Name: ______________________________ (please print)

Signature: ___________________________

ECE 3355 – Exam #1
February 22, 2020

Keep this exam closed and face up until you are told to begin.

1. This exam is closed book, closed notes. You may use one 8.5" x 11" crib sheet, or its equivalent.
2. Show all work on these pages. Show all work necessary to complete the problem. A solution without the appropriate work shown will receive no credit. A solution which is not given in a reasonable order will lose credit.
3. Show all units in solutions, intermediate results, and figures.
4. If the grader has difficulty following your work because it is messy or disorganized, you will lose credit.
5. Do not use red ink. Do not use red pencil.
6. You will have 90 minutes to work on this exam.

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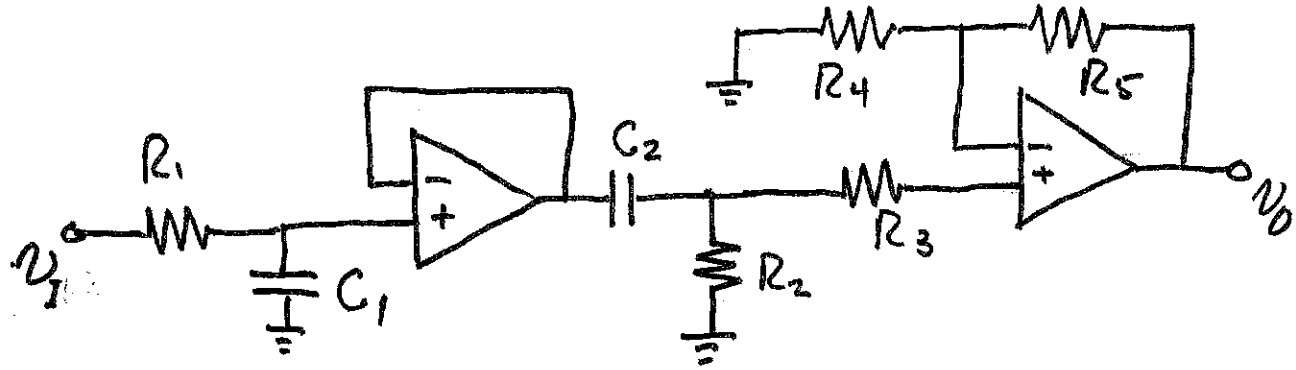
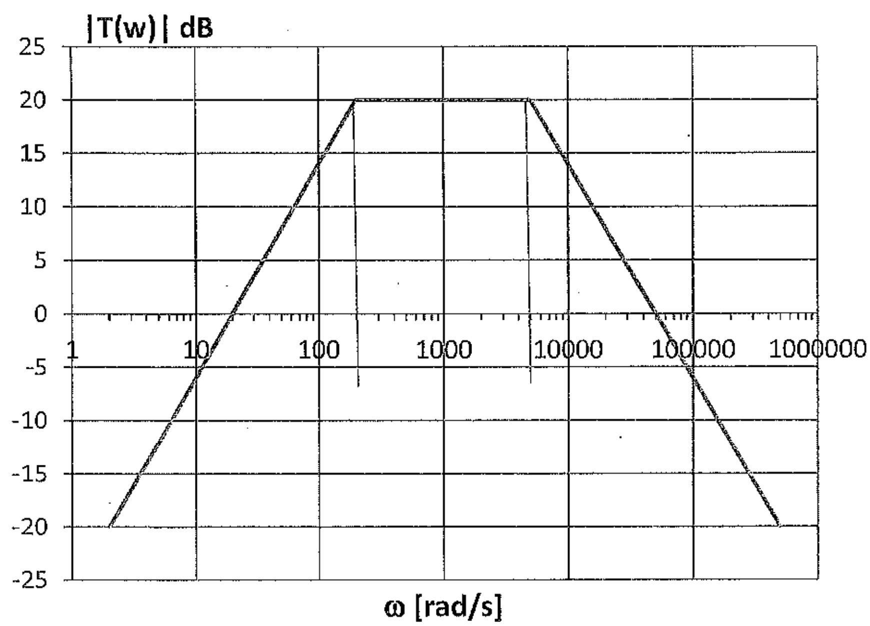
Room for extra work

1. (35 points) For the circuit below, do the following.

