Name: ______________________________ (please print)

Signature: ___________________________

ECE 3355 – Exam #2 ONLINE
April 18, 2020

1. This exam is open book, open notes. Please turn on your video feed during the exam.
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.
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Choose three of these problems to work on, and indicate by circling the problem numbers which ones you want me to grade. No additional credit will be given for working on a fourth problem.

1.__________________/33 1/3

2.__________________/33 1/3

3.__________________/33 1/3

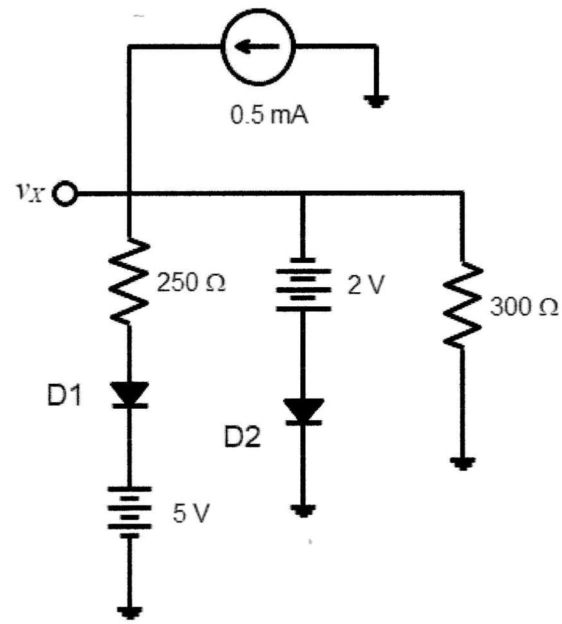
4.__________________/33 1/3

__________________/100

Room for extra work

1. (33 1/3 points) In the circuit below, the diodes are modeled using a piece-wise continuous model with $V_{th} = 1.5$ V, $r_D = 100\ \Omega$, and $I_S = 2$ mA.

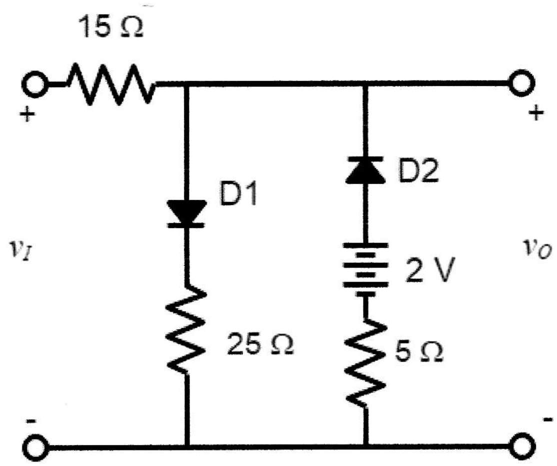
Find v_x. Be sure that any guesses you make as to the state of the diodes are tested. Even if your guess is wrong, you will get credit for proving it is wrong.



Room for extra work

2. (33 1/3 points) For the circuit below, the diodes are modeled using a piece-wise linear model with $V_{th} = 1.0$ V, $r_D = 5\ \Omega$, and $I_S = 0$.

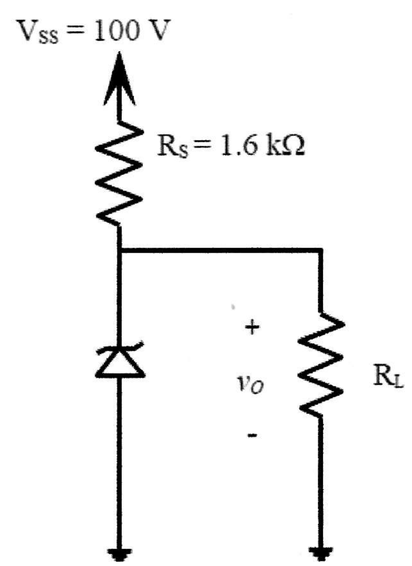
Find v_O for $v_I = 0$ V, 2 V, and 4 V. Be sure to prove that your diodes are in the state you assume them to be in.



