Rectifier

INTRODUCTION

- RECTIFIER is an electrical device that converts alternating current (AC) to direct current (DC).
- The process is called rectification
- Input can be single or multi-phase (e.g. 3-phase).
- • Output can be made fixed or variable
- • **Applications**:
- DC welder,
- DC motor drive,
- Battery charger,
- DC power supply,
- HVDC

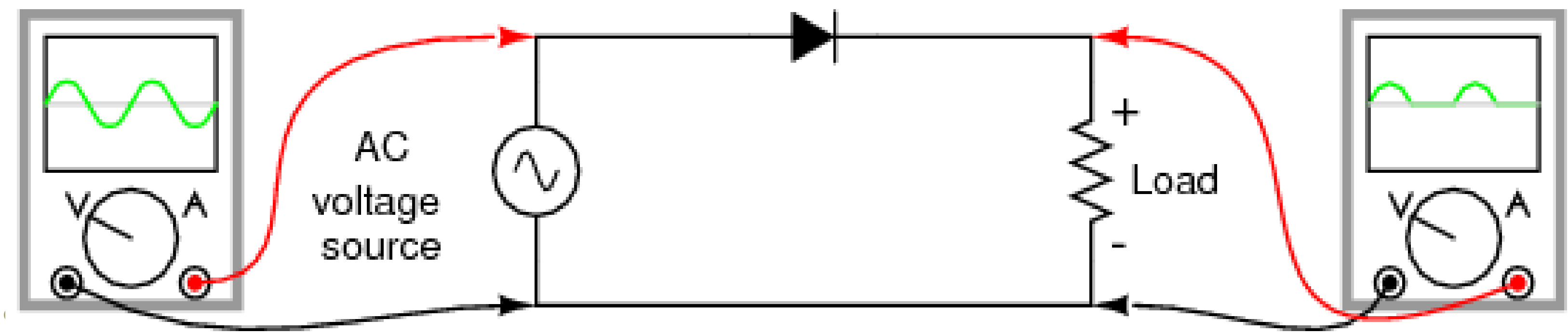
RECTIFIER CIRCUITS

- Single-phase rectifiers
  - Half-wave rectification
  - Full-wave rectification
- Three-phase rectifiers
  - Three-phase, half-wave circuit
  - Three-phase, full-wave circuit

- **single-phase rectifiers** are in use both as low-power stand-alone converters (up to some kilowatts) and as output stage in Switched Mode Power Supplies (SMPS). For domestic equipment.

- **Multi-phase rectifiers- three phase rectifiers** supplies the direct current at very low ripple and at a very very stable to the load (e.g., magnet or klystron) for most industrial and high-power applications, three-phase rectifier circuits are the norm.
- As with single-phase rectifiers, three-phase rectifiers can take the form of a half-wave circuit, a full-wave circuit using a center-tapped transformer, or a full-wave bridge circuit.

Single-phase rectifiers: HALF-WAVE RECTIFICATION



- the harmonic content of the rectifier's output waveform is very large and consequently difficult to filter.

Single-phase rectifiers: HALF-WAVE RECTIFICATION

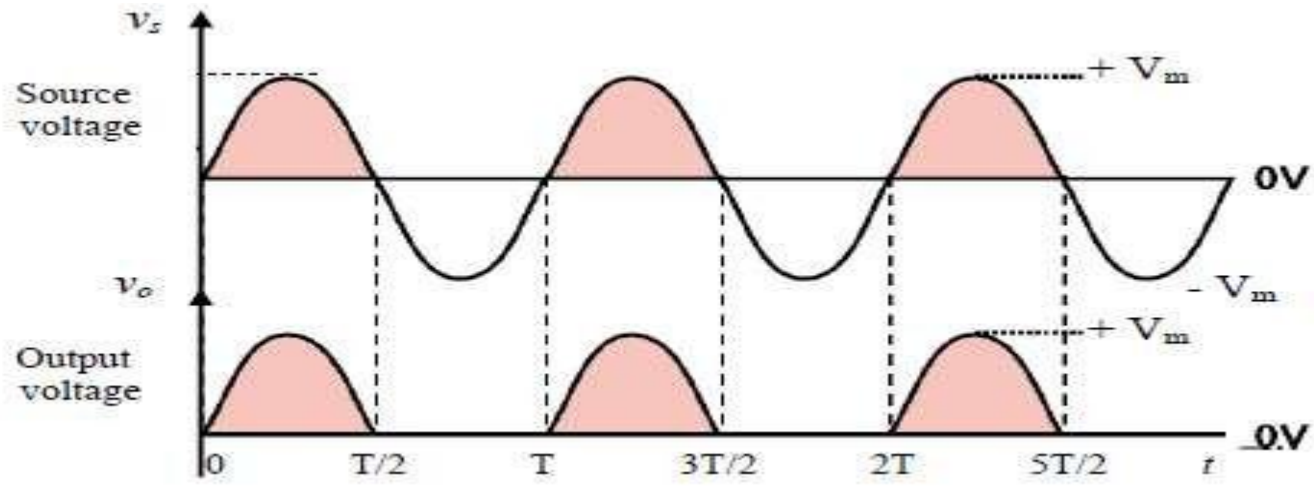
- Single diode rectifier is connected across an alternating voltage source V_s

- Since the diode only conducts when the anode is positive with respect to the cathode, current will flow only during the positive half cycle of the input voltage.

Cont.

- During the positive half cycle of the source, the ideal diode is forward biased and operates as a closed switch.
- The source voltage is directly connected across the load. During the negative half cycle, the diode is reverse biased and acts as an open switch.
- The source voltage is disconnected from the load. As no current flows through the load, the load voltage *vo is zero.*
- *Both the load voltage and current are of one polarity and hence said* to be rectified.

Single-phase rectifiers: HALF-WAVE RECTIFICATION



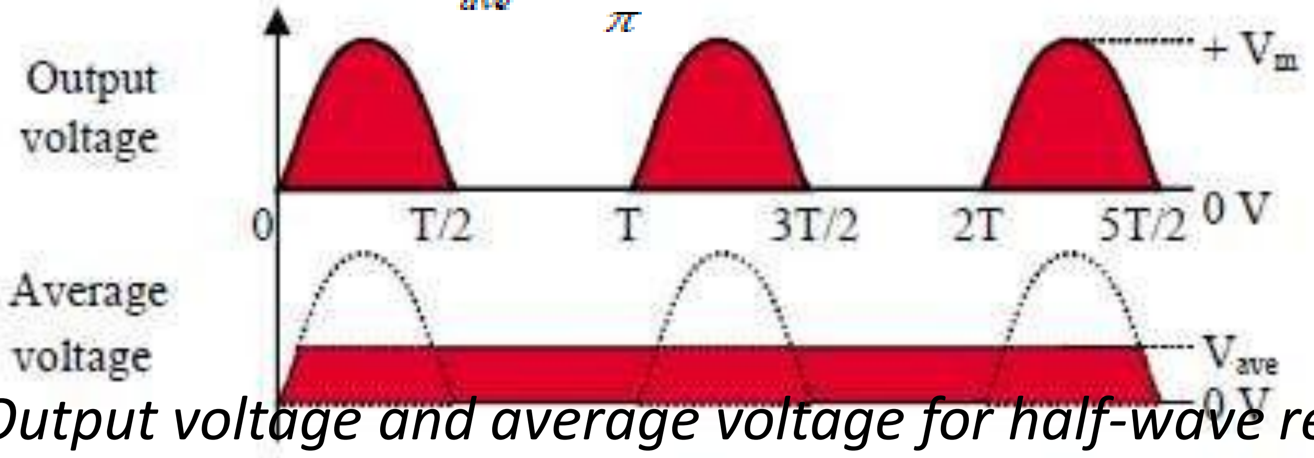
The waveforms for source voltage V_s and output voltage V_o

- The output voltage varies between the peak voltage V_m and zero in each cycle. This variation is called "ripple", and the corresponding voltage is called the peak-to-peak ripple voltage, $V_{p\text{-}p}$.

Single-phase rectifiers: HALF-WAVE RECTIFICATION

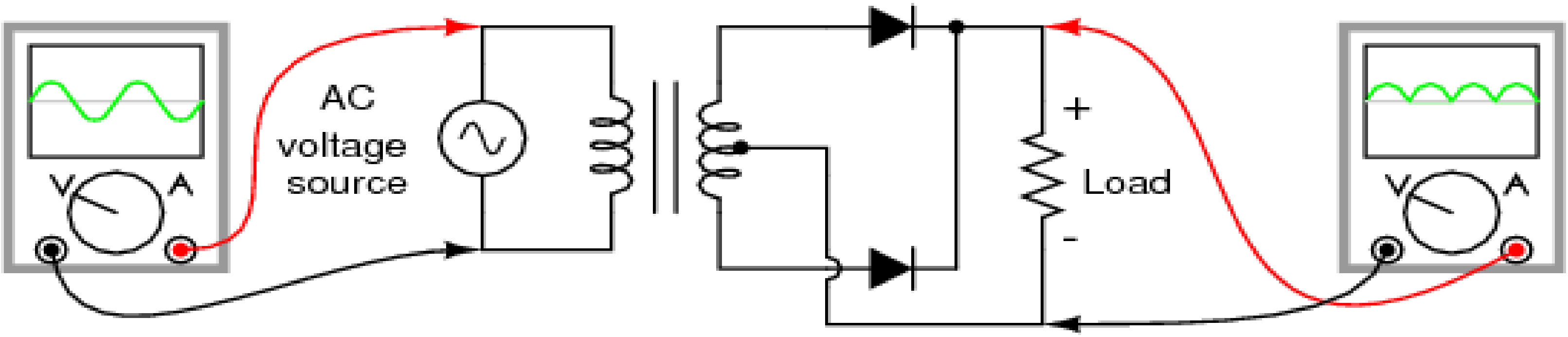
- If a DC voltmeter is connected to measure the output voltage of the half-wave rectifier (i.e., across the load resistance), the reading obtained would be the average load voltage *Vave, also called the DC output voltage.*
- *The* meter averages out the pulses and displays this average.

$$V_{ave} = \frac{V_m}{\pi}$$



Output voltage and average voltage for half-wave rectifier

Single-phase rectifiers: FULL-WAVE RECTIFICATION



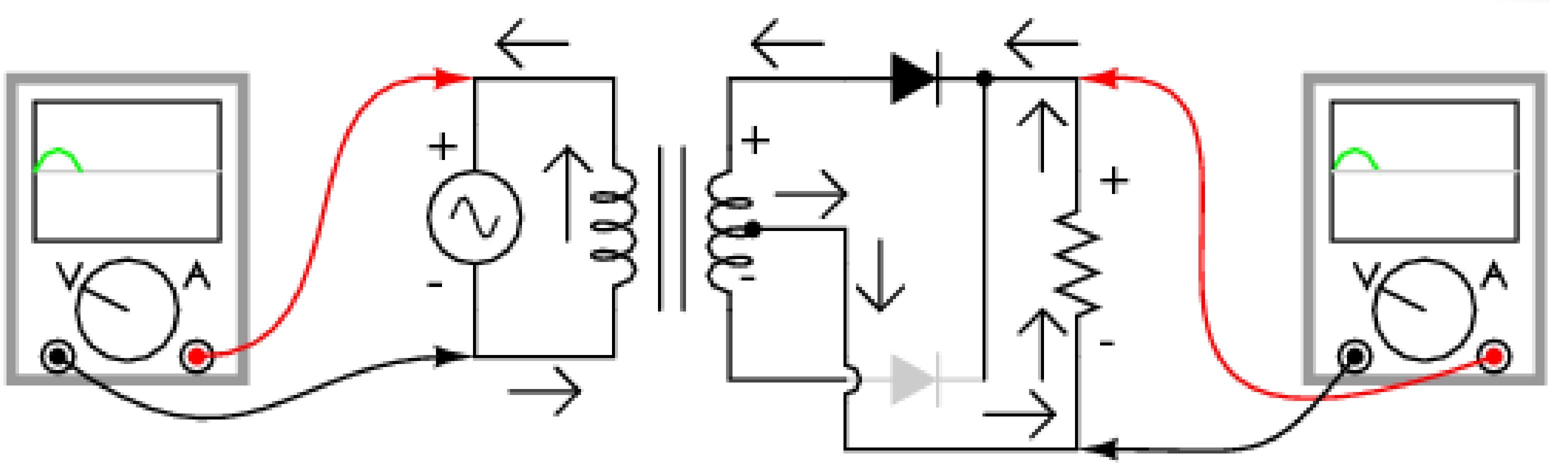
waveform to pulsating DC (direct current), and yields a higher average output voltage.

- if we need to rectify AC power to obtain the full use of *both* half-cycles of the sine wave, a different rectifier circuit configuration must be used. Such a circuit is called a *full-wave* rectifier.

- One kind of full-wave rectifier, called the *center-tap* design, uses a transformer with a center-tapped secondary winding and two diodes, as in Figure above.

- This circuit's operation is easily understood one half-cycle at a time.

