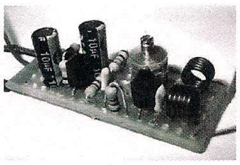


İZMİR UNIVERSITY OF ECONOMICS
Department of Electrical and Electronics Engineering
EEE 331 Analog Electronics
Fall 2016/2017

SOLUTIONS

MIDTERM EXAM I

Nov 5, 2016
110 min

INSTRUCTIONS

- Read all of the instructions and all of the questions before beginning the exam.
- There are 4 questions on this exam, totaling 100 points. The credit are equal for each problem.
- Do not spend all your time on one problem and on one part and attempt to solve all of them.
- Calculators are allowed, but borrowing is not allowed.
- Your mobile phones must be turned off during the exam.
- Turn in the entire exam, including this cover sheet.
- You must show your work for all problems to receive full credit; simply providing answers will result in no credit, even if the answers are correct.
- Please indicate the number of page where your work is to be continued.
- Put your name on any additional material that you submit.
- Be sure to provide units where necessary.
- Please sign the honor pledge that is provided below.

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

Signed:.....................................

Last Name :........................

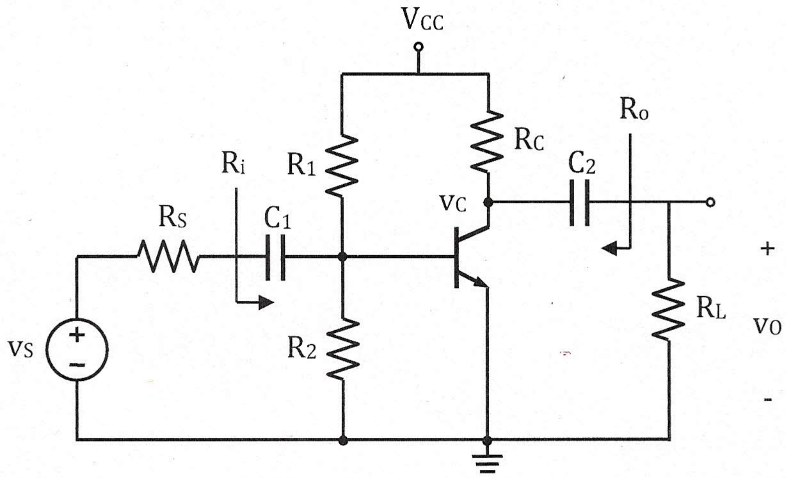
Name :........................

Group :........................

Student No :........................

Question	Points	Grade
1	25	
2	25	
3	25	
4	25	
TOTAL	100	

Q1. (25 pts) Consider the common emitter amplifier given below. The input is v_s and the output is v_o measured over R_L.

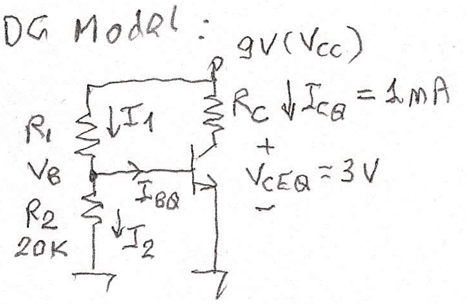


Circuit Parameters
$V_{CC} = 9$ V
$R_2 = 20$ K
$R_L = 18$ K
$R_S = 2$ K

BJT Parameters
$\beta = 100$
$V_{BE(on)} = 0.6$ V
$V_T = 26$ mV
$V_{CE(sat)} = 0$
$V_A \to \infty$

i) Determine the R_1 and R_C to set $I_{CQ} = 1$ mA, $V_{CEQ} = 3$ V.
ii) Determine the voltage gain.
iii) Determine the input resistance R_i and output resistance R_o.
iv) Draw the DC and AC load lines.
v) Determine the limitations on the output signal swing.
vi) If $v_s(t) = 20 \sin \omega_0 t$ mV, determine $v_C(t)$ and $v_O(t)$.

i. DC Model:



$R_C = \frac{V_{CC} - V_{CEQ}}{I_{CQ}} = \frac{9-3}{1mA} = 6K$ $\boxed{R_C = 6K}$

$I_{BQ} = \frac{I_{CQ}}{\beta} = \frac{1mA}{100} = 0.01\,mA = 10\,\mu A$

$V_B = V_{BE} = 0.6V \Rightarrow I_2 = \frac{V_B}{R_2} = \frac{0.6V}{20K} = \frac{600\,mV}{20K} = 30\,\mu A$

