10.10.2023

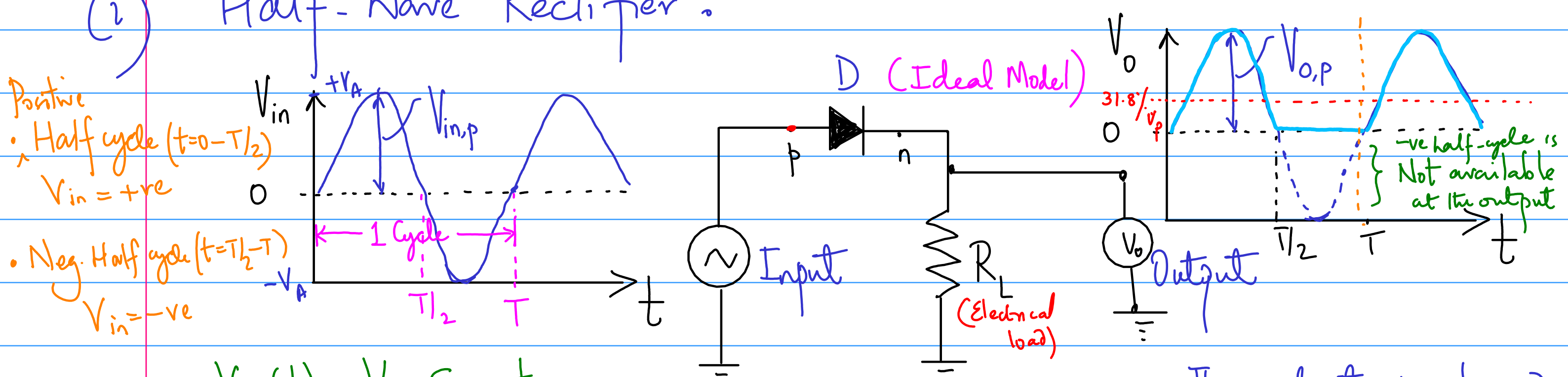
p-n Diode : Applications

Since p-n diodes are unidirectional element, meaning it has ability to conduct current in one direction and block in other direction.

- Diodes are used in circuits called rectifiers that convert ac voltage into dc voltage.
- Rectifier ckt. are found in all dc power supply that operates from an ac source.

A) Rectifier Operation :

(i) Half-Wave Rectifier :



$V_{in}(t) = V_{in,p} \sin \omega t$

The output is observed on the scope/simulator

What would be voltage across R_L when a DC voltmeter is connected across it?

- It measures the average value of the output signal.

Mathematically, it is the area under the output signal over a full (one) cycle and then divided by 2π, the number of radians in a full cycle.

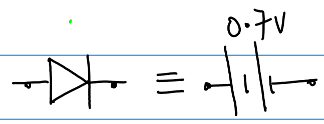
$$V_{ave.} = \frac{1}{2\pi}\int_{t=0}^{t=T/2} \underbrace{V_{0,p}\, \sin\omega t \; d(\omega t)}_{+ve\ \text{half-cycle}} + \underbrace{\frac{1}{2\pi}\int_{t=T/2}^{t=T} V_{0,p}\, \sin\omega t \; d\omega t}_{-ve\ \text{half-cycle} = 0}$$

$$\Rightarrow \boxed{V_{ave.} = \frac{V_{0,p}}{\pi}} \approx 31.8\% \text{ of } V_{0,p}$$

In order to incorporate the effect of barrier potential in p-n diode on half-wave rectifier,

We use "Modified Ideal Diode Model":

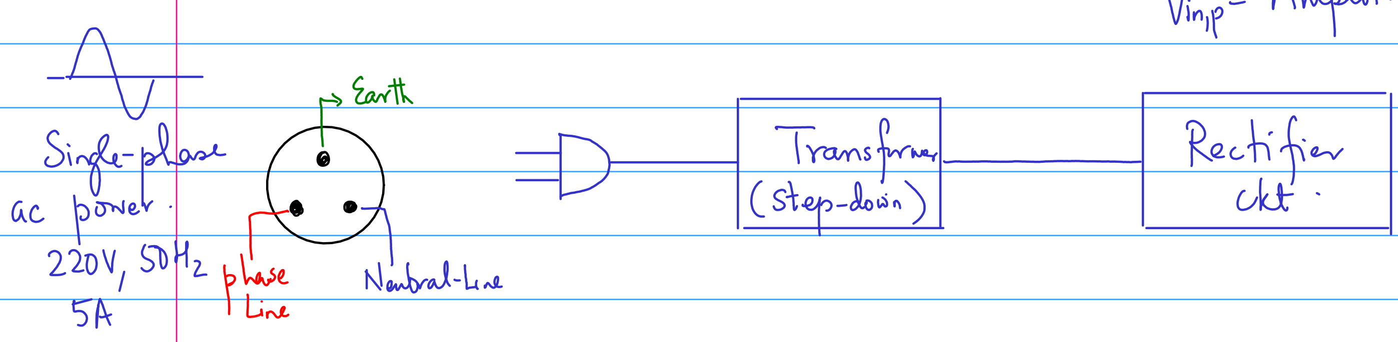
For practical pn diode:



$$V_{0,p} = V_{in,p} - 0.7\,V$$

$$\boxed{V_{ave} = \frac{V_{0,p}}{\pi} = \frac{(V_{in,p} - 0.7\,V)}{\pi}}$$

$V_{in,p}$ = Amplitude of the input signal.

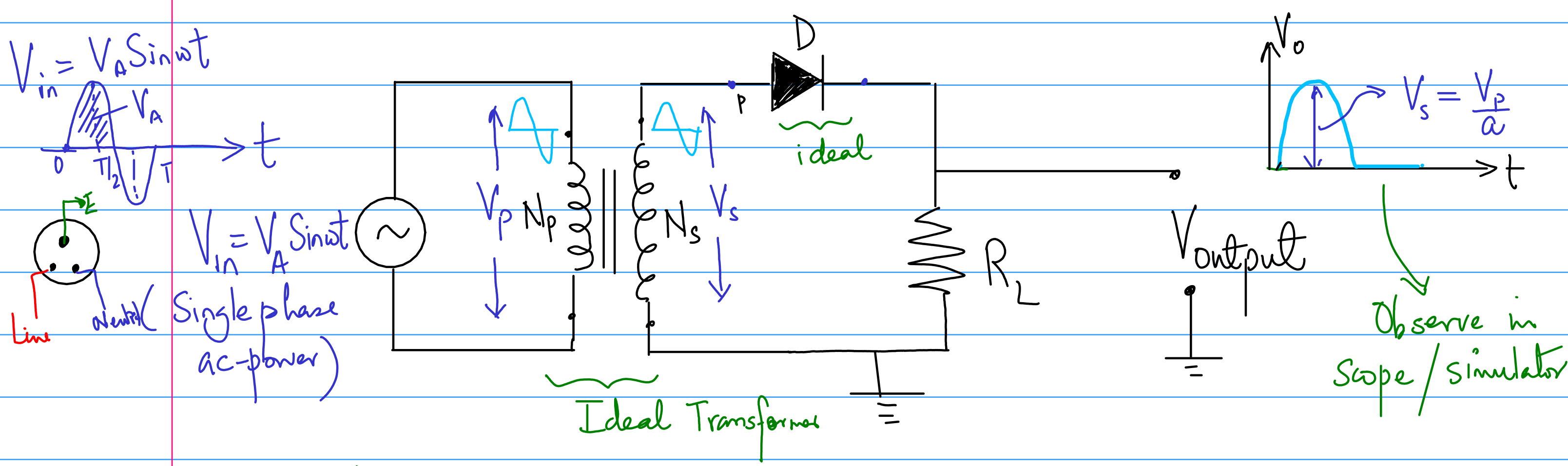


In practice, the rectifier ckt. is connected with the step-down transformer at the input terminal.

Advantages:

i) Allows the source voltage to step-down

ii) Prevents rectifier ckt. with any electrical hazard.



In transformer, we define

$$\text{Turn ratio}; \quad a = \frac{N_p}{N_s} = \frac{V_p}{V_s}$$

$$a > 1 \Rightarrow V_p > V_s \Rightarrow \text{Step-down}$$

$$a < 1 \Rightarrow V_p < V_s \Rightarrow \text{Step-Up}$$

$$\boxed{V_p = a V_s \quad ; \quad N_p = a N_s \quad ; \quad I_p = \frac{1}{a} I_s}$$