Single-phase rectifiers: FULL-WAVE RECTIFICATION



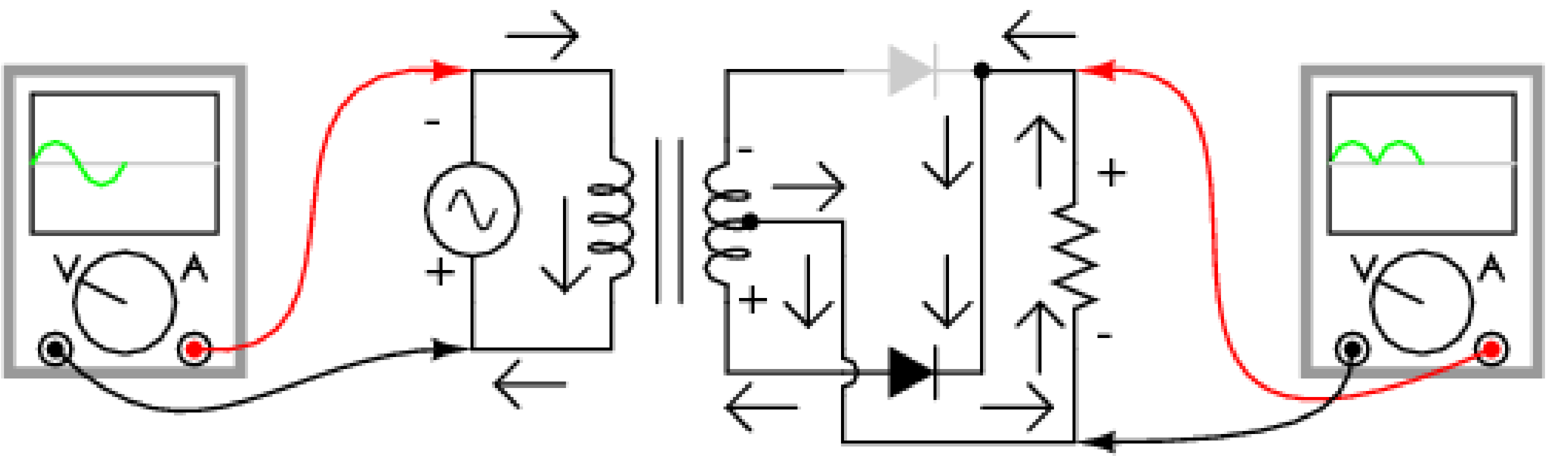
- *half-cycle to load.*

Understanding the circuit's operation one half-cycle at a time.

- Consider the first half-cycle, when the source voltage polarity is positive (+) on top and negative (-) on bottom.

- At this time, only the top diode is conducting; the bottom diode is blocking current, and the load “sees” the first half of the sine wave, positive on top and negative on bottom. Only the top half of the transformer's secondary winding carries current during this half-cycle as in Figure

Single-phase rectifiers: FULL-WAVE RECTIFICATION

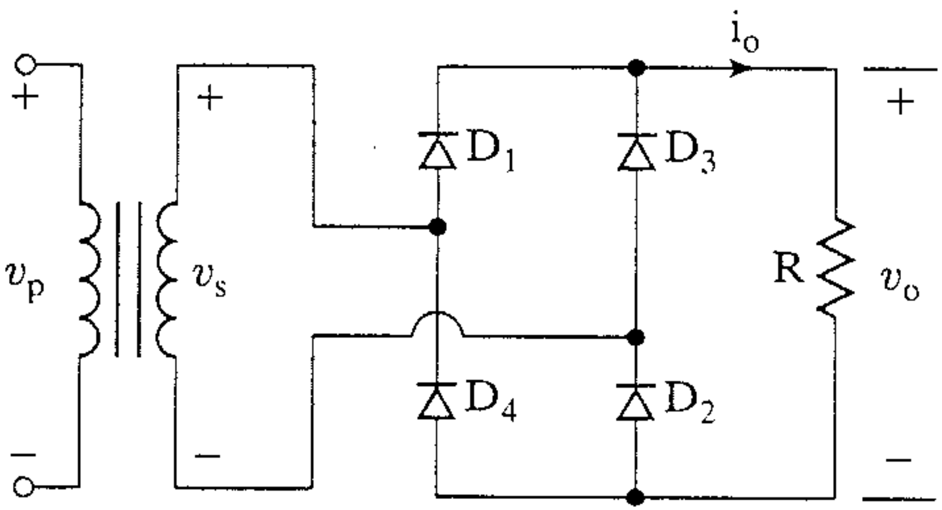
- 

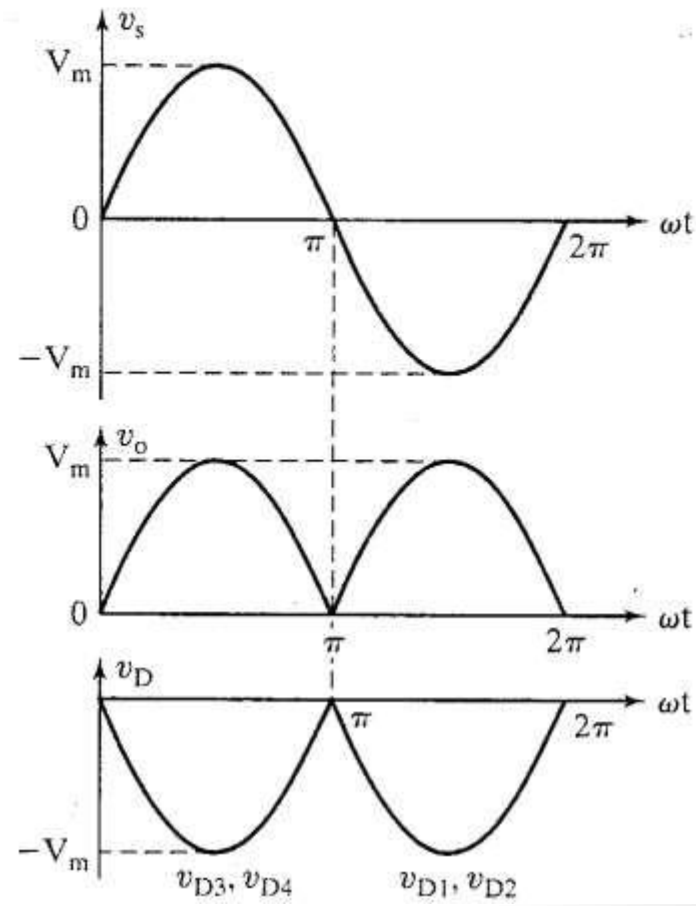
positive half-cycle to the load.

Cont.

- During the next half-cycle, the AC polarity reverses. Now, the other diode and the other half of the transformer's secondary winding carry current while the portions of the circuit formerly carrying current during the last half-cycle sit idle.
- The load still “sees” half of a sine wave, of the same polarity as before: positive on top and negative on bottom

Full-Wave Bridge Rectifier





Conduction pattern

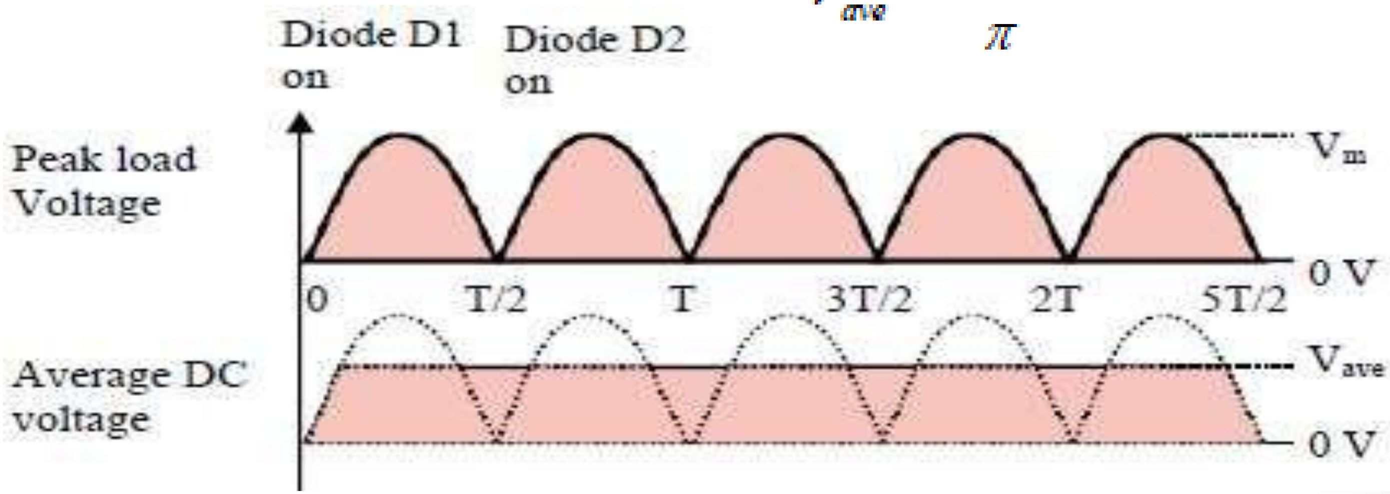
$D_1 - D_2$ $D_3 - D_4$

$PIV = V_m$

Single-phase rectifiers: FULL-WAVE RECTIFICATION

- The full wave rectifier produces twice as many output pulses as the half wave rectifier.
- average load voltage (i.e. DC output voltage) is found as

$$V_{ave} = \frac{2V_m}{\pi}$$



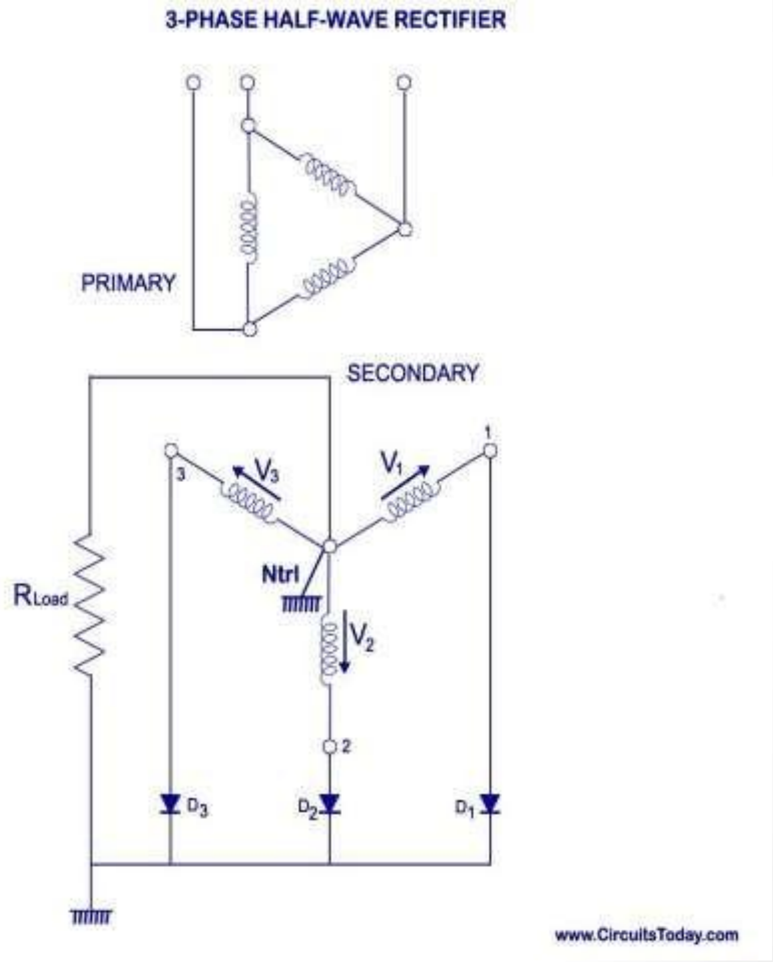
Average DC Voltage for a Full Wave Rectifier

Multi-phase rectification

- The higher the number of pulses:
  - the better the utilization of the rectifier
  - the lesser the ripple amplitude
  - the higher the ripple frequency — this implies that filtering the ripple is easier.
- Systems with a number of pulses higher than 12 (normally obtained by combining two three-phase bridges) are not often used since their advantages are compensated by their growing complexity.

