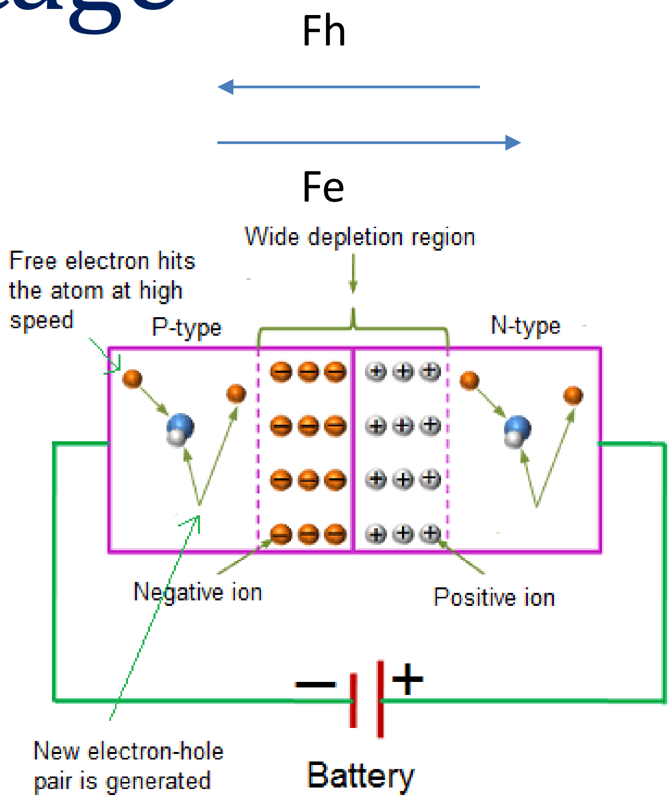
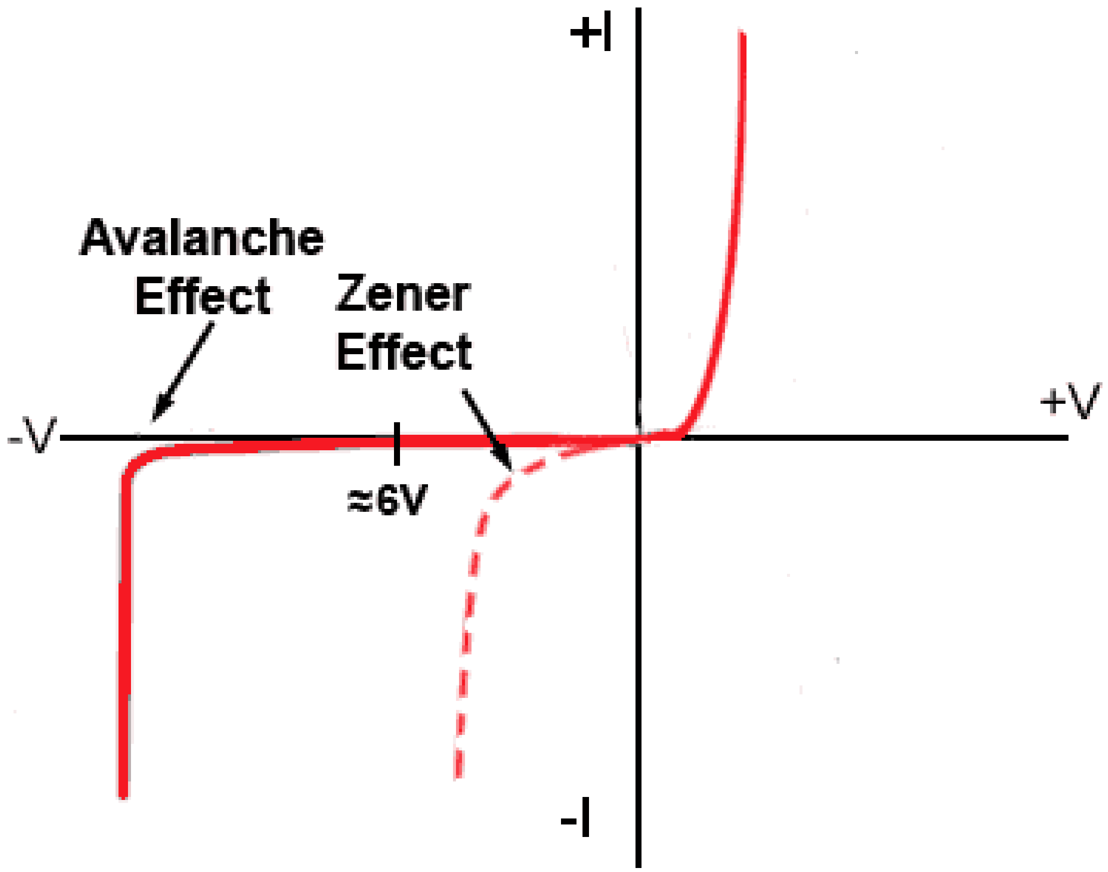
Voltage Regulator