If you connect dc voltmeter across the R_L

$$V_{ave} = \frac{V_s}{\pi} = \frac{V_p/a}{\pi} = \frac{V_{in}/a}{\pi}$$

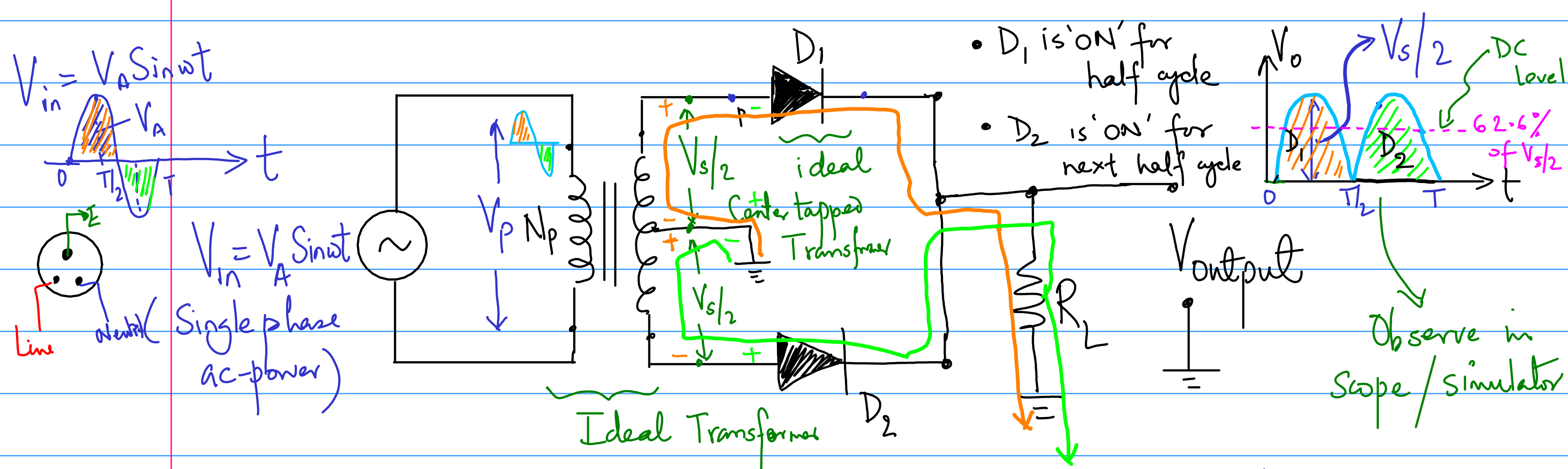
$$\left(V_{ave.}\right)_{\text{Transformer Coupled Rectifier}} = \frac{V_{in}/a}{\pi}$$

For practical diodes :

$$\left(V_{ave.}\right)_{\text{Tran. Coupler}} = \frac{(V_{in}/a) - 0.7V}{\pi}$$

V_{in} = amplitude of the input voltage.

Full-Wave Rectifier:



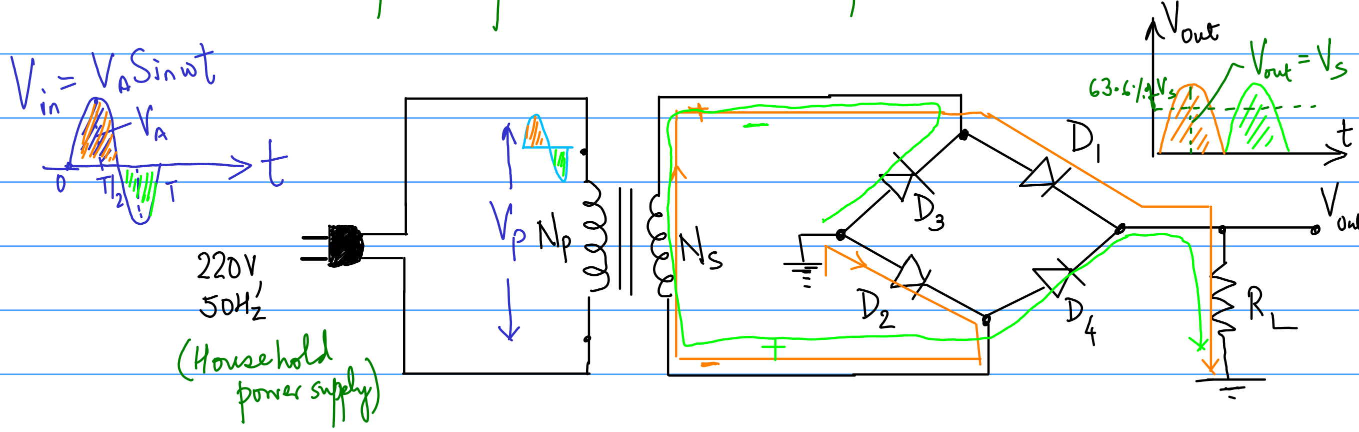
$V_{p,out.} = V_s/2$; $V_{ave.} = \dfrac{2V_{p,out}}{\pi} = \dfrac{2 \cdot V_s/2}{\pi}$