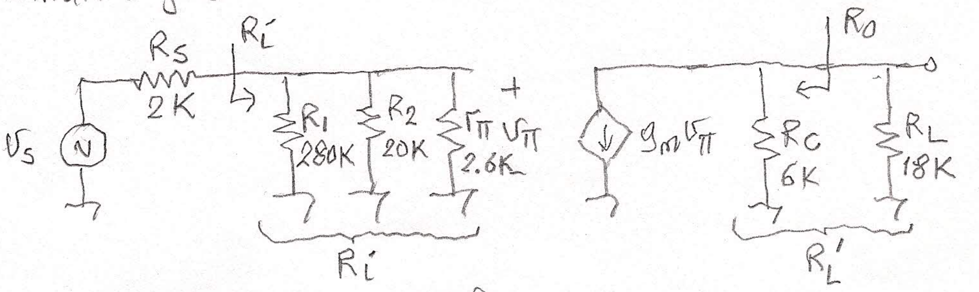
$I_1 = I_B + I_2 = 40\,\mu A \Rightarrow R_1 = \frac{V_{CC} - V_B}{I_1} = \frac{8.4V}{30\mu A} = 0.28\,M\Omega$

$\boxed{R_1 = 280\,k\Omega}$

ii. Small signal parameters:

$r_\pi = \frac{26\,mV}{I_{BQ}} = \frac{26\,mV}{10\,\mu A} = 2.6K$; $g_m = \frac{\beta}{r_\pi} = \frac{100}{2.6K} = 38.5\,m℧$, $r_o = \infty$

Small signal model:



$R_i = R_1 // R_2 // r_\pi$

$R_i = 2.28\,K$

$R_L' = R_C // R_L = 4.5K$

$v_\pi = \frac{R_i}{R_S + R_i} v_s = \frac{2.28}{4.28} v_s = 0.53 v_s$

$v_o = -g_m R_L' v_\pi = -(38.5\,m℧)(4.5K) v_\pi = -173.25\,v_\pi$

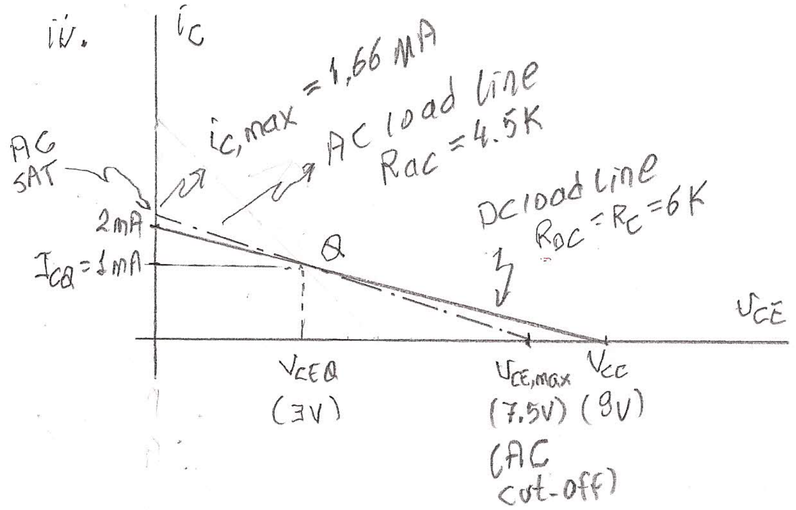
$v_o = -92\,v_s$

$\boxed{A_v = -92}$

iii. $R_i = R_1 // R_2 // r_\pi = 2.28K$

$R_o = R_c = 6K$

iv.



$R_{ac} = R_C // R_L = 4.5K$

$v_{CE,max} = V_{CEQ} + R_{ac} I_{CQ}$
$\simeq 3V + (4.5K)(1 mA)$
$\simeq 7.5V$

$i_{C,max} = I_{CQ} + \frac{V_{CEQ}}{R_{ac}} \simeq 1.66 mA$

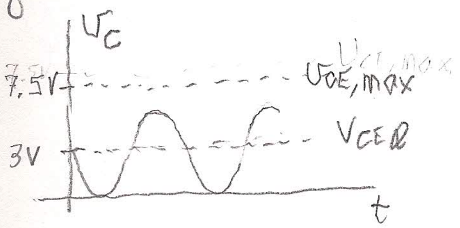
Output voltage swing around V_{CEQ} will be limited by AC-SAT.