Room for extra work

3. (33 1/3 points) A 20 V Zener diode is connected into the circuit below. In the breakdown region, the diode is rated at a resistance $r_Z = 30\ \Omega$ at a current of 50 mA. The Zener is intended to provide a constant output voltage v_O of approximately 20 V to the load R_L.

a) Find the model voltage V_{Z0} for this Zener diode.
b) Using the value of V_{Z0} you just calculated, and r_Z as given, find the output voltage v_O for a load voltage $R_L = 500\ \Omega$.
c) If the power supply V_{SS} can vary to as high as 110 V and as low as 95 V, ***use the small signal diode model*** to find the corresponding variation in the load voltage.
d) Repeat part c) for a load resistance $R_L = 10\ k\Omega$.

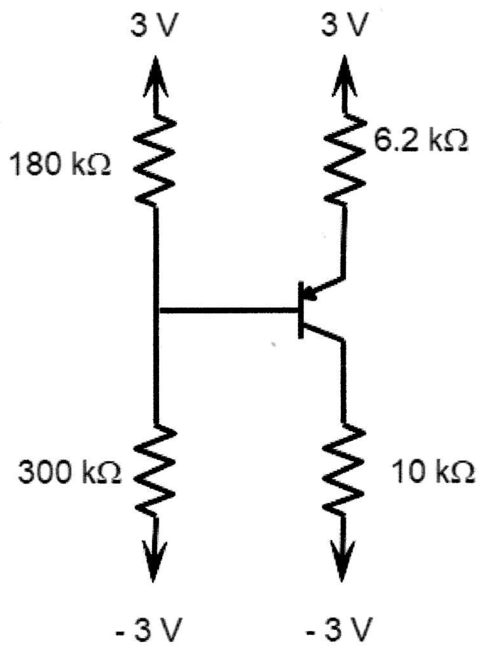


Room for extra work

4. (33 1/3 points) For the BJT below, the rated value of β is β = 100, and V_{CESAT} = 0.4 V. The BJT is biased in the linear region.

a) Find the BJT terminal voltages V_B, V_E, V_C. These are not labeled on the diagram since you should know what they are! Be sure to conduct the tests necessary to prove that the BJT is in the linear region.

b) Suppose that in actual transistors, β can be larger than the rated value. Is it possible that in this circuit, a higher value of β will cause the BJT to be biased into a different region than you found in part a)? If so, what is the smallest value of β that will cause this to happen?



Name: SOLUTIONS ! (please print)

Signature: ______________________

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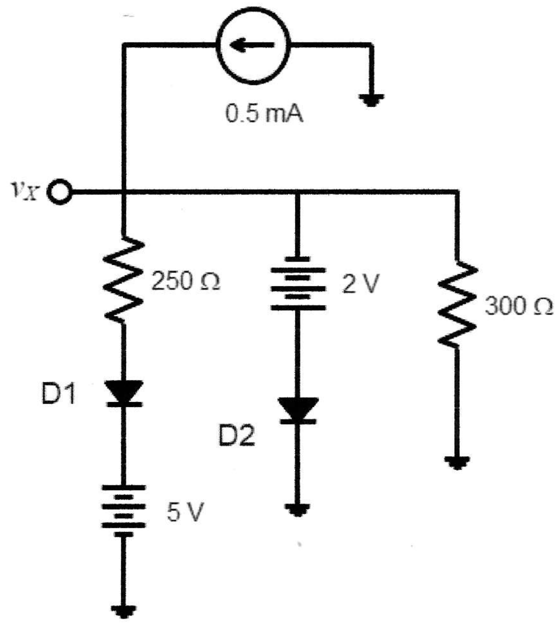
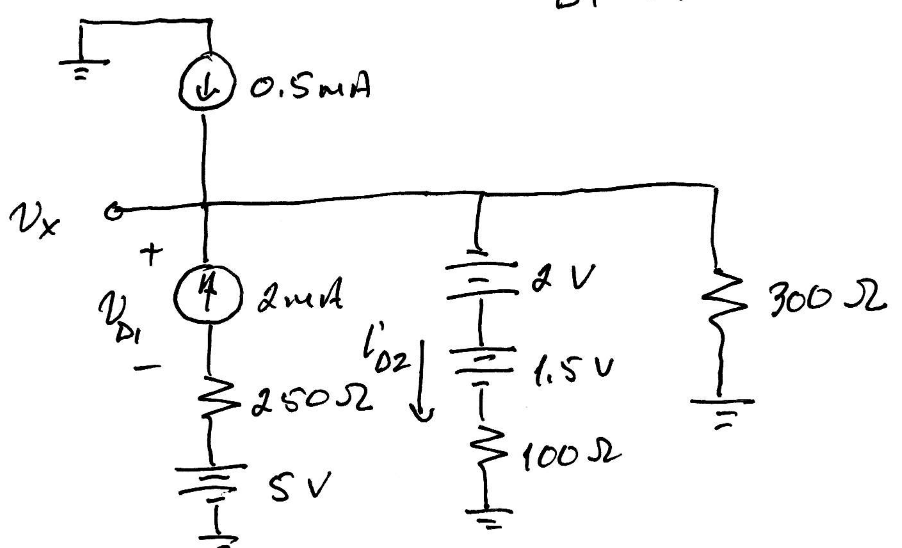
1. (33 1/3 points) In the circuit below, the diodes are modeled using a piece-wise continuous model with $V_{th} = 1.5$ V, $r_D = 100\ \Omega$, and $I_S = 2$ mA.

