ENEE236 & 241

Analog Electronics

L5 Diode Applications 3
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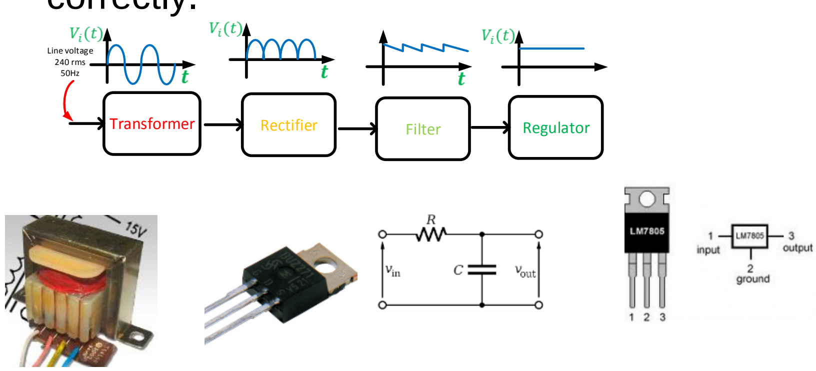
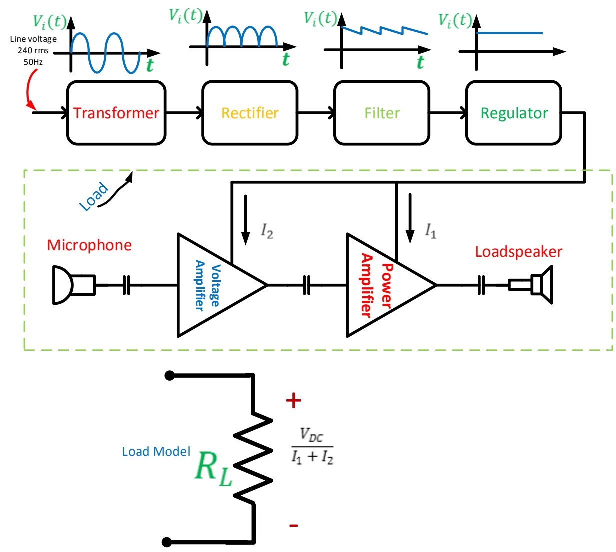
Dc Power Supply

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

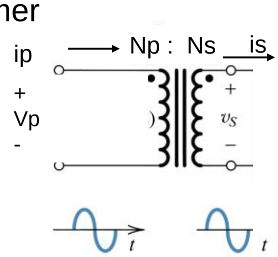


Block diagram of a dc power supply.



Designing a power supply

1) Transformer



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

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

$$\frac{i_s}{i_p} = \frac{N_p}{N_s}$$

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

$$\Rightarrow V_s = nV_p$$

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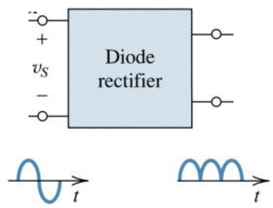
Designing a power supply

2) Rectifier



- ➢ 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

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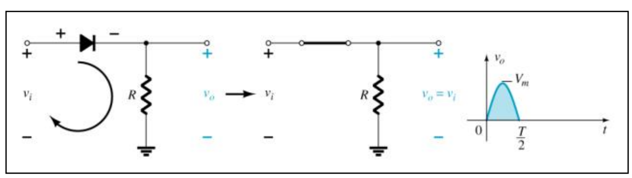
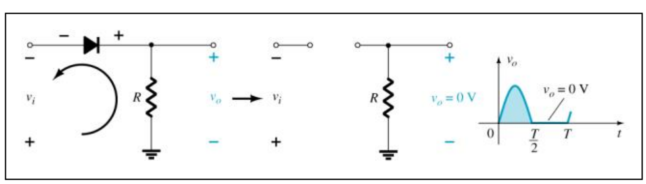
Half Wave Rectifier

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.

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

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Half Wave Rectifier

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

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

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

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

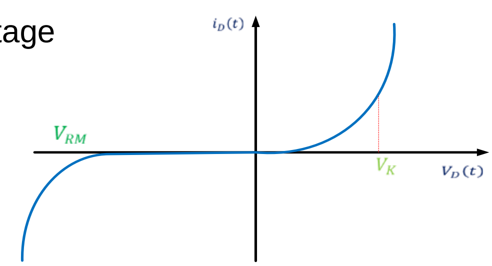
$$= \frac{2V_m}{2\pi} = \frac{V_m}{\pi} \cong 0.318V_m$$

$T = T_o$ and $f = f_o$

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

Important Electrical Ratings

- 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}

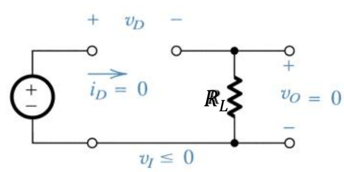


PIV (For Half Wave Rectifier)

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.