v. Therefore for undistorted signal swing

$v_d = v_{CE} = V_{CEQ} + V_{op} \sin \omega_0 t$

and

$|V_{op,max}| = 3V$



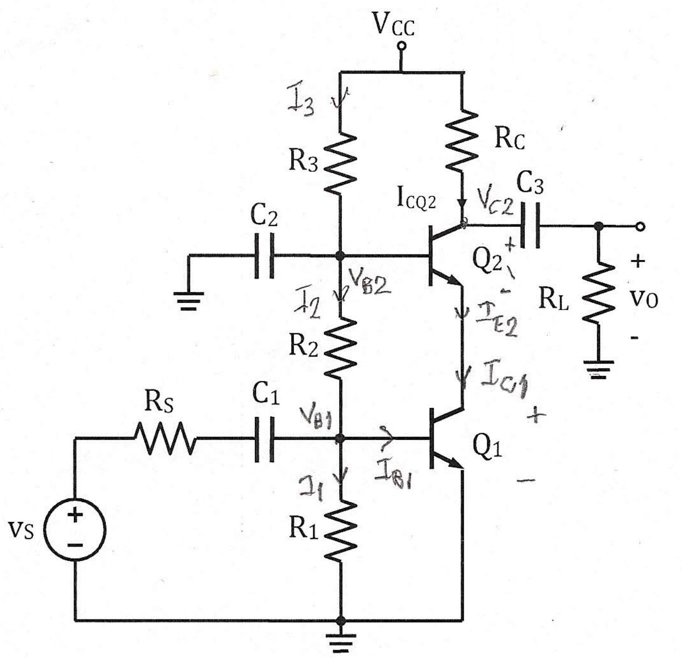
vi. $v_o = A_v v_s$

$v_s = 20 \sin \omega_0 t$ mV ; $A_v = -92$

$v_o = -1840 \sin \omega_0 t$ mV $= -1.84 \sin \omega_0 t$ V

$v_C = V_{CEQ} + v_c = V_{CEQ} + v_o = 3 - 1.84 \sin \omega_0 t$ V

Q2. (25 pts) Consider the cascode amplifier given below.



Circuit Parameters

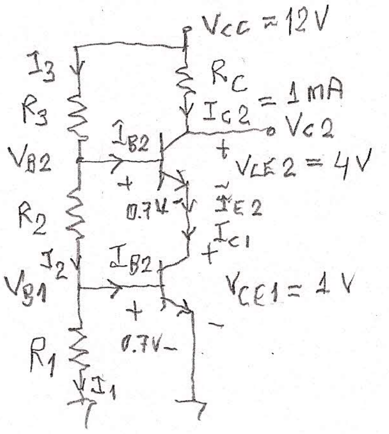
$V_{CC} = 12$ V
$R_S = 1$ kΩ.
$R_1 = 50$ kΩ.
$R_L = 14$ kΩ

Transistor Parameters Q_1 and Q_2

β = 100,
$V_{BE(ON)} = 0.7$ V,
$V_T = 26$ mV,
$V_A = \infty$

(a) Determine R_C, R_2, and R_3 to set $V_{CEQ1} = 1$ V, $V_{CEQ2} = 4$ V and $I_{CQ2} = 1$ mA.
(b) Determine the small-signal parameters for each transistor.
(c) Determine the overall AC small-signal voltage gain $Av = vo / vs$.

(a)



$I_{C2} = 1\,mA,\ \beta = 100 \Rightarrow I_{E2} = 1.01\,mA$

$I_{B2} = I_{C2}/\beta = 10\,\mu A$

$I_{C1} = I_{E2} = 1.01\,mA \Rightarrow I_{B1} = 10.1\,\mu A$

$V_{B1} = V_{BE1} \cong 0.7V \Rightarrow I_1 = \frac{V_{B1}}{R_1} \cong \frac{0.7V}{50K} = 14\,\mu A$

$I_2 = I_1 + I_{B1} = 24.1\,\mu A$

$V_{B2} \cong V_{BE2} + V_{CE1} = 0.7 + 1\,V = 1.7\,V$

$R_2 = \frac{V_{B2} - V_{B1}}{I_2} = \frac{1.7 - 0.7\,V}{24.1\,\mu A} = 4.15\,K\Omega$

