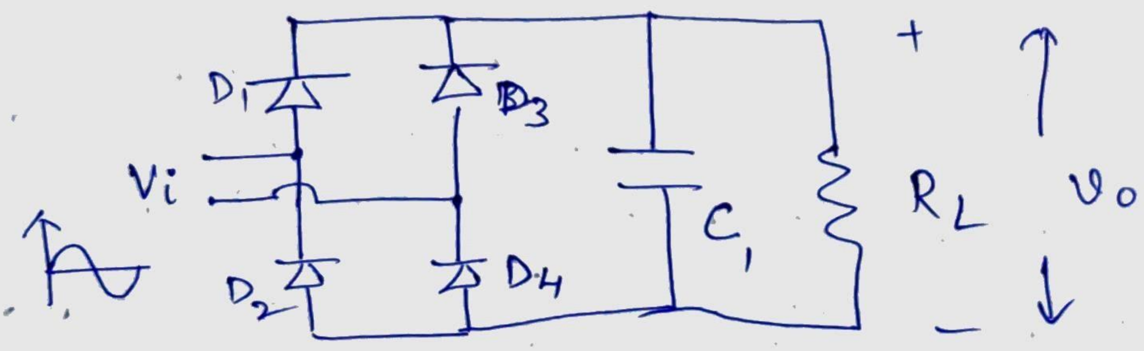
Full wave Rectifier with Capacitor Filter

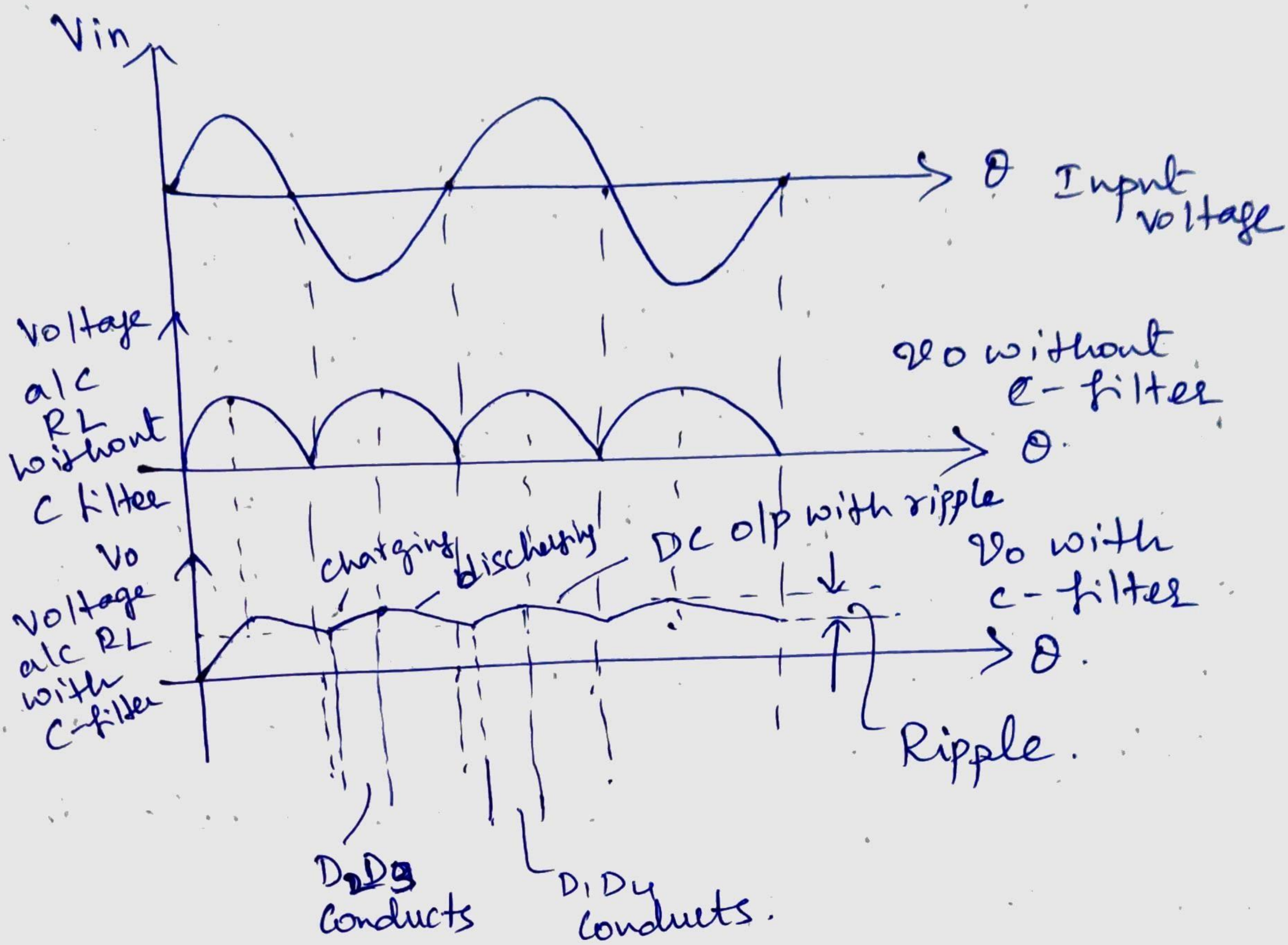
When a sinusoidal alternating voltage is rectified, the resulting output waveform is a series of positive half cycles of the input. It is unidirectional but not direct voltage. To convert to direct voltage (d.c. voltage), a smoothing circuit or filter must be employed.

