15/7/2021
L6 Online

ENEE2360

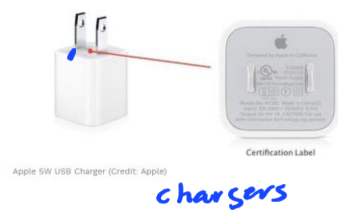
Analog Electronics

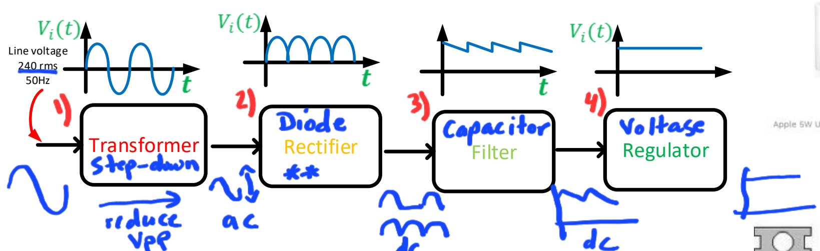
T4:
Diode Applications

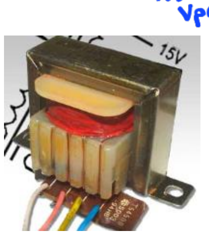
Instructor: Nasser Ismail

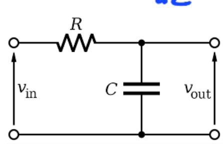
Dc Power Supply

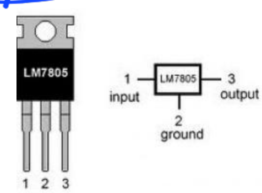
- All electronic circuits and systems require a stable source of dc voltage and current (or dc power) to operate correctly.



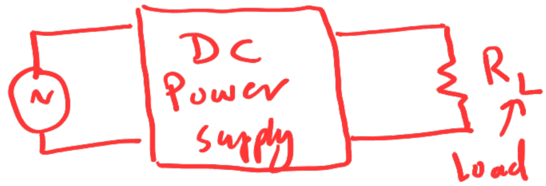


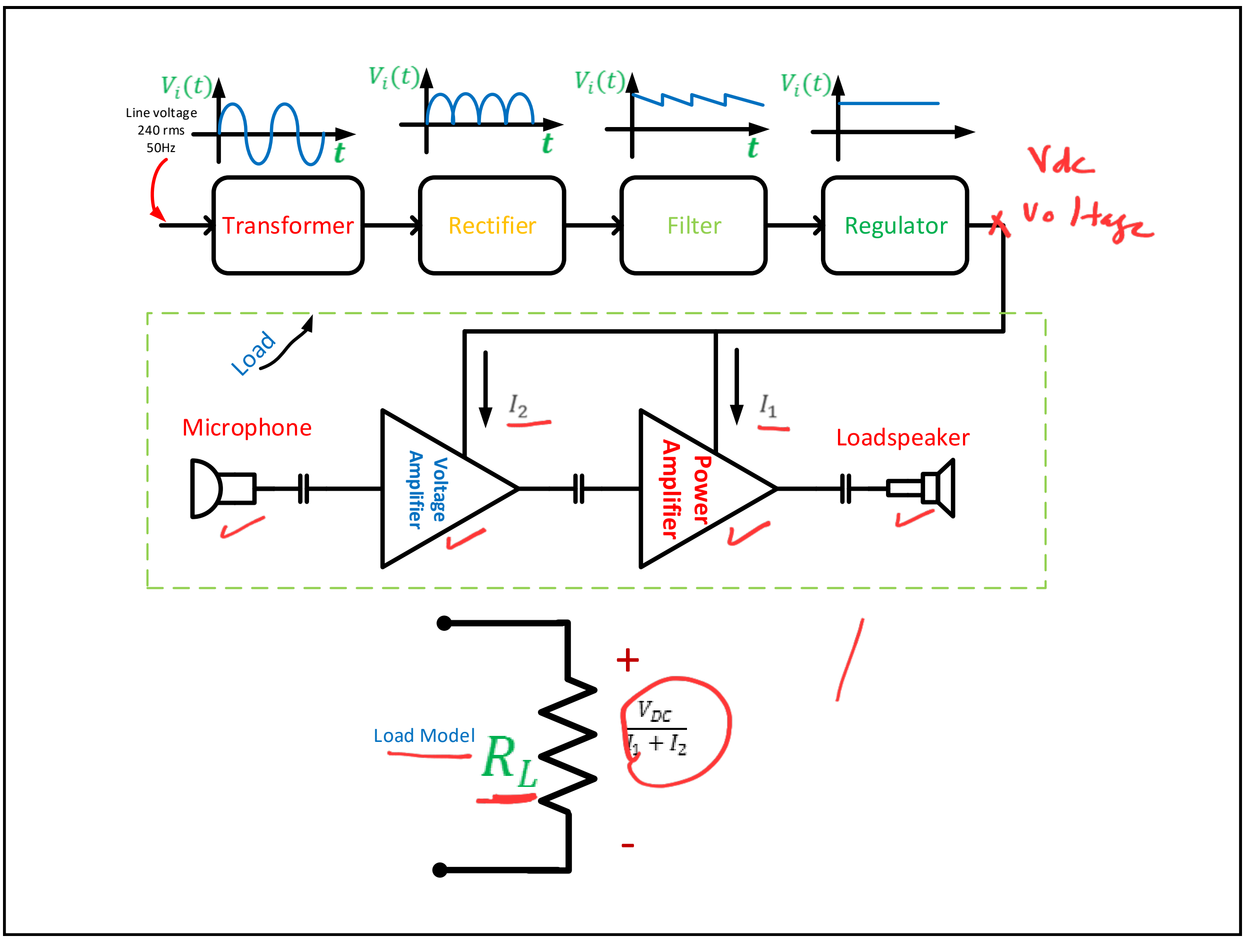




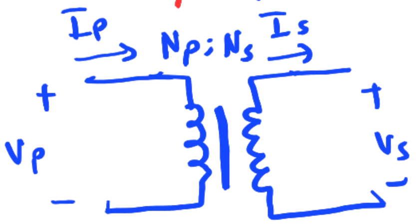


Block diagram of a dc power supply.


DC
Power
supply
R_L
Load

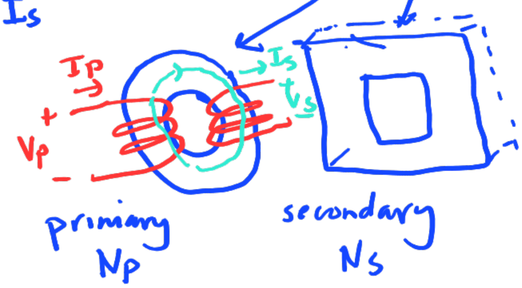

$V_i(t)$
Line voltage
240 rms
50Hz
t
Transformer
Rectifier
Filter
Regulator
Vdc
voltage
Load
Microphone
I_2
I_1
Voltage Amplifier
Power Amplifier
Loadspeaker
+
-
Load Model
R_L
$\frac{V_{DC}}{I_1 + I_2}$

1) Step-down Transformer → Ferromagnetic core → windings



$P_p = P_s$

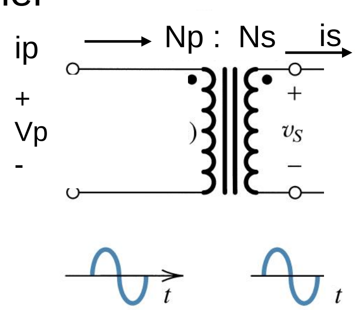
$V_p \cdot I_p = V_s \cdot I_s$



assuming ideal Transformer with effeciency = 100%

Designing a power supply

1) Transformer → used for ac voltages



**
$$\frac{V_p}{V_s} = \frac{N_p}{N_s}$$
$$\frac{I_p}{I_s} = \frac{N_s}{N_p} = n$$

Usually steps down type to decrease the amplitude of the ac line voltage

$$\frac{V_p}{V_s} = \frac{N_p}{N_s} \checkmark \qquad \frac{i_s}{i_p} = \frac{N_p}{N_s} \checkmark$$