$I_3 = I_2 + I_{B2} = 24.1\,\mu A + 10\,\mu A = 34.1\,\mu A$

$R_3 = \frac{V_{CC} - V_{B2}}{I_3} = \frac{12 - 1.7\,V}{34.1\,\mu A} = 331.4\,K$

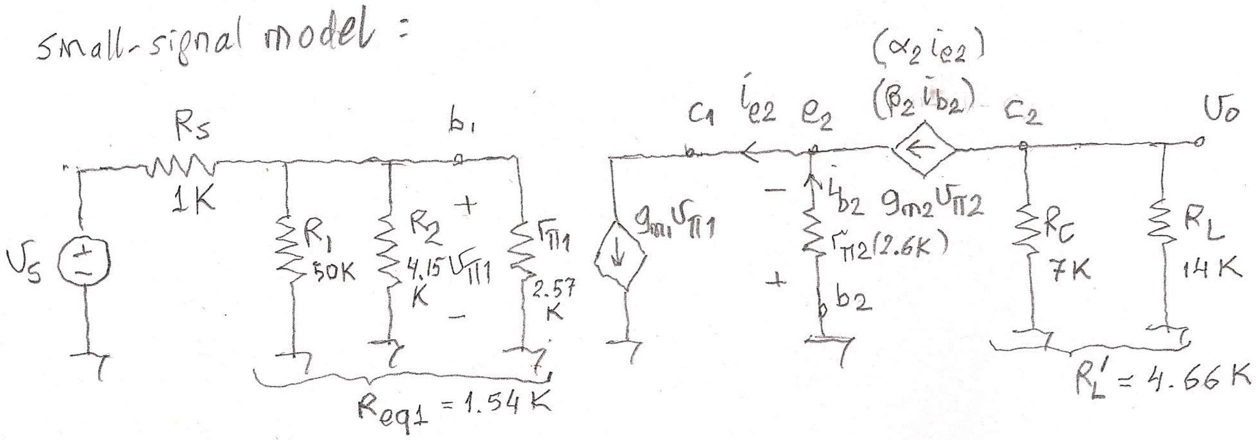
$V_{C2} = V_{CE2} + V_{CE1} = 5V$

$R_C = \frac{V_{CC} - V_{C2}}{I_{C2}} = \frac{12 - 5\,V}{1\,mA} = 7\,K$

(b) $Q_1: r_{\pi 1} = \frac{V_T}{I_{B1}} = \frac{26\,mV}{10.1\,\mu A} = 2.57\,K\ ;\ g_{m1} = \frac{\beta}{r_{\pi 1}} = 38.85\,m℧\ ;\ r_{o1} = \infty$

$Q_2: r_{\pi 2} = \frac{V_T}{I_{B2}} = \frac{26\,mV}{10\,\mu A} = 2.6\,K\ ;\ g_m = \frac{\beta}{r_{\pi 2}} = 38.46\,m℧\ ;\ r_{o2} = \infty$

small-signal model :



$R_{eq1} = R_1 // R_2 // r_{\pi 1} = 1.54K$

$R_L' = R_C // R_L = 4.66K$

$$v_{\pi 1} = \frac{R_{eq1}}{R_s + R_{eq1}} \cdot v_s = \frac{1.54}{2.54} v_s = 0.6\, v_s$$

$$i_{e2} = g_{m1} v_{\pi 1} \Rightarrow i_{b2} = \frac{g_{m1}}{\beta + 1} v_{\pi 1}$$

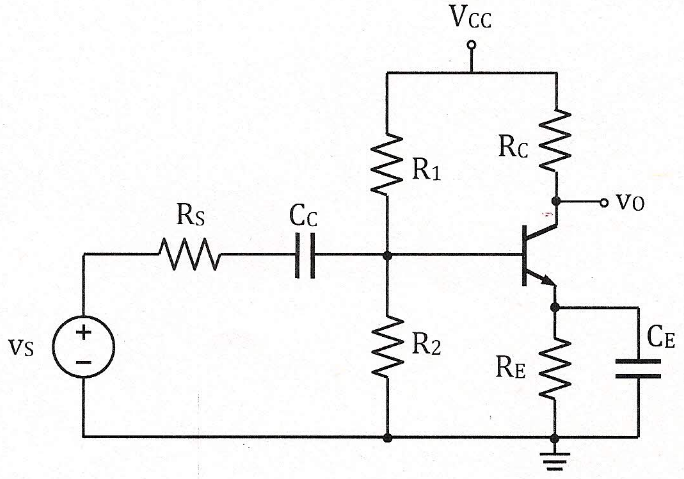
$$v_o = -\beta i_{b2} R_L' = -\beta \frac{g_{m1}}{\beta + 1} R_L' v_{\pi 1} = (-100) \frac{38.85\,m25}{(100)} (4.66K) v_{\pi 1}$$

