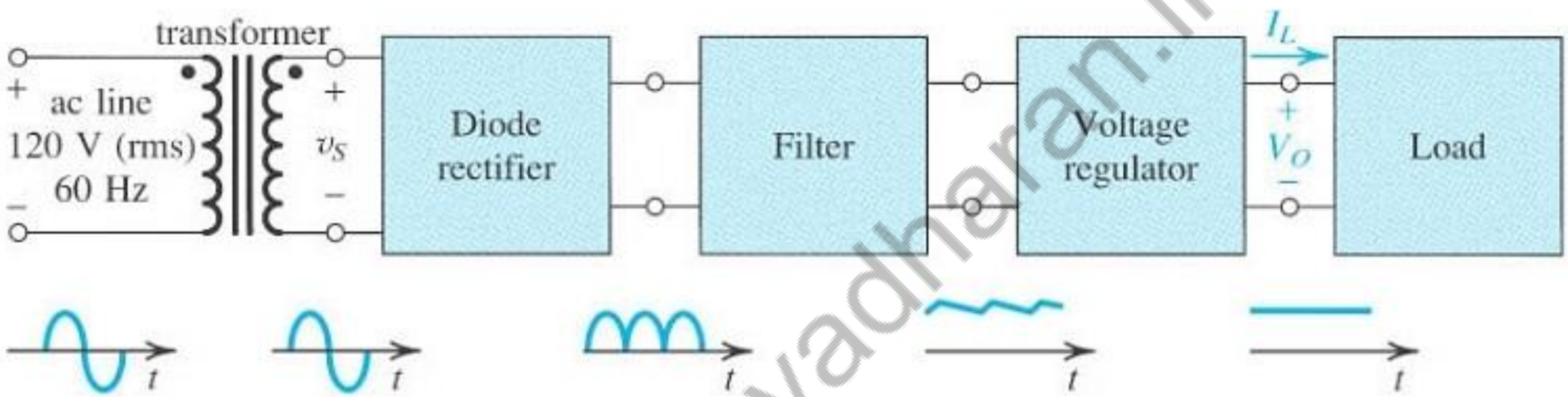
Electrical Science: 2021-22

Lecture 22

Diode Rectifiers

By Dr. Sanjay Vidhyadharan

Rectifiers



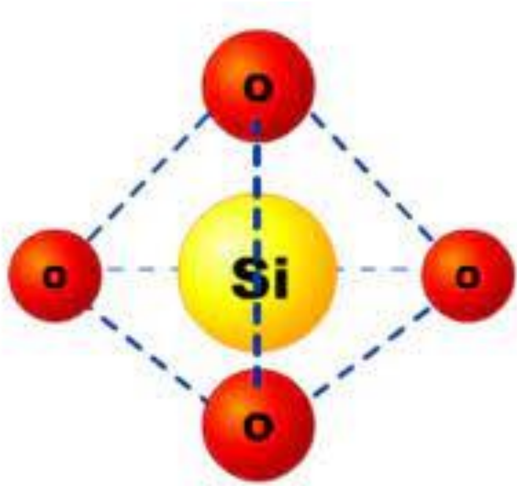
transformer
+
ac line
120 V (rms)
60 Hz
–
+
v_S
–
Diode rectifier
Filter
Voltage regulator
I_L
+
V_O
–
Load
t
t
t
t
t

