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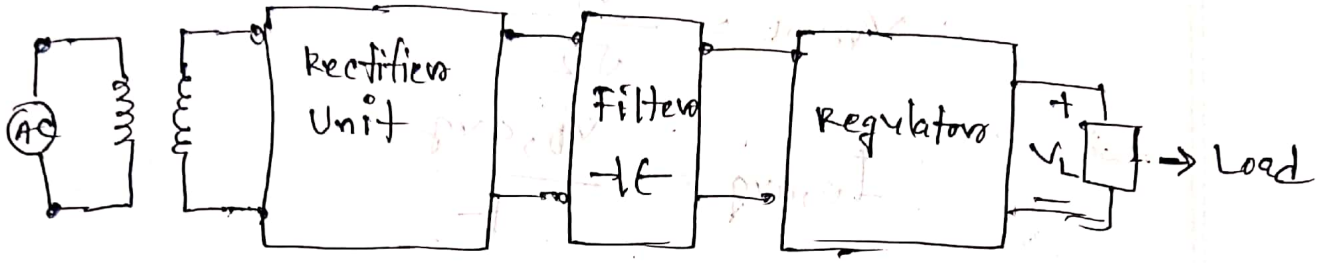
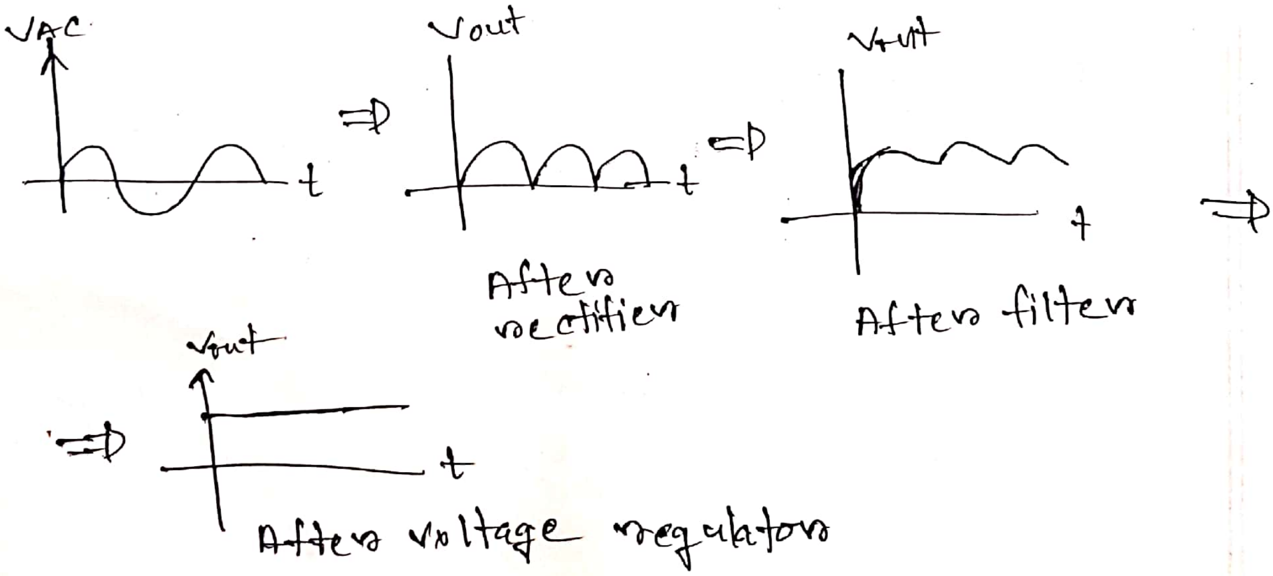
Voltage regulation:



why do we need a regulator?

↳ To make ripple kind of voltage to straight dc voltage output.

Therefore,
1) After filter - Ripples are reduced by regulator.
2) we might want different voltage levels.



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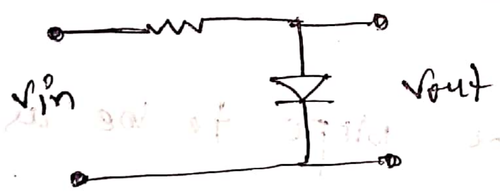
Example of regulator:

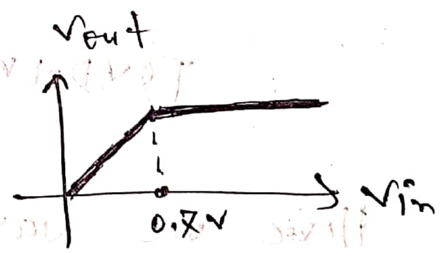
A clipper circuit:

→ A circuit that cuts of the signal at a certain level.