$$\left.\begin{array}{l} v_o = -179.3\, v_{\pi 1} \\ v_{\pi 1} = 0.6\, v_s \end{array}\right\} \Rightarrow v_o = -107.6\, v_s$$

$$A_v = -107.6$$

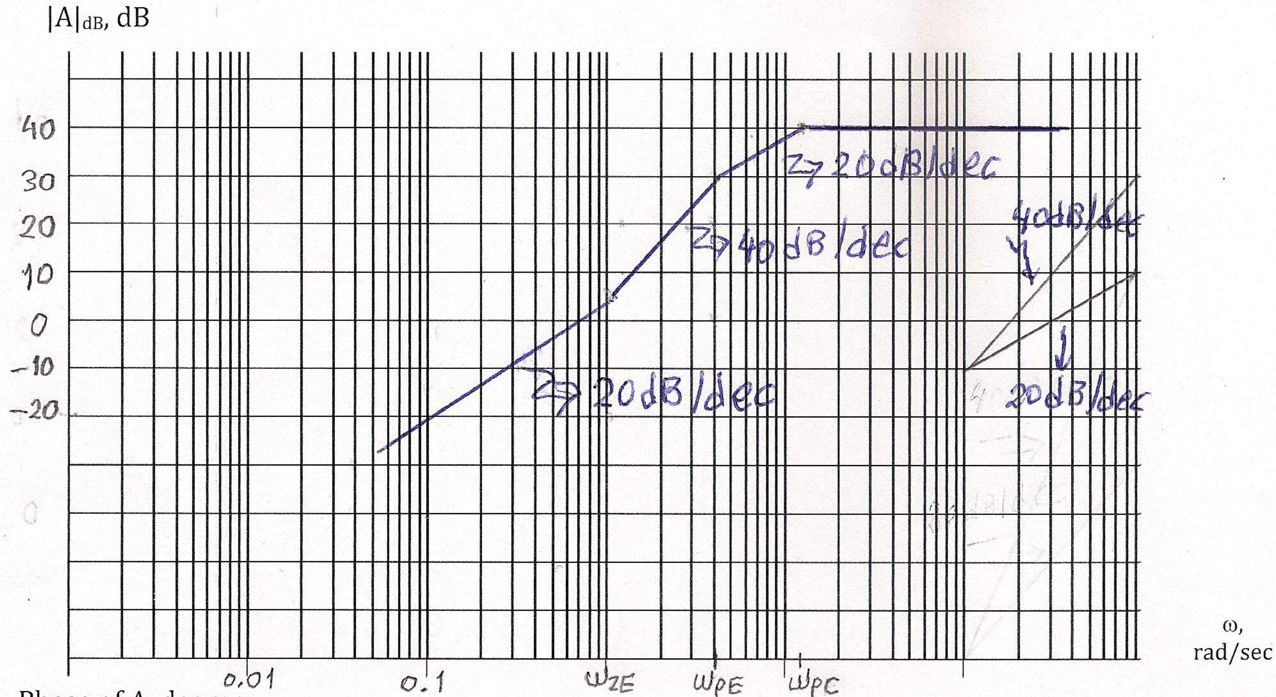
Q3. (25 pts) Consider the common emitter amplifier given below,

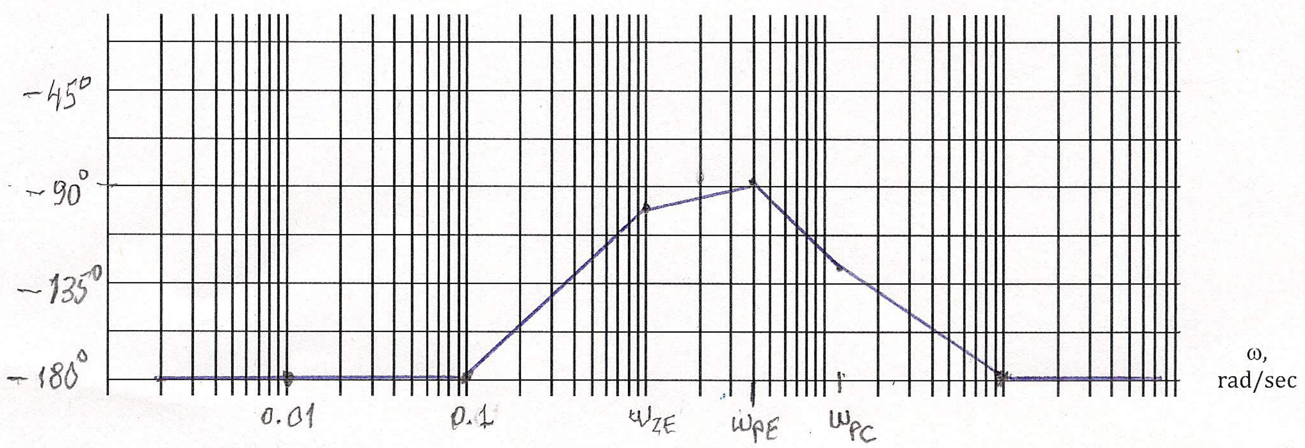
i. Determine the small signal parameters.
ii. Write down the frequency gain expression.
iii. Determine the critical frequencies.
iv. Find the midband voltage gain.
v. Plot the low frequency Bode magnitude and Bode phase responses.