Find the transfer function $T(\omega) = V_o/V_i$. Then choose resistor and capacitor values such that the magnitude Bode plot for this transfer function has the form shown in the graph. Be sure your results account for the breakpoints in the transfer function as well as the magnitude. Assume the op amps are ideal.





Room for extra work

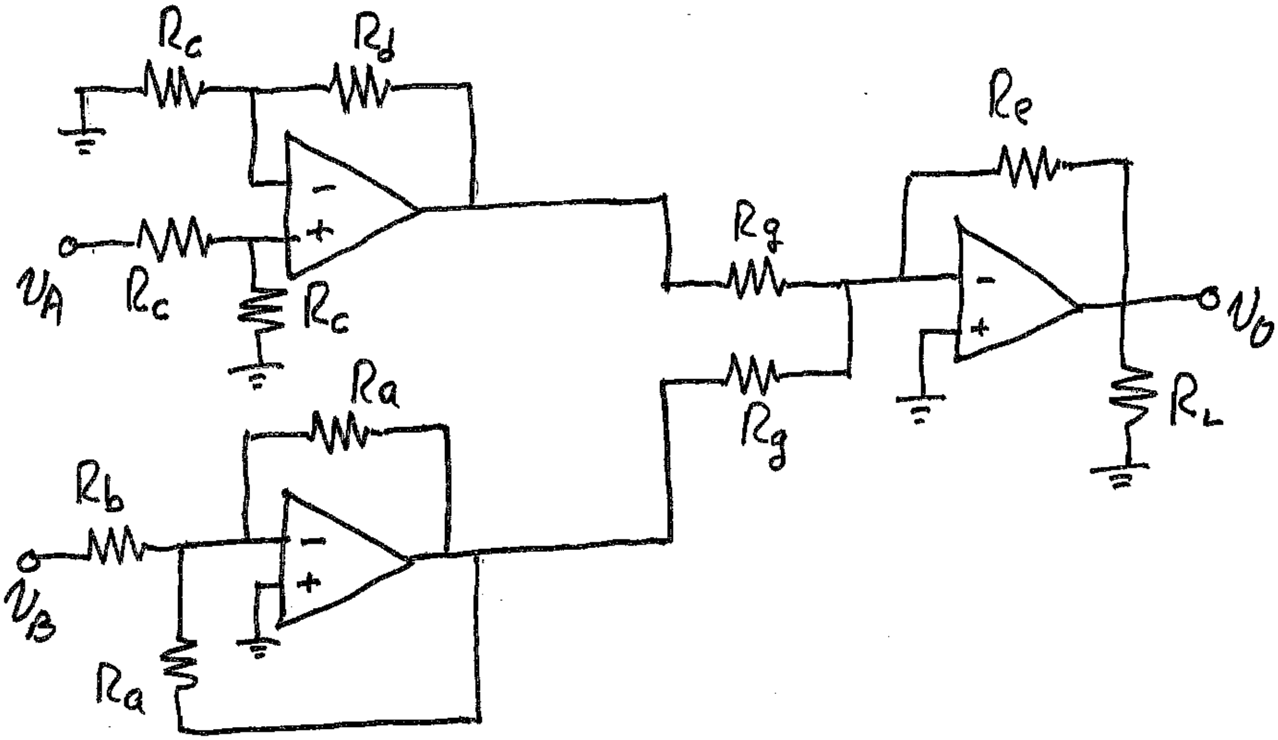
2. (30 points)

a) Using the graph paper on the next page, sketch the straight-line approximation to the phase Bode plot for the following transfer function. Note that the values of C and R are unknown.

$$T(\omega) = -\frac{j\omega CR(j\omega + 2000)(j\omega + 200{,}000)}{(j\omega + 400)^2}$$

3. (35 points) For the circuit below, do the following. Assume the op amps are ideal.

a. Find v_O in terms of v_A and v_B, and the resistances.
b. Find the input resistance seen by v_A.
c. Find the input resistance seen by v_B



Room for extra work

Name: SOLUTIONS (please print)

Signature: ______________________

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1. (35 points) For the circuit below, do the following.