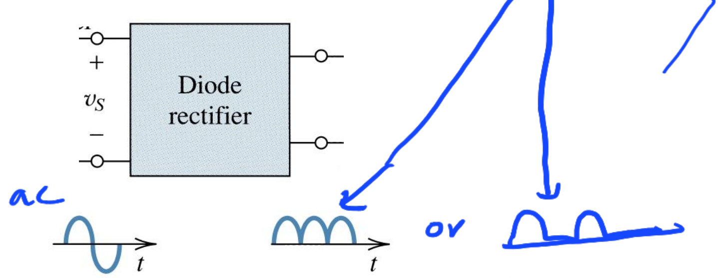
$$\frac{V_s}{V_p} = \frac{N_s}{N_s} = n$$

$$n = \frac{N_s}{N_p} \quad \text{transformer turns ratio}$$

$$\Rightarrow V_s = nV_p$$

Designing a power supply

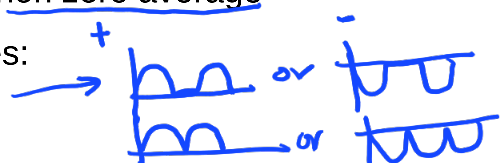
2) Rectifier : converts ac to pulsating dc

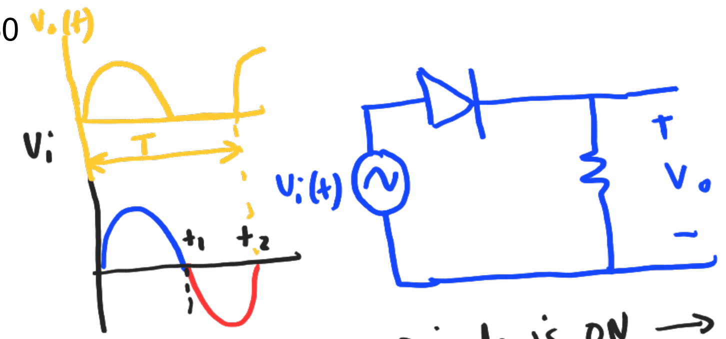


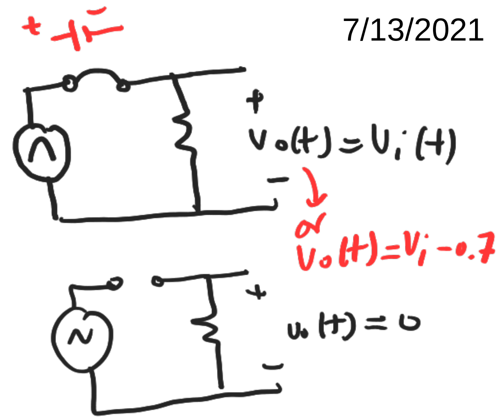
- Used to convert ac voltage (with zero average value) to pulsating dc voltage (non zero average

- Rectifiers are two types:

a) Half Wave Rectifier
b) Full Wave Rectifier
- Bridge Full Wave Rectifier
- Center Tapped Transformer Full Wave Rectifier





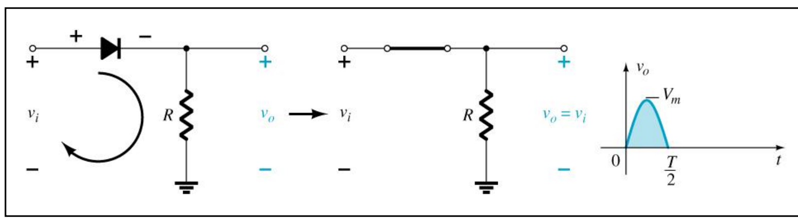


1) if $v_i(t) > 0$ → Diode is ON →

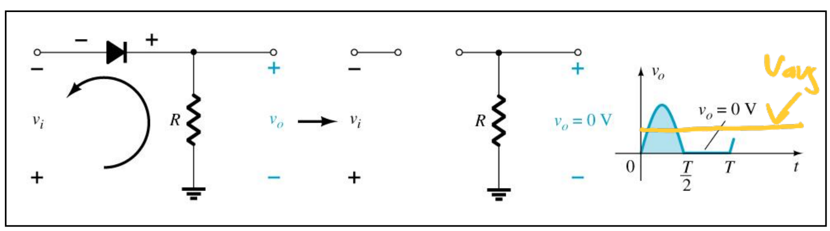
2) " " < 0 → " " off →

Half Wave Rectifier

1)When Vi(t) > 0,
Diode is ON
Vo = Vi



2)When Vi(t) < 0,
Diode is OFF
Vo = 0



The diode conducts only when it is forward biased, therefore only half of the AC cycle passes through the diode to the output.

$$V_{AVG} = \frac{1}{T}\int_0^T V_m Sin(\omega t)dt$$

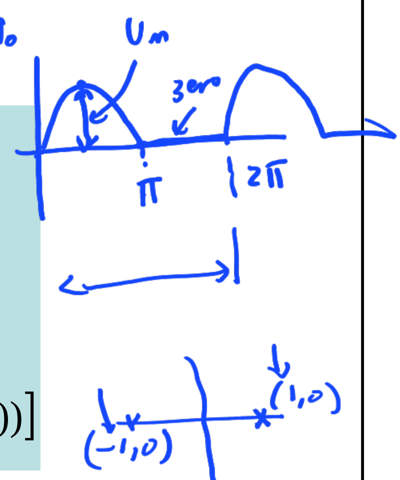
← by definition Vavg ≡ Vdc ≡ Vmean

Half Wave Rectifier

$$V_{AVG} = \frac{1}{T}\int_0^T V_m Sin(\omega t)dt$$

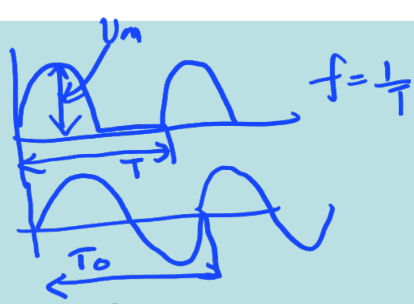
$$= \frac{1}{2\pi}\int_0^{\pi} V_m Sin(\theta)d\theta$$

$$= \frac{1}{2\pi}\left[-V_m Cos(\theta)\right]_0^{\pi} = \frac{V_m}{2\pi}\left[-Cos(\pi) - (-Cos(0))\right]$$



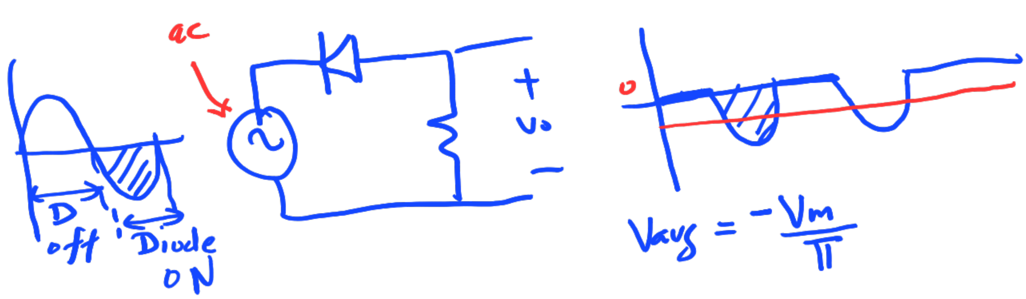
$$V_{AVG} = \frac{V_m}{2\pi}\left[-(-1) - (-1)\right]$$