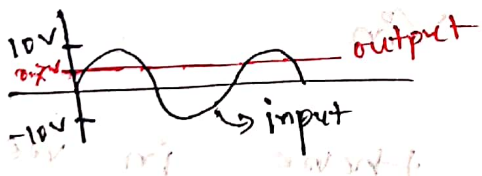
That is whatever the input signal is going to be, the output is just going to be a singe ~~valed~~ valued line.

Or we can say it clips anything above or below a certain level.





if V_{D_0} of diode = 0.7 V [CVD model]



That is it clips the output at 0.7 V

This clipper is also called hard limiter.

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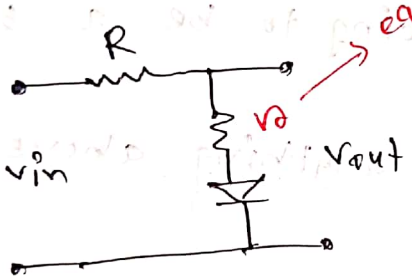
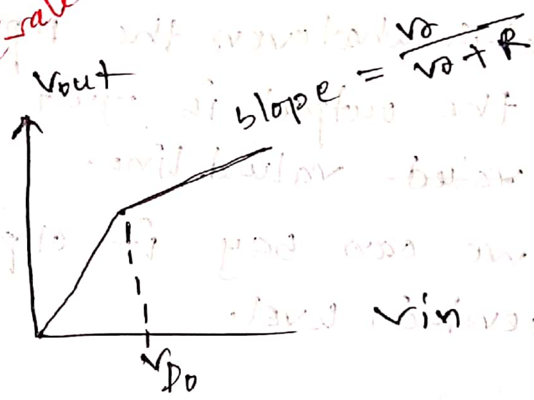
But in real world things are not ideal.

In real world we donot get hard limiter, we get soft limiter.

Soft limiter:





[CVD+r_D] model

Here we want the slope to be as small as possible.

$$V_{out} = V_{D0} + \frac{r_D}{R + r_D} V_{in}$$

So soft limiters are there in real world with CVD+r_D model.

These hard and soft limiters are kind of voltage regulator. because through these we can regulate the output voltage.

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Comparing voltage Regulators:

There are 2 ways:

1. Line Regulation
2. Load Regulation.

Say we want to have a comparison between two regulators — How to do it?

The regulator that doesnot change the output much is a good regulator.

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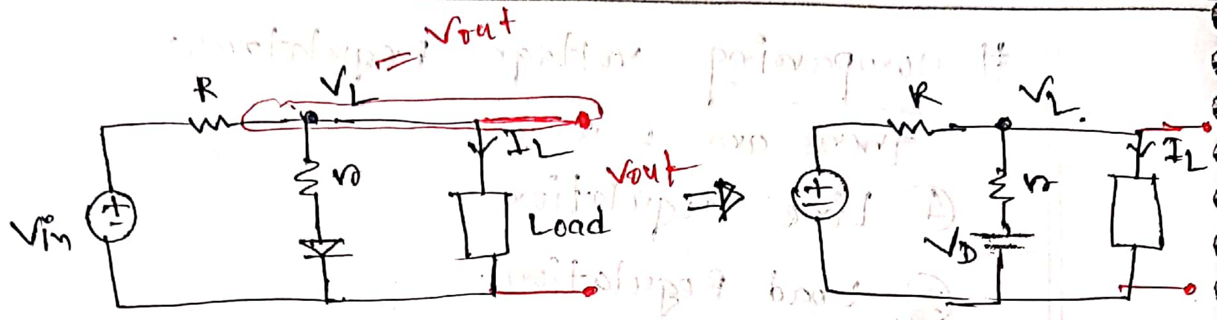

Nodal analysis at V_L :

$$\boxed{\frac{V_L - V_i}{R} + \frac{V_L - V_D}{r_D} + I_L = 0}$$

Line regulation actually works with the change in line that means if there is any change in line voltage/ supply voltage, then how does the output voltage act, does it remain same or does it change with respect to input voltage.

