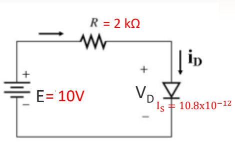
Mathematical Solution by Iterative Method



$$V_D = \eta V_T \ln\left[\frac{(E - V_D)}{R.I_S} + 1\right]$$

$$I = \frac{E - V_D}{R} = \frac{6 - 0.7}{1} = 5.3\,mA$$

$$V_D = 26 \ln\left[\frac{(6000 - V_D)}{1000\ x\ 10.8x10^{-12}} + 1\right] mV$$

$$V_D = 26 \ln\left[\frac{(6000 - 600)}{1000\ x\ 10.8x10^{-12}} + 1\right] = 700.3847$$

$$V_D = 26 \ln\left[\frac{(6000 - 700.3847)}{1000\ x10.8x10^{-12}} + 1\right] = 699.8968$$

$$V_D = 26 \ln\left[\frac{(6000 - 699.8968)}{1000\ x10.8x10^{-12}} + 1\right] = 699.8992$$

$$V_D = 699.8992\ \text{mV} \simeq 0.7\ V$$

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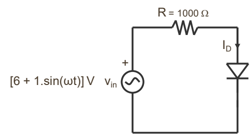
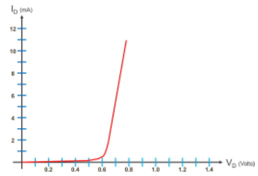
Superimposing an AC drive signal :

Superimpose an AC signal of 1.sin(ωt)V on the DC 6V





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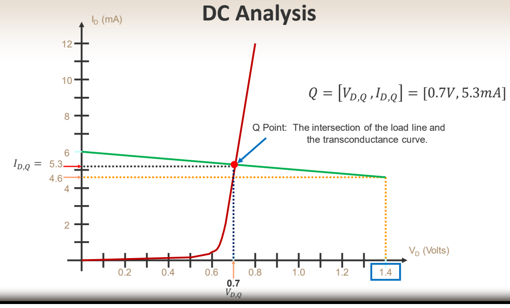
DC Analysis



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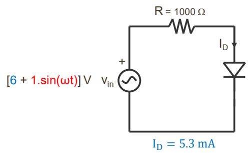
AC Analysis



$$r_d = \frac{\eta V_T}{I_D} = \frac{1x26\ mV}{5.3\ mA} = 4.9\ \Omega$$

$$v_{ac} = \frac{r_d}{r_d + R}\sin(\omega t)$$

$$v_{ac} = \frac{4.9}{4.9 + 1000}\sin(\omega t)$$

$$v_{ac} = 4.88\sin(\omega t)\ mV$$

V_D = [700 + 4.9 sin (ωt)] mV

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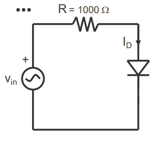
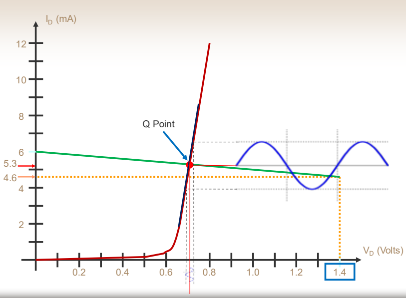
Visualizing graphically

…



$$r_d = \frac{\eta V_T}{I_D} = \frac{1.26\ mV}{5.3\ mA} = 4.9\ \Omega$$



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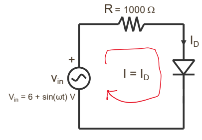
Mathematical Solution (dc+ac)

Let the source voltage is v_{in} = 6 + sin(ωt) Volts.



