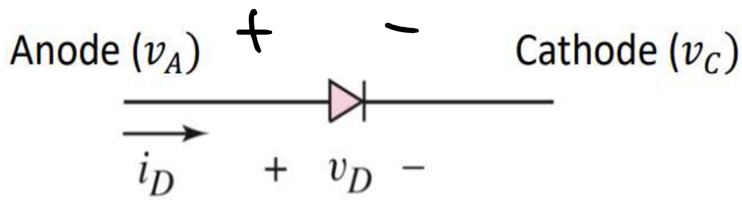
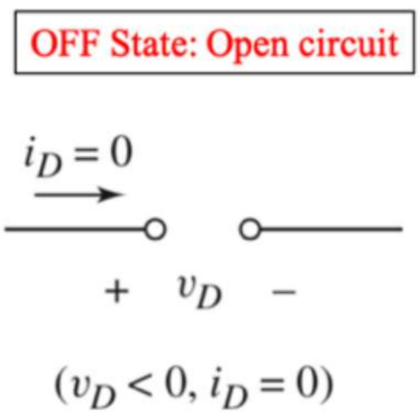
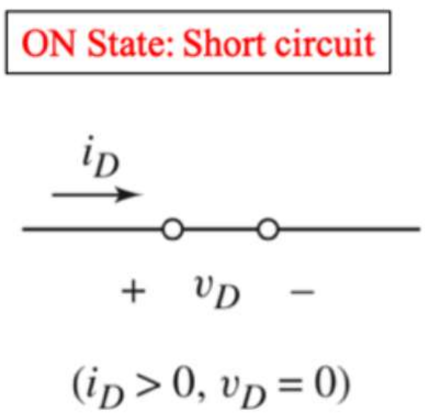
Lecture 9

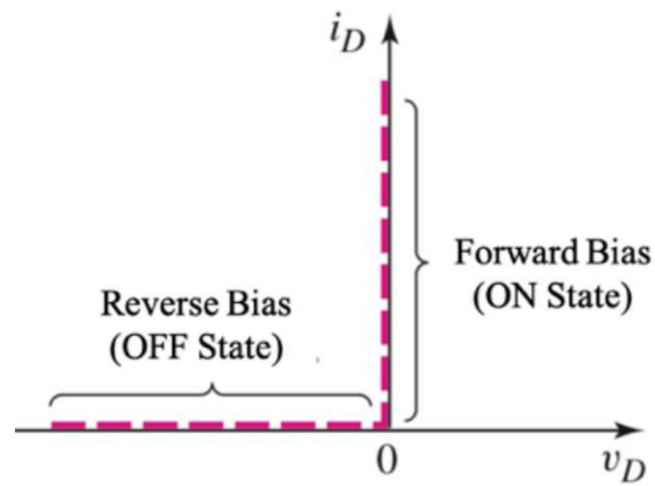
Rectifiers & Filtering

Ideal Diode Model

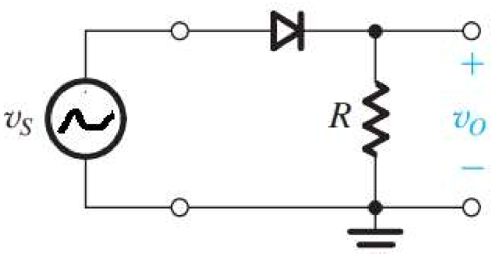


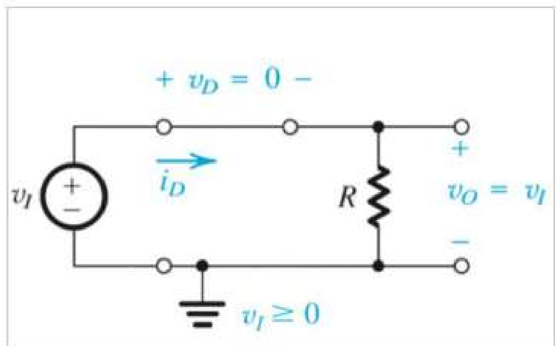


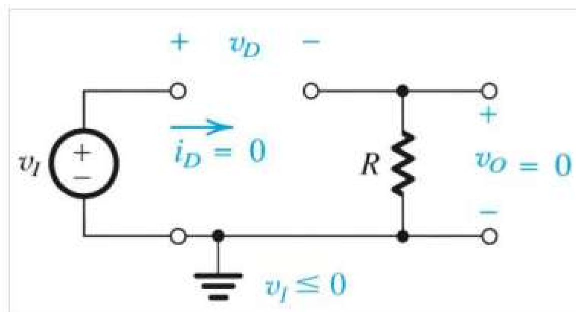


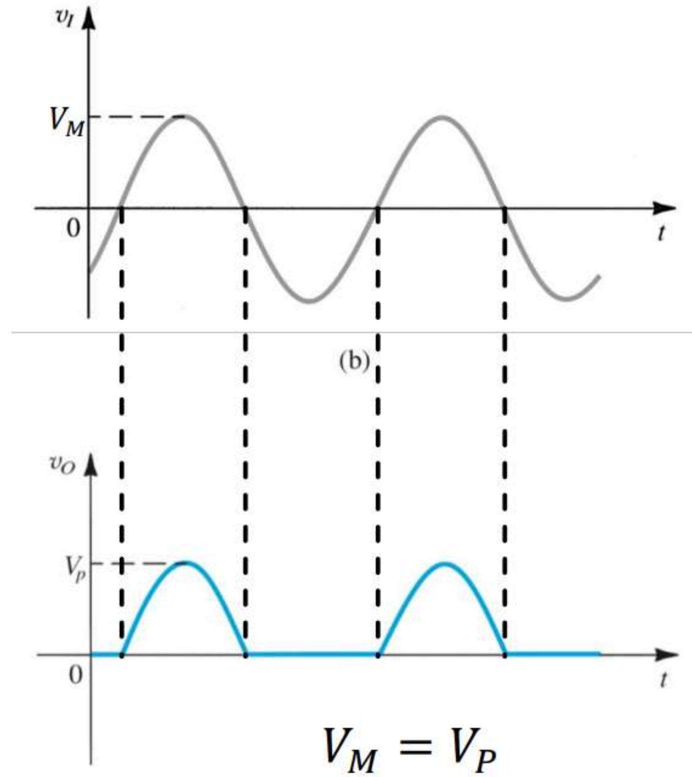


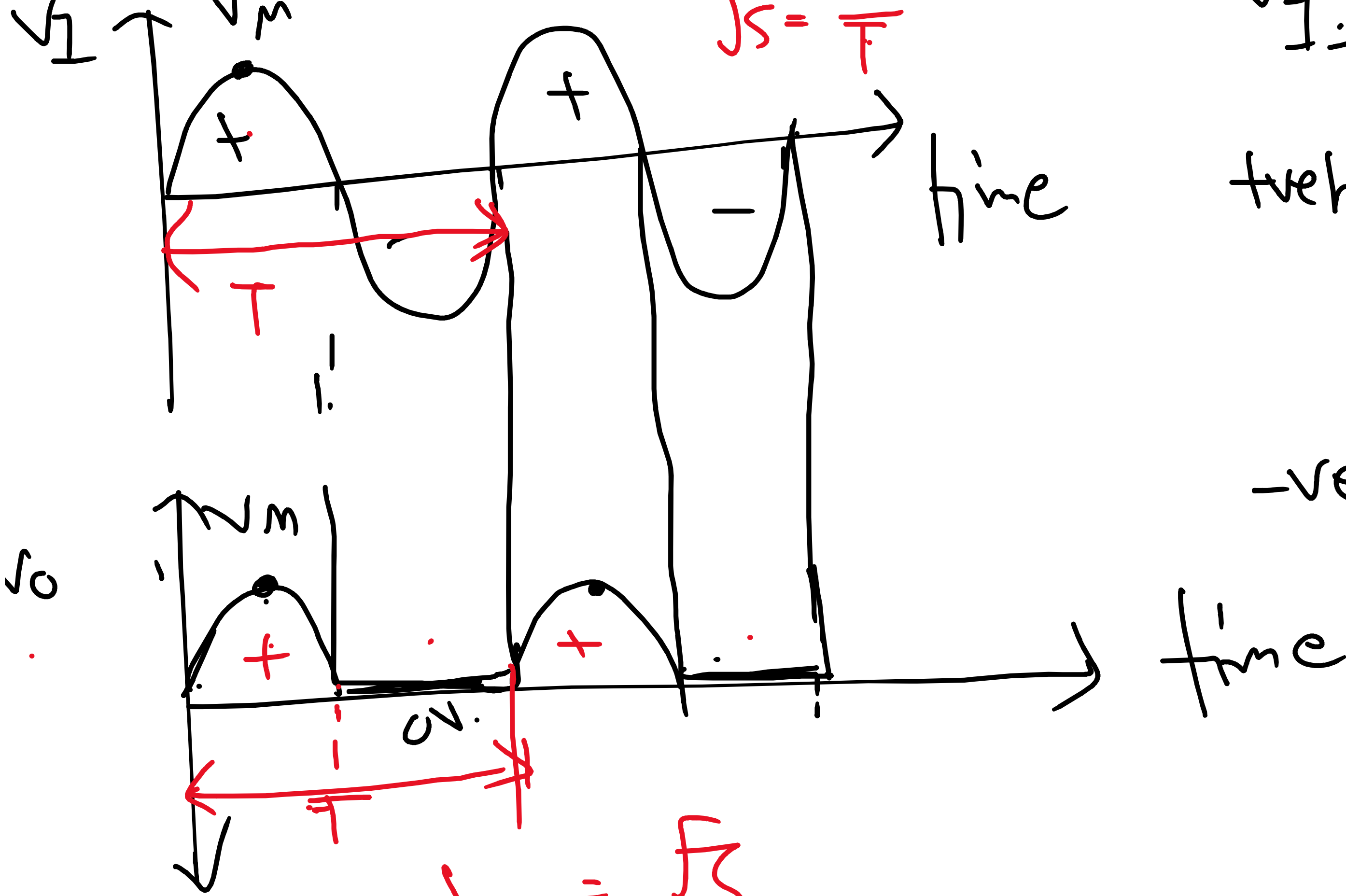
Half-wave rectifier (ideal diode model)











