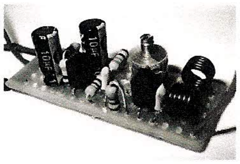


İZMİR UNIVERSITY OF ECONOMICS
Department of Electronics and Communication Engineering
ETE 331 Analog Electronics
Fall 2013/2014

MIDTERM EXAM I

Nov 12, 2014
120 min

INSTRUCTIONS

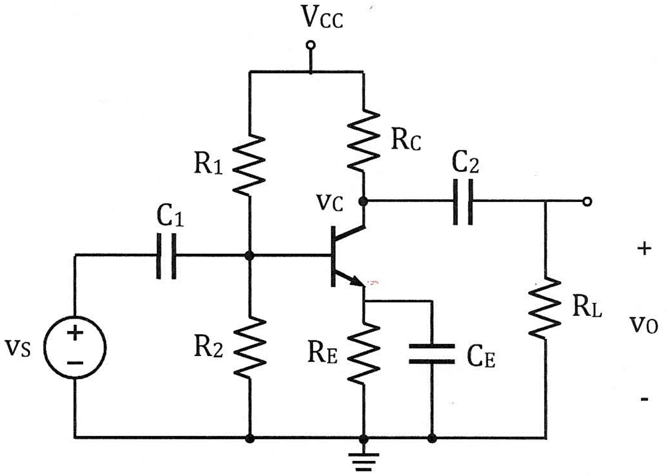
- Read all of the instructions and all of the questions before beginning the exam.
- There are 4 questions on this exam, totaling 100 points. The credit for each problem is given to help you allocate your time accordingly.
- Do not spend all your time on one problem and on one part and attempt to solve 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 only partial 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.

Last Name :........................
Name :........................
Section :........................
Student No :........................

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

The basic equations of the output characteristics of an NMOS transistor		
V_{GS}	**V_{DS}**	**I_D**
i) $V_{GS} < V_{Tn}$	-	0
ii) $V_{GS} > V_{Tn}$	a) $V_{DS} < V_{GS} - V_{Tn}$	$K_n\left[2(V_{GS} - V_{Tn})V_{DS} - V_{DS}^2\right]$
	b) $V_{GS} - V_{Tn} \leq V_{DS}$	$K_n(V_{GS} - V_{Tn})^2$
where $K_n = \frac{K'_n}{2}\left(\frac{W}{L}\right)$ and $K'_n = \mu_n C_{ox}$		

Q1. (25 pts) Consider the following common emitter amplifier. The capacitors are large enough to be considered as short circuit at the frequencies of the input source.



Circuit Parameters

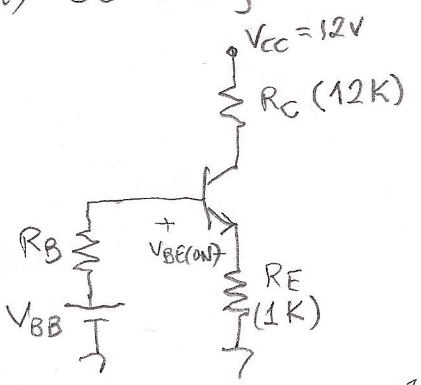
$V_{CC} = 12$ V
$R_1 = 100$ kΩ
$R_2 = 15$ kΩ
$R_C = 12$ kΩ
$R_E = 1$ kΩ
$R_L = 20$ kΩ

Transistor Parameters

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

(a) Draw the DC load line and locate Q point.
(b) Determine the AC small signal voltage gain $A_v = v_o/v_s$.
(c) Draw the AC load line. Determine the limits on the output voltage swing. Which limits the output signal amplitude, AC-SAT or AC-Cut-off?
(d) Determine the total collector voltage v_C and the total output voltage v_O if $v_S = 2 \sin \omega_0 t$ mV (Be careful about the units!)

