Name: ______________________________ (please print)

Signature: ___________________________

ECE 3455
Final Exam
August 11, 2010

Exam duration: 180 minutes

- You may have one 8 ½ x 11 in. "crib" sheet, written on both sides, during the quiz. You may have any calculator you choose, but no computers. No other notes or materials will be allowed.
- Show all work necessary to complete the problem on these pages. A solution without the work shown will receive no credit.
- Show units in intermediate and final results, and in figures.
- If your work is sloppy or difficult to follow, points will be subtracted.

This exam has 11 pages, including the cover sheet. Raise your hand if you are missing a page.

1 ____________/45

2 ____________/35

3 ____________/45

4 ____________/35

5 ____________/40

Total ______________/200

Note: the exam score will be normalized to 100.

1. (**45 points**) Design an op-amp circuit that produces a triangle wave output with a period of 3 ms and an amplitude of 1.2 V. In addition, the triangle wave must have an adjustable dc offset between 0 and 2 V. As for components, assume the following.

- You have ideal dual-power-supply op amps that will function correctly as long as the power supplies are no smaller than +/- 3 V and no larger than +/- 15 V.
- You may use any number of op amps, resistors, capacitors, and inductors; these components may have any value.
- The only power supplies available are 9 V batteries that are otherwise ideal. You may use as many as you like.

2. (**35 points**) The transfer function for a particular amplifier is given below. The magnitude of $T(\omega)$ at $\omega = 4500$ rad/s is -15 dB. K is not given, but it is known to be positive and real. All frequencies are in rad/s.

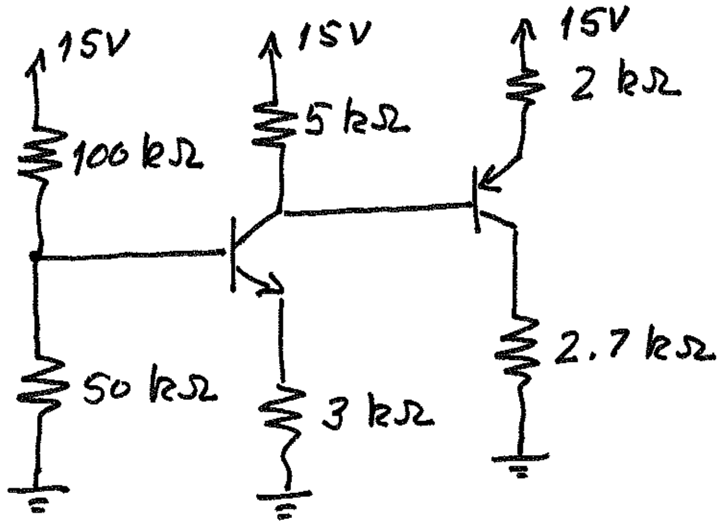
i) Using the graph on the next page, plot the magnitude Bode plot for this amplifier.
ii) Find the phase of $T(\omega)$ as $\omega \rightarrow \infty$.
iii) Find the phase of $T(\omega)$ as $\omega \rightarrow 0$.

$$T(\omega) := K \cdot \frac{(j \cdot \omega + 2000)^2 \cdot (j \cdot \omega + 10000)^2}{j \cdot \omega \cdot (j \cdot \omega + 400)(j \cdot \omega + 50000) \cdot (j \cdot \omega + 100000)}$$

