BFF1303: ELECTRICAL / ELECTRONICS ENGINEERING

Analog Electronics: Rectifier

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Semiconductor Diodes & Circuits

BFF1303 ELECTRICAL/ELECTRONICS ENGINEERING

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Contents:

- Outcomes
- Rectifier Circuit
- Zener Diode

Outcomes

Understand the diode characteristics and its model

Learn the types of diodes

Learn the series and parallel operation of diodes

Analyze and design simple voltage-regulator circuits.

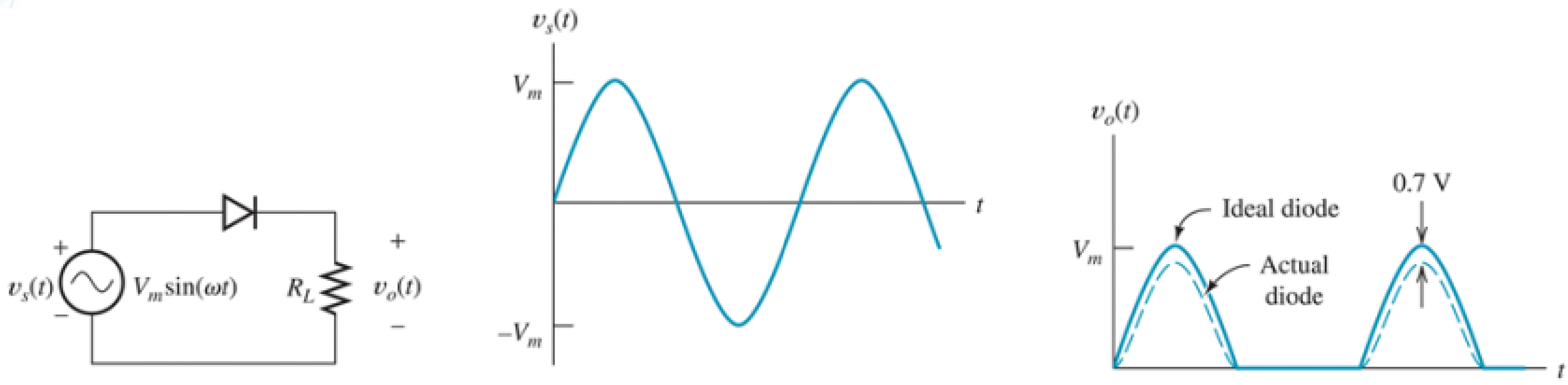
Understand various rectifiers and wave-shaping circuits

Rectifier Circuit

- Convert AC power into DC power.
- The basis for power supply and battery charging.
- For signal processing such as demodulation of signal radio.
- For precision control of an AC voltage to DC in an electronic voltmeter.