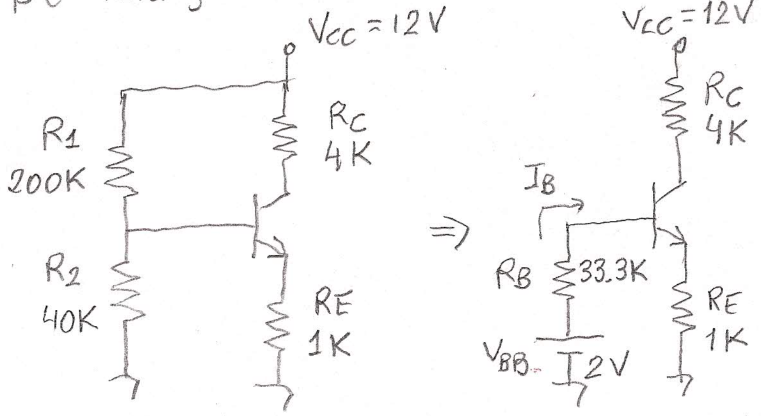
Circuit Parameters
V_{CC} = 12 V
R_S = 1 kΩ
R_1 = 200 kΩ
R_2 = 40 kΩ
R_E = 1 kΩ
R_C = 4 kΩ
C_C = 25 μF
C_E = 1000 μF

The transistor Parameters
β = 100,
$V_{BE(ON)}$ = 0.6 V,
V_T = 26 mV,
V_A = ∞





i. DC Analysis



$R_B = R_1 // R_2 = 33.3\,K$

$V_{BB} = \frac{R_2}{R_1 + R_2} V_{cc} = 2V$

$I_B = \frac{2 - 0.6}{33.3K + 101K} = 10.4\,\mu A$

$I_C = 1.04\,mA$

$V_{CE} = 12 - (4K)(1.04mA) - (1K)(1.05mA)$

$V_{CE} = 6.79V$ ($V_{CE} > V_{CE(SAT)}$)
Forward active ✓

$r_\pi = \frac{26\,mV}{I_B} = 2.5K$; $g_m = \frac{\beta}{r_\pi} = 40\,mS$; $r_o = \infty$

ii. $A(j\omega) = A_o \underbrace{\left(\frac{j\omega}{j\omega + \omega_{PC}}\right)}_{C_C} \underbrace{\left(\frac{j\omega + \omega_{ZE}}{j\omega + \omega_{PE}}\right)}_{C_E} = -|A_o| \left(\frac{j\omega}{j\omega + \omega_{PC}}\right)\left(\frac{j\omega + \omega_{ze}}{j\omega + \omega_{PE}}\right)$

$\omega_{PC} = \frac{1}{R_{EqC} C_C}$, $\omega_{PE} = \frac{1}{R_{eqE} C_E}$; $\omega_{ZE} = \frac{1}{R_E C_E} = \frac{1}{(1K)(1000\mu F)}$

$\omega_{ZE} = 1$ rad/sec

Assume C_E becomes short first; i.e
$\omega_{PE} < \omega_{PC}$

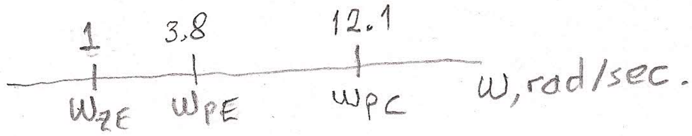
$R_{eqE} = R_E // \frac{R_1 // R_2 + r_\pi}{\beta + 1}$ (C_c is open)