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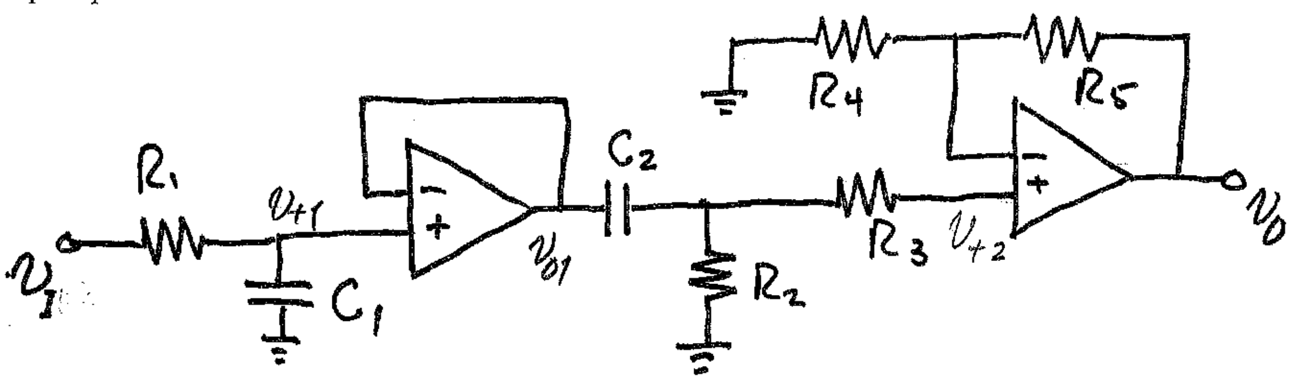
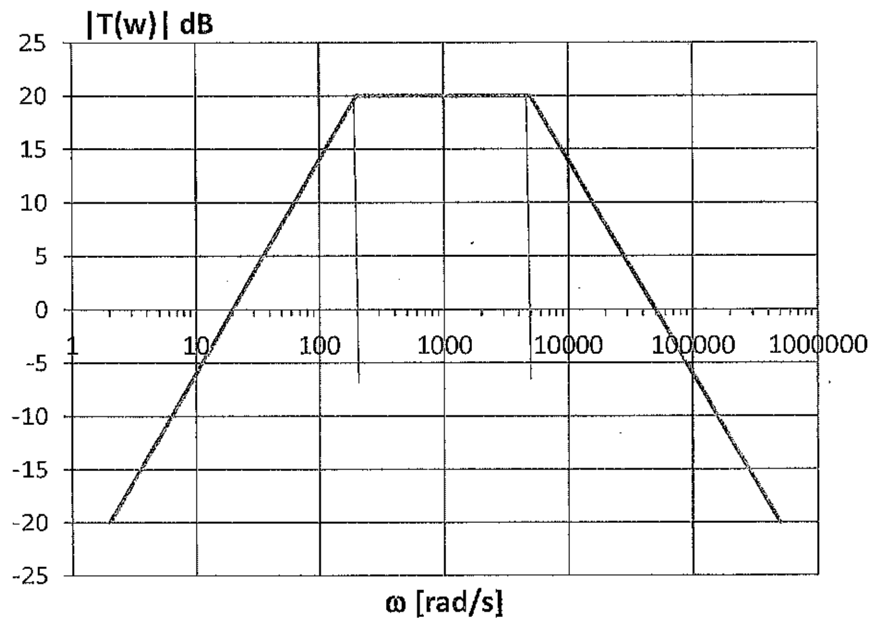




$$\bar{V}_{+1} = \bar{V}_i \frac{1/j\omega C_1}{1/j\omega C_1 + R_1} = \bar{V}_i \frac{1}{1+j\omega C_1 R_1} \qquad \bar{V}_{o1} = \bar{V}_{+1}$$

$$\bar{V}_{+2} = \bar{V}_{o1} \frac{R_2}{R_2 + 1/j\omega C_2} = \bar{V}_{o1} \frac{j\omega C_2 R_2}{1+j\omega C_2 R_2}$$

$$\bar{V}_o = \bar{V}_{+2}\left(1 + \frac{R_5}{R_4}\right)$$

Room for extra work

+15 $\frac{\bar{V}_o}{\bar{V}_i} = \frac{(1+R_5/R_4)}{1+j\omega C_1R_1} \cdot \frac{j\omega C_2R_2}{1+j\omega C_2R_2}$

So we have

zero: 0 rad/s +2

poles: $1/C_1R_1$, $1/C_2R_2$ +2 +2

From the Bode plot, we have poles at 200 rad/s and at 50000 rad/s. There is no way to tell which pole is which, so we'll choose something.

