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Denning, Tristan

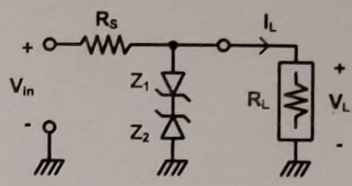
ECE 310 – Microelectronics I

Dr. Suat Ay

Homework #4

Fall 2021

(Due Date: 10/18/2021, 8.30am)



A junior engineer designed following circuit to deliver large amount (?!) of power to a load (R_L) using 1N5237 Zener diodes and a 33Ω shunt resistor (Rs) with 1W rating. Extract necessary information from the posted datasheet for Zener and Diode mode of operations considering constant voltage model (i.e. use provided datasheet for both V_z and $V_{D,on}$ voltages). Assume V_{in} has peak value of 14V and "ripple" voltage of 1.0V (i.e. $13V<V_{in}<14V$). Also assume load is connected to the power supply (PS) unless mentioned othervice.

a. (10 pts) What is the peak load voltage (V_L) for this circuit? Explain how you found it.

b. (15pts) What are the minimum and maximum power rating of the shunt resistor (Rs) that can be chosen for this design? Did the engineer choose correct rating and Rs values? Assume output ripple voltage is almost zero for this part.

c. (10pts) What is the maximum power that could be delivered to the load (it is the power rating of the PS)?

d. (10pts) What is the nominal load resistor (R_L) value that could be used with this PS?

e. (10pts) Calculate to output voltage ($V_{L,ripple}$=?) ripple for the minimum load?

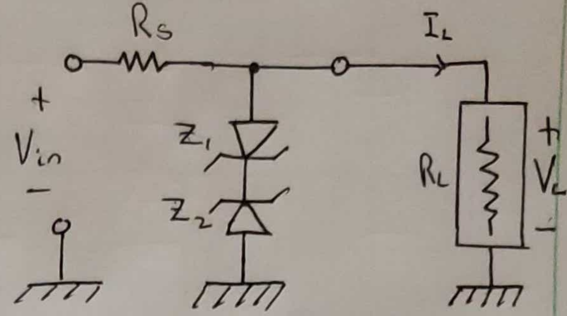
f. (15 pts) If load is disconnected from this PS design, what would be operating conditions of this PS?
   1. Overall: working or not working (explain what causes the failure)
   2. Output voltage (V_L=?). What is your observations in this case comparing nominal case where load is connected?
   3. Output ripple voltage ($V_{L,ripple}$=?). What are your observations (better then, worst then, or same as the nominal case)?

g. (15 pts) If an equivalent load resistance of 100Ω is attached to the PS, what would be operating conditions of this PS?
   1. Overall: working or not working (explain what causes the failure)
   2. Output voltage (V_L=?). What is your observations in this case comparing nominal case where load is connected?
   3. Output ripple voltage ($V_{L,ripple}$=?). What are your observations (better then, worst then, or same as the nominal case)?

h. (15 pts) If an equivalent load resistance of 25Ω is attached to the PS, what would be operating conditions of this PS?
   1. Overall: working or not working (explain what causes the failure)
   2. Output voltage (V_L=?). What is your observations in this case comparing nominal case where load is connected?
   3. Output ripple voltage ($V_{L,ripple}$=?). What are your observations (better then, worst then, or same as the nominal case)?

i. (10pts) Overall what do you think about this the design? (a good one, bad one, ok, etc.) Are there ways to improve or fix issues (if any) with the design? Explain.

1(a)



1 **Situation:** A Junior engineer designed the following circuit to deliver large amount of power to a load (R_L) using 1N5237 Zener diodes and a 33 Ω Shunt resistor (R_S) with a 1 W rating. Extract Necessary information from the posted data sheet for the Zener diode mode of operations Consider Constant Voltage model (i.e. Use Provided datasheet for both V_Z and $V_{D,on}$ Voltages) Assume V_{in} has a peak Value of 14 V and ripple Voltage of 1.0 V (ie. $13V < V_{in} < 14V$) Also assume load is connected to the power supply (PS) unless mentioned otherwise.

a.) What is the peak load Voltage (V_L) For the Circuit? explain.

2 **Goal:** To determine a Value for the circuits peak load Voltage, V_L.

