Name: ______________________________ (please print)

Signature: ___________________________

ECE 3355 – Final Exam
May 5, 2021
Online

1. This exam is open book, open notes. You may not consult another person, verbally or online, for help. You may not submit this exam to any online site to get help.
2. Show all work necessary to complete the problem on these pages. A solution without the work shown will receive no credit.
3. The penalty for mixed domains will be 10 points for <u>each</u> <u>problem</u> showing mixed domains.
4. Show units in intermediate and final results, and in figures.
5. If your work is sloppy or difficult to follow, points will be subtracted.

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- I will be available for questions during the exam. If you need to ask a question, please use the chat option on Zoom.

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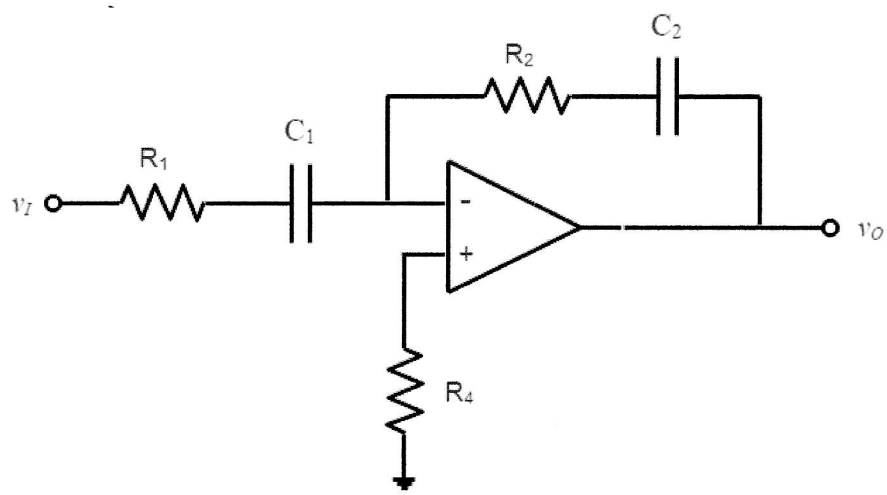
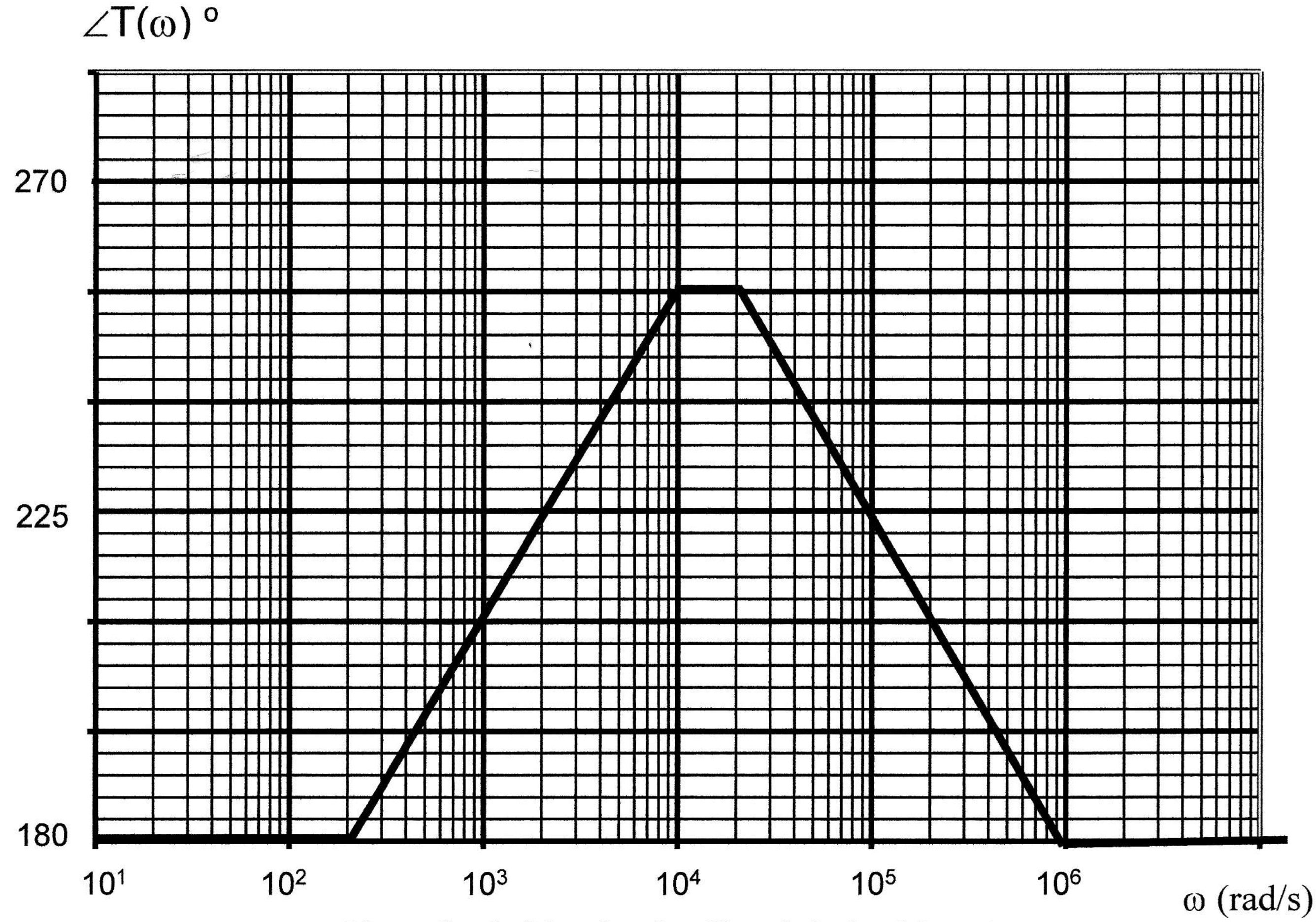
Room for extra work

1. (40 points) In the circuit below, the op amp may be considered ideal, and has power supply voltages of 15 V and -15 V.