Find v_x. Be sure that any guesses you make as to the state of the diodes are tested. Even if your guess is wrong, you will get credit for proving it is wrong.



The 2 V source will act to turn D2 ON. The 5 V source will act to turn D1 OFF. Assume D2 region 4 (fwd bias), D1 OFF (reverse bias).



Prove:

$v_{D1} < 0$

$i'_{D2} > 0$

Room for extra work

$$\frac{v_x + 2 - 1.5}{100} + \frac{v_x}{300} - 0.0025 = 0 \implies v_x = -0.1875\text{ V}$$

✓

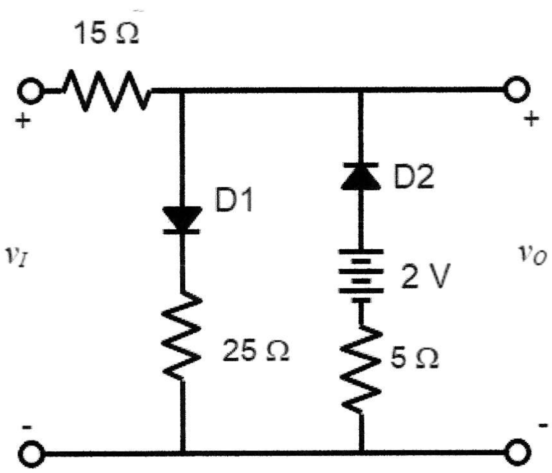
D1: $-5 + 0.002(250) - v_{D1} + v_x = 0 \implies v_{D1} = -4.6875\text{ V}$

D2: $i_{D2} = \frac{v_x + 2 - 1.5}{100} = 3.125\text{ mA}$ ✓

So the guesses were correct, and $v_x = -0.1875\text{V}$

2. (33 1/3 points) For the circuit below, the diodes are modeled using a piece-wise linear model with $V_{th} = 1.0$ V, $r_D = 5\ \Omega$, and $I_S = 0$.

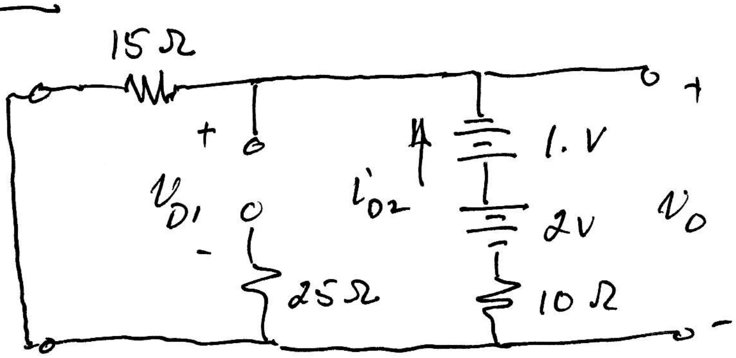
Find v_O for $v_I = 0$ V, 2 V, and 4 V. Be sure to prove that your diodes are in the state you assume them to be in.



