IMPORTANT: Besides your calculator (cell phones are not allowed) 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!***

ELE222E INTRODUCTION TO ELECTRONICS (21058)
Midterm Exam #2 ✎ 25 April 2011 ⌛ 9.30-11.30

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1. Analyze the MOS circuit shown on the right (50 points):

   a. Design the biasing and find the unknown resistor values for the following parameters $V_{tn1} = V_{tn2} = V_{tn} = 1{,}2V$,

   $K_{n1} = K_{n2} = K_n = \frac{1}{2}\mu_n C_{ox}\frac{W}{L} = 800\mu A/V^2$, $V_{A1/2} \to \infty$,

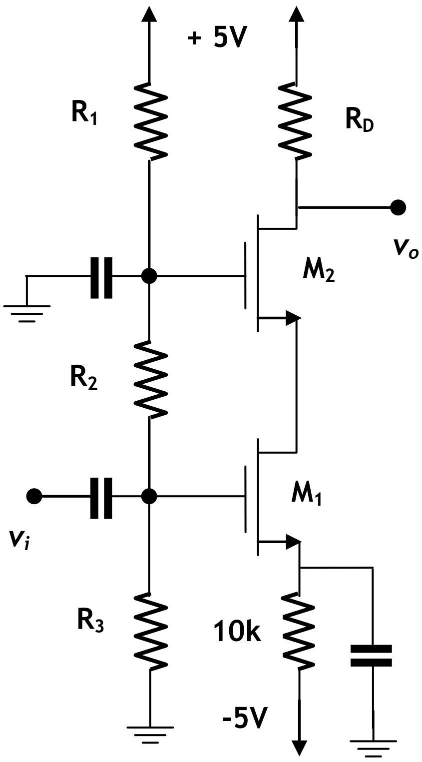
   and $R_1 + R_2 + R_3 = 300k$, so that $I_{DQ} = 0{,}4mA$ and $V_{DSQ1} = V_{DSQ2} = 2{,}5V$.

   In which region does each MOS operate?

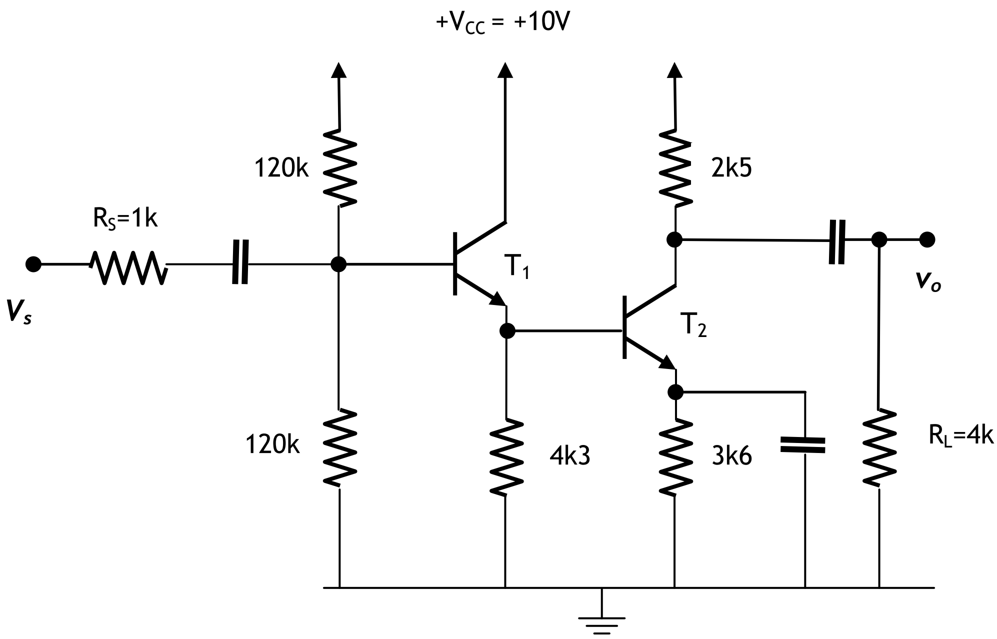
   ASSUME all capacitors are ideal.

   b. Determine the small signal voltage gain $A_v = \frac{v_o}{v_i}$.

   HINT: You need to draw the small signal circuit.



2. Assuming all capacitors are ideal, study the two stage circuit below for ß = h_{FE} = h_{fe} = 150, h_{oe} = h_{re} = 0, V_T = 25 mV, and $|V_{BE}|$ = 0,6 V.



Find collector currents, voltage gain v_o/v_s, r_i, and r_o.
(50 points)

HINT: While calculating collector currents you will obtain 2 loop equations with 2 unknowns!

ASSUME all capacitors are ideal.

GOOD LUCK!

