21-04-2018

BILKENT UNIVERSITY

Department of Electrical and Electronics Engineering

EEE313 Electronic Circuit Design

Midterm Exam II

-- SOLUTION --

Surname: ________________________________

Name: ________________________________

ID-Number: ________________________________

Signature: ________________________________

Duration is 110 minutes. Solve all 4 questions. Show all your work.
No books or notes.

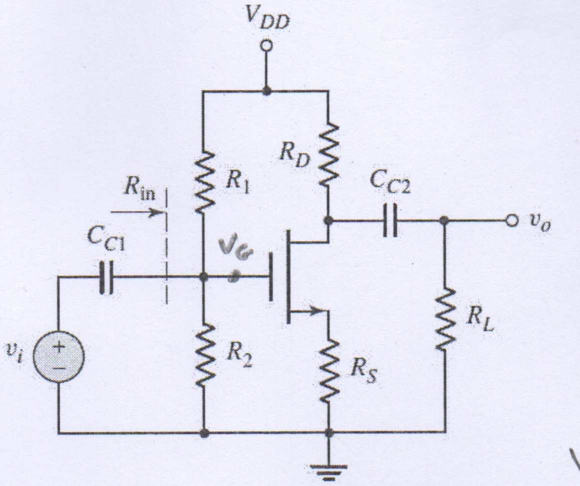
Q1 (24 points)	
Q2 (28 points)	
Q3 (24 points)	
Q4 (24 points)	
Total (100 points)	

Q1. For the NMOS common-source amplifier below, the tarnsistor parameters are: $V_{TN} = 0.8$ V, $K_n = 1$ mA/V^2, and $\lambda = 0$. The circuit parameters are $V_{DD} = 5$ V, $R_S = 1$ kΩ, $R_D = 4$ kΩ, $R_1 = 225$ kΩ, and $R_2 = 175$ kΩ.

a) (8 points) Calculate the quiscent values of I_{DQ} and V_{DSQ}. Check the state of the transistor.

b) (10 points) Draw the small signal ac equivalent circuit; derive and determine the small-signal voltage gain v_o/v_i for $R_L = \infty$.

c) (6 points) Determine the value of R_L that will reduce the small-signal voltage gain to 75 percent of the value in part b)



a) $V_G = \frac{R_2}{R_1+R_2} \times V_{DD} = \frac{175}{175+225} \times 5 = \frac{35}{16} = 2.19$ v.

Assume SAT: $i_D = 1(V_{GS}-0.8)^2$

$V_{GS} = V_G - i_D \times R_s = 2.19 - 1 \times i_D$

$\Rightarrow i_D = 2.19 - V_{GS}$

$2.19 - V_{GS} = (V_{GS}-0.8)^2 = V_{GS}^2 - 1.6V_{GS} + 0.64$

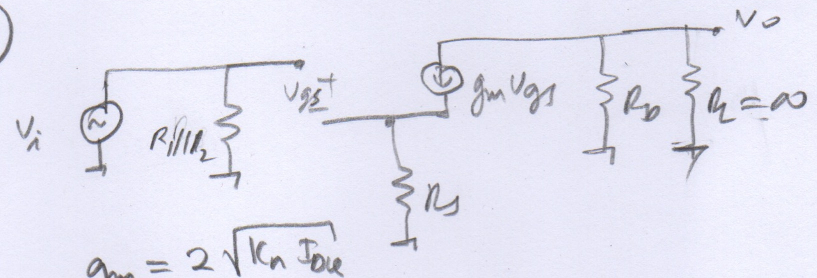
$V_{GS}^2 - 0.6V_{GS} + 0.64 - 2.19 = 0$

$V_{GS} = \begin{cases} 1.58\text{ v} > 0.8 \ ✓ \\ -0.98\text{ v} > 0.8 \ ✗ \end{cases}$ Take $V_{GS} = 1.58$ v.