$f_s = \frac{1}{T}$

$f_o = \frac{1}{T} = f_s$

$v_I = V_m \sin(\omega t)$

+ve half → $V_I > 0$ → on

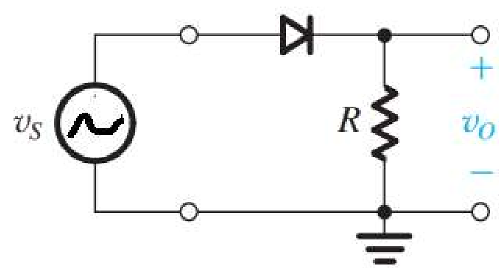
$\boxed{V_o = V_I}$

−ve half → $V_I < 0$ →

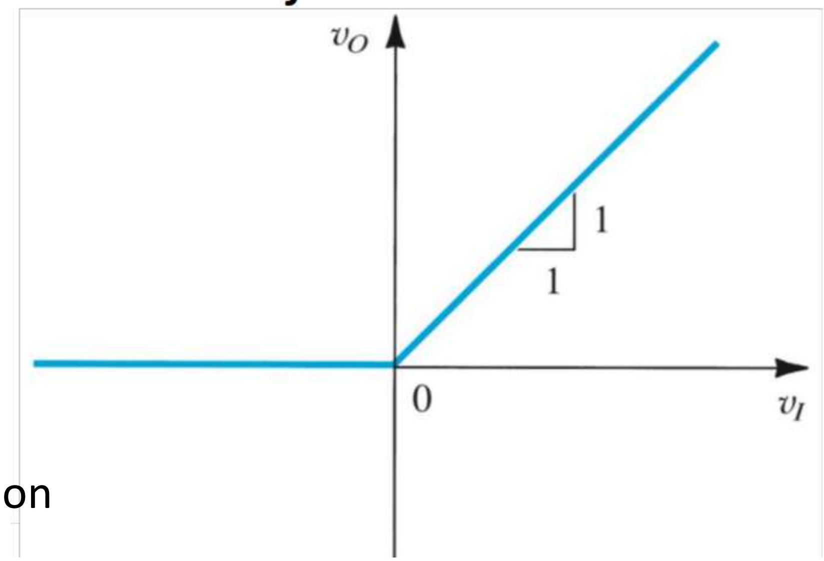
$V_D < 0$ → off

$V_o = 0V$

Half-wave rectifier (ideal diode model)



Transfer Characteristics

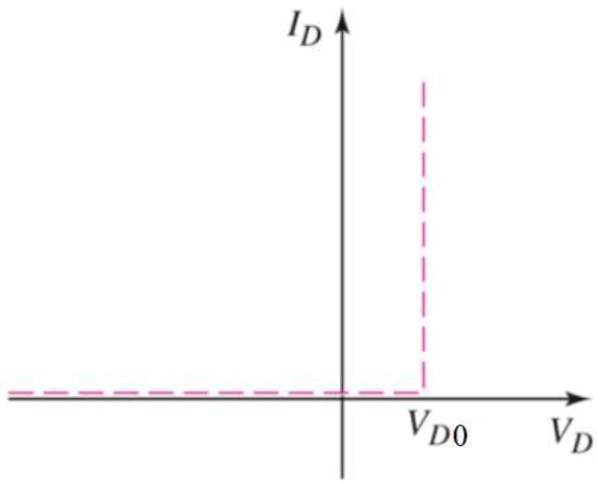


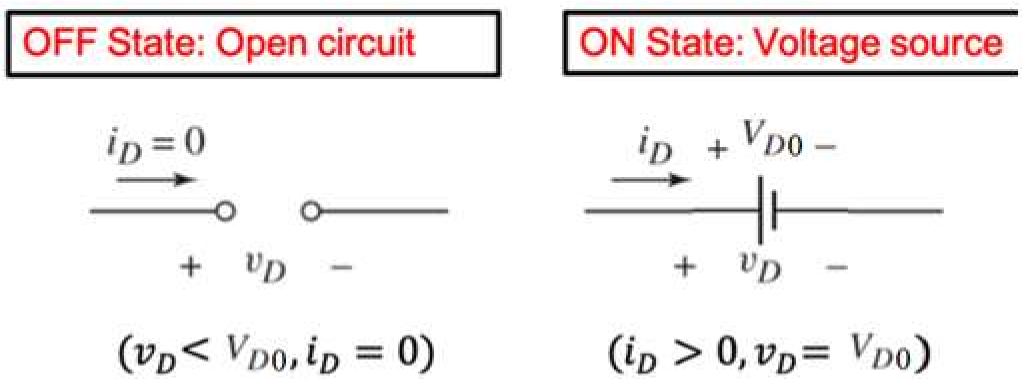
When Vi>0, Diode on→ Vo= Vi→ y=mx type relation where slope, m= 1

Vi<0, Diode off→ Vo= 0 V

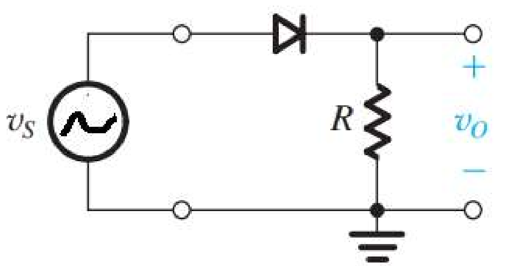
Modeling the real diode

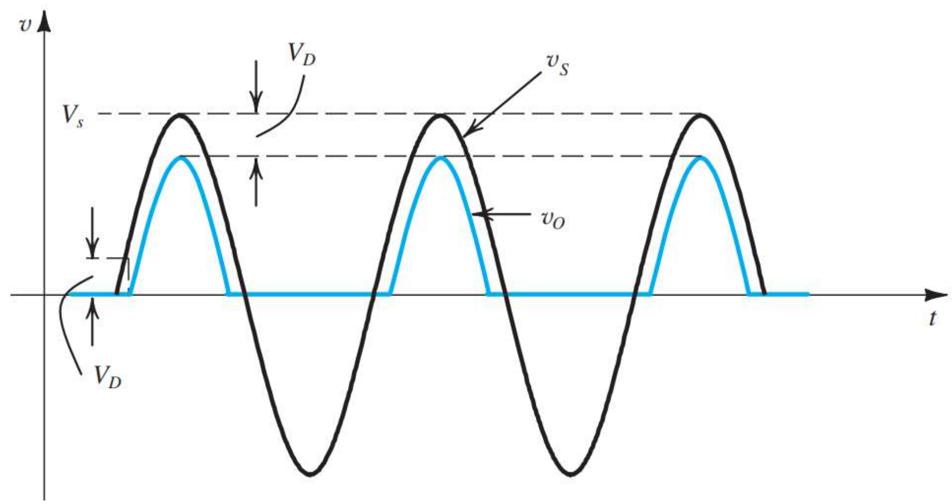
Constant voltage drop (CVD) model

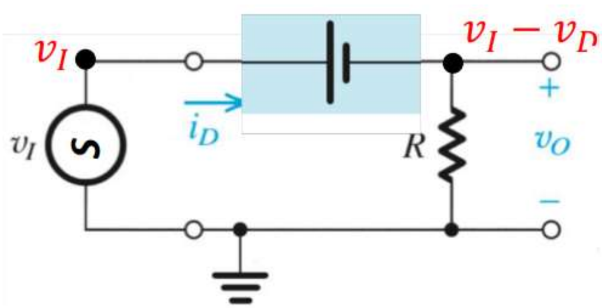




Half-wave rectifier (CVD model)