(1) $1/C_1R_1 = 200$ rad/s (2) $1/C_2R_2 = 5000$ rad/s +2 +2

At 1000 rad/s, where $|T(\omega)|$ does not depend on ω, we have

$\omega_0 = 1000$ rad/s $\omega_0 \gg 1/C_1R_1 \Rightarrow \omega_0 C_1 R_1 \gg 1$

$\omega_0 \ll 1/R_2C_2 \Rightarrow \omega_0 C_2 R_2 \ll 1$

So... $\frac{\bar{V}_o}{\bar{V}_i} \simeq \frac{(1+R_5/R_4)}{j\omega_0 C_1R_1} \cdot \frac{j\omega_0 C_2R_2}{1} = (1+R_5/R_4) \cdot \frac{C_2R_2}{C_1R_1}$ +4

(3) $|T(\omega_0)| = (1+R_5/R_4)\frac{C_2R_2}{C_1R_1} = (1+R_5/R_4)\frac{200}{5000} = 10$ (= 20 dB)

So 1, 2, & 3 are the constraints that must be satisfied.

We'll choose $R_1 = 10\,k\Omega \Rightarrow C_1 = 0.5\,\mu F$ +1 +1

$R_2 = 1\,k\Omega \Rightarrow C_2 = 200\,nF$ +1 +1

$R_4 = 500\,\Omega \Rightarrow R_5 = 0.125\,M\Omega$ +1 +1

pg. 2.

We have neglected 1 in comparison with R_5/R_4

Room for extra work

+1 +1

If we had chosen $1/C_1R_1 = 50\,000$ rad/s , $1/C_2R_2 = 200$ rad/s,
we would have ($\omega_0 = 1000$ rad/s)

$$\omega_0 >> 1/C_2R_2 \Rightarrow \omega_0 C_2R_2 >> 1$$

$$\omega_0 << 1/C_1R_1 \Rightarrow \omega_0 C_1R_1 << 1$$

+5

$$|T(\omega_0)| \simeq (1 + R_5/R_4) \frac{j\omega_0 C_2R_2}{1 (j\omega_0 C_2R_2)} = 1 + R_5/R_4 = 10$$

$R_1 = 1\,k\Omega \Rightarrow C_1 = 20$ nF +1 +1

$R_2 = 10\,k\Omega \Rightarrow C_2 = 0.5\,\mu$F +1 +1

$R_4 = 10\,k\Omega$ $R_5 = 90\,k\Omega$ +1 +1

2. (30 points)

a) Using the graph paper on the next page, sketch the straight-line approximation to the phase Bode plot for the following transfer function. Note that the values of C and R are unknown.

$$T(\omega) = -\frac{j\omega CR(j\omega+2000)(j\omega+200,000)}{(j\omega+400)^2}$$