$i_D = (1.58-0.8)^2 = 0.61$ mA

$\Rightarrow V_{DS} = 5 - 0.61(4+1) = 1.95\text{ v} > V_{GS} - 0.8 = 1.58 - 0.8$ ✓ ∴ SAT.

b)



$v_{gs} = v_i - g_m v_{gs} R_s$

$= \frac{v_i}{1+g_m R_s}$

$v_o = -g_m v_{gs} R_D$

$\frac{v_o}{v_i} = \frac{-g_m R_D}{1+g_m R_s} = \frac{-1.56\times4}{1+1.56\times1}$

$= -2.44$ V/V

$g_m = 2\sqrt{K_n I_{DQ}}$

$= 2\sqrt{1\times0.61} = 1.56$ mA/V

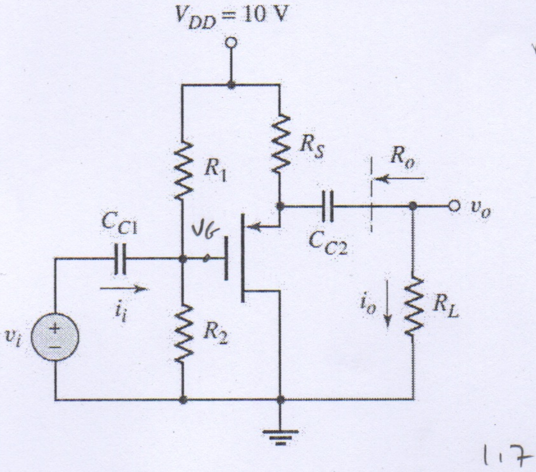
c) If $R_L \neq \infty$ then $\frac{v_o}{v_i} = \frac{-g_m R_D // R_L}{1+g_m R_s}$

$\Rightarrow \frac{R_D // R_L}{R_D} = 0.75 \Rightarrow \frac{R_D R_L}{(R_D+R_L)R_D} = 0.75 \Rightarrow \frac{R_L}{R_D+R_L} = 0.75$

$R_L = 0.75 R_D + 0.75 R_L$ $\quad R_L = \frac{0.75 R_D}{0.25} = 3 R_D = 12$ kΩ.

Q2. The parameters of the circuit below are $R_S = 4\ k\Omega$, $R_1 = 850\ k\Omega$, $R_2 = 350\ k\Omega$, and $R_L = 4\ k\Omega$. The transistor parameters a er $V_{TP} = -1.2$ V, $k_p' = 40\ \mu A/V2$, $W/L = 80$, and $\lambda = 0.05\ V^{-1}$.

a) (8 points) Determine I_{DQ} and V_{SDQ}. Check the state of the transistor.
b) (8 points) Draw the small signal ac equivalent circuit; derive and find the small-signal voltage gain $A_v = v_o/v_i$.
c) (4 points) Determine the small-signal ac circuit transconductance gain $A_g = i_o/v_i$.
d) (8 points) Find the small-signal ac output resistance R_o. Draw the circuit by which you determine the output resistance.



a) $V_G = \frac{R_2}{R_1+R_2} \times V_{DD} = \frac{350}{1200} \times 10 = \frac{35}{12} = 2.92$ v.

$K_p = \frac{40\mu A/V^2}{2} \times 80 = 1600\mu A/V^2 = 1.6 mA/V^2$.