3 **Plan:** To assess whether the diodes are operating in Zener or diode mode, then use the corresponding data sheet to find Values For the Zener diode Voltages. Then the Voltage across both diodes will be equal to the load Voltage Parallel to them.

4 **Solution:**

Observations:
- Z_1 will be operating in diode mode
- Z_2 will be operating in Zener mode

From Data Sheet:

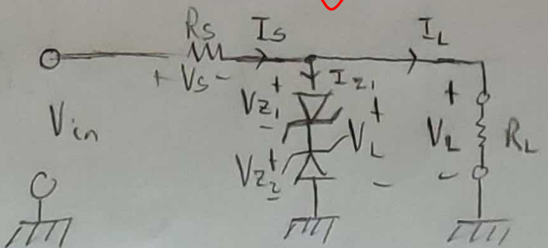
Z_2:

$$I_{Z_1} = I_{Z_2} = 20mA$$
$$R_{Z_2} = 8\Omega$$
$$V_Z = 8.2\ V \qquad (*)$$

Z_1:

$$I_{Z_1} = I_{Z_2} = 20mA$$
$$@\ 20mA,\ V_{Z_2} = V_{D,on} \cong 0.8V \qquad (*)$$

Redraw:



$\boxed{1(a)}$ (continued)

Solution (continued)

Now we have $V_{z_2} = 8.2V$
$V_{z_1} = 0.8V$

$V_L = V_{z_1} + V_{z_2}$ $\because$ KVL Right half

$\therefore V_L = 8.2 + 0.8$

$$\boxed{V_L = 9.0\ V}$$

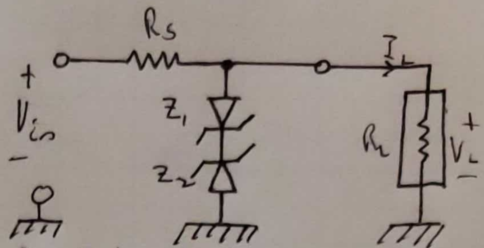
5 Sanity Check

$V_L < V_{in,\,peak}$

$9V < 14\ V$

$\therefore$ The result for V_L is reasonable, and is less than the maximum input of 14 V, — which is expected since there will be a voltage drop across the shunt resistor R_s.

1(b)



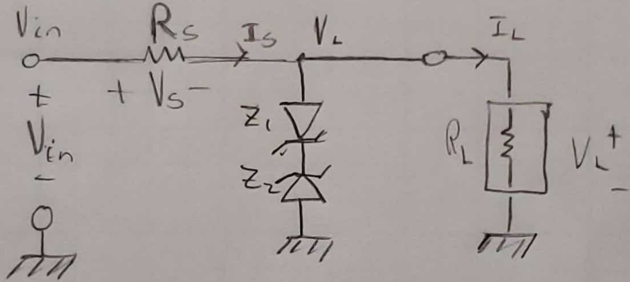
1 **Situation:** For the same situation described in Part 1(a): b.) What are the maximum and minimum power rating of the shunt resistor that can be used for this design? Did the engineer choose the correct rating and R_S values? Assume output ripple voltage is near zero.

2 **Goal:** Determine the max and min power rating for the shunt resistor, R_S. Then state whether the engineer chose the correct rating and R_S values.

3 **Plan:** Use the determined value for V_L from 1(a) along with the given $13V < V_{in} < 14V$ to determine the maximum and minimum voltages across R_S. Then use $P = V^2/R$ to determine the corresponding powers.

4 **Solution:**

Redraw:



$$V_S = V_{in} - V_L$$

Given: $V_{S,max} = 14V$ | $R_S = 33\Omega$

$V_{S,min} = 13V$

Known: $V_L = 9V$ ∵ Calculated

Max Power
$$P_{S,max} = \frac{(V_{in,max} - V_L)^2}{R_S} = \frac{(14-9)^2}{33}$$

$$\boxed{P_{S,max} = 0.758\ W}$$

Min Power
$$P_{S,min} = \frac{(V_{in,min} - V_L)^2}{R_S} = \frac{(13-9)^2}{33}$$

$$\boxed{P_{S,min} = 0.485\ W}$$

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1(b) (continued)

Did the engineer choose correct rating and R_S values?