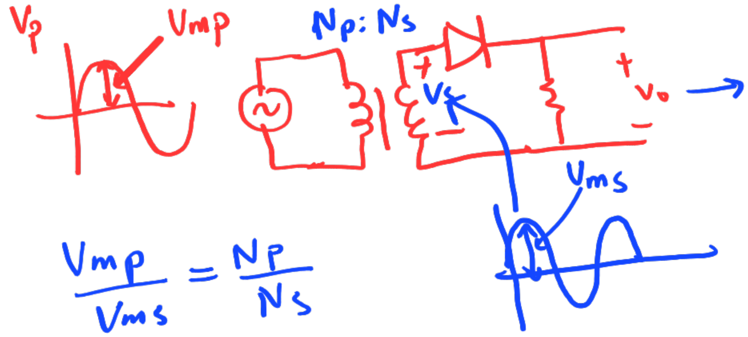
$$= \frac{2V_m}{2\pi} = \frac{V_m}{\pi} \cong 0.318V_m$$



$T = T_o$ and $f = f_o$

(period and frequency of the rectified waveform is the same as ac input)





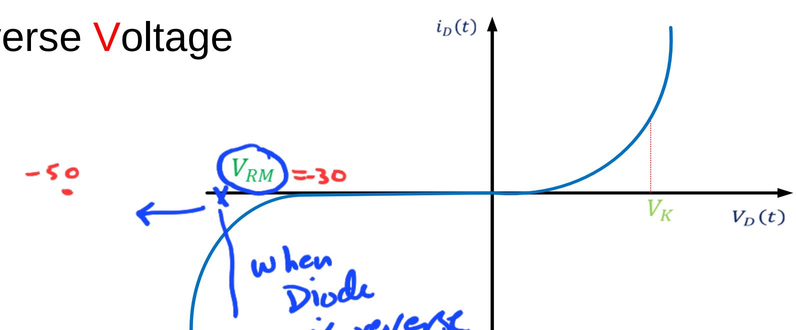
$V_{o(avg)} = \frac{V_{ms}}{\pi}$ ***

$\frac{V_{mp}}{V_{ms}} = \frac{N_p}{N_s}$

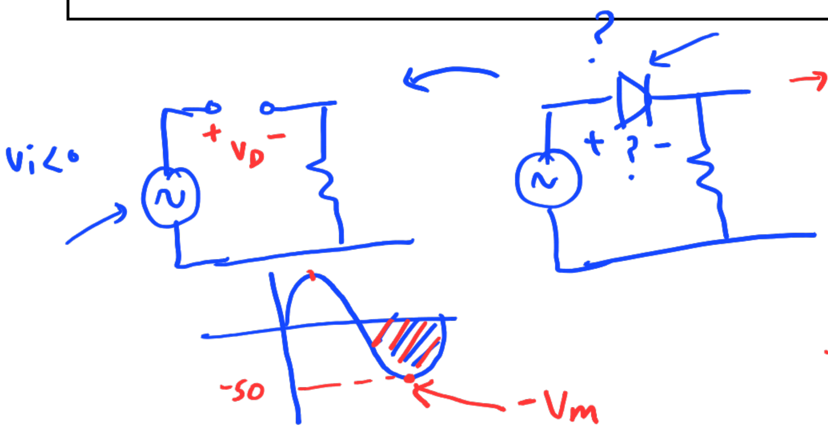
Important Electrical Ratings

later

- I_{FM} = maximum forward current
- I_{FM} = maximum average current that can safely be sustained by the diode when it is forward biased
- V_{RM} = maximum reverse voltage
- V_{RM} = maximum voltage that can be applied to the diode in the reverse bias polarity before voltage break down occur
- PIV ≡ Peak Inverse Voltage
- PIV = V_{RM}



when Diode is reverse biased



→ we inspect what is the maximum reverse voltage that the diode will see in the given circuit

→ PIV = −Vm = −50 V in this case

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PIV (For Half Wave Rectifier)

Because the diode is only forward biased for one-half of the AC cycle, it is also reverse biased for one-half cycle.

It is important that the reverse breakdown voltage rating of the diode be high enough to withstand the peak, reverse-biasing AC voltage.

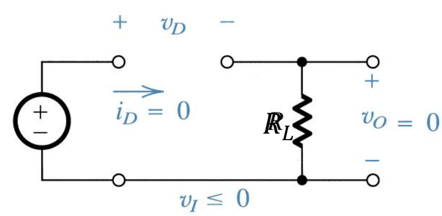
$$V_D(t) = V_i(t)$$

$$V_D(t)_{max} = -V_m$$

$$PIV = -V_m$$

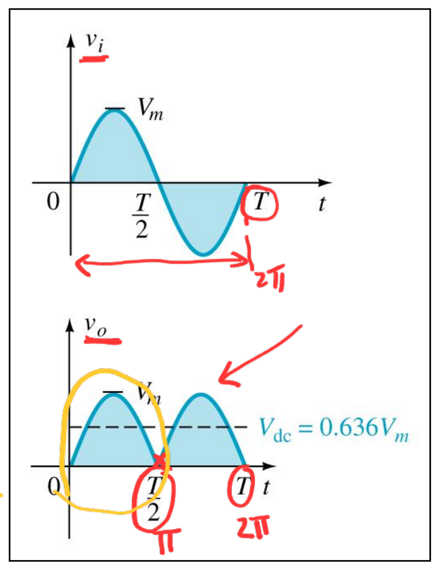
$$I_{FM} = \frac{V_{AVG}}{R_L} = I_{R_L}$$

$$I_{FM} = \frac{V_m}{\pi R_L}$$



Full-Wave Rectification

The rectification process can be improved by using a full-wave rectifier circuit.



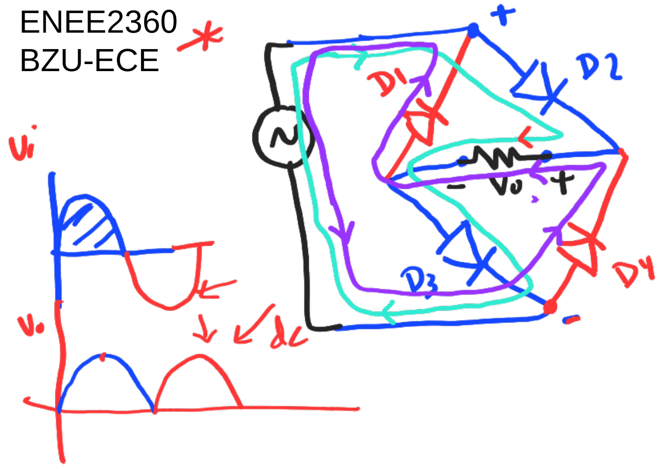
Full-wave rectification produces a greater DC output:

$$V_{avg} = \frac{1}{T}\int_0^T f(t)\,dt = \frac{1}{\pi}\int_0^{\pi} f(t)\,dt$$

Half-wave: $V_{dc} = 0.318\,V_m = \frac{V_m}{\pi}$

Full-wave: $V_{dc} = 0.636\,V_m = \frac{2V_m}{\pi}$

$T_{new} = \pi$



1) $V_i(t) > 0 \rightarrow$ D2, D3 ON
D1, D4 off

$V_o = V_i$

2) $V_i(t) < 0 \rightarrow$ D1, D4 ON; D2, D3 off

$V_o = -V_i$

Bridge Full-Wave Rectifier

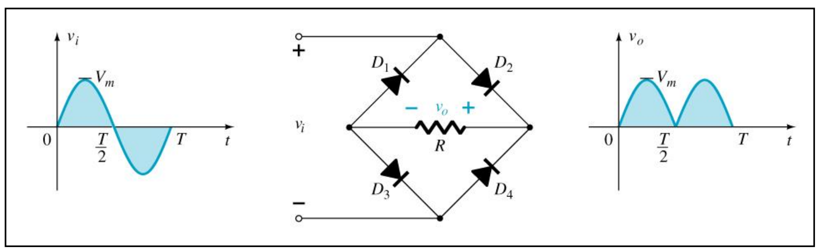
A full-wave rectifier with four diodes that are connected in a bridge configuration