Assume SAT : $i_D = 1.6(V_{SG}-1.2)^2$

$V_{SG} = 10 - i_D \times 4 - V_G = 10 - 4i_D - 2.92$

$i_D = \frac{7.08 - V_{SG}}{4} = 1.77 - 0.25 V_{SG}$

$1.77 - 0.25V_{SG} = 1.6(V_{SG}^2 - 2.4V_{SG} + 1.44)$

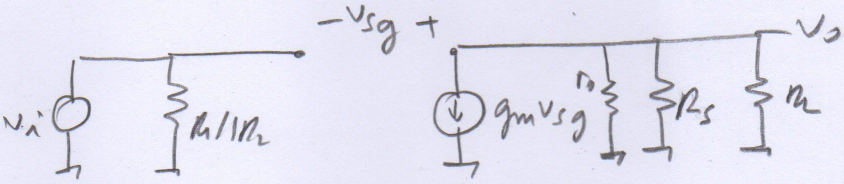
$1.6V_{SG}^2 - (1.6\times 2.4 - 0.25)V_{SG} + 1.6\times 1.44 - 1.77 = 0$

$V_{SG} = \begin{cases} 2.08 > 1.2 \checkmark \\ 0.16 > 1.2 \times \end{cases}$ Take $V_{SG} = 2.08$v.

$I_{DQ} = 1.77 - 0.25\times 2.08$
$= 1.25$ mA.

$V_{SDQ} = 10 - 4\times 1.25 = 10 - 5$
$= 5v > 2.08 - 1.2 \checkmark \therefore$ SAT.

b)



$g_m = 2\sqrt{1.6\times 1.25}$
$= 2.83$ mA/V

$r_o = \frac{1}{0.05\times 1.25} = 16$ K.

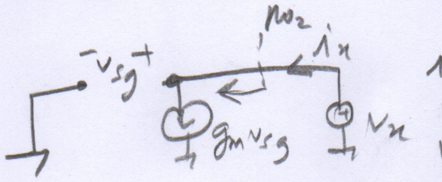
Define $R = r_o // R_S // R_L = 16 // 4 // 4 = 16 // 2 = \frac{32}{18} = \frac{16}{9} = 1.78$ kΩ.

$V_o = -g_mV_{sg}\times R = -g_mR(V_o - V_i) = \frac{+g_mRV_i}{1+g_mR}$

$A_v = \frac{V_o}{V_i} = \frac{g_mR}{1+g_mR} = \frac{2.83\times 1.78}{1+2.83\times 1.78} = 0.83$ v/v.

c) $I_o = \frac{V_o}{R_L} = \frac{V_o}{4}$ $\quad \frac{i_o}{V_i} = \frac{i_o}{V_o}\cdot\frac{V_o}{V_i} = \frac{1}{4}\times 0.83 = 0.208$ mA/V.

d)



$i_x = g_mV_{sg}$
$V_x = V_{sg}$
$\frac{V_x}{i_x} = \frac{1}{g_m}$

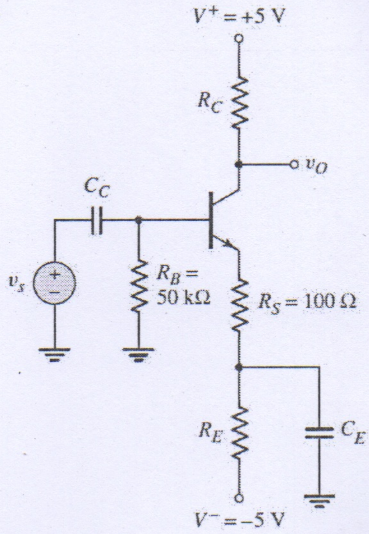
$\Rightarrow R_{out} = \frac{1}{g_m} // r_o // R_S$
$= 353 // 16000 // 4000 = 318\Omega$.
$\approx \frac{1}{g_m}$

Q3. For the circuit below the transistor parameters are $\beta = 100$ and $V_A = \infty$.

a) (8 points) Design the circuit such that $I_{CQ} = 0.25$ mA and $V_{CEQ} = 3$ V. Check the state of the transistor. Assume $V_{BE}(ON) = 0.7$ V and $V_{CE}(SAT) = 0.2$ V.

b) (8 points) Derive and find the small signal ac input resistance seen by the source v_s.

c) (8 points) Derive and find the small signal ac voltage gain $A_v = v_o/v_s$.