(a) DC Analysis :



$R_B = R_1 // R_2 = 13K$

$V_{BB} = \frac{R_2}{R_1 + R_2} V_{CC} = \frac{15}{115} \cdot 12 = 1.565$ V

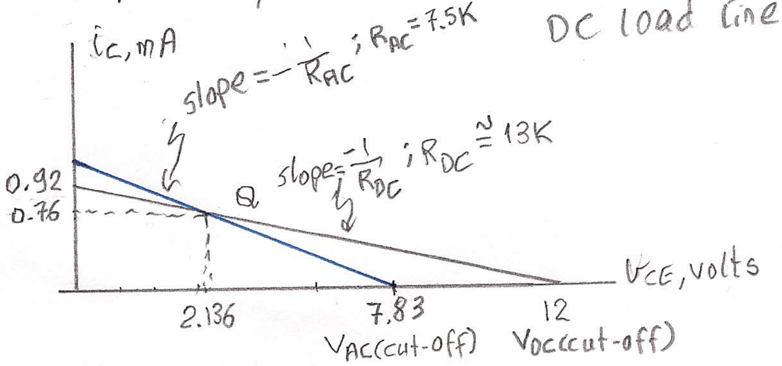
$I_B = \frac{V_{BB} - V_{BE(ON)}}{R_B + (\beta+1) R_E} = \frac{1.565 - 0.7}{13 + 101} = 7.59 \mu A$

$I_C = \beta I_B = 0.759$ mA

$V_{CEQ} = V_{CC} - [R_C + \frac{(\beta+1)}{\beta} R_E] I_C = 2.136$ V

DC load line : $V_{CC} = V_{CE} + [R_C + \frac{\beta+1}{\beta} R_E] I_C$

$R_{DC} \cong R_C + R_E = 13$ K

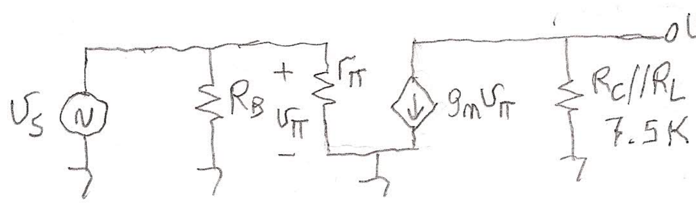


(c) AC load line : $R_{AC} = R_C // R_L = 12K // 20K = 7.5K$

$V_{AC(cut\text{-}off)} = V_{CEQ} + R_{AC} I_{CQ} = 2.136 + (7.5)(0.759) = 7.83$ V

(b) AC small signal model : $r_\pi = \frac{25\,mV}{I_{BQ}} \approx \frac{25\,mV}{7.59\,\mu A} = 3.3K$

$g_m = \frac{\beta}{r_\pi} = 30\,mS$



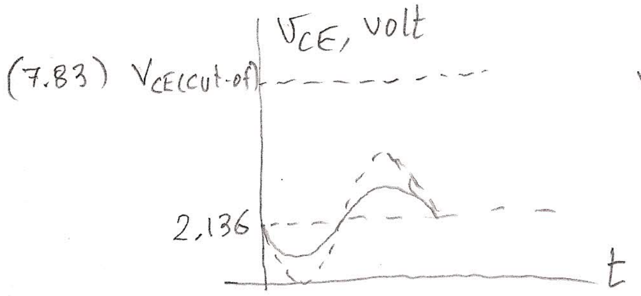
$v_\pi = v_s$;

$v_o = -g_m (R_C // R_L)\, v_\pi$

$= (-30\,ms)(7.5)\, v_s$

$A_v = -225$

(c) AC-SAT limits the output swing.



$V_{o(peak\text{-}to\text{-}peak)} = 2 \times (2.136)$

$= 4.272\ V$

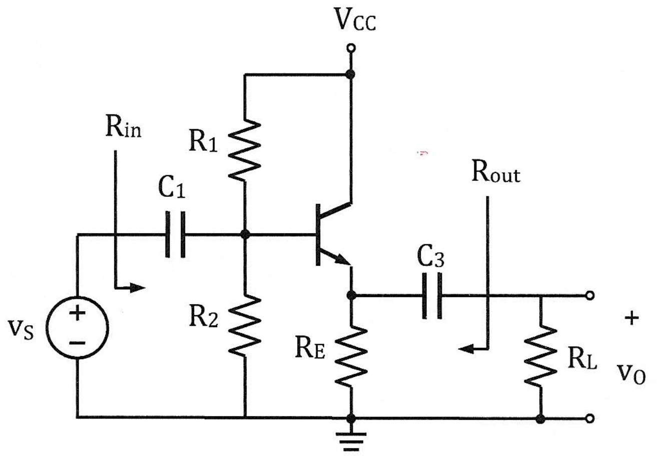
(d) $A_v = -225$

$v_o = V_{o(DC)} + v_o = 0 + A_v v_s$

$= -450 \sin\omega t\ mV = -0.45 \sin\omega t$ volts

Q2. (25 pts) Consider the common-collector (emitter follower) amplifier given below. All capacitors are assumed short at the frequencies interest.