$= 1K // \left[\frac{200K // 40K + 2.5K}{101}\right] = 263\,\Omega \Rightarrow \omega_{PE} = \frac{1}{R_{eqE} C_E} = 3.8$ rad/sec

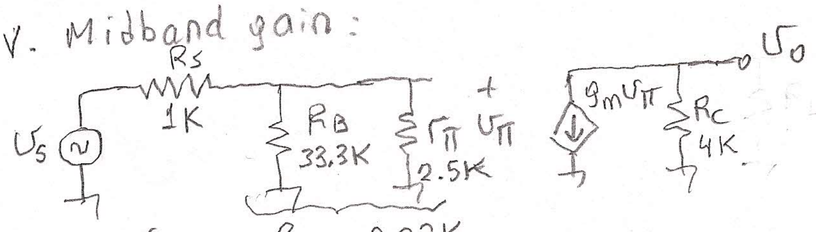
$R_{eqC} = R_S + [R_1 // R_2 // r_\pi]$ (C_E is short)

$= 1K + (200K // 40K // 2.5K) = 3.33K$

$\omega_{PC} = \frac{1}{R_{eqC} C_C} = 12.1$ r/s



iv. Midband gain:



$V_\pi = \frac{2.33}{3.33} V_s = 0.7\,V_s$

$V_o = -g_m R_C V_\pi = (-40\,mS)(4K) V_\pi$
$= -160\,V_\pi = -111\,V_s$

$A_v = -111 \Rightarrow A_{v,dB} = 41\,dB$

Behaviour of gain:

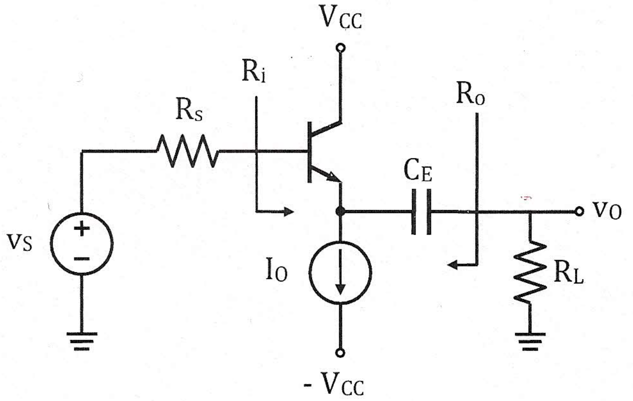
	ω_{ZE}	ω_{PE}	ω_{PC}	
$\|A_v\|$	$A_o \frac{\omega_{ZE}}{\omega_{PE}\omega_{PC}} \omega$	$A_o \frac{\omega^2}{\omega_{PE}\omega_{PC}}$	$A_o \frac{\omega}{\omega_{PC}}$	A_o
	+20 dB/dec	+40 dB/dec	+20 dB/dec	Midband

Phase behaviour

$\phi = \pi + \tan^{-1}\omega + \tan^{-1}\frac{\omega}{\omega_{ZE}} - \tan^{-1}\left(\frac{\omega}{\omega_{PC}}\right) - \tan^{-1}\left(\frac{\omega}{\omega_{PE}}\right)$

Q4. (25 pts) Consider the common emitter amplifier biased with a current source given below.

i. Draw the DC equivalent circuit and determine quiescent point values I_{CQ} and V_{CEQ}.
ii. Determine the small signal parameters.
iii. Draw the small signal equivalent circuit and calculate the small signal voltage gain $A_V = v_O/v_S$.
iv. Determine the input resistance R_i and output resistance R_o.
v. Determine the lower corner frequency.



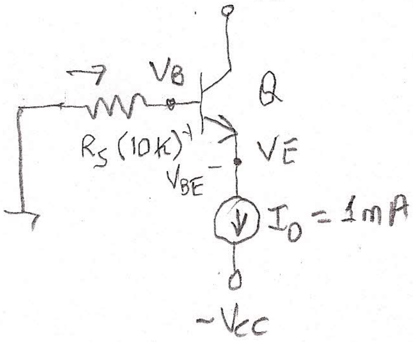
<u>Circuit Parameters</u>

$V_{CC} = 5$ V
$R_S = 10$ kΩ.
$R_L = 10$ kΩ
$I_O = 1$ mA
$C_E = 10$ μF

<u>The transistor Parameters</u>

β = 100,
$V_{BE(ON)} = 0.7$ V,
$V_T = 26$ mV,
$V_A = 100$ V

i. AC sources are short, C's are open!