Multi-phase rectifiers: **Three phase Half Wave Rectifier**

- consists of a three phase transformer
- a star connected secondary three phase transformer with three diodes connected to the three phases
- the neutral point ‘NTRL’ of the secondary is considered as the earth for the circuit and is given as the negative terminal for the load

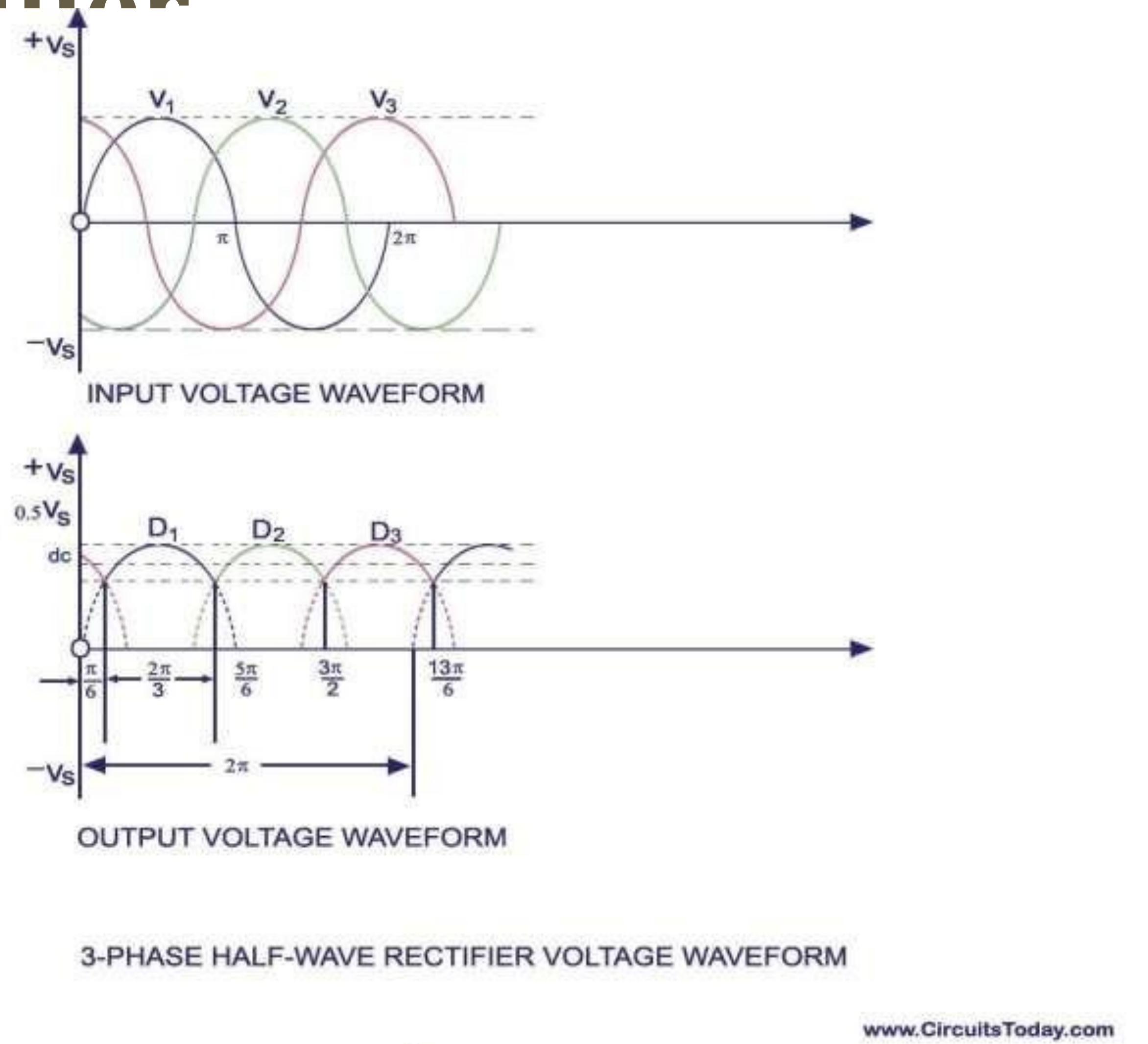


Cont.

- A three phase half wave rectifier, as the name implies , consists of a three phase transformer.
- Given below is a star connected secondary three phase transformer with three diodes connected to the three phases.
- As shown in the figure, the neutral point ‘NTRL’ of the secondary is considered as the earth for the circuit and is given as the negative terminal for the load.

Multi-phase rectifiers:

Three phase Half Wave Rectifier



Cont.

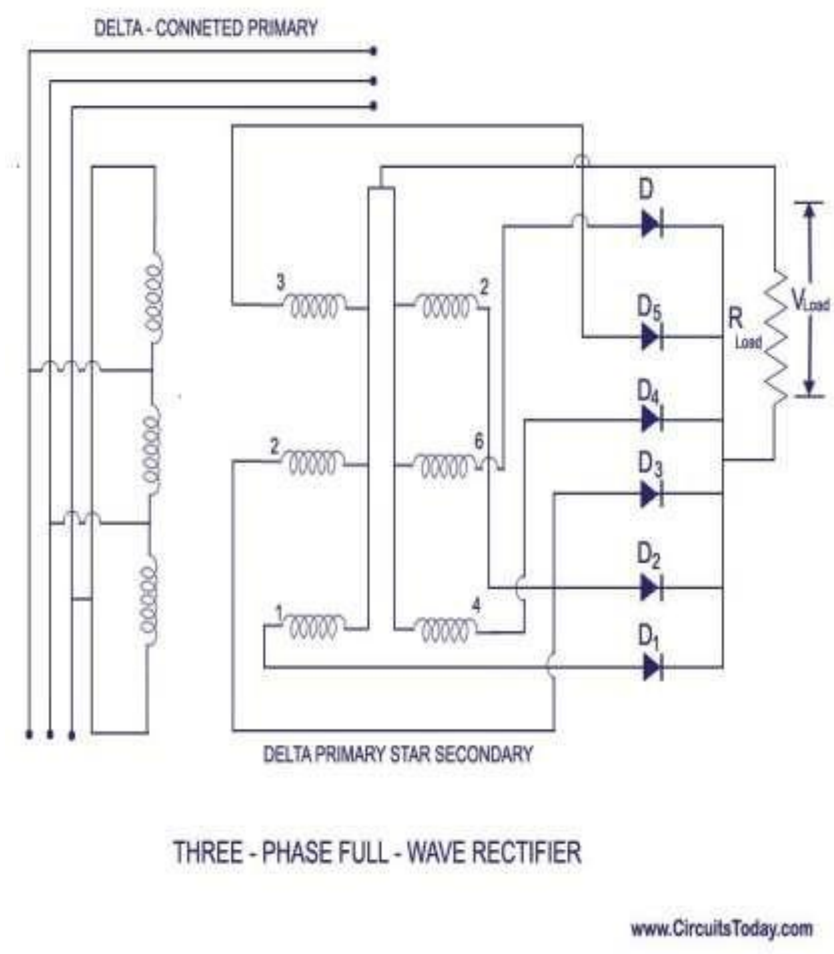
- For each one-third of the cycle, each diode conducts.
- At the instant when one diode out of three is conducting, the other two are left inactive, at that instant their cathodes becomes positive with respect to the anodes.
- Then the process repeats for each of the three diodes.

- The input and the output wave forms for the circuit above is shown below. For each one-third of the cycle, each diode conducts.
- At the instant when one diode out of three is conducting, the other two are left inactive, at that instant their cathodes becomes positive with respect to the anodes. This process repeats for each of the three diodes.

- The voltage between the cathode and ‘NTRL’ (dc voltage Vdc) will have a value between the peak value of alternating voltages per phase Vsm and half this value ½ Vsm.

Multi-phase rectifiers: **Three phase Full Wave Rectifier**

- also called as a six wave half wave rectifier
- in the figure below the diodes D1 to D6 will conduct only for ⅙ th of the period, with a period of pi/3.
- Six diodes are used

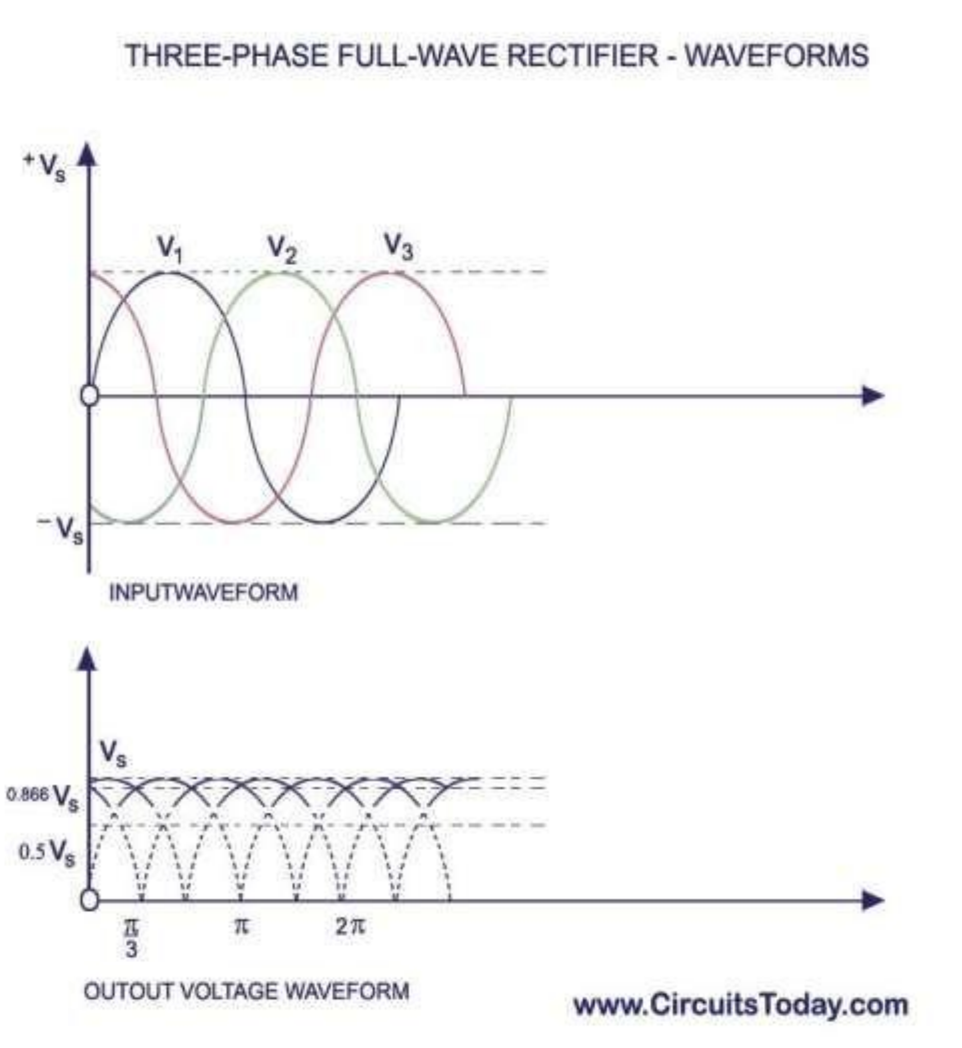


Cont.

- Six diodes are used for the making of this full wave rectifier. As so, it may pose some problems and may also be advantageous in some cases.
- If we need a smoother output, the use of six diodes may be seen as an advantage.But the use of six diodes complicates the circuit and each diode operates for a shorter cycle.
- Also, since no more than six are used, the circuit is cost effective, as long as it is compared with the comparative increase in the output of the rectifier.

Multi-phase rectifiers: **Three phase Full Wave Rectifier**

- the fluctuation of dc voltage is less in a three phase circuit
- the variation lies between the maximum alternation voltage and 86.6% of this, with the average value being 0.955 times the maximum value



Cont.

As shown in the output wave form, the fluctuation of dc voltage is less in a three phase circuit.

The variation lies between the maximum alternation voltage and 86.6% of this, with the average value being 0.955 times the maximum value.

- Thank You

RECTIFIER

Rectifiers

- Rectifier: Rectifier is that circuit, that converts ac to dc.

- The following two types of rectifier circuit can be used:

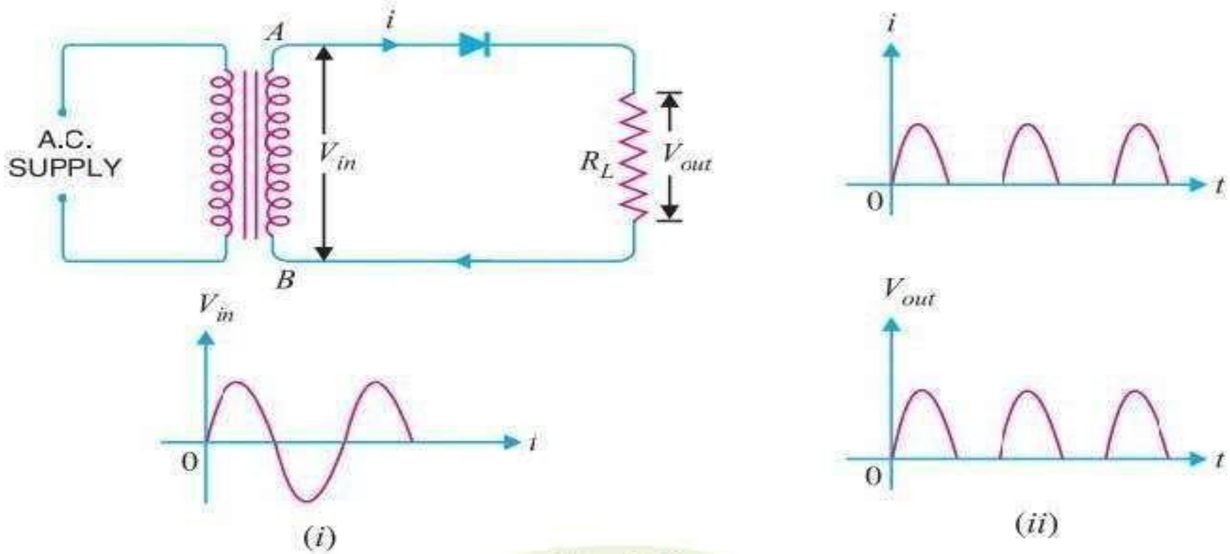
I. Half wave rectifier
II. Full wave rectifier

Half wave Rectifier

- The process of removing one-half the input signal to establish a dc level is called *half-wave rectification*.

- In Half wave rectification, the rectifier conducts current during positive half cycle of input ac signal only.

- Negative half cycle is suppressed or clipped.



Half wave Rectifier

- AC voltage across secondary terminals AB changes its polarity after each half cycle.

- During negative half cycle terminal A is negative so diode reversed biased and conduct no current.so current flows through diode during positive half cycle only.

- In this way current flows through load RL in one direction

Half wave Rectifier

Disadvantage of Half wave rectifier:

- Since, power is delivered only during one half of the cycle of the input alternating voltage, therefore, its power output and rectification frequency is low.
- Transformer utilization factor is also low.
- The DC output power produced from the half wave rectifier is not satisfactory to make a general power supply.

