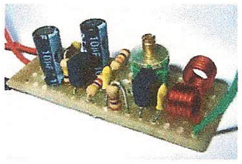
İZMİR UNIVERSITY OF ECONOMICS
Department of Electrical and Electronics Engineering
EEE 232 Microelectronic Devices and Circuits



Spring 2012/2013

MIDTERM #2
May 25, 2013
120 min

SOLUTIONS

INSTRUCTIONS

- Closed book, closed notes.
- Calculators are allowed, but borrowing is not allowed.
- Your mobile phones must be turned off during the exam.
- You must show your work for all problems to receive full credit; simply providing answers will result in only partial credit, even if the answers are correct.
- Put your name on any additional material that you submit.
- Be sure to provide units.
- Please indicate the number of page where your work is to be continued.
- Do not spend all your time on one problem and on one part and attempt to solve all of them.
- Please sign the honor pledge that is provided below.

Honor Pledge: I have neither given nor received any aid on this exam.

Signed:…………………………………..

Last Name :……………………

Name :……………………

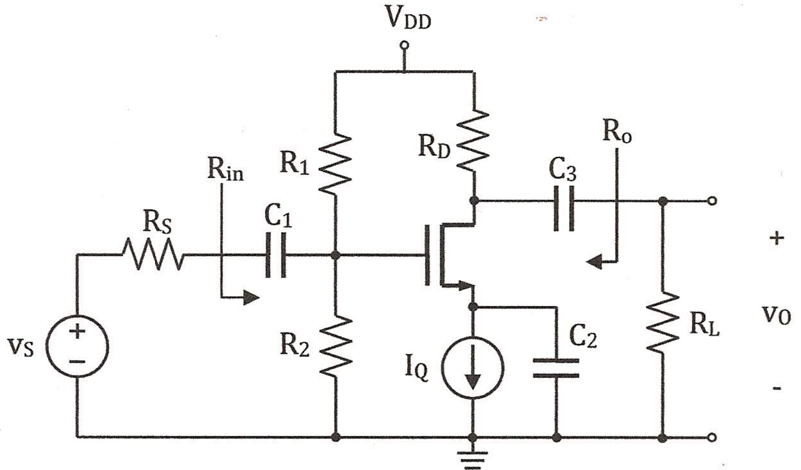
Group :……………………

Student No :……………………

Q	Points	Grade
1	25	
2	25	
3	25	
4	25	
Total	100	

Q1. (25 pts) Consider the CS amplifier given below. All capacitors are large enough so that they behave as short circuits at signal frequencies.

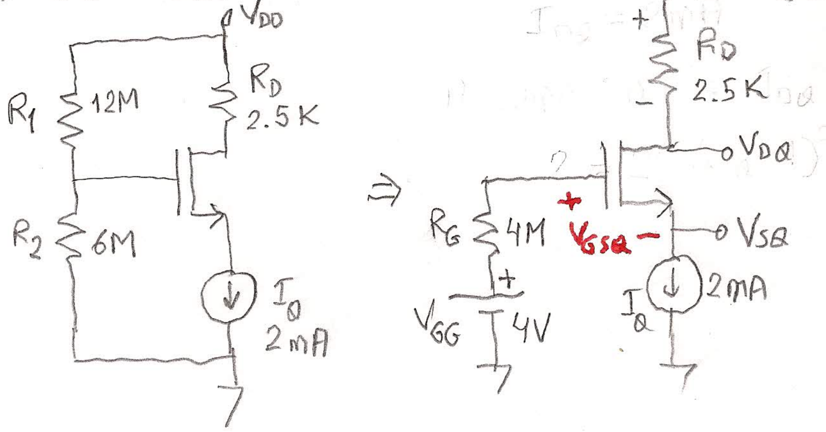
(a) Draw the DC model of the circuit.
(b) Determine the voltages V_{GSQ}, V_{DSQ}. (Check SAT condition)
(c) Determine the small signal parameters g_m and r_o.
(d) Draw the AC small signal equivalent circuit.
(e) Determine the overall voltage gain $A_v = v_o / v_s$.
(f) Determine input resistance (R_{in}), and output resistance (R_{out}).
(g) If $v_s = 0.1 \sin\omega_0 t$ volt, determine the total voltage at drain v_D and total output voltage v_O.