The figure below shows a full wave rectifier circuit with a reservoir capacitor ~~and a surge limiting resistor~~. Known as filter capacitor. This capacitor reduces the ripple in the output voltage.



C_1 = filter capacitor.

The capacitor C_1 charges approximately to the ($\sqrt{2}V_{rms}$) of input voltage (peak value) during positive half cycle and holds the voltage at this value when diodes are in their non-conducting state as shown in the waveforms below.



The capacitor smoothens the rectifier output as shown in the waveform. and reduces the ripple. in the output wave form.

The capacitor charges to $\boxed{V_c = V_{pi} - V_F}$

When instantanous input voltage level falls below V_{pi}, the diodes becomes reverse-biased because the capacitor voltage (V_c) remains close to ($V_{pi} - V_F$) when diode is reverse biased, capacitor charging is stopped & it starts discharging through RL. as V_c falls as shown in waveform.

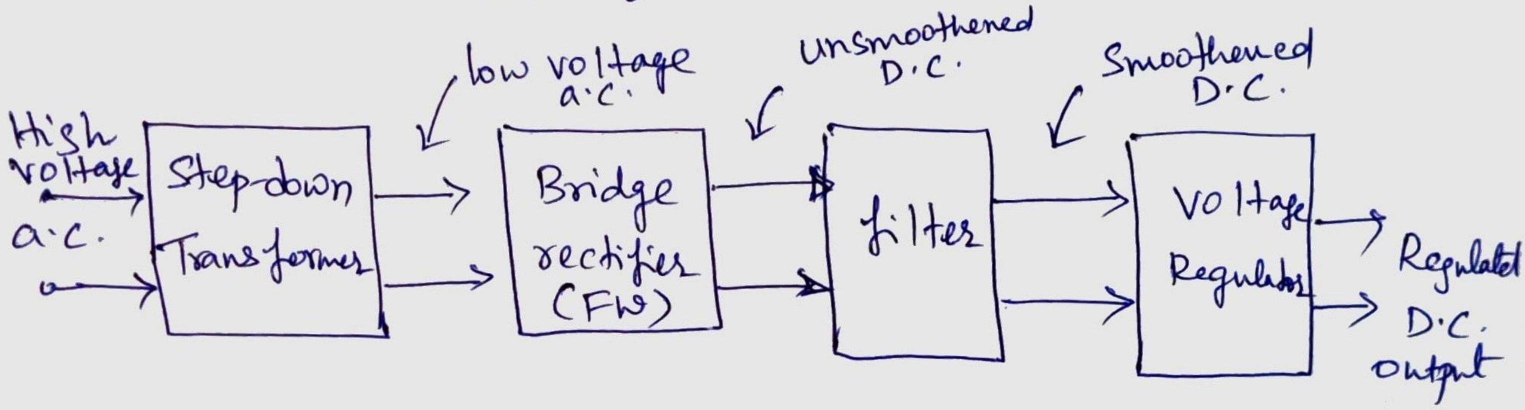
The capacitor starts to charge in the next half cycle when next set of diodes are forward biased.