For practical diode;

$$V_{p,out} = \left(\frac{V_s}{2} - 0.7V\right)$$

$$\Rightarrow \quad V_{ave.} = \frac{2V_{p,out}}{\pi} = \frac{2}{\pi}\left(\frac{V_s}{2} - 0.7V\right)$$

Alternate circuit for full-wave rectifier:



for +ve half cycle: D_1 & D_2 – ON ; D_3, & D_4 – OFF

for -ve half cycle: D_3 & D_4 – ON ; D_1 & D_2 – OFF

$$V_s = V_p/a = V_{app}/a$$

$$V_{out} = V_s \quad \text{(Considering diodes to be Ideal)}$$

$$V_{ave.} = \frac{2V_{out}}{\pi}$$

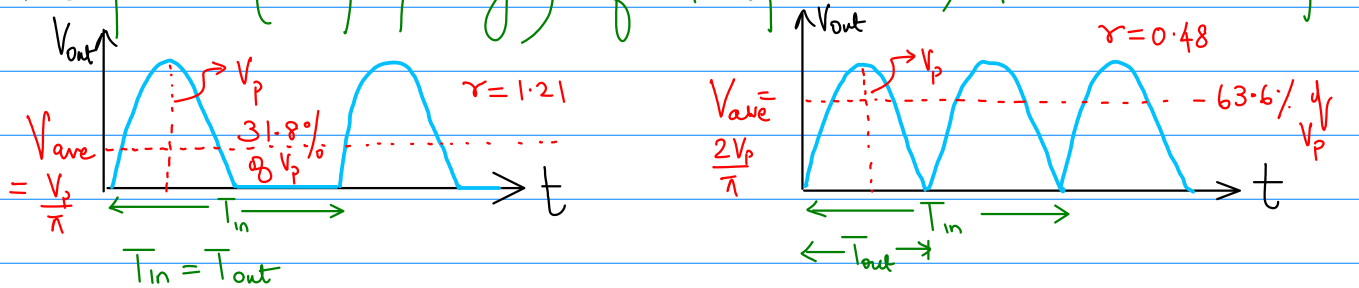
For practical circuit:

$$\boxed{V_{out} = V_s - 1.4\,V}$$

Since two diodes are replaced with two voltage sources of 0.7V each.

$$\boxed{V_{ave} = \frac{2}{\pi}\left(V_s - 1.4\,V\right)}$$

Time-period (or frequency) of Half-wave / Full-wave rectifier

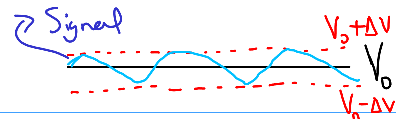


- For half-wave rectifier: Time-period of output voltage is same as input voltage. That is, if input frequency is 50 Hz then output frequency is also 50 Hz.

- For full-wave rectifier, the time-period of output voltage is half of the input voltage. That is, the frequency of output voltage will be 100 Hz for 50 Hz input frequency.

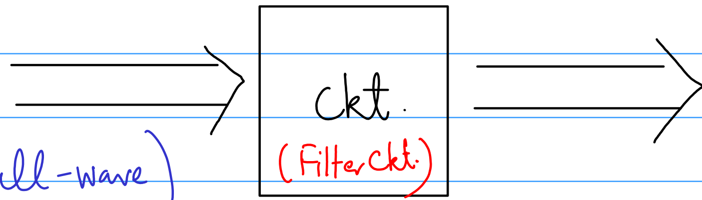
Remember: Output of the rectifier ckt. is Time-varying

⇒ To get time-invariant output, we need another circuit
→ Filter circuit:



As $\Delta V \to 0$; Signal $\to V_0$

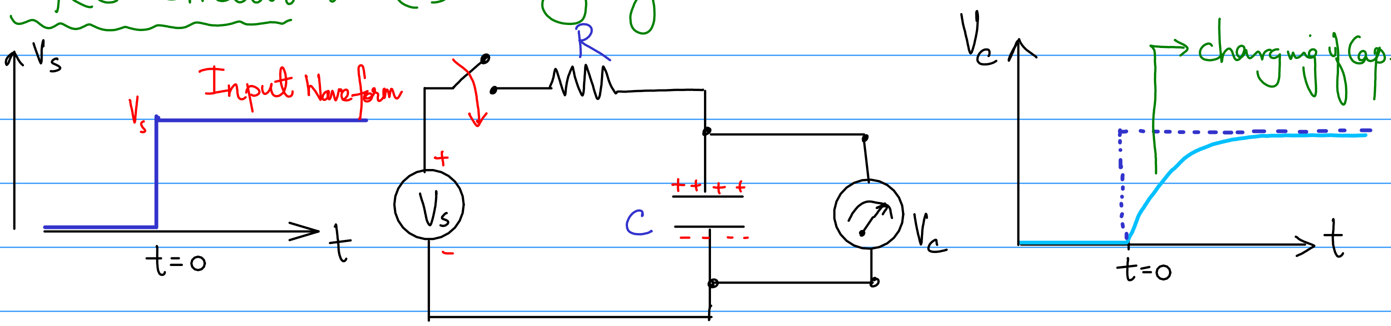
Rectified Output (Half wave / Full-wave) time-varying