Circuit Parameters
$V_{DD} = 12$ V
$R_1 = 12$ MΩ
$R_2 = 6$ MΩ
$R_D = 2.5$ kΩ
$R_L = 20$ kΩ
$I_Q = 2$ mA
$R_S = 1$ K

Transistor Parameters
$V_{Tn} = 1$ V
$K_n = 2$ mA/V²
$V_A = 50$ V

(a) DC Model :



(b) $R_G = R_1 // R_2 = 12M // 6M = 4M$

$V_{GG} = \frac{6}{18} \cdot 12 = 4V$

$I_{DQ} = I_Q = 2mA$

Assume SAT:

$I_{DQ} \approx K_n (V_{GSQ} - V_{Tn})^2$

$1 = 1 (V_{GSQ} - 1)^2$

$V_{GSQ} = 2V$

$V_{SQ} = V_{GG} - V_{GSQ} = 4 - 2 = 2V$

$V_{DQ} = V_{DD} - R_D I_{DQ} = 12 - (2.5K)(1mA) = 9.5V$

$V_{DSQ} = V_{DQ} - V_{SQ} = 7.5V$

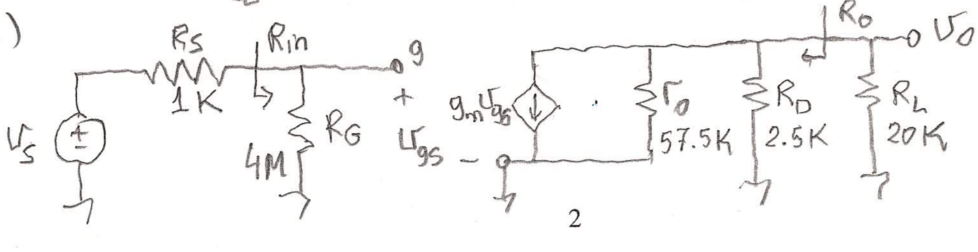
$V_{DSQ} \geq V_{GSQ} - V_{Tn}$

$7.5 \geq 2 - 1$ ✓ SAT

(c) $g_m = 2K_n(V_{GSQ} - V_{Tn}) = 2(1\ mA/V^2)(1V) = 2mA/V$

$r_o = \frac{V_A + V_{DSQ}}{I_{DQ}} = \frac{50 + 7.5V}{1mA} = 57.5K$

(d)



(e) $A_V = -g_m (r_o // R_D // R_L)\left(\frac{R_G}{R_S+R_G}\right)$

$= -(2mA/V)(57.5//2.5//20)\left(\frac{4}{4{,}001}\right) = -2.14$

(f) $R_{in} = R_G = 4M\Omega$

$R_o = R_D // r_o = 2.5K//57.5K = 2.4K$

(g) $v_s = 0.1 \sin w_0 t$ volt.

Since $v_d = v_o$ in the AC smallsignal model

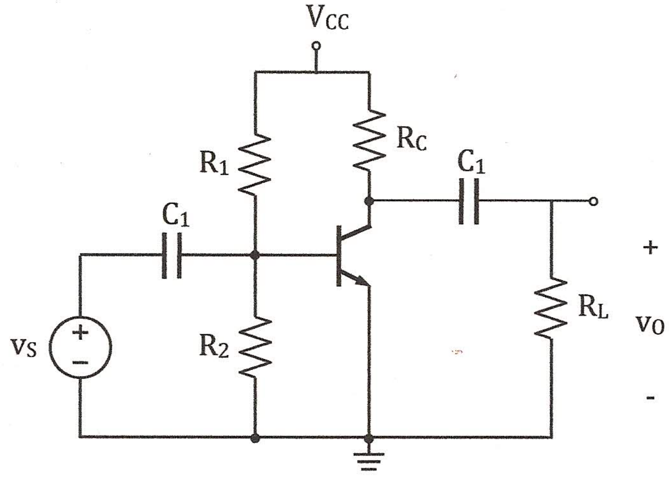
$v_d = v_o = A_V v_s = (-2.14)(0.1 \sin w_0 t \ V) = -0.214 \sin w_0 t$