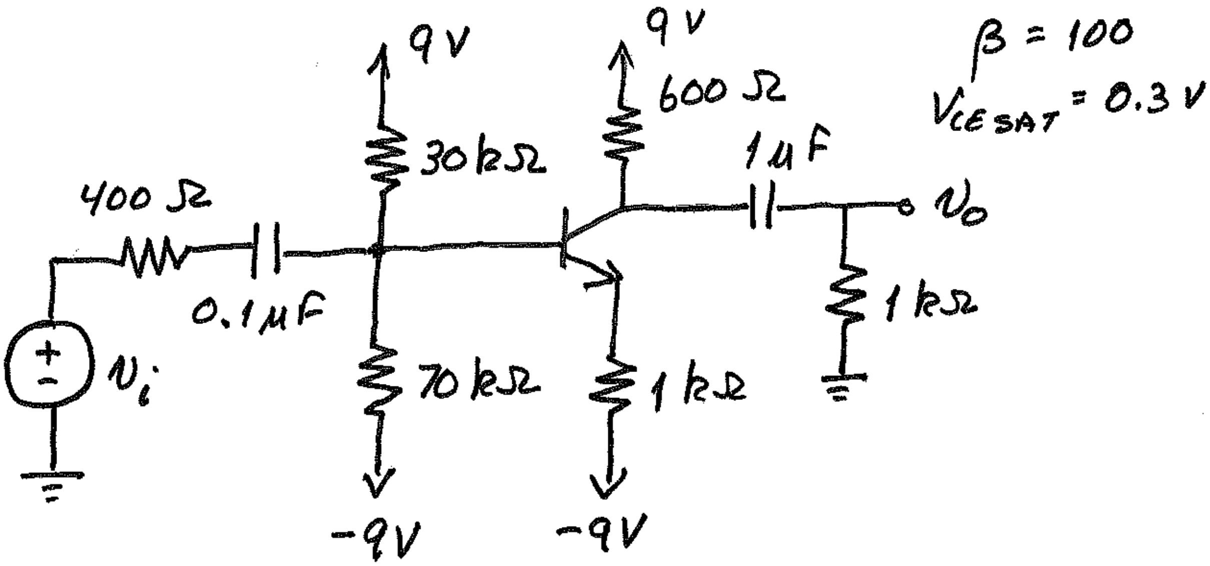
5

3. (**45 points**) For the circuit below, find the dc terminal voltages (at emitter, collector, and base) for each BJT. Be sure to test any assumptions you make about the operating region of the BJTs.

$V_{CE\,SAT} = 0.3\,V$
$\beta = 100$
(both BJT's)



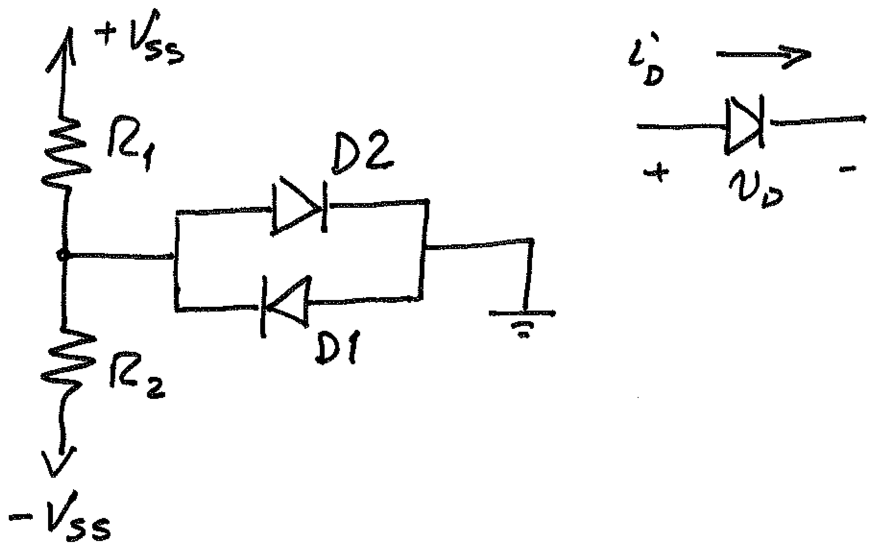
4. (**35 points**) For the circuit below, find the transfer function $T(\omega) = V_o/V_i$.