(a) Determine R_1 to set $I_{CQ} = 1$ mA.
(b) Now assume R_1 =45 kΩ, Draw the AC small signal equivalent circuit.
(c) Determine the AC small signal gain $A_V = v_o/v_S$, input resistance R_{in} and output resistance R_{out}.



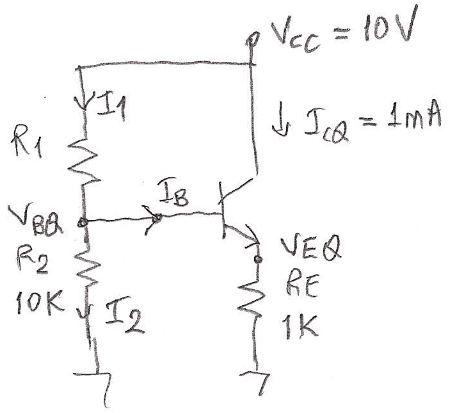
Circuit Parameters

$V_{CC} = 10$V
$R_2 = 10$ kΩ
$R_E = 1$ kΩ
$R_L = 10$ kΩ

Transistor Parameters

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

(a)



$V_{EQ} = I_E R_E \cong (1\,mA)(1\,K) = 1V$

$V_{BQ} = V_{BE(ON)} + V_{EQ} = 1.7\,V$

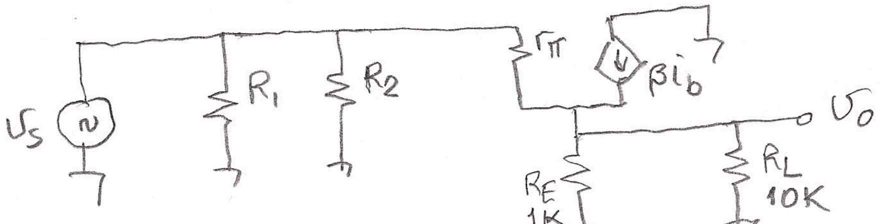
$I_2 = \frac{V_B}{R_2} = \frac{1.7\,V}{10\,K} = 0.17\,mA$

$I_B = \frac{I_C}{\beta} = \frac{1\,mA}{100} = 0.01\,mA$

$\Rightarrow I_1 = I_2 + I_B = 0.18\,mA$

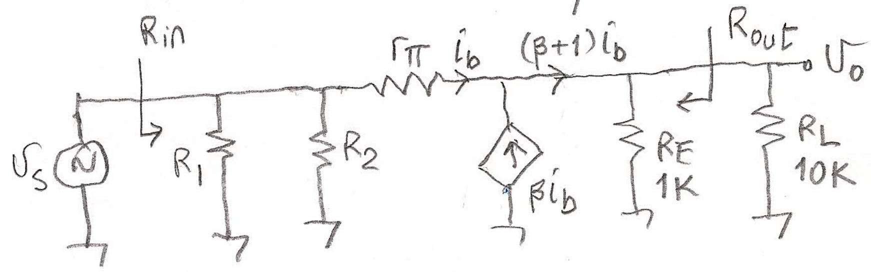
$R_1 = \frac{V_{CC} - V_B}{I_1} = \frac{10 - 1.7\,V}{0.18\,mA} = 46.1\,K$

(b) $R_1 = 45\,K$; $R_1 // R_2 = 45K // 10K = 8.18\,K$



$r_\pi = \frac{25\,mV}{I_{BQ}} = \frac{25\,mV}{0.01\,mA}$

$r_\pi = 2.5\,K$



$R_E // R_L = 0.91\,K$

$$\left.\begin{aligned} v_s &= [r_\pi + (\beta+1)(R_E // R_L)]\, i_b \\ v_o &= (\beta+1)(R_C // R_L)\, i_b \end{aligned}\right\} \quad \frac{v_o}{v_s} = \frac{(\beta+1)(R_C // R_L)}{r_\pi + (\beta+1)(R_C // R_L)}$$