$P_{S,Rated} = 1W$

$P_{S,min} = 0.485W < 1W$

$P_{S,max} = 0.758W < 1W$

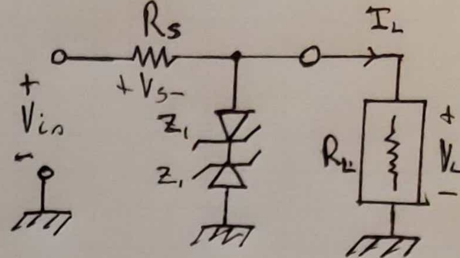
$\therefore$ Yes, the chosen value and rating of 33Ω at 1W are appropriate for the circuit.

<u>Sanity Check</u>

Assuming V_L determined in 1(a) as 9V is correct, the values determined for P_S max and P_S min seem reasonable. Also, $P_{S,max}$ and $P_{S,min}$ were calculated with the common power equation: $(V_S)^2/R_S$, so the chance for error is small.

1(c)

1 **Situation:** For the same situation described in 1(a): c.) What is the maximum power that can be delivered to the load. (it is the power rating of the PS).

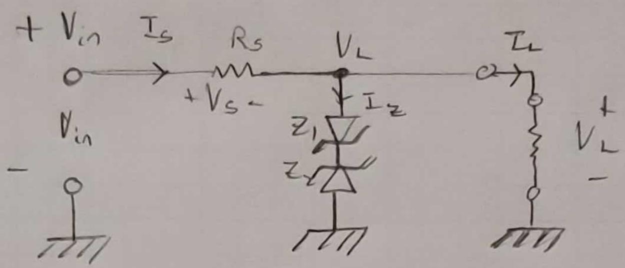


2 **Goal:** To calculate the maximum load power $P_{L,max}$

3 **Plan:** To use fundamental circuit relationships like KCL and KVL to find the current and voltage across R_L, then use $P = V^2/R_L$ to determine the maximum power.

4 **Solution:**

Redraw:



At $V_{in,max} = 14\text{ V}$,

$$I_{s,max} = \frac{V_{in} - V_L}{R_s}$$

$$= \frac{(14-9)}{33}$$

$$= 0.151515 \text{ A}$$

KCL @ V_L $\quad I_s = I_z + I_L$

$$0.151515 = 0.02 + I_L \qquad \because I_z = 20\text{mA from } 1(a)$$

$$I_L = 0.131515$$

$$\therefore P_{L,max} = V_L I_L$$

$*$ V_L Never Varies From 9V

$$\therefore P_{L,max} = 9 \cdot 0.131515$$

$$\boxed{P_{L,max} = 1.184 \text{ W}}$$

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$\boxed{1(c)}$ (continued)

5 Sanity Check

Check Conservation of Power for $V_{in} = 14V$

$$P_{in} \cong P_{out}$$

$$V_{in} I_S \cong V_L I_Z + P_L + P_{S,max}$$

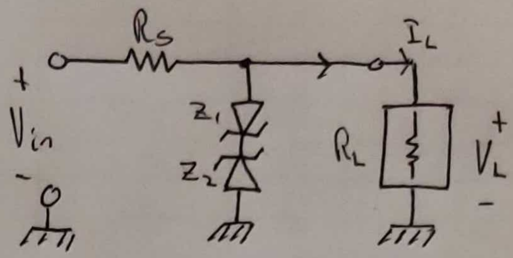
$$14(0.1515) \cong 9(0.02) + 1.184 + 0.758$$

$$2.121 \cong 2.122$$

$\therefore$ Power is conserved for the calculated values.

1(d)

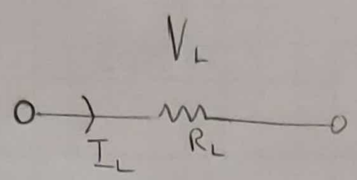
1 **Situation:** For the same situation described in 1(a),
d.) What is the nominal resistance R_L that could be used for this power supply?



2 **Goal:** To find a value for R_L, the load resistance.

3 **Plan:** To use the calculated V_L from part 1(a) and current I_L determined in 1(c) to calculate the resistance.