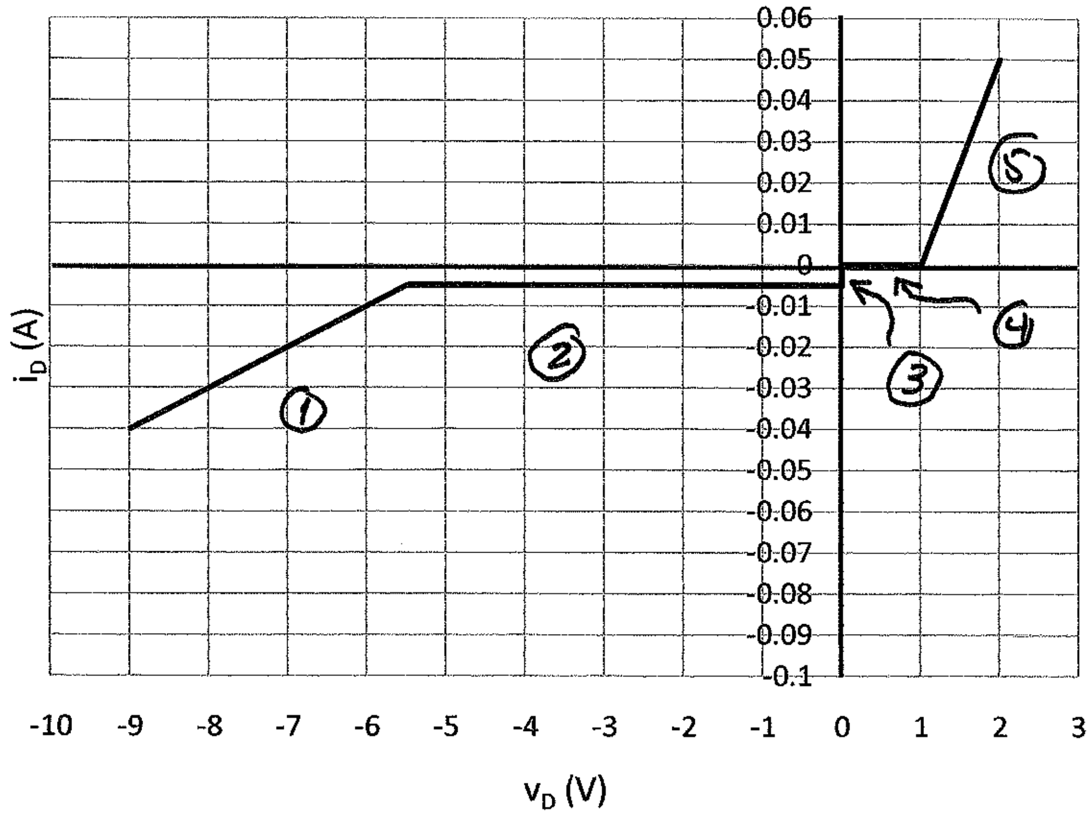


Room for extra work

5. (**40 points**) On the following page is shown the piecewise linear model for the diodes in the circuit below. The diodes are identical.

Choose resistors and a power supply value V_{SS} so that diode D_2 is in region 1. In doing so, limit ~~the magnitude of V_{SS} to no more than 20 V, and~~ the resistor values to no more than 10 kΩ. Be sure to prove that diode D1 is the region you assume it to be.




0.06
0.05
0.04
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
-0.05
-0.06
-0.07
-0.08
-0.09
-0.1
iD (A)
-10
-9
-8
-7
-6
-5
-4
-3
-2
-1
0
1
2
3
vD (V)
1
2
3
4
5

Name: SOLUTIONS (please print)

Signature: ____________________

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2. (**35 points**) The transfer function for a particular amplifier is given below. The magnitude of $T(\omega)$ at ω = 4500 rad/s is -15 dB. K is not given, but it is known to be positive and real. All frequencies are in rad/s.

31 i) Using the graph on the next page, plot the magnitude Bode plot for this amplifier.
+2 ii) Find the phase of $T(\omega)$ as $\omega \to \infty$.
+2 iii) Find the phase of $T(\omega)$ as $\omega \to 0$.

$$T(\omega) := K\cdot\frac{(j\cdot\omega + 2000)^2\cdot(j\cdot\omega + 10000)^2}{j\cdot\omega\cdot(j\cdot\omega + 400)(j\cdot\omega + 50000)\cdot(j\cdot\omega + 100000)}$$

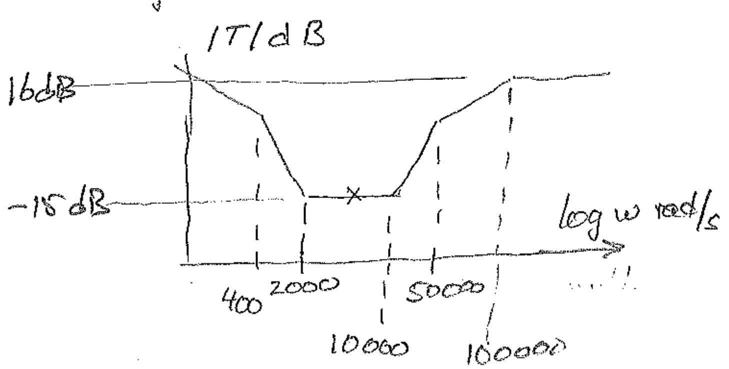
Pole/Zero analysis:

i) Z_1 double at $\omega = 2000$ rad/s Z_2 double at $\omega = 10{,}000$ rad/s

P_1 at 0 P_2 at $\omega = 400$ rad/s

P_3 at $\omega = 50\,000$ rad/s P_4 at $\omega = 100\,000$ rad/s.

Rough sketch:



In principle, knowing $|T(\omega = 4500 \text{ rad/s})|$ and all slopes, we do not need to know K. We will solve for it anyway...

$-15\text{dB} \Rightarrow |T(\omega)| = 10^{-15/20} = 0.1778$

$$|T(\omega)|_{\omega = 4500\text{ rad/s}} = K\cdot 0.02854 \Rightarrow K = \frac{0.1778}{0.02854} = 6.23$$