Breakdown Voltage

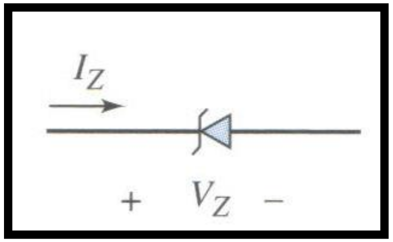


- The breakdown voltage is a function of the doping concentrations in the n- and p-region of the pn junction.
- Large doping concentrations result in smaller break-down voltage.
- Reverse biased voltage – $E_T \uparrow$
- The electric field may become large enough for the covalent bond to break, causing electron-hole pairs to be created.
- So, electrons from p-type are swept to n-region by the electric field and holes from the n-type are swept to the p-region
- The movement will create reverse biased current known as the ***Zener Effect.***


+I
Avalanche Effect
Zener Effect
+V
-V
≈6V
-I

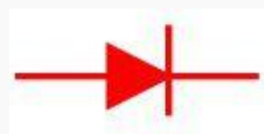
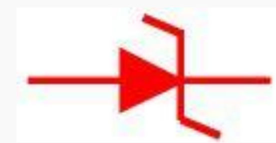
Zener Effect and Zener Diode

- The applied reverse biased voltage cannot increase without limit since at some point breakdown occurs causing current to increase rapidly.
- The voltage at that point is known as the breakdown voltage, V_Z
- Diodes are fabricated with a specifically design breakdown voltage and are designed to operate in the breakdown region are called **Zener diodes.** Circuit symbol of the Zener diode:

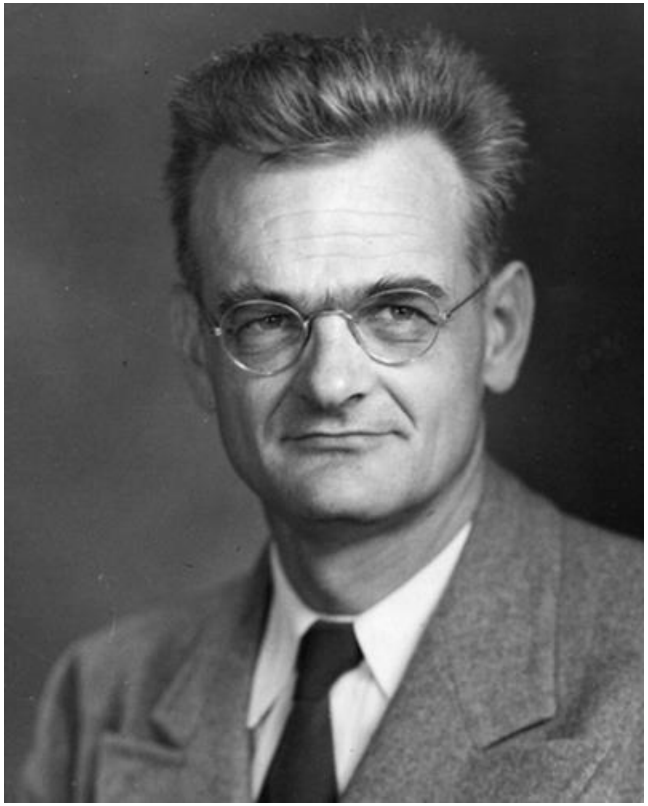


NOTE: When a Zener diode is reverse-biased, it acts at the breakdown region, when it is forward biased, it acts like a normal PN junction diode

- Such a diode can be used as a constant-voltage reference in a circuit.
- The large current that may exist at breakdown can cause heating effects and catastrophic failure of the diode due to the large power dissipated in the device.
- Diodes can be operated in the breakdown region by limiting the current to a value within the capacities of the device.