Rectifier Circuit

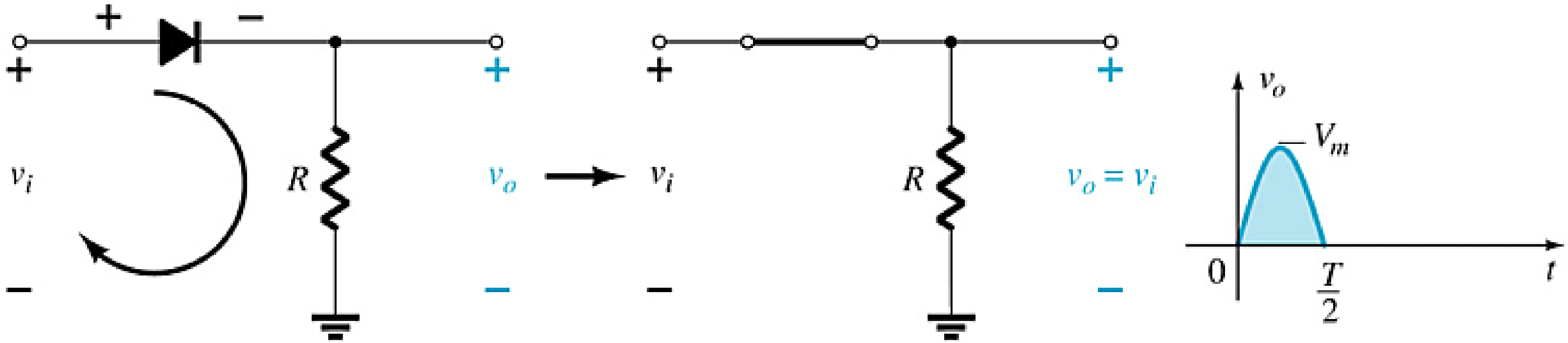
Half-Wave Rectifier



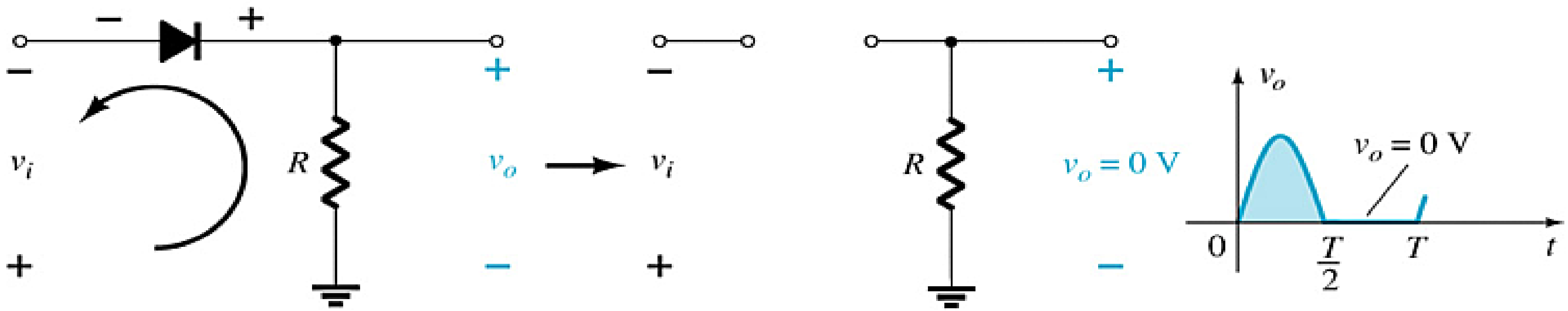
(a) Circuit diagram (b) Source voltage versus time (c) Load voltage versus time

- Over 1 full cycle, the average value of areas (voltage) is zero.
- The output waveform, v_o that generated by the circuit will give an average value that will be use in AC to DC conversion.
- The power and current rating are typically much higher than those of diode employed in other applications.

Half-Wave Rectifier



The DC output voltage is $0.318V_m$, where V_m = the peak AC voltage.

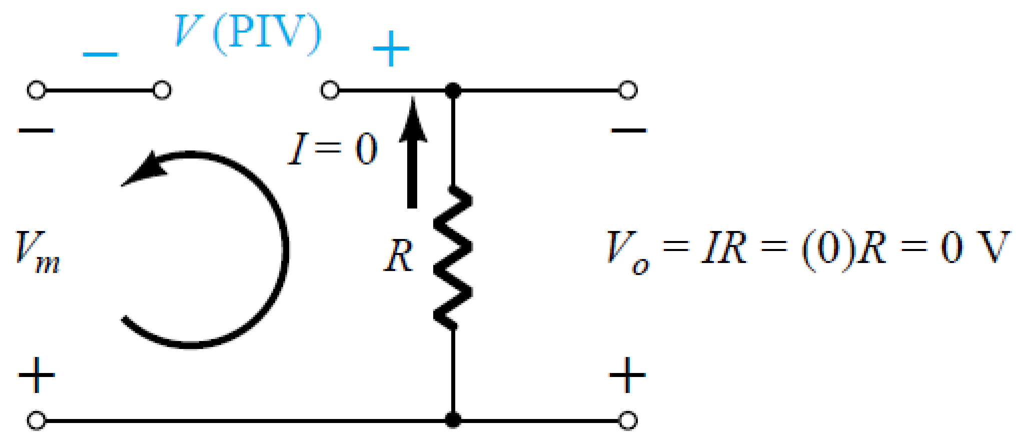


PIV (PRV)

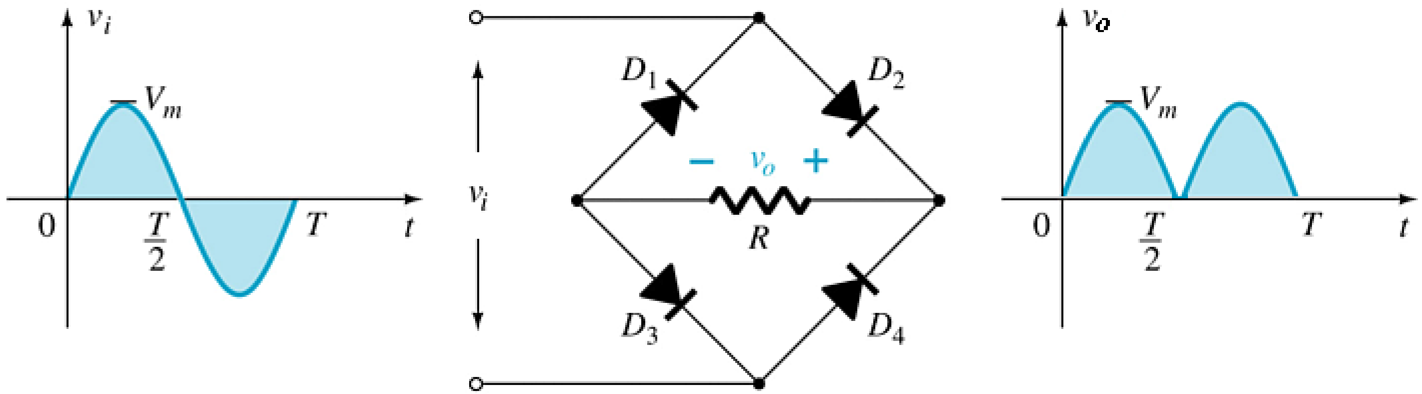
- Because the diode is only forward biased for one-half of the AC cycle, it is also reverse biased for one-half cycle.

