EE 2109 Electronics-I

Credit- 3

Course Teachers: Dr. Md. Jahirul Islam
&
Dr. Monira Islam

Presentation Courtesy: Dr. Mostafa Zaman Chowdhury

Course Contents

Topics Covered

Introduction: Properties of insulators, semiconductors and metals; conduction in solids, conventional current and electron flow, drift and diffusion current, mobility and conductivity; potential barrier; work function; contact potential, Hall effect and Hall devices.

Semiconductors: Intrinsic semiconductors: Crystal and energy band diagram, electrons and holes, conduction in semiconductors, electron and hole concentration, Fermi level. Extrinsic semiconductors: n-type doping, p-type doping, and compensation doping, temperature dependence of conductivity, carrier concentration temperature dependence, degenerate and nondegenerate semiconductors. Diffusion and conduction equations random motion and continuity equation, time-dependent continuity equation, steady-state continuity equation.

Semiconductor Diode Characteristics: Qualitative and quantitative theory of the p-n junction as a diode; Ideal pn junction, pn junction band diagram, current components in p-n diode; volt-ampere characteristics; transition and diffusion capacitance, dynamic resistance, reverse breakdown; avalanche and zener breakdown; zener diode, rectifier diode: controlled & uncontrolled rectification.

Special-Purpose Diodes and Their Applications: Tunnel diode, varactor diode; Metal oxide semi-conductor diode, LED, Laser diode, PIN diode, Schottky diode, current regulator diode.

Transistor: Transistor and its current components, BJT characteristics and different regions of operation, different transistor configurations, transistor as a switch and amplifier, transistor biasing, DC and AC load lines, thermal stabilization.

References

- ❑ Electronic Devices and Circuit Theory By: Robert L. Boylestad
- ❑ Principles of Electronic Materials and Devices By: S.O. Kasap
- ❑ Semiconductor Devices Basic Principles By: Jasprit Singh
- ❑ Semiconductor Physics and Devices Basic Principles By: Donald A. Neamen
- ❑ Electronic Devices and Circuits By: David A. Bell
- ❑ Modern Semiconductor Devices for Integrated Circuits By: Chenming C. Hu
- ❑ Solid State Electronic Devices By: Ben G. Streetman and Sanjay Banerjee
- ❑ Electronic Devices By: Floyd
- ❑ Electronic Devices and Circuits By: Jacob Millman
- ❑ **Electronic Principles-Albert Paul Malvino**

Rectifier: Fundamentals

- **Rectifier – a diode circuit that converts ac to pulsating dc**
- **Filter – a circuit that reduces the variations in the output from the rectifier**
- **Voltage Regulator – a circuit designed to maintain a constant power supply output voltage**

Rectifier: Fundamentals

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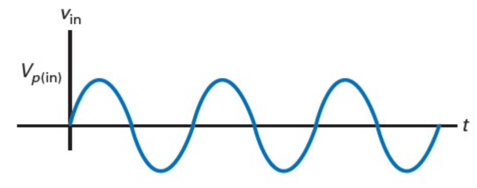
☐ **Sinwave**



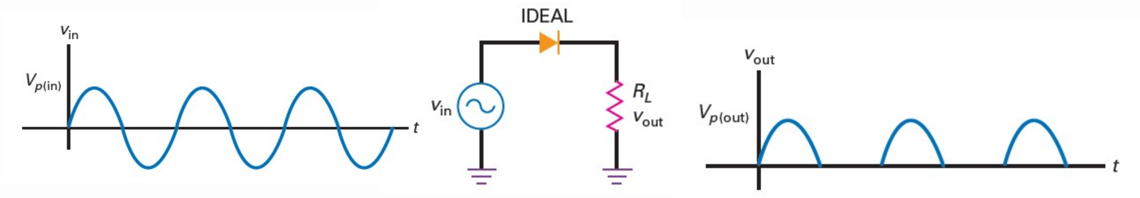
- peak value → V_P
- peak to peak value → $V_{PP} = 2V_P$
- rms value → V_{rms},
- $V_{e,}$, V_{ac} (I_{rms}, I_e, I_{ac})