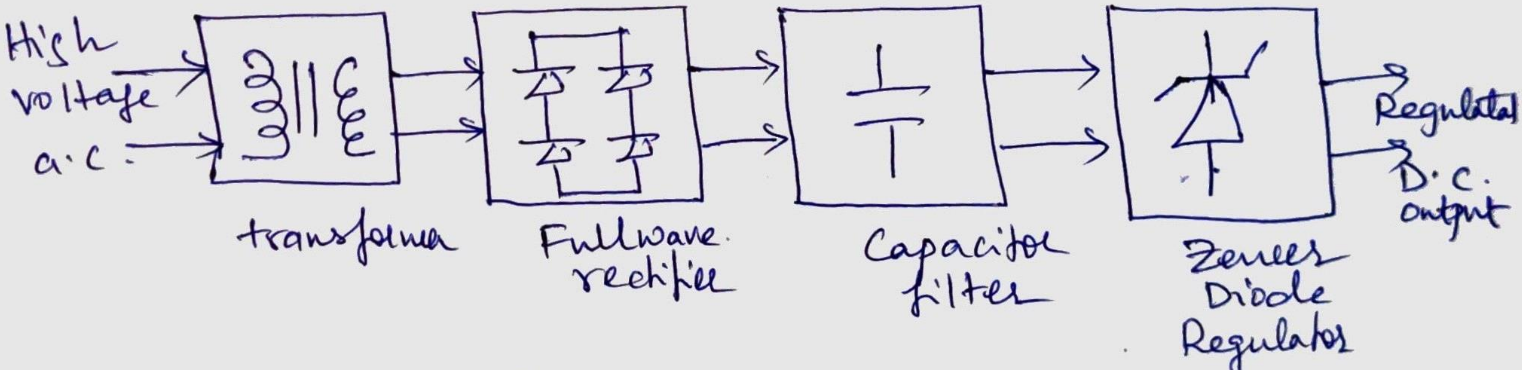
Full-Wave Rectifier Power Supply :

A. D.C. power supply. or a regulated power Supply provides constant output even if the input changes.

This power supply module converts unregulated AC into Regulated | Constant D.C.

The block diagram of a D.C. power supply is as shown below :





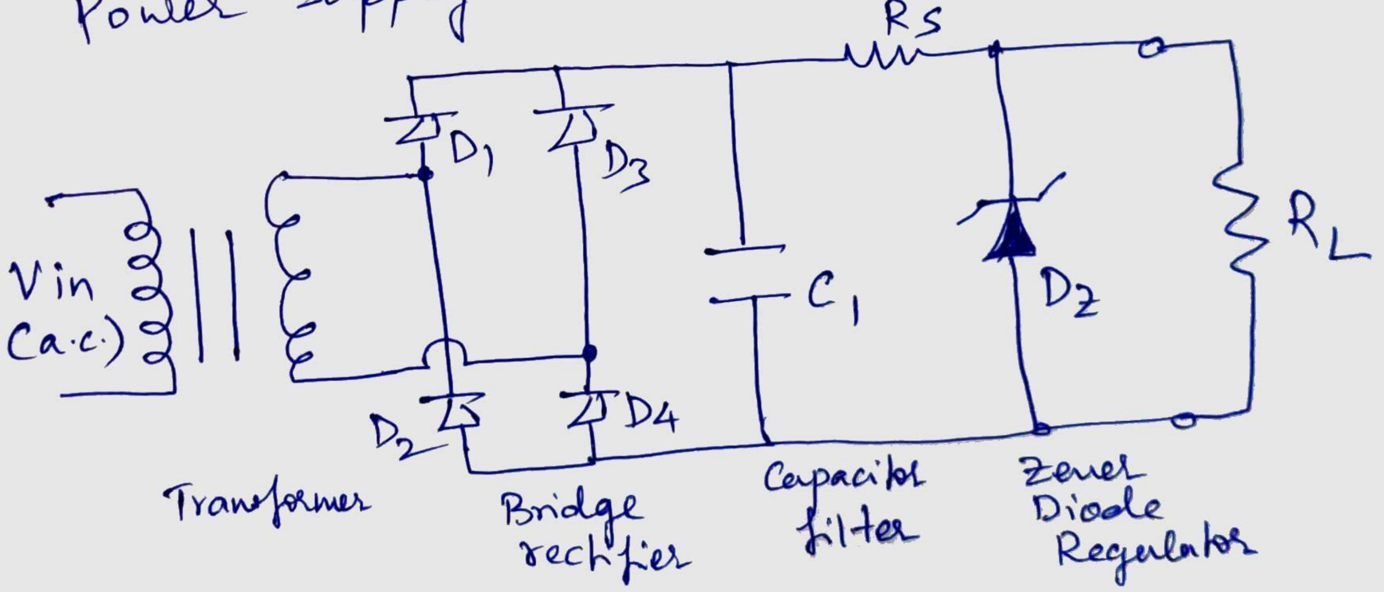
The step-down transformer reduces the magnitude of a.c. input voltage into required level using the formula