a) $V_{CEQ} = V^+ - R_C \times I_{CQ} - (R_S + R_E) I_{EQ} - V^-$

$3 = 5 - 0.25 \times 0.1 + 5 - 0.25(R_C + R_E)$

$R_C + R_E = 4(10 - 3 - 0.025) = 4 \times 6.975 = 27.9\,K.$

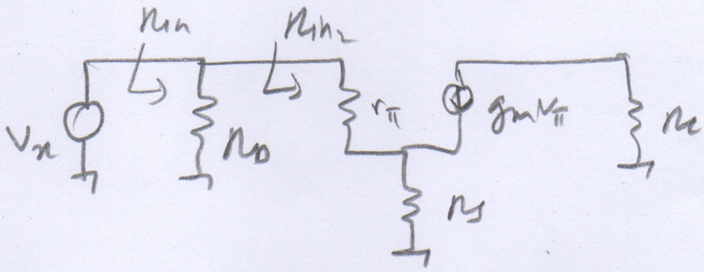
$I_B = \frac{0.25}{100} = \frac{5 - 0.7}{R_B + (\beta+1)(R_S + R_E)} = \frac{4.3}{50 + 101 \times (0.1 + R_E)}$

$12.5 + 25(0.1 + R_E) = 430 \quad 0.1 + R_E = \frac{417.5}{25} = 16.7\,k\Omega$

$R_E = 16.7 - 0.1 = 16.6\,k\Omega \Rightarrow R_C = 11.3\,K.$

$V_{CEQ} = 3V > 0.2$ ✓ $I_B > 0$ ✓ $\Rightarrow$ F.A.

b)



$r_\pi = \frac{0.026}{0.25} = 10.4K.$

$R_{in2} = r_\pi + (\beta+1) R_S$
$= 10.4 + 101 \times 0.1$
$\doteq 20.5\,K\Omega$

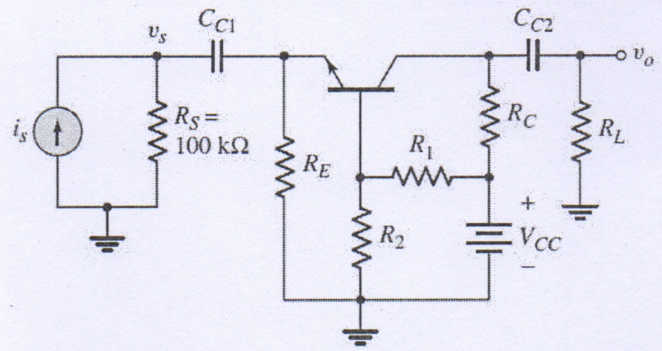
$R_{in} = 50 // 20.5 = 14.5\,K\Omega.$

c) $I_b = \frac{V_{in}}{r_\pi + (\beta+1) R_S} \quad V_o = -\beta I_b R_C \quad \frac{V_o}{V_{in}} = \frac{-\beta R_C}{r_\pi + (\beta+1) R_C}$

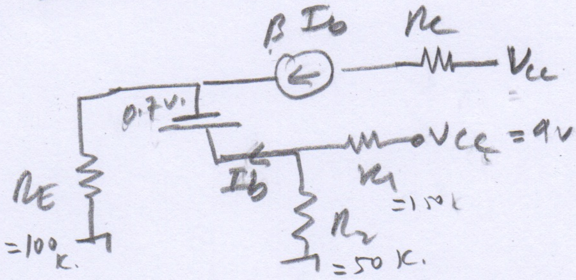
$= \frac{-100 \times 11.3}{20.5} = -56\ V/V.$

Q4. The parameters of the circuit below are $V_{CC} = 9$ V, $R_L = 4$ kΩ, $R_C = 6$ kΩ, $R_E = 3$ kΩ, $R_1 = 150$ kΩ, and $R_2 = 50$ kΩ. The transistor parameters are $\beta = 125$, $V_{BE}(ON) = 0.7$ V, $V_{CE}(SAT) = 0.2$ V, and $V_A = \infty$. The input signal is a current.

a) (8 points) Determine Q-point values. Check the state of the transistor.
b) (10 points) Determine the small signal ac transresistance function $R_m = v_o/i_s$.
c) (6 points) Find the small-signal ac voltage gain $A_v = v_o/v_s$.