Total voltages =

$v_D = V_{DQ} + v_d = 9.5 - 0.214 \sin w_0 t$ volt

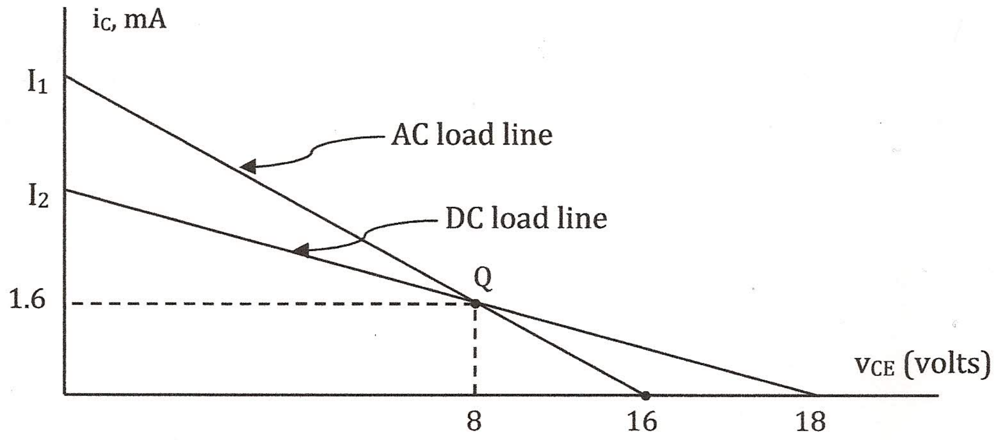
$v_O = V_{OQ} + v_o = -0.214 \sin w_0 t$ volt (NO DC component !)

Q2. (25 pts) Consider the following amplifier. The DC and AC load lines of this amplifier are given below.



Circuit Parameters
$R_1 = 50\ k\Omega$
$R_2 = 2.1\ k\Omega$

Transistor Parameters
$V_{BE(ON)} = 0.7\ V$
$\beta = 100$
$V_A = \infty$



$V_{CEQ} = 8$ volts

$I_{CQ} = 1.6$ mA

(a) Determine the supply voltage V_{CC} and the resistances R_C and R_L.

(b) Assume the voltage gain $A_v = v_o/v_s = -308$, determine the total collector voltage v_C and the total output voltage v_O if $v_S = 5 \sin \omega_0 t$ mV (Be careful about the units!)

(a) DC load line equation

$V_{CC} = R_C I_C + V_{CE} \Rightarrow I_C = 0 \Rightarrow V_{CE} = V_{CC} = 18\ V \quad (V_{CC} = 18\ V)$

Q point is ON the DC load line:

$V_{CC} = R_C I_{CQ} + V_{CEQ} \Rightarrow R_C = \frac{18 - 8\ V}{1.6\ mA} = 6.25K$

($V_{CC} = 18$, $I_{CQ} = 1.6mA$, $V_{CEQ} = 8V$)

The slope of the AC load line: $R_{ac} = \frac{\Delta V}{\Delta I} = \frac{16 - 8}{1.6} = 5K$

$R_{ac} = R_C // R_L \Rightarrow \frac{1}{R_L} = \frac{1}{R_{ac}} - \frac{1}{R_C} \Rightarrow R_L = \frac{R_{ac} R_C}{R_C - R_{ac}} = 25K$

(b) $A_v = -308$; $v_s = 5 \sin \omega_0 t$ mV)

From AC small signal analysis :