$I_{rms} = 0.707\ I_m$

$I_{avg} = 0.636\ I_m$

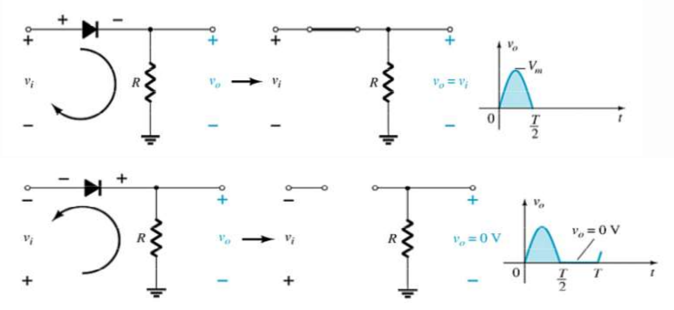
(rms → root-mean-square value)

Half-wave Rectifier



Half-wave Rectifier

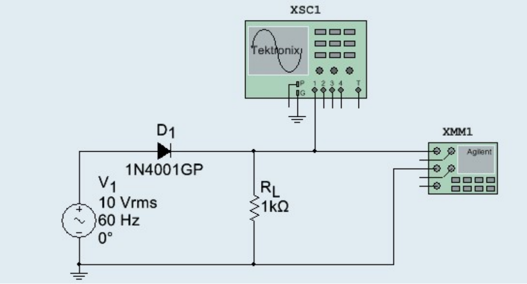
The diode only conducts when it is forward biased, therefore only half of the AC cycle passes through the diode to the output.



Half-wave Rectifier

The DC output voltage is 0.318V_m, where V_m = the peak AC voltage

Output Frequency **Half wave: $f_{out} = f_{in}$**



$$V_{rms} = 0.707V_p$$

Therefore, the peak source voltage in Fig. 4-3 is:

$$V_p = \frac{V_{rms}}{0.707} = \frac{10\ \text{V}}{0.707} = 14.1\ \text{V}$$

With an ideal diode, the peak load voltage is:

$$V_{p(out)} = V_{p(in)} = 14.1\ \text{V}$$

The dc load voltage is:

$$V_{dc} = \frac{V_p}{\pi} = \frac{14.1\ \text{V}}{\pi} = 4.49\ \text{V}$$

With the second approximation, we get a peak load voltage of:

$$V_{p(out)} = V_{p(in)} - 0.7\ \text{V} = 14.1\ \text{V} - 0.7\ \text{V} = 13.4\ \text{V}$$

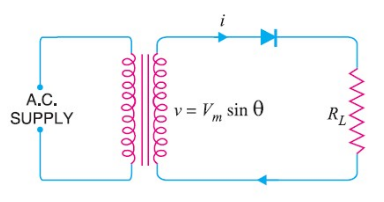
and a dc load voltage of:

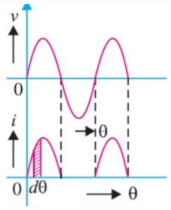
$$V_{dc} = \frac{V_p}{\pi} = \frac{13.4\ \text{V}}{\pi} = 4.27\ \text{V}$$

Efficiency of Half-Wave Rectifier

The ratio of d.c. power output to the applied input a.c. power is known as **rectifier efficiency** *i.e.*

$$\text{Rectifier efficiency, } \eta = \frac{\text{d.c. power output}}{\text{Input a.c. power}}$$





Efficiency of Half-Wave Rectifier

d.c. power. The output current is pulsating direct current. Therefore, in order to find d.c. power, average current has to be found out.