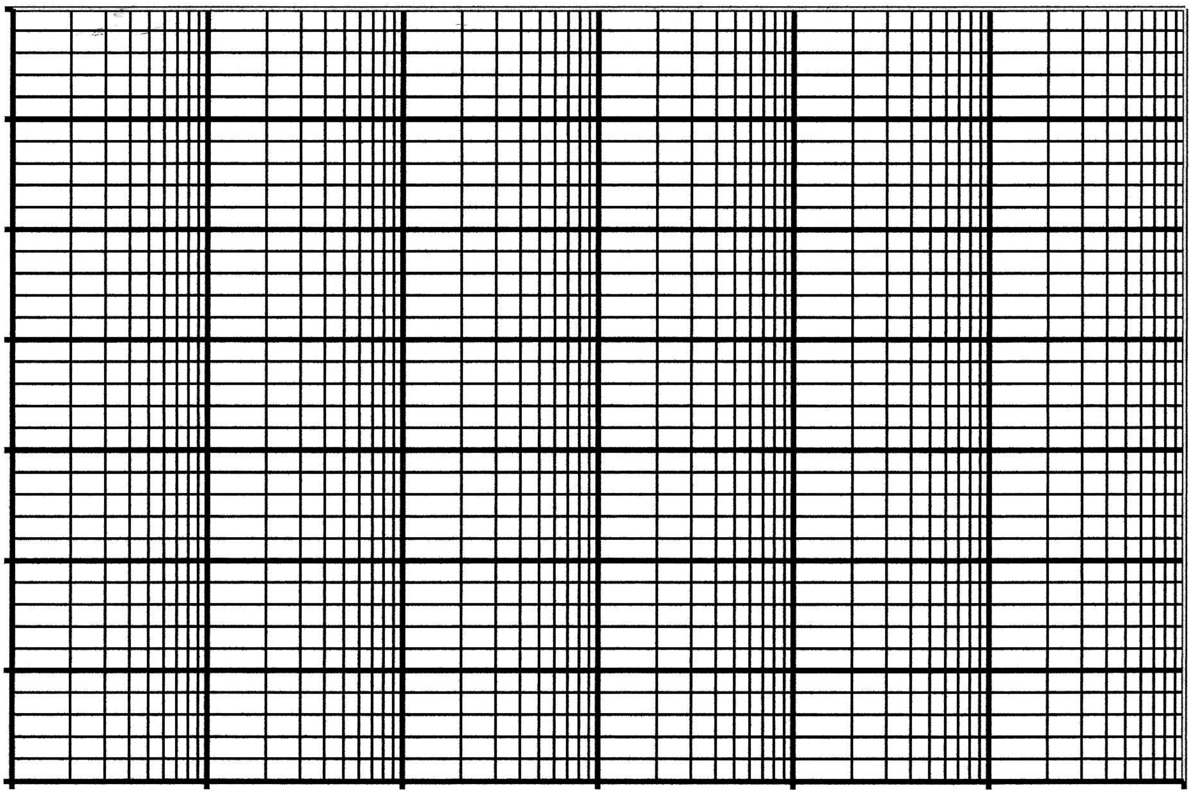
   a. Find the transfer function $T(\omega) = \dfrac{\overline{V}_o}{\overline{V}_i}$ in terms of the variables given.
   b. This circuit produces the phase Bode plot shown on the next page. Find values for the resistances and capacitances that will result in this phase Bode plot.
   c. On the paper given on the second page following, sketch the magnitude Bode plot corresponding to the transfer function for this circuit.





Phase Bode Plot for the Circuit in Problem 1.

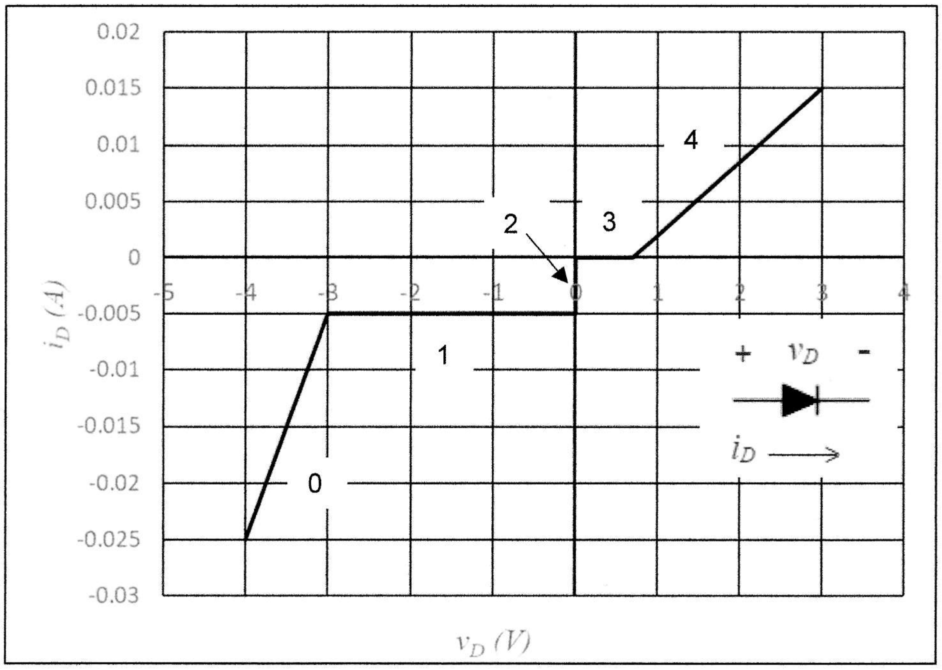
Plot the magnitude Bode plot for this circuit here. Make sure your plot is properly labeled.



Room for extra work

2. (50 points) In the circuit shown on the next page, the diodes have current-voltage characteristics as shown in the plot below. In region 4, the threshold voltage is 0.7 V, and the resistance is 153 Ω.

a. By inspection of the i_D-v_D characteristics, draw a circuit model that could be used to model the diodes in region 0. Specify what test or tests would need to be done to prove that a diode is in this region.
b. For an input voltage of 8 V, find the output voltage v_O.
c. Find the minimum positive value of v_I required to cause one of the diodes to be in region 0.