4 **Solution:**



$$R_L = V_L / I_L$$

From 1(a): $V_L = 9V$ * with no ripple

From 1(c): $I_L = 0.13152$

$$\therefore R_L = 9 / 0.13152$$

$$\boxed{R_L = 68.43\ \Omega}$$

5 **Sanity Check**

This answer is reasonable as it is nearly a direct result from part (c)

Check: $V_L^2 / R_L = I_L^2 R_L$

$$9^2 / 68.43 = 0.13152^2 (68.43)$$

$$1.184\ W = 1.184\ W$$

Two eqns for P_L yield the same result.

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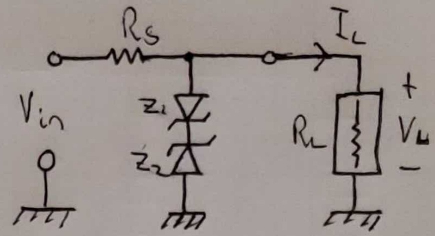
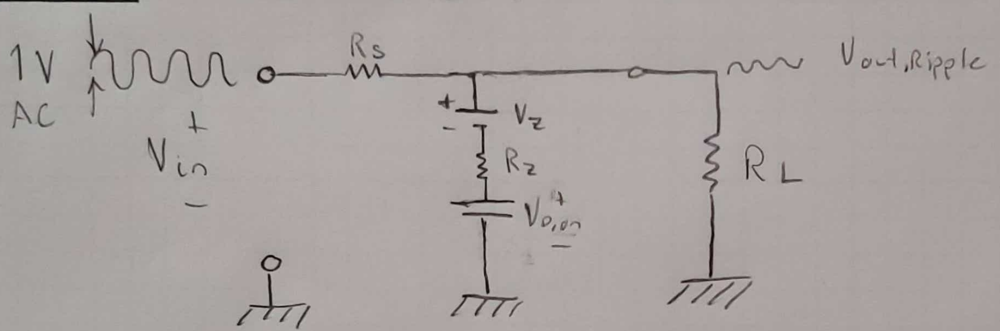


$\boxed{1(e)}$ **1 Situation:** For the same situation described in part 1(a), e.) Calculate the output voltage, V_L Ripple for the nominal load:

2 Goal: To calculate the output voltage V_L Ripple for the Load calculated in part 1(d).

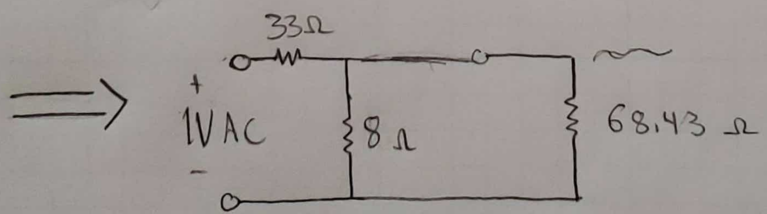
3 Plan: Use AC analysis with the CVM for the zeners in series, then voltage division to determine the output ripple voltage

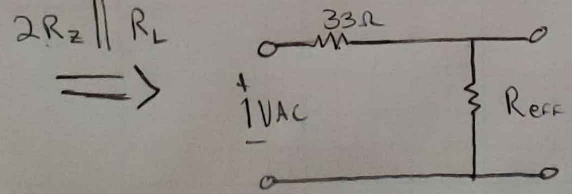
4 Solution: Redraw as (AC) all DC sorces → 0



DC Sources → 0 , $R_Z = 8\,\Omega$ (From data sheet)

$R_L = 68.43\,\Omega$ (From 1(d)) , $R_S = 33\,\Omega$





$R_{eff} = \left(\frac{8(68.43)}{8+68.43}\right) = 7.16\,\Omega$

Voltage Division:

$$V_{out,Ripple} = V_{Ripple}\left(\frac{7.16}{33+7.16}\right)$$

$$= 1\left(7.16/(33+7.16)\right)$$

$$\boxed{V_{out,Ripple} = 0.178\ V\ (AC)}$$

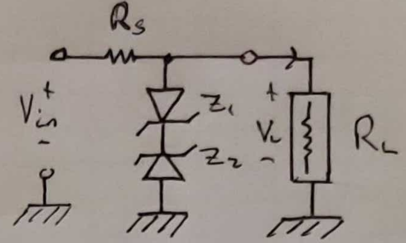
$\boxed{1(e)}$ (continued)

<u>Sanity Check:</u> The result is reasonable because the output ripple should be less than the input ripple.