$$I = I_S\left[e^{\frac{V_D}{\eta V_T}} - 1\right]$$

$$I = I_S\left[e^{\frac{V_D}{\eta V_T}} - 1\right]$$

$$\frac{I}{I_S} = e^{\frac{V_D}{\eta V_T}} - 1$$

$$\frac{I}{I_S} + 1 = e^{\frac{V_D}{\eta V_T}}$$

$$\frac{V_D}{\eta V_T} = \ln\left[\frac{I}{I_S} + 1\right]$$

$$V_D = \eta V_T \ln\left[\frac{I}{I_S} + 1\right]$$

$$V_D + IR = V_{in}$$

$$I = \frac{V_{in} - V_D}{R}$$

$$V_D = \eta V_T \ln\left[\frac{(V_{in} - V_D)}{I_S R} + 1\right]$$

$$V_D = \eta V_T \ln\left[\frac{(6 + \sin\omega t - V_D)}{I_S R} + 1\right] !!$$

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Mathematical Solutions with Different Diode Abstraction Models

- Different abstractions can be used when analyzing diode circuits.
- Choice depends on the desired accuracy of your circuit calculations.
- These are also called Piecewise linear models

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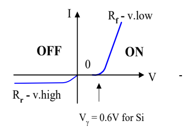
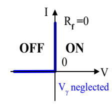
Model 1 : Ideal Diode Model



(a) Practical diode



(c) Ideal diode

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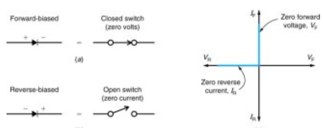
Model 1 : Ideal Diode Model

This abstraction treats a forward-biased diode like a switch with a voltage drop of zero volts.



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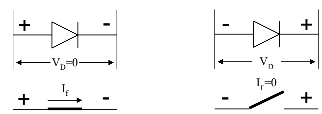
Model 1 : Ideal Diode Model



$I_f \neq 0$; $V_D = 0$
Diode ON; Switch ON
(a) Forward biased ideal diode

$I_r = 0$; $|V_D| \neq 0$
Diode OFF; Switch OFF
(b) Reverse biased ideal diode

ON DIODE **OFF DIODE**

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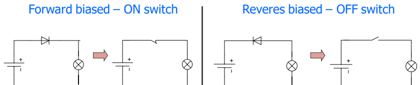
Model 1 : Ideal Diode Model

- Ideal diode model.

  Ideal diode (which is hypothetical but makes the analysis simpler) is like an ON-OFF switch.

Forward biased – ON switch | Reveres biased – OFF switch



Replace the diode with an ON (Closed) switch

Replace the diode with an OFF (Open) switch

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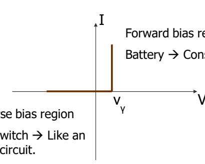
Model 2 : Near(Nearly) Ideal Diode Model

- The earlier model (approximation) didn't consider the barrier potential which is peculiar to diodes. This model takes that also in to account, hence it is more realistic.



Forward bias region
Battery → Constant barrier potential

Reverse bias region
OFF switch → Like an open circuit.

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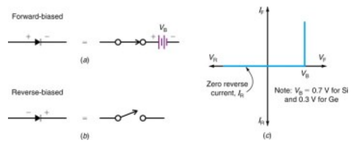
Model 2 : Near(Nearly) Ideal Diode Model

This approximation treats a forward-biased diode like an ideal diode in series with a battery.



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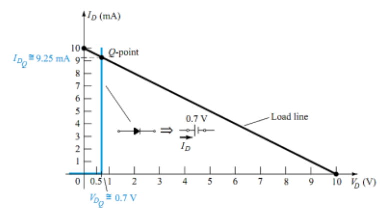
Nearly Ideal Diode Graphical Abstraction



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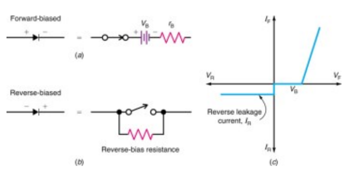
Model 3 : Three-piece Diode Model

- The third approximation of a diode includes the bulk resistance, r_B.
- The bulk resistance, r_B is the resistance of the p and n materials.