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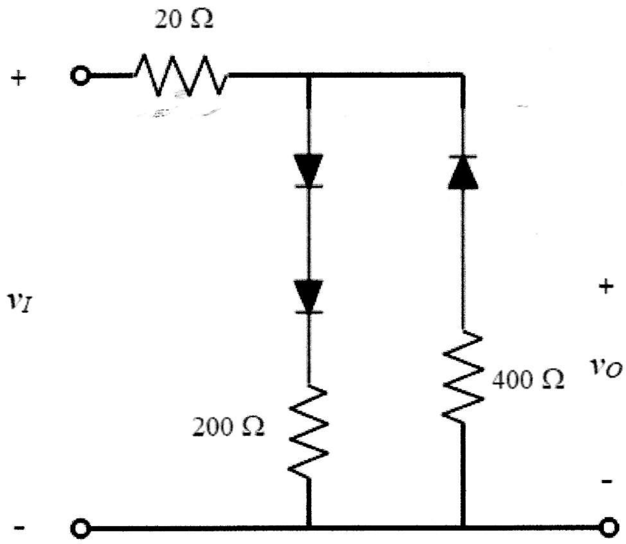
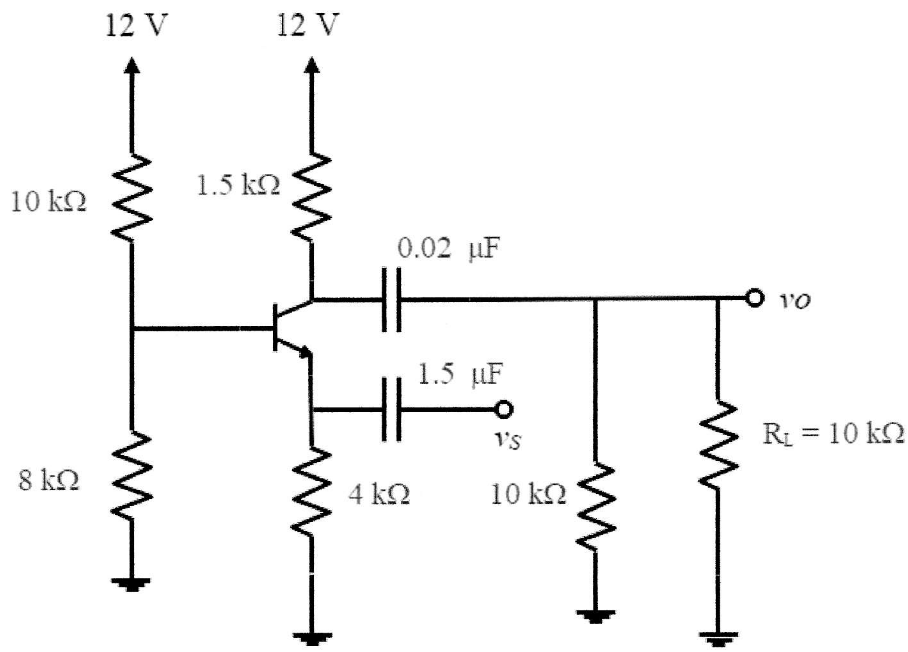


3. (40 points) In the circuit below, the BJT has $\beta = 75$ and $V_{CE,sat} = 0.3$ V.

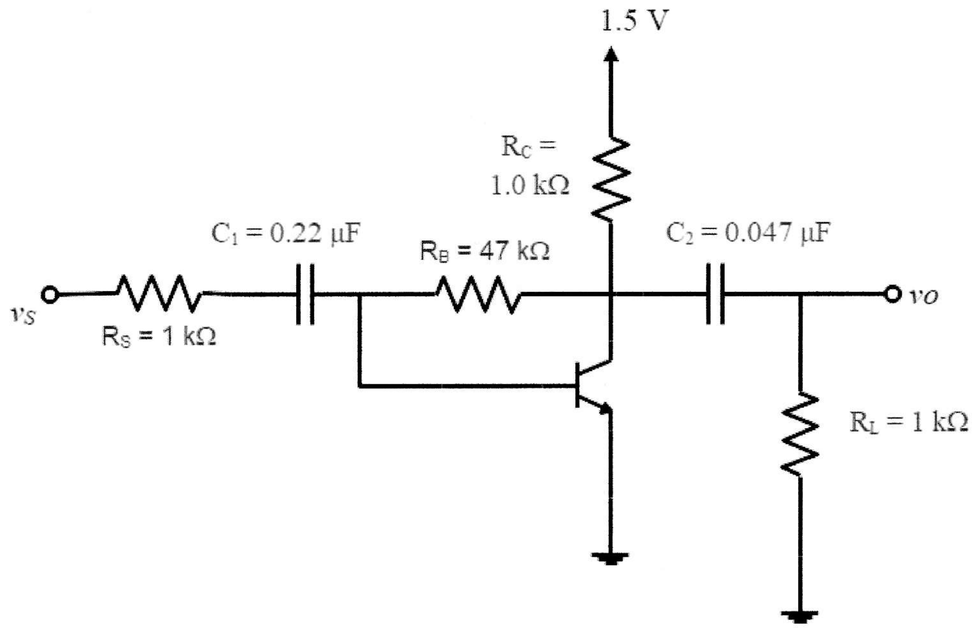
a) Verify that the BJT is biased in the linear region.
b) Find the small signal voltage gain v_o/v_s in the passband.
c) Find the input resistance R_{in} seen by the source v_s and the output resistance R_{out} seen by the load R_L, both in the passband.



Room for extra work

4. (40 points) In the circuit below, the BJT has $\beta = 100$ and $V_{CE,sat} = 0.3$ V. It is biased in the linear region.

a. Show that the BJT is biased in the linear region.
b. Is there a value for R_C such that the BJT is biased in saturation? If so, find this value. If there is not, state how you know this.
c. Write a set of equations that could be used to find the transfer function $T(\omega) = \frac{\overline{V}_o}{\overline{V}_s}$ for this circuit. Write these equations in terms of the circuit parameters R and C. **Do not substitute numerical values for these parameters.**



Room for extra work

5. (30 points) Draw a circuit that uses an astable multivibrator to produce a square wave of amplitude 10 V and period of 2.5 ms. This circuit should connect to the input of an integrator to produce a triangle wave with an amplitude of 5 V.

For the multivibrator and the integrator, use ideal op amps. You may use any number and value of resistors and capacitors, and you may use any voltage source(s) to power the op amps. Assume that all capacitor voltages are initially 0.

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1. (40 points) In the circuit below, the op amp may be considered ideal, and has power supply voltages of 15 V and -15 V.

   a. Find the transfer function $T(\omega) = \frac{\bar{V}_o}{\bar{V}_i}$ in terms of the variables given.
   b. This circuit produces the phase Bode plot shown on the next page. Find values for the resistances and capacitances that will result in this phase Bode plot.
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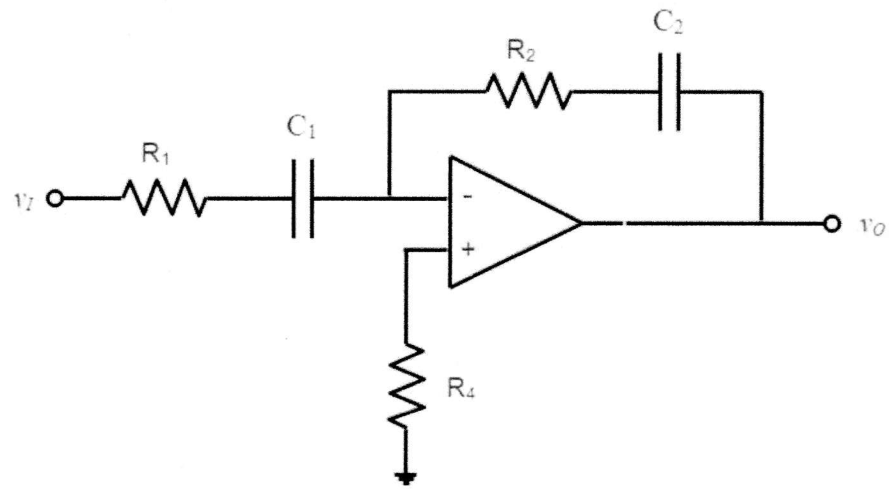


a) Inverting configuration:

+8 $$\frac{\bar{V}_o}{\bar{V}_i} = -\frac{R_2 + 1/j\omega C_2}{R_1 + 1/j\omega C_1} = -\frac{j\omega C_1 R_2 + C_1/C_2}{1 + j\omega C_1 R_1} = T(\omega)$$

b) From the phase plot, we see there is a zero at 2000 rad/s and a pole at 100 000 rad/s. So we have...

