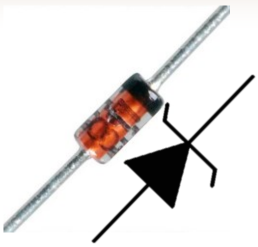
The Zener Diode



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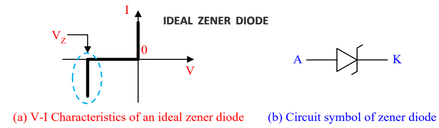
Ideal Zener Diode



Designed to operate in the reverse breakdown region.

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The Zener Diode

1) Some Zener diodes use Zener breakdown (< 5V)
2) Some Zener diodes use Avalanche breakdown (>5V)
3) Neither Zener nor avalanche breakdown are inherently destructive
4) The heat generated by the large current flowing can cause damage in both cases.

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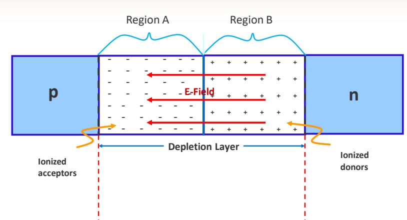

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Avalanche Breakdown

- Doping is small. Depletion region is wide.
- The minority charge carriers get accelerated in this depletion region and gain kinetic energy.
- They knock off, other electrons from the valence
- Avalanche effect caused by Impact Ionization process.
- Occurs at higher reverse bias voltages (>5V)
- More heat is generated.

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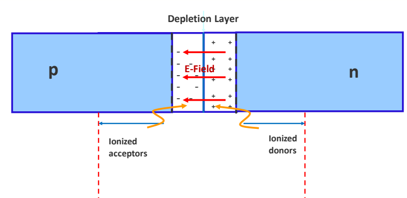

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Zener Breakdown

- Doping is High. Depletion region is very thin.
- Electric field very strong
- Narrow depletion region does not allow many charge carriers to get accelerated.
- No impact ionization. The Electric force pull off electrons from valance band and make them conduct. The effect is called quantum tunneling.
- Occurs at lower reverse bias voltages (<5V)
- Less heat is generated.

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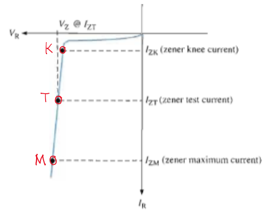
The Zener Diode



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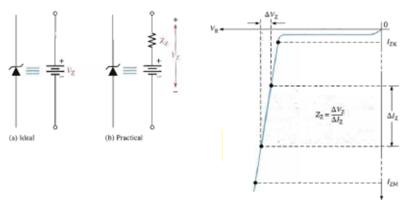
The Zener Diode



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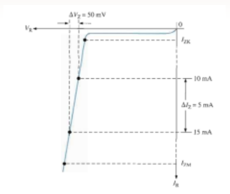
Eg. Zener Impedance



$$Z_Z = \frac{\Delta V_Z}{\Delta I_Z} = \frac{50 \text{ mV}}{5 \text{ mA}} = \mathbf{10\ \Omega}$$

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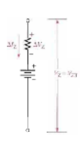
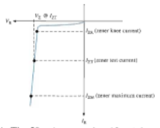
Eg.

A 1N4736 zener diode has a Z_{ZT} of 3.5 Ω. The data sheet gives $V_{ZT} = 6.8$ V at $I_{ZT} =$ 37 mA and $I_{ZK} = 1$ mA. What is the voltage across the zener terminals when the current is 50 mA?





For $I_Z = 50$ mA: The 50 mA current is a 13 mA increase above $I_{ZT} = 37$ mA.

$$\Delta I_Z = I_Z - I_{ZT} = +13 \text{ mA}$$
$$\Delta V_Z = \Delta I_Z Z_{ZT} = (13 \text{ mA})(3.5\ \Omega) = +45.5 \text{ mV}$$

$$V_Z = 6.8 \text{ V} + \Delta V_Z = 6.8 \text{ V} + 45.5 \text{ mV} = \mathbf{6.85\ V}$$

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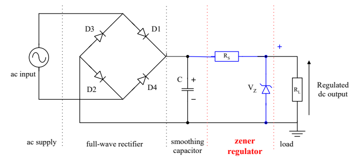
FWR with a smoothing circuit and a Zener Regulator



A simple zener voltage regulated dc power supply

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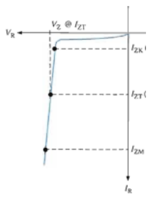
Voltage Regulation Using Zener Diode

In order to ensure the voltage regulation

$I_{ZK} < I_Z < I_{ZM}$

To make sure that the Zener diode enters to the reverse breakdown region

To make sure that the Zener diode is not destroyed



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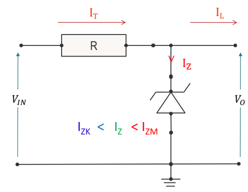
Simple Zener Regulator Circuit

I_L here is the current drawn by the load. Its another variable.

