EE 355 Analog Electronics
Test 2

Name Solutions
November 9, 2017

RULES

This is a closed book, closed notes test. You are, however, allowed one piece of paper (both sides, hand-written) for notes and definitions. You must staple your equations sheet to the back of your test when you hand your test in.

You are permitted to use a calculator.

You have 75 minutes to complete the test. Please read through the entire test before starting, and read through the directions carefully. To receive partial credit, you must show your work.

I you have any questions, please raise your hand, and I will come to you to answer them. Do not hesitate to ask questions.

Circle/box all of your answers.

Use the following parameters unless otherwise specified

Diode Parameters

$V_{ON} = 0.7$, $V_Z = 5.6V$, $n = 1$, $I_0 = 0.1pA$

Transistor Parameters

$\beta = 99$, $V_{BE,ON} = 0.7V$, $V_{CE,SAT} = 0.2V$

$V_{EB,ON} = 0.7V$, $V_{EC,SAT} = 0.2V$

$V^+ = 10V$, $V^- = -10V$

$U_T = 26mV$, $V_A = 100V$

Problem	Value	Score
1	20	
2	10	
3	20	
4	25	
5	25	
Total	100	

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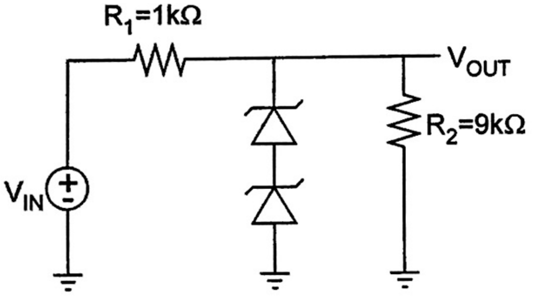
PROBLEM 1 (20 Points)

For the following circuit, sketch V_{OUT} versus V_{IN} as V_{IN} varies from 0 to 20V.
(Note. x-axis = V_{IN} and y-axis = V_{OUT})



When the zener diodes are in reverse-b. breakdown, $V_{out} = 2(5.6V) = 11.2V$

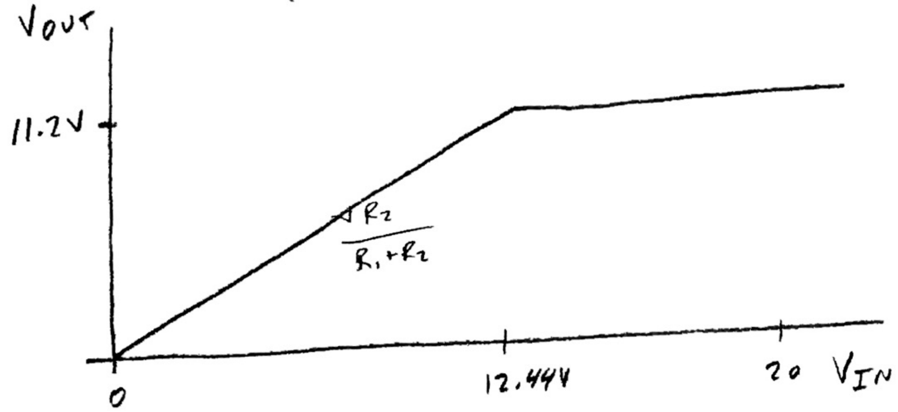
If the diodes are not in breakdown, then the circuit looks like a voltage divider

$$\therefore V_{OUT} = \min\left(V_{IN}\frac{R_2}{R_1+R_2},\ 11.2V\right)$$

when does $V_{IN}\frac{R_2}{R_1+R_2} = 11.2V$?

$$V_{IN} = \frac{R_1+R_2}{R_2}(11.2V) = \left(\frac{10k\Omega}{9k\Omega}\right)(11.2V) = 12.44V$$

$$V_{OUT} = \begin{cases} \frac{R_2}{R_1+R_2}V_{IN} & \text{for } V_{IN} \le 12.44V \\ 11.2V & \text{for } V_{IN} > 12.44V \end{cases}$$



Alternately, for regulation to occur $I_Z > 0$

$$I_Z = \frac{V_{IN}-V_{OUT}}{R_1} - \frac{V_{OUT}}{R_2} > 0 \quad \text{where } V_{OUT} = 2V_Z$$

$$V_{IN} > R_1 2V_Z\left(\frac{1}{R_1}+\frac{1}{R_2}\right) = 2V_Z\left(\frac{R_1+R_2}{R_2}\right) = 12.44V$$