$\omega \to \infty \Rightarrow T(\omega) \to K \to 15.9$ dB

ii) $\omega \to \infty \Rightarrow T(\omega) \to K \to 0°$

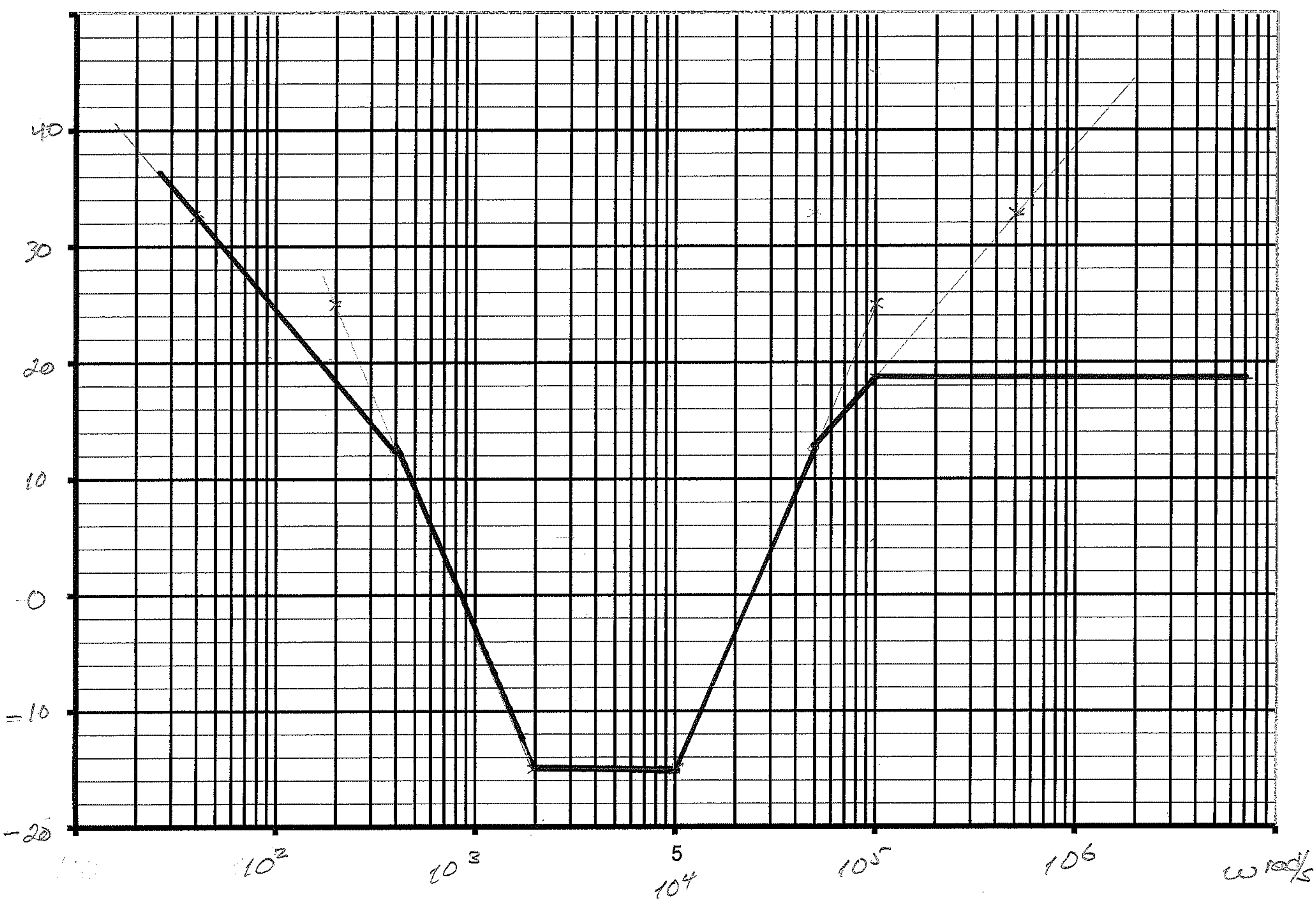
iii) $\omega \to 0 \Rightarrow T(\omega) \to \frac{K'}{j\omega} \to -90°$