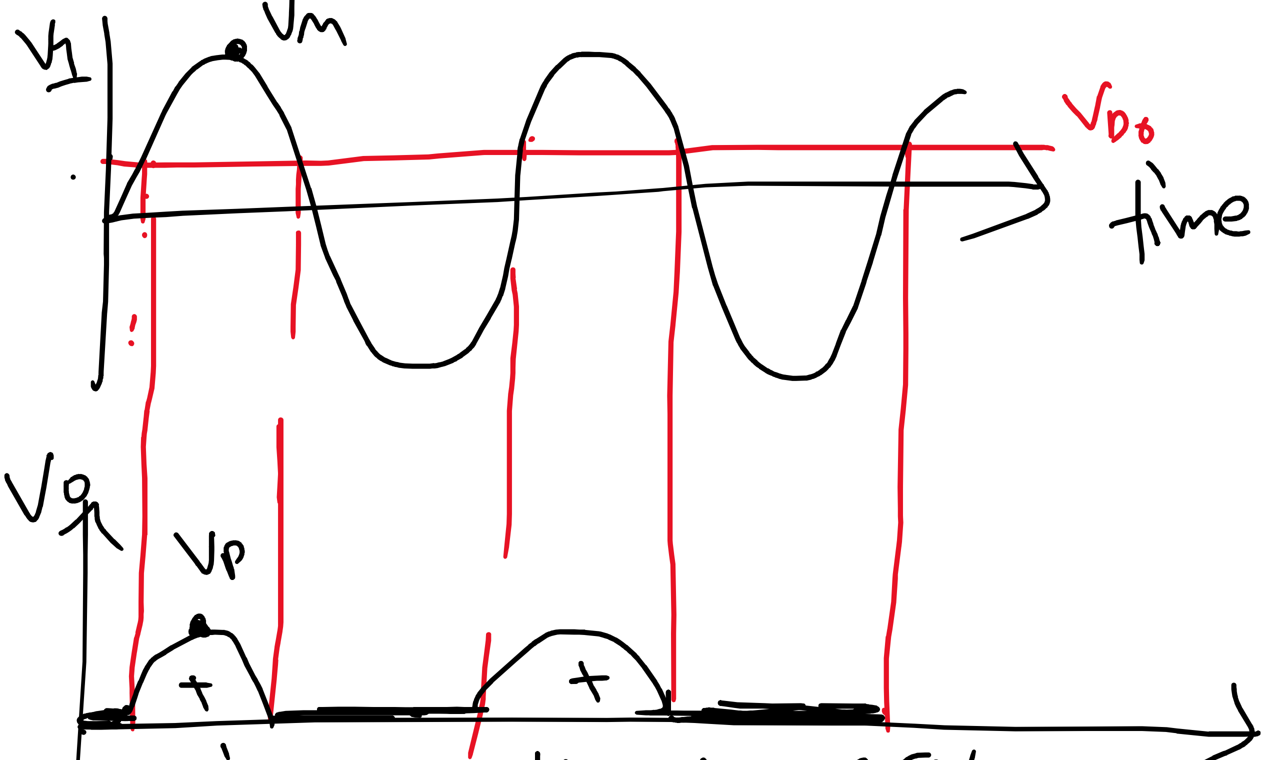
$$v_I = V_M \sin \omega t$$

$$v_o = V_M \sin \omega t - V_D$$

$$V_p = peak\ of\ output$$

$$= V_M - V_D$$

Half-wave rectifier (CVD model)



$v_i = 3\sin(\omega t)$, $V_{D0} = 0.6V$

$V_p = V_m - V_{D0} = 3 - 0.6 = 2.4V$

$V_o = V_I - V_D$

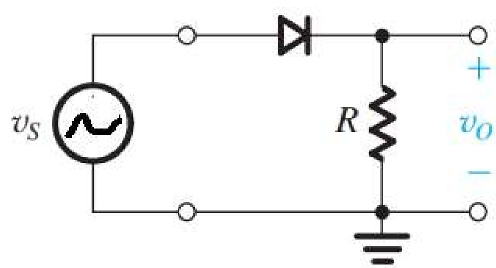
$V_o = 0V$

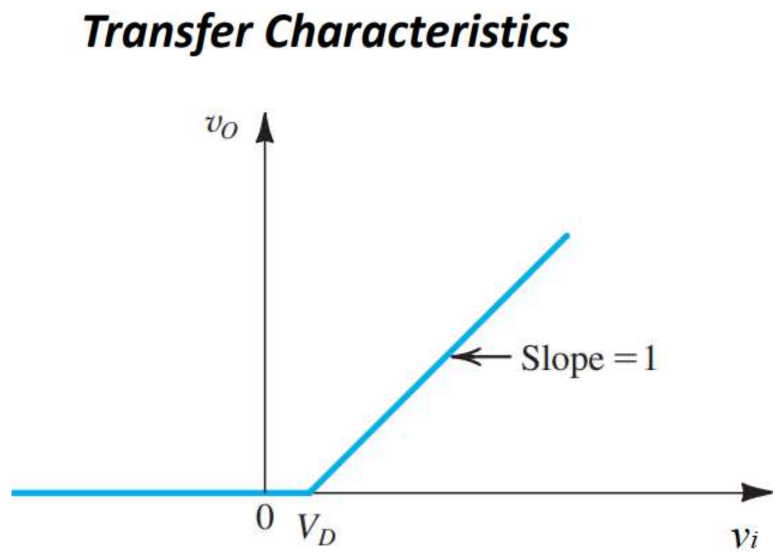
$V_I < V_{D0} \rightarrow$ off $\rightarrow$ $V_o = 0V$

$V_I > V_{D0} \rightarrow$ $\boxed{V_o = V_I - V_D}$

$\boxed{V_p = V_m - V_{D0}}$

Half-wave rectifier (CVD model)

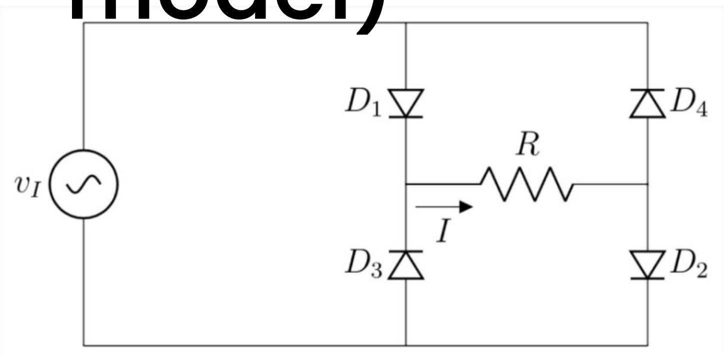


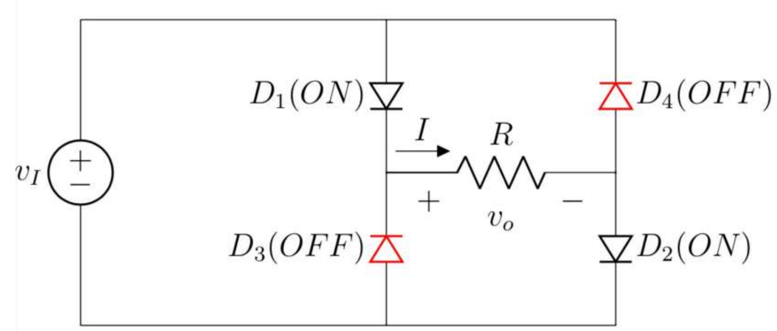


When $V_i > V_{D0}$, Diode on→ $V_o = V_i - V_{D0}$→ $y=mx+c$ type relation where slope, $m = 1$

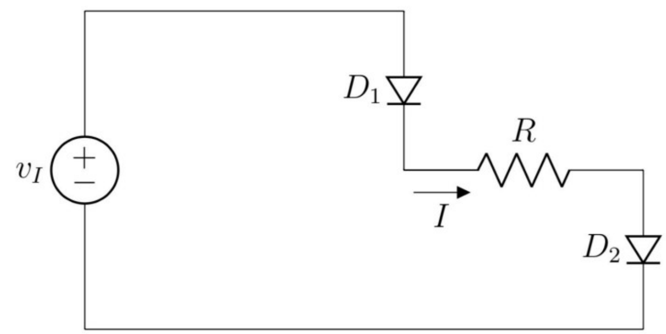
$V_i < V_{D0}$, Diode off→ $V_o = 0$ V

Full-wave rectifier (ideal diode & CVD model)



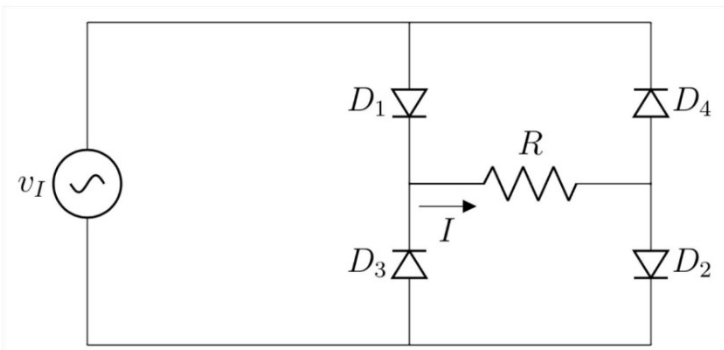


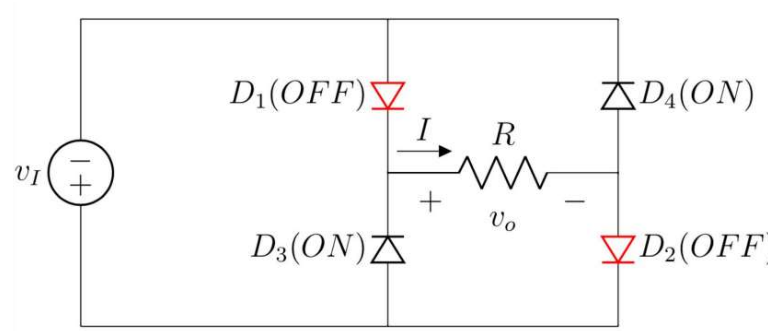
(+) half-cycle



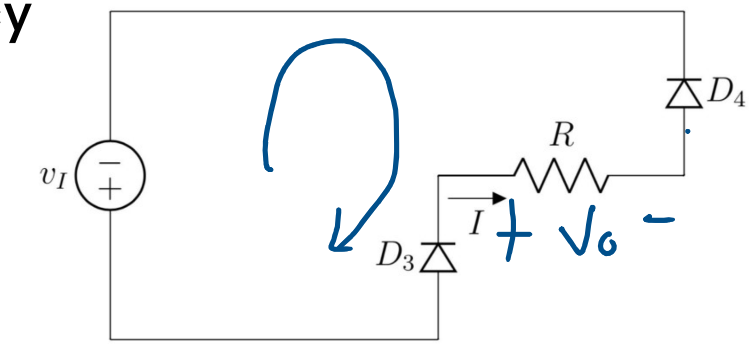
$$v_o = v_I - 2V_D$$

Full-wave rectifier (ideal diode & CVD model)