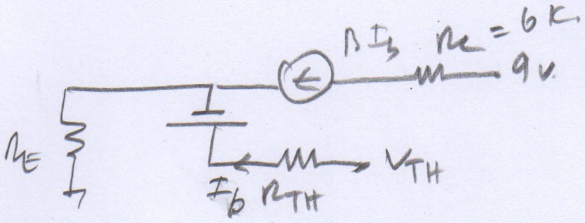


a) DC circuit



$V_{TH} = \frac{50}{50+150} \times 9 = 2.25$ V.

$R_{TH} = 50 // 150 = 37.5$ K.

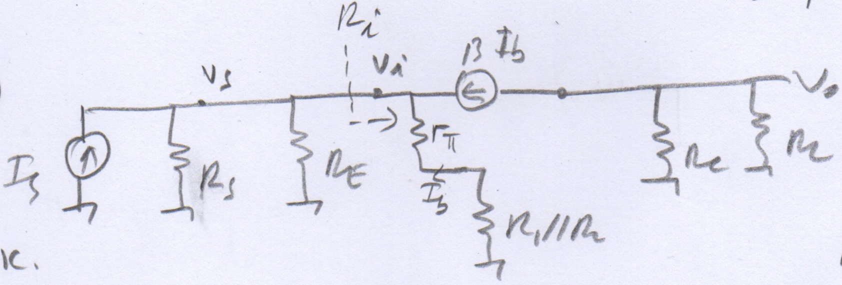


$V_{TH} = R_{TH} \times I_b + 0.7 + (\beta+1) I_b \times R_E$

$I_b = \frac{2.25 - 0.7}{37.5 + 126 \times 3} = 3.7 \mu A.$ $\Rightarrow I_{CQ} = 0.47 mA.$ $I_{EQ} \cong 0.47 mA$

$V_{CEQ} = 9 - 0.47 \times 6 - 0.47 \times 3$
$= 4.77 v > 0.2$ ✓ F.A.

b)



$v_i = - I_b (r_\pi + R_1 // R_2)$

$i_i = -(\beta + 1) I_b$

$R_i = \frac{v_i}{i_i} = \frac{r_\pi + R_1 // R_2}{\beta + 1}$
$= \frac{7 + 37.5}{126} = 0.353 k.$

$g_m = \frac{0.47}{0.026} = 18 K.$

$r_\pi = \frac{125}{18} = 7K.$

$V_i = I_s \times R_S // R_E // R_i \Rightarrow \frac{V_i}{I_s} = R_S // R_E // R_i$

$R_C // R_L = 6 // 4 = 2.4 K.$

$I_b = \frac{-V_i}{r_\pi + R_1 // R_2} \Rightarrow V_o = -\beta I_b R_C // R_L = \beta R_C // R_L \times \frac{V_i}{r_\pi + R_1 // R_2}$

$\frac{V_o}{I_s} = \frac{V_o}{V_i} \cdot \frac{V_i}{I_s} = \frac{\beta R_C // R_L}{r_\pi + R_1 // R_2} \times (R_S // R_E // R_i) = \frac{125 \times 2.4}{44.5} \times 100 // 3 // 0.353$
≈ 2.36 V/mA

c) $\frac{V_o}{V_s} \triangleq \frac{V_o}{V_i} = \frac{\beta R_C // R_L}{r_\pi + R_1 // R_2} = \frac{125 \times 2.4}{44.5} = 6.74$