$$*I_{av} = I_{dc} = \frac{1}{2\pi}\int_0^{\pi} i\, d\theta = \frac{1}{2\pi}\int_0^{\pi} \frac{V_m \sin\theta}{r_f + R_L}\, d\theta$$

$$= \frac{V_m}{2\pi(r_f + R_L)}\int_0^{\pi} \sin\theta\, d\theta = \frac{V_m}{2\pi(r_f + R_L)}[-\cos\theta]_0^{\pi}$$

$$= \frac{V_m}{2\pi(r_f + R_L)} \times 2 = \frac{V_m}{(r_f + R_L)} \times \frac{1}{\pi}$$

$$= \frac{**I_m}{\pi} \qquad \left[\because I_m = \frac{V_m}{(r_f + R_L)}\right]$$

$$P_{dc} = I_{dc}^2 \times R_L = \left(\frac{I_m}{\pi}\right)^2 \times R_L \qquad ...(i)$$

a.c. power input : The a.c. power input is given by :

$$P_{ac} = I_{rms}^2 (r_f + R_L)$$

For a half-wave rectified wave, $I_{rms} = I_m/2$

$$\therefore \quad P_{ac} = \left(\frac{I_m}{2}\right)^2 \times (r_f + R_L)$$

$$\therefore \quad \text{Rectifier efficiency} = \frac{\text{d.c. output power}}{\text{a.c. input power}} = \frac{(I_m/\pi)^2 \times R_L}{(I_m/2)^2\ (r_f + R_L)}$$

$$= \frac{0.406\ R_L}{r_f + R_L} = \frac{0.406}{1 + \frac{r_f}{R_L}}$$

The efficiency will be maximum if r_f is negligible as compared to R_L.

$\therefore$ Max. rectifier efficiency = 40.6%

PIV (PRV)

- ☐ **The peak inverse voltage (PIV) [or PRV (peak reverse voltage)] rating of the diode is of primary importance in the design of rectification systems.**
- ☐ **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 b high enough to withstand the peak, reverse-biasing AC voltage.**

$$\text{PIV (or PRV)} > V_m$$

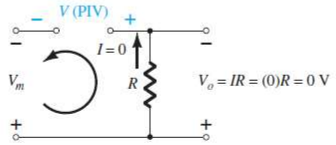
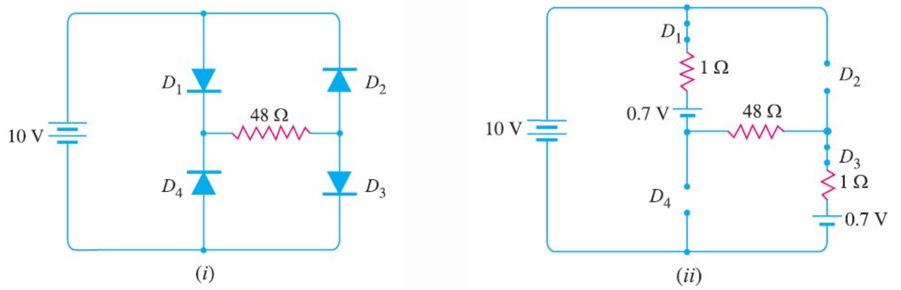


FIG. 2.52
Determining the required PIV rating for the half-wave rectifier.

- **PIV = Peak inverse voltage**
- **PRV = Peak reverse voltage**
- **V_m = Peak AC voltage**

Example

Example 6.4. *Calculate the current through 48 Ω resistor in the circuit shown in Fig. 6.11 (i). Assume the diodes to be of silicon and forward resistance of each diode is 1 Ω. (V. K. Mehta)*



