbf{V_{CC}}$ = 10 V and $\mathbf{V_{EE}}$ =0 V. ($\mathbf{V_{o+}}$= 10V and $\mathbf{V_{o-}}$ = 0V; that is, OPAMPs are fed by a single power supply) $\mathbf{V_i}$ varies between –5V and +5V.
a) Find the range of $\mathbf{V_A}$.
b) Find the range of $\mathbf{V_B}$ and correlate it with $\mathbf{V_i}$ (that is, <u>for a sinusiodal input signal</u> show the variation of $\mathbf{V_i}$, and $\mathbf{V_B}$ <u>comparatively using the same coordinate system</u>).

$$V_i < 0 \rightarrow V_A = -2V_i$$

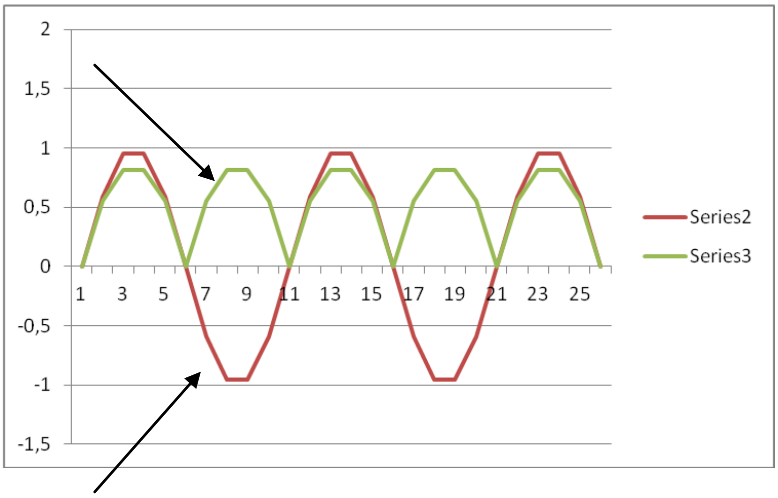
OPAMP1: $V_i > 0 \rightarrow V_A = V_o^- = 0V$

$$\Rightarrow 0 \le V_A \le 10V$$

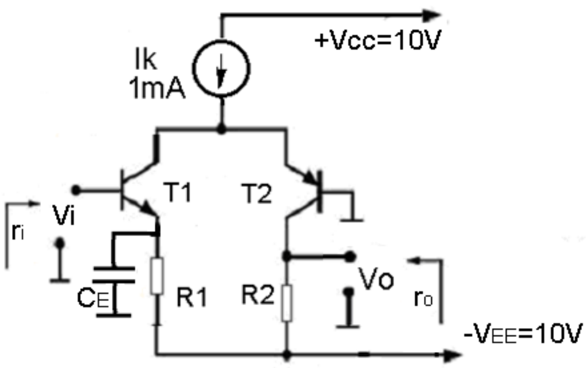
$$V_B = V_i + V_A$$

OPAMP2: $V_i > 0 \rightarrow V_B = V_i + V_A = V_i + V_o^- = \underline{\underline{V_i}}$

$$V_i < 0 \rightarrow V_B = V_i - 2V_i = \underline{\underline{-V_i}}$$



In the chart on the right the red curve gives the input voltage V_i whereas the green one shows the output voltage V_B.



PROBLEM-4 ***<u>This is not a differential amplifier!</u>***
For the circuit shown on the left, $\boldsymbol{\beta_F = h_{fe} = 200}$, $\mathbf{|V_{BE}| = 0{,}6\ V}$, $\mathbf{V_T = 25mV}$ and $\mathbf{V_A = \infty}$. Recalling $\mathbf{V_i = 0V}$ for biasing, find $\mathbf{R_1}$ and $\mathbf{R_2}$ for $\mathbf{r_i = 50k}$ and the gain $\mathbf{|v_o/v_i| = 10}$. Also calculate the output resistance $\mathbf{r_o}$

DC analysis: 2 stages- 1st common-E, 2nd common-B.

$$V_i = 0V \Rightarrow V_{E1} = -0{,}6V \Rightarrow I_{E1} = \frac{-0{,}6V - (-10V)}{R_1} = \frac{9{,}4V}{R_1}$$

$$r_i = h_{fe}(r_{e1} + R_e) = 50k = 200(r_{e1} + 0) \Rightarrow r_{e1} = \frac{50k}{200} = 250\Omega \Rightarrow I_{C1} = \frac{25mV}{r_{e1}} = \frac{25mV}{250\Omega} = \underline{\underline{0{,}1mA}}$$

$$\Rightarrow I_{E1} = \frac{h_{FE}+1}{h_{FE}} I_{C1} \cong \underline{\underline{0{,}1mA}} \Rightarrow R_1 = \frac{9{,}4V}{I_{E1}} = \underline{\underline{93k5}}$$