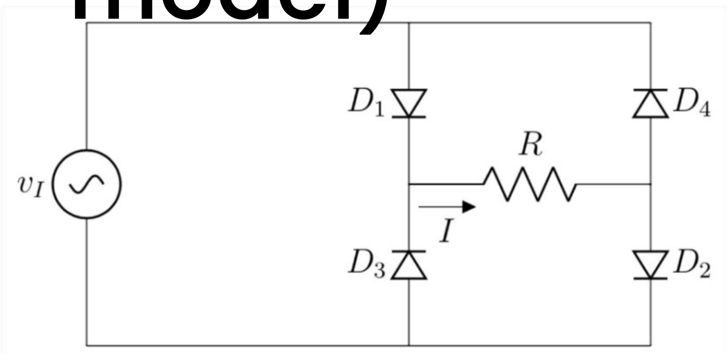


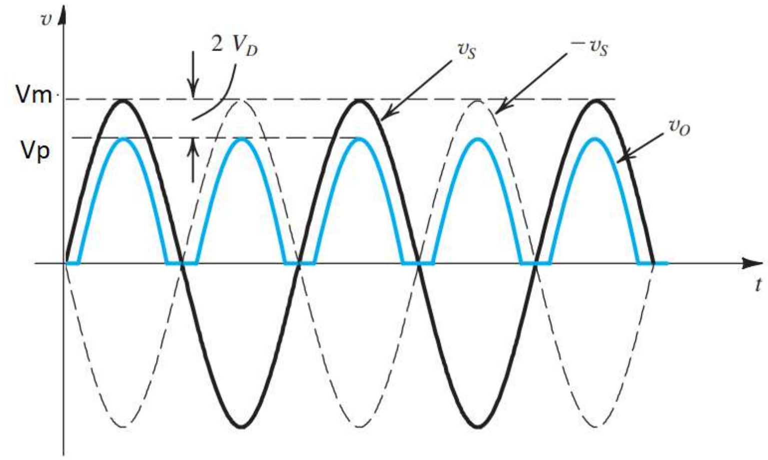
(-) half-cy



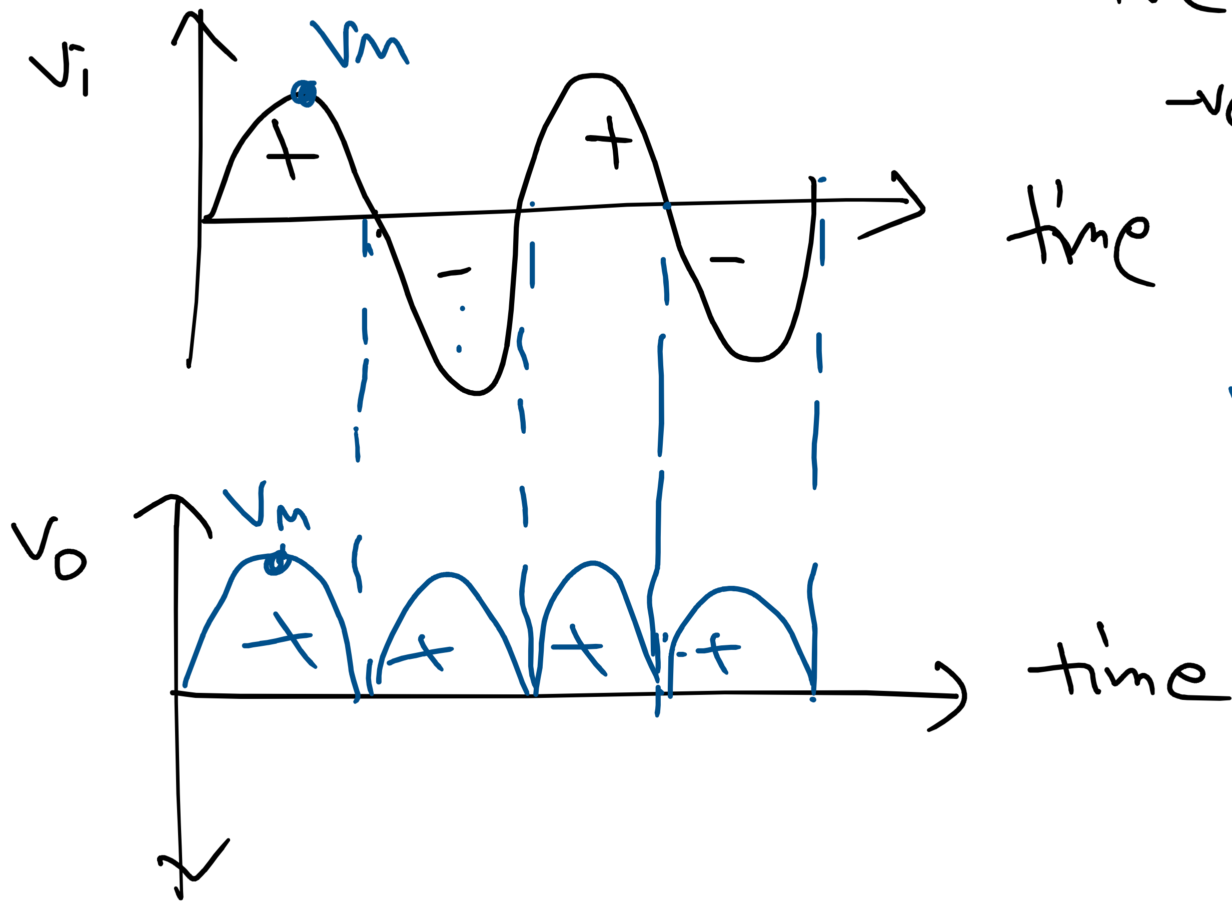
$$v_o = +v_I - 2V_D$$

Full-wave rectifier (ideal diode & CVD model)





Ideal



+ve half → $V_o = V_1$

−ve half → $V_o = -V_1$

$V_p = V_m$

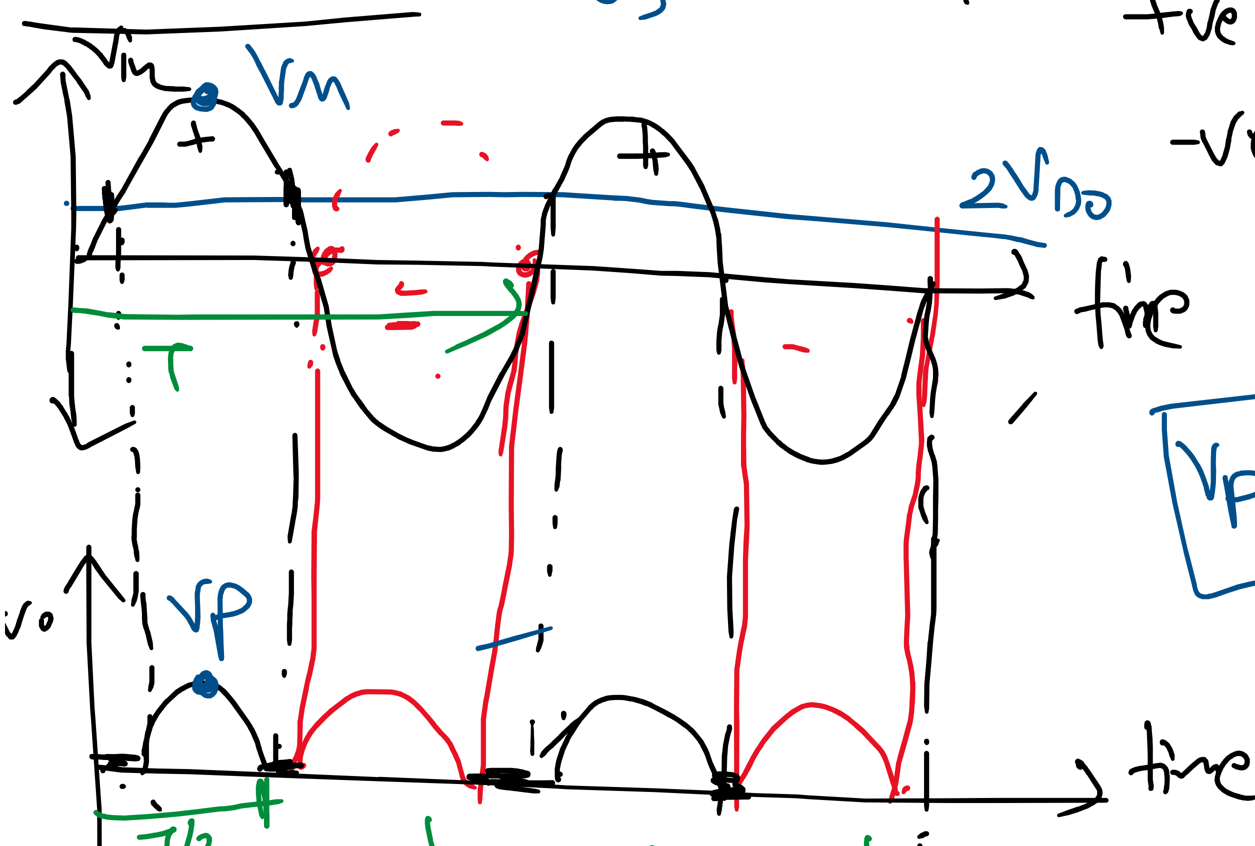
CVD model

f_s

$V_i > 2V_{D0}$

+ve half $\rightarrow V_o = V_i - 2V_{D0}$

−ve " $\rightarrow V_o = -V_i - 2V_{D0}$

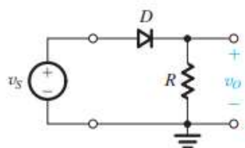


$$\boxed{V_p = V_m - 2V_{D0}}$$

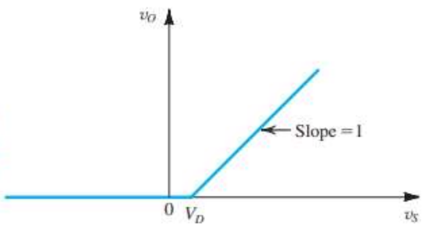
$$f_o = \frac{1}{T/2} = \frac{2}{T} = 2 \cdot \frac{1}{T} = 2f_s$$