$$\frac{V_s}{V_p} = \frac{N_2}{N_1}$$

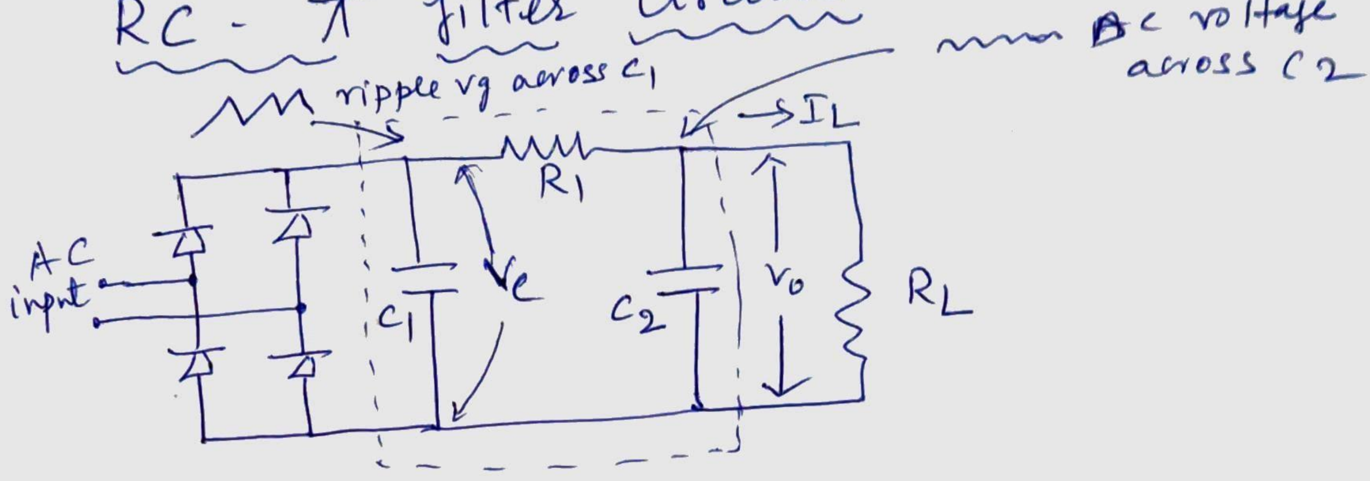
where V_s & V_p are secondary (output) and primary (input) side voltage of transformer and N_2 & N_1 are secondary and primary Side number of turns in the transformer.

The output of transformer is fed to the full wave bridge rectifier. It converts the a.c. voltage to D.C. voltage. A capacitor filter ~~xxx~~ is used to reduce the ripple and smoothen the DC waveform. The filter output then passes through a regulator, which is typically a Zener diode in reverse-bias condition that holds the output voltage at a constant value irrespective of any change in the input voltage.

The circuit diagram for a full wave rectifier Power supply is as shown in the diagram.



RC - π filter Circuit



The ripple voltage which appears across the capacitor in a rectifier power supply can be attenuated by the use of additional resistor and capacitor which together function as voltage divider.

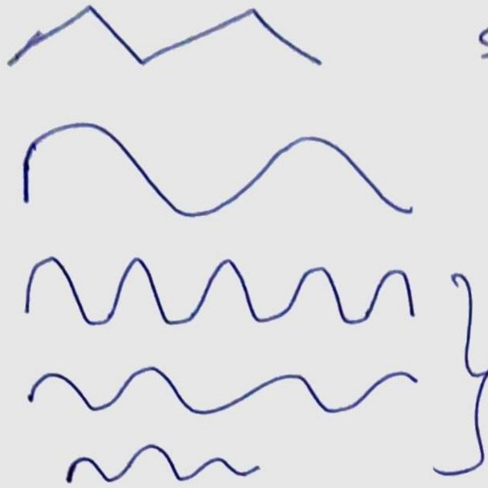
As seen in the diagram, C_1 is the main capacitor, R_1 & C_2 are the additional components. The combination of $C_1 R_1 C_2$ is known as RC-π filter due to their arrangement.