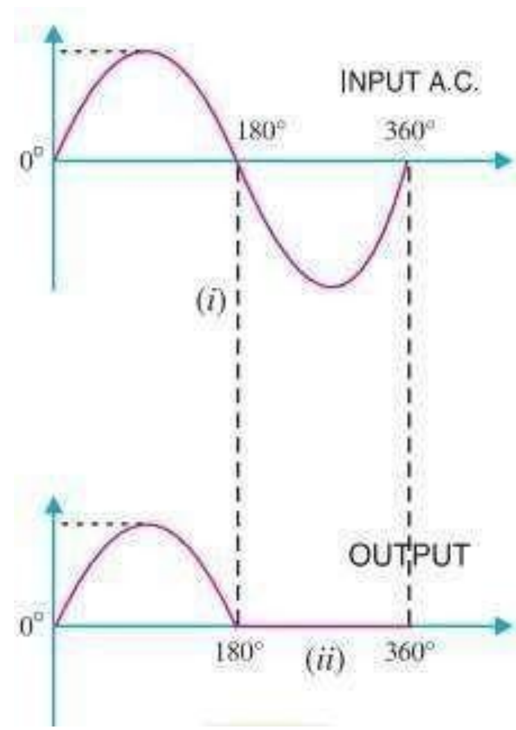
Half wave Rectifier

- Output frequency of HWR:

➢Output frequency of HWR is equal to input frequency.

➢This means when input ac completes one cycle, rectified wave also completes one cycle.

$$f_{out} = f_{in}$$

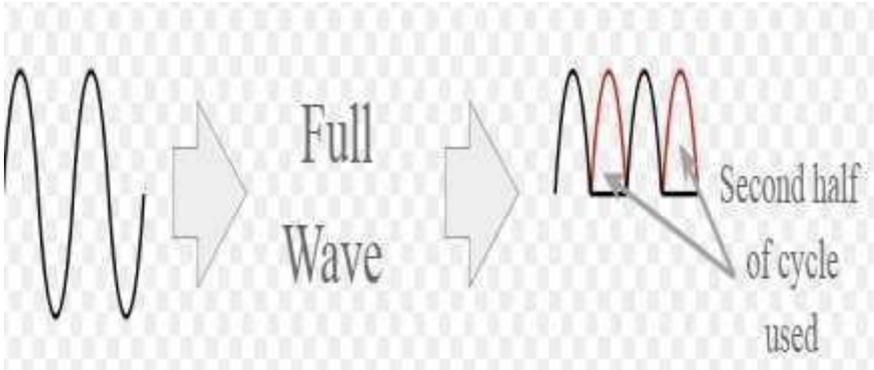


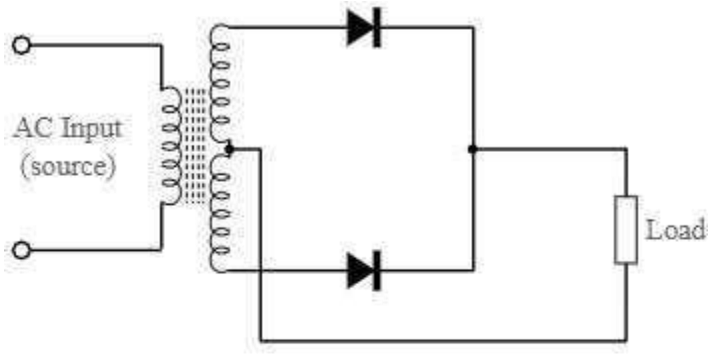
Full-Wave Rectifier

In Full wave rectification current flow through the load in same direction for both half cycle of input ac.

This can be achieved with two diodes working alternatively.

For one half cycle one diode supplies current to load and for next half cycle another diode works.



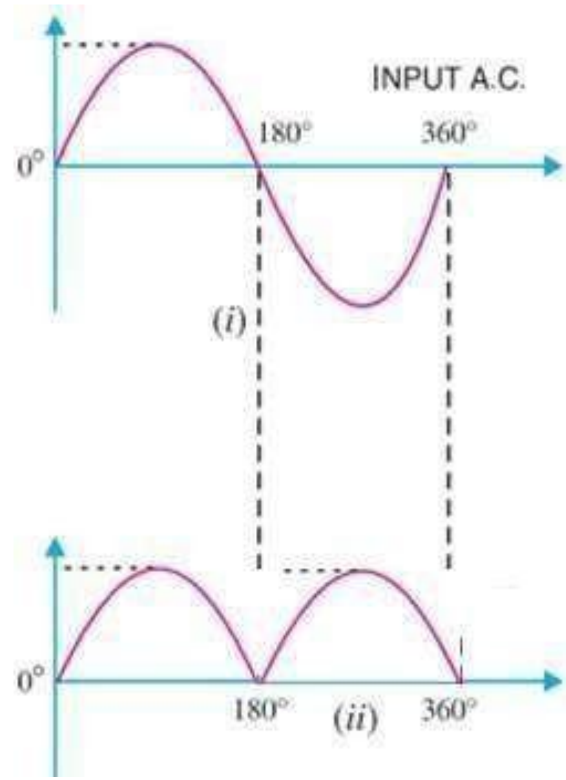


Full wave Rectifier

- Output frequency of FWR:

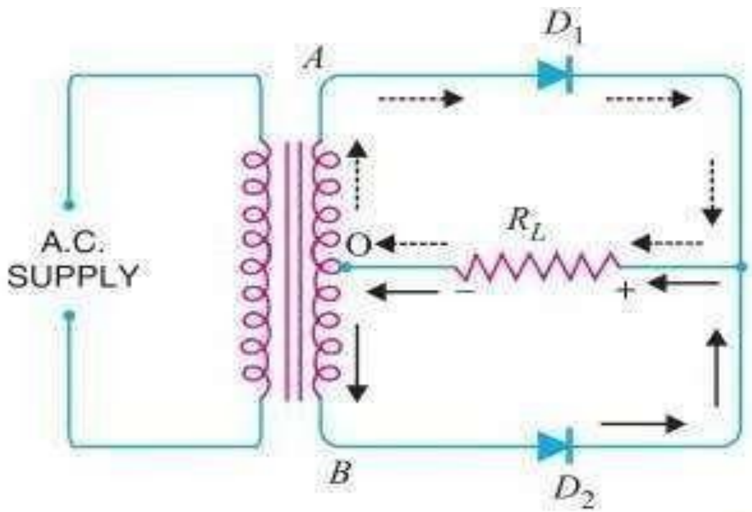
➢Output frequency of FWR is equal to double of input frequency.

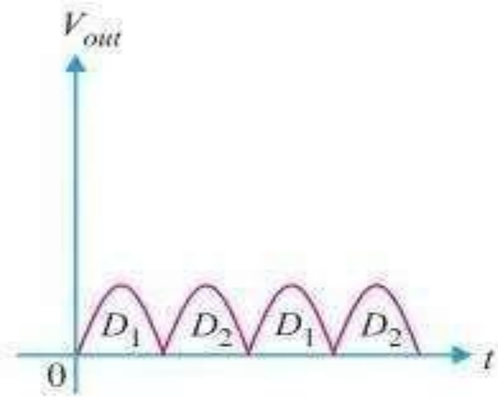
➢This means when input ac completes one cycle, rectified wave completes two cycles



$$f_{out} = 2 f_{in}$$

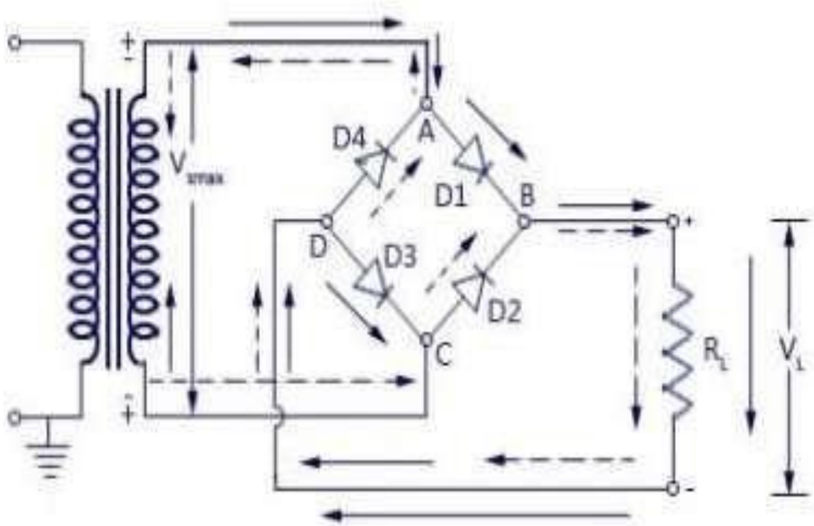
Centre Tap Full Wave Rectifier

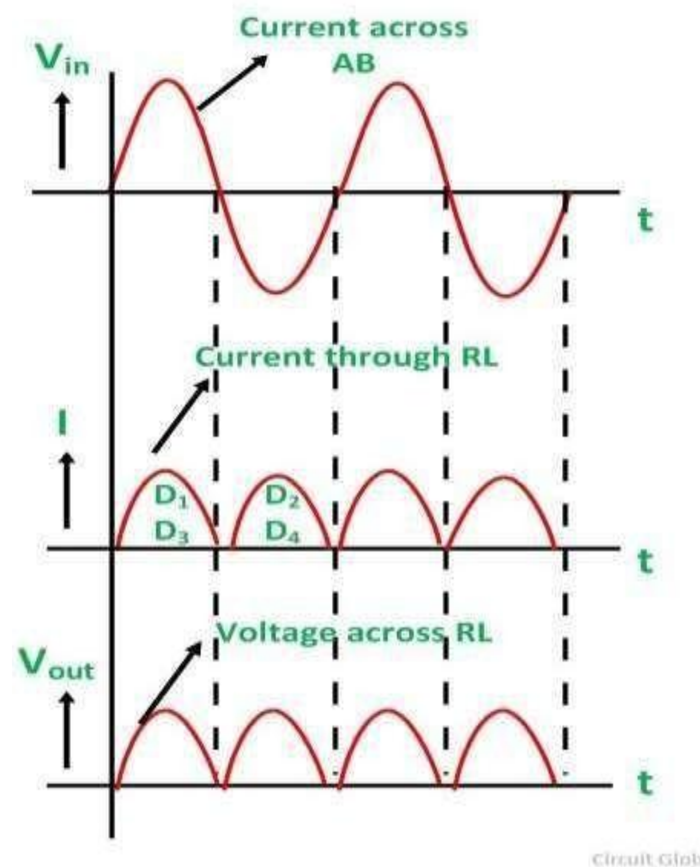




- Circuit has two diodes D1 , D2 and a centre tap transformer.
- During positive half cycle Diode D1conducts and during negative half cycle Diode D2 conducts.
- It can be seen that current through load RL is in the same direction for both cycle.

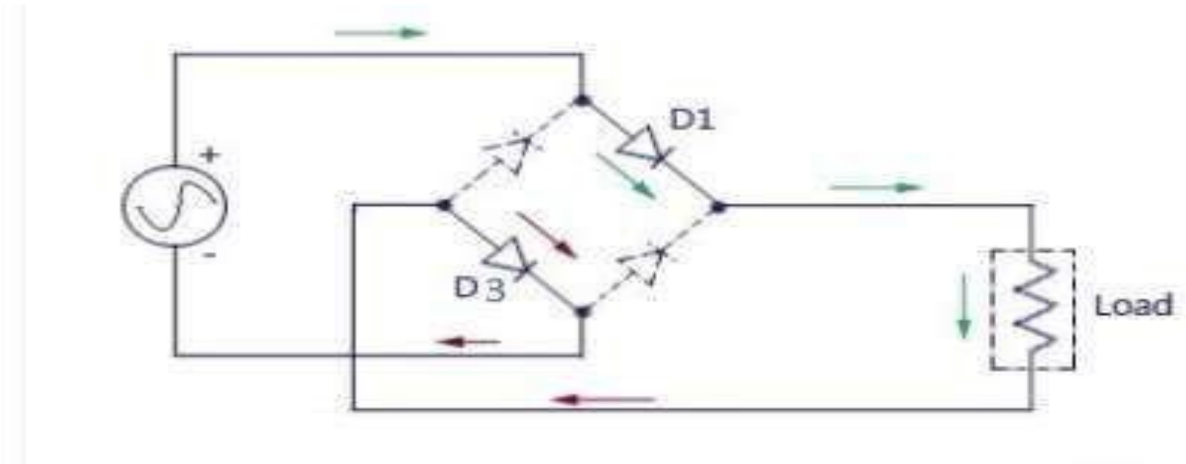
Full Wave Bridge Rectifier

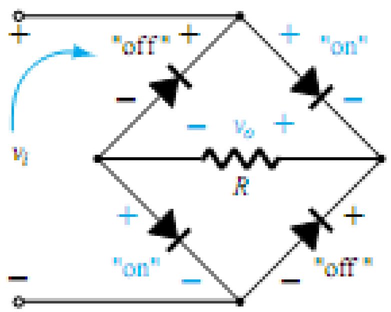




- Consists of 4 diodes instead of 2.