This problem is essentially a transfer characteristics problem, but a plot of v_O vs. v_I is not asked for.

The 2 V source will act to turn D2 ON. But if v_I gets large enough, it will turn off.

$v_I = 0$ Assume D1 OFF, D2 ON



$$\frac{v_O}{15} + \frac{v_O - 2 + 1}{10} = 0$$

$$\Rightarrow \boxed{v_O = 0.6\text{ V}}$$

$$v_{D1} = v_O = 0.6\text{ V} \checkmark$$

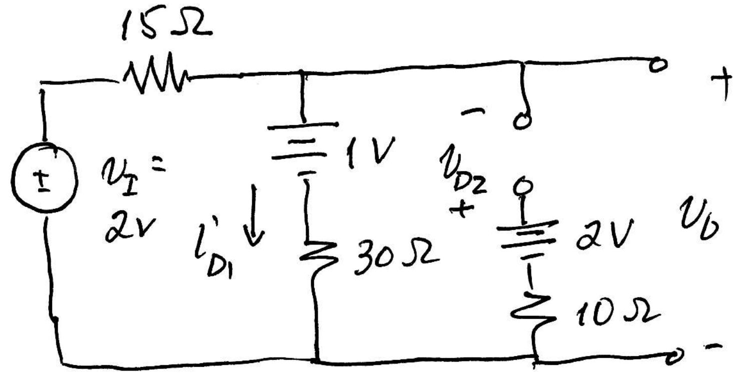
$$i_{D2} = -\frac{v_O - 2 + 1}{10} = 40\text{ mA} \checkmark$$

Prove: $i_{D2} > 0$

$v_{D1} < 1.0$ V

Room for extra work

$v_I = 2V$ We will guess that 2 V is enough to turn D1 ON, and that it's enough to turn D2 OFF.



Prove:

$i_{D1} > 0$

$v_{D2} < 1V$

$$-2 + i_{D1} \cdot 45 + 1 = 0 \Rightarrow i_{D1} = \frac{1}{45} A \checkmark$$

$$v_O = 1.667 V$$

$$v_O = 1 + 30 i_{D1} = 1\tfrac{2}{3} V$$

$$v_O - 2 + v_{D2} = 0 \Rightarrow v_{D2} = 2 - v_O = \frac{1}{3} V \checkmark$$

$v_I = 4V$ This will leave both diodes in the same region, but v_O will change.

$$-4 + i_{D1} \cdot 45 + 1 = 0 \Rightarrow i_{D1} = \frac{3}{45} A \checkmark$$

$$v_O = 3V$$

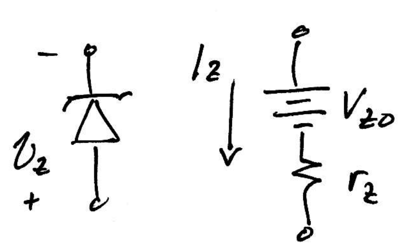
$$v_O = 1 + 30 i_{D1} = 3V$$

$$v_O - 2 + v_{D2} = 0 \Rightarrow v_{D2} = 2 - v_O = -1 V \checkmark$$

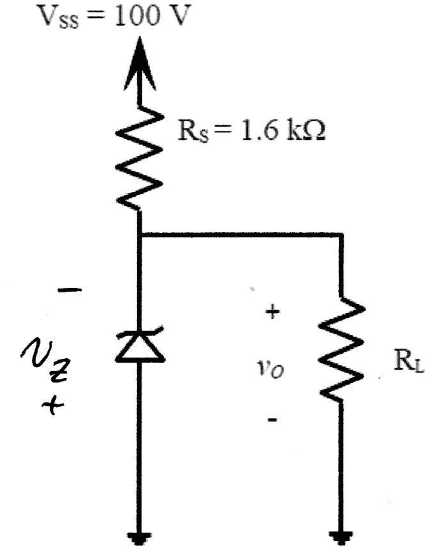
3. (33 1/3 points) A 20 V Zener diode is connected into the circuit below. In the breakdown region, the diode is rated at a resistance $r_Z = 30\ \Omega$ at a current of 50 mA. The Zener is intended to provide a constant output voltage v_O of approximately 20 V to the load R_L.