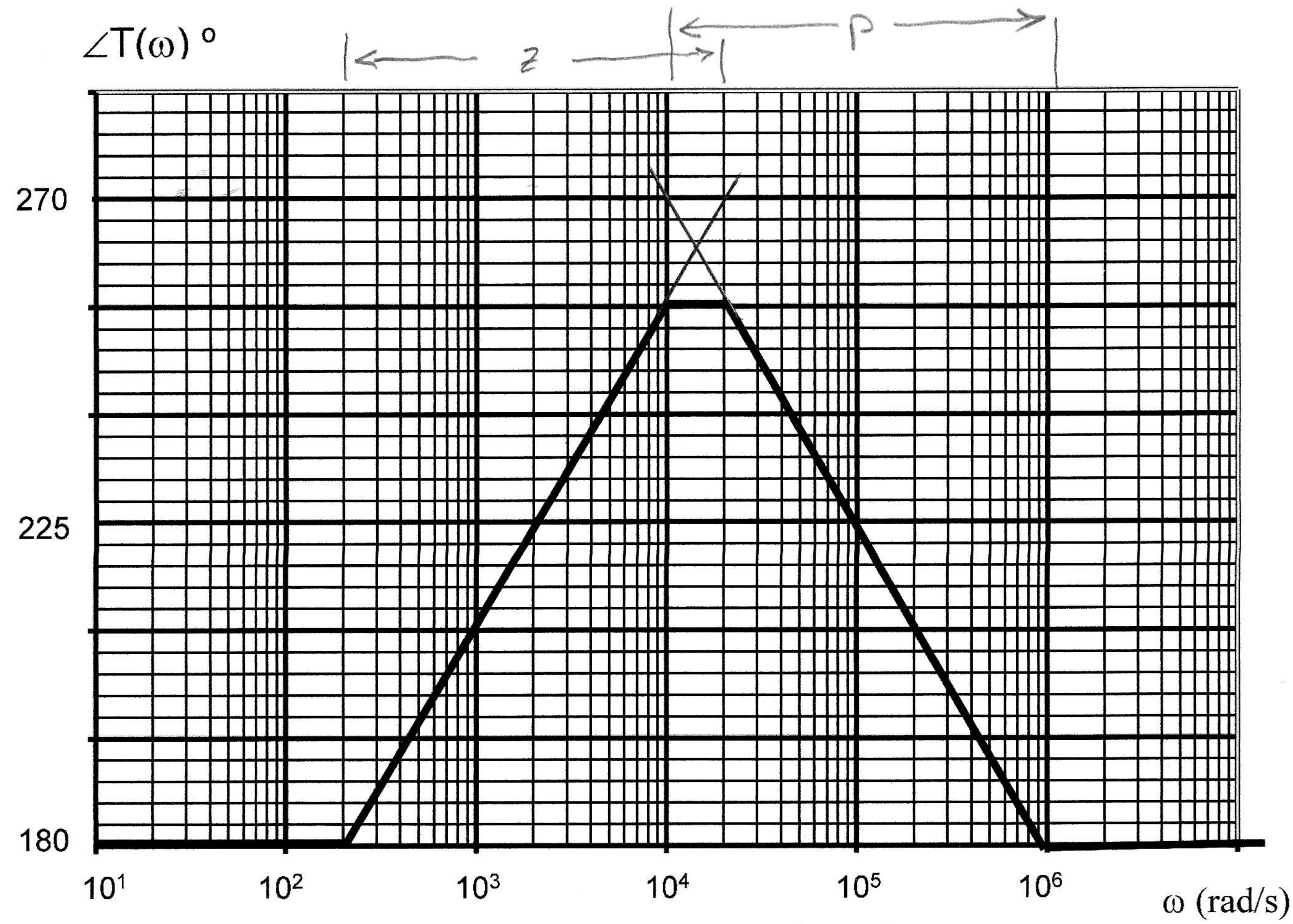
+4 $\omega_z = 2000$ rad/s $= 1/C_2 R_2$

(− real part = imaginary part ⇒
$\omega C_1 R_1 = C_1/C_2$)

A 3

+4 $\omega_p = 1/C_1 R_1 = 100000$ rad/s

23



Phase Bode Plot for the Circuit in Problem 1.

b) con't

$1/C_2R_2 = 2000$

choose $R_2 = 10\ k\Omega \Rightarrow C_2 = 50\ nF$ +1 +1

$1/C_1R_1 = 100000$

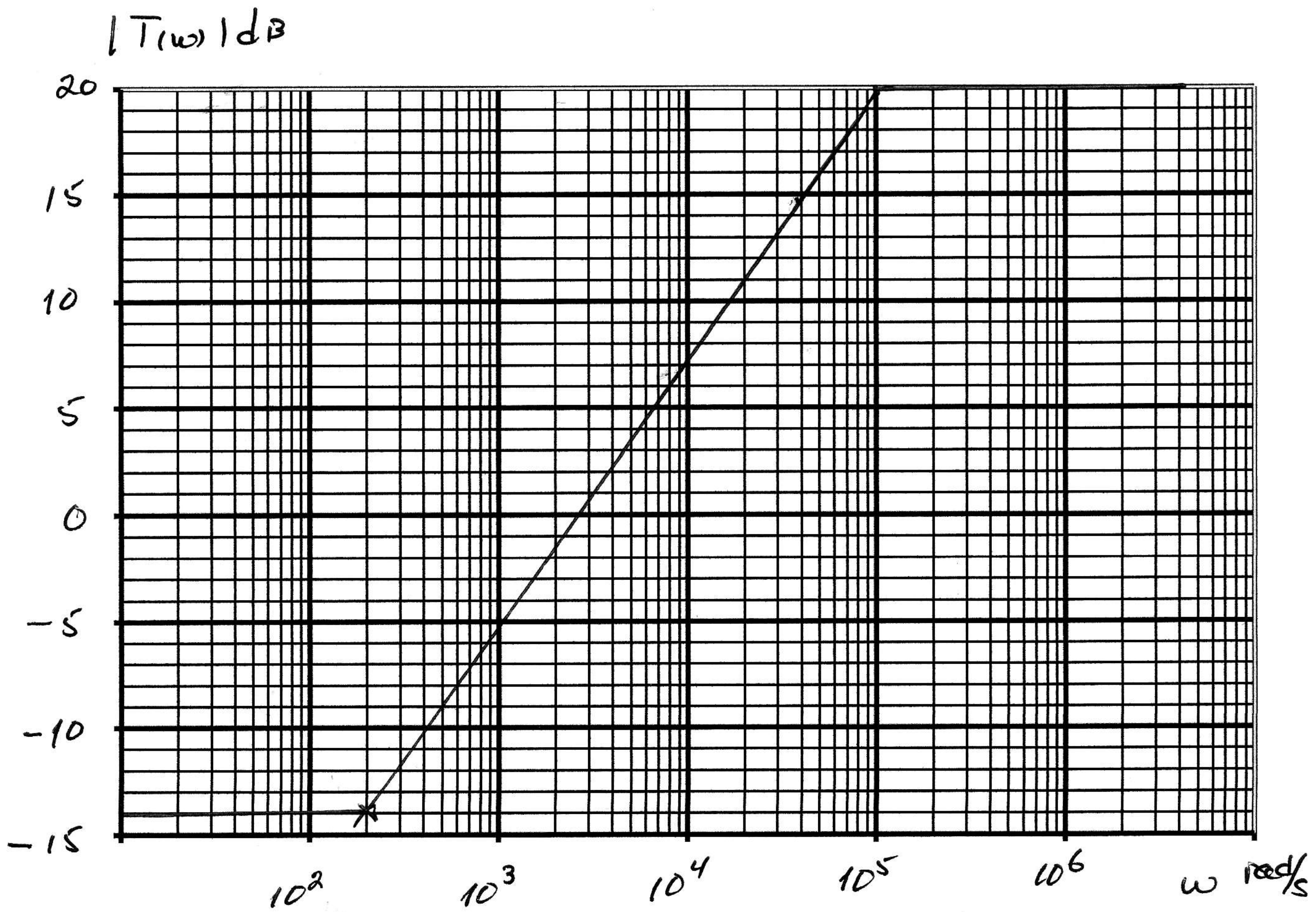
choose $R_1 = 1\ k\Omega \Rightarrow C_1 = 10\ nF$ +1 +1