Time-invariant output (Small-variation w.r.t time)

design of the ckt.

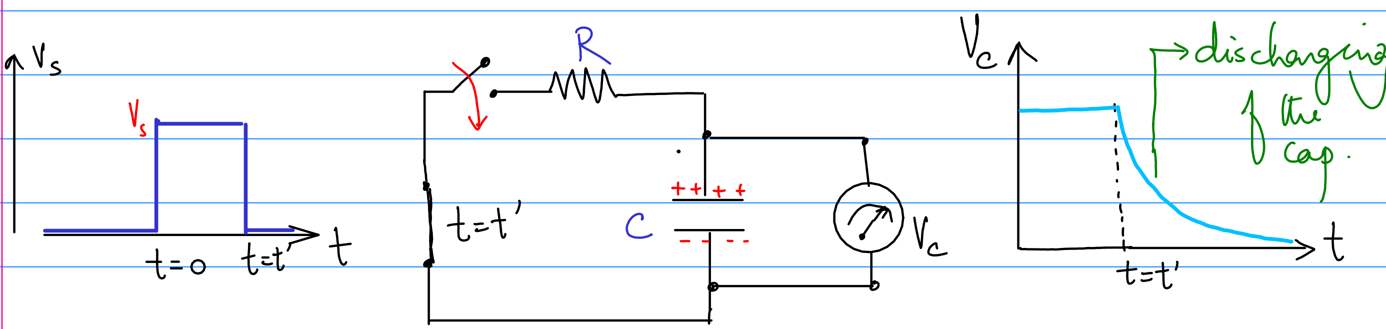
RC circuit : (a) Charging



$$V_c(t) = V_s\left(1 - e^{-t/\tau}\right)$$

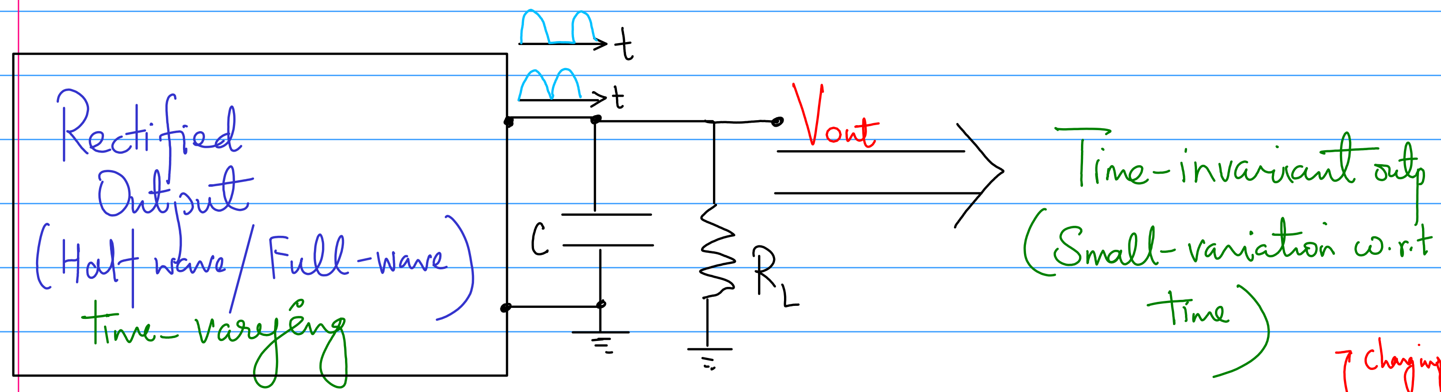
Time constant: $\tau = RC$; $t = 5\tau$; $V_c(t) \approx V_s$