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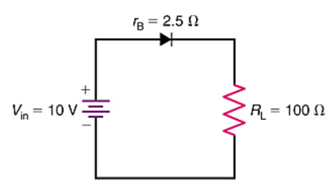
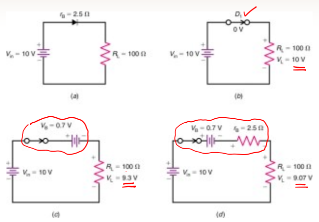
Tutorial Question:
Find the Load voltage using each model…



100



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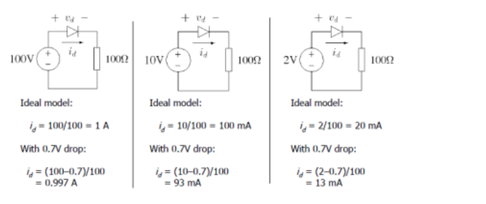
Tutorial Question : Circuit current? Which model to use?



% Error in each case?

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Which model to use?

The choice depends on the external voltage magnitudes.

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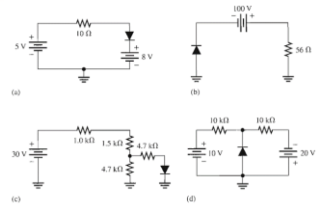
Tutorial Question

Find the potential across the diode in each circuit.

Use Near Ideal Model.



(a) −3 V (b) 0.7 V (c) 0.7 V (d) 0.7 V

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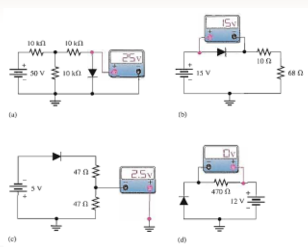
Troubleshooting…

Find the problem in each circuit



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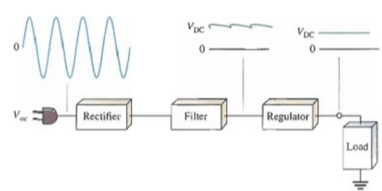
DC Power Supply

Block schematic diagram



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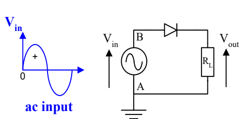
Diode as a Rectifier



(a) Half-wave rectifier

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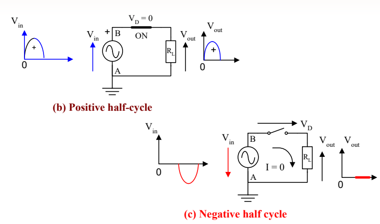
Half wave Rectifier (HWR)



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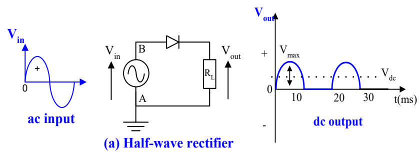
Half wave Rectifier



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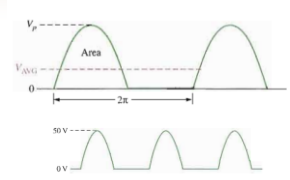
Average Voltage (DC Level)



$$V_{AVG} = \frac{V_p}{\pi} = \frac{50\text{ V}}{\pi} = 15.9\text{ V}$$

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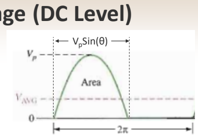
Average Voltage (DC Level)



$$v = V_p \sin\theta$$

$$V_{AVG} = \frac{\text{area}}{2\pi} = \frac{1}{2\pi}\int_0^{\pi} V_p \sin\theta \, d\theta = \frac{V_p}{2\pi}(-\cos\theta)\Big|_0^{\pi}$$

$$= \frac{V_p}{2\pi}[-\cos\pi - (-\cos 0)] = \frac{V_p}{2\pi}[-(-1) - (-1)] = \frac{V_p}{2\pi}(2)$$