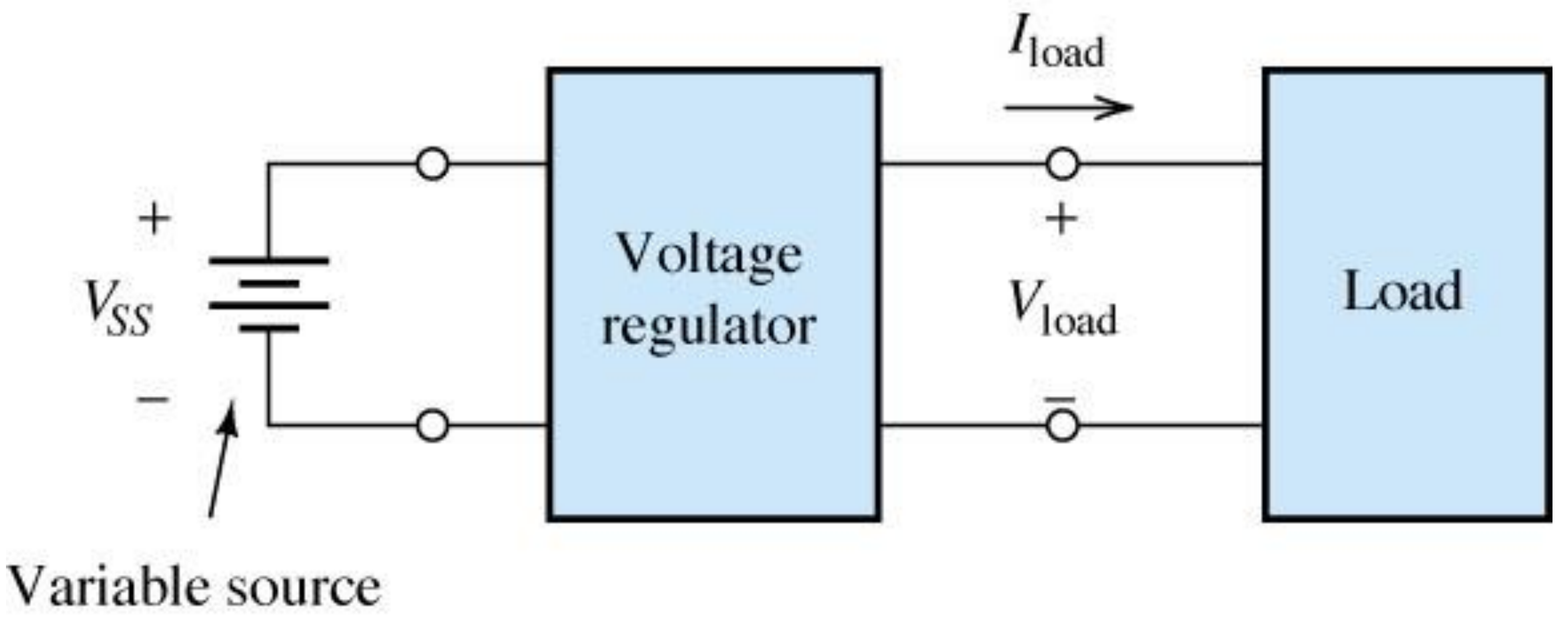
Basis For Comparison	PN Junction Diode	Zener Diode
Definition	It is a semiconductor diode which conducts only in one direction, i.e., in forward direction.	The diode which allows the current to flow in both the direction i.e., forward and reverse, such type of diode is known as the Zener diode.
Symbol		
Reverse Current Effect	Damage the junction.	Do not damage the junction.
Doping Level	Low	High
Breakdown	Occurs in higher voltage.	Occur in lower voltage.