- It is important that the reverse breakdown voltage rating of the diode be high enough to withstand the peak, reverse-biasing AC voltage.

$$\mathrm{PIV}(\mathrm{PRV}) \geq V_m$$

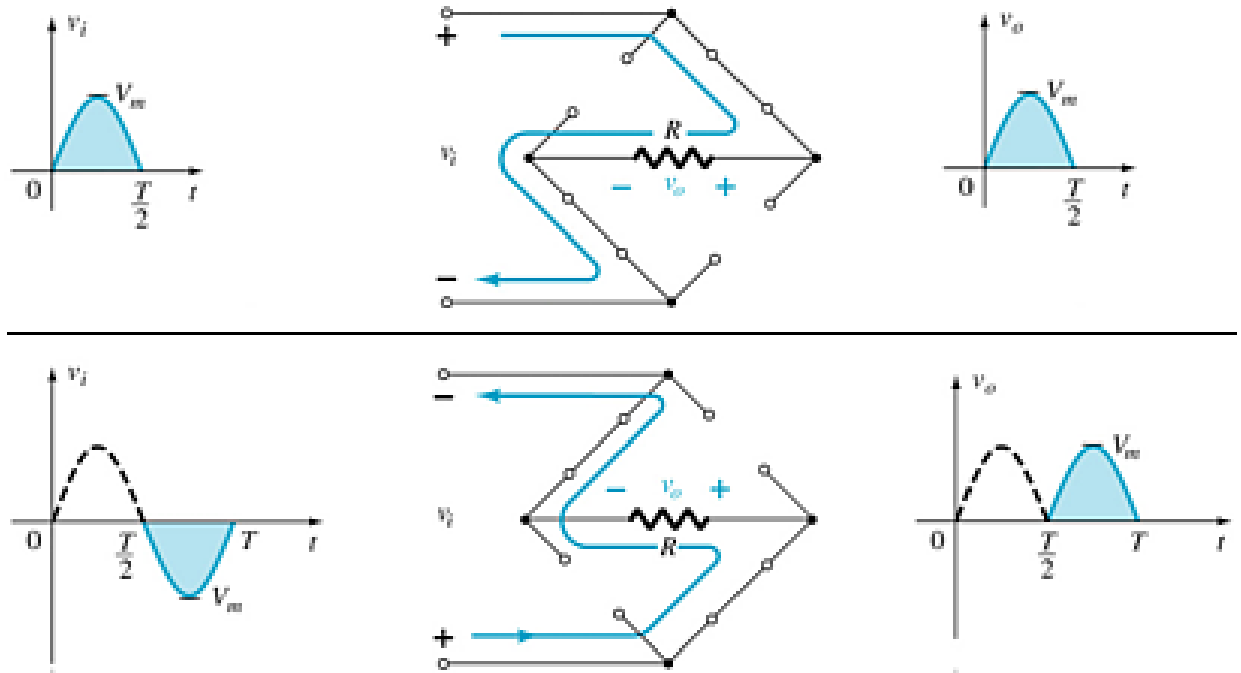


Full-Wave Rectifier



- The rectification process can be improved by using a full-wave rectifier circuit.
- Full-wave rectification produces a greater DC output:
  - Half-wave: $V_{dc} = 0.318V_m$
  - Full-wave: $V_{dc} = 0.636V_m$

Full-Wave Rectifier (Bridge Network)