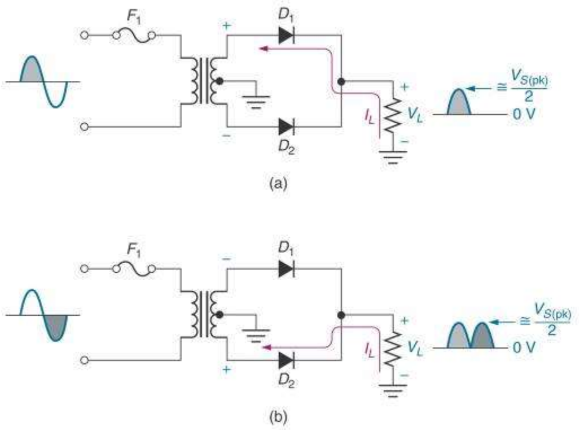
(*i*) (*ii*)

$$\begin{aligned} \text{Net circuit voltage} &= 10 - 0.7 - 0.7 = 8.6 \text{ V} \\ \text{Total circuit resistance} &= 1 + 48 + 1 = 50\ \Omega \\ \text{Circuit current} &= 8.6/50 = 0.172 \text{ A} = \textbf{172 mA} \end{aligned}$$

Full-Wave Rectifier

The following two circuits are commonly used for full-wave rectification:

(i) Centre-tap full-wave rectifier *(ii)* Full-wave bridge rectifier



Disadvantages

(*i*) It is difficult to locate the centre tap on the secondary winding.

(*ii*) The d.c. output is small as each diode utilises only one-half of the transformer secondary voltage.

(*iii*) The diodes used must have high peak inverse voltage.

Full-Wave Rectifier

Disadvantages of Centre-Tap

(*i*) It is difficult to locate the centre tap on the secondary winding.

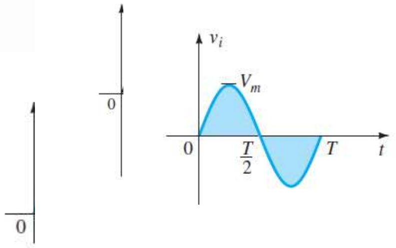
(*ii*) The d.c. output is small as each diode utilises only one-half of the transformer secondary voltage.

(*iii*) The diodes used must have high peak inverse voltage.

Calculating Load Voltage and Current Values

$$V_{L(pk)} = \frac{V_{S(pk)}}{2} - 0.7\ \text{V} \qquad V_{ave} = \frac{2\,V_{L(pk)}}{\pi} = 0.637\,V_{L(pk)}$$

Full-Wave Bridge Rectifier (Bridge)



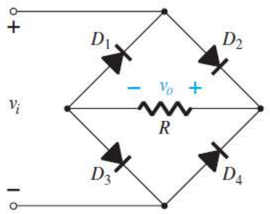


FIG. 2.53
Full-wave bridge rectifier.

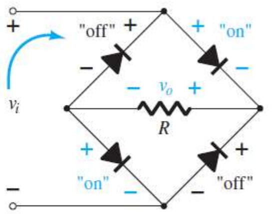


FIG. 2.54
Network of Fig. 2.53 for the period $0 \rightarrow T/2$ of the input voltage v_i.

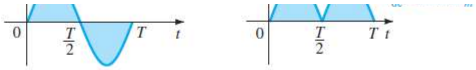


FIG. 2.57
Input and output waveforms for a full-wave rectifier.

Full-Wave Bridge Rectifier (Bridge)

Advantages

(*i*) The need for centre-tapped transformer is eliminated.

(*ii*) The output is twice that of the centre-tap circuit for the same secondary voltage.

(*iii*) The PIV is one-half that of the centre-tap circuit (for same d.c. output).

Disadvantages

(i) It requires four diodes.

(ii) As during each half-cycle of a.c. input two diodes that conduct are in series, therefore, voltage drop in the internal resistance of the rectifying unit will be twice as great as in the centre tap circuit.

Frequency and Efficiency of Full-Wave Rectifier

The DC output voltage is 0.636V_m, where V_m = the peak AC voltage.