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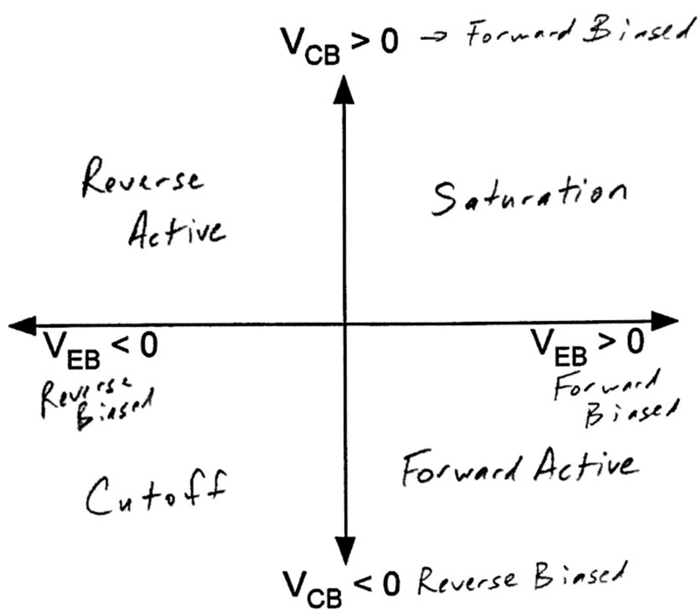
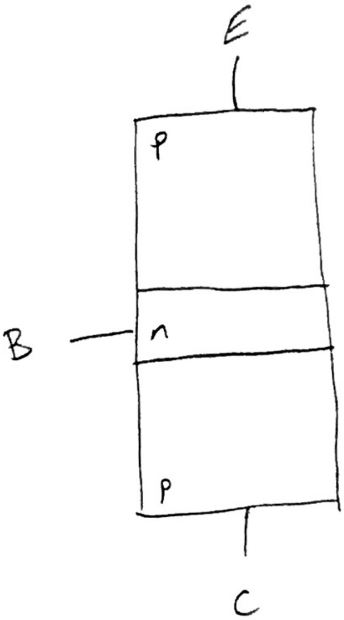
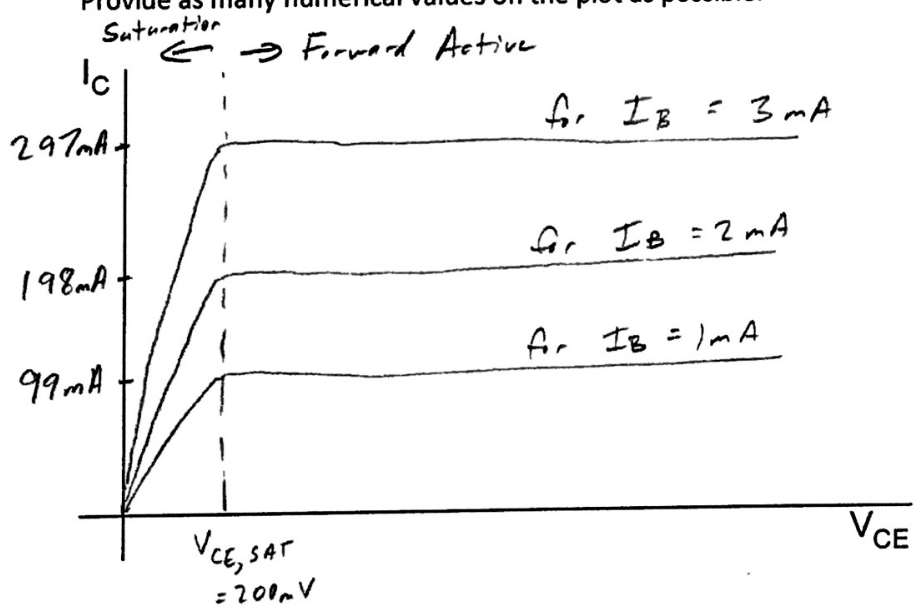
PROBLEM 2 (10 Points)

A. For a pnp BJT, label the region of operation for each quadrant of the figure below. (5 Points)





B. For an npn BJT, sketch the DC collector current for three values of base current, I_B = 1mA, 2mA, 3mA. Label the regions of operation (and the boundaries between them). For this problem, you may let $V_A=\infty$. Provide as many numerical values on the plot as possible. (5 Points)