Assuming constant output, the main capacitor C_1 charges and discharges periodically regardless of other components connected to the load. Here, we have a sawtooth wave form across C_1. The additional component R_1 and C_2 helps in reducing the voltage and in turn the amount of ripple that was present across C_1

$$V_o = \frac{V_i \cdot X_{C2}}{(R_1^2 + X_{C2}^2)} \quad ; \quad X_{C2} = \frac{R_1}{\sqrt{\left(\frac{V_i}{V_o}\right)^2 - 1}}$$

$$\simeq \frac{R_1}{V_i/V_o}$$

The peak value of fundamental component of Sawtooth waveform is $V_p = \frac{V_r}{\pi}$;



Saw tooth waveform at filter input.

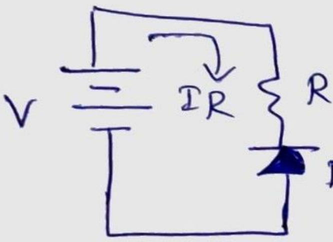
Fundamental freq. component

Higher freqency smaller magnitude components.

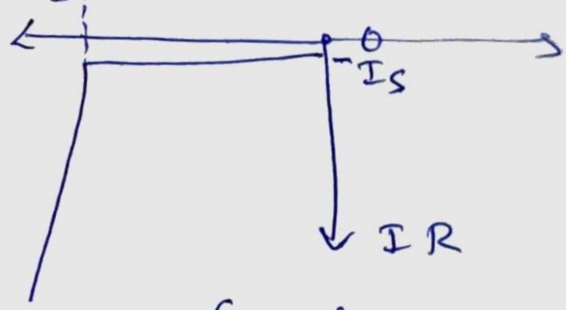
Zener Diodes

Introduction:

When a normal diode or junction diode is reverse biased, there may be small reverse current which may flow through the diode (I_s)



(Diode reverse Current)
(Normal Diode)



(Diode reverse characteristics)

When the reverse voltage is sufficiently large, then junction breaks down and there will be large amount of reverse current. this current will lead to breakdown of normal diode.

There may be few applications, where, the diode has to operate in reverse breakdown or reverse biased condition. such as voltage reference source...

In such cases, a special diode known as zener diode can be used.

A zener diode is created by heavily doped P & N type semiconductors.

The symbolic representation of zener diode is

- In the forward bias, zener behaves like ordinary diode.
- In reverse bias, there is practically no current flow until the breakdown voltage is reached. When breakdown occurs, the zener diode starts conducting and operates in breakdown region.

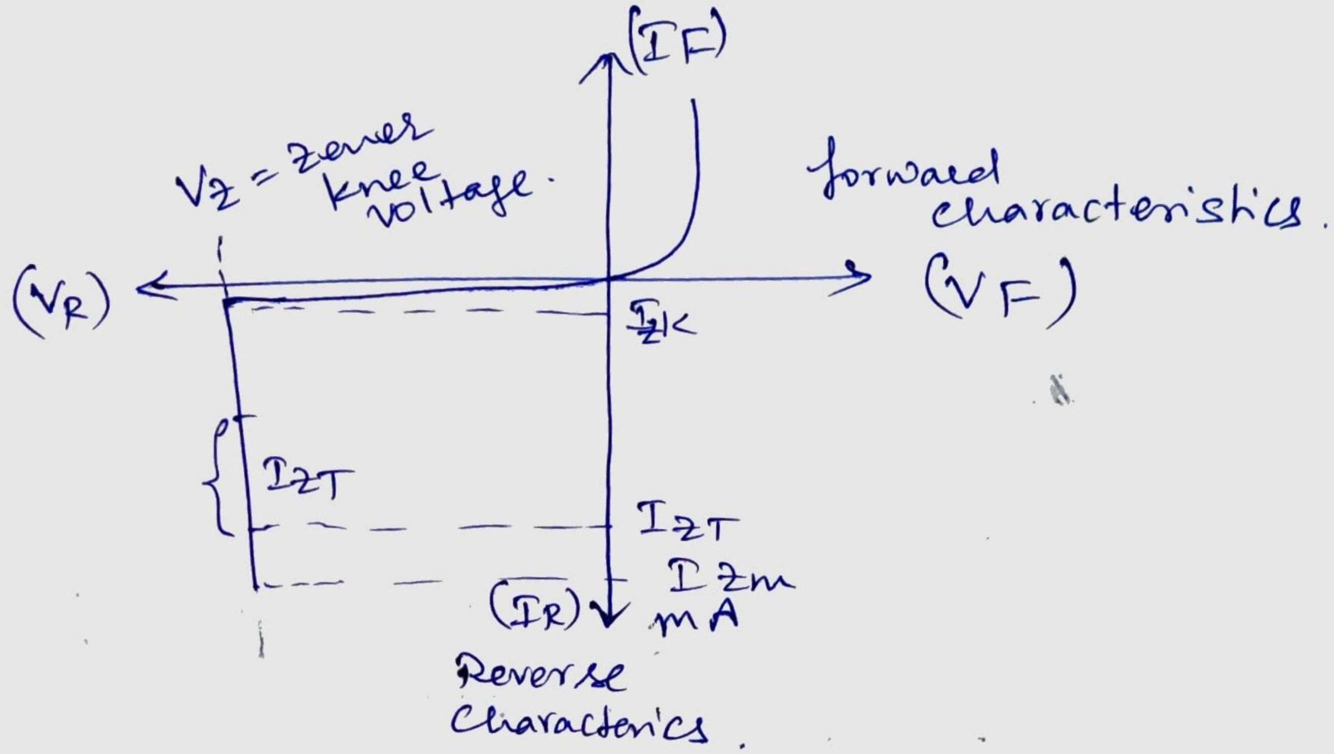
At this stage the voltage across zener diode will remain constant at 'V_Z' and current is controlled by an external resistance.