Any product CR satisfying the values ω_z and ω_p will be accepted.

~~5~~ 4

Plot the magnitude Bode plot for this circuit here. Make sure your plot is properly labeled.

+2



+2

Different choices for R and C will result in different magnitudes for |T(ω)| but breakpoints are of course fixed. With my choices we have...

+6 $\omega \to 0 \Rightarrow |T(\omega)| \to C_1/C_2 = 0.2 = -14$ dB

+2 $\omega \to \infty \Rightarrow |T(\omega)| \to R_2/R_1 = 10 = 20$ dB

slope: +4

Scales: +2

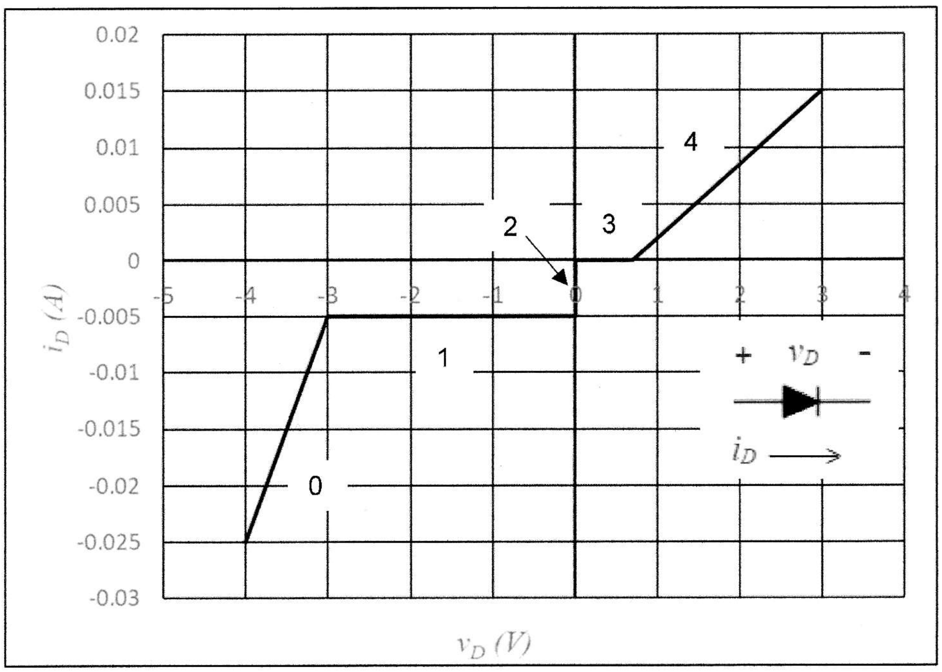
+2

~~8~~5

Room for extra work

2. (50 points) In the circuit shown on the next page, the diodes have current-voltage characteristics as shown in the plot below. In region 4, the threshold voltage is 0.7 V, and the resistance is 153 Ω.

a. By inspection of the i_D-v_D characteristics, draw a circuit model that could be used to model the diodes in region 0. Specify what test or tests would need to be done to prove that a diode is in this region.
b. For an input voltage of 8 V, find the output voltage v_O.
c. Find the minimum positive value of v_I required to cause one of the diodes to be in region 0.



a) A straight line on the i_D - v_D graph is modeled by a voltage source in series with a resistance. We can find these in a few ways, including following.

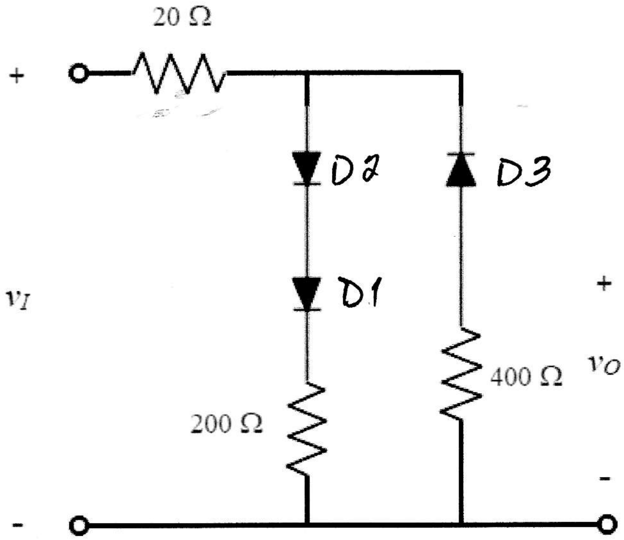
$i_D = m v_D + b$

$v_D = -3\text{ V} \Rightarrow i_D = -0.005\text{ A}$

$v_D = -4\text{ V} \Rightarrow i_D = -0.025\text{ A}$

87

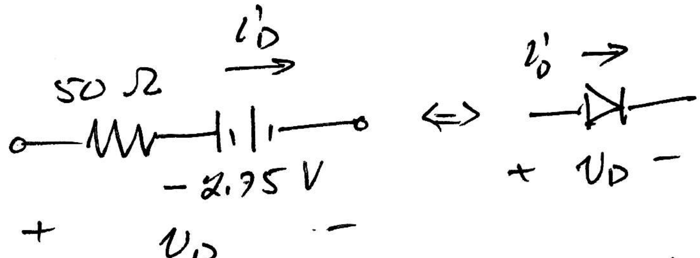
Room for extra work



So...

$$-0.005 = -3m + b$$
$$-0.025 = -4m + b$$
$$\Rightarrow \quad m = 0.02 \text{ A/V}$$
$$b = 0.055 \text{ A}$$
$$\Rightarrow \quad i_D' = 0.02 v_D + 0.055 \text{ A}$$
$$\therefore \quad r = 1/0.02 = 50\ \Omega$$
$$i_D' = 0 \Rightarrow v_D = -2.75 \text{ V}$$

So the model is



V_D +8 r_D +6

To prove a diode is in this region, we need to show either that $i_D < -5$ mA or that $v_D \le -3$ V.