$V_{in,Ripple} = 1V$, $V_{out\ ripple} = 0.178\ V$

$0.178 < 1$

$\therefore$ Answer seems reasonable.



1(f) 1 Situation: For the Same Situation described in 1(a).

F.) If the load is disconnected what would be the operating conditions

1.) Overall: Working or failure. (explain)
2.) Output Voltage compared to Vout at nominal load.
3.) Output Ripple Voltage (better or worse than nominal case)

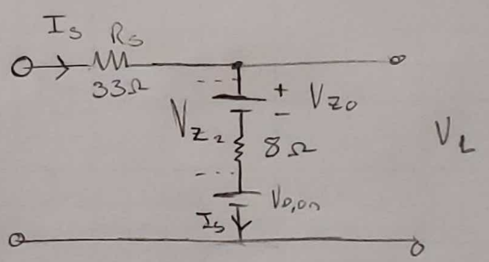
2 Goal: Determine the operating conditions outlined above.

3 Plan: To use equations for V_{Z0} and I_s to determine if the R_s exceeds its 1W power rating, or if either diode exceeds its datasheet rating of 500mW.

4 Solution:

1.)

Redraw CVM



$$V_{Z0} = V_{Z2} - I_{Z2}R_{Z2}$$
$$= 8.2 - 0.02(8)$$
$$V_{Z0} = 8.04 \text{ V}$$

$$I_s = \frac{(V_{in,nom} - V_{Z0} - V_{D,on})}{R_s + R_Z}$$
$$= \frac{(14 - 8.04 - 0.8)}{33 + 8}$$
$$I_s = 0.126 \text{ A}$$

Power in R_s

$$P_{R_s} = 0.126^2(33) = 0.52 \text{ W}$$

$$0.52 \text{ W} < 1 \text{ W}$$

∴ R_s does not fail

$\boxed{1(f)}$ (continued)

Power in Zeners

$$P_{Z_1} = V_{Z_1} I_s$$
$$= 0.126(0.8)$$
$$= 0.1008 \quad \checkmark \quad \because < 500\,mW$$
$$P_{Z_2} = V_{Z_2} I_s$$
$$= 0.126(8.2)$$
$$= 1.0332\ W$$
$$1.0332\,W > 0.5\ W$$

$\therefore Z_2$ Fails.

So overall, the PS will not be working with the load removed because Z_2 will exceed its max power of 500mW

2.) Output Voltage

If Z_2 fails, it would either go to a short or an open circuit.

If Open Circuit Across Z_2: $V_L = V_{in,nominal}$

If Shorted, Z_1 would increase in Voltage slightly

$\therefore V_{Z_1} > 0.8V = V_{D,on}$, so the output Voltage would be V_{Z_1} slightly greater than 0.8V

3.) V_{Ripple}

Open Circuit: $V_{out,Ripple} = V_{in,Ripple}$

or

Short Circuit: $V_{out\ Ripple} = 0$

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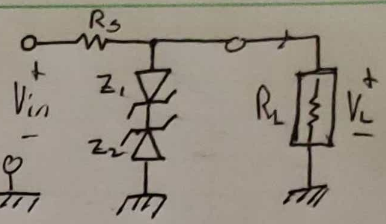
$\boxed{1(f)}$ (continued)

s Sanity Check:

With Z_2 exceeding the maximum power rating for the 1N5237 Zener diode, the Zener diode would likely burn up. (It is at 1.0332 W $\cong$ twice its rated 500mW)

Tristan Denning | Problem 1(g) | HW #04



1(g) 1 **Situation:** For the Same Situation described in 1(a),

g.) If an equiavalent resistance of $100\,\Omega$ is attached to the power Supply, what would be the operating Conditions:

1.) Overall: Working or Not Working

2.) Output Voltage $V_L = ?$ (Compare to nom.)