The zener diodes are available with a wide range of breakdown voltages

$V_Z = 1.4\,V$ to $200\,V$.

A zener diode when operated in the breakdown region provides a constant voltage across the terminals of the zener diode and hence can be used as voltage regulator.

The I–V characteristics of a Zener diode is as shown below:



The forward characteristics is just like any other normal diode.

The important features of reverse characteristics are

V_Z → Zener breakdown voltage (Zener-knee voltage)

I_{ZT} → Test current for measuring V_Z

I_{ZK} → Reverse Current near knee of the characteristic, It is minimum reverse current to sustain breakdown

I_{ZM} → Maximum Zener current, limited by maximum power dissipation.

Z_Z → Dynamic impedance

$$Z_Z = \frac{\Delta V_Z}{\Delta I_Z}$$

Z_Z defines how V_Z changes with variation in diode reverse current.

The zener diode may be operated at any reverse current level between I_{ZK} and I_{ZM}

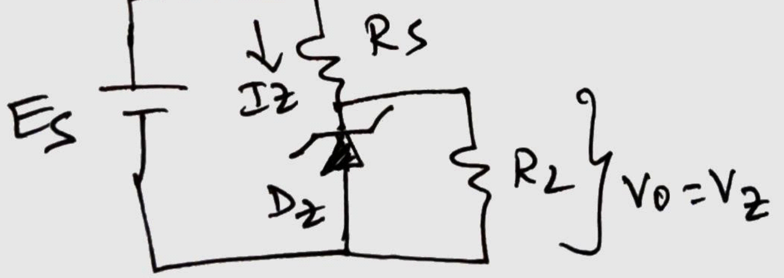
For greater voltage stability, the diode is normally operated at test current (I_{ZT})

Many low power zener diodes have a test current specified as 20mA; however some devices have lower test currents.

Zener Diode Voltage Regulator

The most important application of zener diode is in d.c. voltage regulator / D.C. power supply

The most common circuit for voltage regulator or reference voltage circuit is as shown below:



E_S = Unregulated d.c. input

V_O = Regulated d.c. output

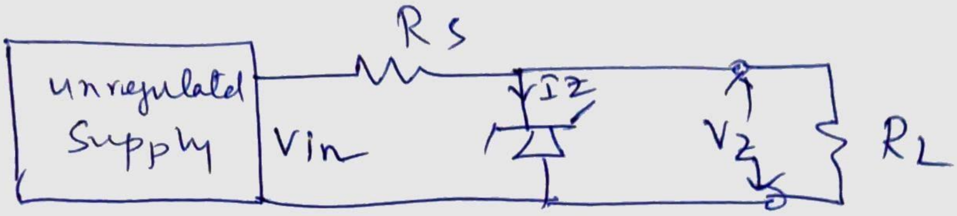
R_S = Surge limiting Resistor

R_L = load resistor

$$I_Z = \frac{E_S - V_Z}{R_S}$$

The zener current may be just greater than diode knee current I_{ZK}.