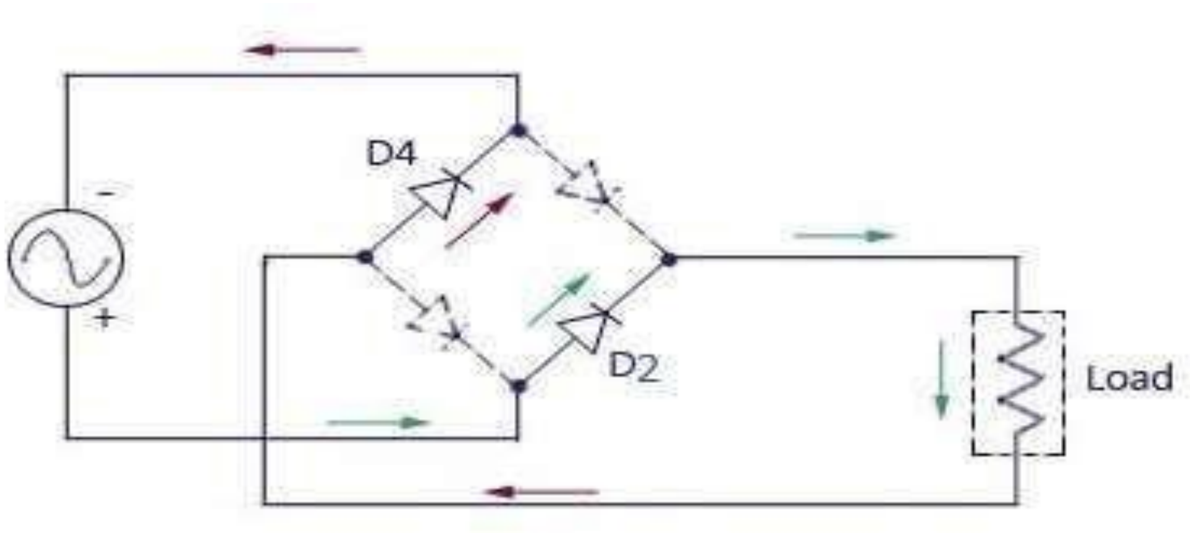
Full Wave Bridge Rectifier





- During first half cycle D1 and D3 are conducting while D2 and D4 are in the “off” state.

Full Wave Bridge Rectifier



➢During 2nd half cycle D2 and D4 are conducting while D1 and D3 are in the “off” state.

Full Wave Bridge Rectifier

Advantage:

I. Need for centre tap trnsformer is eliminated.
II. Output is twice than that of centre tap circuit.

Disadvantage

I. Requires 4 diodes.
II. Internal resistance voltage drop is twice than that of Centre Tap Circuit.

Voltage Regulator

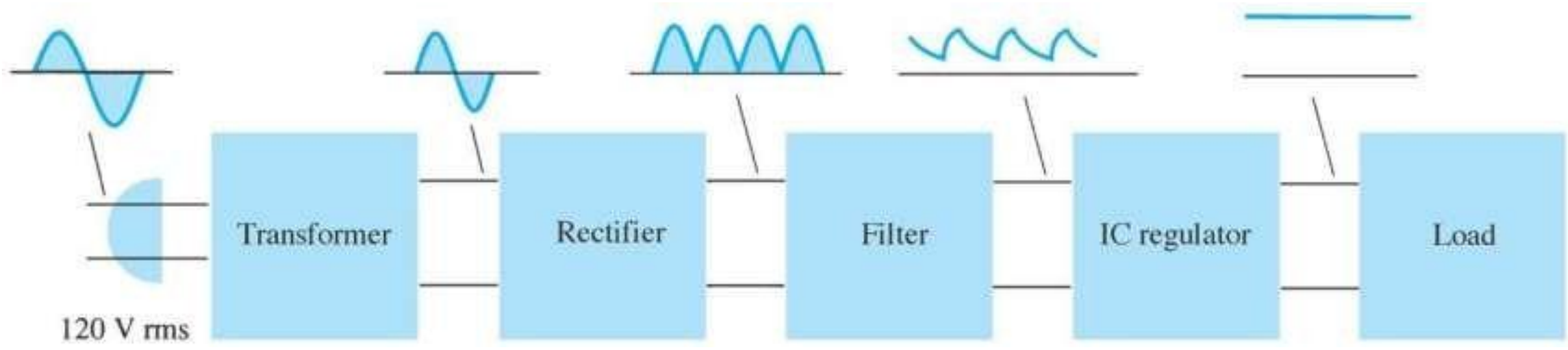
Outline

- Introduction
- Voltage Regulation
- Line Regulation
- Load Regulation
- Series Regulator
- Shunt Regulator
- Switching Regulator
- IC Voltage Regulator

Introduction

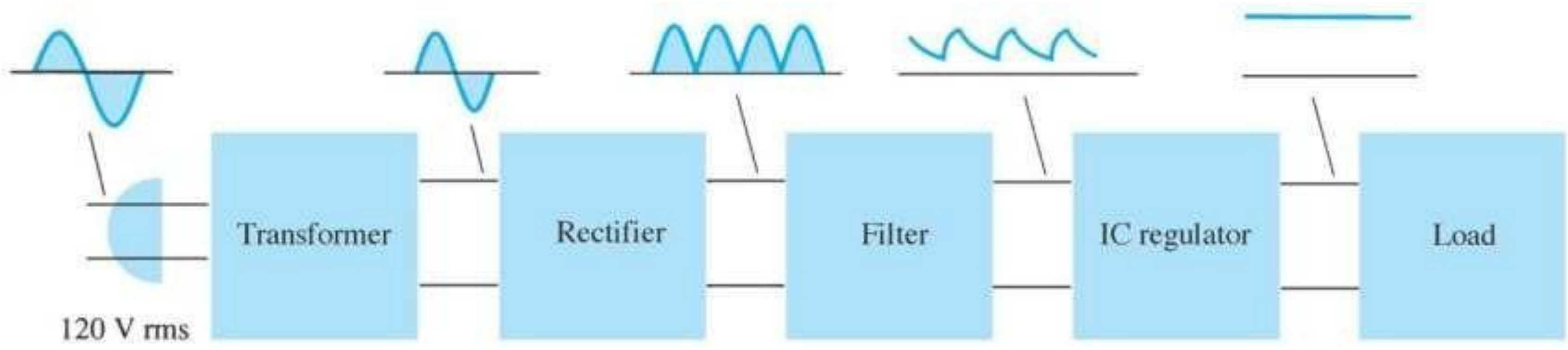
- Batteries are often shown on a schematic diagram as the source of DC voltage but usually the actual DC voltage source is a power supply.
- There are many types of power supply. Most are designed to convert high voltage AC mains electricity to a suitable low voltage supply for electronics circuits and other devices.
- A more reliable method of obtaining DC power is to transform, rectify, filter and regulate an AC line voltage.
- A power supply can by broken down into a series of blocks, each of which performs a particular function.

Introduction



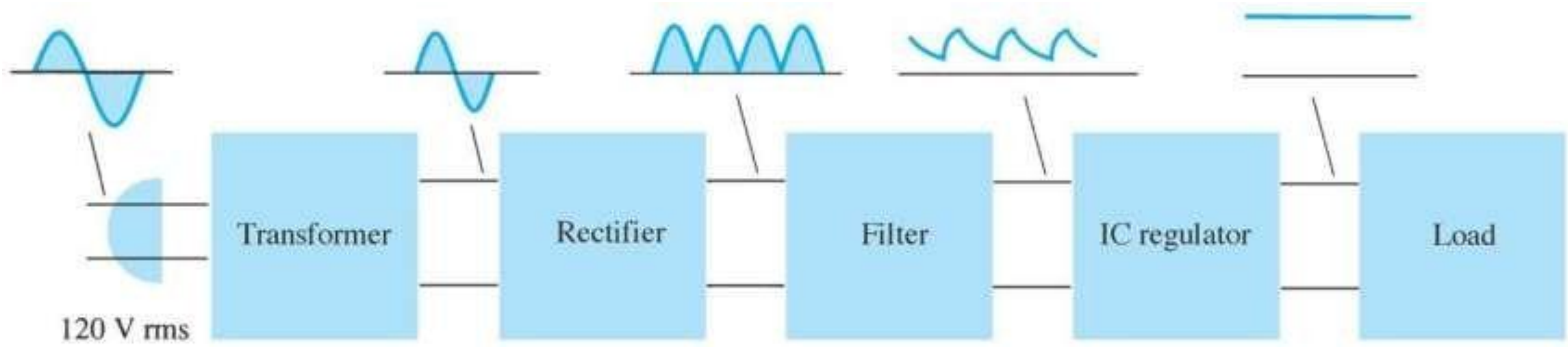
- ***Power supply***: a group of circuits that convert the ***standard ac voltage*** (120 V, 60 Hz) provided by the wall outlet to ***constant dc voltage***
- ***Transformer*** : a device that step up or step down the ***ac voltage*** provided by the wall outlet to a desired amplitude through the *action* of a *magnetic field*

Introduction



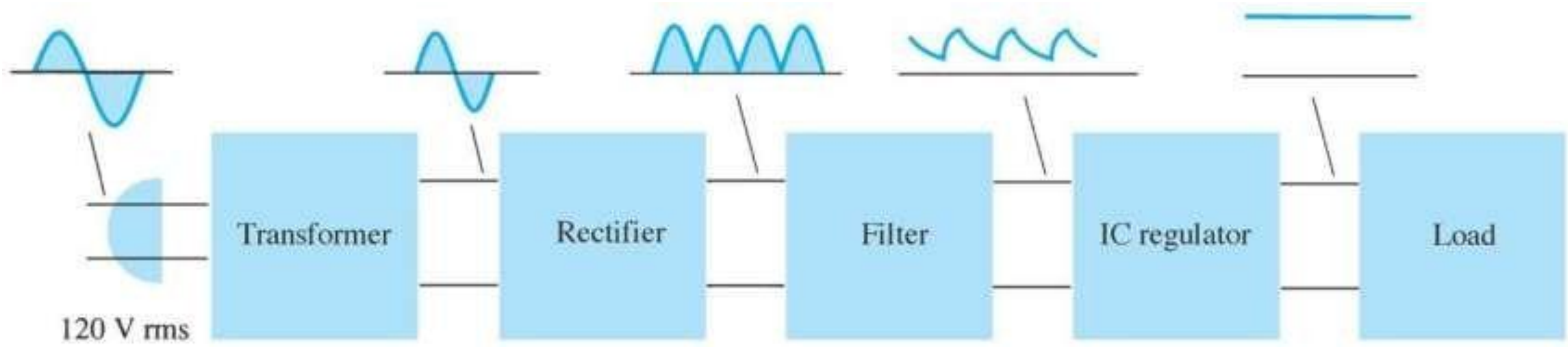
- ***Rectifier***: a diode circuits that converts the ***ac input voltage*** to a ***pulsating dc voltage***
- The pulsating dc voltage is **only suitable** to be used as a battery charger, but **not good enough** to be used as a dc power supply in a radio, stereo system, computer and so on.

Introduction



- There are two basic types of rectifier circuits:
  - Half-wave rectifier
  - Full-wave rectifier - Center-tapped & Bridge full-wave rectifier
- In summary, a full-wave rectified signal has **less ripple** than a half-wave rectified signal and is thus better to apply to a filter.

Introduction

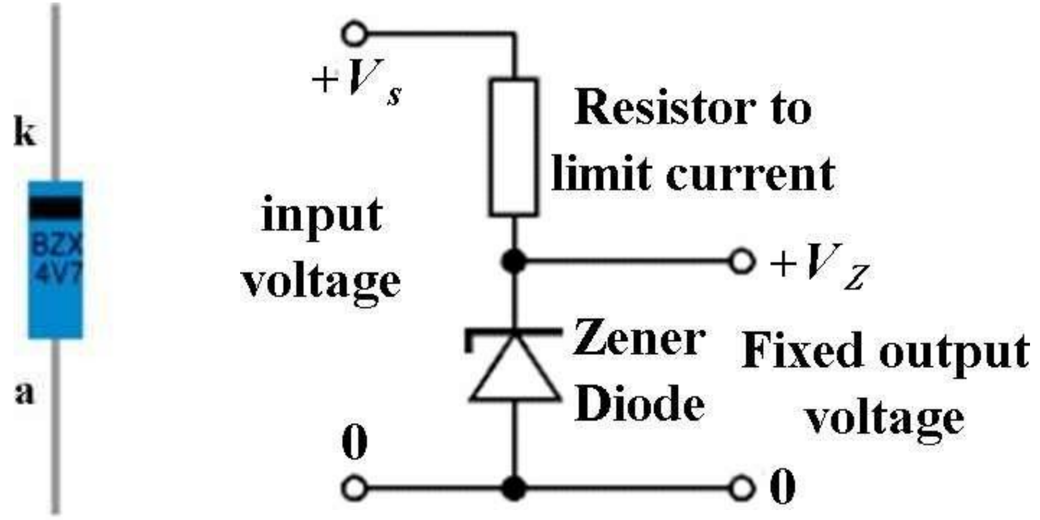


- ***Filter***: a circuit used to reduce the fluctuation in the rectified output voltage or ripple. This provides a ***steadier*** dc voltage.
- ***Regulator***: a circuit used to produces a ***constant*** dc output voltage by reducing the ripple to negligible amount. One part of power supply.