$\beta = 99$

$I_C = \beta I_B$

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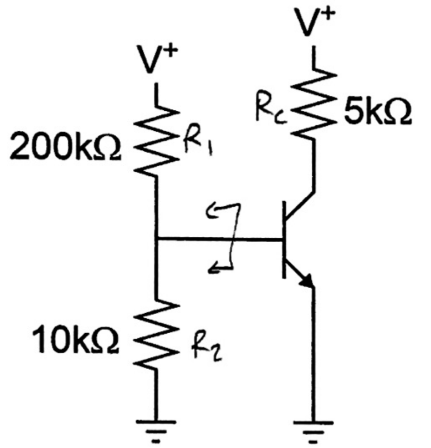
PROBLEM 3 (20 Points)

For the following two circuits, determine which region of operation the transistor is in and determine its operating point (all terminal voltages and currents). Write your answers on the lines that have been provided.

A. (10 Points)



Region of Operation: Cutoff

V_B = 0.4762 V

V_E = 0 V

V_C = 10 V

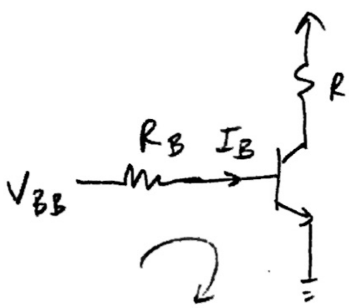
I_B = 0 A

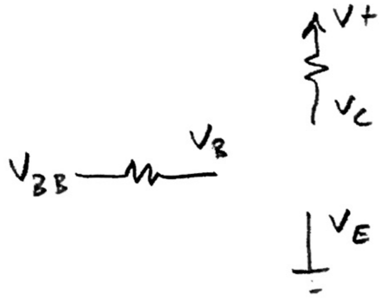
I_E = 0 A

I_C = 0 A

$$V_{BB} = V^+ \frac{R_2}{R_1 + R_2} = 0.4762\text{V}$$

$$R_B = R_1 // R_2 = 9.52\ k\Omega$$





$$\text{KVL} \rightarrow V_{BB} = I_B R_B + V_{BE,on}$$

$$I_B = \frac{V_{BB} - V_{BE,on}}{R_B}$$

$$I_B = -23.5\ \mu A$$

Negative

∴ The transistor is in cutoff!

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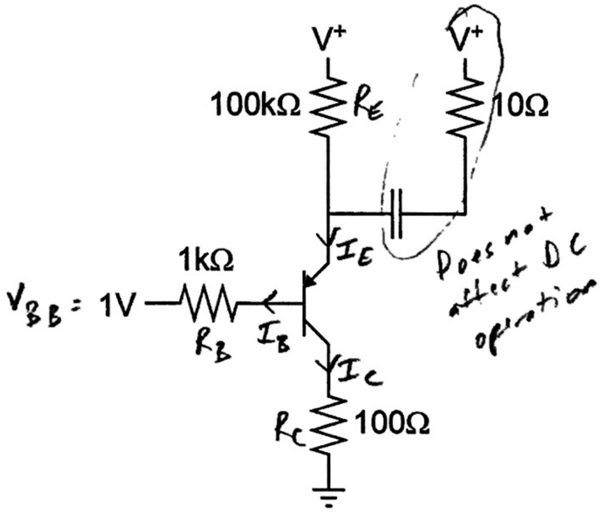
B.

(10 Points)



Region of Operation *Forward Active*

V_B = 1V

V_E = 1.7V

V_C = 0.01V

I_B = 0.8299 μA

I_E = 82.99 μA

I_C = 82.16 μA

Assume Forward Active

$$V^+ = (1+\beta) I_B R_E + V_{EB,ON} + I_B R_B + V_{BB}$$

$$I_B = \frac{V^+ - V_{EB,ON} - V_{BB}}{R_B + (1+\beta) R_E} = 0.8299\,\mu A$$ ⇒ Therefore, not Cutoff

$$V^+ = (1+\beta) I_B R_E + V_{CE} + \beta I_B R_C$$

$$V_{EC} = V^+ - \beta I_B R_C - (1+\beta) I_B R_E = 1.69V > V_{EC,SAT}$$ ⇒ ∴ Forward Active

$$I_C = \beta I_B = 82.16\,\mu A$$

$$I_E = (1+\beta) I_B = 82.99\,\mu A$$

$$V_B = V_{BB} + I_B R_B = 1.00083\,V \approx 1V$$

$$V_E = V_B + V_{EB,ON} = 1.7V$$

$$V_C = V_E - V_{EC} = 0.01V$$

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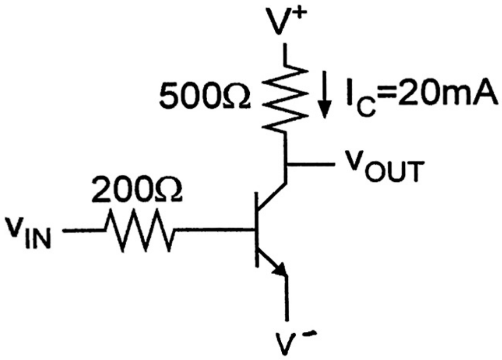
PROBLEM 4 (25 Points)