Clarence Melvin Zener

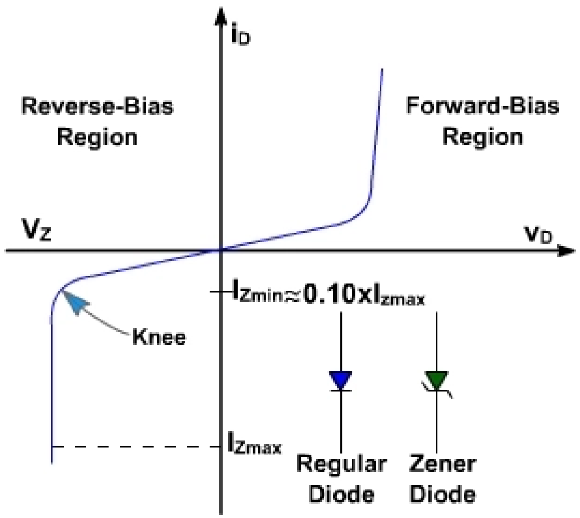


REF: https://www.rheology.org/sor/Awards/Bingham/ZenerC

Voltage Regulator - Zener Diode

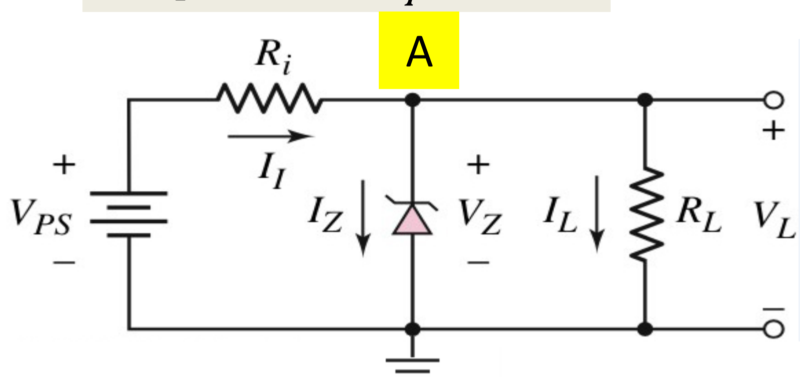


A voltage regulator supplies constant voltage to a load.



- The breakdown voltage of a Zener diode is nearly constant over a wide range of reverse-bias currents.
- This make the Zener diode useful in a **voltage regulator**, or a constant-voltage reference circuit.

3. The remainder of V_{PS} drops across R_i

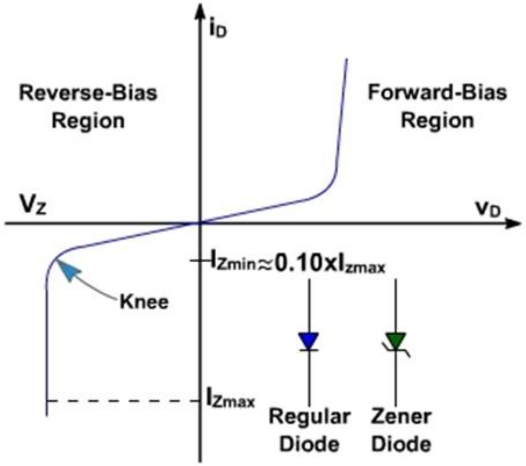


2. The load resistor sees a constant voltage regardless of the current

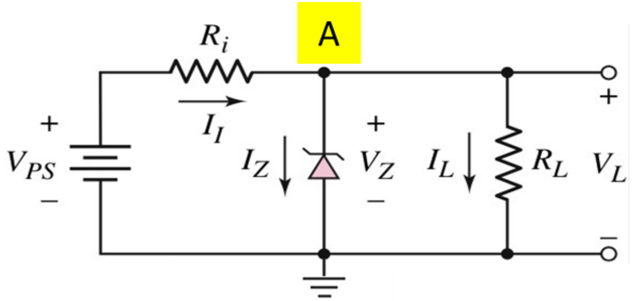
1. The Zener diode holds the voltage constant regardless of the current

Notes on Voltage Regulator

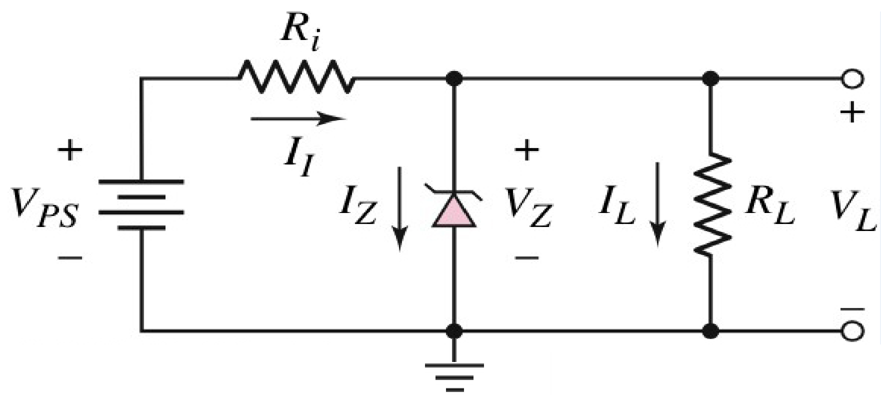
1. To operate, a Zener diode requires a minimum current, I_{Zmin} and the maximum current that it can operate is known as I_{zmax}