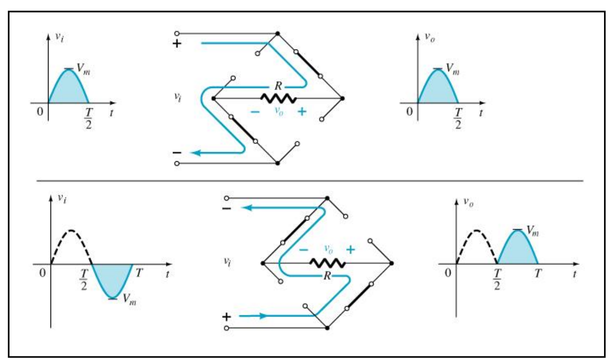
1) When $Vi(t) > 0$,
D2 , D3 are ON
D1 , D4 are OFF

$\Rightarrow Vo(t) = Vi(t)$

2) When $Vi(t) < 0$,
D2 , D3 are OFF
D1 , D4 are ON

$\Rightarrow Vo(t) = -Vi(t)$

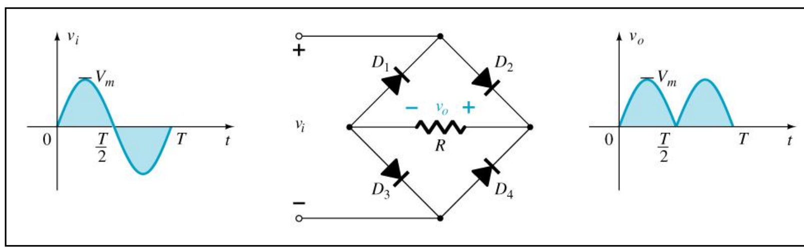




Bridge Full-Wave Rectifier

$$V_{AVG} = \frac{1}{T}\int_0^T V_m Sin(\omega t)dt$$

$$= \frac{1}{\pi}\int_0^\pi V_m Sin(\theta)d\theta$$



$$V_{AVG} = \frac{2V_m}{\pi} \cong 0.636V_m$$

$$T = \frac{T_o}{2} \text{ and } f = 2f_o$$

(period and frequency of the rectified waveform is not the same as ac input)

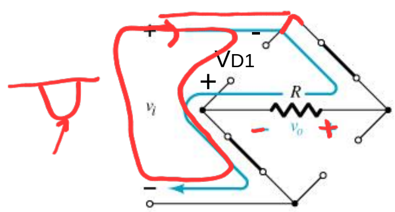
PIV for each of the 4 diodes

For ideal diode

$V_{D1}(t) = -V_i(t)$

$V_{D1}(t)_{max} = -V_m$

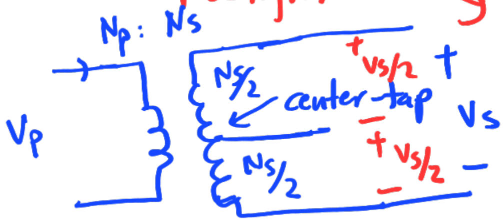
$PIV = -V_m$



$V_i + V_{D1} = 0$

$V_{D1} = -V_i$

Full-wave Rectifier → Bridge Full-wave Rectifier
→ Center-tapped Transformer Full-wave rectifier



$$\frac{V_p}{V_s} = \frac{N_p}{N_s}$$

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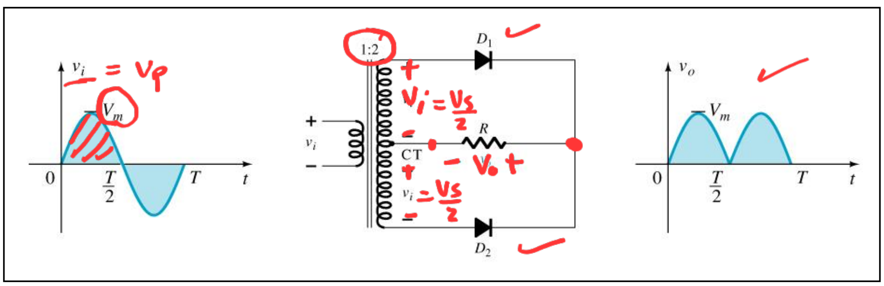
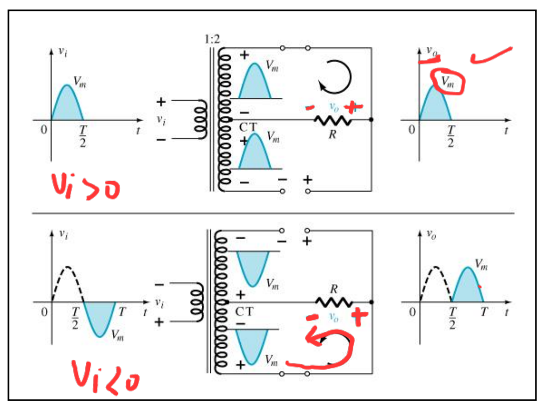
Center Tapped Transformer Full-Wave Rectifier

special case
$N_p = 1$
$N_s = 2$
$\frac{V_p}{V_s} = \frac{1}{2}$
$V_s = 2V_p$
$\frac{V_s}{2} = V_p$



Requires two diodes and a center-tapped transformer



Note: ملاحظة هامة جداً

if turns ratio is other than 1:2 , make sure to calculate Vm at the secondary side correctly

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CT Transformer Full-Wave Rectifier

1)When $Vi(t) > 0$,
D1 is ON
D2 is OFF

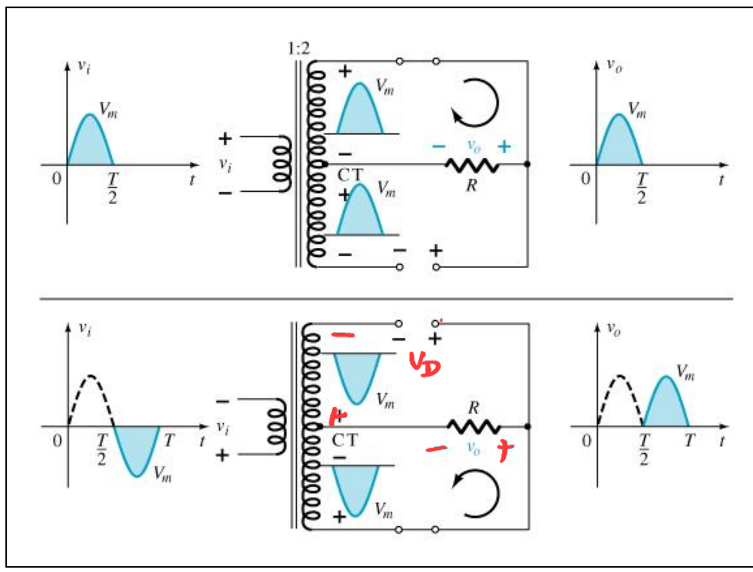
$\Rightarrow Vo(t) = Vi(t)$

2)When $Vi(t) < 0$,
D1 is OFF
D2 is ON

$\Rightarrow Vo(t) = -Vi(t)$

$$V_{AVG} = \frac{2V_m}{\pi} \cong 0.636V_m$$

$$T = \frac{T_o}{2} \text{ and } f = 2f_o$$



PIV = -2Vm

	Half wave	Bridge	center-tapped
Diodes	1	4	2
Transforme	regular	regular	center-tapped
avg-voltage	0.318 Vm	0.636 Vm	0.636 Vm
PIV	-Vm	-Vm	-2Vm