- Four diodes are connected in a bridge configuration

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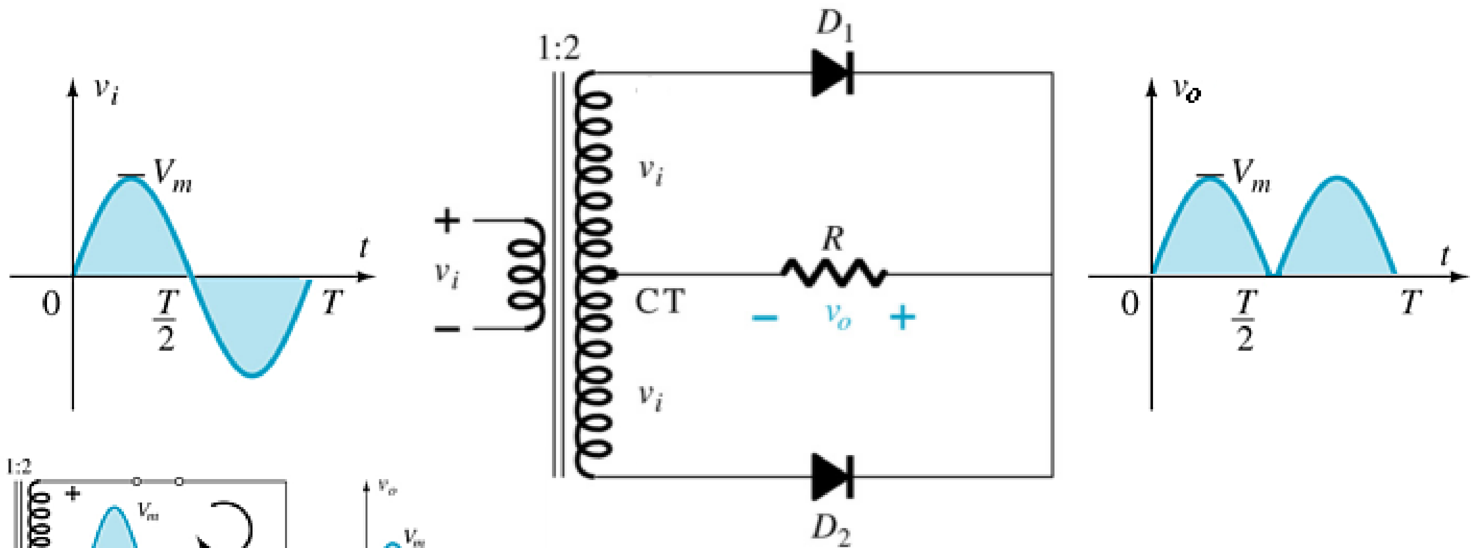
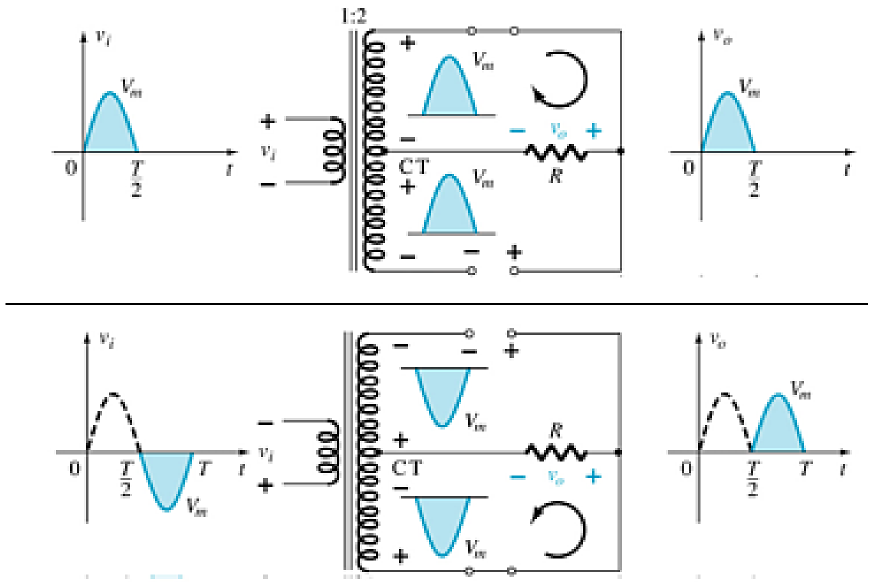
Full-Wave Rectifier (Center-Tapped Transformer)





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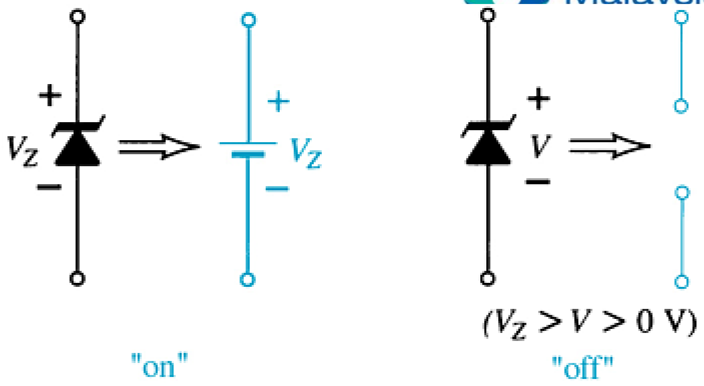
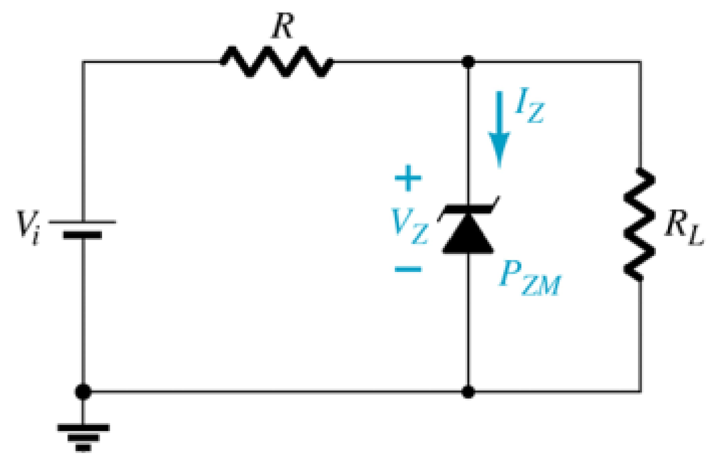
Summary of Rectifier Circuit