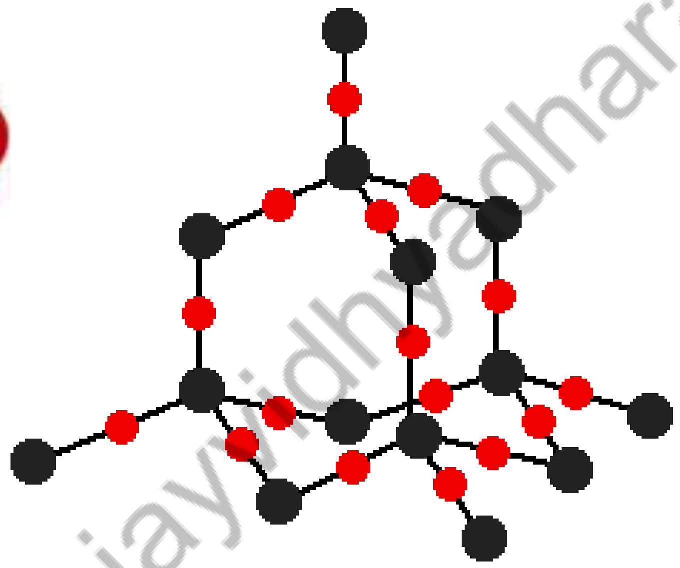
VS550

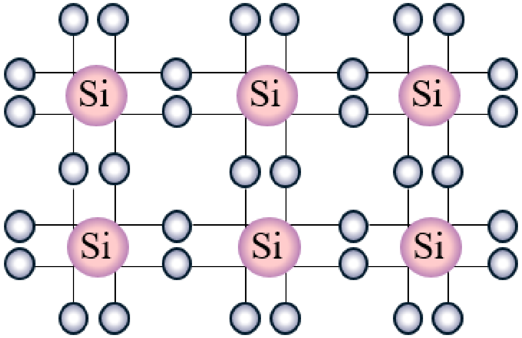
Adaptive Fast Charging

ES-III
ElectroAir
QUALITY AND INNOVATION

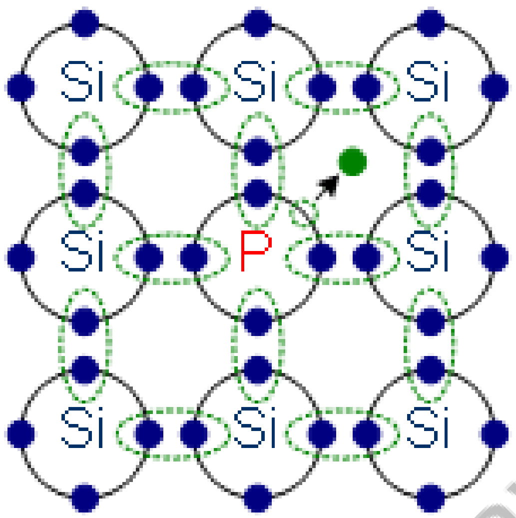
Basics of Semiconductors



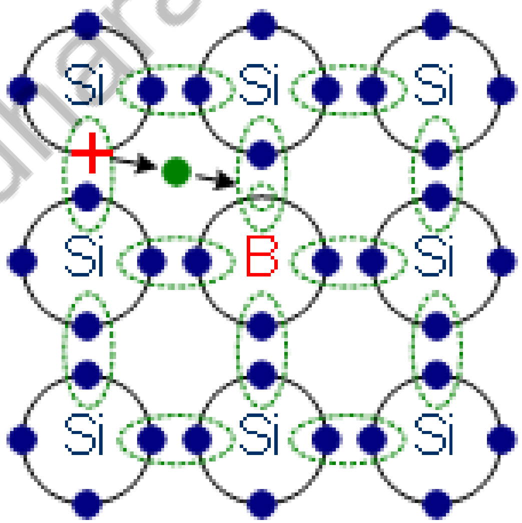




Basics of Semiconductors

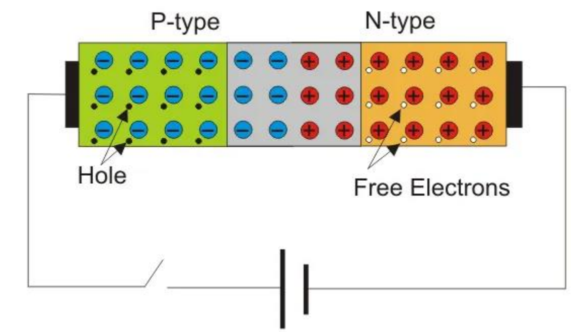


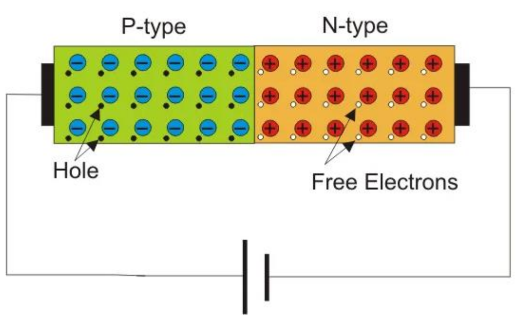
N Dopant- Phosphorus

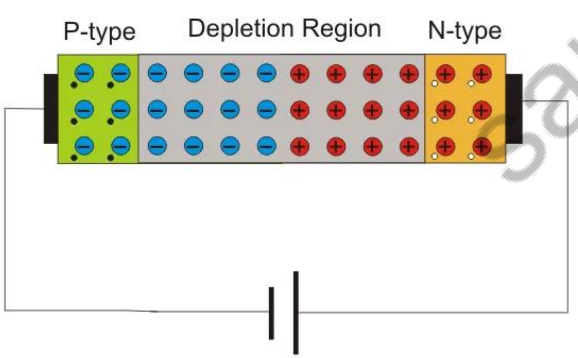


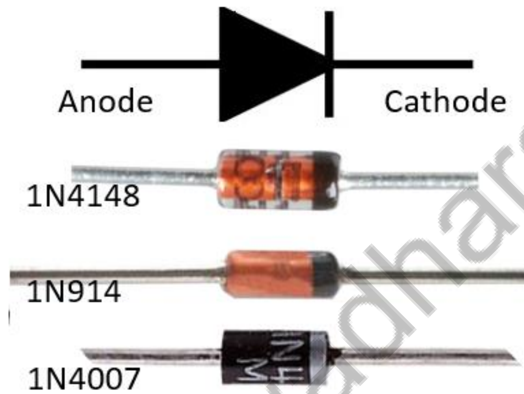
P Dopant- Boron

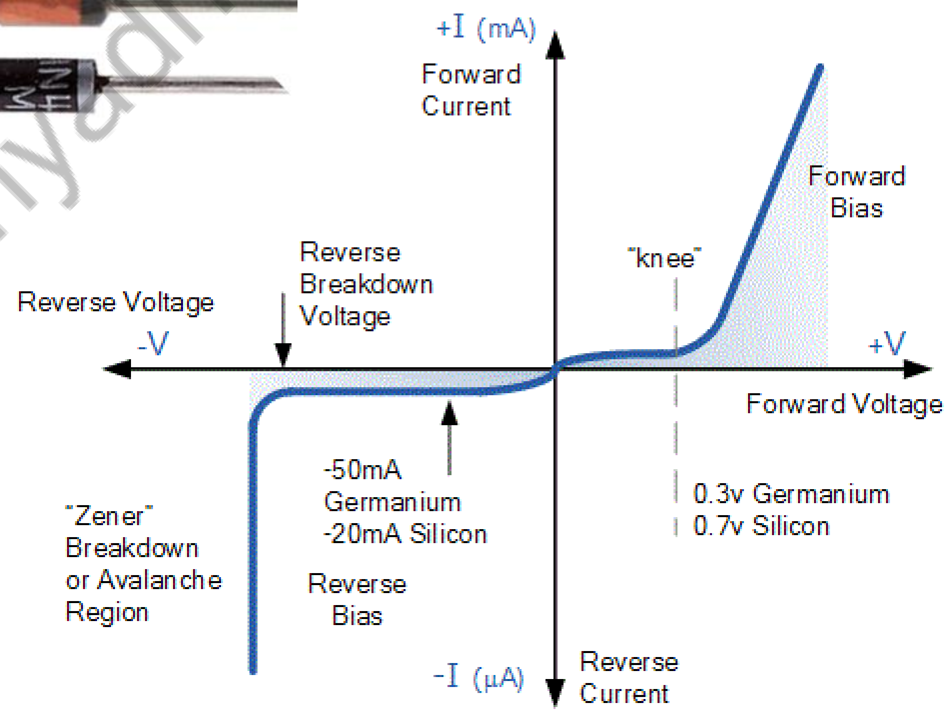
Diode Characteristics



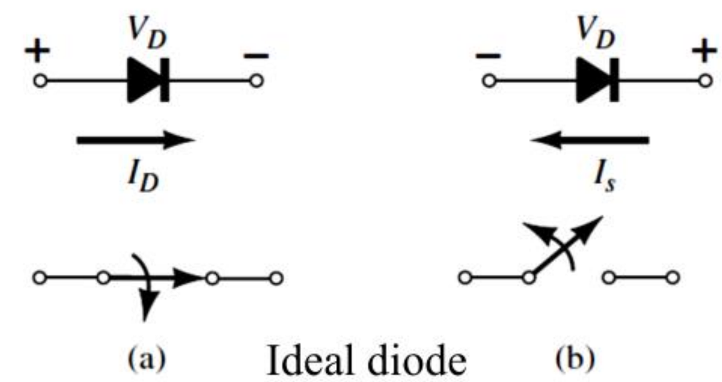


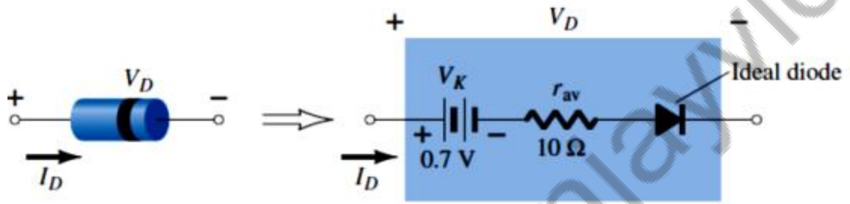




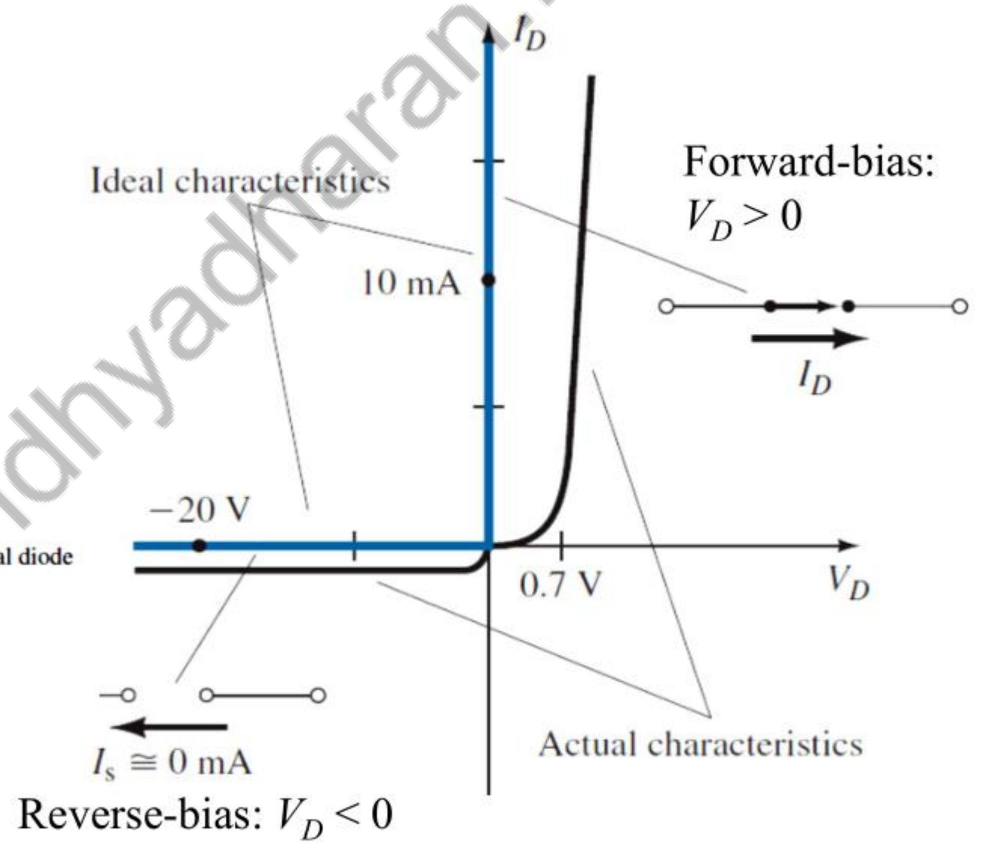


Diode Characteristics