Load regulation we will see for adding ~~to~~ the load, how this load current affect the output voltage.

$$\Rightarrow (V_L - V_i) r_D + (V_L - V_D) R = -I_L R r_D$$

A-A [Here $V_L = V_{out}$]

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$$\boxed{V_L = \left(\frac{r_z}{R+r_z}\right)V_i - \left(\frac{Rr_z}{R+r_z}\right)I_L - \left(\frac{R}{(R+r_z)}\right)V_D}$$

From this equation,

(i) Line Regulation	(ii) Load regulation
Change in output voltage with respect to input voltage	change in output voltage with respect to Load current.
$\boxed{\frac{\Delta V_L}{\Delta V_i} = \frac{r_z}{R_i + r_z}}$	$\boxed{\frac{\Delta V_L}{\Delta I_L} = \frac{-Rr_z}{R+r_z}}$
	Here the '—' means if changes in load current increases, then change in output voltages decreases, and vice versa.
unit: $\frac{mV}{V}$	unit: $\frac{mV}{mA}$

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Now the question :
which Regulator is better in terms of values of Regulation?

⇒ The one that has the lower value means it does not change the value of output too much.

? 5mV/V

4mV/V ⟹ better than 5mV/V

Interpretation: 5mV/V ?
if our output is previously ~~5 volt~~ at 6 volt.
Now if the input is changed by 1 volt,
then the output will be 6 Volt + 5mV

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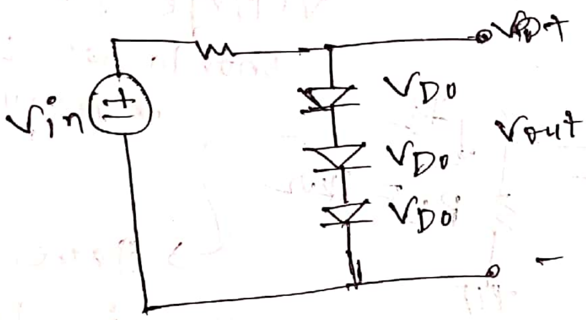
How can we get different kind of value at output rather than 0.7V. Lets we want 2.1V at output.

↳ We can do this by connecting 3 diodes in series. [$V_{D0} = 0.7V$, CVD model]



Hard limiter

But CVD + R model is used for practical purpose.

drawback of regulator using diodes.

So as we saw before as a soft limiter, its regulation depends on the resistance of diode, and 3 diodes provide equivalent resistance of $3r_d$ which increases the slope $\boxed{\frac{3r_d}{3r_d + R}}$.

Hence give poor regulation.

Therefore we need to have alternative so that this increasing resistance donot create problems.

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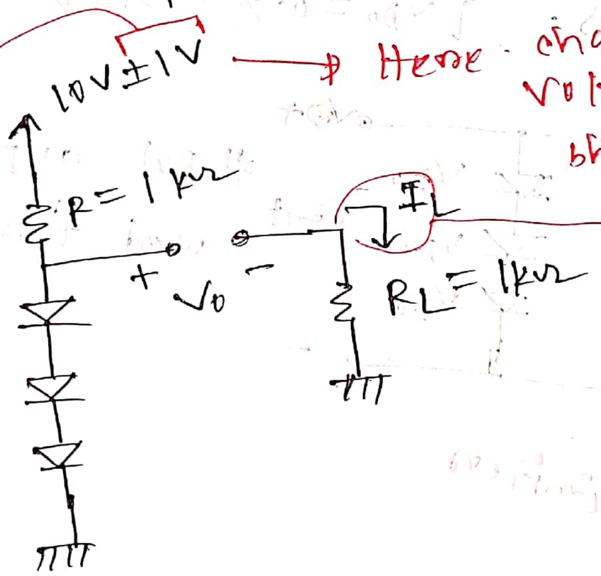
The alternative is $\boxed{\text{zener diode}}$

Example

[Line ; Load regulation using diode]



→ Here change in input voltage that is it should be line regulation.

→ Here change in IL, that is Load regulation.

\# A string of 3 diode is used to provide constant voltage drop of 2.1V. rd = 3.2Ω

calculate ΔVo

(a) a ±10% change in power supply voltage.

(b) a connecting load of 1kΩ load resistor.