zeros: 0, 2000, 200000 rad/s

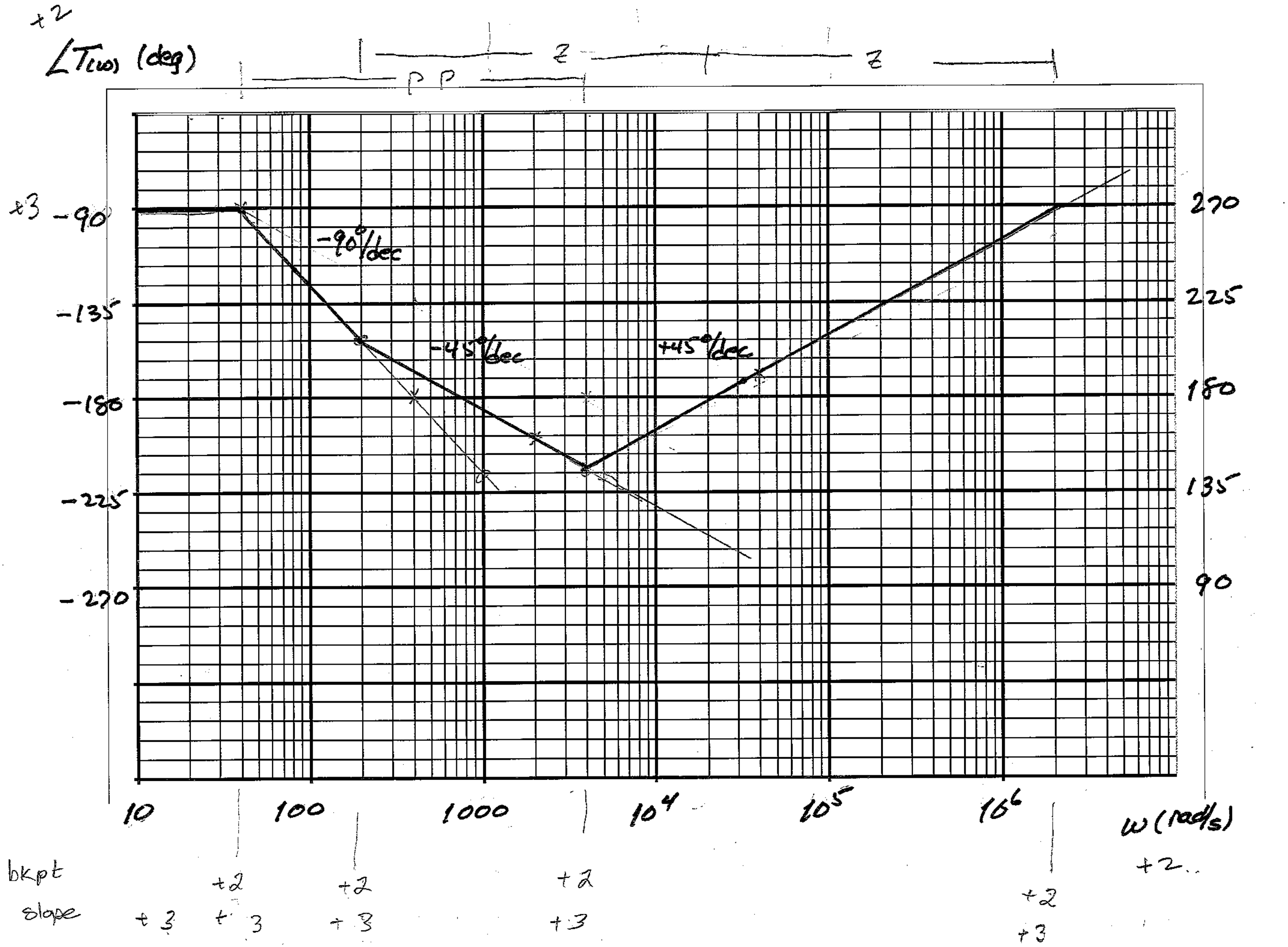
poles: 400, 400 rad/s (double pole)

$T(\omega \to 0) \to -j\omega CR \quad \angle T(\omega \to 0) = -90^\circ$

The plot on the next page shows the result.

Check: $T(\omega \to \infty) \to -j\omega CR \quad \angle T(\omega \to \infty) = -90^\circ$