$$= \frac{(101)(0.91)}{2.5 + (101)(0.91)} = \frac{92}{2.5+92}$$

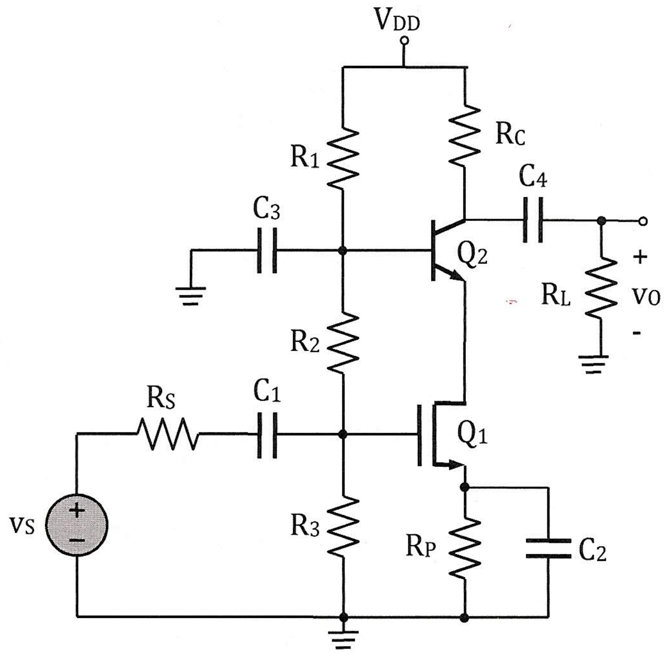
$$A_v = \frac{v_o}{v_s} = 0.973$$

$$R_{in} = \underbrace{R_1 // R_2}\, // [r_\pi + (\beta+1)(R_E // R_L)]$$

$$= 8.12 // 94.5 \cong 7.5K$$

$$R_{out} = \frac{r_\pi}{\beta+1} = 24.75\,\Omega$$

Q3. (25 pts) Consider the cascode amplifier given below.



<u>Circuit Parameters</u>

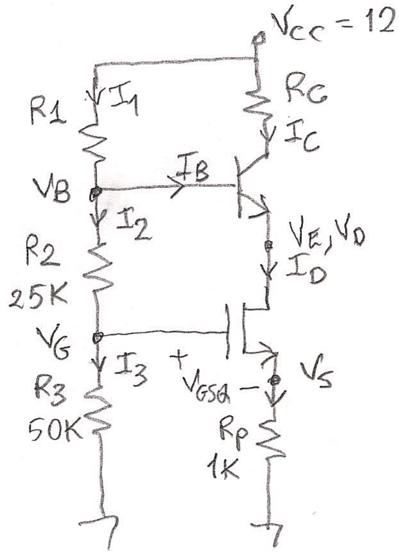
V_{DD} = 12V
R_2 = 25 kΩ.
R_3 = 50 kΩ.
R_L = 10 kΩ
R_S = 1 kΩ
R_P = 1 kΩ.

<u>Transistor Parameters</u>

Q1: K_N = 2 mA/V², V_{TN} = 1 V, $V_A = \infty$
Q2: β = 100, $V_{BE(ON)}$ = 0.7 V, $V_A = \infty$

(a) Determine R_1 to set V_{GSQ1} = 2 V.
(b) Check the SAT conditions for the transistors.
(c) Determine the small-signal parameters for each transistor.
(d) Determine the overall AC small-signal voltage gain $Av = vo / vs$.

(a)



$V_{GSQ} = 2V \Rightarrow I_{DQ} = K_n(V_{GS} - V_{TN})^2$
$= (2\ mA/V^2)(2-1)^2$

$\Rightarrow I_{DQ} = 2\ mA$

$V_S = I_D R_P = (2mA)(1K) = 2V$

$V_G = V_{GSQ} + V_S = 2 + 2 = 4V$

$I_3 = \frac{V_G}{R_3} = \frac{4V}{50K} = 0.08\ mA$

$I_2 = I_3 = 0.08\ mA$

$V_B = R_2 I_2 + V_G = (25K)(0.08mA) + 4$

$V_B = 6V$

$I_B = \frac{I_D}{\beta + 1} \cong \frac{2\ mA}{100} = 0.02\ mA \Rightarrow I_1 = I_2 + I_B = 0.1\ mA$

$R_1 = \frac{V_{cc} - V_B}{I_1} = \frac{12 - 6\ V}{0.1\ mA} = \frac{6\ V}{0.1\ mA} = 60\ K$