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$a - 10\%$ of a

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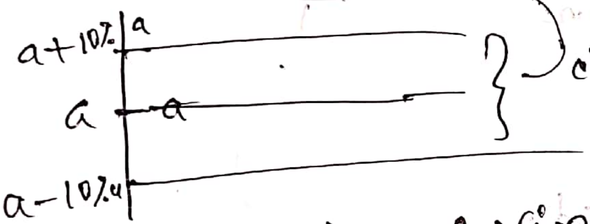
a) $a \pm 10\%$; $a = 10V$

$$(a + 0.1 * a) - (a - 0.1 * a) = 0.2a$$

so, $\Delta V_{in} = 0.2 * 10 V$

$= 2V$ (peak to peak)

or $\pm 1V$.



changes

or simply $\Delta V_{in} = 1 - (-1) = 2V$

Now 3 diodes in series so $r = 3 r_d = 9.6 \Omega$

so from line regulation we know,

$$\frac{\Delta V_o}{\Delta V_{in}} = \frac{r}{R + r}$$

Here.
$\Delta V_{in} = 2V$
$r = 9.6 \Omega$
$R = 1 k\Omega$

$\therefore \Delta V_o = 19 mV$ (Ans)

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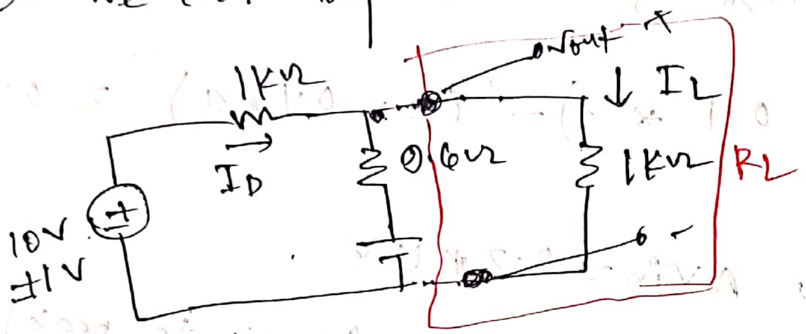
(b) We can represent the above circuit like.



Before the load was connected.

$$I_D = \frac{10 - V_{out}}{1K\Omega} = \frac{10 - 2.1}{1} = 7.9\ mA$$

Now After adding Load,

$$I_L = \frac{2.1V}{1K\Omega} = 2.1\ mA.$$

$\therefore \Delta I_L = 2.1\ mA - 0 = 2.1\ mA$

[(cause previously load was not connected so $I_L = 0$) so change is 2.1 mA]

Now from Load regulation;

$$\frac{\Delta V_o}{\Delta I_L} = \frac{-R r_d}{R + r_d}$$

$R = 1K\Omega$
$r_d = 0.6\Omega$
$\Delta I_L = 2.1\ mA$

$\therefore \Delta V_o = ~~20mA~~ -20mV$

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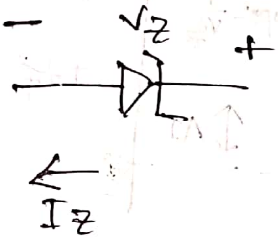
Zener diode

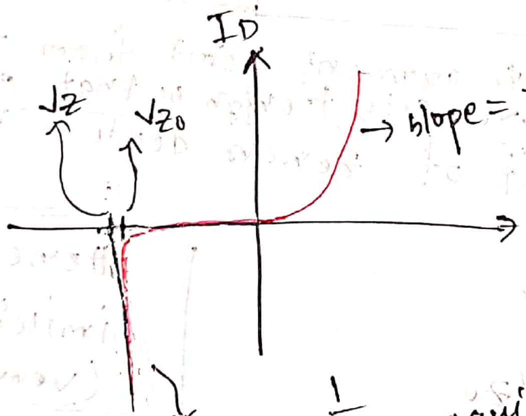
i) we can use it in reverse region

ii) we use it in its breakdown region ~~(reverse region)~~



For voltage regulator we use it in its **breakdown** region

that is why $V_Z = V_C - V_A$



$\rightarrow$ slope $= \frac{1}{r_d} \rightarrow$ equivalent resistor of zener diode in F.B. (Forward Bias)

slope $= \frac{1}{r_Z} \rightarrow$ equivalent resistor of zener diode in ~~[illegible]~~ breakdown region.