$$V_D(t) = V_i(t)$$
$$V_D(t)_{max} = -V_m$$
$$PIV = -V_m$$
$$I_{FM} = \frac{V_{AVG}}{R_L}$$
$$I_{FM} = \frac{V_m}{\pi R_L}$$



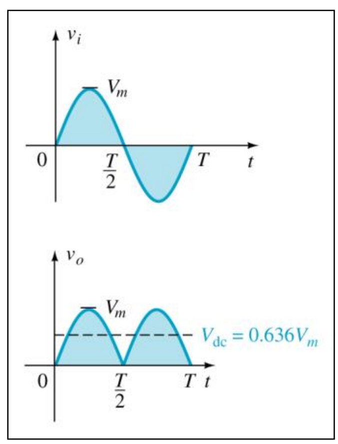
Full-Wave Rectification

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

Full-wave rectification produces a greater DC output:

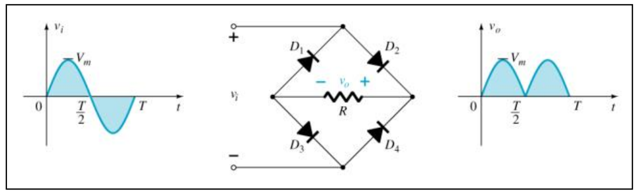
Half-wave: $V_{dc} = 0.318V_m$

Full-wave: $V_{dc} = 0.636V_m$



Bridge Full-Wave Rectifier

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

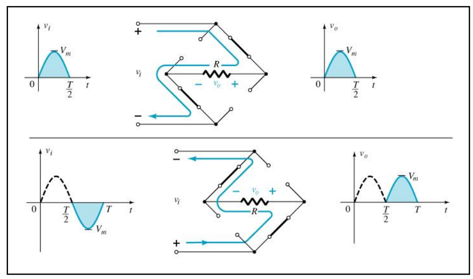


1)When $Vi(t) > 0$,
D2 , D3 are ON
D1 , D4 are OFF

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

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

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



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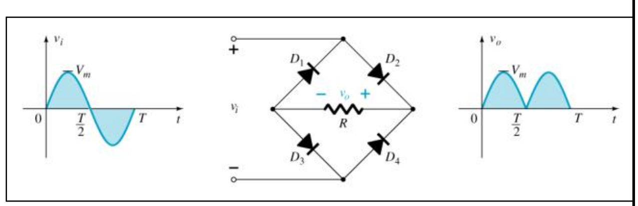
Bridge Full-Wave Rectifier

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



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

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

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

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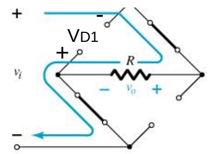
PIV for each of the 4 diodes

For ideal diode

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

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

$PIV = -V_m$



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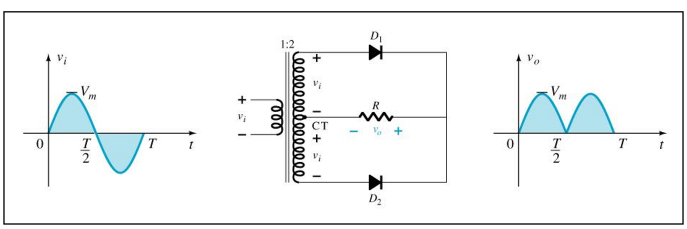
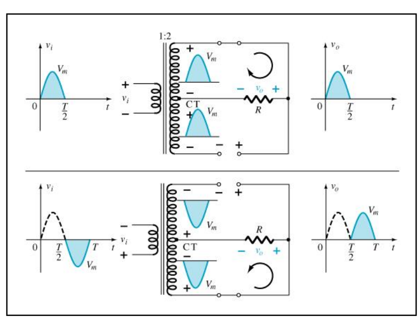
Center Tapped Transformer Full-Wave Rectifier



Requires two diodes and a center-tapped transformer



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CT Transformer Full-Wave Rectifier

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

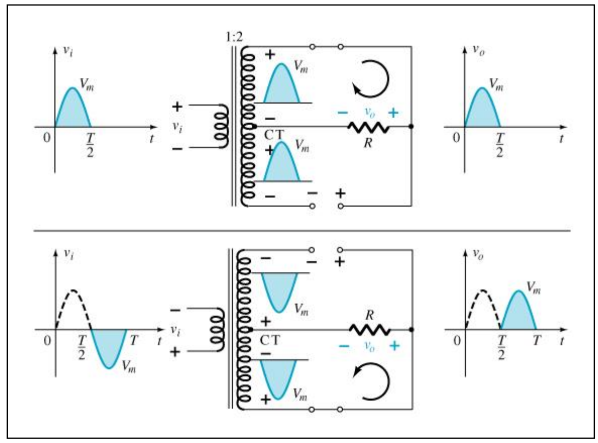
$\Rightarrow Vo(t) = Vi(t)$

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

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

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

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



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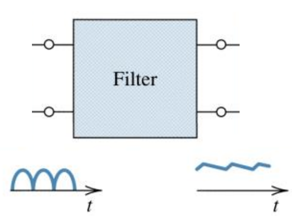
3) Filter