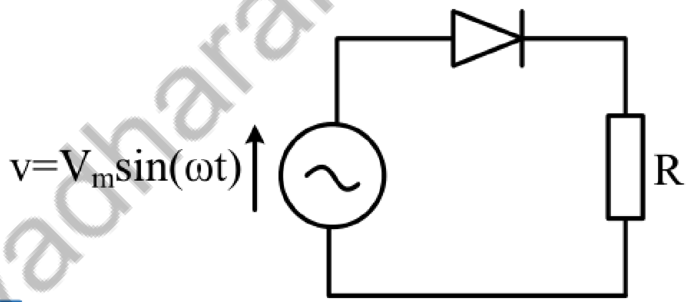
Real diode



Half-Wave Rectifier

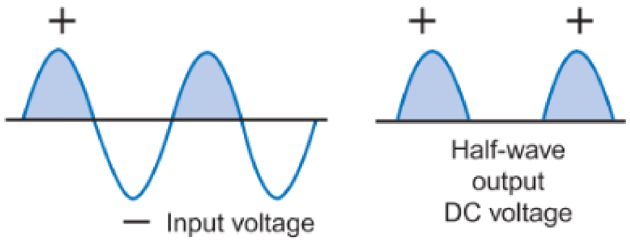
Mean/DC value of the load voltage V_R:

$$V_{dc} = \frac{1}{2\pi}\int_0^{\pi} V_m \sin\omega t \, d(\omega t) = \frac{V_m}{\pi}$$



RMS value of the load voltage V_R:

$$V_{rms} = \sqrt{\frac{1}{2\pi}\int_0^{\pi} (V_m \sin\omega t)^2 d(\omega t)} = \frac{V_m}{2}$$



Rectification efficiency $\eta = (V_{dc}/V_{rms})^2 = 4/\pi^2 \sim 40\%$

$$V_{DC} = V_{avg} = 0.318\, V_m$$

$$I_{DC} = \frac{V_m}{\pi R} \qquad I_{rms} = \frac{V_m}{2R} \qquad I_{MAX} = \frac{V_m}{R} \qquad Peak\ Inverse\ Voltage\ PIV = V_m$$

Half-Wave Rectifier

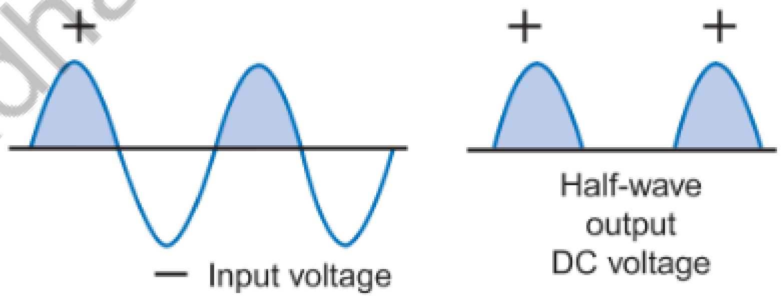
$$Form\ Factor = \frac{V_{rms}}{V_{av}}\ or\ \frac{I_{rms}}{I_{av}}$$