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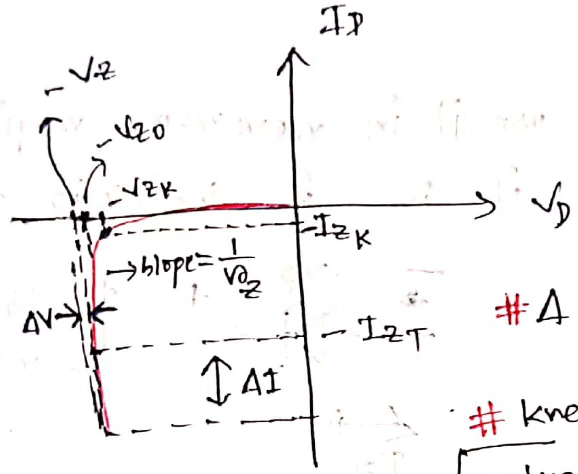
~~Reverse bias~~ ~~in~~ Breakdown region :



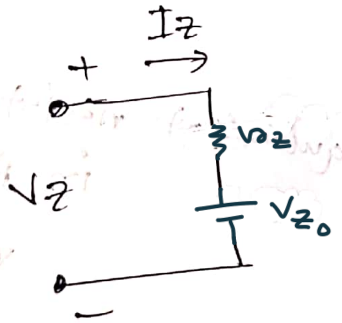
$\Delta V = r_Z \Delta I$

knee current = I_{ZK}

knee voltage = V_{ZK}

→ The voltage or current point from that the curve get almost parallel to Y axis, slope of curve gets too high so that zener diode.

equivalent circuit of zener diode



Here V_{Z0} is almost similar to V_{ZK} (very close) almost same

$$V_Z = V_{Z0} + r_Z I_Z$$

$I_Z > I_{ZK}$; $V_Z > V_{Z0}$

condition ~~when there~~ the zener diode works in breakdown region.

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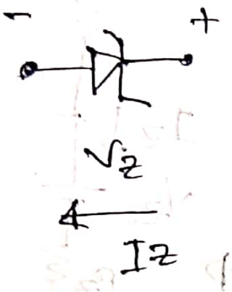
Different working region of zener diode:

P.O.B.

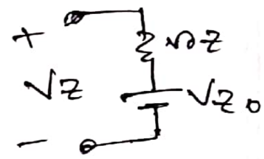


$I_z < I_{zk}$ and $I_z > 0$ ⇒ open circuit

Reverse Bias / OFF

$I_z \geq I_{zk}$ ⇒

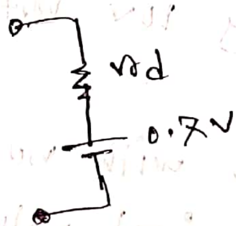
Breakdown region



$I_z < 0$

Forward Bias (ON)

(like normal diode)



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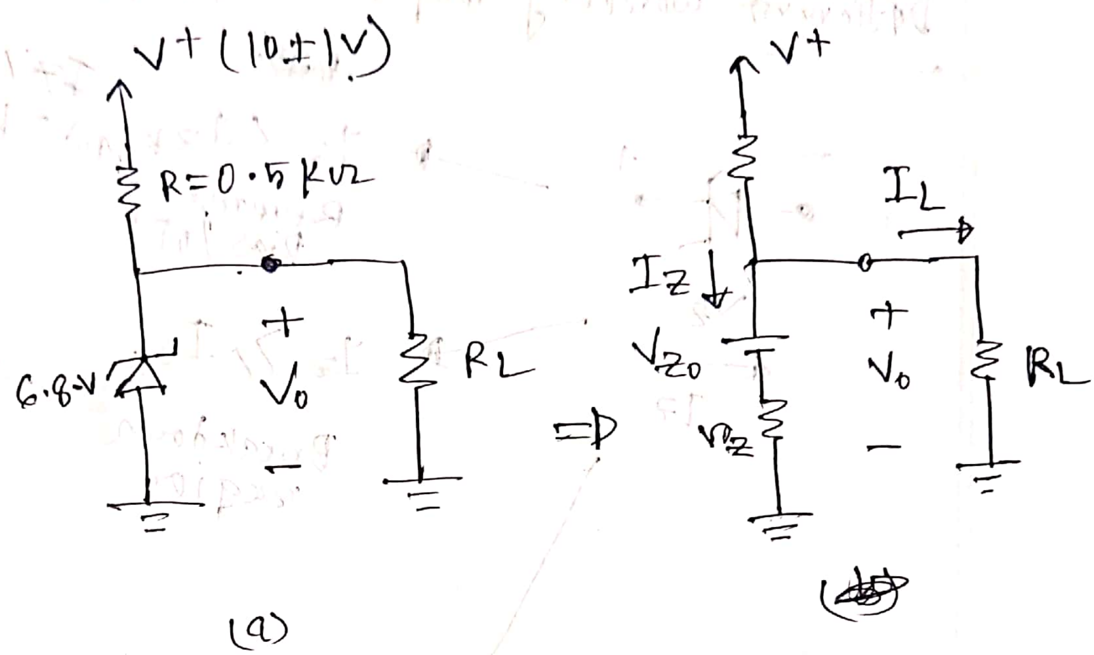
Ex 1 :