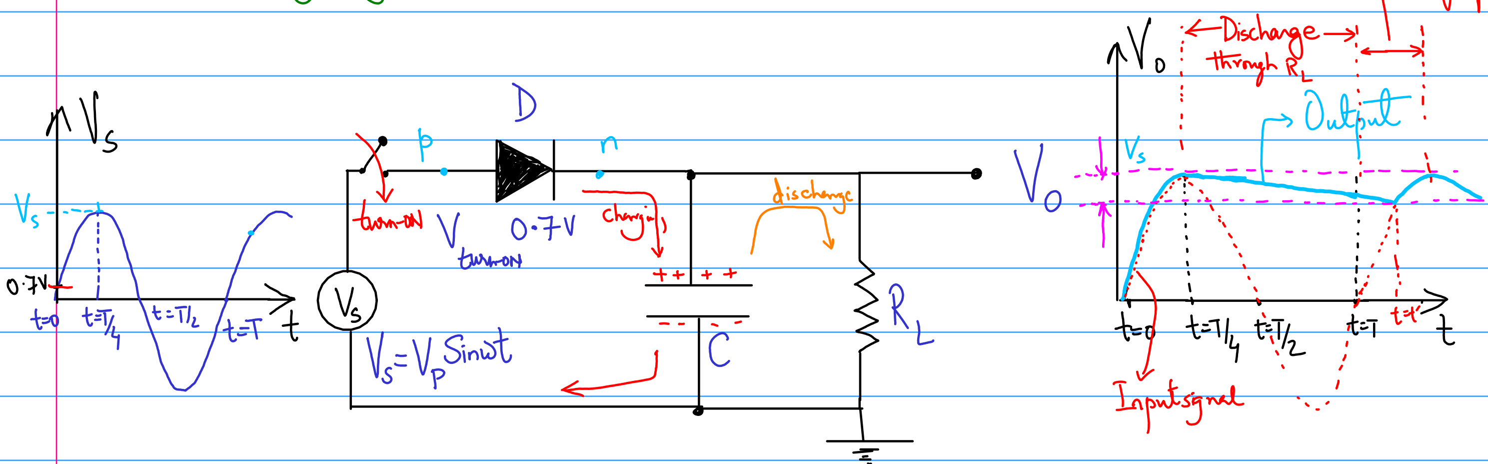
b) Discharging :



$$V_c(t) = V_s\, e^{-t/\tau} \qquad \tau = RC$$

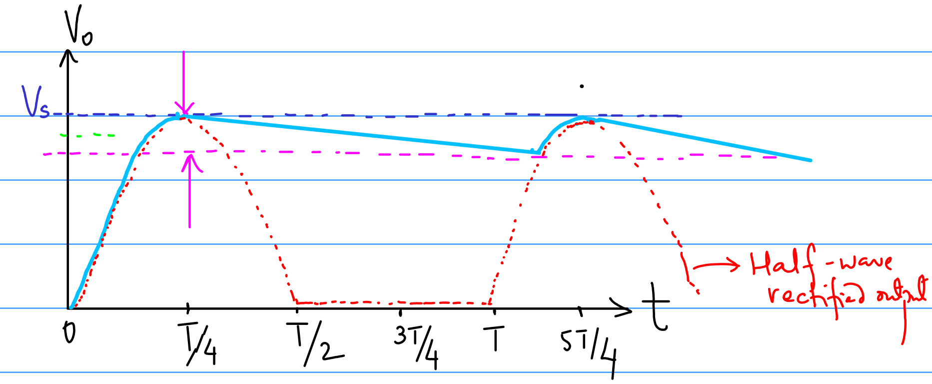
when $t = 5\tau$, then $V_c \approx 0$



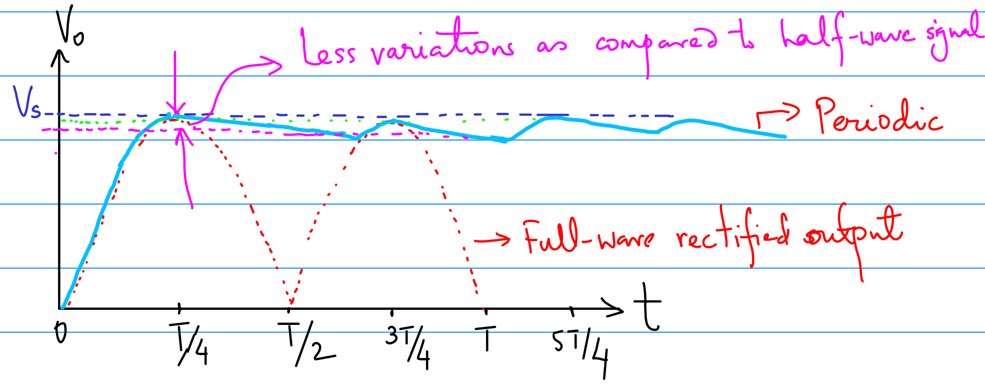


at $t = T/4$ and beyond: p-side becomes negative w.r.t n-side
⇒ the diode goes into the reverse bias condn.
ie, the input ckt. is "OPEN".