SOLUTIONS:

1. The DC voltage at the source of M_1 is $V_{S1} = -5V + I_{DQ}R_S = -5V + 0{,}4mA \cdot 10k = \underline{\underline{-1V}}$. M_1 and M_2 are identical, then $V_{GS1} = V_{GS2}$. Since $I_{DQ} = K_n(V_{GS} - V_{tn})^2 \Rightarrow 0{,}4mA = 0{,}8(V_{GS} - 1{,}2V)^2[mA]$, from

$$V_{GS1} = V_{GS2} = V_{GS} = \pm\sqrt{\frac{0{,}4}{0{,}8}} + 1{,}2 = \begin{cases} -0{,}71 + 1{,}2V \\ +0{,}71 + 1{,}2V \end{cases}$$, the correct solution is $V_{GS} = \underline{\underline{1{,}91V}}$.

$$V_{G1} = \left(\frac{R_3}{R_1 + R_2 + R_3}\right)5V = \left(\frac{R_3}{300k}\right)5V = V_{GS} + V_{S1} = 1{,}91 - 1 = 0{,}91V \Rightarrow R_3 = \frac{0{,}91V \cdot 300k}{5V} = \underline{\underline{54k4}}$$

In a similar fashion

$$V_{G2} = \left(\frac{R_2 + R_3}{R_1 + R_2 + R_3}\right)5V = \left(\frac{R_2 + 54k5}{300k}\right)5V = V_{GS} + V_{S2} = V_{GS} + V_{S1} + V_{DSQ} = 0{,}91 - 1 + 2{,}5 = \underline{\underline{3{,}41V}}$$

$$\Rightarrow R_2 = \frac{V_{G2} \cdot 300k}{5V} - 54k5 = \underline{\underline{150k}} \Rightarrow R_1 = 300k - R_2 - R_3 = 300k - 150k - 54k4 = \underline{\underline{95k6}}$$

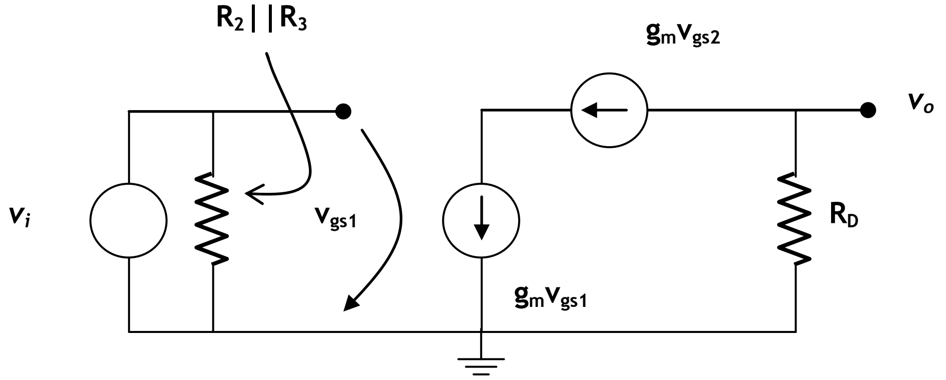
$$V_{D2} = V_{S2} + V_{DSQ} = V_{S1} + V_{DSQ} + V_{DSQ} = -1 + 2{,}5 + 2{,}5 = \underline{\underline{4V}}$$

$$\Rightarrow R_D = \frac{5V - V_{D2}}{I_{DQ}} = \frac{5V - 4V}{0{,}4mA} = \underline{\underline{2k5}}$$

We realize $V_{DSQ} = 2{,}5V > 1{,}91V = V_{GS}$, therefore both MOS are biased in the saturation region.

M_1 and M_2 are identical, then $g_{m1} = g_{m2} = g_m = 2K_n(V_{GS} - V_{tn}) = 2 \cdot 0{,}8m \cdot (1{,}91 - 1{,}2) = \underline{\underline{1{,}13mA/V}}$.

Now we have to draw the small signal circuit:

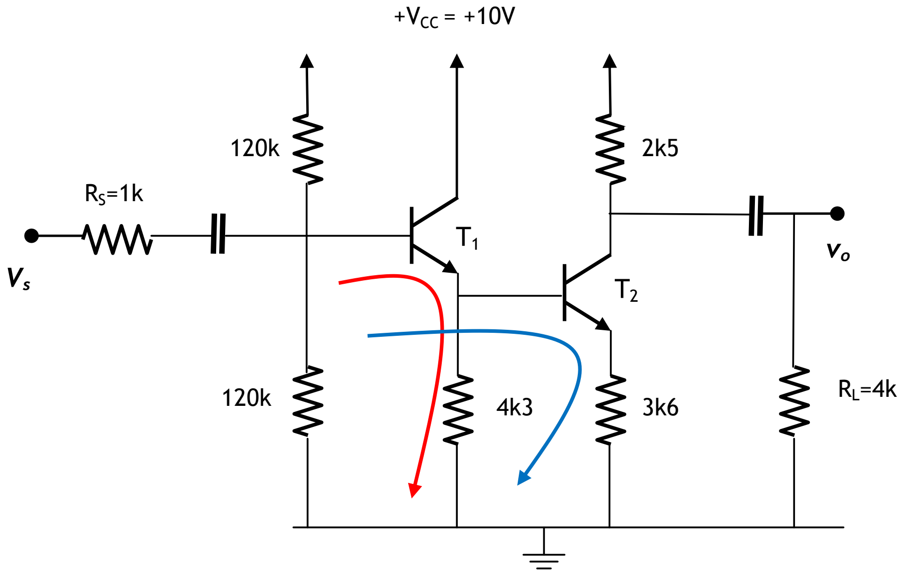


Realize that $g_m v_{gs2} = g_m v_{gs1} \Rightarrow v_o = -g_m v_{gs1} R_D$

Also realize $v_i = v_{gs1} \Rightarrow A_v = \frac{v_o}{v_i} = -g_m R_D = -1{,}13 \cdot 2k5 = \underline{\underline{-2{,}83}}$