The 6.8-V zener diode in the circuit of (a) is specified to have $V_Z = 6.8\,V$ at $I_Z = 5\,mA$, $r_Z = 20\Omega$ and $I_{ZK} = 0.2\,mA$. The supply voltage $V+$ is nominally 10V but can vary by ±1V.

a) Find V_o with no load ~~width~~ and with $V+$ at its nominal value.

b) Find the change in V_o resulting from the ±1V change in $V+$. Note that $(\Delta V_o / \Delta V+)$, usually expressed in mV/V, is known as line regulation.

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(c) Find the change in V_o resulting from connecting a load resistance R_L that draws a current ~~$I_L = 1m$~~ $I_L = 1mA$, and ~~here~~ hence find the load regulation $(\Delta V_o / \Delta I_L)$ in mV/mA.

(d) Find the change in V_o where $R_L = 2\,k\Omega$

(e) Find the value of V_o when $R_L = 0.5\,k\Omega$

(f) what is the minimum value of R_L for which the diode still operates in the breakdown region?

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Solution :

Here, Given,

$V_Z = 6.8\,V$

$I_Z = 5\,mA$

$r_Z = 20\,\Omega$

$I_{ZK} = 0.2\,mA$

Now, can vary $\pm 1V$ $\therefore \Delta V_{in} = 1 - (-1) = 1+1 = 2V$

Again since $I_Z > I_{ZK}$

$\therefore V_Z = V_{Z0} + I_Z r_Z$

$\Rightarrow 6.8V = V_{Z0} + 5 \times \frac{20}{1000}$

$\Rightarrow V_{Z0} = 6.7\,V$

(a) V+ nominal value : 10V

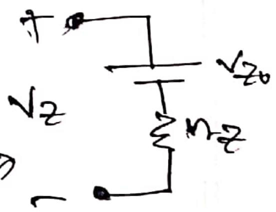
$$I_Z = \frac{10 - 6.7}{500 + 20} = 6.35\,mA$$

$V_o = V_{Z0} + I_Z r_Z$

$= 6.7 + 6.35 \times 0.02$

$= 6.83\,V$

[$V_Z = V_o = 6.83V$ also]



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(b) $\pm 1V$ change, $\Delta V_{in} = \pm 1V = 2V$

$$\Delta V_0 = \Delta V_{in} * \frac{r_Z}{R + r_Z}$$

$$= 2 * \frac{20}{20+500}$$

$$= 77 \, mV$$

From line regulation.

$$\frac{\Delta V_0}{\Delta V_{in}} = \frac{r_Z}{R + r_Z}$$

Line regulation $= \frac{\Delta V_0}{\Delta V_{in}} = \frac{77mV}{2V}$

$= 38.5 \, mV/V$

(c) $\Delta I_L = 1 - 0 = 1 \, mA$

So, I_Z will be decreased by 1mA.

$$\Delta V_0 = \frac{-R r_Z}{R + r_Z} \Delta I_L$$

$$= - \frac{500 * 20}{500 + 20} * 1mA$$

$$= -19.2 \, mV$$

From load regulation.

$$\frac{\Delta V_0}{\Delta I_L} = \frac{-R r_Z}{R + r_Z}$$

$\therefore$ Load regulation; $-19.2 \, mV/mA$

$\frac{\Delta V_0}{\Delta I_L}$

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(d) $R_L = 2k\Omega \rightarrow \frac{V_o}{R_L}$