Output Frequency **Half wave: $f_{out} = 2f_{in}$**

∴ Full-wave rectification efficiency is

$$\eta = \frac{P_{dc}}{P_{ac}} = \frac{(2\,I_m/\pi)^2 R_L}{\left(\frac{I_m}{\sqrt{2}}\right)^2 (r_f + R_L)}$$

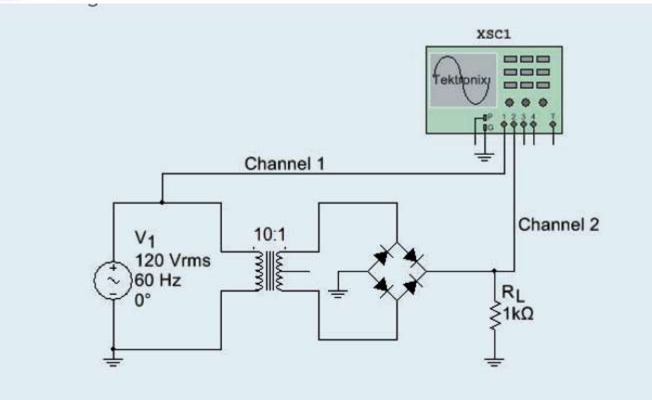
$$= \frac{8}{\pi^2} \times \frac{R_L}{(r_f + R_L)} = \frac{0.812\,R_L}{r_f + R_L} = \frac{0.812}{1 + \frac{r_f}{R_L}}$$

The efficiency will be maximum if r_f is negligible as compared to R_L.

∴ Maximum efficiency = 81.2%

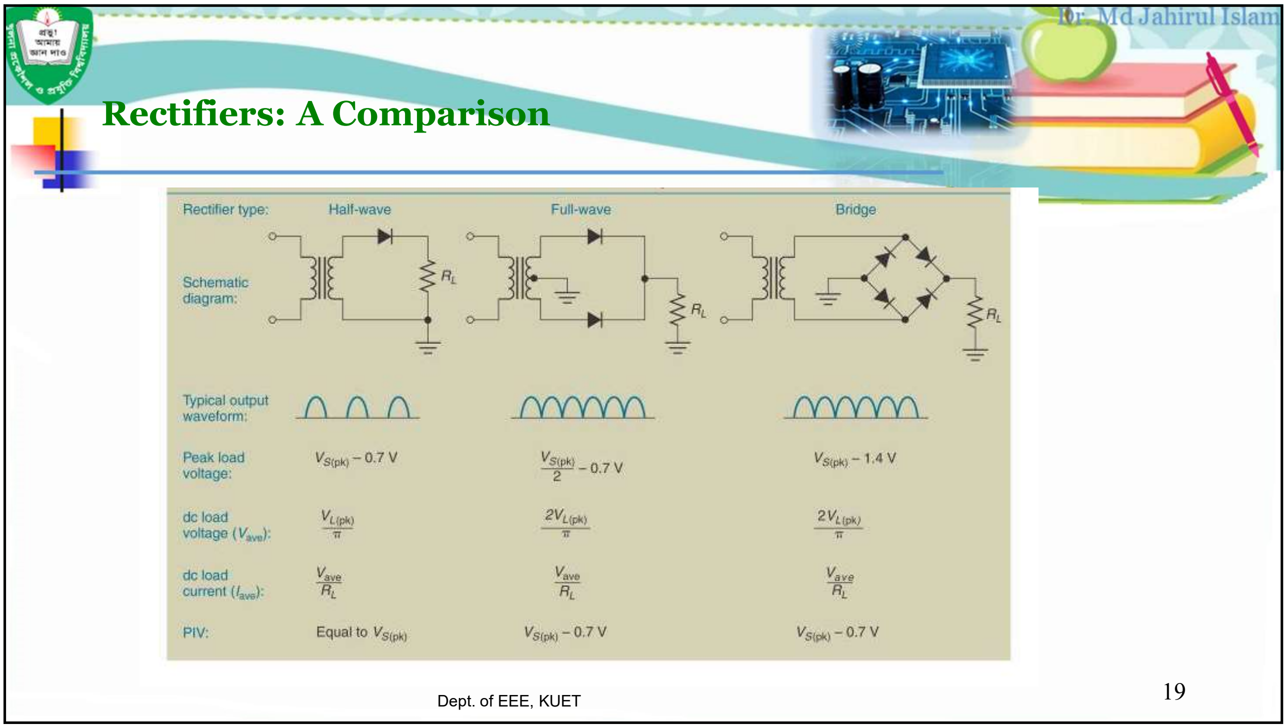
This is double the efficiency due to half-wave rectifier. Therefore, a full-wave rectifier is twice as effective as a half-wave rectifier.