2. $V_{LOAD} = V_Z$ → because they are connected in parallel
3. Using KCL at node A: $I_I = I_Z + I_L$
4. The voltage across Ri, $V_{Ri} = V_{PS} - V_Z$ so, you can use Ohm's law to calculate I_I



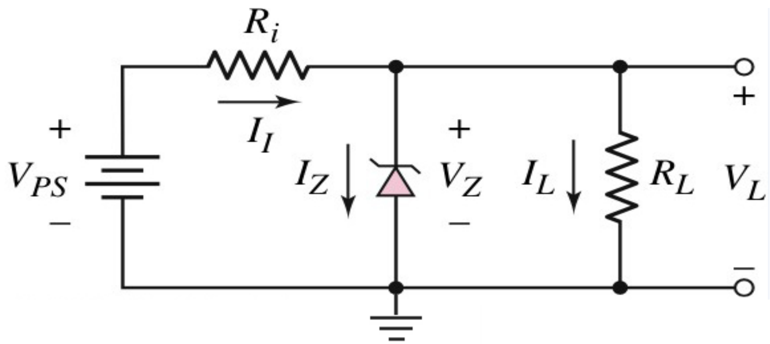
Example



A Zener diode is connected in a voltage regulator circuit. It is given that $V_{PS} = 20\text{V}$, the Zener voltage, $V_Z = 10\text{V}$, $R_i = 222\ \Omega$ and $P_{Z(\max)} = 400$ mW.

a. Determine the values of I_L, I_Z and I_I if $R_L = 380\ \Omega$.
b. Determine the value of R_L that will establish $P_{Z(\max)} = 400$ mW in the diode.

Voltage Regulator – with a range of power supply



For proper function the circuit must satisfied the following conditions.

1. The power dissipation in the Zener diode is less than the rated value
2. When the power supply is a minimum, V_{PS}(min), there must be minimum current in the Zener diode I_Z(min), hence the load current is a maximum, I_L(max),
3. When the power supply is a maximum, V_{PS}(max), the current in the diode is a maximum, I_Z(max), hence the load current is a minimum, I_L(min)

$$R_i = V_{Ri} / I_I = (V_{PS} - V_Z) / (I_Z + I_L)$$

$$R_i = \frac{V_{PS}(\min) - V_Z}{I_Z(\min) + I_L(\max)}$$ **AND** $$R_i = \frac{V_{PS}(\max) - V_Z}{I_Z(\max) + I_L(\min)}$$ So, if we **equate** these two equations

$$[V_{PS}(\min) - V_Z] \,.\, [I_Z(\max) + I_L(\min)] = [V_{PS}(\max) - V_Z].\, [I_Z(\min) + I_L(\max)]$$

$$R_i = \frac{V_{PS}(\text{min}) - V_Z}{I_Z(\text{min}) + I_L(\text{max})}$$ **AND** $$R_i = \frac{V_{PS}(\text{max}) - V_Z}{I_Z(\text{max}) + I_L(\text{min})}$$ So, if we **equate** these two equations

$$[V_{PS}(\text{min}) - V_Z] \, . \, [I_Z(\text{max}) + I_L(\text{min})] = [V_{PS}(\text{max}) - V_Z] . \, [I_Z(\text{min}) + I_L(\text{max})]$$

Considering designing this circuit by substituting **$I_Z(min) = 0.1\, I_Z(max)$,** now the last equation becomes:

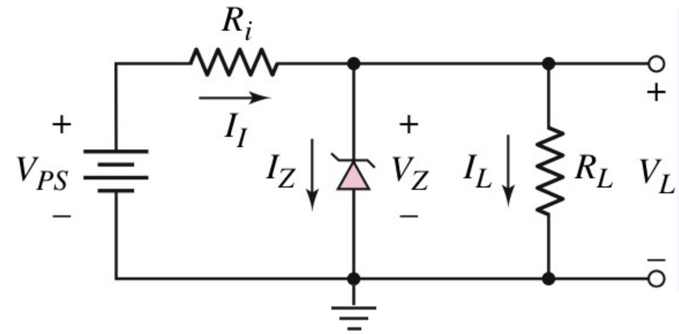
$$I_Z(\max) = \frac{I_L(\max).[V_{PS}(\max) - V_Z] - I_L(\min).[V_{PS}(\min) - V_Z]}{V_{PS}(\min) - 0.9V_Z - 0.1V_{PS}(\max)}$$