End of L6
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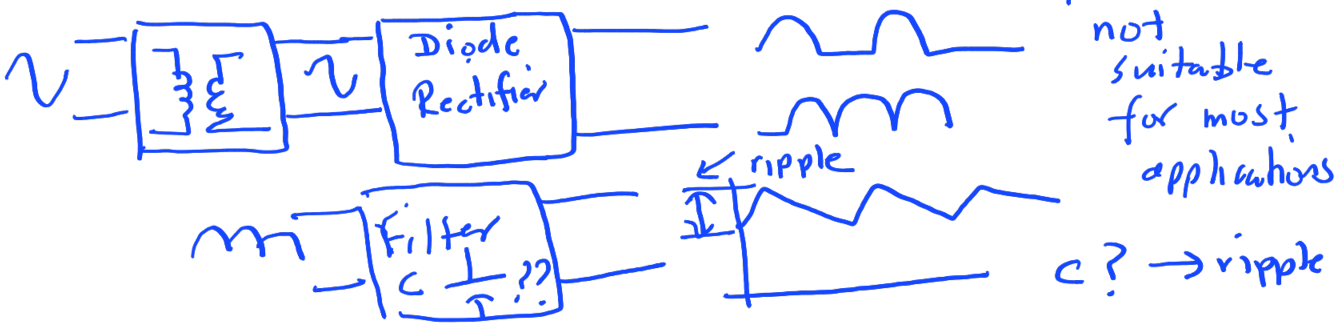
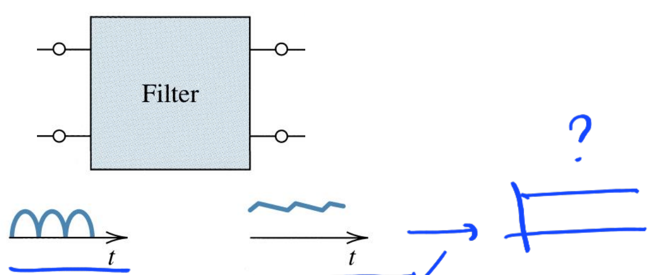
L7 – 17/7/2021 sec 1

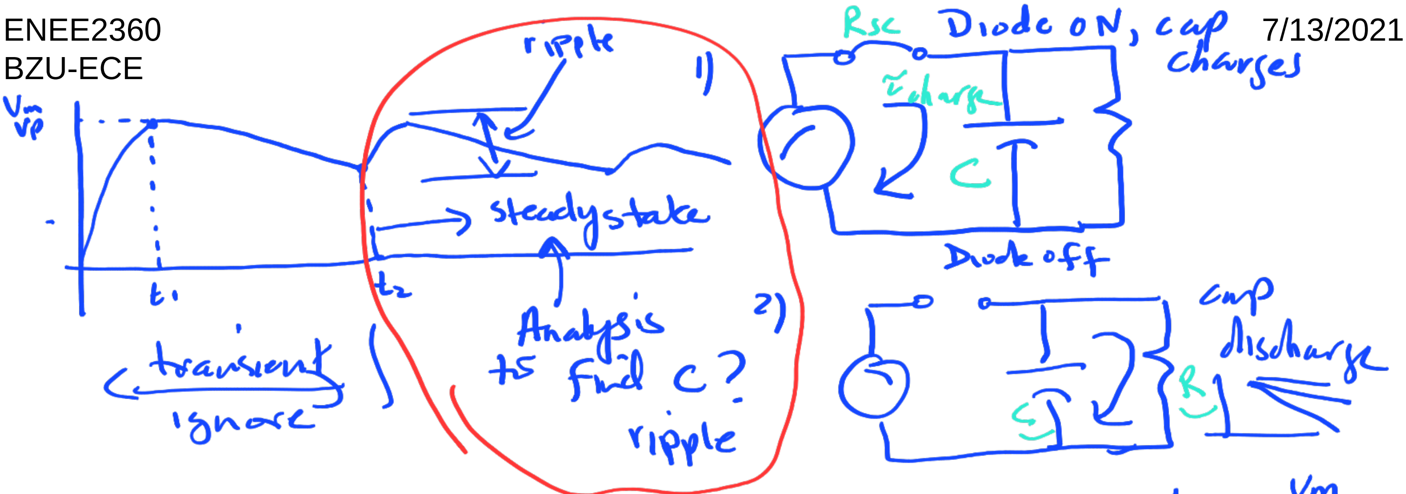
dc Power supply



3) Filter

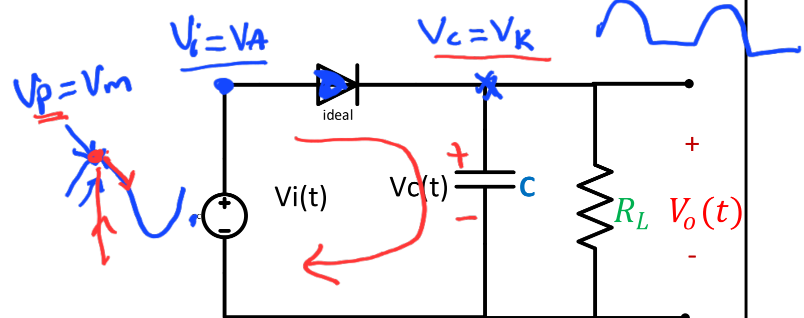


- One of dc power supply components
- Used to smooth out (remove) the pulsating DC produced by the rectifiers and to pass only the DC component (average value; mean value)