$$\boxed{f_o = f_s}$$

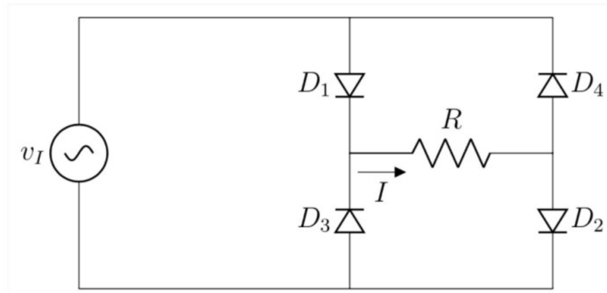
Half-wave and Full-wave rectifier



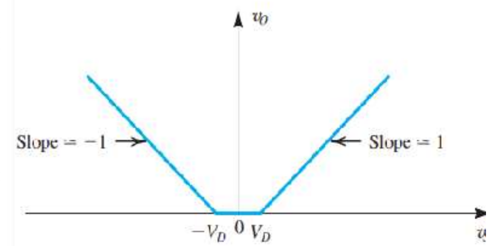
(a)



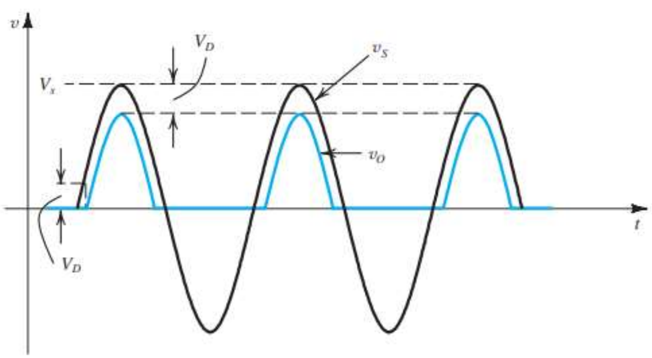
(b)



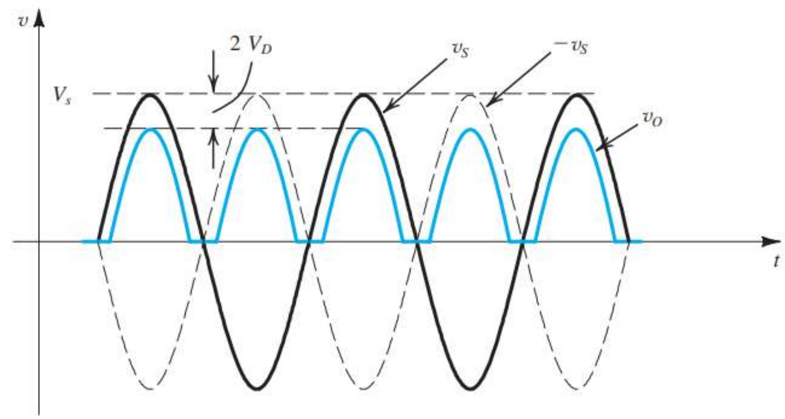
(a)



(b)



(c)



Half-wave

Full-wave

$V_{in} = 5\sin(200\pi t) \longrightarrow V_m \sin(\omega t)$

$HW \to (CVD) \to V_p,\ f_o = ?$ $\quad V_{DO} = 0.3V$

$FW \to (CVD) \to V_p,\ f_o = ?$

a) HW

$\omega = 2\pi f$, $V_m = 5V$

$\omega = 200\pi = 2\pi f_s \therefore f_s = \dfrac{200\pi}{2\pi} = 100\,Hz$

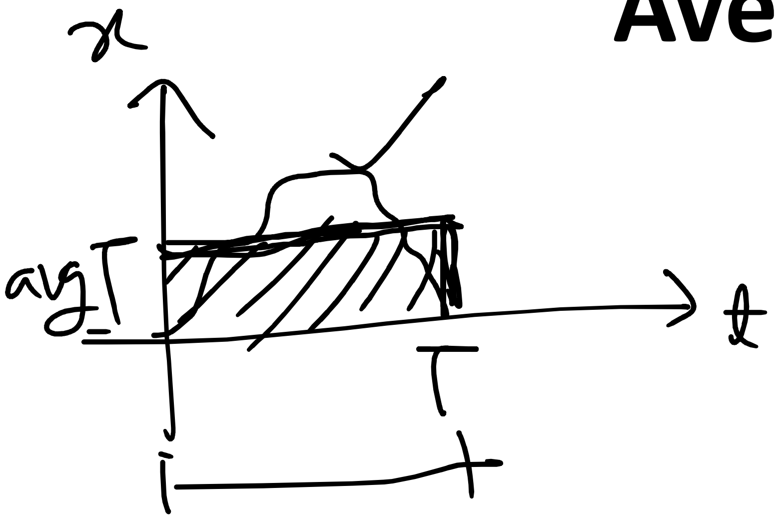
$V_p = V_m - V_{DO} = 5 - 0.3 = 4.8V.$

b) FW

$f_o = 2f_s = 200\,Hz,\ V_p = V_m - 2V_{DO}$

$= 5 - 2\times0.3 = 4.4V$

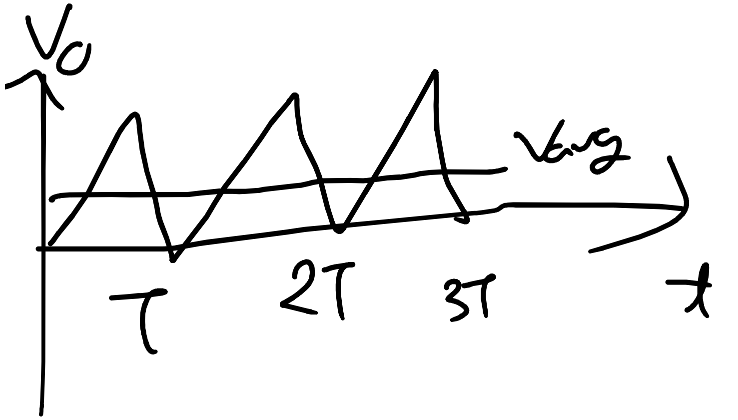
Average Value



$$\text{area} = \int_0^T x \, dt$$

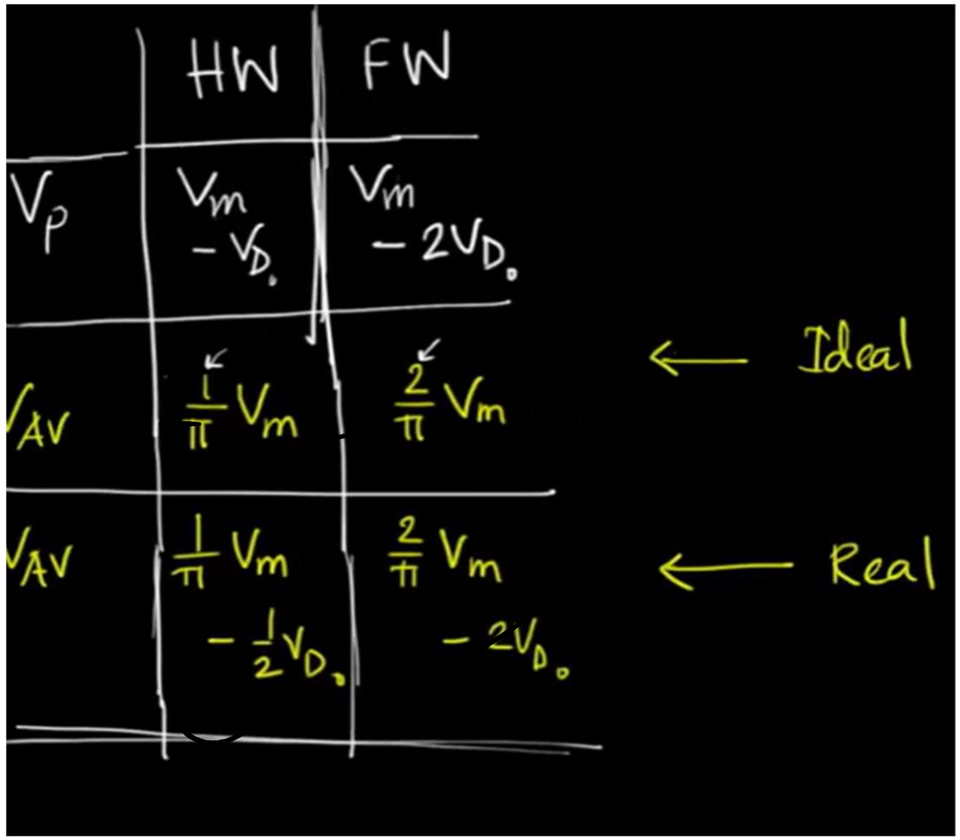
$$\text{area} = \text{avg} \times T = \int_0^T x \, dt$$

$$\Rightarrow \text{avg} = \frac{1}{T} \int_0^T x \, dt$$

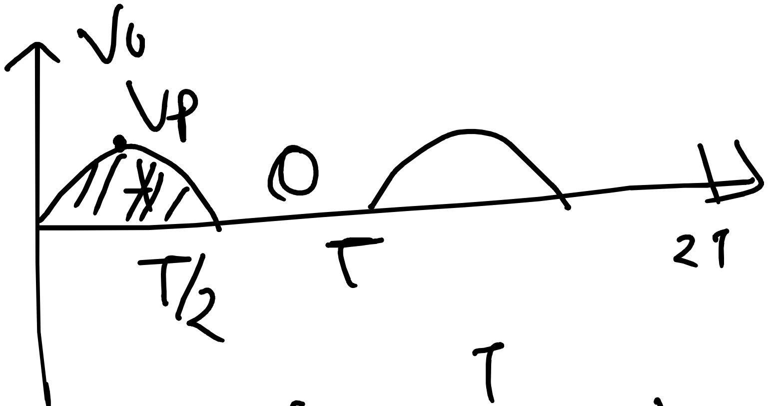


$$\boxed{V_{avg} = \frac{1}{T} \int_0^T v_o \, dt}$$

Average Value of Rectifier Output



Average Value of HW Rectifier Output (Ideal)