$$Form\ Factor = \frac{V_{rms}}{V_{av}}$$

$$Form\ Factor = \frac{\frac{Vm}{2}}{\frac{V_m}{\pi}}$$

$$Where\ V_m is\ the\ peak\ value\ of\ AC\ volatge$$

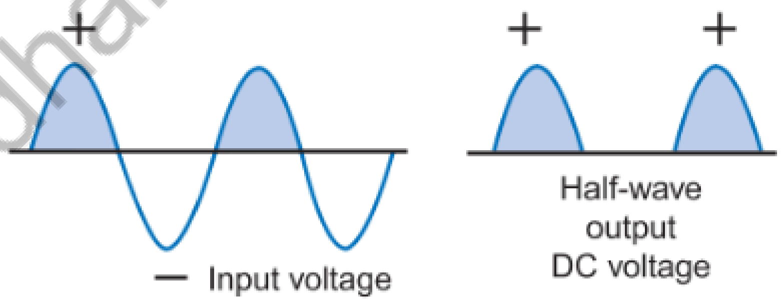
$$Form\ Factor = \frac{\pi}{2} = 1.57$$



Half-Wave Rectifier

$$\textit{Ripple Factor}, \gamma = \frac{\sqrt{(Irms)^2 - (Idc)^2}}{Idc}$$

$$= \frac{\sqrt{(Vrms)^2 - (Vdc)^2}}{Vdc}$$



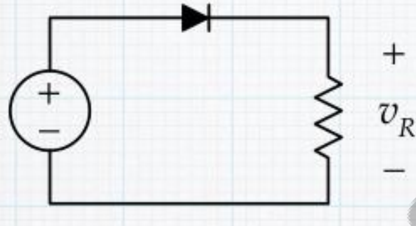
$$\textit{Ripple Factor} = \frac{\sqrt{(0.5Im)^2 - (0.318Im)^2}}{0.318Im}$$

$$= 1.21$$

Half-Wave Rectifier

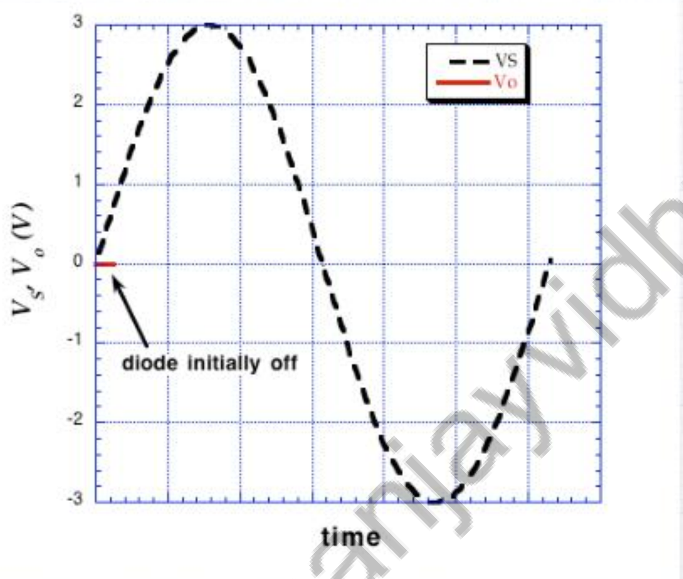
$$V_S(t) = V_p \sin\left(\frac{2\pi}{T}t\right)$$

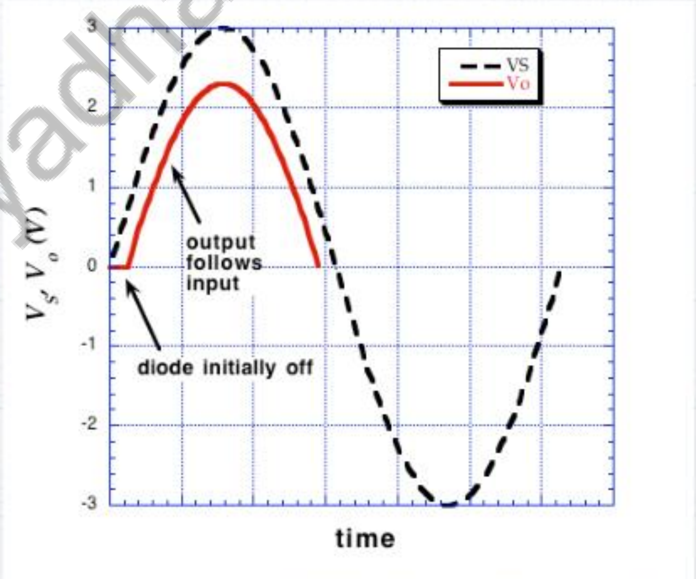
$$V_p = 3\text{ V}.$$



Resistor represent a load.

We are trying to deliver DC power to the load.





Diode is off until $V_S > 0.7$ V.

Current flows when diode is in forward conduction. The output tracks the input during positive half cycle.

Half-Wave Rectifier

$$Rectifier\ efficiency, \eta = \frac{DC\ output\ power}{Input\ AC\ power}$$

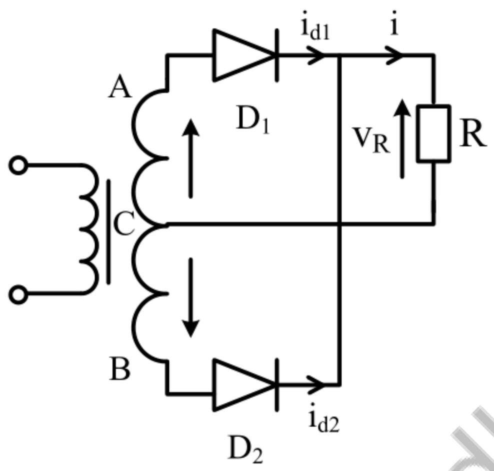
$$DC\ output\ power\ P_{dc} = I^2{}_{dc} * R_L = \left(\frac{I_m}{\pi}\right)^2 * R_L$$

$$AC\ Input\ Power\ P_{ac} = I^2{}_{rms}\,(r_f + R_L) = \left(\frac{I_m}{2}\right)^2 * (r_f + R_L)$$

$$\eta = \frac{4}{\pi^2\left(\frac{r_f + R_L}{R_L}\right)} = \frac{0.406}{1 + \frac{r_f}{R_L}} \simeq 0.406$$

Maximum rectifier efficiency = 40.6%.
This means only 40.6% of the input AC power is converted into DC power.