a) Find the model voltage V_{Z0} for this Zener diode.
b) Using the value of V_{Z0} you just calculated, and r_Z as given, find the output voltage v_O for a load voltage $R_L = 500\ \Omega$.
c) If the power supply V_{SS} can vary to as high as 110 V and as low as 95 V, ***use the small signal diode model*** to find the corresponding variation in the load voltage.
d) Repeat part c) for a load resistance $R_L = 10\ \text{k}\Omega$.

Zener model:



$I_Z > 0 \quad v_Z < 0$



$v_Z = 20\ V$

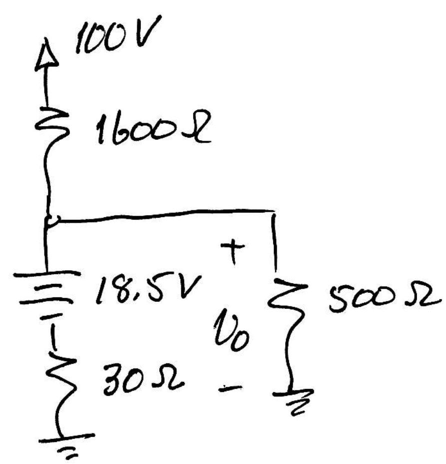
$V_{Z0} + I_Z r_Z = 20\ V$

$\Rightarrow V_{Z0} = 18.5\ V$

at $I_Z = 50\ mA$

a) $V_{Z0} = 18.5\ V$

b)

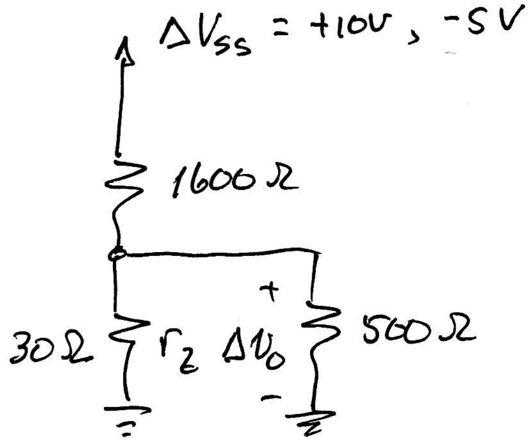


$$\frac{v_O}{500} + \frac{v_O - 100}{1600} + \frac{v_O - 18.5}{30} = 0$$

$v_O = 18.89\ V$

Room for extra work

c) Small signal model ⇒ deactivate DC components.



$$\Delta v_O = \Delta V_{SS} \frac{500 \| 30}{500\|30 + 1600}$$

$$\Delta v_O^+ = 10V \cdot \frac{28.3}{28.3+1600} = 0.1738 V$$

$$\Delta v_O^- = 5V \cdot \frac{28.3}{28.3+1600} = 0.0869 V$$

d) For $R_L = 10 k\Omega$, $\quad 10k\Omega \| 30 = 29.91 \Omega$

$$\Delta v_O^+ = 10 \frac{29.91}{29.91+10000} = 29.82 mV$$

$$\Delta v_O^- = 5 \frac{29.91}{29.91+10000} = 14.91 mV$$

4. (33 1/3 points) For the BJT below, the rated value of β is β = 100, and V_{CESAT} = 0.4 V. The BJT is biased in the linear region.

a) Find the BJT terminal voltages V_B, V_E, V_C. These are not labeled on the diagram since you should know what they are! Be sure to conduct the tests necessary to prove that the BJT is in the linear region.