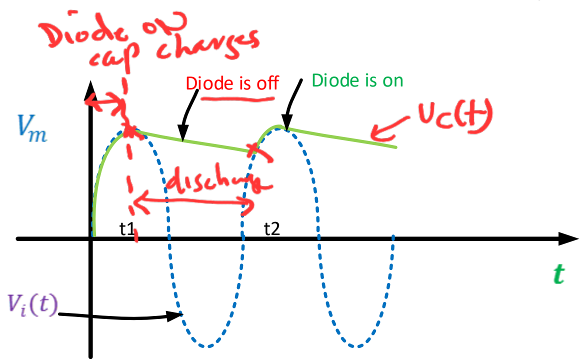


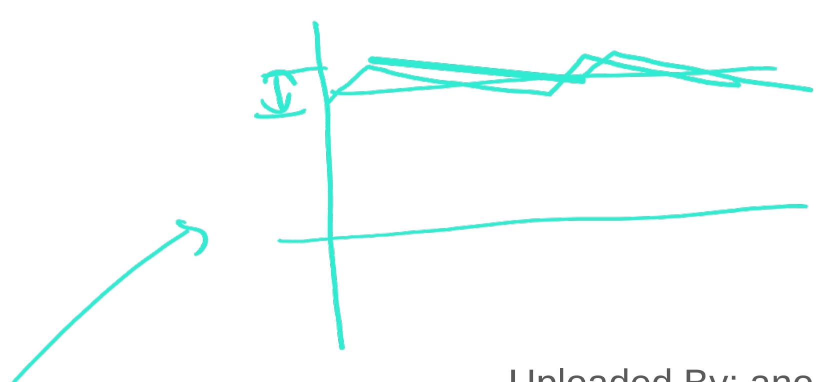
Simplified Circuit

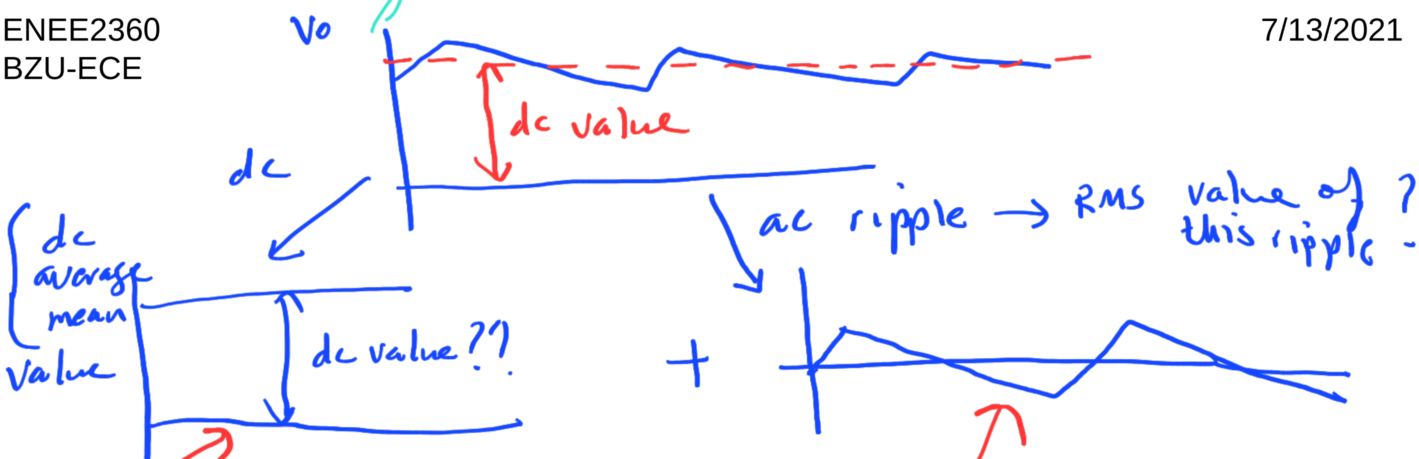
- A) when $V_i(t) > V_c(t)$; Diode is on and $V_o(t) = V_c(t) = V_i(t)$



- B) when $V_i(t) < V_c(t)$; Diode is off and the capacitor starts discharging



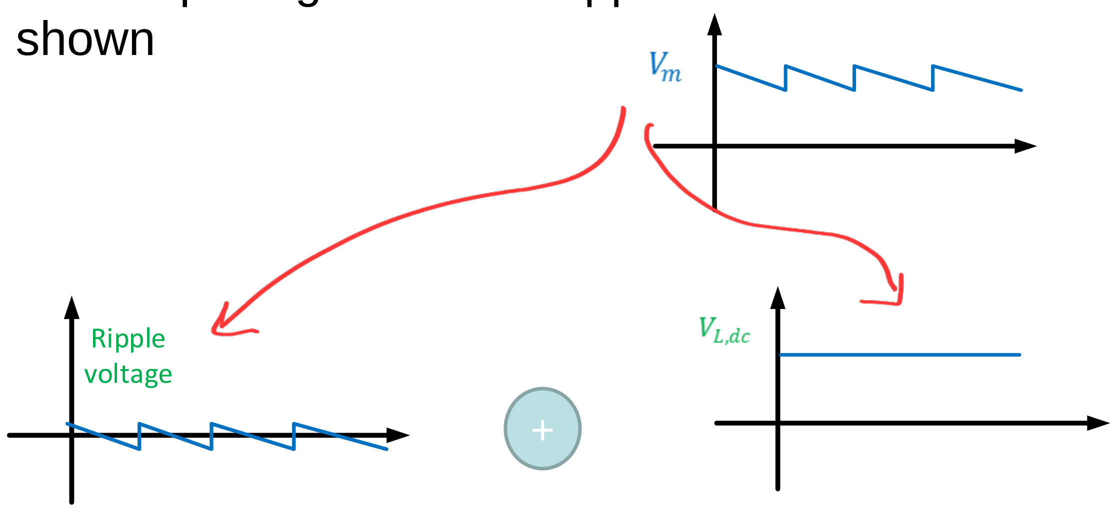




- Ripple factor is an indicator for the effectiveness of the filter

$$r = \frac{RMS(ripple\ of\ output\ \ voltage\ )}{Average\ value\ of\ the\ output\ signal} \times 100\%$$

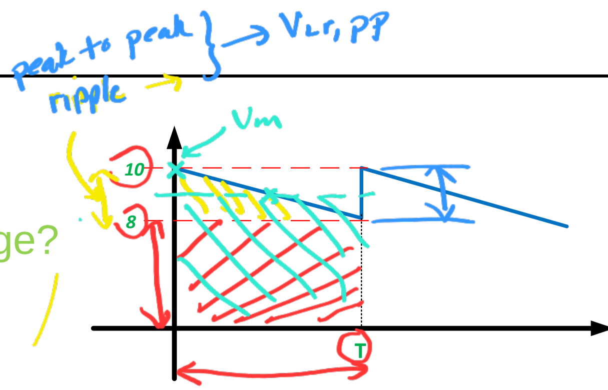
- The output signal can be approximated as shown



Example

Find average output voltage?

$V_{dc} = V_{avg} = \frac{1}{T}\int_0^T f(t)\,dt$



$$V_{O,DC} = V_{O,AVG} = \frac{1}{T}\int_0^T V_O(t)dt$$
$$= \frac{1}{T}(\text{Area})$$
$$= \frac{1}{T}(8T + \frac{2T}{2}) = 9\text{ V}$$

OR

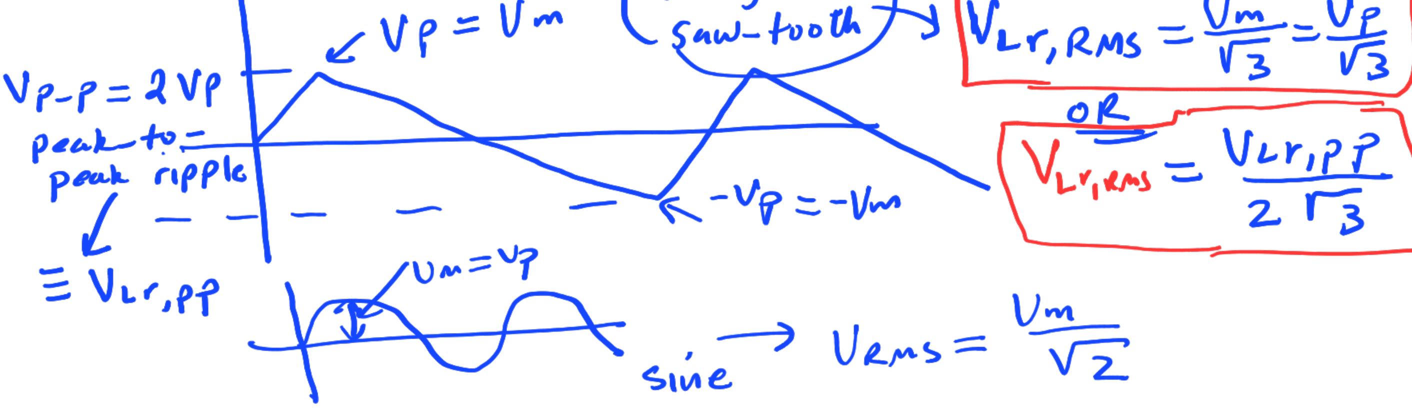
$$V_{O,DC} = V_m - \frac{1}{2}V_{Lr,p-p}$$

where Vm = 10

$V_{Lr,p-p} = 2$

$$V_{O,DC} = 10 - \frac{1}{2}.2 = 9\text{ V}$$

$r\% = \frac{\text{RMS value}}{\text{average}} \cdot 100\%$

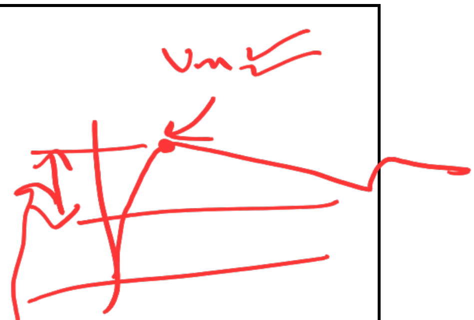


- Also for a triangular signal,

$$\text{RMS Value} = \frac{\text{Peak Value}}{\sqrt{3}}$$

OR

$$\text{RMS Value} = \frac{\text{Peak to peak Value}}{2\sqrt{3}} = \frac{V_{Lr,p-p}}{2\sqrt{3}}$$



$$\therefore \quad r\,\% = \frac{\dfrac{V_{Lr,p-p}}{2\sqrt{3}}}{V_m - \dfrac{1}{2}V_{Lr,p-p}} 100\%$$