Rectifier	Ideal V_{DC}	Realistic V_{DC}
Half Wave Rectifier	$V_{DC} = 0.318V_m$	$V_{DC} = 0.318V_m - 0.7$
Bridge Rectifier	$V_{DC} = 0.636V_m$	$V_{DC} = 0.636V_m - 2(0.7\ V)$
Center-Tapped Transformer Rectifier	$V_{DC} = 0.636V_m$	$V_{DC} = 0.636V_m - 0.7\ V$

Zener Diode

- The Zener is a diode operated in reverse bias at the Zener Voltage V_z.
- When $V \geq V_Z$
  - The Zener is on
  - Voltage across the Zener is V_Z
  - Zener current: $I_Z = I_R - I_{RL}$
  - The Zener Power: $P_Z = V_Z I_Z$
- When $V < V_Z$
  - The Zener is off
  - The Zener acts as an open circuit

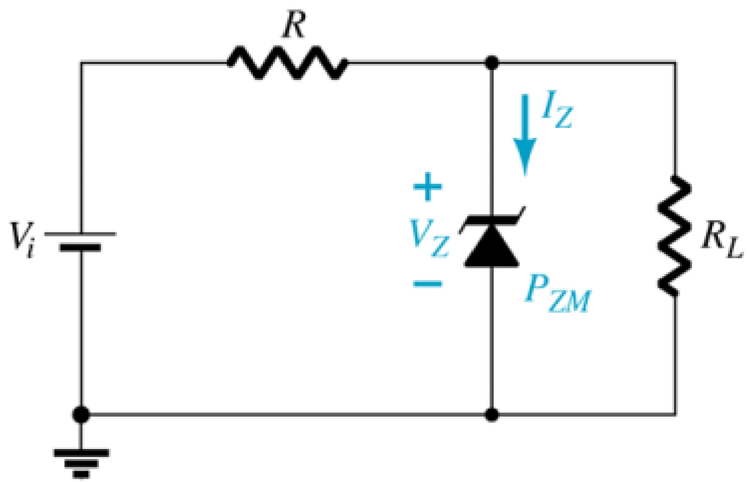




Zener Diode

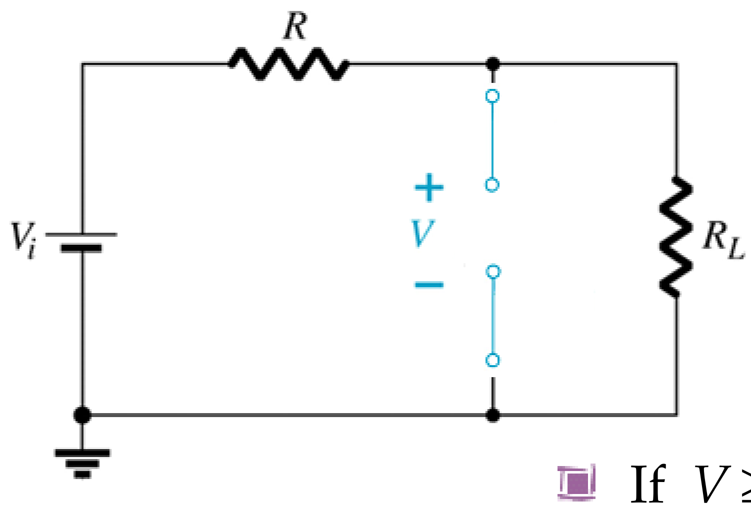
- To use of the Zener diode as a regulator we must considered 3 cases

i. V_i and R fixed



Step #1: Determine the state of Zener diode by removing it from the network and calculating the voltage across the resulting open circuit.