Examples



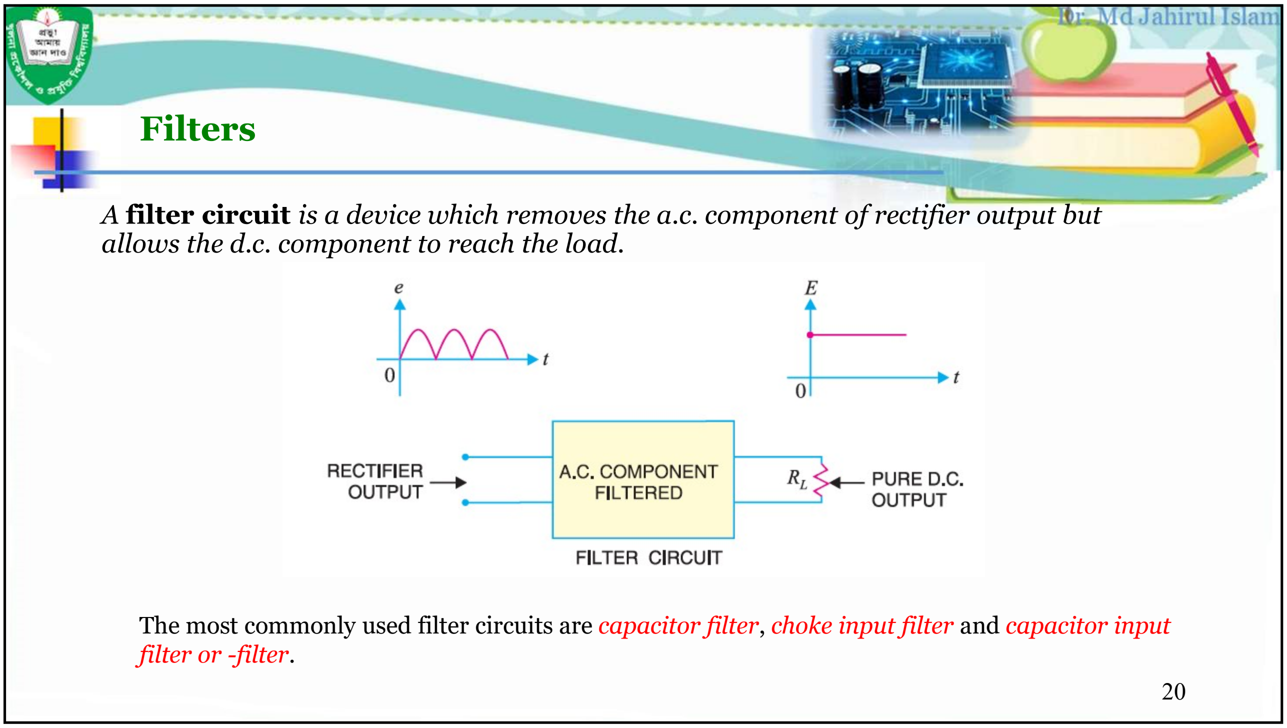
$$V_{p(\text{out})} = 17\text{ V} - 1.4\text{ V} = 15.6\text{ V}$$

Example 6.18.