$v_c = v_o = A_v v_s = (-308)(5 \sin \omega_0 t \text{ mV})$

$= -1540 \sin \omega_0 t \text{ mV} = -1.54 \sin \omega_0 t \text{ V}$

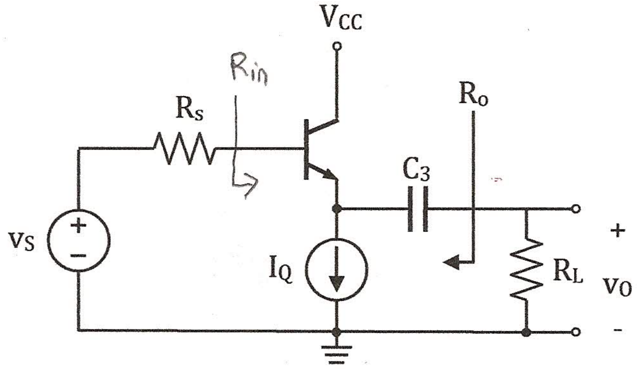
Then

$v_C = V_{CQ} + v_c = 8 - 1.54 \sin \omega_0 t \text{ V}$

$v_o = -1.54 \sin \omega_0 t \text{ V}$

Q3. (25 pts) Consider the common-collector amplifier given below. All capacitors are assumed short at the frequencies interest.

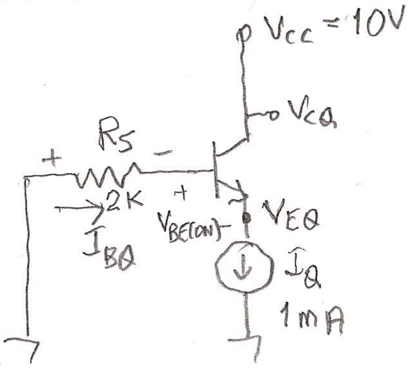
(a) Determine the DC values I_{CQ} and V_{CEQ}.
(b) Determine the small signal parameters of the transistor.
(c) Draw the AC small signal equivalent circuit.
(d) Determine the AC small signal gain $A_V = v_o/v_S$, input resistance R_{in} and output resistance R_o.



Circuit Parameters
$V_{CC} = 10$ V
$I_Q = 10$ mA
$R_S = 2$ kΩ
$R_L = 2$ kΩ

Transistor Parameters
$\beta = 100$
$V_{BE} = 0.7$ V
$V_A = 50$ V
$V_T = 26$ mV

(a) DC Model : (AC voltage source is short)



$I_{EQ} = I_Q = 10$ mA ; $I_{CQ} = \frac{\beta}{\beta+1} I_{EQ} = 9.9$ mA

$I_{BQ} = \frac{I_{EQ}}{\beta+1} = \frac{10}{101} \cong 0.1$ mA

$V_{EQ} = -V_{BE(ON)} - R_S I_{BQ} = -0.7 - (2K)(0.1mA)$

$V_{EQ} = -0.9V$

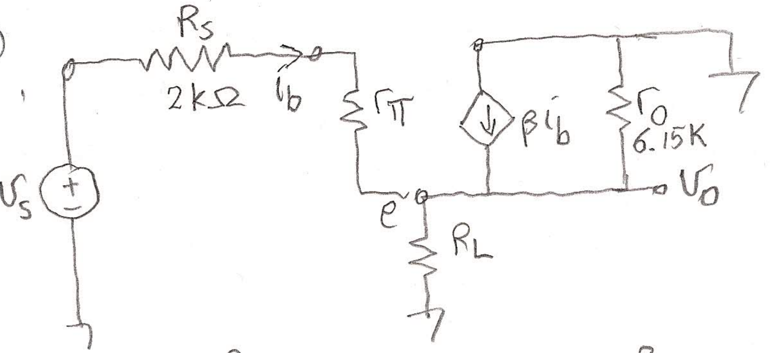
$V_{CQ} = V_{CC} = 10V$

$V_{CEQ} = V_{CQ} - V_{EQ} = 10.9V$

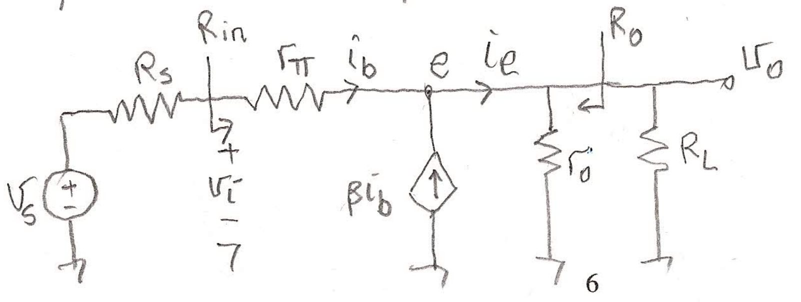
(b) $\beta = 100$; $r_o = \frac{V_A + V_{CEQ}}{I_{CQ}} = \frac{50 + 10.9V}{9.9 mA} = \frac{60.9 V}{9.9 mA} = 6.15 K$