$$V_{AVG} = \frac{V_p}{\pi}$$

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RMS value

$$V_{rms} = \sqrt{\frac{1}{T}\int_0^T v^2(t)dt}$$

$$= [\frac{1}{2\pi}[\int_0^{T/2} V_m^2 \sin^2 \omega t \, d(\omega t) + \int_{T/2}^{T} 0 d(\omega t)]^{1/2}$$

$$= [\frac{V_m^2}{2\pi}\int_0^{T/2} \sin^2 \omega t \, d(\omega t)]^{1/2}$$

$$\sin^2 \omega t = \frac{1}{2}(1-\cos 2\omega t),\ \omega T = 2\pi,\ \theta = \omega t$$

$$V_{rms} = [\frac{V_m^2}{4\pi}\int_0^{\pi}(1-\cos 2\theta)d\theta]^{1/2}$$

$$= [\frac{V_m^2}{4\pi}(t - \frac{1}{2}\sin 2\theta)\Big|_0^{\pi}]^{1/2}$$

$$= [\frac{V_m^2}{4\pi}(\pi - \frac{1}{2}\sin(2\pi) - 0 + \frac{1}{2}\sin 2(0)]^{1/2}$$

$$= [\frac{V_m^2}{4\pi}(\pi - 0 - 0 + 0)]^{1/2}$$

$$= \frac{V_m}{2}$$

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Form Factor

$$\text{Form Factor(F)} = \frac{\text{rms value}}{\text{average value}}$$

$$F = \frac{\frac{Vm}{2}}{\frac{Vm}{\pi}}$$

$$F = \frac{\pi}{2}$$

F = 1.52

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Efficiency at DC Load

η = (dc output power/total input power to load) x 100%

$$\eta = \frac{V_{dc}^2 / R_L}{V_{rms}^2 / R_L} = \frac{(V_m / \pi)^2}{(V_m / 2)^2} = \frac{4}{\pi^2} = 0.406$$

or

$$\eta = 40.6\%$$

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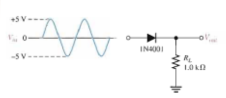
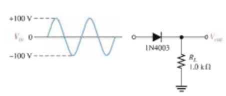
Ex: Find Average Voltage (DC Level)



$V_{p(out)} = V_{p(in)} - 0.7\text{ V} = 5\text{ V} - 0.7\text{ V} = \mathbf{4.30\text{ V}}$



$V_{p(out)} = V_{p(in)} - 0.7\text{ V} = 100\text{ V} - 0.7\text{ V} = \mathbf{99.3\text{ V}}$

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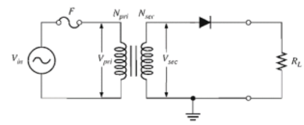
With Transformer Coupling



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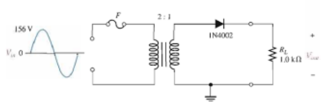
With Transformer Coupling



$V_{p(out)} = V_{p(sec)} - 0.7\text{ V} = 78\text{ V} - 0.7\text{ V} = \mathbf{77.3\text{ V}}$

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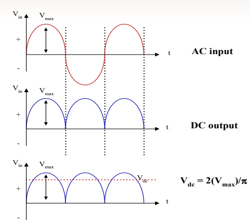
Full Wave Rectifier



AC input and DC output voltage waveforms

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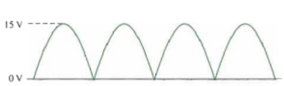
Example…



$V_{AVG} = \frac{2V_p}{\pi} = \frac{2(15\text{ V})}{\pi} = \mathbf{9.55\text{ V}}$

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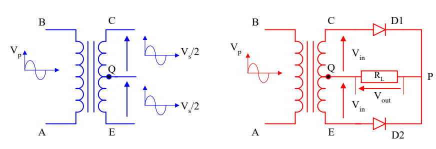
Diode in a Full Wave Rectifier