Slopes: 6×2 ea. $= 12$

Breakpts: 6×2 ea $= 12$

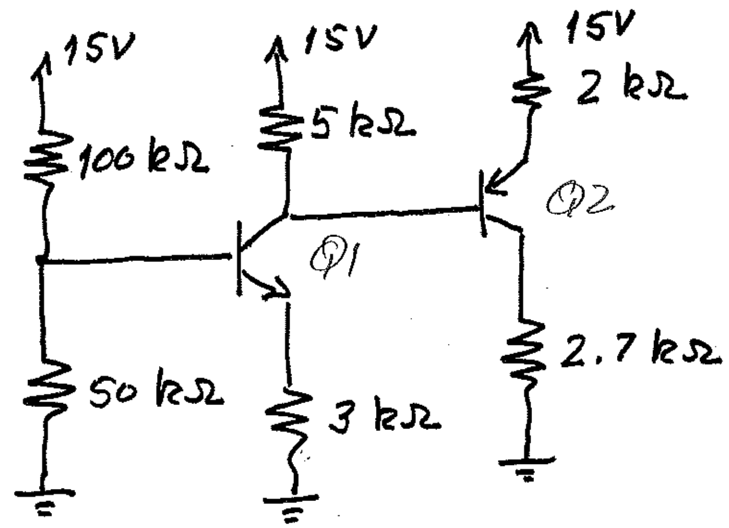
magnitude: 3

axes: 2×2 ea $= 4$

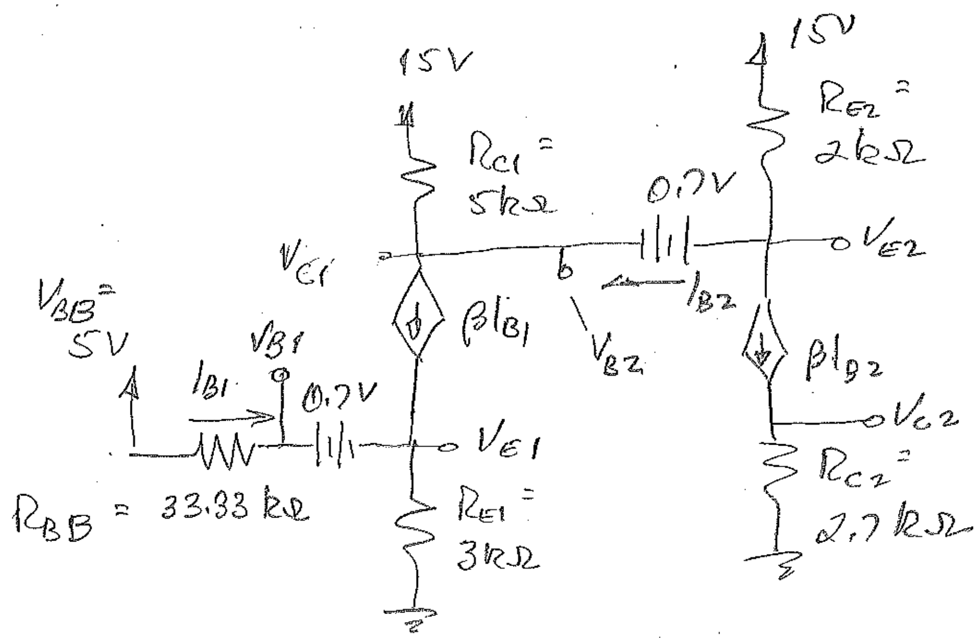


3. (**45 points**) For the circuit below, find the dc terminal voltages (at emitter, collector, and base) for each BJT. Be sure to test any assumptions you make about the operating region of the BJTs.

$V_{CE SAT} = 0.3V$
$\beta = 100$
(both BJT's)



We will guess linear region for both. Given 15V and 0 as shown, we expect current to be flowing top to bottom, which is linear region for both BJT's.



model #12

$V_{BB} = 15 \cdot \frac{50}{150}$ $\qquad R_{BB} = 100k \| 50k = 33.33\ k\Omega$

$= 5V.$

✓ ⇒ TEST

Room for extra work

$$\frac{V_{C1}-15}{5000} + \beta I_{B1} + \frac{V_{C1}+0.7-15}{2000} + \beta I_{B2} = 0 \quad (1)$$

$$-5 + 33.33\times10^3\, I_{B1} + 0.7 + 101\, I_{B1}\cdot 3000 = 0 \quad (2)$$

$$\Rightarrow I_{B1} = 12.78\,\mu A \checkmark$$

+12

+2

$$(\beta+1)I_{B2} = \frac{15-V_{E2}}{2000} = \frac{15-(V_{C1}+0.7)}{2000} \quad (3)$$

$$\Rightarrow I_{B2} = \frac{1}{101}\cdot\frac{14.3-V_{C1}}{2000}$$

$$(1)+(2)+(3) \Rightarrow \boxed{V_{C1} = 8.747\,V} \; +3$$

$$\Rightarrow I_{B2} = 27.49\,\mu A \checkmark$$

+2

+2

$$\boxed{V_{E1} = (\beta+1)I_{B1}\cdot 3000 = 3.87\,V}$$

$$V_{C1} - V_{E1} = 8.75 - 3.87 = 4.88\,V \checkmark$$

+2

$$\boxed{V_{C2} = \beta I_{B2}\cdot 2700 = 7.42\,V} \; +2$$

+2

$$\boxed{V_{E2} = V_{C1} + 0.7 = 9.45\,V}$$

$$V_{C2} - V_{E2} = 7.42 - 9.45 = -2.03\,V \checkmark$$

+2

$$\boxed{V_{B1} = V_{BB} - I_{B1}\cdot R_{BB} = 4.57\,V} \; +2$$

So tests for I_{B1}, I_{B2} and V_{CE1}, V_{CE2} are OK.