Zener Diode

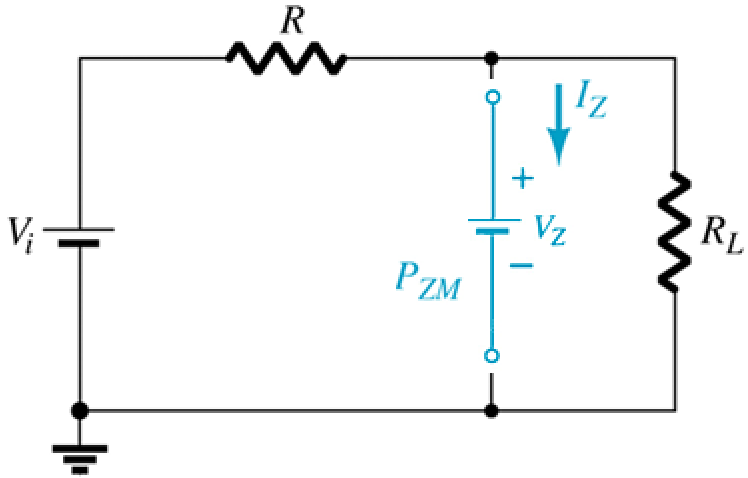


$$V = V_L = \frac{R_L V_i}{R + R_L}$$

- If $V \geq V_Z$ the Zener is on and appropriate model can be substituted.
- If $V < V_Z$ the Zener is off open circuit is substituted.

Step #2: Substitute the appropriate equivalent circuit and solve for the desired unknown

Zener Diode



$$V_L = V_Z$$

where

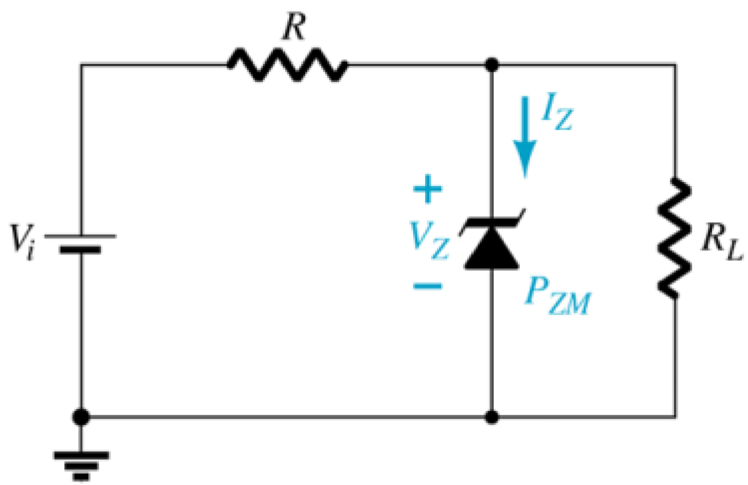
$$I_R = I_Z + I_L$$

$$I_R = \frac{V_R}{R} = \frac{V_i - V_L}{R}$$

$$I_L = \frac{V_L}{R_L}$$

$$P_Z = V_Z I_Z$$

ii. Fixed V_i and variable R_L



- Due to the offset voltage V_Z, there is a specific range of resistor values and load current that will ensure that Zener is in the on state.
- Too small a load resistance R_L will result in a voltage V_L across the load resistor less than V_Z, and the Zener device will be in the off state

$$V_L = V_Z = \frac{R_L V_i}{R + R_L}$$

Zener Diode

Solving for R_L

$$R_{L\min} = \frac{RV_Z}{V_i - V_Z}$$

- Any load resistance value greater than the R_L will ensure that the Zener diode is in the on state and the diode can be replaced by its V_Z source equivalent.
- For minimum R_L the Zener current exceeds the maximum current rating, I_{ZM} . The maximum current for the circuit is given by:

$$I_{L\max} = \frac{V_L}{R_L} = \frac{V_Z}{R_{L\min}}$$

Zener Diode

- Once the diode is in on state, the voltage across R remains fixed at

$$V_R = V_i - V_Z \quad \text{and} \quad I_R = \frac{V_R}{R}$$

Zener current $I_Z = I_R - I_L$

- I_Z is **minimum** when I_L is a **maximum**
- I_Z is **maximum** when I_L is a **minimum**

} Since I_R is constant

$$I_{L\min} = I_R - I_{Z\max}$$

$$R_{L\max} = \frac{V_Z}{I_{L\min}}$$

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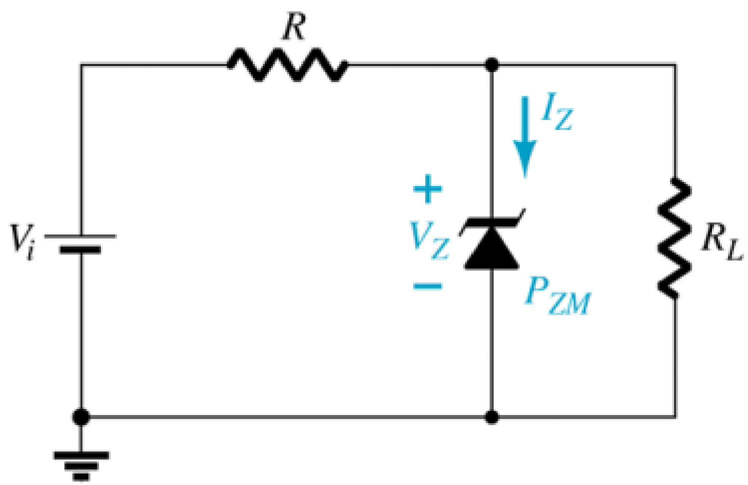
iii. Fixed R_L and variable V_i



- For a fixed value of R_L, the voltage V_i must be sufficiently large to turn the Zener diode on.