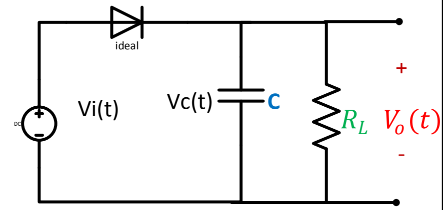


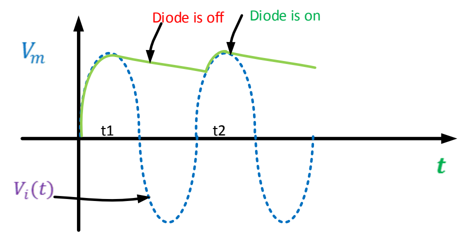
- One of dc power supply components
- Used to smooth out (remove) the pulsating DC produced by the rectifiers and to pass only the DC component (average value; mean value)

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

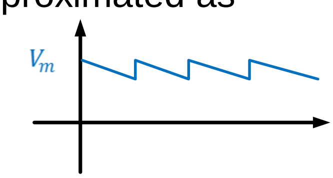


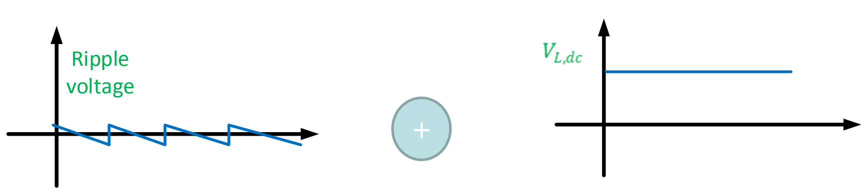


- Ripple factor is an indicator for the effectiveness of the filter

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

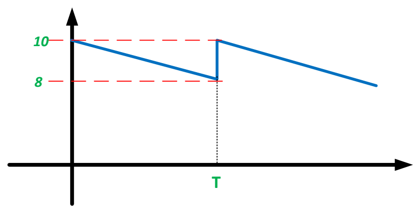
- The output signal can be approximated as shown





Example

Find average output voltage?



$$V_{O,DC} = V_{O,AVG} = \frac{1}{T}\int_0^T V_O(t)dt$$

$$= \frac{1}{T}(\text{Area})$$

$$= \frac{1}{T}(8T + \frac{2T}{2}) = 9\text{ V}$$

OR

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

where $Vm = 10$

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

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

- Also for a triangular signal,

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

OR

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

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

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

Ripple Factor

For $t_2 > t > t_1$

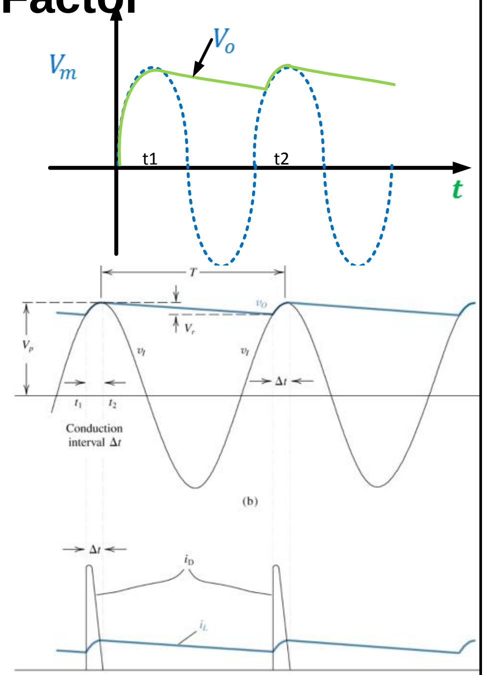
$$V_L(t) = V_m\, e^{\frac{-(t-t_1)}{RC}}$$

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

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

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

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



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

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

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

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a) For Half Wave Rectifier

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

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

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

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

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

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

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

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b) For Full Wave Rectifier

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

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

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

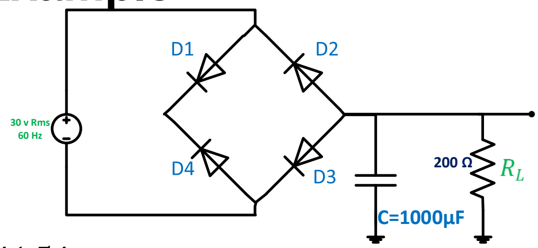
$$\left(V_{L,r}\right)_{RMS} = \frac{V_{Lr,p\text{-}p}}{2\sqrt{3}}$$

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

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

Example

- Find the ripple factor r



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

  $V_{Lr,p-p} = \frac{V_m}{2f_{oR_{Lc}}} = 1.7677v$

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

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

  $r = 1.2277\ \%$