Rectifiers: A Comparison

Rectifier type:	Half-wave	Full-wave	Bridge
Schematic diagram:			
Typical output waveform:			
Peak load voltage:	$V_{S(pk)} - 0.7$ V	$\frac{V_{S(pk)}}{2} - 0.7$ V	$V_{S(pk)} - 1.4$ V
dc load voltage (V_{ave}):	$\frac{V_{L(pk)}}{\pi}$	$\frac{2V_{L(pk)}}{\pi}$	$\frac{2V_{L(pk)}}{\pi}$
dc load current (I_{ave}):	$\frac{V_{ave}}{R_L}$	$\frac{V_{ave}}{R_L}$	$\frac{V_{ave}}{R_L}$
PIV:	Equal to $V_{S(pk)}$	$V_{S(pk)} - 0.7$ V	$V_{S(pk)} - 0.7$ V



Filters

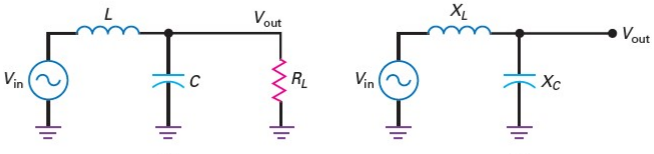
A **filter circuit** *is a device which removes the a.c. component of rectifier output but allows the d.c. component to reach the load.*

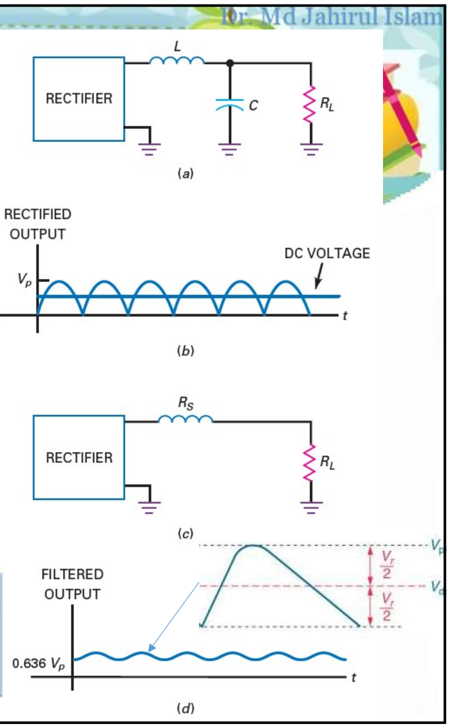
The most commonly used filter circuits are *capacitor filter*, *choke input filter* and *capacitor input filter or -filter*.

Filters

1. The Choke-Input Filter

Figure 4-10 (*a*) Choke-input filter; (*b*) ac-equivalent circuit.





The inductor has a reactance given by:

$$X_L = 2\pi fL$$

The capacitor has a reactance given by:

$$X_C = \frac{1}{2\pi fC}$$

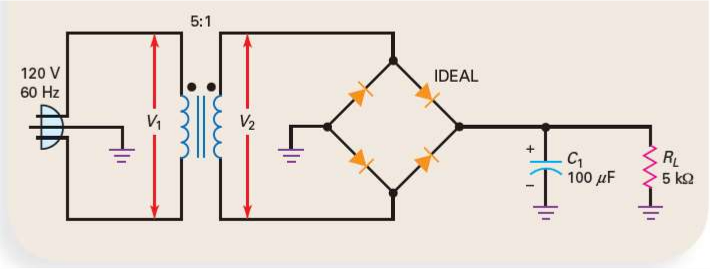
- **LC Filter limits surge current**
- **High current low voltage problems**

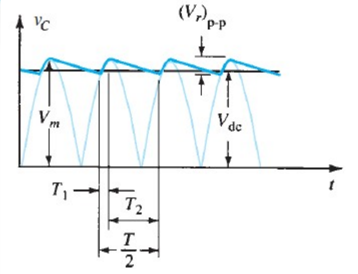
Filter Output Voltages $V_{dc} = V_{pk} - \frac{V_r}{2}$

The choke (or inductor) has the primary characteristic of opposing a change in current. Because of this, a choke-input filter ideally reduces the ac current in the load resistor to zero. To a second approximation, it reduces the ac load current to a very small value.