$$\boxed{V_{B2} = V_{C1} = 8.747\,V} \; +2$$

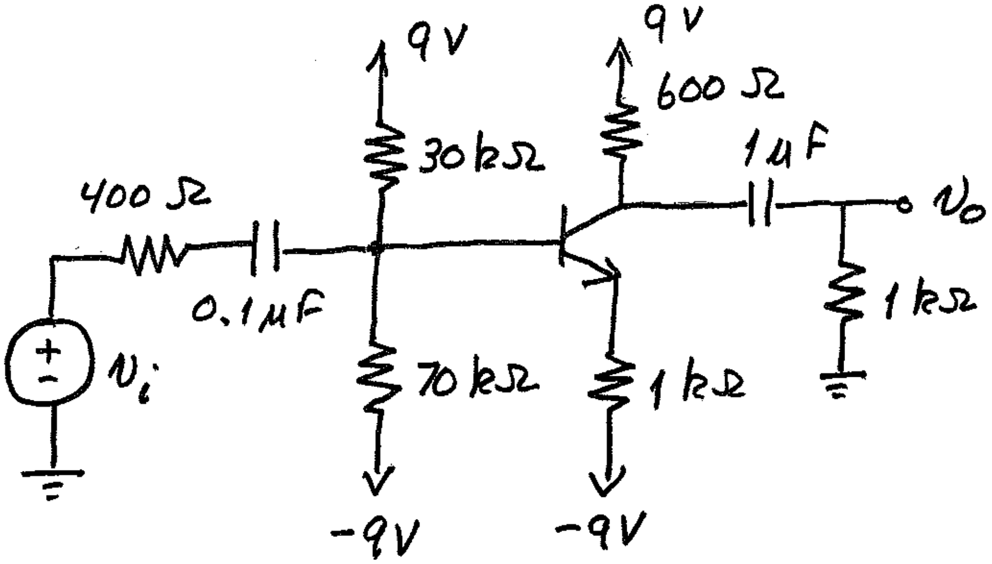
V's : +13

Tests : +8

4. (**35 points**) For the circuit below, find the transfer function T(ω) = V_o/V_i.

$V_{CESAT} = 0.3\ V$

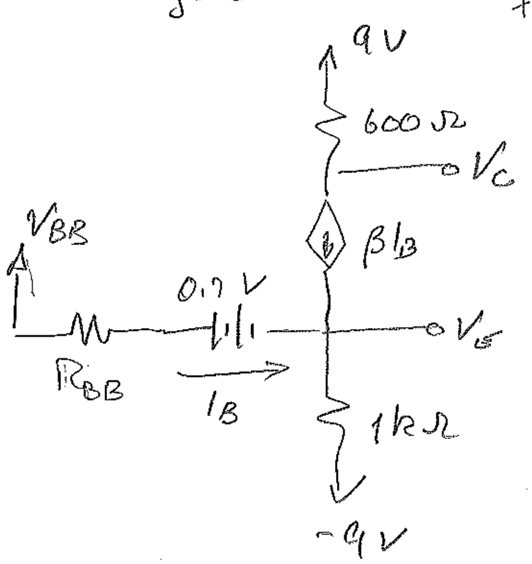
$\beta = 100$



We will assume active mode since the 4-resistor bias scheme shown seems to be designed for this region.

DC analysis:

+8



$$I_B = \frac{3.6 + 9 - 0.7}{21\,000 + 101(1000)}$$

$$= 97.54\ \mu A\ ✓$$

$$V_C = 9 - \beta I_B \cdot 600 = 3.15\ V$$

$$V_E = 1000(\beta + 1) I_B - 9$$

$$= 0.85\ V$$

$$V_{CE} = 3.15 - 0.85 = 2.30\ V.\ ✓$$

$$V_{BB} = 18 \cdot \frac{70}{70+30} - 9 = 3.6\ V.$$

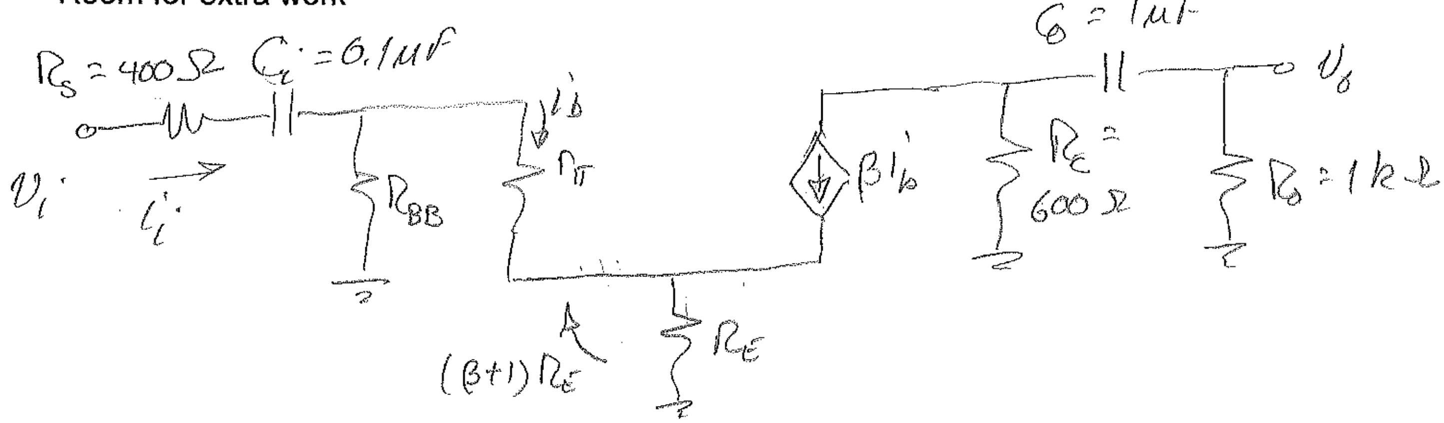
$$\Rightarrow r_\pi = \frac{V_T}{I_B} = \frac{0.025}{97.54 \times 10^{-6}}$$