The minimum turn on voltage

$$V_{i\min} = \frac{(R + R_L)V_Z}{R_L}$$

Zener Diode

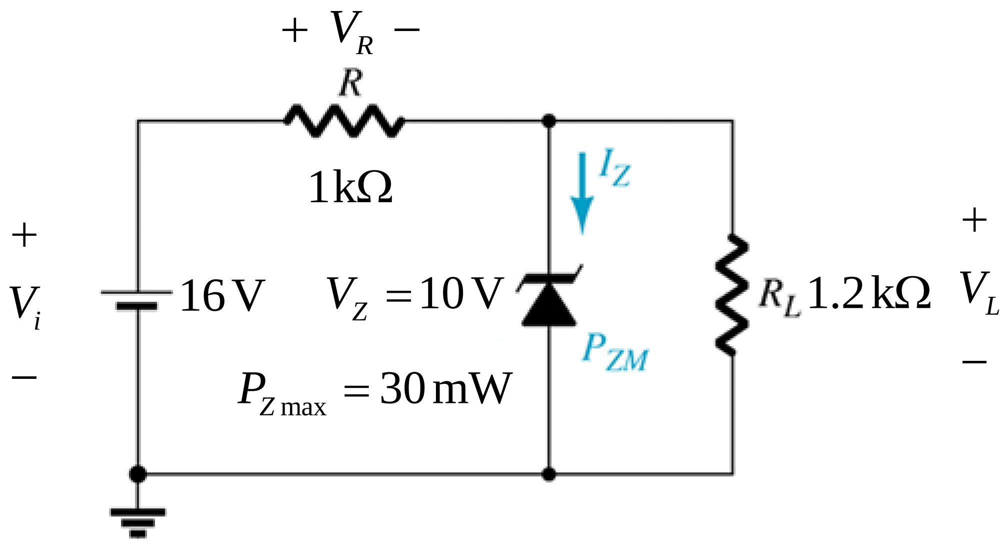
- The maximum value of V_i is limited by the maximum Zener current

$$I_{R\max} = I_{Z\max} + I_L$$

$$V_{i\max} = I_{R\max} R + V_Z$$

Example #1

For the Zener diode network of figure below, determine V_L, V_R, I_Z, and P_Z.



Solution

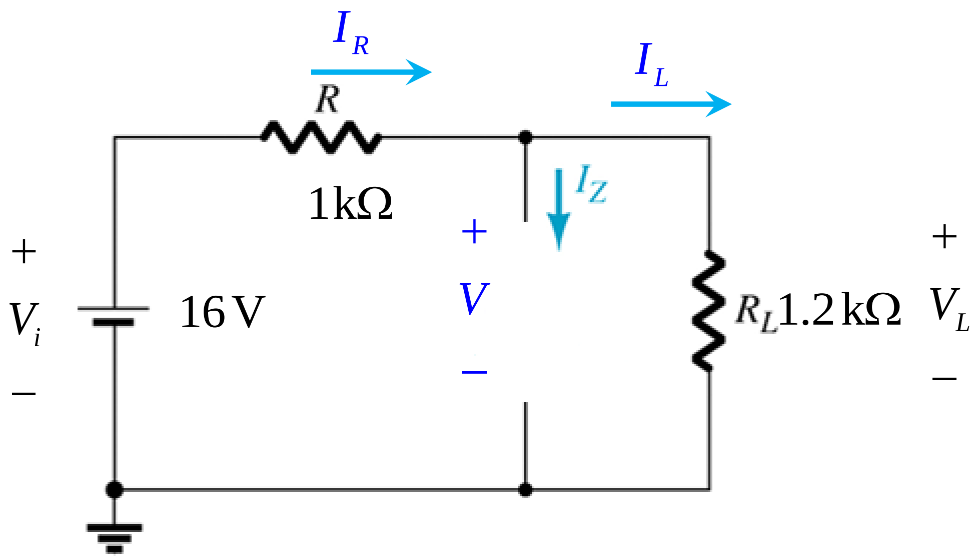
Since V_i and R is fixed, then

$$V = V_L = \frac{R_L V_i}{R + R_L}$$

$$V = \frac{1.2\text{k}(16)}{1\text{k} + 1.2\text{k}} = 8.73\,\text{V}$$

Example #1

Since $V < V_Z$ the Zener is off state and open circuit is substituted.