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

diode on → $V_o = V_{in}$

" off → $V_o = 0V$

$$\text{avg} = \frac{1}{T}\int_0^T V_o\,dt = \frac{1}{T}\int_0^T V_{in}\,dt$$

$$= \frac{1}{T}\int_0^{T/2} V_m \sin\omega t \quad dt$$

$$w = 2\pi f = \frac{2\pi}{T}$$

Average Value of HW Rectifier Output (Ideal)

$$= \frac{V_m}{T} \times \frac{-1}{\omega} \left[\cos \omega t\right]_0^{T/2}$$

$$= \frac{V_m}{\cancel{T}} \times \frac{-\cancel{T}}{2\pi} \left[\cos \frac{2\pi}{T} \times \frac{T}{2} - \cos 0\right]$$

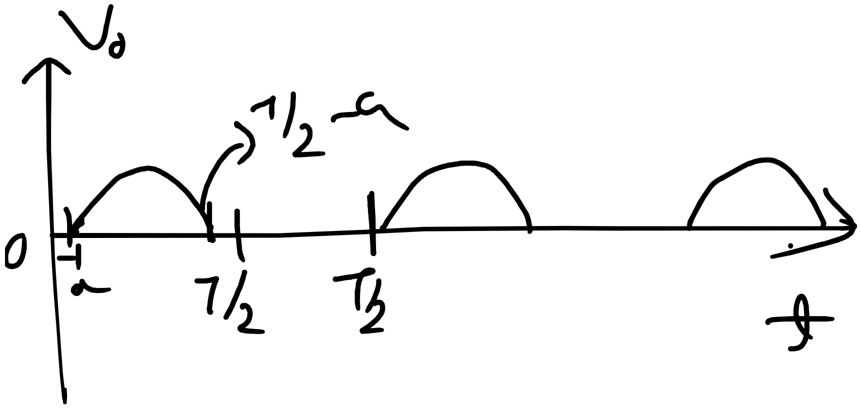
$$\left[\cos \pi - 1\right]$$

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

$$= \frac{-V_m}{2\pi} \times \left[-1 - 1\right] = \frac{-V_m}{2\pi} \times -2$$

$$\boxed{V_{avg} = \frac{V_m}{\pi}}$$

Average Value of HW Rectifier Output (CVD)



$$v_o = v_{in} - V_{D0}$$

$$\text{avg} = \frac{1}{T}\int_0^{T} v_o \, dt$$

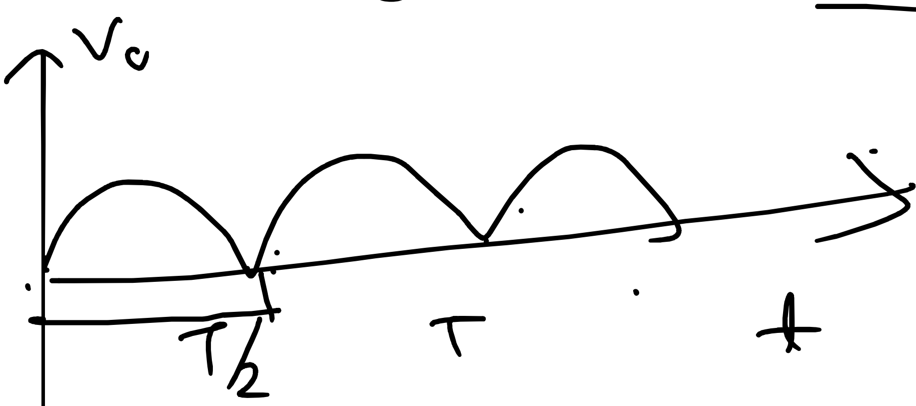
$$= \frac{1}{T}\int_0^{T/2} v_{in} - V_{D0} \, dt$$

$$= \frac{1}{T}\int_0^{T/2} V_m \sin\omega t - V_{D0} \, dt$$

$$= \frac{V_m}{\pi} - \frac{1}{T}\int_0^{T/2} V_{D0}$$

$$\boxed{= \frac{V_m}{\pi} - \frac{V_{D0}}{2}}$$

Average Value of FW Rectifier Output (ideal)



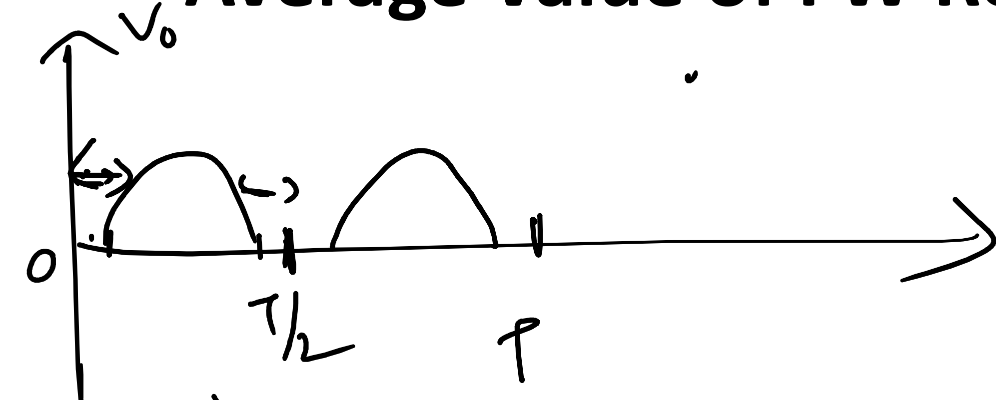
$$\boxed{V_o = V_m}$$

$$avg = \frac{1}{(T/2)} \int_0^{T/2} v_{in}\, dt$$

$$= \frac{2}{T} \int_0^{T/2} V_m \sin \omega t \; dt$$

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

Average Value of FW Rectifier Output (CVD)



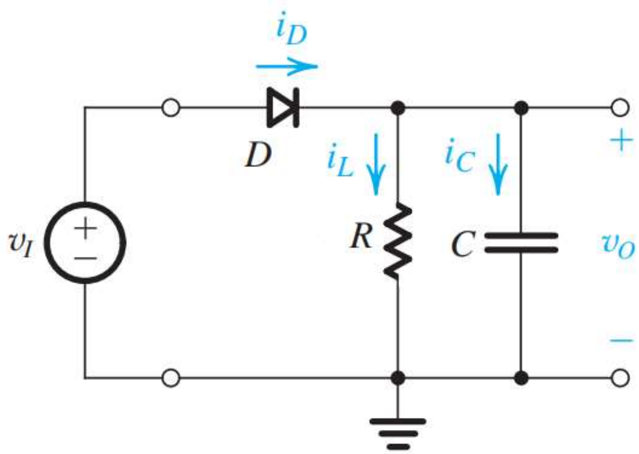
$$V_o = V'_m - 2V_{Do}$$

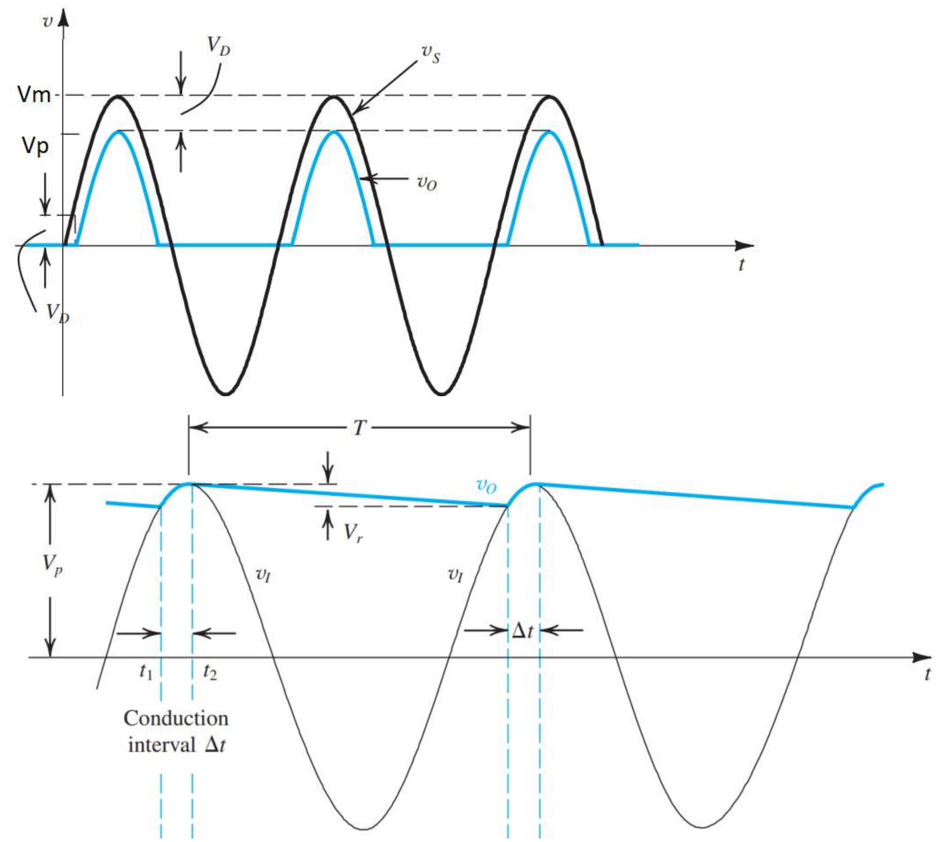
$$avg = \frac{1}{(T/2)} \int_0^{T/2} v_o \, dt$$