$I_L = \frac{6.83}{2k\Omega} = 3.42 mA$

$\Delta I_L = 3.42mA - 0 = 3.42mA$

$\Delta V_o = \frac{-500 * 20}{500+20} * 3.42 mA$

$= 65.7 mV$

(e) ~~ID~~ $R_L = 0.5k\Omega$

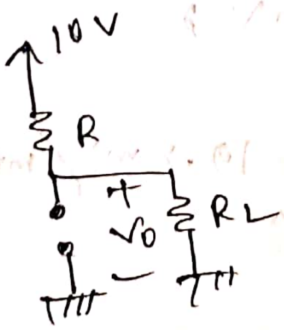
$I_L = \frac{6.83}{0.5k} = 13.6 mA$

But initially $I_i = 6.35 mA$ without load.

So this is not possible.

Means the zener diode is in cut-off.

∴



$\therefore V_o = \frac{R_L}{R+R_L} * 10$

$= 5V$ (Ans)

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(f) Worst case : $V_{in} = 9V$

cause $V_{in} = 10 \pm 1V$

And for zener diode to operate at breakdown region, $I_Z > I_{ZK}$

$I_{ZK} = 0.2 mA$ | V_Z ~~is~~ $6.7V$ cause $V_{Z0} = 6.7V$

So lowest current through R is,

$$\frac{9-6.7}{500} = 4.6 \text{ mA} = I_i$$

So, $I_i = I_Z + I_L$

$\Rightarrow I_L = I_i - I_Z = 4.4 mA$

$\therefore R_L = \frac{V_L}{I_L} = \frac{6.7}{4.4} = 1.5k\Omega$

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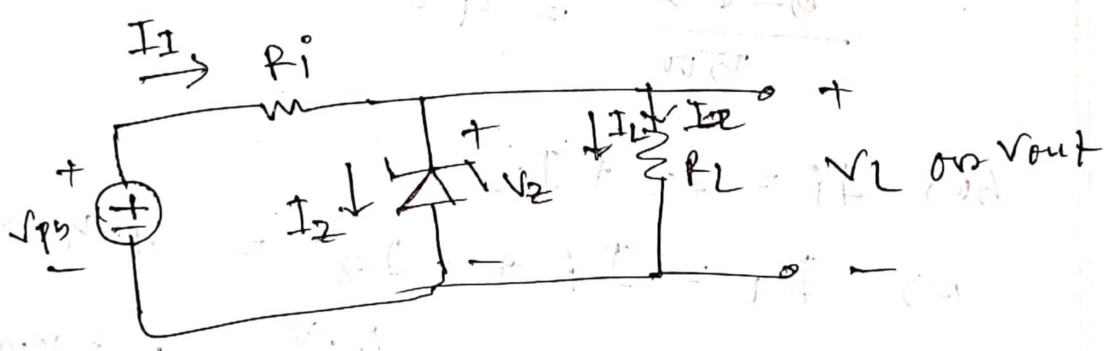
Selection of the correct value of R or Ri for zener diode :

It is necessary because depending upon this the current through the zener diode will change.

For maintaining $I_Z \geq I_{ZK}$ so that the zener diode operate in breakdown region.



KCL :

$$I_I = I_L + I_Z$$

$$\therefore R_i = \frac{V_{PS} - V_Z}{I_I} = \frac{V_{PS} - V_Z}{I_Z - I_L}$$

again $$I_Z = \frac{V_{PS} - V_Z}{R_i} - I_L$$

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$I_L = \frac{V_Z}{R_L}$, so V_{PS} and I_L are variables.

Here if R_i is too small I_Z will be ~~therefo~~ too high on that case power dissipation will be too high that we dont want as in this case it works on breakdown region.

Again if R_i is ~~to~~ too high then I_Z will be too low. that on that case the I_Z cant be $\cancel{>}I_Z$. So in this case the diode wont operate in breakdown region.

Therefore, we need a limit.

so that for the proper operation of the circuit, the diode must remain at breakdown region, and power dissipation in the diode, should not be exceed its ~~valued~~ rated value.

So To choose R_i

i) $I_Z(min) \Rightarrow V_i(min),\ I_L(max)$

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

ii) $I_Z(max) \Rightarrow V_i(max),\ I_L(min)$

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

iii) equating these two :

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

Rule of thumb, $I_Z(min) = 0.1\ I_Z(max)$

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