Filters

2. Capacitor-Input Filter





Capacitor

- **Charges with V_p**
- **Discharges through R_L.**

A capacitor offers infinite reactance to d.c. For d.c., $f = 0$.

$$\therefore \quad X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi \times 0 \times C} = \infty$$

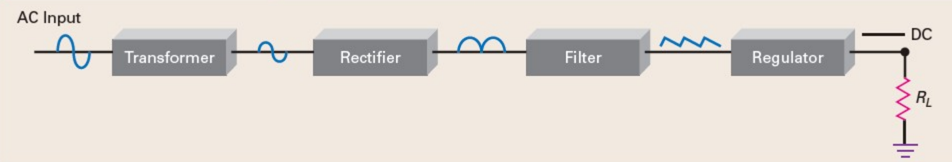
Hence, a capacitor does not allow d.c. to pass through it.

Definition: Ripple is defined as

$$r = \frac{\text{ripple voltage (rms)}}{\text{dc voltage}} = \frac{V_r(\text{rms})}{V_{dc}} \times 100\%$$

Power Supply

Summary Table 4-3 Power Supply Block Diagram



Purpose	Provides proper secondary ac voltage and ac ground isolation	Changes ac input to pulsating dc	Smooths out dc pulses	Provides a constant output voltage under varying loads and ac input voltage
Types	Step-up, step-down, isolation (1:1)	Half-wave, full-wave, full-wave bridge	Choke-input, capacitor-input	Discrete components, integrated circuit (IC)

Regulator IC

- ☐ The series 78 regulators provide fixed regulated voltages from 5 V to 24 V.
- ☐ LM 309 also gives +5 V.
- ☐ The regulator IC not only reduces the ripple, it also holds the output voltage constant.
- ☐ Zener diode can also be used as voltage regulator.

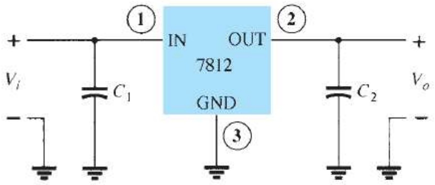


FIG. 15.26
Connection of a 7812 voltage regulator.

Positive-Voltage Regulators in the 7800 Series

IC Part	Output Voltage (V)	Minimum V_i (V)
7805	+5	7.3
7806	+6	8.3
7808	+8	10.5
7810	+10	12.5
7812	+12	14.6
7815	+15	17.7
7818	+18	21.0
7824	+24	27.1

A Complete +5V power supply

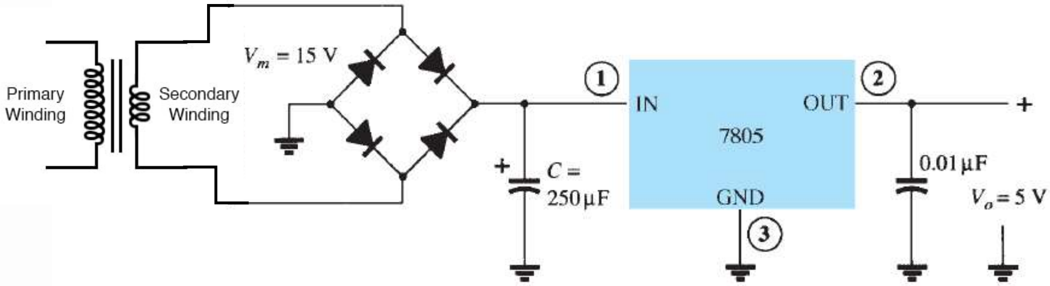


FIG. 15.29
A +5-V power supply.

Thank You!