+4

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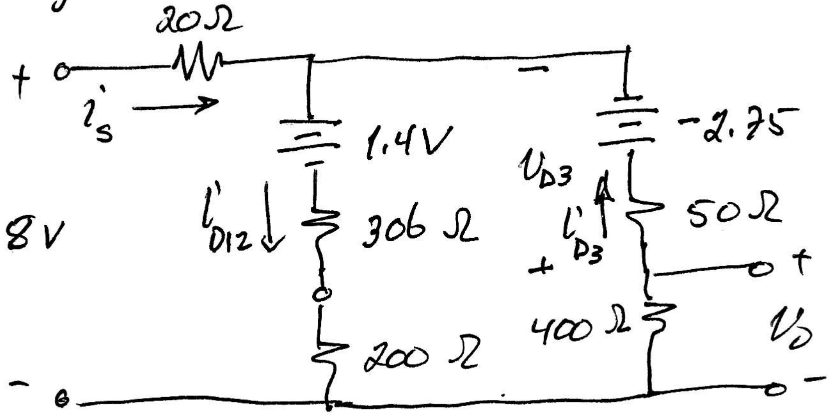
b) An input of 8 V seems large enough to put D1 and D2 in region 4. We will also guess D3 in region 0.



Note the polarity of v_{D3} and i_{D3}'!

$$i_s' = i_{D12}' - i_{D3}'$$

27
p2

Room for extra work

$-8 + 20 i_{D12}' - 20 i_{D3}' + 506 i_{D12}' + 1.4 = 0$

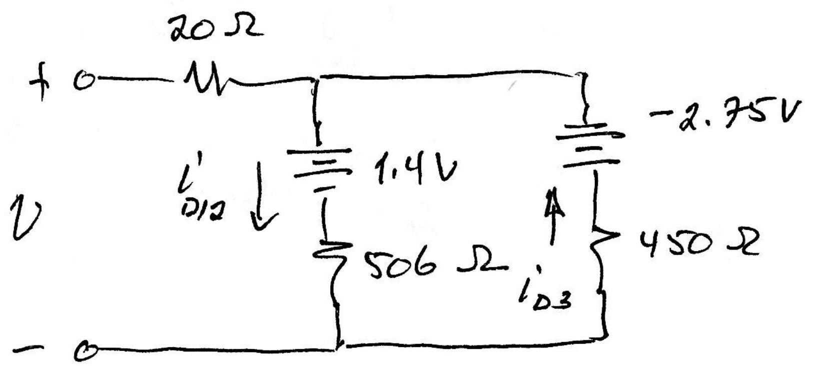
$-8 + 20 i_{D12}' - 20 i_{D3}' - 450 i_{D3}' + 2.75 = 0$

$\Rightarrow \quad i_{D12}' = 12.1\ mA$ ✓ $\quad i_{D3}' = -10.65\ mA$ ✓

So these guesses are correct!

+14 Then $\boxed{v_o = -i_{D3}' \cdot 400 = 4.26\ V}$

c) For positive v_I, D3 will be the only diode in region 0. At a minimum, i_{D3}' will be -0.005 A. So...



$i_{D3}' = -0.005\ A$

$-v + 20 i_{D12}' - 20 i_{D3}' + 1.4 + 506 i_{D12}' = 0$

$-v + 20 i_{D12}' - 20 i_{D3}' + 2.75V - 450 i_{D3}' = 0$

+18 $\Rightarrow \quad v = 5.24\ V \quad i_{D12}' = 7.115\ mA$

So 5.24 will satisfy the requirement. We have also verified that D1 and D2 are still in region 4.

x2

3. (40 points) In the circuit below, the BJT has $\beta = 75$ and $V_{CE,sat} = 0.3$ V.

a) Verify that the BJT is biased in the linear region.
b) Find the small signal voltage gain v_o/v_s in the passband.
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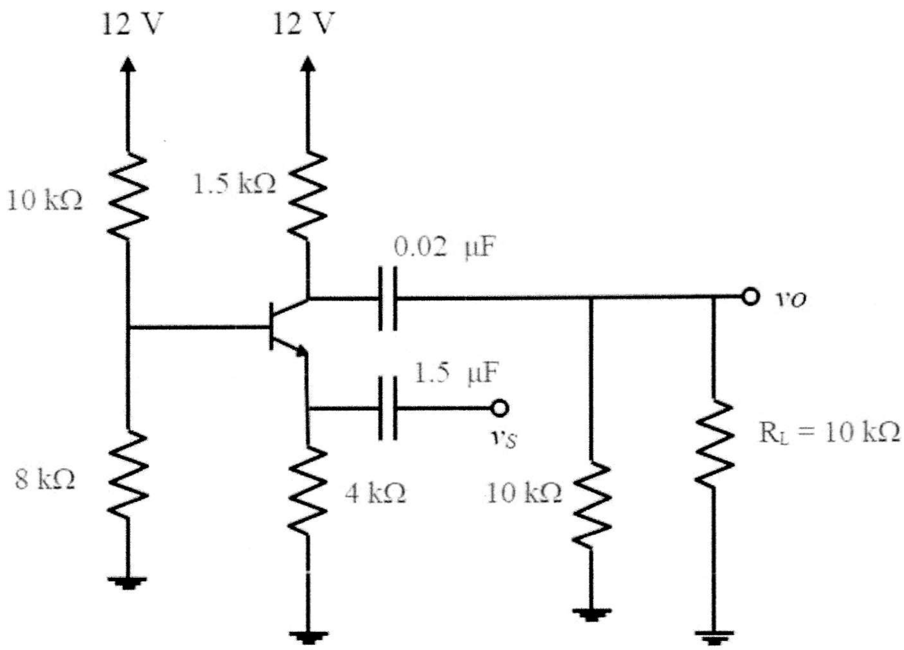
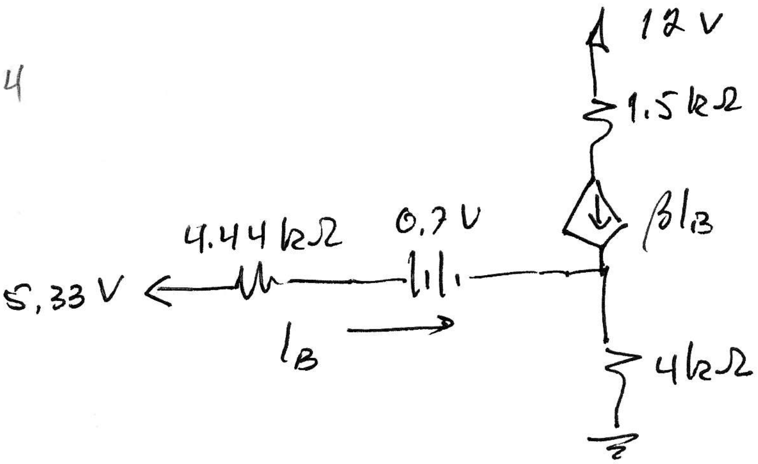


a) Thevenizing the base and setting C → open we have:

+4



$$I_B = \frac{5.33 - 0.7}{76(4000) + 4444} = 15.01\ \mu A \checkmark$$

+4

$$V_{CE} = 12 - 1500(75 I_B) - 76(4000) I_B = 5.75\ V \checkmark$$

+4

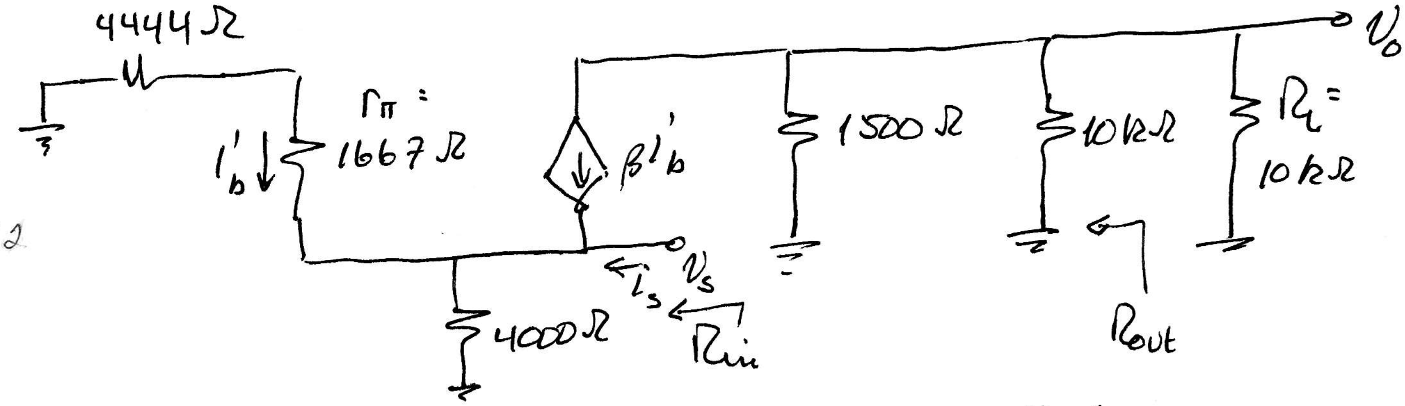
~~10~~ 9

Room for extra work

b) $r_\pi = V_T / I_B = 1667\ \Omega$

+2

In the passband, C → short



+12

$$v_o = -\beta i_b' \cdot (10k\Omega // 10k\Omega // 1.5k\Omega) \qquad i_b' = -v_s / (4444 + 1667)$$

1.15 k

+6 $v_o / v_s = 14.2\ \frac{V}{V}$

c) $$i_s' = \frac{v_s}{4444+1667} + \frac{v_s}{4000} + \beta \frac{v_s}{4444+1667}$$

+5 $R_{in} = v_s / i_s' = 78.8\ \Omega$

+3 $R_{out} = 10k\Omega // 1.5k\Omega = 1.3\ k\Omega$

4. (40 points) In the circuit below, the BJT has $\beta = 100$ and $V_{CE,sat} = 0.3$ V. It is biased in the linear region.

a. Show that the BJT is biased in the linear region.
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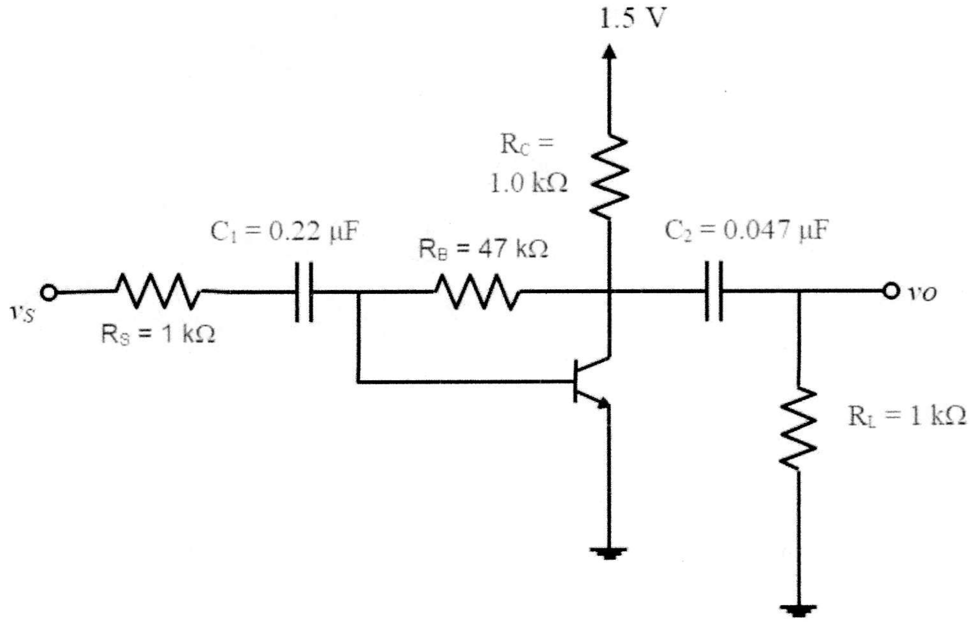
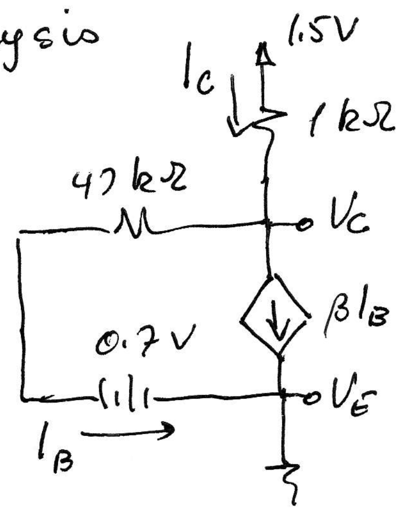


a) DC analysis

+4



$-1.5 + 1000\, I_c + 47000\, I_B + 0.7 = 0$

$I_c = (\beta + 1) I_B$

+4

$I_B = 5.4\ \mu A$ ✓

$V_{CE} = V_c = 1.5 - 1000 I_c$

$= 0.955\ V$ ✓

+4

Room for extra work

b) For saturation, we need $V_{CE} = V_C = 0.3$ V. But a KVL shows...