With $r_{i2} = R_{e2} \parallel r_{e2} = \underline{\underline{r_{e2}}} \Rightarrow r_{e1} + r_{e2} = \dfrac{V_T}{I_{C1}} + \dfrac{V_T}{I_{C2}} = \dfrac{50k}{200} = 250\Omega$

$$\frac{v_o}{v_i} = K_v = K_{v1}K_{v2} = -\frac{R_{c1} \parallel R_{y1}}{r_{e1} + R_{e1}} \cdot \frac{R_2}{r_{e2}} = -\frac{\infty \parallel r_{i2}}{250\Omega + 0} \cdot \frac{R_2}{r_{e2}} = -\frac{r_{i2}}{250\Omega} \cdot \frac{R_2}{r_{e2}} = -\frac{r_{e2}}{250\Omega} \cdot \frac{R_2}{r_{e2}} = -\frac{R_2}{250\Omega} = -10$$

$$R_2 = 10 \cdot 250\Omega = \underline{\underline{2k5}}$$

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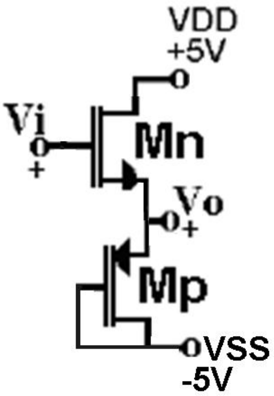


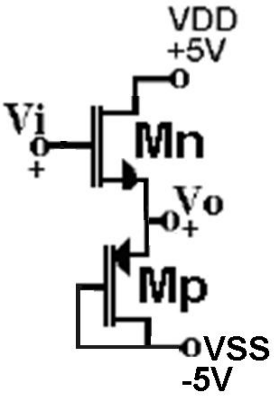
PROBLEM-5

The MOS transistors shown are conjugate with **|V$_{TH}$| = 1 V**. At the operation point we require that **V$_i$ = 0V** and **I$_{DN}$ = I$_{DP}$ = 1mA**. Find **β** that satisfies these conditions.

$I_{Dn} = I_{Dp} = \beta(V_{GSn} - V_{Tn})^2 = \beta(V_{GSp} - V_{Tp})^2 = 1mA$. Since the two MOS are conjugate, their **|V$_{TH}$|** and their **β** are identical. Thus, their **|V$_{GS}$|** should also be the same. Looking at the circuit we realize $V_i - V_o = V_o - (-V_{SS}) \rightarrow 0 - V_o = V_o + 5 \Rightarrow V_o = \underline{\underline{-2{,}5V}}$.

That also means $V_{GSn} = -V_{GSp} = \underline{\underline{2{,}5V}}$. Inserting this into

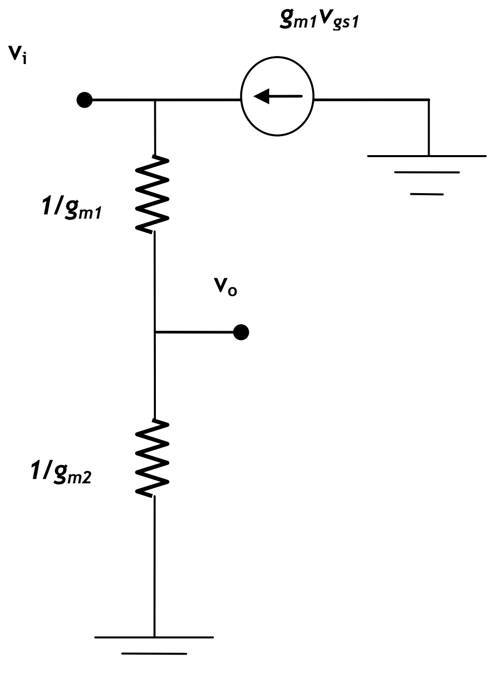
$I_{Dn} = I_{Dp} = \beta(2{,}5 - 1V)^2 = \beta(-2{,}5 + 1V)^2 = 1mA$ yields $\beta = \dfrac{1mA}{(2{,}5 - 1V)^2} = \underline{\underline{444\mu A / V^2}}$



PROBLEM-6

The MOS transistors shown are conjugate with **|V$_{TH}$| = 1,5 V** and **β = 2 mA/V^2**. At the operation point **I$_{DN}$ = I$_{DP}$ = 1mA**. Calculate the AC gain **v$_o$/v$_i$** with no load connected to the output.

This might be a little confusing but not as difficult as it seems. I chose to use the equivalent circuit approach. Hereby realize that both resistors should have the same value because the MOS are conjugate and the same current passes through them (**I$_{DN}$ = I$_{DP}$ = 1mA**). Also note that the gate and drain of M$_p$ are grounded at AC.