(b) NMOS

$V_D = V_E = V_B - V_{BE(ON)} = 6 - 0.7 = 5.3V$

$V_S = 2V$

$V_{DS} = V_D - V_S = 3.3V$

$V_{DS} \geq V_{GS} - V_{TN}$

$3.3 \geq 2 - 1 = 1V$ ✓ SAT

BJT

$V_E = 5.3V$; $V_C = V_{CC} - R_C I_C = 12 - 2R_C$ $(I_C \cong I_D = 2mA)$

$V_{CE} \geq V_{CE(SAT)} \Rightarrow (12 - 2R_C) - 5.3 \geq 0.2V$

$\underbrace{12 - 5.3 - 0.2}_{6.5} \geq 2R_C \Rightarrow R_C \leq 3.25K$ satisfies SAT,

Assume $R_C = 1K \Rightarrow V_{CE} = 10V \geq V_{CE(SAT)}$

(c) NMOS

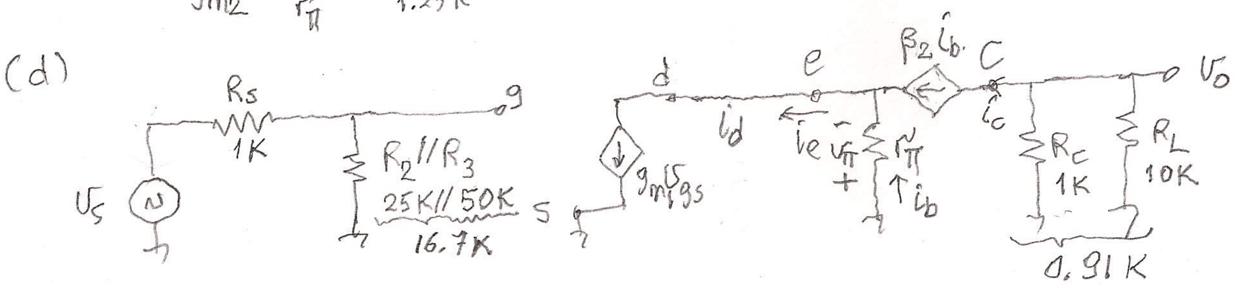
$g_{m1} = 2K_n(V_{GS} - V_{TN}) = (2)(2)(2-1) = 4mS$; $r_0 = \infty$

BJT

$r_{\pi 2} = \dfrac{25mV}{I_B} = \dfrac{25mV}{0.02mA} = 1.25K$

$g_{m2} = \dfrac{\beta}{r_\pi} = \dfrac{10}{1.25K} = 8mS$; $r_0 = \infty$

(d)



$v_{gs} = \dfrac{16.7}{1 + 16.7} v_s = 0.94 v_s$

$i_d = g_m v_{gs} = (4)(0.94)v_s = 3.77 v_s = i_e \Rightarrow i_b = \dfrac{3.77}{\beta + 1} v_s$

$i_c = \beta i_b = \dfrac{\beta}{\beta + 1}(3.77)v_s = 3.72 v_s$

$v_o = -i_c(R_C // R_L) = -(3.72)(0.91)v_s = -3.38 v_s$

$\Rightarrow A_V = -3.38$

Q4. (25 pts) Consider the circuit given below.

i. Show that the transfer function is given as

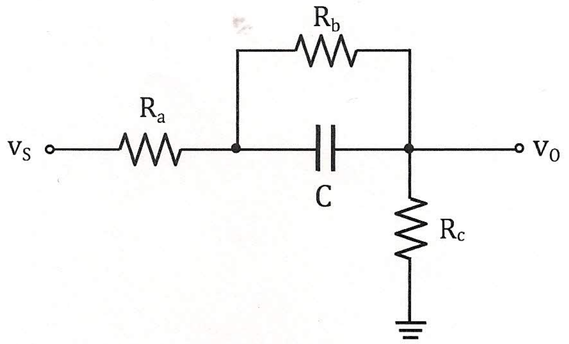
$$H(j\omega) = A_0 \frac{1 + j\frac{\omega}{\omega_1}}{1 + j\frac{\omega}{\omega_2}}$$