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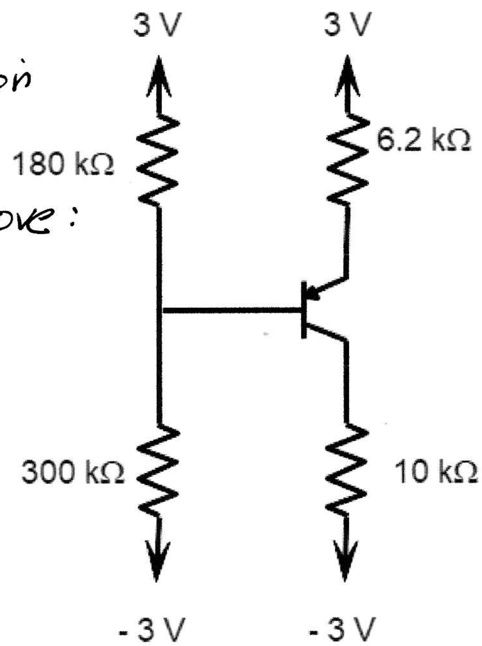


The pnp linear region model is shown below. We need to prove:

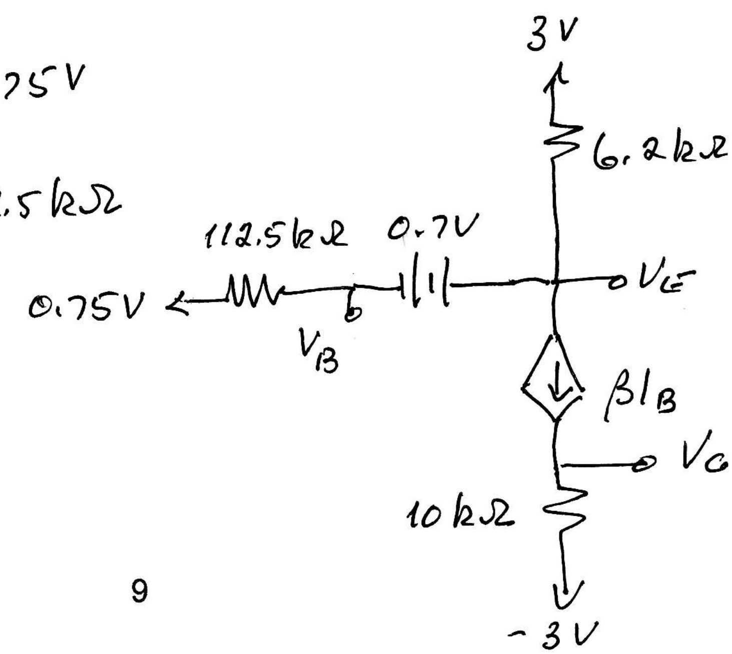
$I_B > 0$

$V_{CE} < -0.4\ V$

Thevenize the base:

$$V_{BB} = 6 \cdot \frac{300}{300+180} - 3 = 0.75\,V$$

$$R_B = 300\,k\Omega // 180\,k\Omega = 112.5\,k\Omega$$



Room for extra work

$I_E = (\beta+1) I_B$

KVL

$$-3 + 6200(101) I_B + 0.7 + 112.5\times10^3 I_B = 0$$

$$\Rightarrow I_B = 2.0983 \mu A \checkmark$$

$$V_C = 100 I_B (10\,000) - 3 = -0.9017 V$$

$$V_E = 3 - 101 I_B (6200) = 1.689 V$$

$$V_{CE} = -0.9017 - 1.689 = -2.591 V \checkmark$$

$$V_B = 112.5\times10^3 I_B + 0.75 = 0.9861 V$$

b) If β increases, we expect a larger V_C and smaller V_E, and at some point, V_{CE} will no longer be less than $-0.4V$. Let's see where that point is: set $V_{CE} = -0.4V$

$$V_{CE} = (\beta I_B (10\,000) - 3) - (3 - 6200(\beta+1) I_B) = -0.4$$

Since $\beta+1 \approx \beta$, we can make that approximation and solve for β:

$$\beta I_B (10\,000 + 6200) = 6 - 0.4 \Rightarrow \beta = 158.9$$

This would be a very large deviation ($\sim 60\%$)! But if it happened, the BJT would be in saturation.