$r_\pi \approx \frac{V_T}{I_{BQ}} = \frac{26mV}{0.1 mA} = 260 \Omega$

(c)



Redraw ⇒



$v_o = i_e (r_o // R_L)$

$v_o = (\beta+1) i_b (r_o // R_L)$ (1)

$v_S - v_o = i_b (R_S + r_\pi)$ (2)

From (1)

$$i_b = \frac{v_o}{(\beta+1)(r_o // R_L)}$$

Substituting into (2)

$$v_s - v_o = \frac{(R_S + r_\pi)}{(\beta+1)(r_o // R_L)} v_o = \frac{(2+0.26)K}{(101)(6.15//2)K} v_o = \frac{2.26}{152.4} v_o$$

$$v_s - v_o = \frac{1}{67.5} v_o \Rightarrow 67.5 v_s - v_o = 67.5 v_o$$

$$67.5 v_s = 68.5 v_o \Rightarrow v_o = \frac{67.5}{68.5} v_s$$

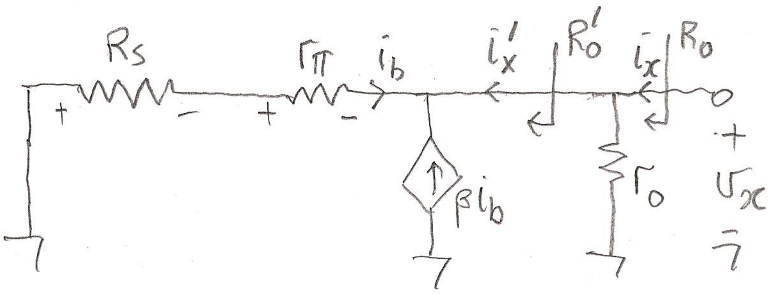
$$A_v = \frac{v_o}{v_s} = 0.985$$

<u>R_{in}</u>

$$v_i = r_\pi i_b + v_o = r_\pi i_b + (\beta+1) i_b (r_o // R_L)$$

$$R_{in} = \frac{v_i}{i_b} = r_\pi + (\beta+1)(r_o // R_L) = 0.26 + (101)(6.15//2) = 152.66K$$

<u>R_o</u> : Connect v_x to the output and short circuit the input.



$$i_x' = -(\beta+1) i_b \Rightarrow i_b = -\frac{i_x'}{\beta+1}$$

$$-(R_S + r_\pi) i_b = v_x$$

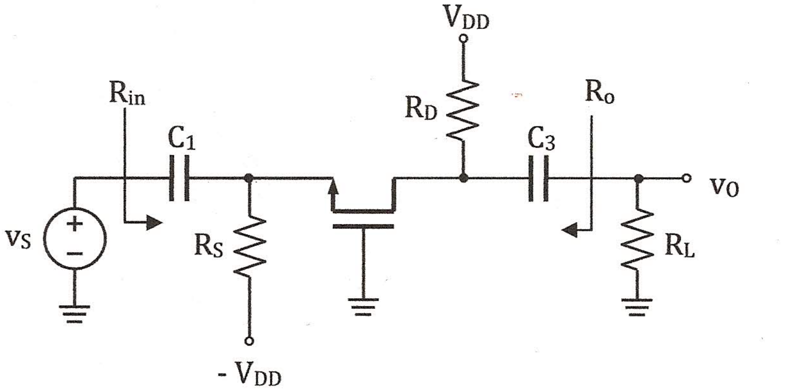
$$\frac{R_S + r_\pi}{\beta+1} i_x' = v_x$$

$$R_o' = \frac{v_x}{i_x'} = \frac{R_S + r_\pi}{r_o}$$

$$R_o = R_o' // r_o = \left(\frac{R_S + r_\pi}{\beta+1}\right) // r_o = \underbrace{\left(\frac{2+0.26K}{101}\right)}_{22.4\Omega} // 57.5K \cong 22.4\Omega$$

Q4. (25 pts) Consider the common-gate amplifier given below. All capacitors are assumed short at the frequencies interest.