2. The same BJT problem was to be solved last in last year's ELE 222E midterm exam #2.

With ideal capacitors load and source resistors are isolated for biasing purposes. Thus using Thevenin Eq. circuit: R_{BB} = 60K, V_{BB} = 5V and



Red loop: $V_{BB} = R_{BB}I_{B1} + V_{BE1} + 4k3(I_{E1} - I_{B2})$

Blue loop: $V_{BB} = R_{BB}I_{B1} + V_{BE1} + V_{BE2} + 3k6 \cdot I_{E2}$

From blue loop:
$$V_{BB} = R_{BB}I_{B1} + 0{,}6V + 0{,}6V + 3k6(1+\beta)I_{B2}$$
$$\Rightarrow I_{B2} = \frac{V_{BB} - R_{BB}I_{B1} - 1{,}2V}{3k6(1+\beta)}$$

Insert I_{B2} into red loop:

$$V_{BB} = R_{BB}I_{B1} + 0{,}6V + 4k3 \cdot I_{E1} - 4k3 \cdot \frac{V_{BB} - R_{BB}I_{B1} - 1{,}2V}{3k6(1+\beta)}$$

$$\Rightarrow V_{BB} - 0{,}6V + 4k3 \cdot \frac{V_{BB} - 1{,}2V}{3k6(1+\beta)} = R_{BB}I_{B1} + 4k3 \cdot I_{E1} + 4k3\frac{R_{BB}I_{B1}}{3k6(1+\beta)}$$

$$\Rightarrow I_{B1} = \frac{V_{BB} - 0{,}6V + 4k3 \cdot \frac{V_{BB} - 1{,}2V}{3k6(1+\beta)}}{R_{BB} + 4k3(1+\beta) + 4k3\frac{R_{BB}}{3k6(1+\beta)}} = \frac{5V - 0{,}6V + 4k3 \cdot \frac{5V - 1{,}2V}{3k6(1+150)}}{60k + 4k3(1+\beta) + 4k3\frac{60k}{3k6(1+150)}} = 7{,}33\mu A$$

$$\Rightarrow \underline{\underline{I_{C1} = 0{,}94mA}} \Rightarrow \underline{\underline{r_{e1} = 26{,}7\Omega}}$$

$$\Rightarrow I_{B2} = \frac{V_{BB} - R_{BB}I_{B1} - 1{,}2V}{3k6(1+\beta)}$$

Insert this value into $I_{B2} = \frac{5V - 60k \cdot 7{,}33\mu A - 1{,}2V}{3k6(1+150)} = 6{,}18\mu A$

$$\Rightarrow \underline{\underline{I_{C2} = 0{,}95mA}} \Rightarrow \underline{\underline{r_{e2} = 26{,}4\Omega}}$$

Now we can do AC analysis:

$$Gain = \frac{v_o}{v_s} = \frac{v_o}{v_{b2}} \cdot \frac{v_{b2}}{v_{b1}} \cdot \frac{v_{b1}}{v_s} = \left(-\frac{R_{C2}'}{R_{e2} + r_{e2}}\right)\left(\frac{R_{e1}}{R_{e1} + r_{e1}}\right)\left(\frac{r_i'}{r_i' + R_s}\right)$$

Where

$$r_i' = R_{BB} \parallel r_i$$
$$r_i = h_{fe}(r_{e1} + R_{e1})$$
$$R_{e1} = R_{E1} \parallel r_{i2}$$
$$r_{i2} = h_{fe} r_{e2} = 150 \cdot 27\Omega = 3k97$$
$$R_{e1} = R_{E1} \parallel r_{i2} = 2k06$$
$$R_{C2}' = R_{C2} \parallel R_L = 2k5 \parallel 4k = 1k54$$

Realize that R_{E2} is shunted.

$$r_i = h_{fe}(r_{e1} + R_{e1}) = 150(27\Omega + 2k08) = \underline{\underline{314k}}$$

Thus $r_i' = R_{BB} \parallel r_i = 60k \parallel 316k = \underline{\underline{50k4}}$

$$r_o = R_{C2} = \underline{\underline{2k5}}$$

Finally:

$$\frac{v_o}{v_s} = \left(-\frac{R_{C2}'}{0 + r_{e2}}\right)\left(\frac{R_{e1}}{R_{e1} + r_{e1}}\right)\left(\frac{r_i'}{r_i' + R_s}\right) = (-58{,}2) \cdot 0{,}987 \cdot 0{,}981 = \underline{\underline{-56{,}3}}$$