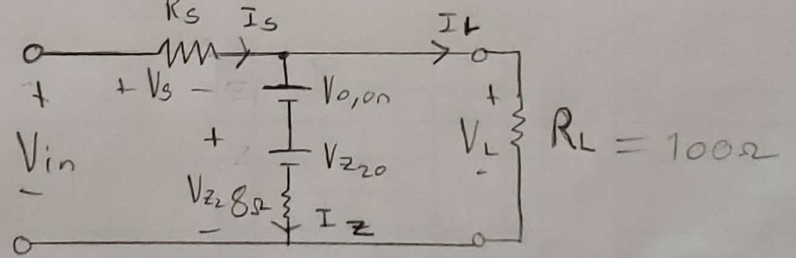
3.) Ripple output $V_{L,Ripple}$ (Compare to nom.)

2 **Goal:** Determine the operating Conditions listed above

3 **Plan:** To Assess the circuit with the load ($100\,\Omega$) attached to see if the Current through R_S Changes enough to make it fail. Then determine the new ripple Voltage.

4 **Solution:**

CVM:



1.) Overall Condition

$$V_Z = V_{Z_0} + I_{Z_0} R_{Z_0}$$

* V_{Z0} does Not Change
* R_{Z0} does Not Change

V_Z and I_{Z_0} must Change to fulfill KCL when Current I_L Changes. (it must)

Start with $V_L = 9V$

$$\text{KCL: } \frac{14-9}{33} = \frac{9 - 8.04 - 20\times10^{-3}(8)}{8} + \frac{9}{100}$$

$$0.1515 = 0.1 + 0.09$$

$$0.1515 \neq 0.19$$

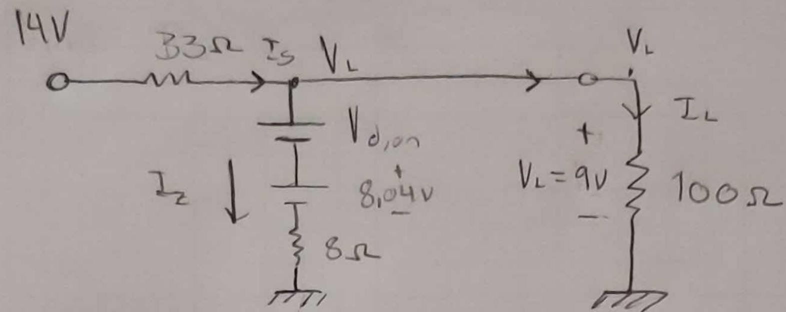
Need to find new I_Z to fulfill KCL

$\boxed{1(g)}$ (continued)

For $V_L = 9V$

$$V_{zo} = V_z - I_{zo} R_{zo}$$
$$= 8.2 - 20\times10^{-3}(8)$$
$$= 8.04\,V$$

redraw:



let $V_{D,on} = 0.8\,V$

$$I_s = \frac{(14-9)}{33}$$
$$= 0.1515\,A$$
$$I_L = 9/100\,A$$

$$I_z = I_s - I_L$$
$$= 0.1515 - 0.09$$
$$I_z = 0.0615$$

From Figure 7, @ $I_z = 0.0615\,A$,
$V_{D,on} \cong 0.9$

then, $V_L = V_{d,on} + V_{zo} + I_z R_z$
$$= 0.9 + 8.04 + 0.0615(8)$$
$$V_L = 9.432$$

$\boxed{1(a)}$ (continued)

For $V_L = 9.432\text{ V}$, $V_{D,on} = 0.9$

$$I_S = I_Z + I_L$$

$$\frac{14 - V_L}{33} = \frac{(V_L - V_{D,on} - V_{Z_0})}{8} + \frac{V_L}{100}$$

$$0.1384 = \frac{(9.432 - 0.9 - 8.04)}{8} + \frac{9.432}{100}$$

$$0.1384 \neq 0.15582$$

* Need more balancing to fulfill KCL

$$I_S = \frac{14 - 9.432}{33} = 0.1384$$

$$I_L = 9.432/100 = 0.09432$$

$$I_Z = 0.1384 - 0.09432$$

$$= 0.04408$$

From Figure 7, @ $I_Z = 0.4408$, $V_{D,on} = 0.87$

Then, $V_L = V_{d,on} + V_{Z_0} + I_Z R_Z$

$$= 0.87 + 8.04 + 0.04408(8)$$

$$V_L = 9.263$$

$\Longrightarrow$ For $V_L = 9.263$, $V_{D,on} = 0.87$

$$\frac{14 - 9.263}{33} = \frac{9.263 - 0.87 - 8.04}{8} + \frac{9.263}{100}$$

$$0.1435 \neq 0.1367$$

* Almost there, one more stage

$\boxed{1(g)}$ (continued)