where

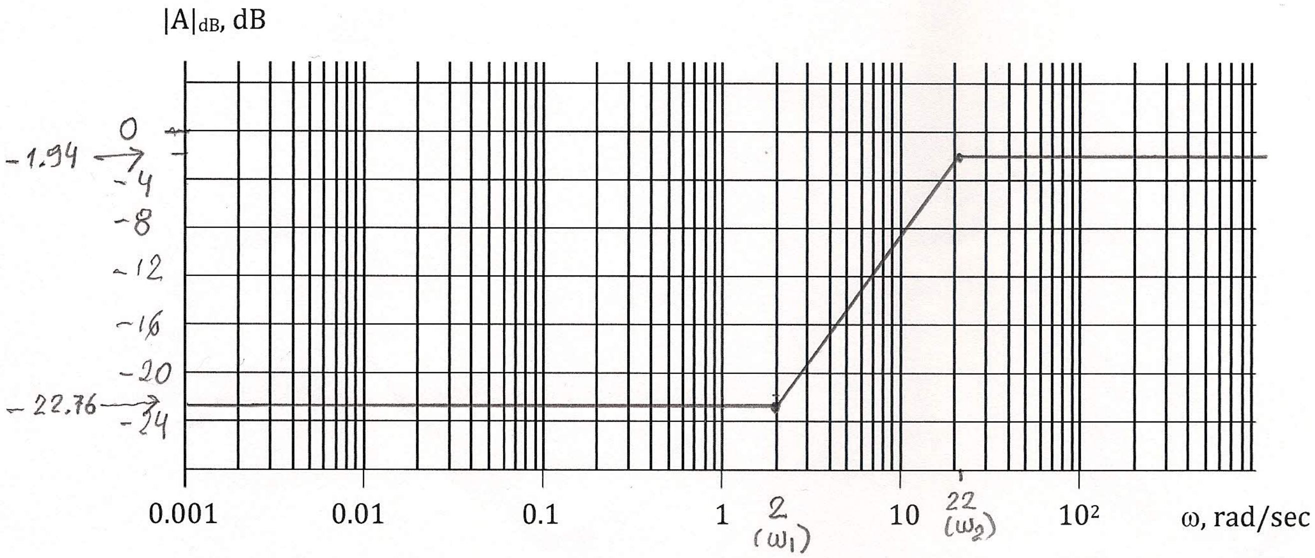
$\omega_1 = \frac{1}{R_b C}$ and

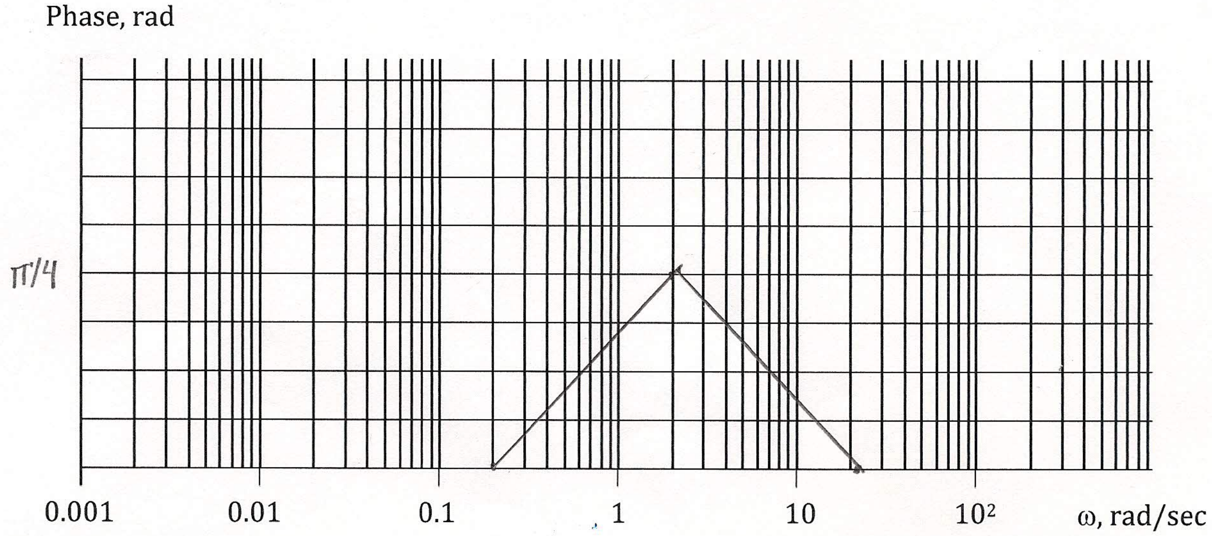
$\omega_2 = \frac{1}{R_{eq2} C}$; $R_{eq2} = (R_a + R_c)//R_b$