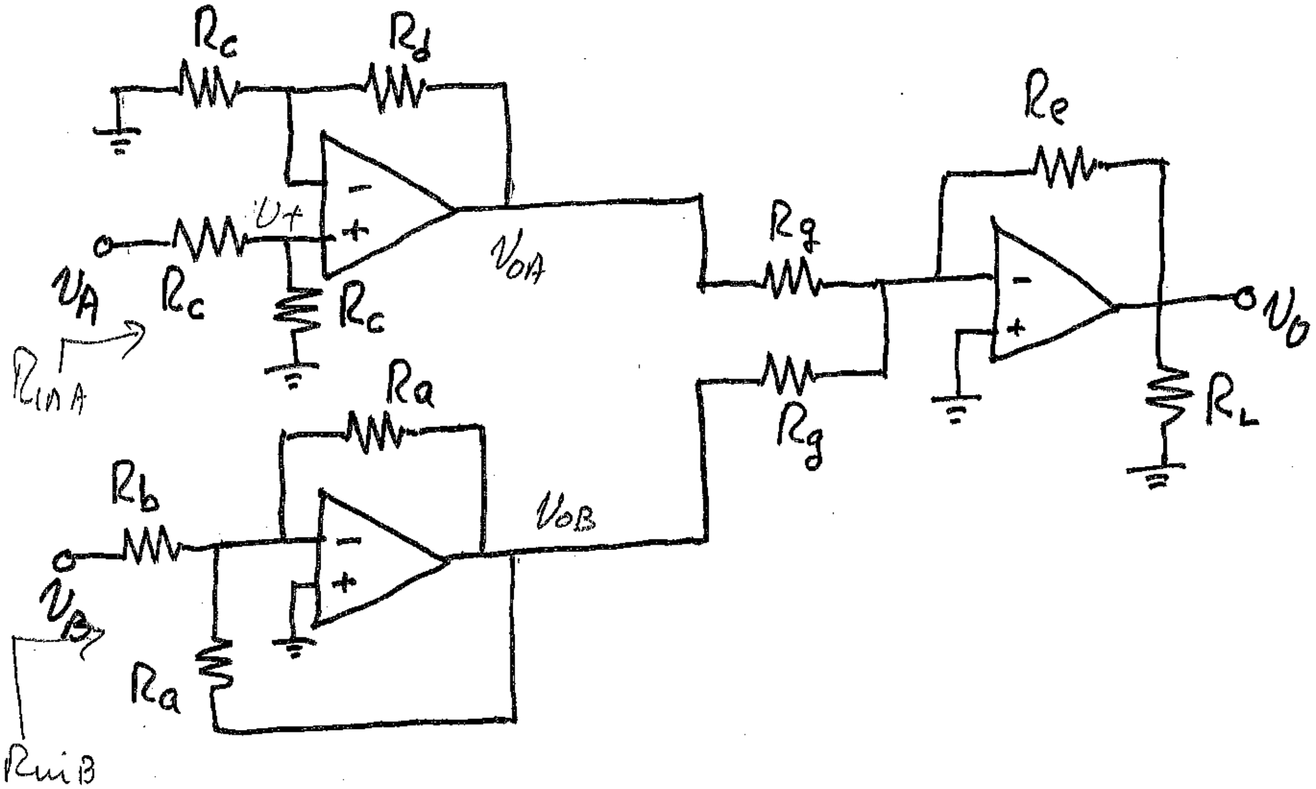
So we come back to where we started, as the plot shows.



+2
∠T(jω) (deg)
P P
Z
Z
+3 -90
-135
-180
-225
-270
270
225
180
135
90
-90°/dec
-45°/dec
+45°/dec
10
100
1000
10^4
10^5
10^6
ω (rad/s)
bkpt
slope
+2
+3

3. (35 points) For the circuit below, do the following. Assume the op amps are ideal.

a. Find v_O in terms of v_A and v_B, and the resistances.
b. Find the input resistance seen by v_A.
c. Find the input resistance seen by v_B



$V_+ = \frac{1}{2} \cdot V_A \qquad V_{OA} = \frac{1}{2}\left(1 + \frac{R_d}{R_c}\right) V_A$ + 10

Note that R_a and R_a are in parallel $\rightarrow \frac{1}{2} R_a$

$V_{OB} = -V_B \frac{\frac{1}{2} R_a}{R_b} = -V_B \frac{R_a}{2R_b}$ + 10

So

$$V_O = -V_{OB}\left(R_e/R_g\right) - V_{OA}\left(R_e/R_g\right)$$

$$V_O = V_B \frac{R_a}{2R_b} \frac{R_e}{R_g} - \frac{1}{2} V_A \left(1 + \frac{R_d}{R_c}\right) \frac{R_e}{R_g}$$

✓ + 10

Room for extra work

$R_{in_A} = 2R_c$ +3

$R_{in_B} = R_b.$ +2