$$I_s = \frac{(14 - 9.263)}{33} = 0.14354$$

$$I_L = 0.09263$$

$$I_z = 0.050915$$

For $I_z = 0.50915$, let $V_{D,on}$ increase to 0.88 V, $V_{D,on} = 0.88$

Then $V_L = V_{D,on} + V_{z0} + I_z R_z$

$$= 0.88 + 8.04 + 0.050915(8)$$

$$= 9.32732$$

For $V_L = 9.33\,V$, $V_{D,on} = 0.88$

$$\frac{(14 - 9.33)}{33} = \frac{(9.33 - 0.88 - 8.04)}{8} + \frac{9.33}{100}$$

$$0.141515 \cong 0.1408$$

* This Value of V_L Satisfies KCL with relatively low error.

1.) Overall Condition:

$$P_{R_s} = 0.141515^2(33)$$

$$= 0.661\ W$$

√

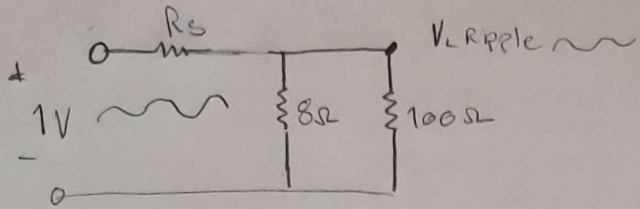
The PS is working because R_s is within rated power.

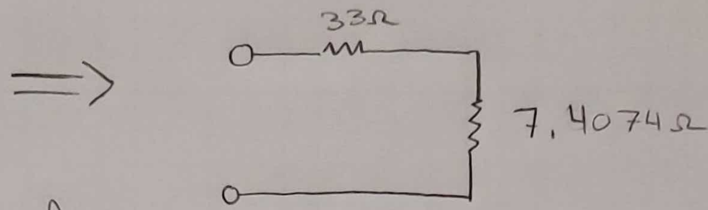
2.) $\boxed{V_L \cong 9.33\ V}$

9.33 > 9 V, Now the power supply is outputting a slightly higher Voltage than at Nominal R_L

$\boxed{1(g)}$ (Continued)

3.) $V_{L,Ripple}$





Voltage Division

$$V_{L,Ripple} = 1\left(\frac{7.4074}{33+7.4074}\right)$$

$$\boxed{V_{L,Ripple} = 0.18332\ V}$$

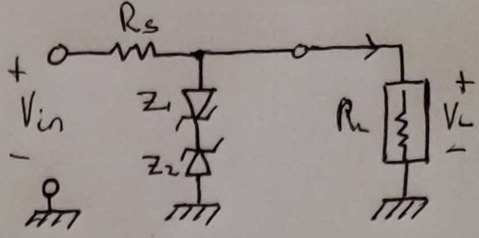
Nominal, $V_{L,Ripple} = 0.178V$

The ripple voltage for higher $R_L = 100$ is slightly higher than at nominal $R_L = 68.43$

5 Sanity Check

My method for solving V_L was not very straight forward or clear to follow. I essentially used iterations of guess and check until the KCL for V_L was fulfilled. This makes sense because as R_L increases, the excess current must go somewhere other than the zener diodes, as V_{Zo} stays constant.