$\Rightarrow$ To Determine the ripple factor we need to find the peak to peak ripple $V_{Lr,p-p}$

$V_m = V_{max}$ (at t_1) → $V_c = V_{max}\, e^{-\frac{t}{\tau}}$; at t_2: V_{min}! → in general $= V_{max}\, e^{-\frac{(t-t_0)}{\tau}}$

Ripple Factor

For $t_2 > t > t_1$

$$V_L(t) = V_m\, e^{\frac{-(t-t_1)}{RC}}$$

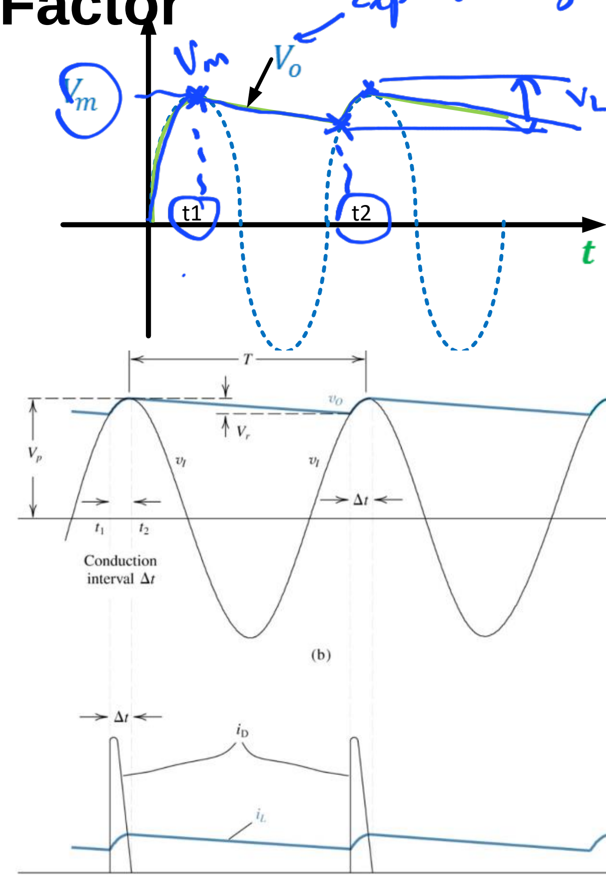
← discharge equation

$$V_{Lr,p\text{-}p} = V_L(t_1) - V_L(t_2)$$

$$V_{Lr,p\text{-}p} = V_m - V_m\, e^{\frac{-(t_2-t_1)}{RC}}$$

$$V_{Lr,p\text{-}p} = V_m\left[1 - e^{\frac{-(t_2-t_1)}{RC}}\right]$$

using $e^{-x} \cong 1 - x$



* $V_{Lr,pp} = V_m\left[1 - \left(1 - \frac{t_2 - t_1}{RC}\right)\right] = V_m\left[\frac{t_2 - t_1}{RC}\right]$ **

* $V_{L,dc} = V_{L,avg} = V_m - \frac{1}{2} V_{Lr,pp}$

* $r\,\% = \frac{\text{RMS ripple}}{V_{L,dc}} \cdot 100\%$

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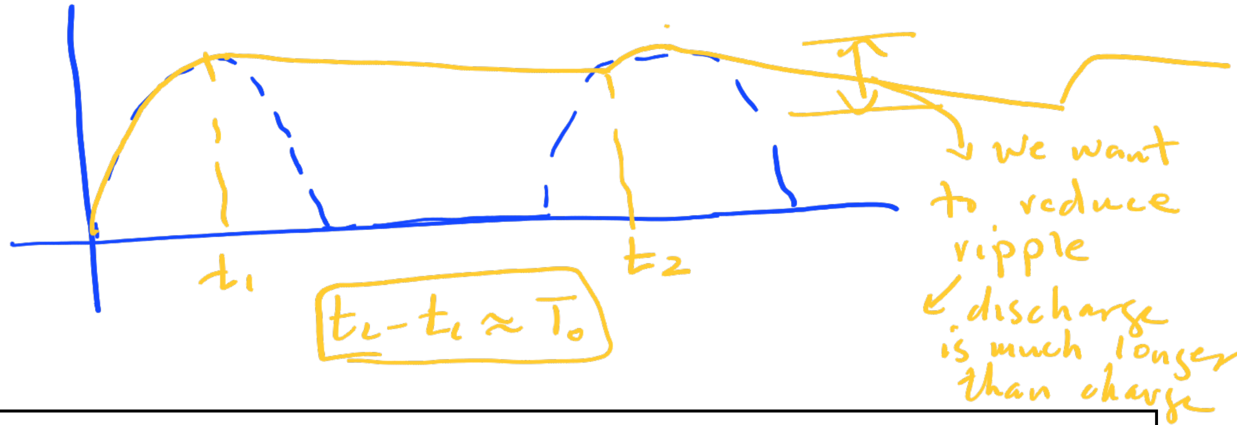
using $e^{-x} \cong 1 - x$

$$V_{Lr,p\text{-}p} = V_m \left[1 - e^{\frac{-(t_2 - t_1)}{RC}} \right] \Rightarrow V_{Lr,p\text{-}p} = V_m \left(\frac{(t_2 - t_1)}{RC} \right)$$

$$V_{L,dc} = V_m - \frac{1}{2} V_{Lr,p-p}$$



ENEE236 – Analog Electronics

a) For Half Wave Rectifier

$$t_2 - t_1 \cong T_O = \frac{1}{f_O}$$

$$V_{Lr,p\text{-}p} = V_m\left(\frac{T_O}{RC}\right) = V_m\left(\frac{1}{f_O RC}\right)$$

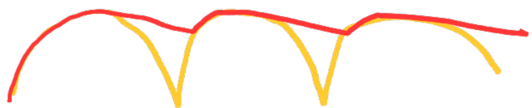
$$V_{L,dc} = V_m\left(1 - \frac{1}{2f_O RC}\right)$$

$$(V_{L,r})_{RMS} = \frac{V_{Lr,p\text{-}p}}{2\sqrt{3}}$$

$$(V_{L,r})_{RMS} = \frac{V_m}{2\sqrt{3}f_O RC}$$

$$\therefore \quad r\,\% = \frac{(V_{L,r})_{RMS}}{V_{L,dc}}100\%$$

$$\therefore \quad r\,\% = \frac{1}{\sqrt{3}[2f_O RC - 1]}100\%$$



ENEE236 – Analog Electronics

b) For Full Wave Rectifier

$$t_2 - t_1 \cong \frac{1}{2} T_O = \frac{1}{2 f_O}$$

$$V_{Lr,p\text{-}p} = V_m \left(\frac{T_O}{2RC} \right) = V_m \left(\frac{1}{2 f_O RC} \right)$$