Center tapped transformer type

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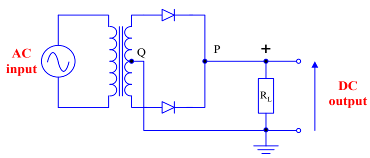
Diode in a Full Wave Rectifier



Centre-tapped transformer type full-wave rectifier giving a dc output across a load resistor R_L

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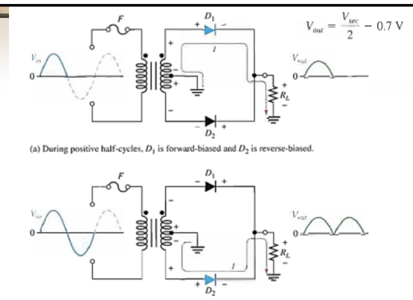

(a) During positive half-cycles, D_1 is forward-biased and D_2 is reverse-biased.

(b) During negative half-cycles, D_2 is forward-biased and D_1 is reverse-biased.

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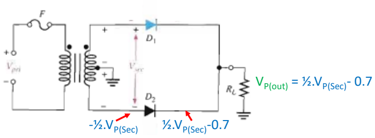
Peak Inverse Voltage of Each Diode



PIV $= V_{P(Sec)} - 0.7 \quad = 2V_{P(out)} + 0.7$

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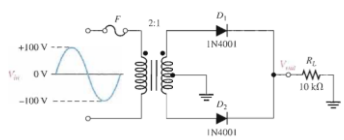
Tutorial Question: Find PIV of the diodes



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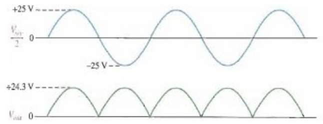
Solution



$PIV = 2V_{p(out)} + 0.7\text{ V} = 2(24.3\text{ V}) + 0.7\text{ V} = \mathbf{49.3\text{ V}}$

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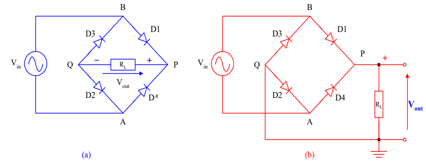
Bridge Type Full Wave Rectifier



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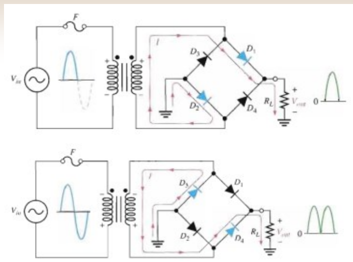
Current flow during positive half cycle

Current flow during negative half cycle



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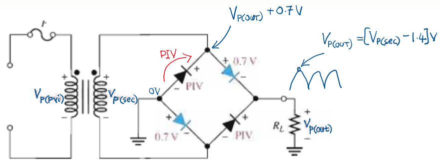
Peak Inverse Voltage of Each Diode



$$PIV = [V_{P(out)} + 0.7] V$$
$$= [V_{P(sec)} - 0.7] V$$

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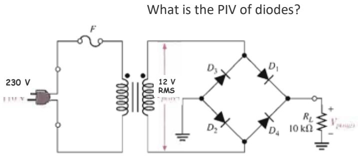
Tutorial Question :

What is the PIV of diodes?



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Ex. Rectification Methods Comparison

	HWR	FWR - Bridge	FWR - Transformer
No. of diodes			
PIV rating of each diode			
Average out put voltage			
Average diode current			

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Ex. Rectification Methods Comparison

	HWR	FWR - Bridge	FWR - Transformer
No. of diodes	1	4	2
PIV rating of each diode	$V_{P(out)} + 0.7$	$V_{P(out)} + 0.7$	$2V_{P(out)} + 0.7$
Average out put voltage	$\frac{V_{P(out)}}{\pi}$	$\frac{2V_{P(out)}}{\pi}$	$\frac{2V_{P(out)}}{\pi}$
Average diode current	$\frac{V_{P(out)}}{\pi R_L}$	$\frac{2V_{P(out)}}{\pi R_L}$	$\frac{2V_{P(out)}}{\pi R_L}$