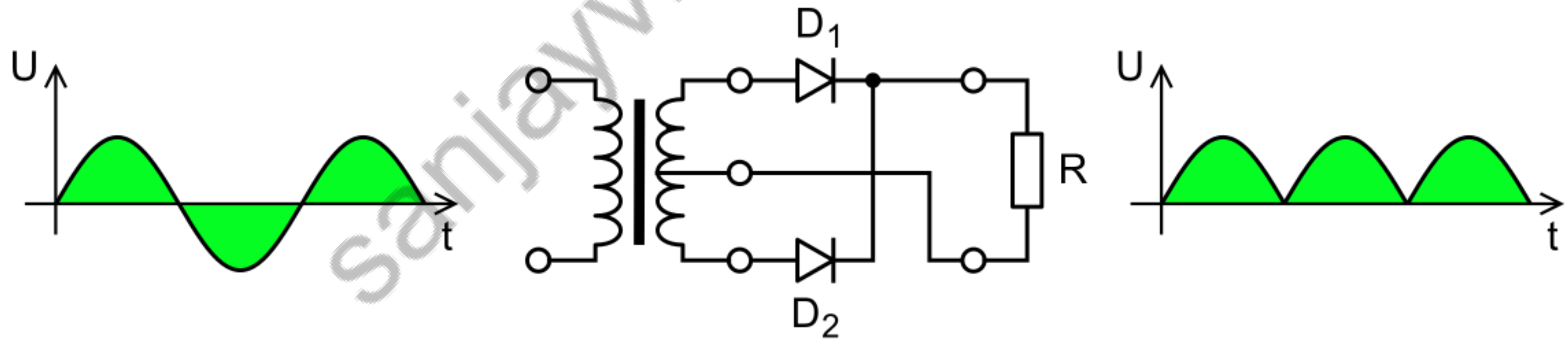
Full-Wave Rectifier



Here C is a centre tap on the secondary of the transformer, thus the e.m.f.s induced in each section of the secondary are equal, and when the potential of A is positive with respect to C, so is that of C positive with respect to B i.e.

$$v_{AC} = v = V_m \sin(\omega t)$$

$$v_{BC} = -v = -V_m \sin(\omega t)$$

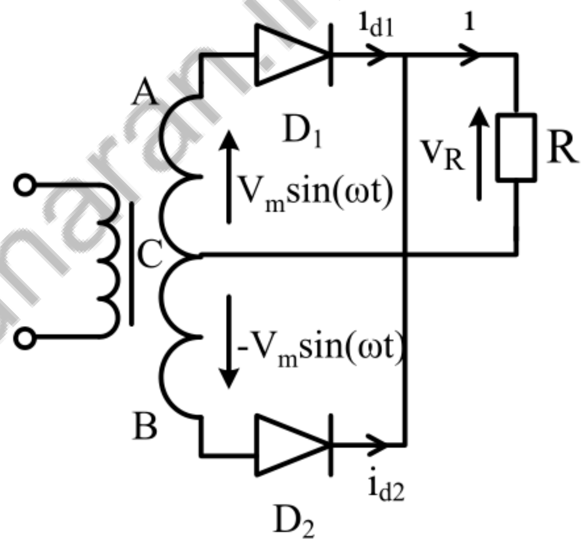


$$Peak\ Inverse\ Voltage\ PIV = 2\,V_m$$

Full-Wave Rectifier

Mean/DC value of the load voltage V_R:

$$V_{dc} = \frac{1}{\pi}\int_0^{\pi} V_m \sin\omega t \; d(\omega t) = \frac{2V_m}{\pi}$$



RMS value of the load voltage V_R:

$$V_{rms} = \sqrt{\frac{1}{\pi}\int_0^{\pi} (V_m \sin \omega t)^2 d(\omega t)} = \frac{V_m}{\sqrt{2}}$$

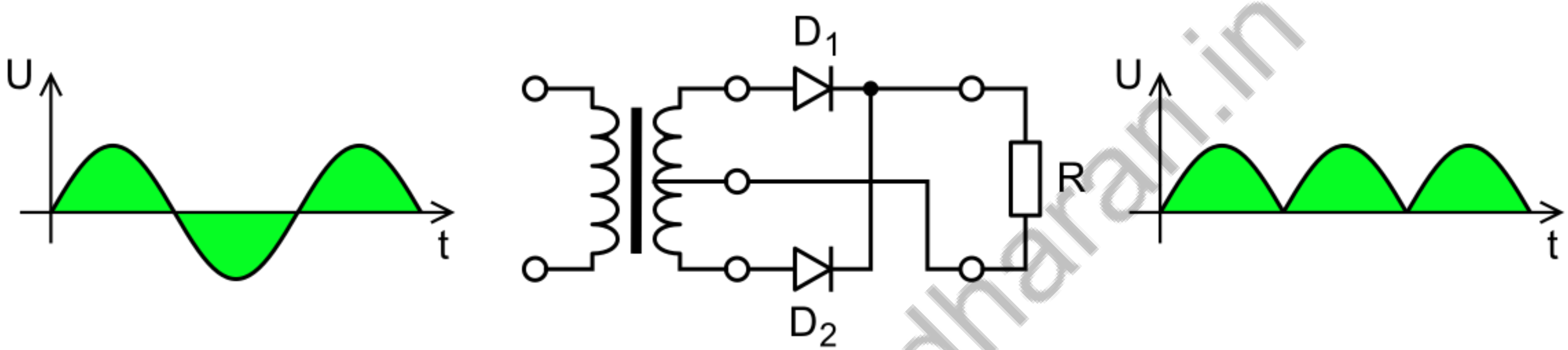
Rectification efficiency $\eta = (V_{dc}/V_{rms})^2 = 8/\pi^2 \sim 80\%$

$$V_{DC} = V_{avg} = 0.64\, V_m$$

$$I_{DC} = \frac{2V_m}{\pi R} \qquad I_{rms} = \frac{V_m}{\sqrt{2}R} \qquad I_{MAX} = \frac{V_m}{R}$$

Peak Inverse Voltage PIV $= 2V_m$

Full-Wave Rectifier



$$Form\ Factor = \frac{V_{rms}}{V_{avg}} = \frac{V_m/\sqrt{2}}{2V_m/\pi} = \frac{\pi}{2\sqrt{2}} = 1.11$$