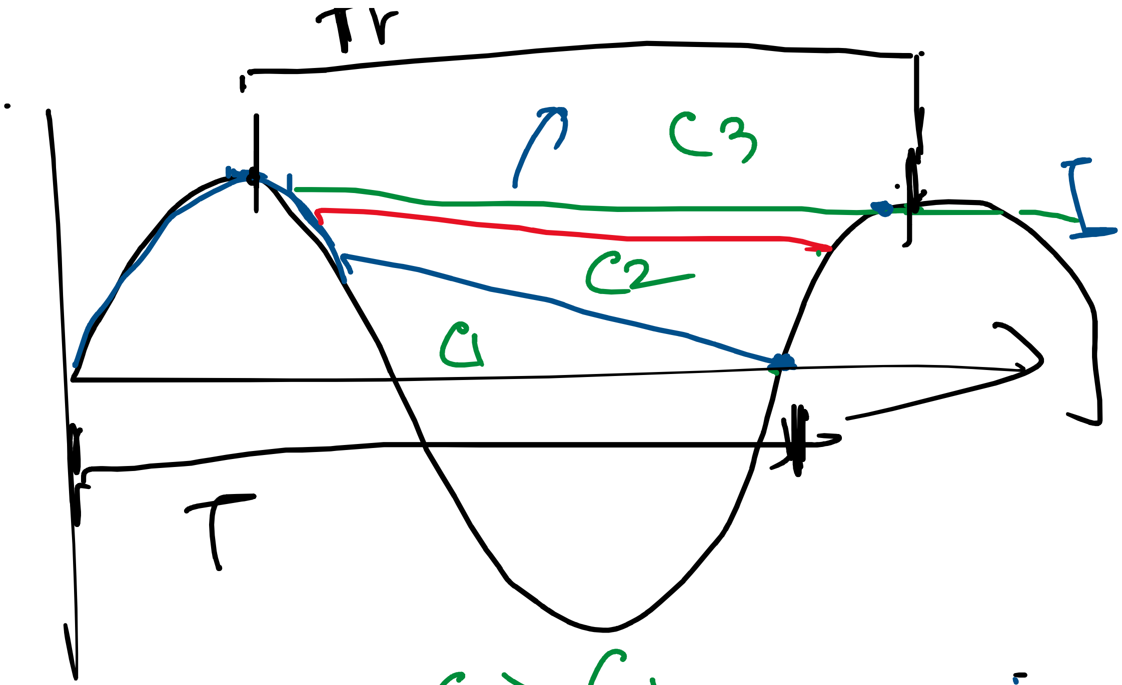
$$= \frac{2}{T} \int_0^{T/2} (V'_m - 2V_{Dc}) \, dt$$

$$= \boxed{\frac{2V_m}{\pi} - 2V_{Do}}$$

Filtering: Half-wave rectifier







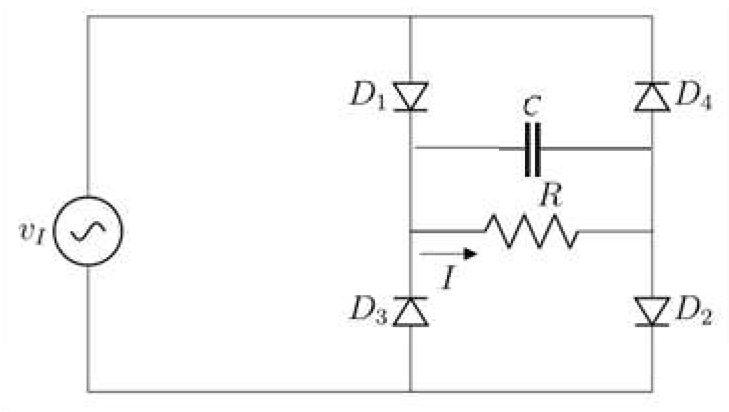
a) C_1, C_2, C_3

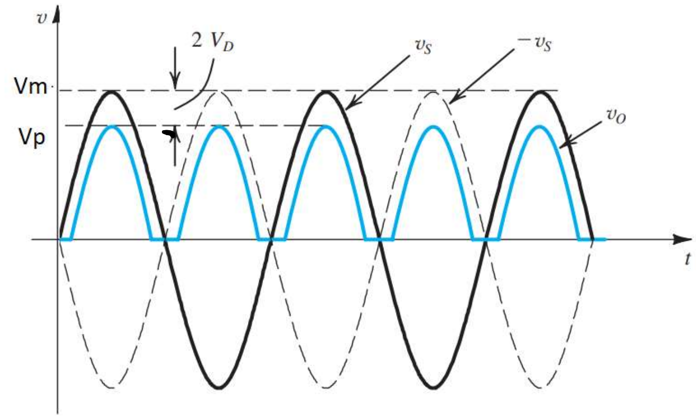
b) which capacitor?

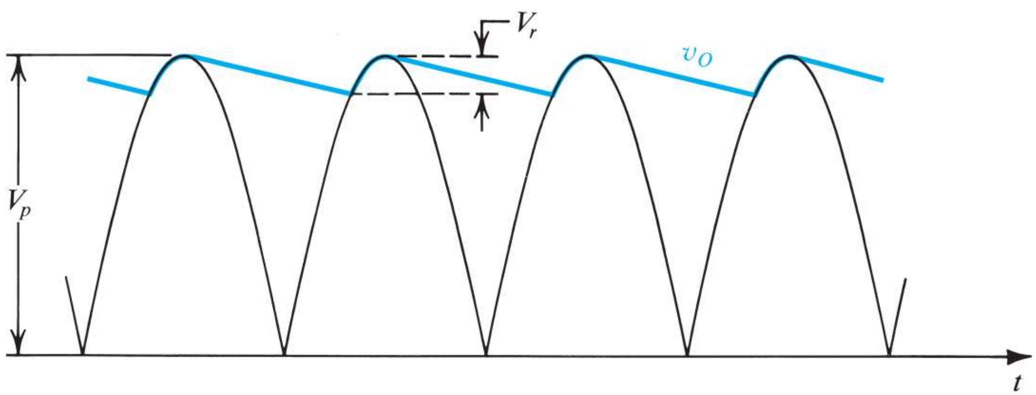
a) $C_3 > C_2 > C_1$

b) C_3

Filtering: Full-wave rectifier







From Microelectronic Circuits by Adel S. Sedra & Kenneth C. Smith: Chapter 4. 7th edition. Published by Oxford University Press. Used for educational purposes only.

Without capacitor

Rectifier	i/p peak	o/p peak	average
H/W	V_M	V_P	$V_{avg}=V_{DC}=\frac{1}{\pi}V_M-\frac{1}{2}V_{Do}$
F/W	V_M	V_P	$V_{avg}=V_{DC}=\frac{2}{\pi}V_M-2V_{Do}$

With capacitor

Rectifier	i/p peak	o/p peak	frequency	Ripple voltage	average
H/W	V_M	$V_P=V_M-V_{Do}$	$f_r=f_i$	$V_r=\frac{V_P}{f_r R C}$	$V_{avg}=V_{DC}=V_P-\frac{1}{2}V_r$
F/W	V_M	$V_P=V_M-2V_{Do}$	$f_r=2f_i$	$V_r=\frac{V_P}{f_r R C}$	$V_{avg}=V_{DC}=V_P-\frac{1}{2}V_r$

$$I_{o,avg}=V_{o,avg}/R,\ V_{rms}=V_p/\sqrt{2}$$

Example

A voltage waveform $v_i = 8sin(2000\pi t)V$ is input to a full-wave rectifier. A resistance of $R = 50k\ \Omega$ is connected at the load. [Assume that the diodes used in the circuit have a forward drop of 0.8V].