V_{in} here is the DC voltage coming out from the capacitor filter. Its one variable



Irrespective of the variation of V_{in} and I_L the output voltage V_o should be regulated to the Zener voltage V_Z

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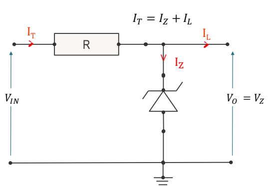
Case 1 : Variable source with a constant load



$I_Z = I_T - I_L$

$I_Z = \left(\frac{V_{IN}-V_Z}{R}\right) - I_L$

$I_{ZK} < I_Z < I_{ZM}$

$I_{ZK} < \left(\frac{V_{IN}-V_Z}{R}\right) - I_L < I_{ZM}$

$I_{ZK} + I_L < \left(\frac{V_{IN}-V_Z}{R}\right) < I_{ZM} + I_L$

$[(I_{ZK}+ I_L)R + V_Z] < V_{IN} < [(I_{ZM}+ I_L)R + V_Z]$

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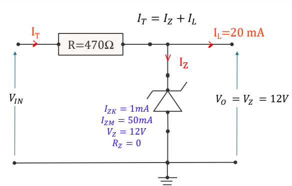
E.g. Variable source with a constant load



$I_Z = I_T - I_L$

$I_Z = \left(\frac{V_{IN}-V_Z}{R}\right) - I_L$

$I_{ZK} < I_Z < I_{ZM}$

$1\ mA < \left(\frac{V_{IN}-12}{0.47}\right) - 20\ mA < 50\ mA$

$21 < \left(\frac{V_{IN}-12}{0.47}\right) < 70$

$21\ x\ 0.47 + 12 < V_{IN} < 70\ x\ 0.47 + 12$

$21.9\ V < V_{IN} < 44.9\ V$

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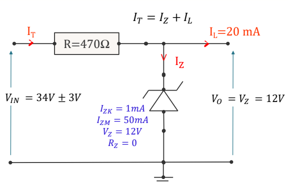
Ex. Variable source with a constant load



Find,

1. Minimum and maximum currents in the Zener diode
2. Minimum and maximum power dissipated in the Zener diode
3. The rated power dissipation that the R should have.

maximum power that R disipates

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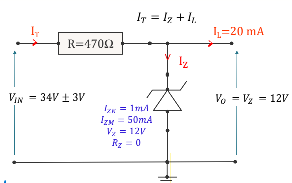
Solution : Variable source with a constant load



$I_Z = \left(\frac{V_{IN}-V_Z}{R}\right) - I_L$

$I_Z = \left(\frac{V_{IN}-12}{0.47}\right) - 20\ mA$

Solution:

1.) 20.4 to 33.2 mA

2.) 245.1 to 398.4 mA

3.) 1. 33W

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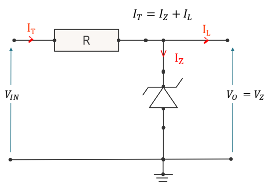
Case 2 : Constant source with a variable load



$$I_Z = I_T - I_L$$

$$I_Z = \left(\frac{V_{IN}-V_Z}{R}\right) - I_L$$

$$I_{ZK} < I_Z < I_{ZM}$$

$$I_{ZK} < \left(\frac{V_{IN}-V_Z}{R}\right) - I_L < I_{ZM}$$

$$-I_{ZK} > -\left(\frac{V_{IN}-V_Z}{R}\right) + I_L > -I_{ZM}$$

$$\left(\frac{V_{IN}-V_Z}{R}\right) - I_{ZK} > I_L > \left(\frac{V_{IN}-V_Z}{R}\right) - I_{ZM}$$

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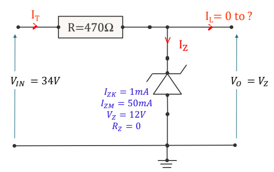
Eg : Constant source with a variable load

$$I_T = \left(\frac{34-12}{0.47}\right) = 46.8\ mA$$



$$I_{ZK} < I_Z < I_{ZM}$$

$$\left(\frac{V_{IN}-V_Z}{R}\right) - I_{ZK} > I_L > \left(\frac{V_{IN}-V_Z}{R}\right) - I_{ZM}$$

$$\left(\frac{34-12}{0.47}\right) - 1 > I_L > \left(\frac{34-12}{0.47}\right) - 50$$

$$46.8 - 1 > I_L > 46.8 - 50$$

$$45.8\ mA > I_L > 0$$

$$I_{Z,min} = 1\ mA \qquad R_{L,min} = \left(\frac{V_Z}{45.8}\right) = 262\Omega$$

$$I_{Z,max} = 46.8\ mA$$

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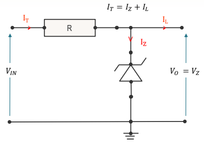
Case 3 : Variable source with a variable load