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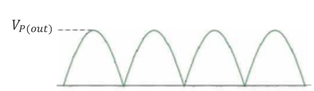
Ripple Factor of a pulsating DC signal



$$\gamma = \frac{V_{ac}}{V_{DC}}$$

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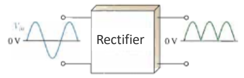
Ripple Factor at the Rectifier Output



$$HWR\ RF = \sqrt{\left[\frac{\frac{V_{P(out)}}{2}}{\frac{V_{P(out)}}{\pi}}\right]^2 - 1} = 1.21$$

$$V_{rms} = \sqrt{(V_{DC})^2 + (V_{ac})^2}$$

$$FWR\ RF = \sqrt{\left[\frac{\frac{V_{P(out)}}{\sqrt{2}}}{\frac{2V_{P(out)}}{\pi}}\right]^2 - 1} = 0.48$$

$$\frac{V_{ac}}{V_{DC}} = \sqrt{\left[\frac{V_{rms}}{V_{DC}}\right]^2 - 1}$$

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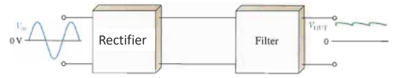
Connecting a Smoothing Circuit



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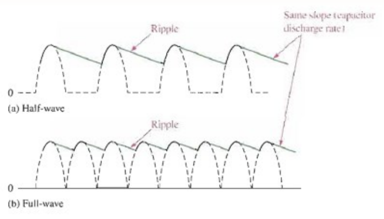
Smoothing by a capacitor filter



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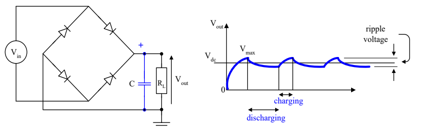
E.g. Consider a FWR with a capacitor smoothing circuit



(b) Full-wave rectifier with a smoothing capacitor

(b) Rectifier output with the capacitor

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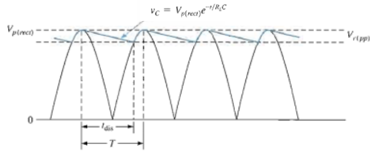
Ripple Voltage

$$v_C = V_{p(rect)}e^{-t/R_LC}$$

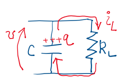


$$i_L = C\frac{dv}{dt}$$

$V_{r(pp)}$

T

$$\frac{V_{p(rect)}}{R_L}$$



$$q = cv$$

$$\frac{dq}{dt} = c \cdot \frac{dv}{dt}$$

$$\frac{V_{p(rect)}}{R_L} = c.f.\ V_{r(pp)}$$

$$\boxed{V_{r(pp)} = \frac{V_{p(rect)}}{c.f.R_L}}$$

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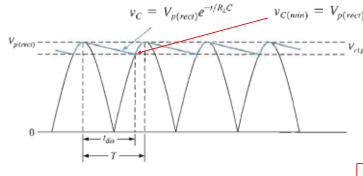
Ripple Voltage

$$v_C = V_{p(rect)}e^{-t/R_LC} \qquad v_{C(min)} = V_{p(rect)}e^{-T/R_LC}$$



$$e^x = 1 + \frac{x}{1!} + \cancel{\frac{x^2}{2!}} + \cancel{\frac{x^3}{3!}} + \cancel{\frac{x^4}{4!}} + \ldots\ldots$$

$x <<$

$$v_{C(min)} = V_{p(rect)}\left(1 - \frac{T}{R_LC}\right)$$

$$\boxed{V_{r(pp)} \cong \left(\frac{1}{fR_LC}\right)V_{p(rect)}}$$

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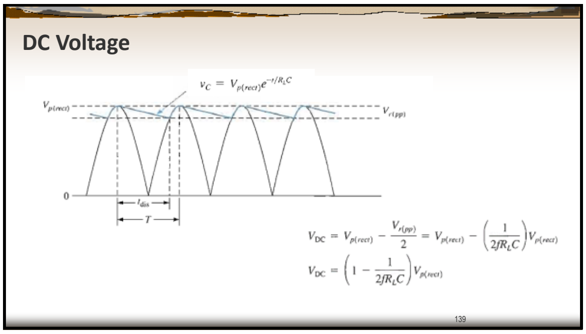