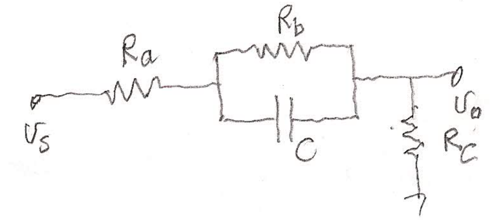
Determine A_0

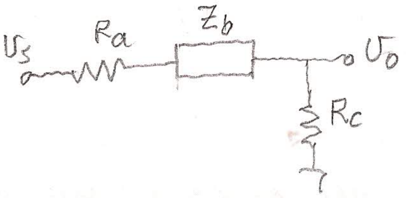


ii. If R_a = 1 K, R_b = 50 K, R_c = 4 K, and C = 10 μF, determine and plot
   (a) The Bode magnitude plot
   (b) The Bode phase plot





i. 

$\Rightarrow$ 

$$Z_b = \frac{R_b}{1 + j\omega R_b C}$$

$$H(j\omega) = \frac{V_o(j\omega)}{V_s(j\omega)} = \frac{R_C}{R_a + Z_b + R_C} = \frac{R_C}{R_a + \frac{R_b}{1+j\omega R_b C} + R_C} = \frac{R_C}{R_a + R_C + \frac{R_b}{1+j\omega R_b C}}$$

$$= \frac{R_C(1+j\omega R_b C)}{R_a + R_b + R_C + j\omega R_b (R_a + R_C) C} = \frac{R_C(1+j\omega R_b C)}{R_a + R_b + R_C\left[1 + j\omega \frac{R_b(R_a+R_C)}{R_a+R_b+R_C} C\right]}$$

$$= \underbrace{\frac{R_C}{R_a + R_b + R_C}}_{A_0} \frac{1+j\omega R_b C}{1+j\omega R_{eq2}} \quad ; \; R_{eq2} = \frac{R_C(R_a+R_C)}{R_a+R_b+R_C} = (R_a+R_C)//R_b$$

$$= A_0 \frac{1+j\frac{\omega}{\omega_1}}{1+j\frac{\omega}{\omega_2}} \quad ; \; A_0 = \frac{R_C}{R_a+R_b+R_C} \; ; \; \omega_1 = \frac{1}{R_b C} \; ; \; \omega_2 = \frac{1}{R_{eq2} C}$$

ii. $R_a = 1K$, $R_b = 50K$, $R_C = 4K$, $C = 10\mu F$

$$A_0 = \frac{R_C}{R_a+R_b+R_C} = \frac{4}{1+50+4} = \frac{4}{55} = 0.073 \Rightarrow A_{0,dB} = -22.76\,dB$$

$$\omega_1 = \frac{1}{R_b C} = \frac{1}{50\times10^3 \times 10\times10^{-6}} = \frac{10^3}{500} = 2 \text{ rad/sec}$$

$$R_{eq2} = (R_a+R_C)//R_b = 5K//50K = 4.55K$$

$$\omega_2 = \frac{1}{R_{eq2} C} = \frac{1}{4.55\times10^3\times10\times10^{-6}} = \frac{10^3}{45.5} = 22 \text{ rad/sec}$$

$\omega < \omega_1$: $|H(j\omega)|_{dB} = 20\log A_0 = -22.76\,dB$

$\omega_1 < \omega < \omega_2$: $|H(j\omega)|_{dB} = 20\log A_0 \frac{\omega}{\omega_1} = 20\log\omega + 20\log(\frac{A_0}{\omega_1})$ (20dB/dec)

$\omega_2 < \omega$ $|H(j\omega)|_{dB} = 20\log A_0 \frac{\omega/\omega_1}{\omega/\omega_2} = 20\log A_0 \cdot \frac{\omega_2}{\omega_1} = 20\log \frac{4}{55}\cdot\frac{22}{2}$

$= 20\log(\frac{4}{5}) = \sim 1.94\,dB$ Magnitude plot is above.

<u>Phase</u> $\varphi = \tan^{-1}(\frac{\omega}{\omega_1}) - \tan^{-1}(\frac{\omega}{\omega_2})$

ω(rad/sec)	$\tan^{-1}(\omega/2)$	$\tan^{-1}(\omega/22)$	φ(rad)
0.2	0	0	0
2	π/4	0	π/4
22	π/2	π/4	π/4
220	π/2	π/2	0

Phase plot is above.