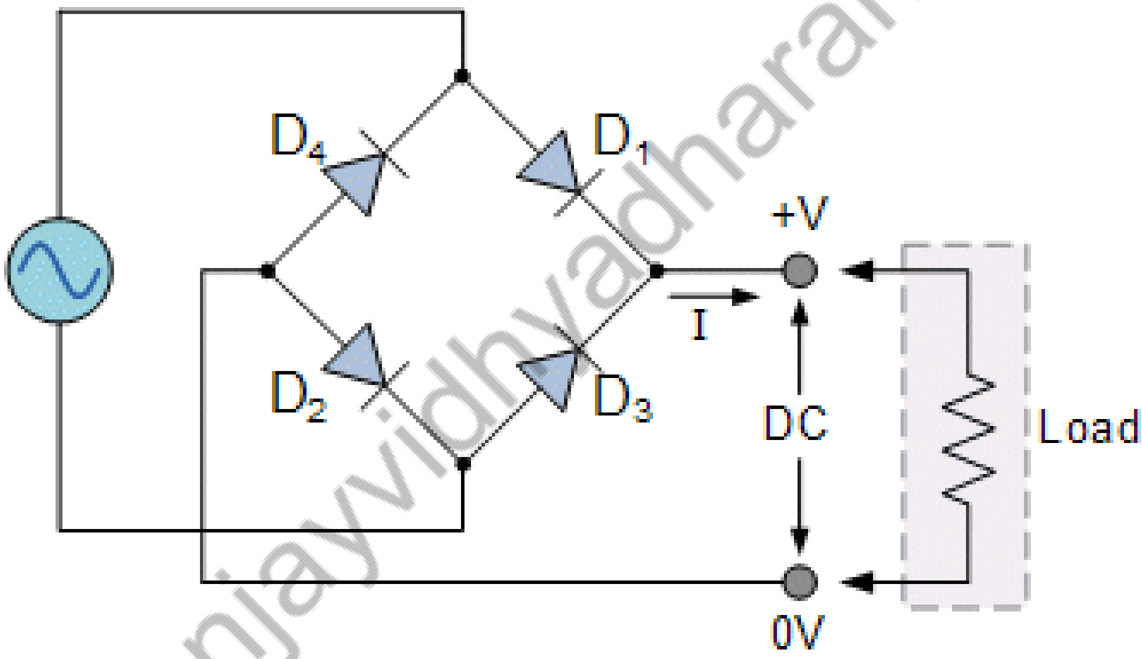
$$\text{Ripple factor} = \sqrt{\left(\frac{I_m/\sqrt{2}}{2I_m/\pi}\right)^2 - 1} = 0.48$$

$$\eta = \frac{Pdc}{Pac} = \frac{4}{\pi*\pi} I^2max\,R_L / \frac{1}{2} I^2max\,(R_L + R_F)$$

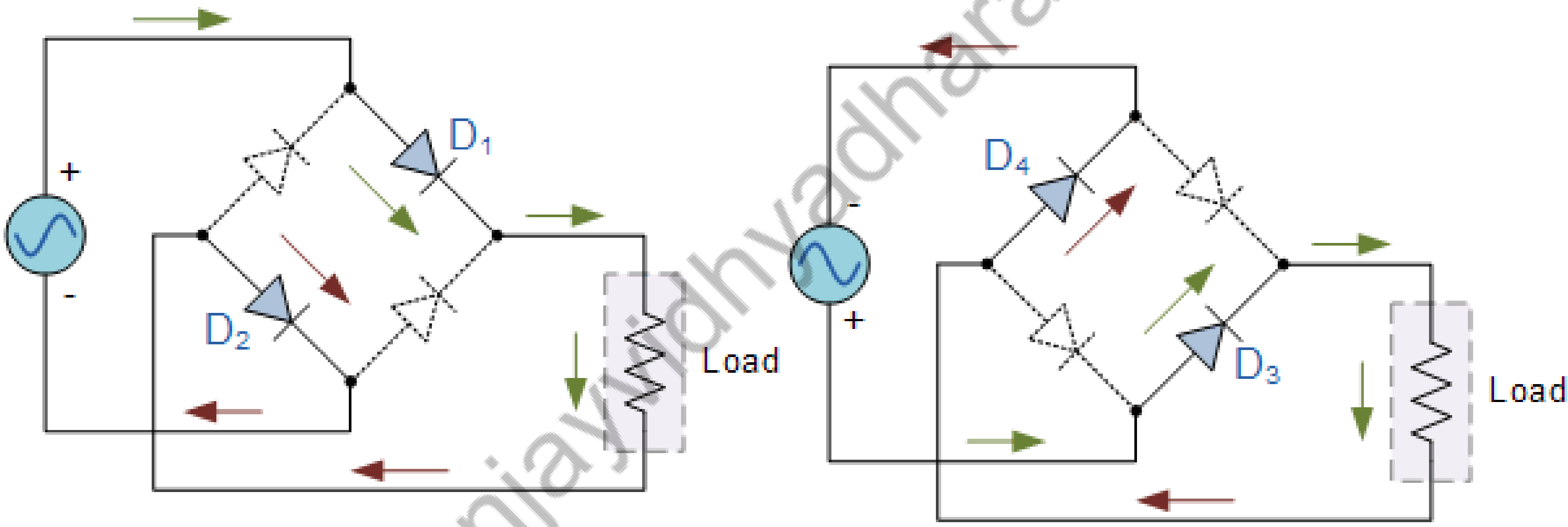
$$= \frac{8}{\pi*\pi}\frac{1}{(1+2RF/RL)} = \frac{0.812}{(1+2RF/RL)}$$

Efficiency of an ideal Full Wave Rectifier Circuit is = 81.2%

Bridge Rectifier



Bridge Rectifier



$$Peak\ Inverse\ Voltage\ PIV = V_m$$

Bridge Rectifier

Average value of output voltage: $V_{do} = (2\sqrt{2}/\pi)V_s \approx 0.9V_s = (2/\pi)V_m = 0.637V_m$

where V_s and V_m are the RMS and peak values of input voltage.