Use the following circuit for this problem. The DC value of v_{IN} is not provided.



A. Calculate the transconductance of the transistor. (3 Points)

$$g_m = \frac{I_C}{U_T} = \frac{20mA}{26mV} = 0.7692\ S$$

↖ from front page

B. Calculate r_π term of the transistor. (3 Points)

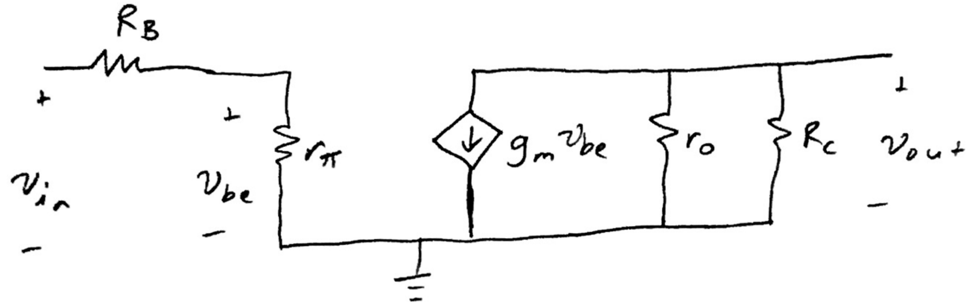
$$r_\pi = \frac{\beta U_T}{I_C} = \frac{(99)(26mV)}{20mA} = 128.7\Omega$$

C. Calculate r_o term of the transistor. (3 Points)

$$r_o = \frac{V_A}{I_C} = \frac{100V}{20mA} = 5k\Omega$$

Name *Solutions*

C. Draw the small-signal equivalent circuit for this amplifier (Hint. Use the hybrid-π model). **(8 Points)**



D. Calculate the small-signal voltage gain for this circuit. **(8 Points)**

$$v_{out} = -g_m v_{be} \; r_o // R_C$$

$$v_{be} = v_{in} \frac{r_\pi}{r_\pi + R_B}$$

$$\therefore \quad a_v = \frac{v_{out}}{v_{in}} = -\left(\frac{r_\pi}{r_\pi + R_B}\right)(g_m)(r_o // R_C)$$

$$a_v = -\left(\frac{128.7\Omega}{128.7\Omega + 200\Omega}\right)(0.7692\,S)(5k\Omega // 500\Omega) = \boxed{-136.9}$$

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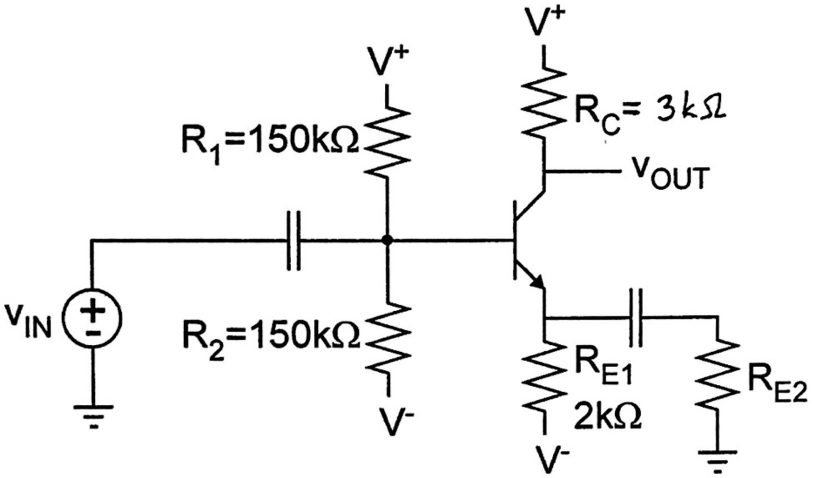
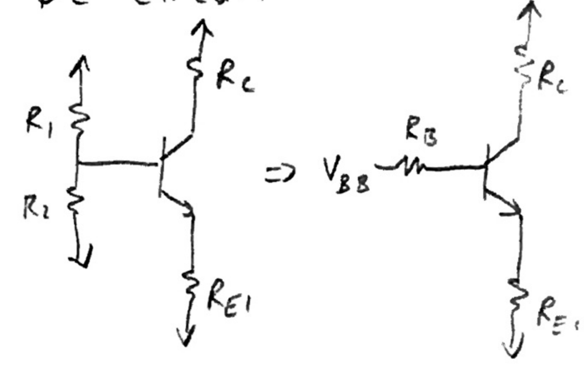
PROBLEM 5 (25 Points)