Numericals : Formula for Zener Diodes



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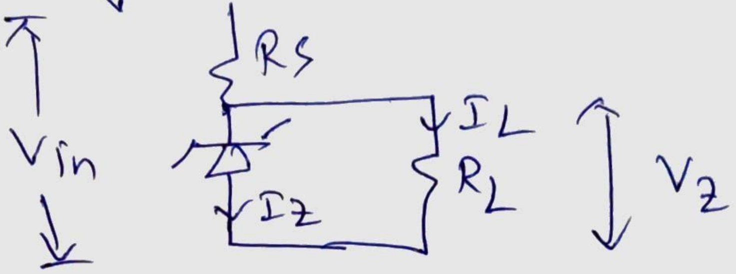


$$V_Z = V_{in} \cdot \frac{R_L}{R_L + R_S}.$$

$$R_L + R_S = \frac{V_{in}}{V_Z} \cdot R_L$$

$$R_S = \frac{V_{in}}{V_Z} R_L - R_L$$

$$R_S = R_L \left(\frac{V_{in}}{V_Z} - 1 \right)$$

$$\boxed{R_{S\,max} = R_L \left(\frac{V_{in}}{V_Z} - 1 \right)}$$

The power dissipated in zener is given by $P_Z = V_Z I_Z$.

$$R_{S(min)} = \frac{(V_{in} - V_Z)}{I_Z}$$

$$= \frac{V_{in} - V_Z}{\left(\frac{P_{max}}{V_Z} \right)}$$

$$R_{S\,min} = \frac{(V_{in} - V_Z) V_Z}{P_{Z\,max}}$$

① Calculate the max. current that may flow through a zener diode at tempr of 50°C & 100°C. The zener diode is IN755 for which $V_Z = 7.5V$ & $P_D = 400mW$ at 50°C and derating factor = 3.2 mW/°C

Soln. $I_{Z\,max} = \dfrac{P_D}{V_Z} = \dfrac{400\times10^{-3}}{7.5} = \underline{53.3\,mA}$

$$P_{D_{100}} = P_{D_{50}} - (100-50)\times 3.2\times10^{-3}$$

$$P_{D_{100}} = P_{D_{50}} - 50\times 3.2\times10^{-3}$$

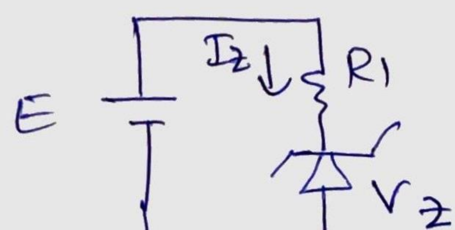
Solving $P_{D_{100}} = \underline{240\,mW}$

$$I_{Z\,max_{100}} = \frac{P_D/100}{V_Z}$$

$$I_{Z\,max_{100}} = \frac{240\,mW}{V_Z}$$

$$I_{Z\,max_{100}} = \frac{240\,mW}{7.5} = \underline{32}$$

② For the given zener diode, $V_Z = 7.5V$ $R_1 = 620\Omega$ and $E = 20V$. Calculate diode current & power dissipation



$$P_D = V_Z \times I_Z$$
$$= \cancel{20 \times 7.5}$$
$$= 20 \times 10^{-3} \times 7.5$$
$$= \underline{15\ mW}$$

$$I_Z = \frac{E_S - V_Z}{R_1}$$
$$= \frac{20 - 7.5}{620}$$
$$= \underline{20\ mA.}$$

(3) A Zener diode with $V_Z = 4.3V$, $Z_{\cancel{x}} = 22$ $I_Z = 20mA$. Calculate the upper limits & lower limits of V_Z when I_x is changed by $\pm 5\ mA$.

Soln

$$Z_{\cancel{x}} = \frac{\Delta V_Z}{\Delta I_{\cancel{x}}}$$

$$\Delta V_{\cancel{z}} = Z_{\cancel{z}} \cdot \Delta I_Z$$
$$= 22 \times 25$$
$$= \underline{\pm 110\ mA}$$

$$\Delta V_{Z max} = V_Z + \Delta V_Z$$
$$= 4.3 + 110 \times 10^{-3}$$
$$= \underline{4.41V}$$

$$\Delta V_{min} = V_Z - \Delta V_Z$$
$$= 4.3 - 110 \times 10^{-3}$$
$$= \underline{4.19\ V}$$

(4) A 9V reference source is to use a series connected zener diode and resistor connected to a 30V supply. Select suitable components and calculate circuit current when supply voltage drops to 27V.
Given that $V_Z = 9.1V$ & $I_{ZT} = 20mA$.