$I_C \cong I_E = I_0 = 1\,mA$

$I_B = \frac{I_C}{\beta} = 10\,\mu A$

$V_B = -R_S I_B = 0.1\,V$

$V_B = V_{BE} + V_E \Rightarrow V_E = V_B - V_{BE} = -0.8\,V$

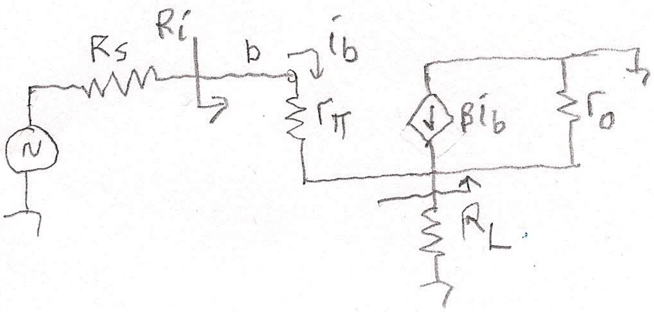
$V_E = -0.8\,V$, $V_C = 5\,V$ } $V_{CE} = V_C - V_E = 5.8\,V$

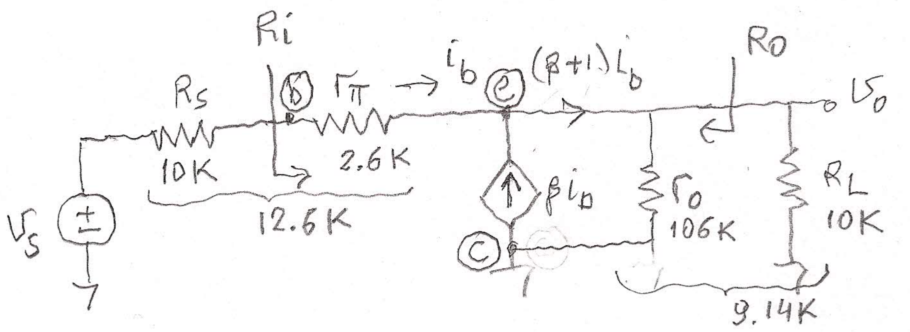
($V_{CE} > V_{CE,SAT}$; Q is forward active)

ii. $r_\pi = \frac{V_T}{I_B} = \frac{26\,mV}{10\,\mu A} = 2.6\,K$; $g_m = 0.44\,mS$;

$r_o = \frac{V_A + V_{CEQ}}{I_{CQ}} = \frac{105.8\,V}{1\,mA} = 106\,K$

iii. Small signal model (Midband)





$$i_b = \frac{v_s - v_o}{R_s + r_\pi} \; ; \quad v_o = (\beta+1) i_b (r_o // R_L)$$

$$v_o = (\beta+1)\left(\frac{v_s - v_o}{R_s + r_\pi}\right)(r_o // R_L)$$

$$(R_s + r_\pi) v_o = (v_s - v_o)(\beta+1)(r_o // R_L)$$

$$[(R_s + r_\pi) + (\beta+1)(r_o//R_L)]\, v_o = (\beta+1)(r_o//R_L)\, v_s$$

$$A_v = \frac{v_o}{v_s} = \frac{(\beta+1)(r_o//R_L)}{(R_s + r_\pi) + (\beta+1)(r_o//R_L)}$$

$$\simeq \frac{(101)(9.14K)}{12.6K + (101)(9.14K)} = \frac{923.14K}{935.74K} = 0.987$$

iv. $R_i = r_\pi + (\beta+1)(r_o//R_L)$

$$= 2.6K + 923.14K = 925.74K$$

$$R_o = r_o // \left(\frac{R_s + r_\pi}{\beta+1}\right) = 106K // \frac{12.6K}{101} = 106K // 125\Omega = 125\Omega$$

v. $A_v(j\omega) = A_o\left(\frac{j\omega}{j\omega + \omega_{pE}}\right)$

$$\omega_{pE} = \frac{1}{R_{eqE} C_E} \; ; \quad R_{eqE} = \left(r_o // \frac{R_s + r_\pi}{\beta+1}\right) + R_L$$

$$= 125\Omega + 10K = 10.1K$$

$$C_E = 10\mu F$$

$$\omega_{pE} = \frac{1}{(10.1K)(10\mu F)} \simeq 9.9 \text{ rad/sec} \quad (f_{pE} = 1.58 Hz)$$