$$R_{BB} = 30k \| 70k = 21\ k\Omega$$

$$= 256\ \Omega$$

Room for extra work

+15



$$\bar{V}_o = -\beta \bar{I}_b \cdot \frac{R_c}{1/j\omega C_o + R_o + R_c} R_o = -\beta \bar{I}_b \cdot \frac{j\omega C_o R_o \cdot R_c}{1 + j\omega C_o (R_o + R_c)}$$

$$Z_i = R_s + 1/j\omega C_i + R_{BB} \,//\, (r_\pi + (\beta+1)R_E)$$

$$\simeq R_S + R_{BB}//(\beta+1)R_E + 1/j\omega C_i$$

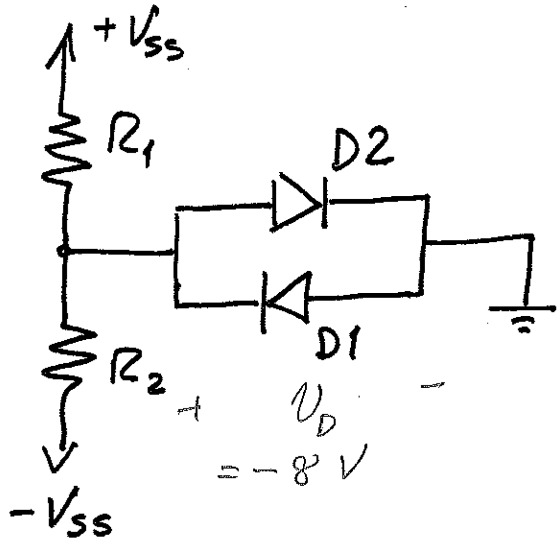
$$\bar{I}_i = \frac{\bar{V}_i}{Z_i} \qquad \bar{I}_b = \bar{I}_i \cdot \frac{R_{BB}}{R_{BB} + (\beta+1)R_E + r_\pi} \quad (r_\pi \sim 0)$$

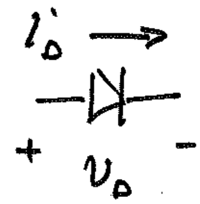
+12

$$\frac{\bar{V}_o}{\bar{V}_i} = \frac{-j\omega C_o R_o R_c}{1 + j\omega C_o (R_o + R_c)} \cdot \beta \frac{R_{BB}}{R_{BB} + (\beta+1)R_E} \cdot \frac{1}{R_S + R_{BB}//(\beta+1)R_E + 1/j\omega C_i}$$

5. (**40 points**) On the following page is shown the piecewise linear model for the diodes in the circuit below. The diodes are identical.

Choose resistors and a power supply value V_{SS} so that diode D_2 is in region 1. In doing so, limit ~~the magnitude of V_{SS} to no more than 20 V, and~~ the resistor values to no more than 10 kΩ. Be sure to prove that diode D1 is the region you assume it to be.

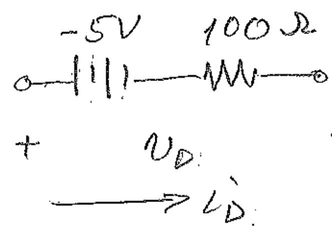


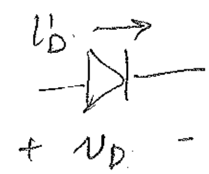


Since we require only that D2 be in region 1, we can simply choose an operating point in that region:

D2: $v_{D2} = -8V$ $\quad i_{D2} = -0.03\ A$ (arbitrary choice)