Rectification Ratio = Pdc/Pac = 0.81 or 81%

Form Factor (FF) of DC side voltage (or current) = Vrms/Vdc = 1.11

Ripple Factor = rms value of AC component/DC component = $(FF^2-1)^{1/2}$ = 0.48

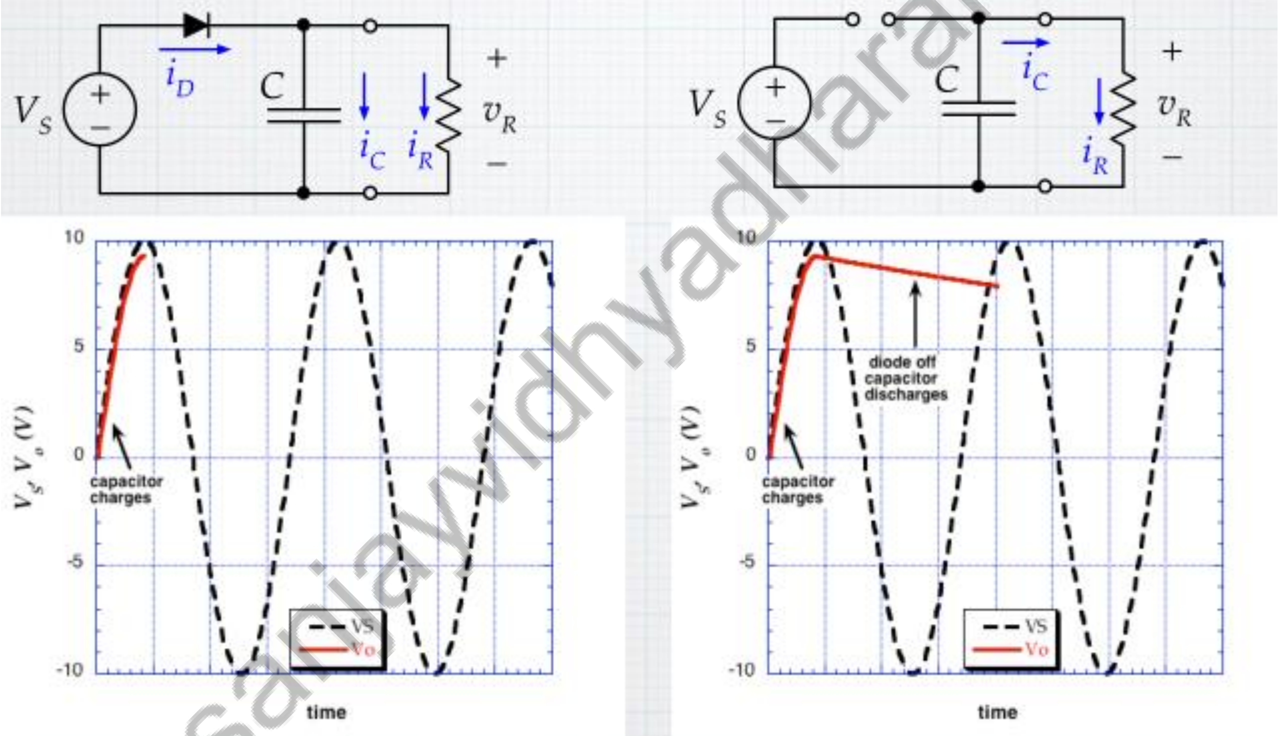
$$Peak\ Inverse\ Voltage\ PIV = V_m$$

Comparison Of Rectifiers

Parameters	Half-Wave Rectifiers	Full-Wave Rectifiers
Rectification Efficiency	40.6%	81.2%
Ripple Factor	1.21	0.482
Voltage Regulation	Good	Better
Fundamental frequency of ripple	Equal to Supply Frequency, f	Double of Supply Frequency, 2f
Form Factor	1.57	1.11
Peak Factor	2	1.414
Number of diodes	Only 1	2 (4 in case of bridge rectifier)
Peak Inverse Voltage	Vs	2 Vs / (Vs for Bridge)
DC Output Voltage	Imax/π RL	2/π RL Imax

Peak Rectifier

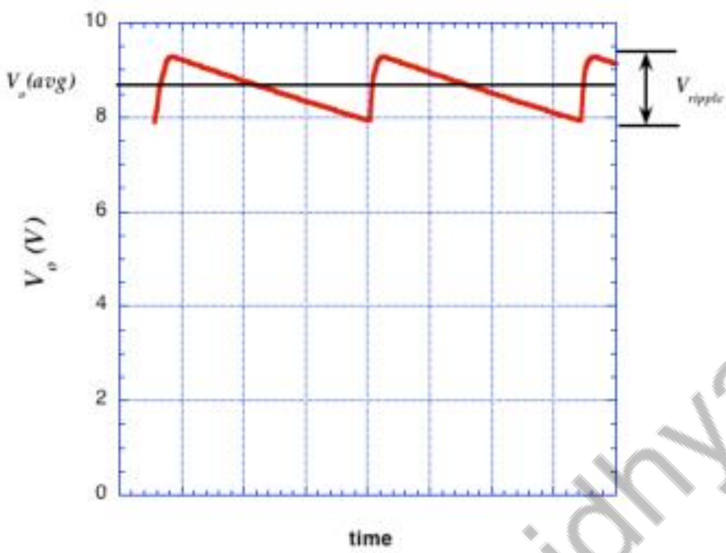
Add a largish capacitor after the diode, in parallel with the load.

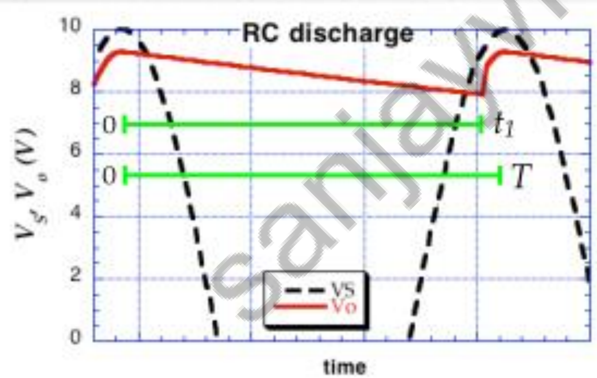


Initially, diode is on & cap charges to V_P - 0.7 V.

While $V_S < v_C$, diode is off! Cap discharges through load.

Peak Rectifier





t_1 = time when diode conducts again.

Not a a perfect DC voltage at output. There is some variation (ripple) around an average value.

$$V_o\,(max) = V_P - 0.7\text{V}$$

$$V_o\,(min) = [V_P - 0.7\text{V}]\exp\left(-\frac{t_1}{RC}\right)$$

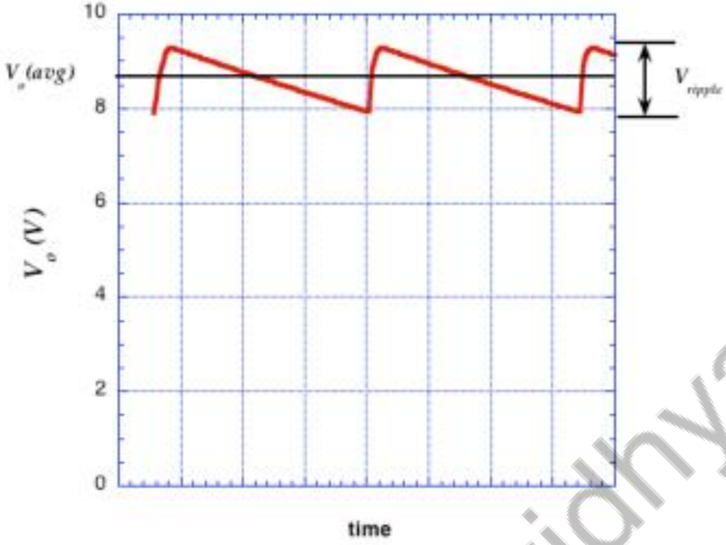
$$\approx [V_P - 0.7\text{V}]\exp\left(-\frac{T}{RC}\right)$$