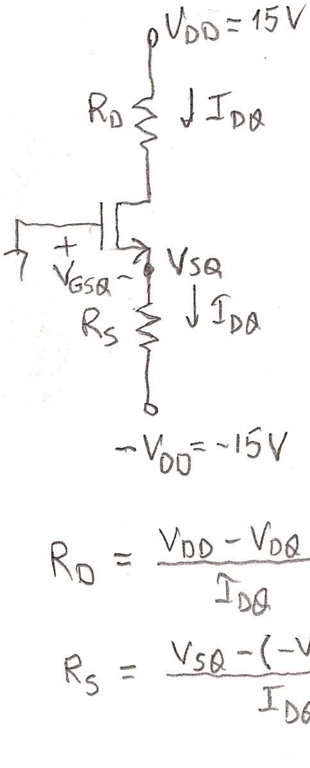
(a) Draw the DC model of the circuit.
(b) Determine the values of the resistors R_S and R_D to set I_{DQ} = 2 mA and V_{DSQ} = 8 V.
(c) Determine the small signal parameters g_m and r_o of the transistor.
(d) Draw the AC small signal equivalent circuit.
(e) Determine the overall voltage gain $A_v = v_O/v_S$.
(f) Determine the input resistance R_{in} and the output resistance R_o.



Circuit Parameters
V_{DD} = 15 V
R_L = 9 kΩ

Transistor Parameters
V_{Tn} = 1 V
K_n = 2 mA/V²
λ = 0

(a)



(b) $I_{DQ} = 2mA$

Assume SAT :

$I_{DQ} = K_n(V_{GS} - V_{Tn})^2$

$2 = 2(V_{GS}-1)^2 \Rightarrow V_{GSQ} = 2V$

$V_{SQ} = -V_{GSQ} = -2V$

$V_{DSQ} = 8V = V_{DQ} - V_{SQ} = V_{DQ} - (-2V)$

$8V = V_{DQ} + 2V \Rightarrow V_{DQ} = 6V$

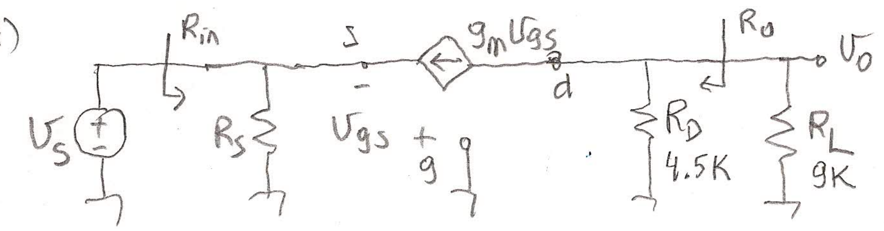
$$R_D = \frac{V_{DD} - V_{DQ}}{I_{DQ}} = \frac{15-6V}{2mA} = 4.5K$$

$$R_S = \frac{V_{SQ} - (-V_{DD})}{I_{DQ}} = \frac{-2+15V}{2mA} = 6.5K$$

(c) $g_m = 2K_n(V_{GS} - V_{Tn}) = (2)(2mA/V^2)(1)V = 4 mA/V$

$r_o = \frac{1}{\lambda I_{DQ}} = \infty$ (open circuit !)

(d)



(e) $v_{gs} = -v_s$

$v_o = (-g_m v_{gs})(R_D // R_L) = g_m v_s (R_D // R_L)$

$\Rightarrow A_v = \frac{v_o}{v_s} = g_m (R_D // R_L) = (4mA/V)(\underbrace{4.5K // 9K}_{3K}) = 12$

(f) $R_{in} = R_S // (\frac{1}{g_m}) = 6.5K // (\frac{1}{4mA/V}) = 6.5K // 0.25K = 0.24K$

$R_o = R_D = 4.5K$