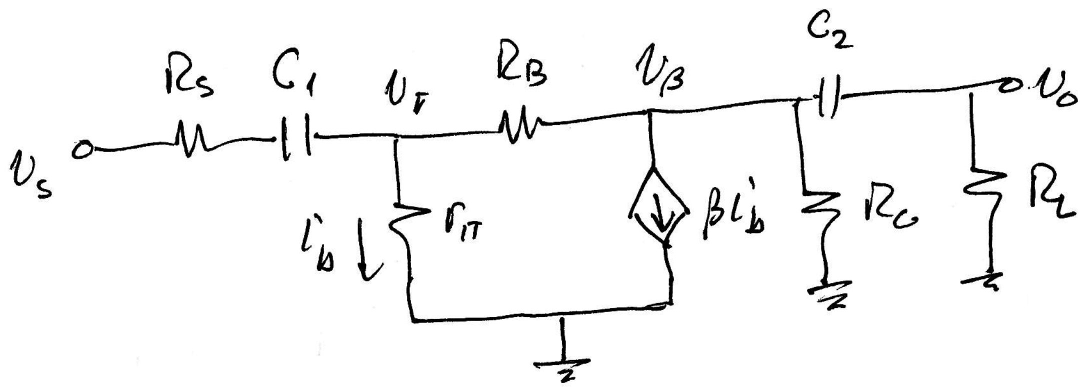
+5 $$-0.3 + 47000\, I_B + 0.7 = 0$$

$$\Rightarrow \quad I_B = \frac{-0.4}{47000}$$ which is not acceptable.

This transistor is biased in such a way that it cannot be put in saturation.

c)

+10



+4 $$\frac{\bar{V}_\pi - \bar{V}_s}{R_S + 1/j\omega C_1} + \frac{\bar{V}_\pi}{r_\pi} + \frac{\bar{V}_\pi - \bar{V}_\beta}{R_B} = 0$$

+4 $$\frac{\bar{V}_\beta - \bar{V}_\pi}{R_B} + \beta \bar{I}_b + \frac{\bar{V}_\beta}{R_C} + \frac{\bar{V}_\beta - \bar{V}_o}{1/j\omega C_2} = 0$$

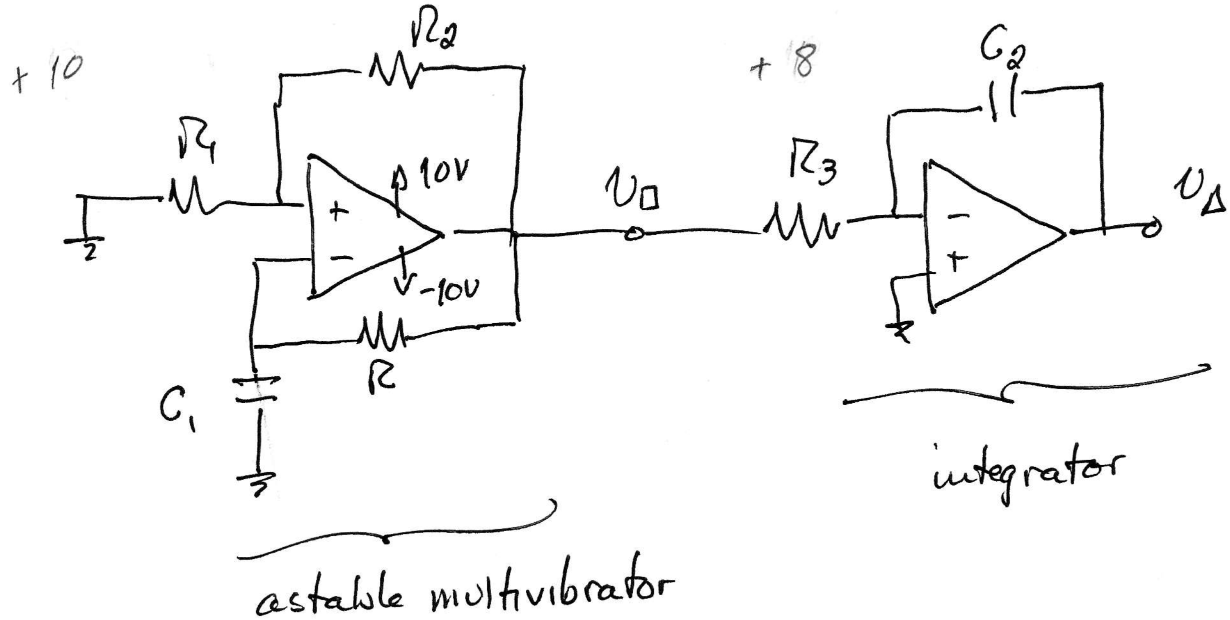
+2 $$\bar{I}_b = \frac{\bar{V}_\pi}{r_\pi}$$

+3 $$\bar{V}_o = \bar{V}_\beta \cdot \frac{R_L}{R_L + 1/j\omega C_2}$$

5. (30 points) Draw a circuit that uses an astable multivibrator to produce a square wave of amplitude 10 V and period of 2.5 ms. This circuit should connect to the input of an integrator to produce a triangle wave with an amplitude of 5 V.

For the multivibrator and the integrator, use ideal op amps. You may use any number and value of resistors and capacitors, and you may use any voltage source(s) to power the op amps. Assume that all capacitor voltages are initially 0.

+ 10



The astable multivibrator will output a square wave of amplitude 10V and period T:

$T = 2RC_1 \ln \frac{1+\beta}{1-\beta}$ $\beta = R_1 / R_1 + R_2$

If we choose $R_1 = 1\ k\Omega$, $R_2 = 2\ k\Omega$, we have

$T = 2RC_1 \cdot 0.692 = 0.0025 \Rightarrow RC_1 = 1.806 \times 10^{-3}$ s

$R = 10\ k\Omega \Rightarrow C_1 = 180.6$ nF

Values + 6

Room for Extra Work

The integrator output is

$$v_\Delta = -\frac{1}{C_2}\int_0^{1.25\times10^{-3}\,s} \frac{v_\square}{R_3}\,dt = -5$$

where we have assumed that the initial capacitor voltage is 0, and that the integration has taken place for half the period, or 1.25×10^{-3} s.

Assuming $v_\square$ is at it's positive limit of 10V, we have

$$\frac{1}{C_2}\,\frac{10}{R_3}\,1.25\times10^{-3} = 5 \Rightarrow C_2 R_3 = 2.5\times10^{-3}\ \text{s}$$

Choose $R_3 = 2.5\ k\Omega \Rightarrow C_2 = 1\ \mu F$.

Values +6