Is it NOT obvious that $\dfrac{v_o}{v_i} = \dfrac{1/g_{m2}}{1/g_{m1} + 1/g_{m2}} = \dfrac{1/g_m}{1/g_m + 1/g_m} = 1/2$????

We could have analyzed this circuit otherwise by using gain equations. M$_n$ is in common-D configuration. M$_p$ acts like a resistor because the gate and drain are gounded at AC. Thus:

$$\frac{v_o}{v_i} = \frac{R_s}{1/g_{m1} + R_s} = \frac{1/g_{m2}}{1/g_{m1} + 1/g_{m2}} = \frac{1/g_m}{1/g_m + 1/g_m} = 1/2$$

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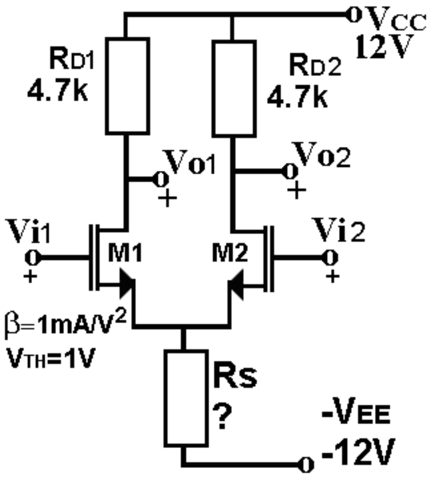


PROBLEM-7

The MOS transistors shown on the left are identical with $|V_{TH}| = 1\ V$ and $\beta = 1\ mA/V^2$. $I_{D1} = I_{D2} = 1mA$ when $V_{i1} = V_{i2} = 0V$. Calculate CMRR for single (v_{O2}) and differential output ($v_{O2} - v_{O1}$).

Again using an equation we have seen before and adapting it to MOS we can see:

$$CMRR_{BJT} = 20\log\left|\frac{2R_E + r_e}{r_e}\right| \Rightarrow CMRR_{MOS} = 20\log\left|\frac{2R_S + 1/g_m}{1/g_m}\right|$$

$$I_{Dn} = \beta(V_{GSn} - V_{Tn})^2 = 1mA/V^2(V_{GSn} - 1V)^2 = 1mA$$

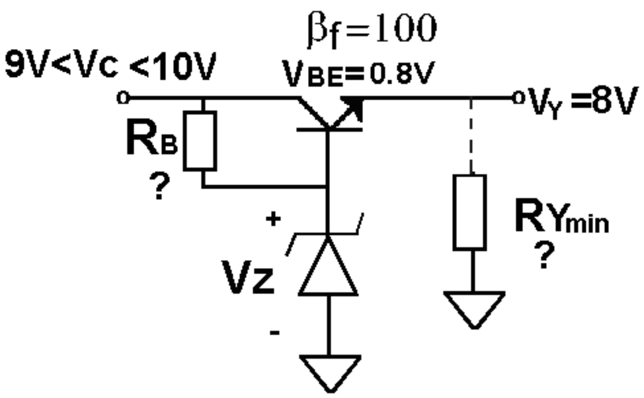
$$\Rightarrow V_{GS} = 1V \pm \sqrt{\frac{1mA}{1mA/V^2}} = \begin{cases} 2V > V_{Tn} = 1V \\ 0V \end{cases}$$

Thus the meaningful solution would be $V_{GS} = \underline{\underline{2V}}$. On the other side

$$V_i - (-V_{EE}) = V_{GS} + 2I_D R_S \Leftrightarrow 0 + 12V = 2V + 2\cdot 1mA\cdot R_S \Rightarrow R_S = \frac{12V - 2V}{2\cdot 1mA} = \underline{\underline{5k}}$$

$$g_m = 2\sqrt{\beta I_{D1/2}} = 2mA/V \underline{\underline{= (500\Omega)^{-1}}}$$

$$\Rightarrow CMRR_{MOS} = 20\cdot\log\left|\frac{2R_S + 1/g_m}{1/g_m}\right| = 20\cdot\log\left|\frac{2\cdot 5k + 500\Omega}{500\Omega}\right| = \underline{\underline{26{,}44dB}}$$



PROBLEM-8

The circuit will provide a regulated voltage at 8 V from a voltage varying between 9 to 10 V.

For the BJT used $\beta_F = 100$ and $V_{BE} \approx 0{,}8\ V$, and Zener voltage is **8,8 V.** The maximum power dissipated by the Zener diode is $P_{Zmax} = 0{,}1\ W$. Find R_B and the minimum value of load resistor (R_{Ymin}) that can be connected to the output.

Check Problem 1 in Midterm Exam #2 solutions at:
http://web.itu.edu.tr/cilesiz/courses/ELE222E/ELE222E-Spring-2012-MT2.doc