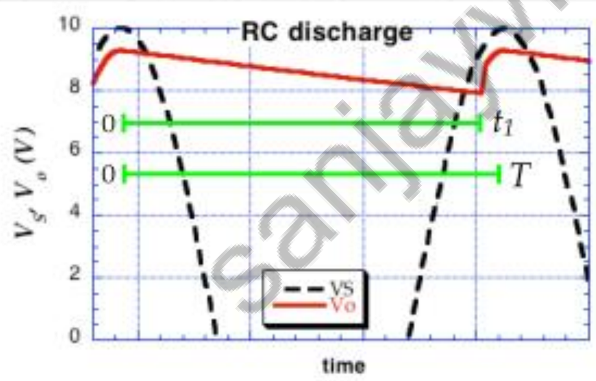
$$V_{ripple} = V_o\,(max) - V_o\,(min)$$

$$= [V_P - 0.7\text{V}]\left[1 - \exp\left(-\frac{T}{RC}\right)\right]$$

$$V_o\,(avg) \approx V_o\,(max) - \frac{V_{ripple}}{2}$$

Peak Rectifier





t_1 = time when diode conducts again.

Not a a perfect DC voltage at output. There is some variation (ripple) around an average value.

$$V_o\,(max) = V_P - 0.7\text{V}$$

$$V_o\,(min) = [V_P - 0.7\text{V}]\exp\left(-\frac{t_1}{RC}\right)$$

$$\approx [V_P - 0.7\text{V}]\exp\left(-\frac{T}{RC}\right)$$

$$V_{ripple} = V_o\,(max) - V_o\,(min)$$

$$= [V_P - 0.7\text{V}]\left[1 - \exp\left(-\frac{T}{RC}\right)\right.$$

$$V_o\,(avg) \approx V_o\,(max) - \frac{V_{ripple}}{2}$$

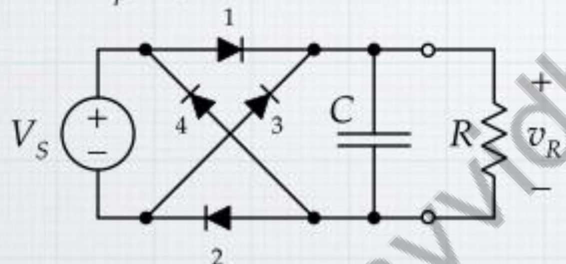
Peak Rectifier

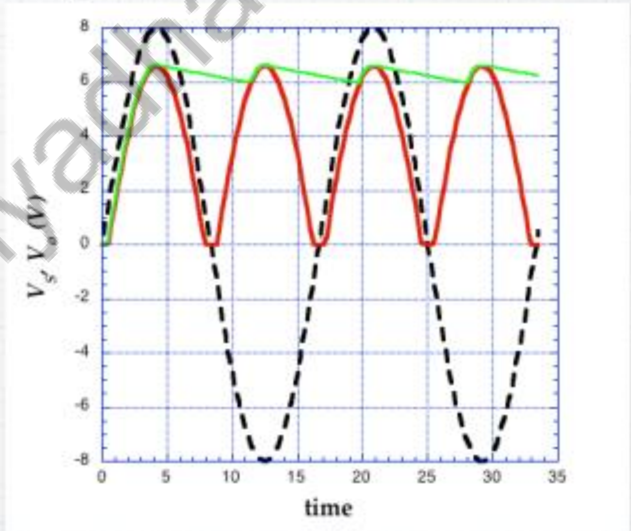
Full-wave peak rectifier

Placing a capacitor in parallel with the load, turns the circuit into a full-wave peak rectifier. It behaves essentially the same as the half-wave peak rectifier except with twice the frequency (half the period).

$$V_S(t) = V_p \sin\left(\frac{2\pi}{T} t\right)$$

$$V_p = 8\text{ V}.$$





The ripple voltage is calculated in exactly the same way, except that the period is cut in half (frequency doubled).

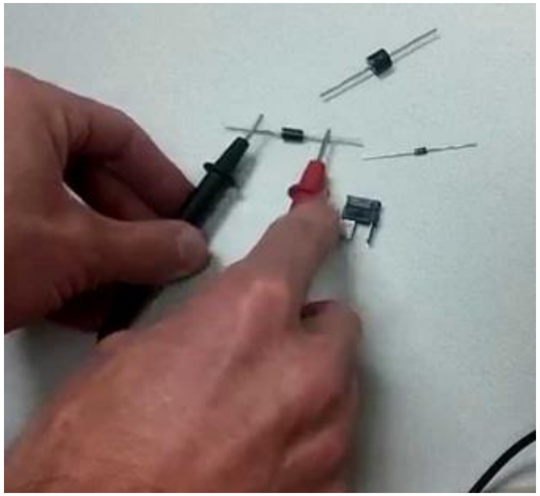
$$V_{ripple} = [V_P - 1.4\text{V}]\left[1 - \exp\left(-\frac{T}{2RC}\right)\right]$$

Same as doubling capacitance!

Practical Diode Specifications

1N4007 Characteristics:

•Maximum Recurrent Peak Reverse Voltage 1000V
•Maximum RMS Voltage 700V
•Maximum DC Blocking Voltage 1000V
•Average Forward Current: 1.0A
•Peak Forward Surge Current: 30A
•Maximum Instantaneous Forward Voltage: 1.0V
•Maximum DC Reverse Current At Rated DC Blocking Voltage: 5.0µA @ 25°C
•Typical Junction Capacitance: 15pF
•Typical Reverse Recovery Time: 2.0us
•Operating Temperature: -55°C ~ 150°C



Practical Diode Specifications

VS-95PF80

MAJOR RATINGS AND CHARACTERISTICS			
PARAMETER	**TEST CONDITIONS**	**VALUES**	**UNITS**
$I_{F(AV)}$		95	A
	T_C	140	°C
$I_{F(RMS)}$		149	A
I_{FSM}	50 Hz	2000	A
	60 Hz	2090	
I^2t	50 Hz	20 000	A^2s
	60 Hz	18 180	
V_{RRM}	Range	400 to 1200	V
T_J		- 55 to 180	°C

ELECTRICAL SPECIFICATIONS

VOLTAGE RATINGS				
TYPE NUMBER	**VOLTAGE CODE**	**V_{RRM}, MAXIMUM REPETITIVE PEAK REVERSE VOLTAGE V**	**V_{RSM}, MAXIMUM NON-REPETITIVE PEAK REVERSE VOLTAGE V**	**I_{RRM} MAXIMUM AT T_J = 150 °C mA**
95PF(R)...(W)	40	400	500	9
	80	800	960	
	120	1200	1440	

Thank you