Introduction

Regulator - Zener diode regulator

- For low current power supplies - a simple voltage regulator can be made with a resistor and a zener diode connected in reverse.
- Zener diodes are rated by their breakdown voltage V_z and maximum power P_z (typically 400mW or 1.3W)

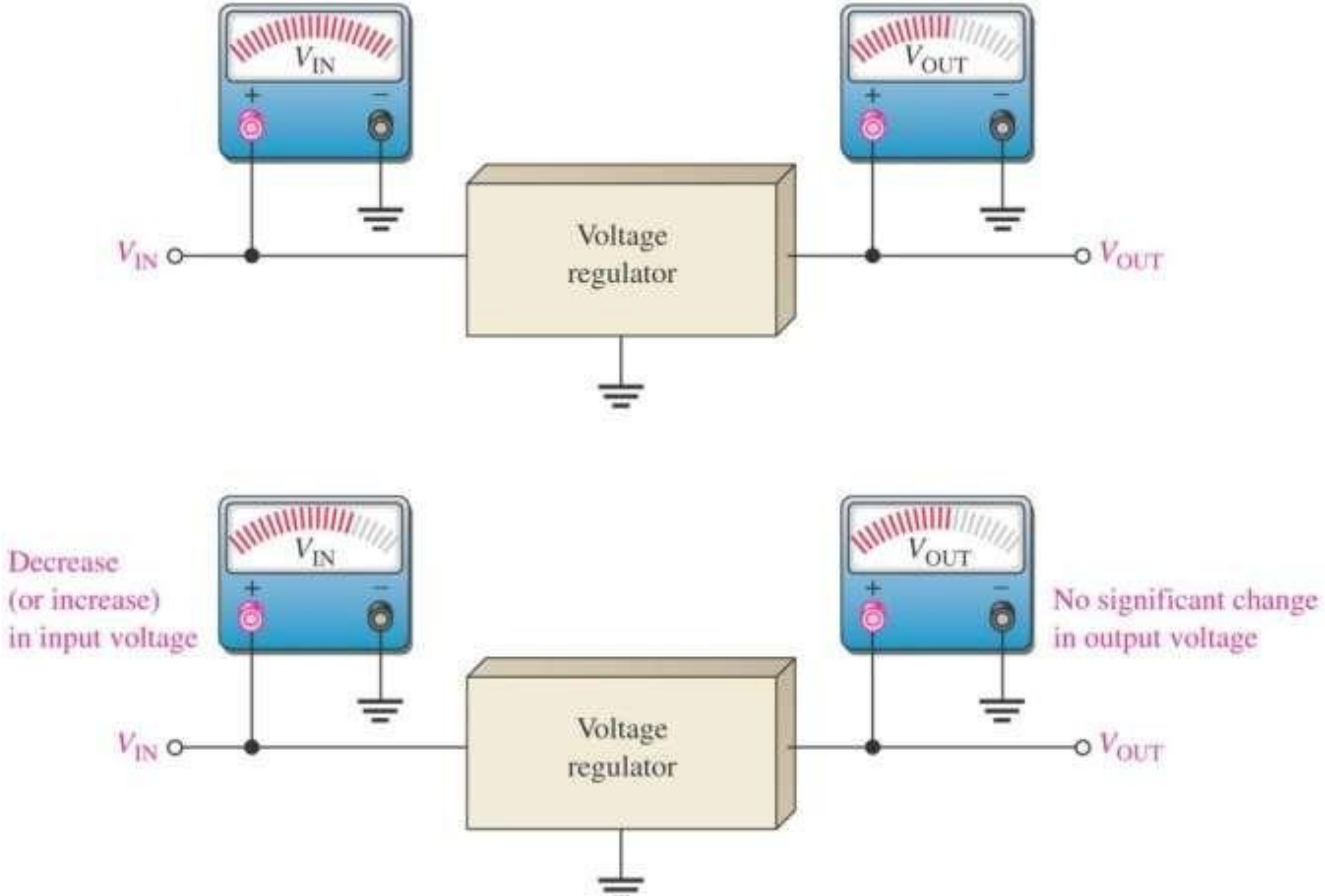


Voltage Regulation

- Two basic categories of voltage regulation are:
  - line regulation
  - load regulation

- The purpose of **line regulation** is to maintain a nearly constant output voltage when the **input voltage** varies.
- The purpose of **load regulation** is to maintain a nearly constant output voltage when the **load** varies

Line Regulation



Line regulation: A change in input (line) voltage does not significantly affect the output voltage of a regulator (within certain limits)

Line Regulation

- Line regulation can be defined as the percentage change in the output voltage for a given change in the input voltage.

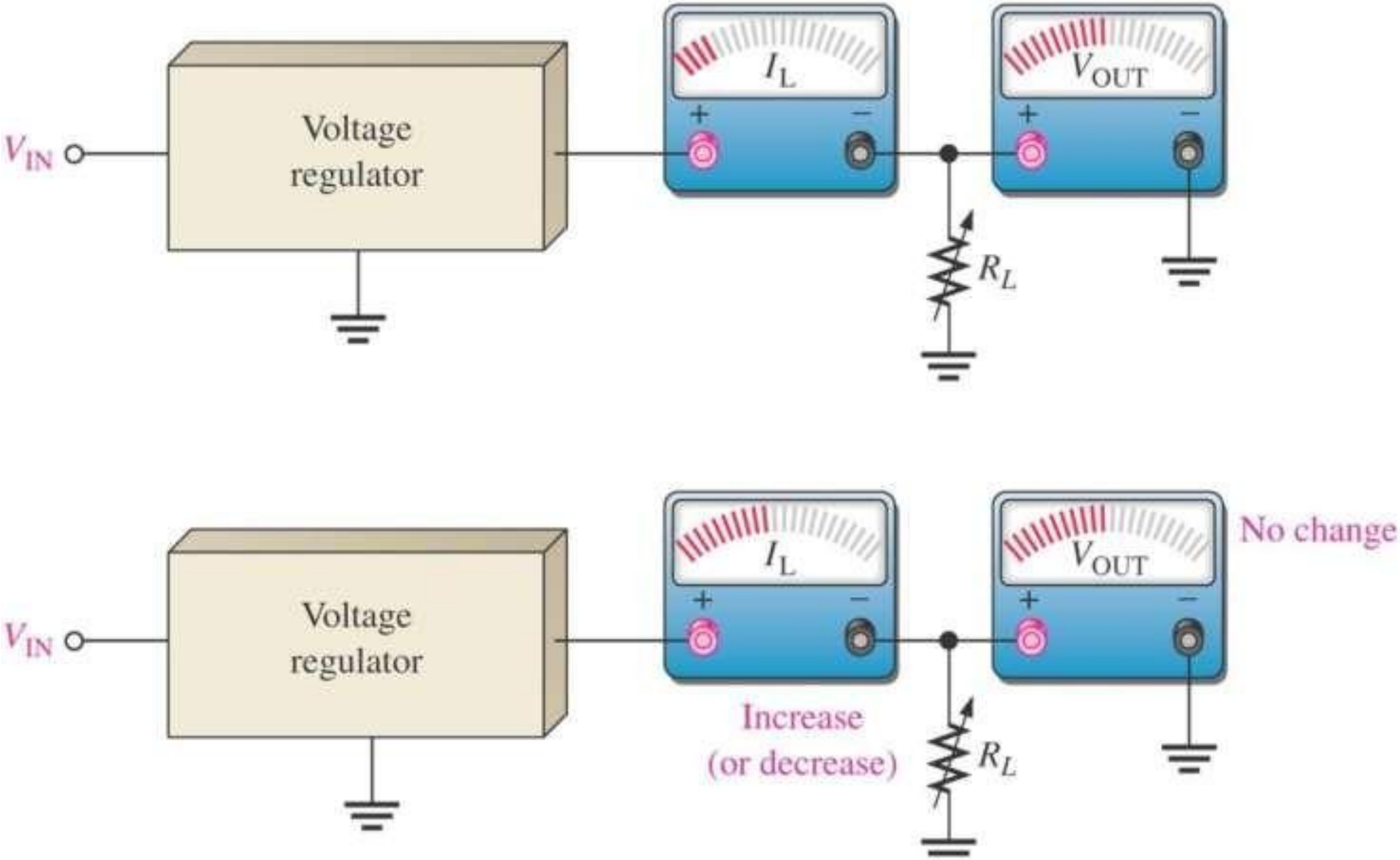
$$Line\ regulation = \left(\frac{\Delta V_{OUT}}{\Delta V_{IN}} \right) \times 100\%$$

Δ means "a change in"

- Line regulation can be calculated using the following formula:

$$Line\ regulation = \frac{\left(\Delta V_{OUT} \ / V_{OUT} \right) \times 100\%}{\Delta V_{IN}}$$

Load Regulation



Load regulation: A change in load current (due to a varying R_L) has practically no effect on the output voltage of a regulator (within certain limits)

Load Regulation

- Load regulation can be defined as the percentage change in the output voltage from no-load (NL) to full-load (FL).

$$Load\ regulation = \left(\frac{V_{NL} - V_{FL}}{V_{FL}} \right) \times 100\%$$

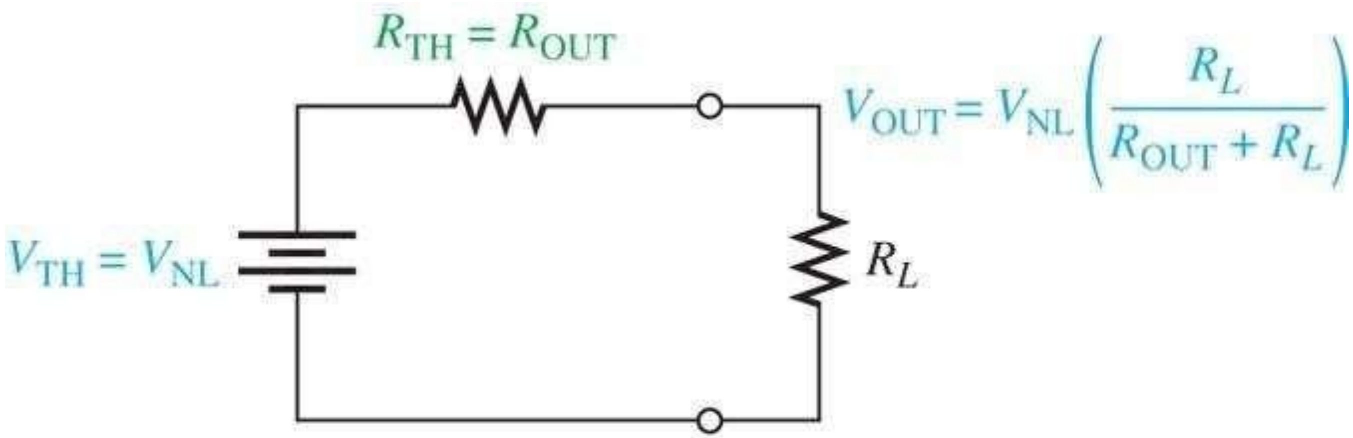
- Where:

  V_{NL} = the no-load output voltage

  V_{FL} = the full-load output voltage

Load Regulation

- Sometimes power supply manufacturers specify the equivalent output resistance (R_{out}) instead of its load regulation.



- R_{FL} equal the smallest-rated load resistance, then V_{FL}:

$$V_{FL} = V_{NL}\left(\frac{R_{FL}}{R_{OUT} - R_{FL}}\right)$$

Load Regulation

- Rearrange the equation:

$$V_{NL} = V_{FL}\left(\frac{R_{OUT} - R_{FL}}{R_{FL}}\right)$$

$$Load\ regulation = \frac{V_{FL}\left(\frac{R_{OUT} - R_{FL}}{R_{FL}}\right) - V_{FL}}{V_{FL}} \times 100\%$$

$$Load\ regulation = \left(\frac{R_{OUT} - R_{FL}}{R_{FL}} - 1\right) \times 100\%$$

$$Load\ regulation = \left(\frac{R_{OUT}}{R_{FL}}\right) \times 100\%$$

Example

1. The input of a certain regulator increases by 3.5 V.As a result, the output voltage increases by 0.042 V. The nominal output is 20 V. Determine the line regulation in both % and in %/V.

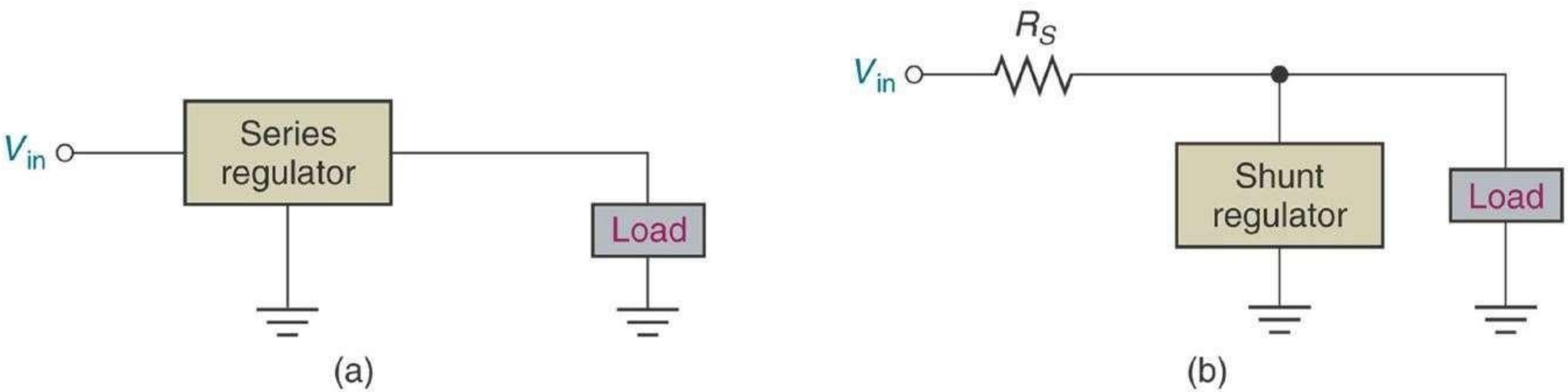
   (Solution: 1.2% ; 0.06%/V)

2. If a 5 V power supply has an output resistance of 80 mΩ and a specific maximum output current of 1 A. Calculate the load regulation in % and %/mA.