$$V_L = V$$

$$V_L = 8.73\,\text{V}$$

$$V_R = V_i - V_L$$

$$V_R = 16 - 8.73$$

$$V_R = 7.27\,\text{V}$$

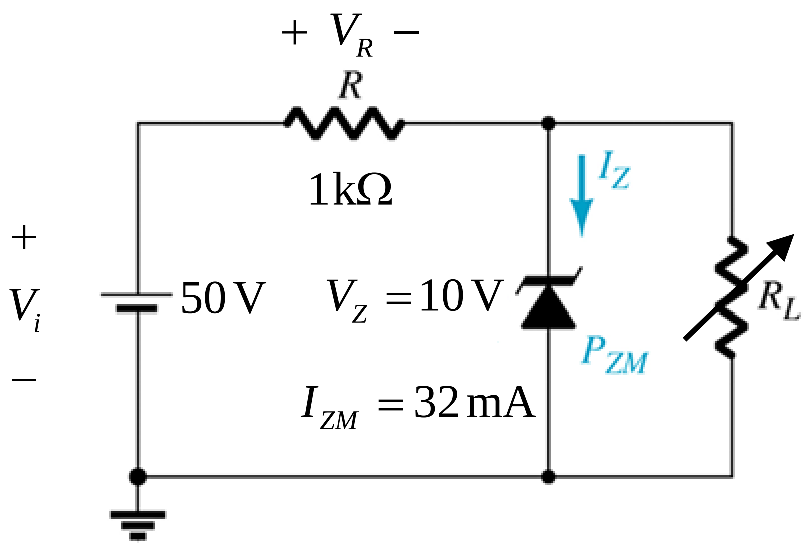
$$I_Z = 0\,\text{A}$$

$$P_Z = V_Z I_Z$$

$$P_Z = 0\,\text{W}$$

Example #2

For the network of figure below, determine the range R_L and I_L that will result in V_{RL} being maintained at 10 V. Then determine the maximum wattage rating of the diode



Example #2

Solution

Since V_i is fixed for the circuit shown and R_L is a variable

To turn on the Zener diode, we need a small load resistance, then

$$R_{L\min} = \frac{RV_Z}{V_i - V_Z}$$

$$R_{L\min} = 250\,\Omega$$

$$V_R = V_i - V_Z$$

$$V_R = 40\,\text{V}$$

$$I_R = \frac{V_R}{R}$$

$$I_R = 40\,\text{mA}$$

$$I_{L\min} = I_R - I_{Z\max}$$

$$I_{L\min} = 40\,\text{m} - 32\,\text{m}$$

$$I_{L\min} = 8\,\text{mA}$$

$$R_{L\max} = \frac{V_Z}{I_{L\min}}$$

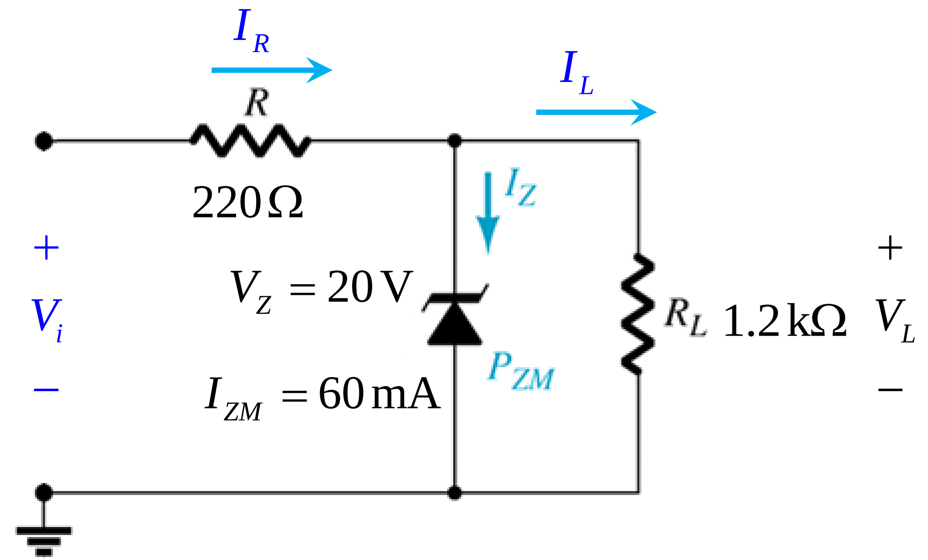
$$R_{L\max} = 1.25\,\text{k}\Omega$$

$$P_{\max} = V_Z I_{Z\max}$$

$$P_{\max} = 320\,\text{mW}$$

Example #3

Determine the range of values of V_i that will maintain the Zener diode of figure shown in the on state



Solution

Since V_i is a variable, then

$$V_{i\min} = \frac{(R + R_L)V_Z}{R_L} \qquad I_L = \frac{V_L}{R_L} = \frac{V_Z}{R_L}$$

$$V_{i\min} = 23.67\,V \qquad I_L = 16.67\,A$$

Example #3

$$I_{R\max} = I_{Z\max} + I_L$$

$$I_{R\max} = 76.67\,\text{mA}$$

$$V_{i\max} = I_{R\max} R + V_Z$$

$$V_{i\max} = 36.87\,\text{V}$$