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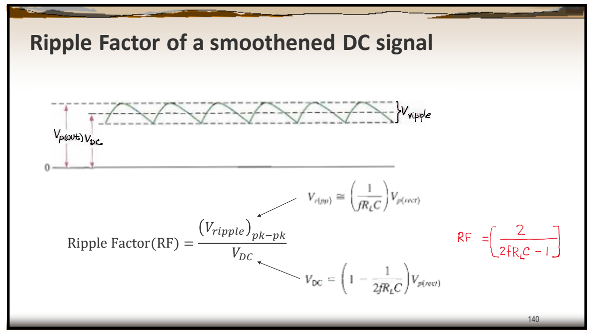

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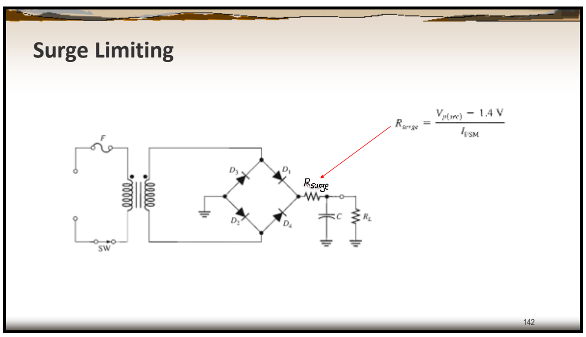

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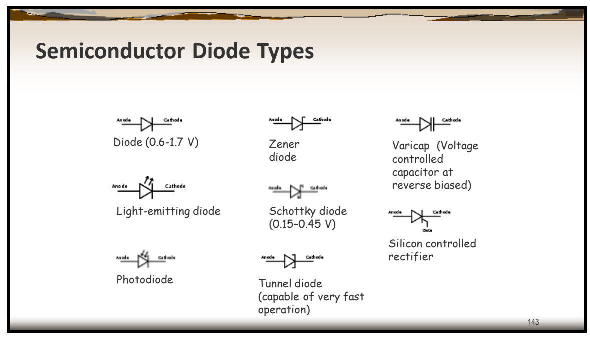

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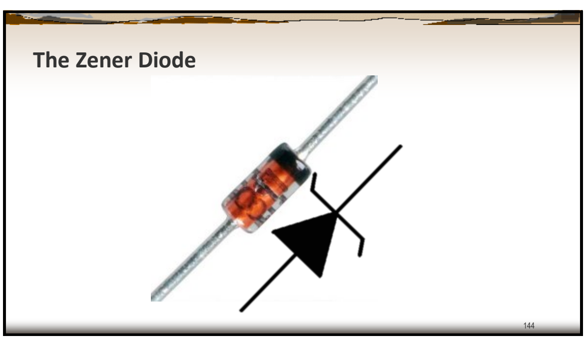

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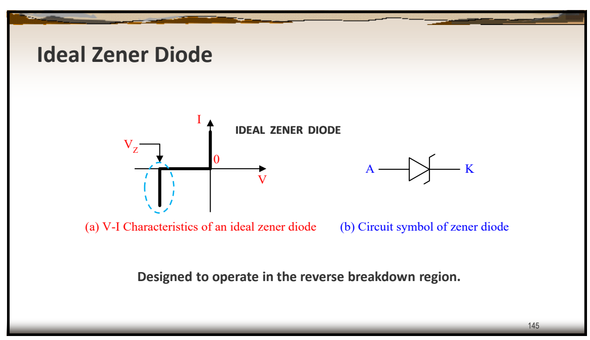

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The Zener Diode

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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