For the following circuit, calculate the value of R_{E2} that yields a voltage gain of $a_v = -50$. Let $V_A=\infty$ for this problem.



DC Circuit



$$V_{BB} = V^+ \frac{R_2}{R_1+R_2} + V^- \frac{R_1}{R_1+R_2} =$$

$$V_{BB} = 5V - 5V = 0V$$

$$R_B = R_1 \| R_2 = 75k\Omega$$

KVL around B-E junction

$$V_{BB} = I_B R_B + V_{BE,ON} + (1+\beta) I_B R_{E1} + V^-$$

$$I_B = \frac{V_{BB} - V_{BE,ON} - V^-}{R_B + (1+\beta) R_{E1}} = 33.82\mu A$$

($V_{BB} \to 0$)

(positive $\to$ ∴ not cutoff)

Assuming Forward Active

KVL around C-E loop

$$V^+ = \beta I_B R_C + V_{CE} + (1+\beta) I_B R_{E1} + V^-$$

$$V_{CE} = V^+ - V^- - \beta I_B R_C - (1+\beta) I_B R_{E1} = 3.19V > V_{CE,SAT}$$

∴ Forward Active Operation

$$I_C = \beta I_B = 3.35mA$$

$$g_m = \frac{I_C}{V_T} = 0.1288\,S$$

$$r_\pi = \frac{\beta V_T}{I_C} = 768.4\Omega$$

$$r_o = \frac{V_A}{I_C} = \frac{\infty}{I_C} = \infty\Omega$$

From problem statement (∞)

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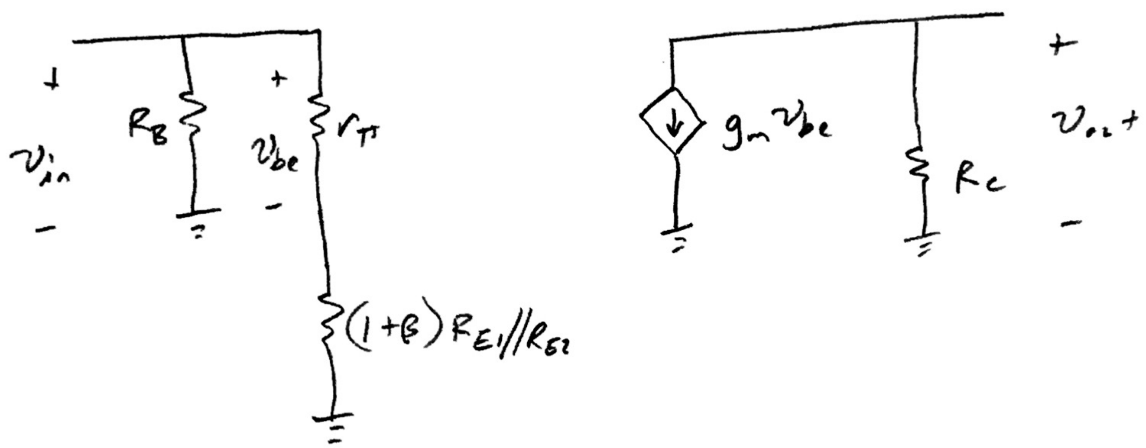
(Extra Work Page for Problem 5)

Small-Signal Equivalent Model



$$v_{out} = -g_m v_{be} R_C$$

$$v_{be} = v_{in} \frac{r_\pi}{r_\pi + (1+\beta) R_{E1} // R_{E2}}$$

$$a_v = -g_m \left(\frac{r_\pi}{r_\pi + (1+\beta) R_{E1} // R_{E2}} \right) R_C = \boxed{-45.03}$$

Sanity Check

For this configuration, the gain should be approximately

$$a_v \approx \frac{-R_C}{R_{E1} // R_{E2}} = -51.5$$

→ This is reasonably close for a sanity check