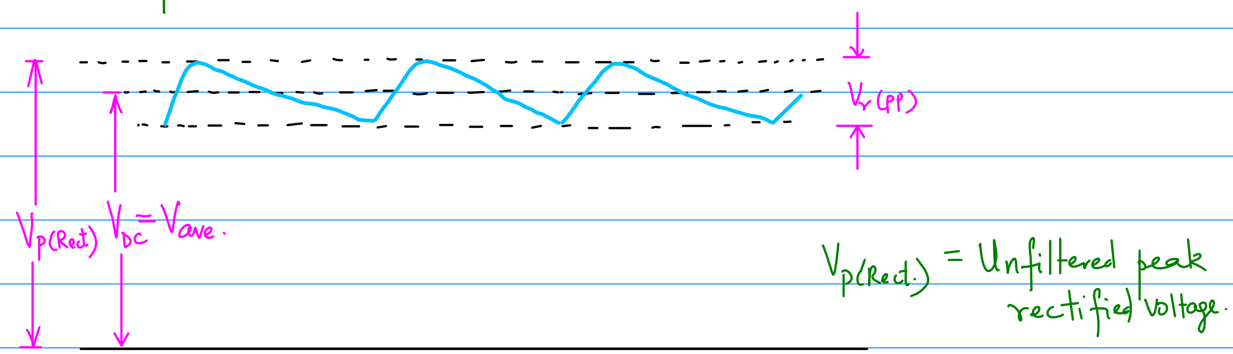
In half-wave rectifier with filter circuit, we get the following output:



In full-wave rectifier with filter circuit, we get the following output



Ripple & Ripple factor :



here, $V_{r(PP)}$ = Ripple voltage peak-to-peak

V_{DC} = Average value of the filtered output voltage (DC voltage)

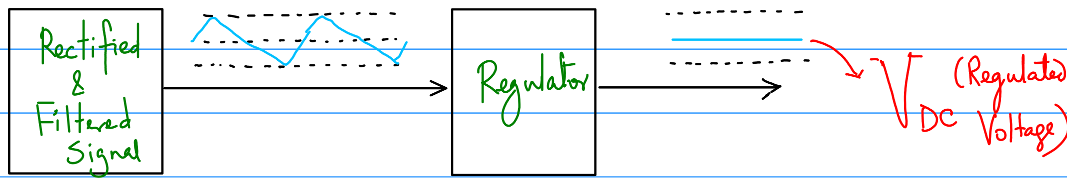
Ripple factor, $\gamma = \dfrac{V_{r(PP)}}{V_{DC}}$

where, $V_{r(PP)} \sim \left(\dfrac{1}{f R_L C}\right) V_{p(Rect.)}$

$V_{DC} \sim \left(1 - \dfrac{1}{2 f R_L C}\right) V_{p(Rect.)}$

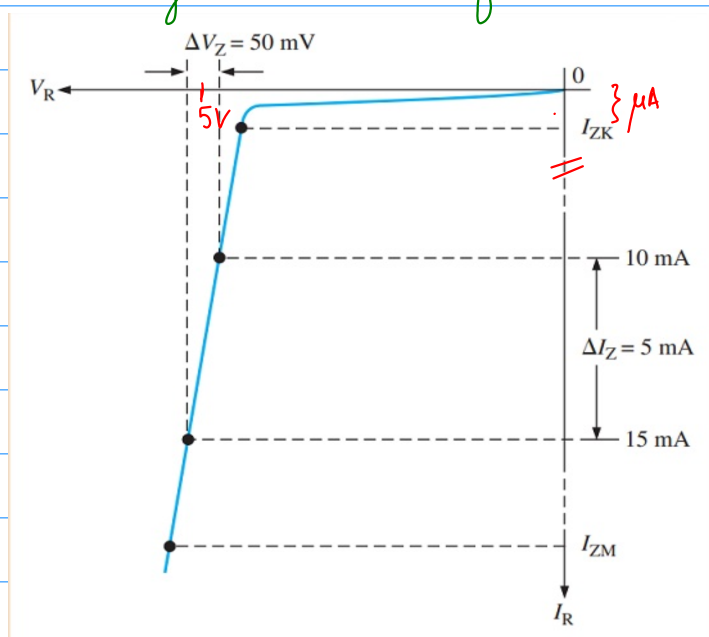
The lower the ripple factor 'γ', better is the filter design.