(a) Draw the circuit of the full wave rectifier. Label the input and output voltages properly. [1]

(b) Draw the waveforms of the input and output voltages. What are the peak values of input and output? Show them in the graph. [1+1]

(c) Find the average voltage measured at the output. [1]

d) Draw VTC curve with proper labelling.

e) If 1uF capacitor is connected in parallel with the resistor, what will be the average output voltage then?

b) input $\rightarrow V_m = 8V$

out $\rightarrow V_p = V_m - 2V_{D0} = 8 - 2 \times 0.8 = 6.4V$

$\omega = 2000\pi$

$\Rightarrow 2\pi f_s = 2000\pi$

$\therefore f_s = 1000\,Hz$

$= 1\,kHz$

$f_0 = 2f_s = 2\,kHz$

c) FW (CVD):

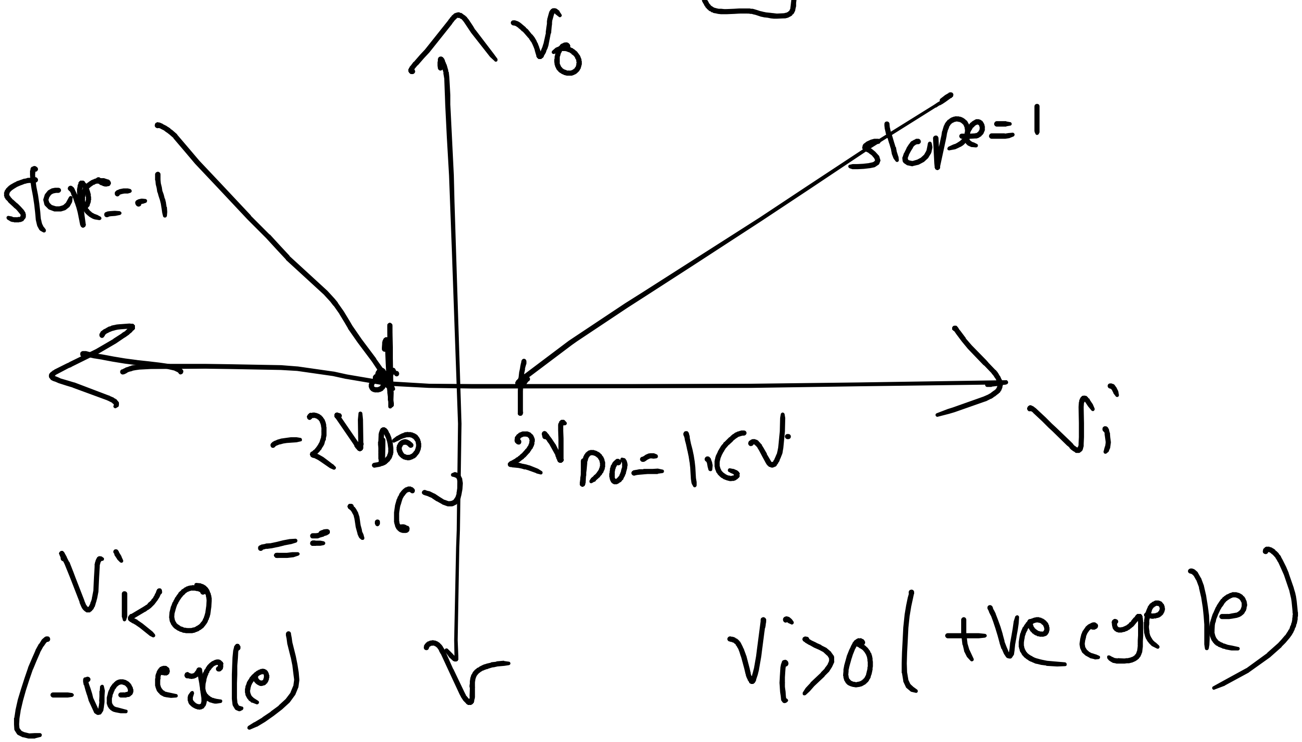
avg $= \frac{2V_m}{\pi} - 2V_{D0}$

$= \frac{2 \times 8}{\pi} - 2 \times 0.8$

$= \underline{3.4 \ldots V}$

d) +ve cycle $\rightarrow V_o = V_{in} - 2V_{D0}$ $\rightarrow y = mx + c$

-ve " $\rightarrow V_o = \underbrace{-V_{in}} - 2V_{D0}$ $\rightarrow y = mx + c$



e) Filtering

$V_{avg} = V_p - V_r/2$ $\boxed{C\uparrow, V_r\downarrow}$

$f_r = 2f_3 = f_0$

$= 2kHz$

$V_r = \dfrac{V_p}{f_r RC}$

$R = 50k\Omega$

$C = 1\mu F$

$\Rightarrow V_r = \dfrac{6.4}{2000 \times 50 \times 10^3 \times 1 \times 10^{-6}}$

$= 0.064V$

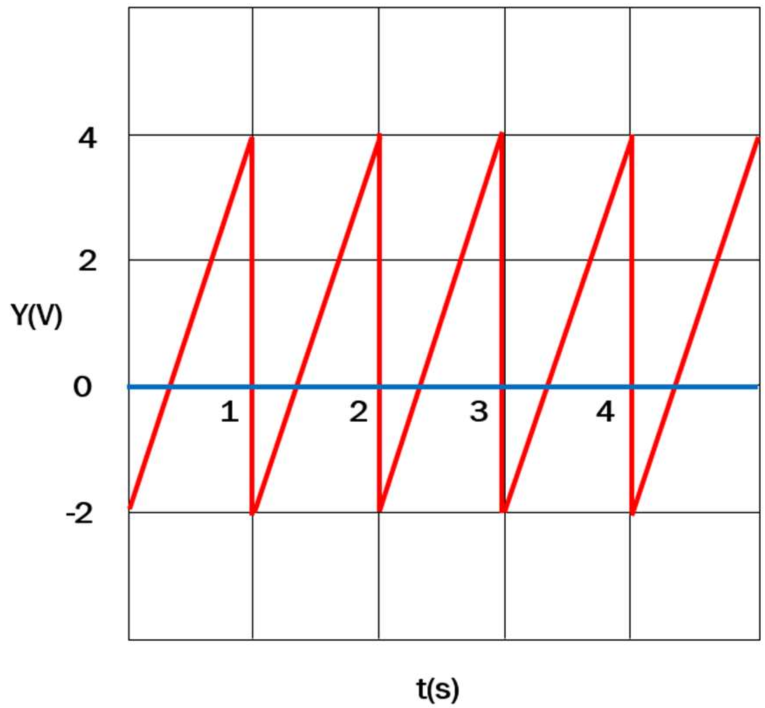
1uF, 5uf

$V_r\downarrow$ $V_r\downarrow$

$V_{avg} = V_p - V_r/2$

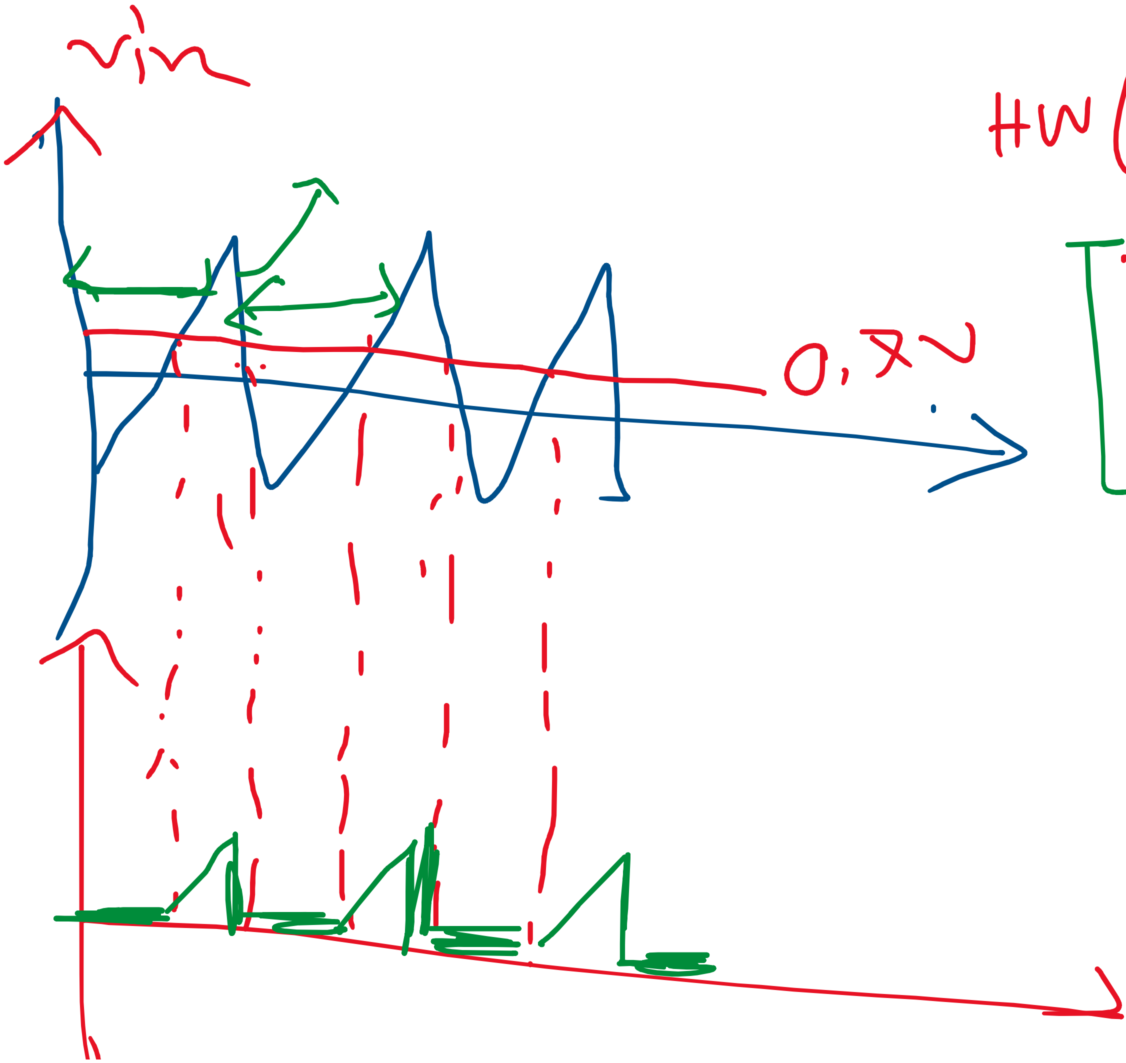
$= 6.4 - 0.064/2$

$= 6.3\ldots V$



The input of a Half-wave rectifier is exhibited in the Figure above and output load resistance is R = 5 kΩ. Silicon diodes are used in this circuit for which the forward drop is VD0 = 0.7 V.

i. Show the input and output waveforms.
ii. Draw the VTC curve



HW (eVD):

$V_i > V_{D0} \to V_o = V_i - V_{D0}$

$V_i < V_{D0} \to V_o = 0V$

Thank you