   (Solution: 1.6% ; 0.0016%/mA)

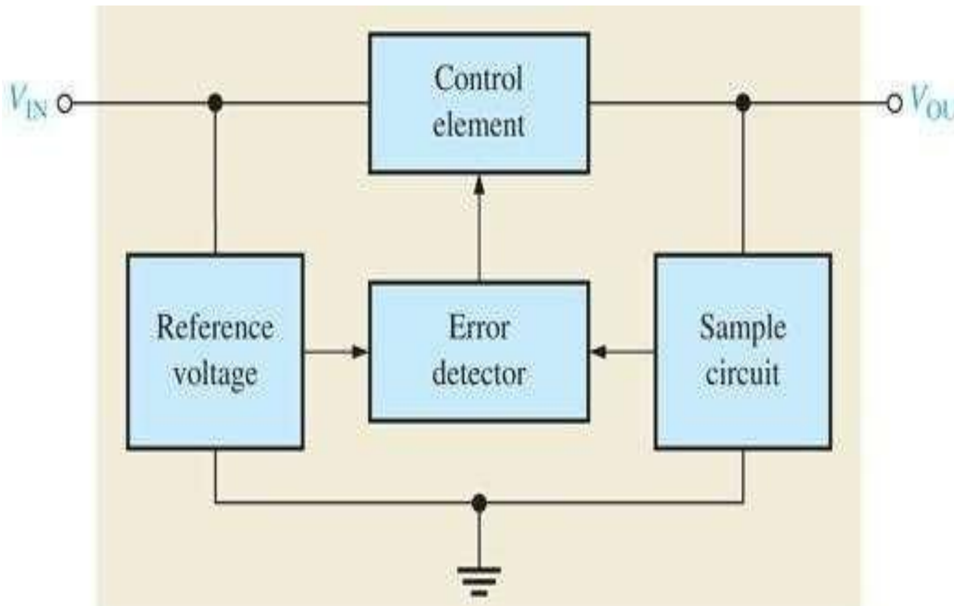
Types of Regulator

- Fundamental classes of voltage regulators are **linear regulators** and **switching regulators**.
- Two basic types of linear regulator are the **series regulator** and the **shunt regulator** .
- The series regulator is connected in **series** with the load and the shunt regulator is connected in **parallel** with the load.

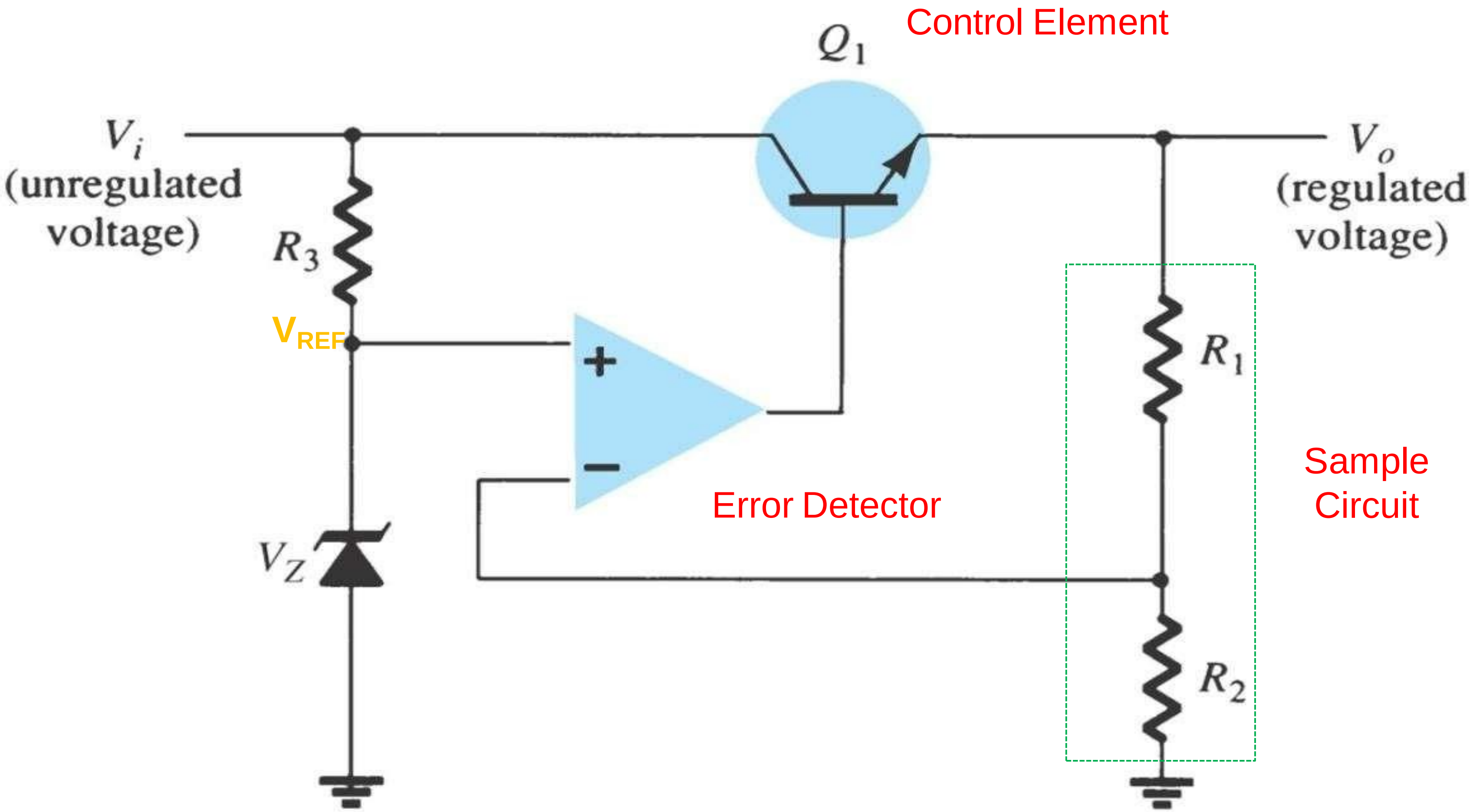


Series Regulator Circuit

- **Control element** in series with load between input and output.
- Output **sample circuit** senses a change in output voltage.
- **Error detector** compares sample voltage with reference voltage → causes control element to compensate in order to maintain a constant output voltage.



Op-Amp Series Regulator

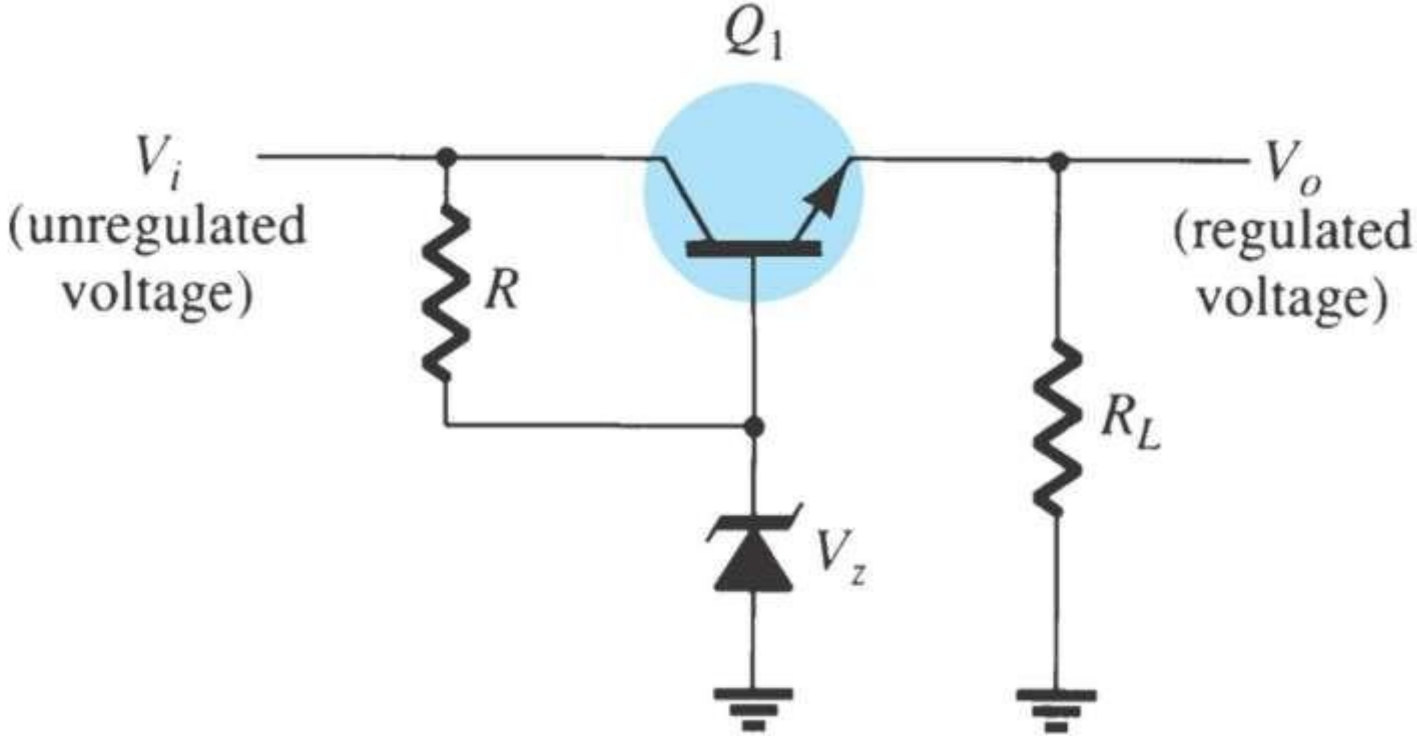


Op-Amp Series Regulator

- The resistor R_1 and R_2 sense a change in the output voltage and provide a feedback voltage.
- The error detector compares the feedback voltage with a Zener diode reference voltage.
- The resulting difference voltage causes the transistor Q_1 controls the conduction to compensate the variation of the output voltage.
- The output voltage will be maintained at a constant value of:

$$V_o = \left(1 + \frac{R_1}{R_2}\right) V_Z$$

Transistor Series Regulator



- The transistor Q_1 is the series control element.
- Zener diode provides the reference voltage.

Transistor Series Regulator

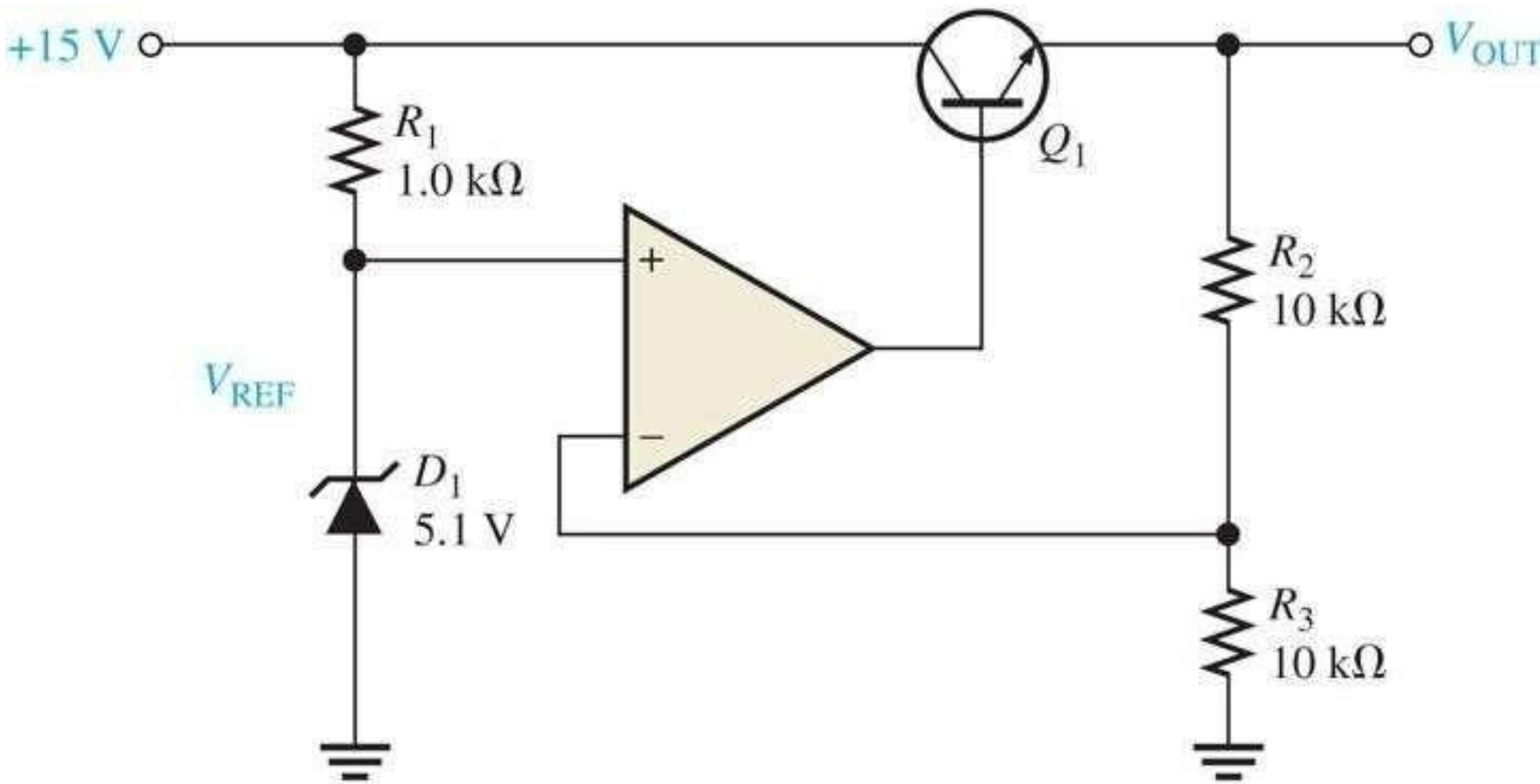
- Since Q_1 is an npn transistor, V_o is found as:

$$V_{BE} = V_Z - V_o$$

- the response of the pass-transistor to a change in load resistance as follows:
  - If load resistance increases, load voltage also increases.
  - Since the Zener voltage is constant, the increase in V_o causes V_{BE} to decrease.
  - The decrease in V_{BE} reduces conduction through the pass- transistor, so load current decreases.
  - This offsets the increase in load resistance, and a relatively constant load voltage is maintained