$\boxed{1(h)}$ **1 Situation:** For the Same Situation described in 1(a),



h.) If an equivalent load resistance of 25 Ω is attached to the PS what would be the operating Conditions:

1.) Overall: Working or Not Working

2.) Out put Voltage $V_L = ?$ (Compare to Nominal)

3.) Output Ripple $V_{L,Ripple}$ (compare to Nominal)

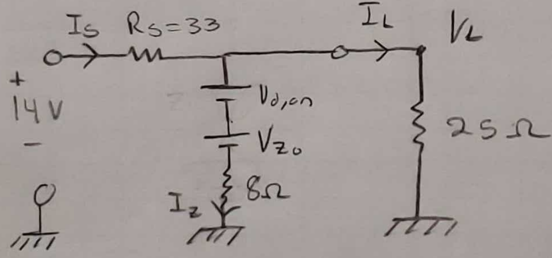
2 Goal: To Determine the operating Conditions listed above

3 Plan: To Assess the circuit with the 25 Ω load attached to see if the Current through Rs Changes enough to make it Surpass the 1W limit. Then determine the new Ripple Voltage through AC Analysis / Voltage division + Iteration.

4 Solution:

Start with $V_L = 9V$, $I_z = 20\times10^{-3}$ mA

Redraw



KCL: $I_s = I_z + I_L$

$$\frac{14-9}{33} = 0.02 + 9/25$$

$$0.1515 = 0.02 + 0.36$$

$$0.1515 = 0.38$$

KCL is not fulfilled

$I_s = 0.1515$

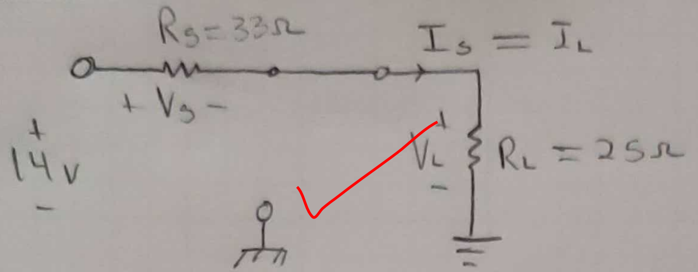
$I_L = 0.36$

$I_z = 0.1515 - 0.36 = -0.2048$ * Not Possible

$\boxed{1(h)}$ (continued)

With R_L @ 25Ω, I_z would be negative, which is not possible, so the two zeners are shut OFF, and are treated as an open circuit

1.) Overall Condition



$I_z = 0$

$$V_L = 14\left(\frac{25}{25+33}\right)$$

$$= 6.03 \text{ V}$$

However, $I_S = V_{in}/_{25+33}$

$$= 241.4 \text{ mA}$$

Then $P_{RS} = 33(0.2414)^2$

$$= 1.92 \text{ W} > 1\text{ W}$$

$\therefore$ So R_S Fails and the circuit is $\boxed{\text{Not working}}$

2.) V_L

R_S would burn up, causing a short circuit, then R_L would also burn up.

$\therefore \boxed{V_L \cong 0}$

$\boxed{1(h)}$ (continued)

3.) $V_{L,Ripple}$

With R_S, R_L Shorted (and burned up), $V_L = 0$

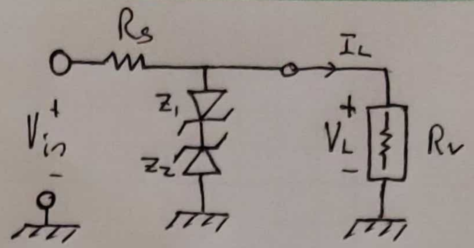
$\therefore \boxed{V_{L,Ripple} = 0}$

5 Sanity Check

Tristan Denning | Problem 1(i) | HW # 04

$\boxed{1(i)}$

1 Situation: For the Same Situation defined in 1(a),
i.) Overall, what do you think of this design?



2 Goal: To make a Statement about the effectiveness of the Provided design, and Suggest Changes.

3 Plan: To Analyze the results from parts 1(a) – 1(h) to make a Statement about the functionality of the power Supply.

4 Solution:

In Summary, this power Supply works Very well at a load of $68.43\ \Omega = R_L$. At this load, the PS delivers the desired 9 V to the load and all components are within their maximum power ratings.

For Significantly different loads, my results indicate that the power Supply fails, ie: at No load and at $R_L = 25\ \Omega$. This issue may be resolved by replacing the $R_S = 33\ \Omega$ Shunt resistor with a larger Resistor with a higher power rating.

Then, For the Case of diode failure in Part 1(F), more power could be dissipated across the Shunt resistor, Then the Zener would not surpass its maximum Power rating.

So; is it good, bad, OK, poor? do you pay an buy this 1.1W PS?

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