Maximum power dispassion in the Zener diode is

$$P_Z(\max) = I_Z(\max) \times V_Z$$

EXAMPLE 1

Consider voltage regulator is used to power the cell phone at 2.5 V from the lithium ion battery, which voltage may vary between 3 and 3.6 V. The current in the phone will vary 0 (off) to 100 mA(when talking). Calculate the value of R_i and the Zener diode power dissipation



Solution:

The stabilized voltage $V_L = 2.5$ V, so the Zener diode voltage must be $V_Z = 2.5$ V. The maximum Zener diode current is

$$R_i = \frac{V_{PS}(\min) - V_Z}{I_Z(\min) + I_L(\max)} \qquad R_i = \frac{V_{PS}(\max) - V_Z}{I_Z(\max) + I_L(\min)}$$

$$[V_{PS}(\min) - V_Z] \,.\, [I_Z(\max) + I_L(\min)] = [V_{PS}(\max) - V_Z]. \,[I_Z(\min) + I_L(\max)]$$

$I_Z(\min) = 0.1\, I_Z(\max),$

$$(3 - 2.5)\,(I_Z\max + 0) = (3.6 - 2.5)\,(0.1\, I_Z\max + 100 \text{ mA})$$

$$0.5\, I_Z\max = (1.1)\,(0.1\, I_Z\max + 100 \text{ mA})$$

$$0.5\, I_Z\max = 0.11\, I_z\max + 110$$

$$0.39\, I_Z\max = 110$$

$$I_Z\max = 282.05 \text{ mA}$$

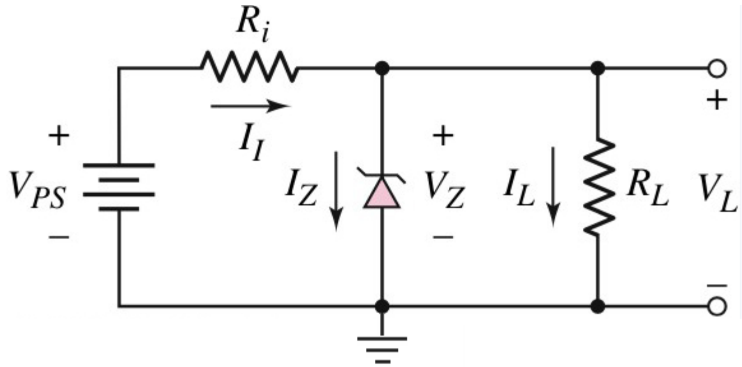
The maximum power dissipation in the Zener diode is

$$P_Z(\text{max}) = I_Z(\text{max}) \times V_Z = 282.05 \times 2.5 = 705.13 \text{ mW}$$

The value of the current limiting resistance, R_i is

$$R_i = \frac{V_{PS}(\text{max}) - V_Z}{I_Z(\text{max}) + I_L(\text{min})} = \frac{3.6 - 2.5}{282.05 + 0} \approx 3.9\ \Omega$$

- Example 2



Range of V_{PS} : 10V– 14V
R_L = 20 – 100 Ω
V_Z = 5.6V
Find value of R_i and calculate the maximum power rating of the diode

$I_{L\,max} = V_L / R_{L\,min} = 0.28$ A

$I_{L\,min} = V_L / R_{L\,max} = 0.056$ A

Solution:

The Zener diode voltage is given as 5.6 V. The maximum Zener diode current is

$$[V_{PS}(\text{min}) - V_Z] \, . \, [I_Z(\text{max}) + I_L(\text{min})] = [V_{PS}(\text{max}) - V_Z]. \, [I_Z(\text{min}) + I_L(\text{max})]$$

$I_Z(\text{min}) = 0.1\, I_Z(\text{max})$,

$(10 - 5.6)\ (I_Z\text{max} + 56\ \text{mA}) = (14 - 5.6)\ (0.1\ I_Z\text{max} + 280\ \text{mA})$

$4.4\ I_Z\text{max} + 246.4 = (8.4)\ (0.1\ I_Z\text{max} + 280\ \text{mA})$

$4.4\ I_Z\text{max} + 246.4 = 0.84\ I_z\text{max} + 2352$

$3.56\ I_Z\text{max} = 2105.6$

$I_Z\text{max} = 591.46\ \text{mA}$

The maximum power dissipation in the Zener diode is

$P_Z max = 5.6 \times 591.46 = 3.312$ W

The value of the current limiting resistance, R_i is

$$R_i = \frac{V_{PS}(\max) - V_Z}{I_Z(\max) + I_L(\min)}$$

→

$R_i = 8.4 / 647.46 = 13\ \Omega$