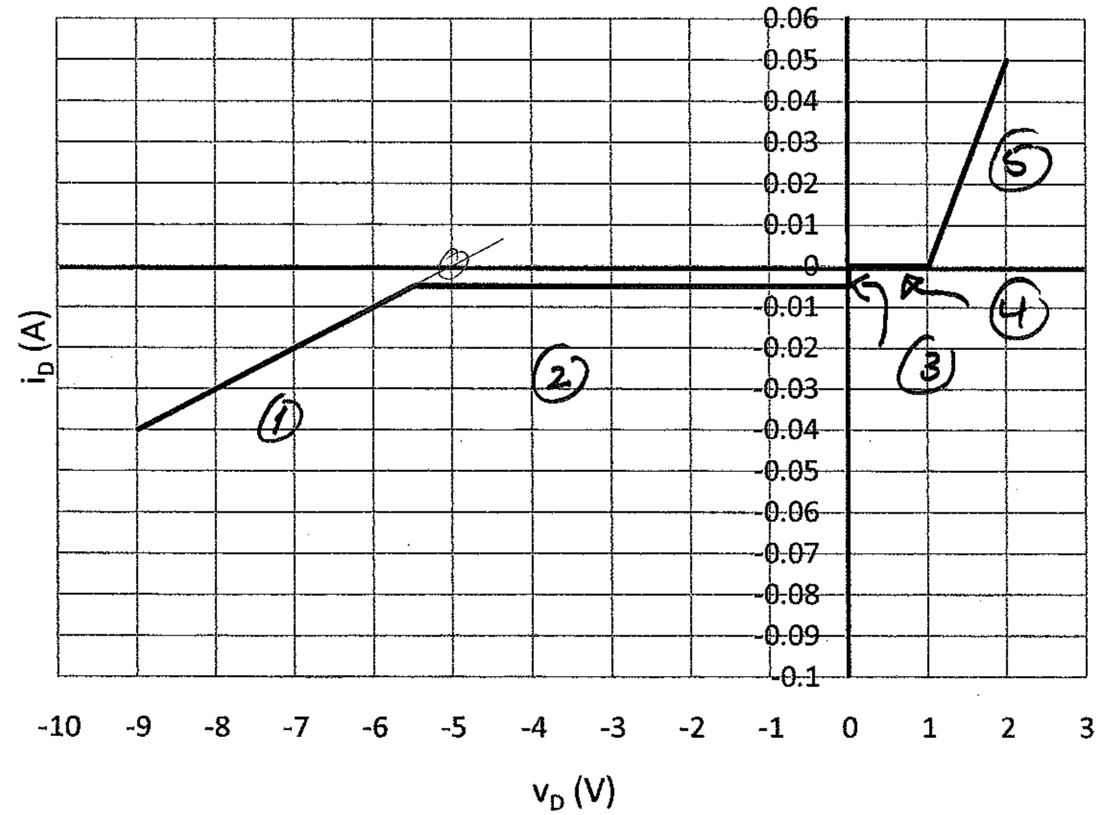
Model for region ①:





{ Extrapolating the i_D-v_D curve to the $i_D = 0$ axis ⇒ voltage source is −5 V. Taking the inverse of the slope ⇒ resistance is $\frac{\Delta V}{\Delta I} = \frac{1\ V}{10\ mA} = 100\ \Omega$.

{ Check: $v_D = -8V \Rightarrow i_D = -0.03A$. Then according to the model, $v_D = -5 + 100(-0.03) = -8V$ so this checks.

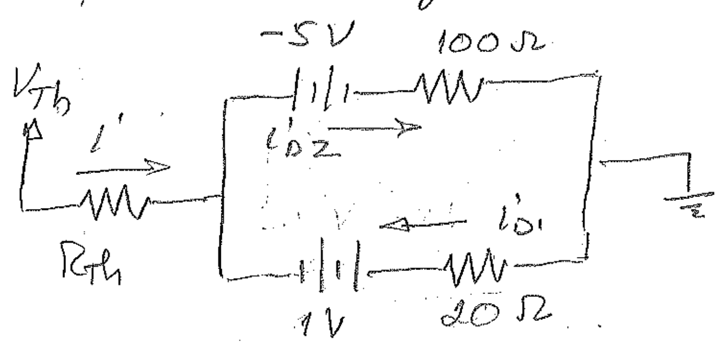


Now the Thevenin equivalent of the biasing circuit is

$$V_{Th} = 2V_{SS} \cdot \frac{R_2}{R_1+R_2} - V_{SS}$$

$$R_{Th} = R_1 // R_2$$

$\Rightarrow$



We have assumed D1 in region 5. $V_D = -8V$

Also we have that $v_D = -8V$ so

$$-V_{Th} + i' R_{Th} - 8 = 0 \qquad i' = i_{D2} - i_{D1}$$

to pg. 3

Room for extra work

$i'_{D2} = -0{,}03\,A$

$i'_{D1} = \dfrac{8-1}{20} = 0{,}35\,A$ $\Rightarrow$ $i' = -0{,}38\,A$

So we need to satisfy

$$V_{Th} = -0{,}38\,R_{Th} - 8$$

If $R_{Th}' = 100\,\Omega$, $V_{Th} = -46\,V$. $\Rightarrow$

$\dfrac{R_1 R_2}{R_1+R_2} = 100.$ $\quad 2V_{SS} \cdot \dfrac{R_2}{R_1+R_2} - V_{SS} = -46$

$\Rightarrow \dfrac{R_2}{R_1+R_2} = \dfrac{100}{R_1}$ $\Rightarrow$ $2V_{SS} \cdot \dfrac{100}{R_1} - V_{SS} = -46$

If $V_{SS} = -100\,V$, $R_1 = 137\,\Omega$.

$\Rightarrow$ $R_2 = 370\,\Omega$.

Check: $R_1 /\!/ R_2 = 137/370 = 100\,\Omega$ ✓

$V_{Th} = -200 \cdot \dfrac{R_2}{R_1+R_2} + 100 = -46$ ✓

D1 is clearly in (S) since $i'_{D1} = 0{,}14\,A$.