Soln:

with $E_S = 30V$;

$$R_1 = \frac{E_S - V_Z}{I_Z} = \frac{30 - 9.1}{20\times10^{-3}}$$

$$= \underline{\underline{1.05\,k\Omega}} \approx 1\,k\Omega$$

$$P_D = I_1^2 R_1 = (20\times10^{-3})^2 \times 1.0\times10^3$$

$$\simeq \underline{\underline{0.4\,W}}$$

with $E_S = 27V$

$$I_Z = \frac{E_S - V_Z}{R_1} = \frac{27 - 9.1}{1\times10^3}$$

$$= \underline{\underline{17.9\,mA}}$$

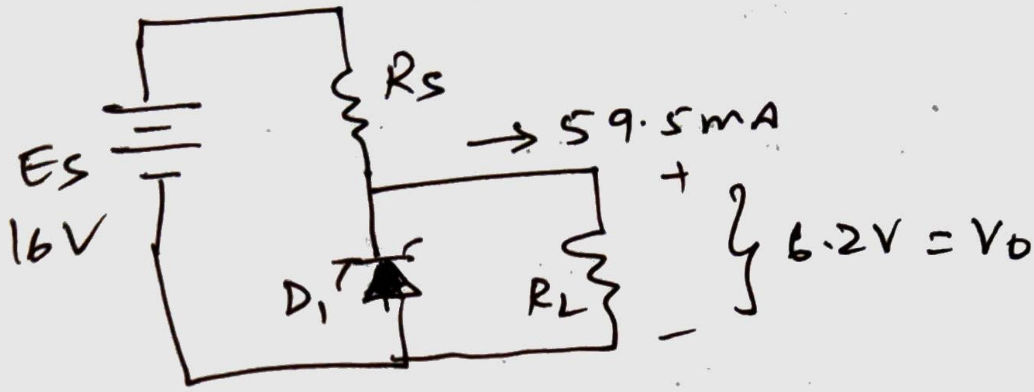
(5) Design a 6V dc reference source to operate from a 16V supply using low-power zener diode and is to produce the maximum possible load current. Calculate maximum load current that can be taken from the circuit.

Given : $V_Z = 6.2V$ & $P_D = 400\,mW$.

Soln

$$I_{ZM} = \frac{P_D}{V_Z} = \frac{400 \times 10^{-3}}{6.2} = \underline{\underline{64.5\,mA}}$$

$$I_{Lmax} + I_{Zmin} = I_{Zm} = 64.5\,mA$$



$$R_1 = R_S = \frac{E_S - V_Z}{I_{Zm}} = \frac{16 - 6.2}{64.5 \times 10^{-3}}$$

$$= \underline{\underline{152\,\Omega}} \simeq \underline{\underline{150\,\Omega}}$$

$$P_{R1} = I_1^2 R_1 = (64.5 \times 10^{-3})^2 \times 150$$

$$= \underline{\underline{0.62\,W}}$$

Selecting $\underline{I_{Zmin} = 5\,mA}$

$$I_{Lmax} = I_{ZM} - I_{Zmin} = 64.5 - 5m$$

$$= \underline{\underline{59.5\,mA}}$$

(6) A 5V zener diode has a max. rated power dissipation of 500 mW. If the diode is to be used in a simple regulator to supply a output of 5V to a load having 400Ω, determine a suitable value of series resistor for operation in series with supply.

Soln Given :

$V_z = 5V$

$V_{in} = 9V$

$R_L = 400\Omega$

$P_{zmax} = 500mW = 0.5W$

WKT $R_{smax} = R_L\left(\frac{V_{in}}{V_z} - 1\right)$

$= 400\left(\frac{9}{5} - 1\right)$

$R_{smax} = \underline{320\Omega}$

$R_{smin} = \frac{V_{in}V_z - V_z^2}{P_{zmax}}$

$= \frac{9 \times 5 - 5^2}{0.5}$

$= \underline{40\Omega}.$

∴ The suitable value for Rs should be the average of min & max values

$R_s = \frac{R_{smax} + R_{smin}}{2}$

$= \frac{440 + 40}{2}$

$R_s \simeq \underline{\underline{150\Omega}}$