$$I_{ZK} < I_Z < I_{ZM}$$

$$I_{ZK} < \left(\frac{V_{IN}-V_Z}{R}\right) - I_L < I_{ZM}$$

$$I_{ZK} < \left(\frac{V_{IN}-V_Z}{R}\right) - I_L \qquad \left(\frac{V_{IN}-V_Z}{R}\right) - I_L < I_{ZM}$$

$$I_{ZK} < Min\left[\left(\frac{V_{IN}-V_Z}{R}\right) - I_L\right] \qquad Max\left[\left(\frac{V_{IN}-V_Z}{R}\right) - I_L\right] < I_{ZM}$$

$$I_{ZK} < \left[\left(\frac{V_{IN,MIN}-V_Z}{R}\right) - I_{L,MAX}\right] \qquad \left[\left(\frac{V_{IN,MAX}-V_Z}{R}\right) - I_{L,MIN}\right] < I_{ZM}$$

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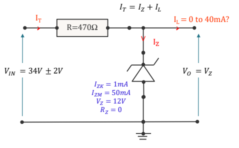
Case 3 : Variable source with a variable load



$$I_{ZK} < \left[\left(\frac{32-12}{0.47}\right) - 40\right] \qquad \left[\left(\frac{36-12}{0.47}\right) - 0\right] < I_{ZM}$$

$$I_{ZK} < 2.55\ mA \qquad 51.06 < I_{ZM}$$

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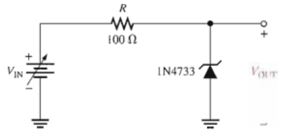
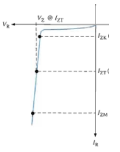
Considering Zener Impedance

Determine the minimum and the maximum input voltages that can be regulated





V_Z = 5.1 V at I_{ZT} = 49 mA, I_{ZK} = 1 mA, and Z_Z = 7 Ω at I_{ZT}. For simplicity, assume this value of Z_Z over the range of current values.

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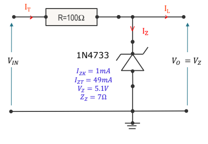
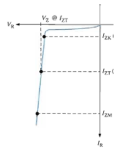
When Zener Impedance is to be considered…





Determine the range of input voltages that can be regulated.

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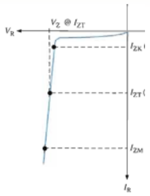
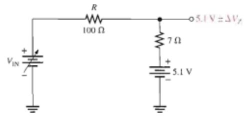
Equivalent cct…





At $I_{ZK} = 1$ mA, the output voltage is

$$V_{OUT} \cong 5.1\text{ V} - \Delta V_Z = 5.1\text{ V} - (I_{ZT} - I_{ZK})Z_Z$$
$$= 5.1\text{ V} - (48\text{ mA})(7\ \Omega) = 5.1\text{ V} - 0.336\text{ V} = 4.76\text{ V}$$

$$V_{IN(min)} = I_{ZK}R + V_{OUT} = (1\text{ mA})(100\ \Omega) + 4.76\text{ V} = \mathbf{4.86\text{ V}}$$

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Equivalent cct…

$$I_{ZM} = \frac{P_{D(max)}}{V_Z} = \frac{1\text{ W}}{5.1\text{ V}} = 196\text{ mA}$$

At I_{ZM}, the output voltage is

$$V_{OUT} \cong 5.1\text{ V} + \Delta V_Z = 5.1\text{ V} + (I_{ZM} - I_{ZT})Z_Z$$
$$= 5.1\text{ V} + (147\text{ mA})(7\ \Omega) = 5.1\text{ V} + 1.03\text{ V} = 6.13\text{ V}$$

Therefore,

$$V_{IN(max)} = I_{ZM}R + V_{OUT} = (196\text{ mA})(100\ \Omega) + 6.13\text{ V} = \mathbf{25.7\text{ V}}$$

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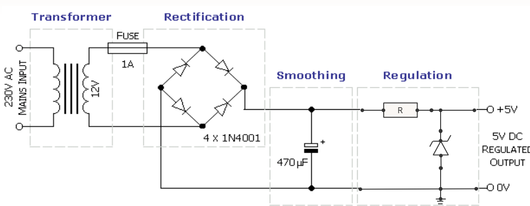
DC Power Supply



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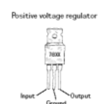
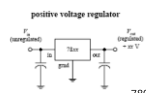
Voltage Regulator ICs

IC regulators are available in the market.

Regulator ICs





7805 → 5V regulator

7809 → 9V regulator

7812 → 12V regulator

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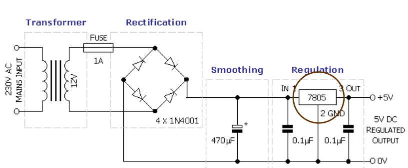
Regulated DC Power Supply with IC regulator



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