Voltage-Regulator :



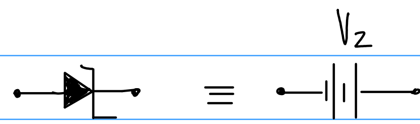
- Zener Diode in reverse bias
- IC 7805

Current-Voltage Characterstics of Zener Diode :

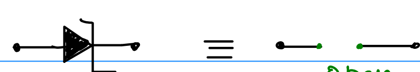


Circuit Model of Zener Diode :

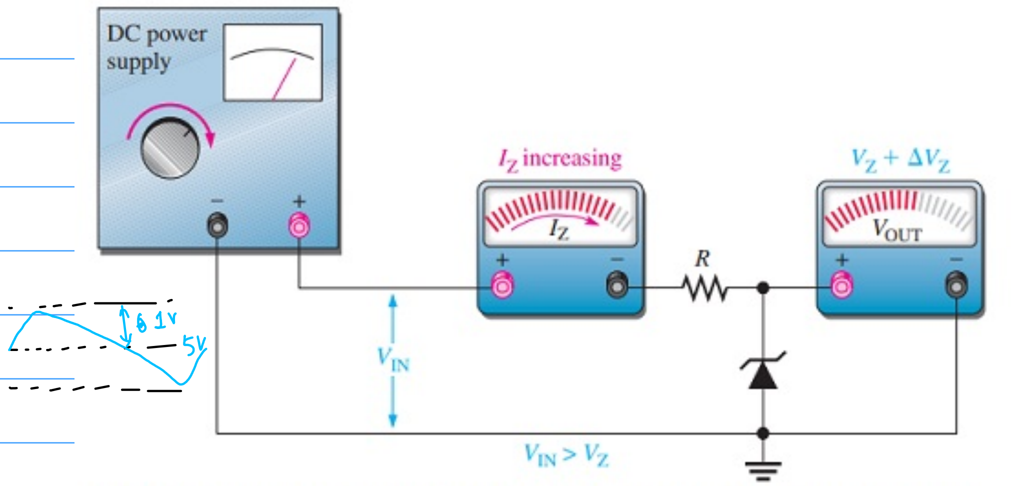
ie, for $V_R \geq V_Z$;



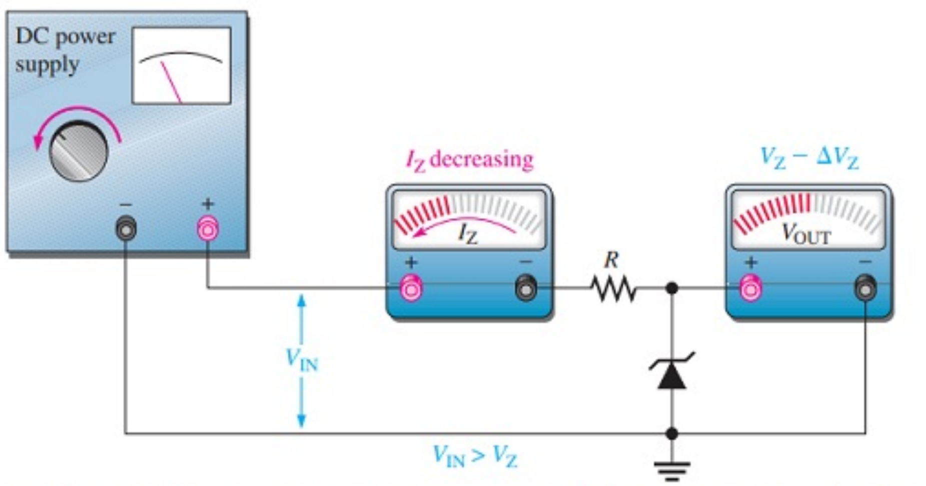
for $V_R < V_Z$;



Working of Zener Regulator:



(a) As the input voltage increases, the output voltage remains nearly constant ($I_{ZK} < I_Z < I_{ZM}$).



(b) As the input voltage decreases, the output voltage remains nearly constant ($I_{ZK} < I_Z < I_{ZM}$).

Percentage of Voltage Regulation:

- It is a figure of merit that specify the performance of the voltage regulator.

(a) Line Regulation:
(Any variation in inputs)

$$\boxed{\text{Line Reg.} = \frac{\Delta V_{out}}{\Delta V_{in}} \times 100}$$

(b) Load Regulation:

$$\boxed{\text{Load Reg.} = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100}$$