$$V_{L,dc} = V_m \left(1 - \frac{1}{4 f_O RC} \right)$$

$$\left(V_{L,r} \right)_{RMS} = \frac{V_{Lr,p\text{-}p}}{2\sqrt{3}}$$

$$\left(V_{L,r} \right)_{RMS} = \frac{V_m}{4\sqrt{3} f_O RC}$$

$$\therefore \quad r\,\% = \frac{1}{\sqrt{3}\left[4 f_O RC - 1 \right]} 100\%$$

Half wave

$$V_{r,ripp} = \frac{V_m}{f_o RC}$$

$r\% = \frac{\text{RMS ripple}}{\text{dc value}} \cdot 100\%$

$V_{Lr,RMS} = \frac{V_{Lr,pp}}{2\sqrt{3}}$; $V_{Lr,pp} = \frac{V_m}{2 f_o R C}$

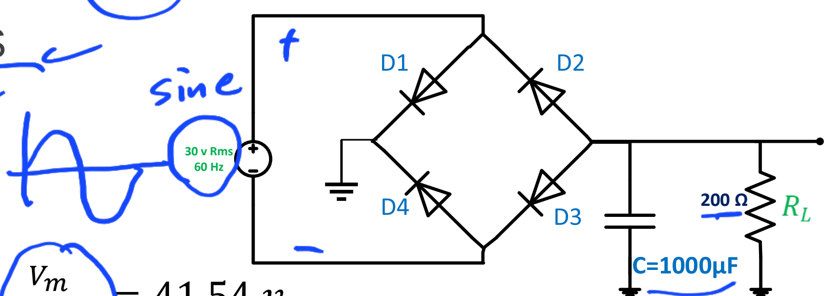
$V_{in,p} = V_m = 30\sqrt{2}$

Example

Full-wave rectifier

- Find the ripple factor r%
- Input=30V RMS
- F=60 Hz

$30\sqrt{2}$



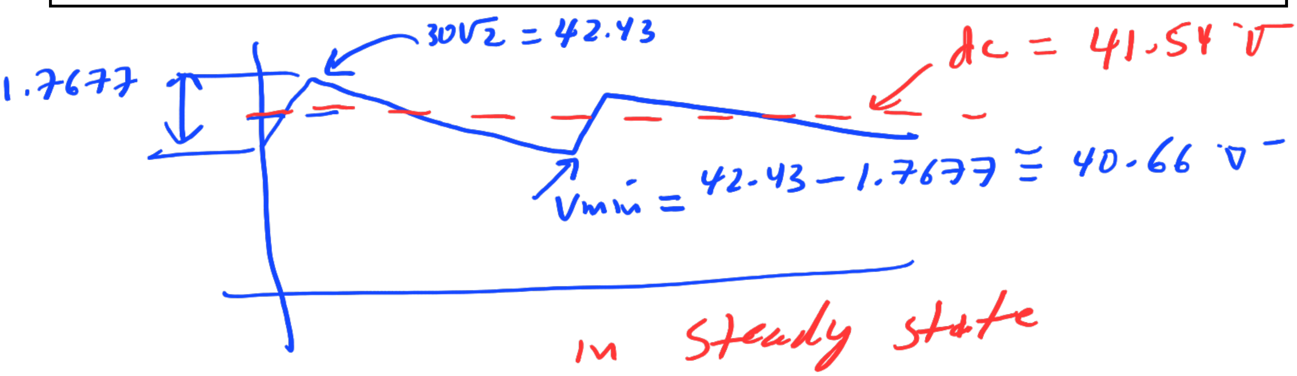
- $V_{L,dc} = V_m - \frac{1}{2}\frac{V_m}{2 f_o R_{Lc}} = 41.54\ v$

$V_{Lr,p-p} = \frac{V_m}{2 f_o R_{Lc}} = 1.7677 v = \frac{30\sqrt{2}}{2 \times 60 \times 200 \times 1000\,\mu F} =$

- RMS (ripple voltage) $= \frac{V_{Lr,p-p}}{2\sqrt{3}} = 0.51 v\ rms$

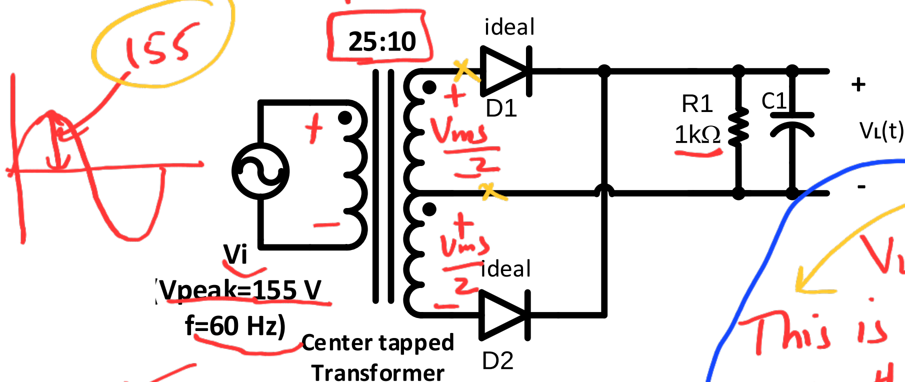
$\therefore r = \frac{0.51}{41.54} \times 100\%$

$r = 1.2277\ \%$



- Calculate VL(avg) and r% if C=400uF

Full-wave



$V_{Lr,ipp} = \frac{V_m}{2 f_o R C}$

This is Vm on the ½ secondary $\frac{V_{ms}}{2}$

$\frac{V_{mp}}{V_{ms}} = \frac{N_p}{N_s}$

$V_{ms} = V_{mp} \cdot \frac{N_s}{N_p} = 155 \times \frac{10}{25} = 62\ V$

$\frac{V_{ms}}{2} = \frac{62}{2} = 31\ V$

$V_{Lr,ipp} = \frac{31}{2 \times 60 \times 1k \times 400\ uf} = 0.6458\ V$

$V_{L,avg} = V_m - \frac{1}{2} V_{Lr,ipp} = 31 - \frac{1}{2}(0.6458) = 30.677\ V$

$$r\% = \frac{\frac{V_{L,ripple}}{2\sqrt{3}}}{V_{L,avg}} \cdot 100\% = \frac{\frac{0.6458}{2\sqrt{3}}}{36.677} \cdot 100\% = 0.607\%$$

Home Work 1

Sample not to be solved

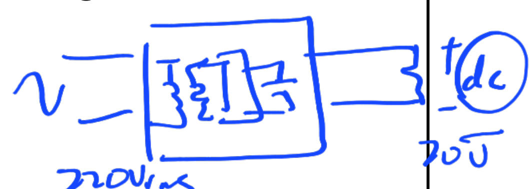
NOTE THAT EACH STUDENT WILL HAVE DIFFERENT DESIGN TARGET

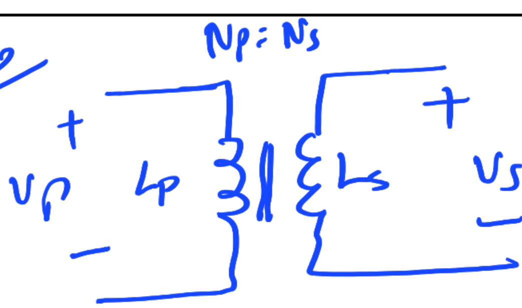
- Design a rectifier with filter to provide an a load (RL= 0.45 kohm) with an average voltage equal to 20 Vdc with a ripple factor =4.5%, Vin is sinusoidal with 220Vrms, f=50 Hz
- Perform the design three times using :

1. Half Wave rectifier
2. Bridge Full wave rectifier
3. Center tapped full wave rectifier

Simulate your designed circuits using Pspice

Transformer + Filter





K- coupling

K = 1

$$\frac{V_p}{V_s} = \frac{N_p}{N_s} = \sqrt{\frac{L_p}{L_s}}$$