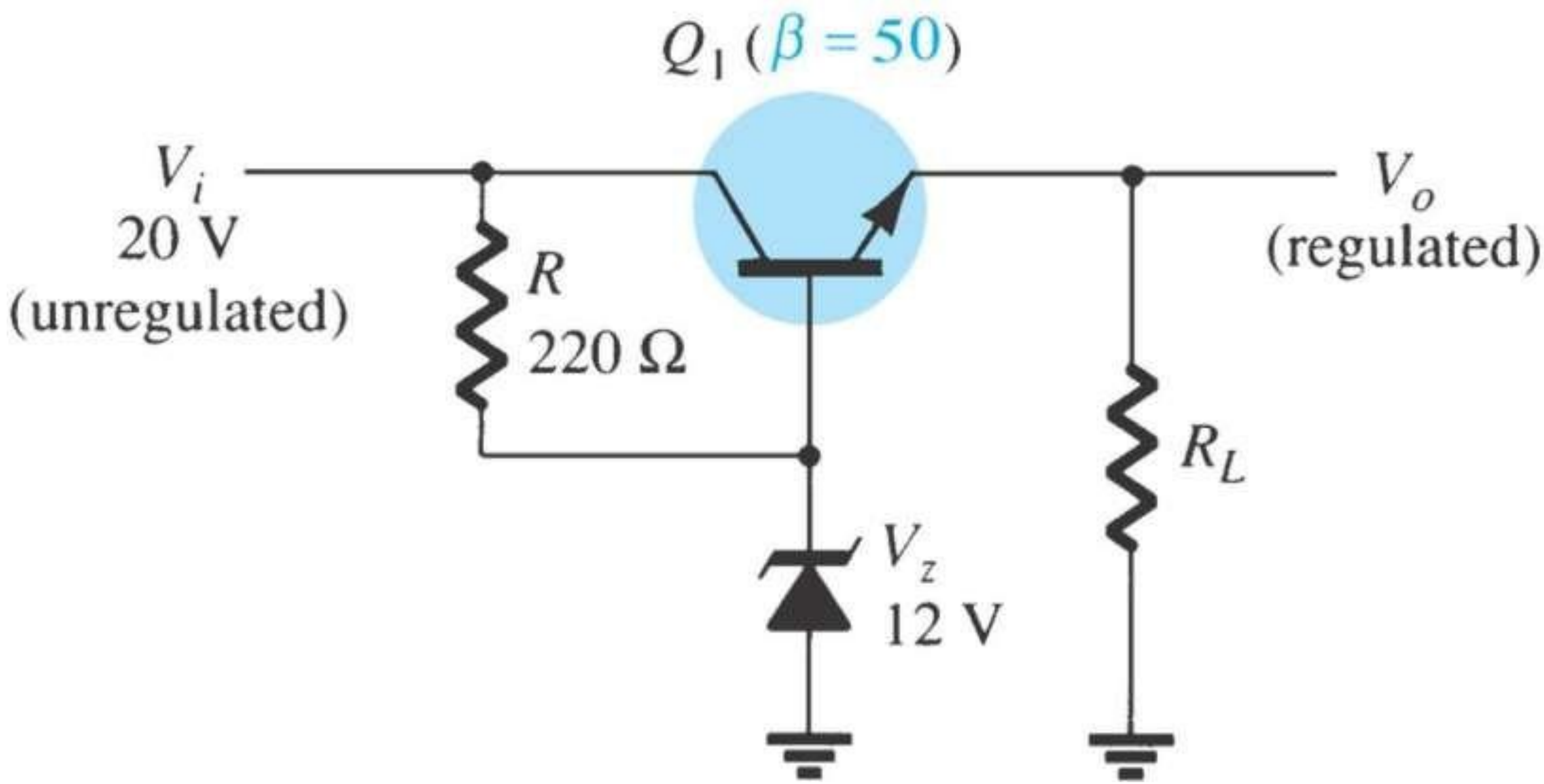
Example

- Determine the output voltage for the regulator below. (Solution: 10.2 V)



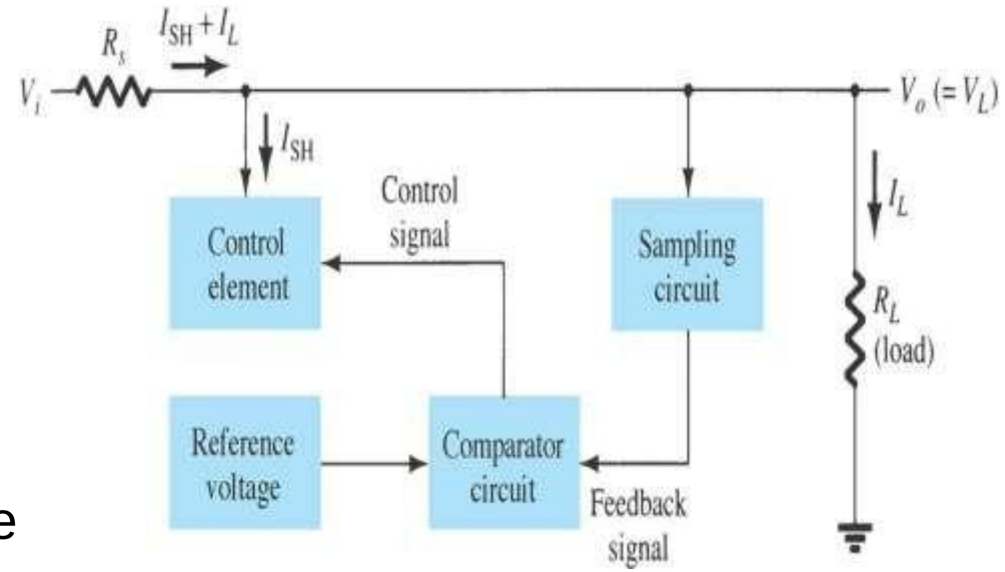
Example

- Calculate the output voltage and Zener current for R_L=1kΩ. (Solution: V_o=11.3 V; I_z≈36 mA)

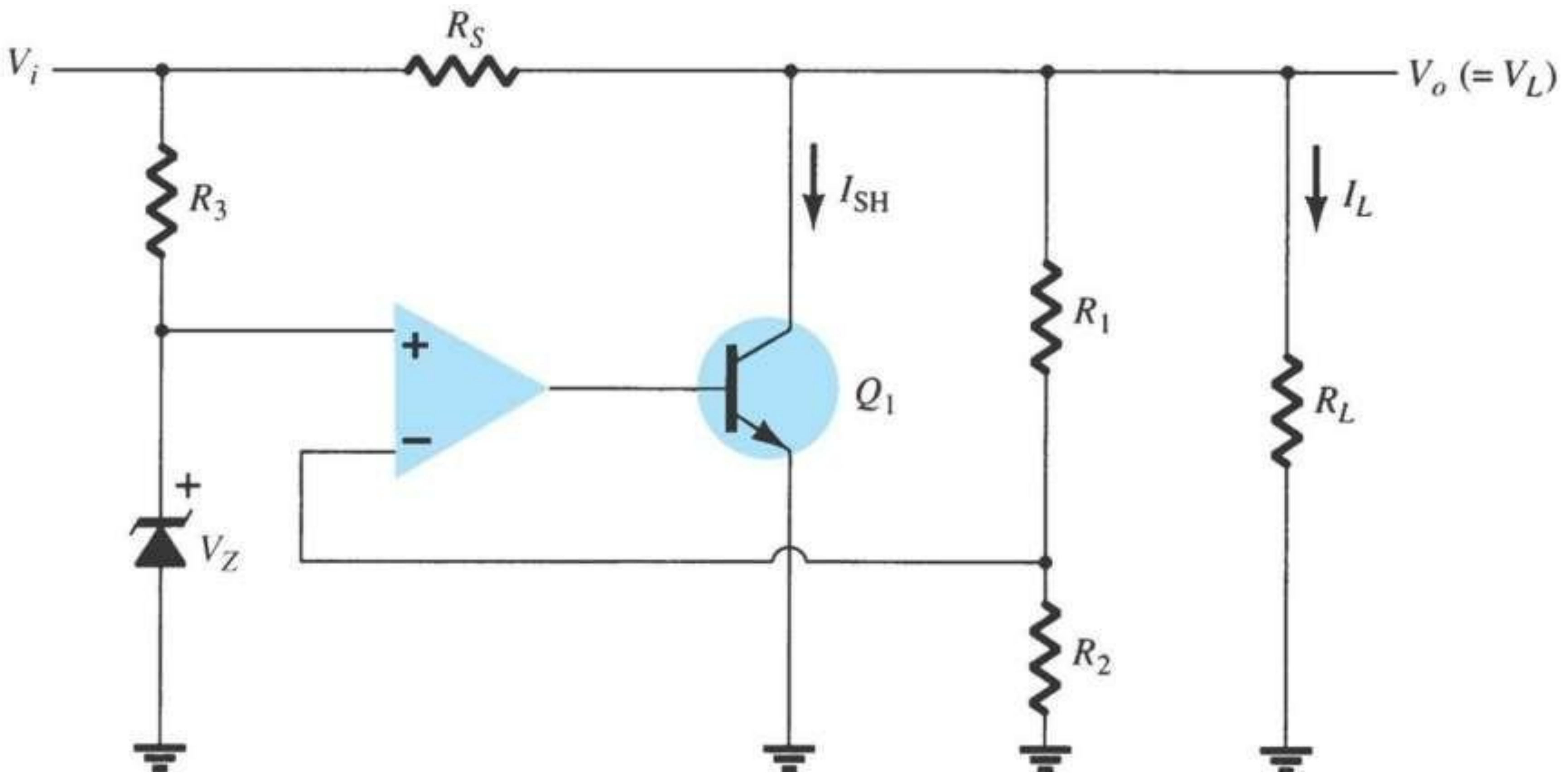


Shunt Regulator Circuit

- The unregulated input voltage provides current to the load.
- Some of the current is pulled away by the **control element**.
- If the load voltage tries to change due to a change in the load resistance, the **sampling circuit** provides a feedback signal to a **comparator**.
- The resulting difference voltage then provides a control signal to vary the amount of the current shunted away from the load to maintain the regulated output voltage across the load.



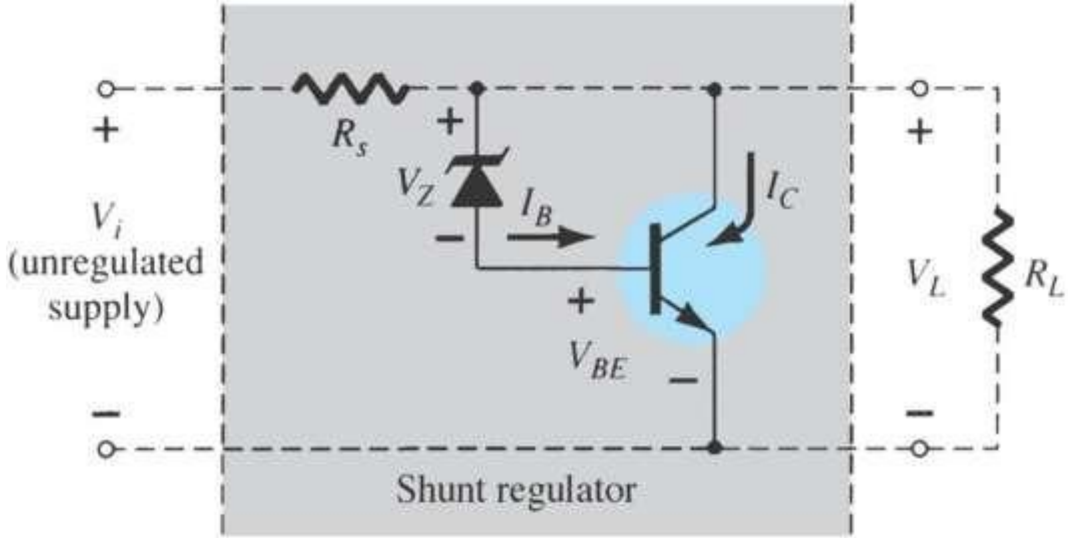
Op-Amp Shunt Regulator



Op-Amp Shunt Regulator

- When the output voltage tries to decrease due to a change in input voltage or load current caused by a change in load resistance, the decrease is sensed by R_1 and $R_{2.}$
- A feedback voltage obtained from voltage divider R_1 and R_2 is applied to the op-amp's non-inverting input and compared to the Zener voltage to control the drive current to the transistor.
- The current through resistor R_S is thus controlled to drop a voltage across R_S so that the output voltage is maintained.

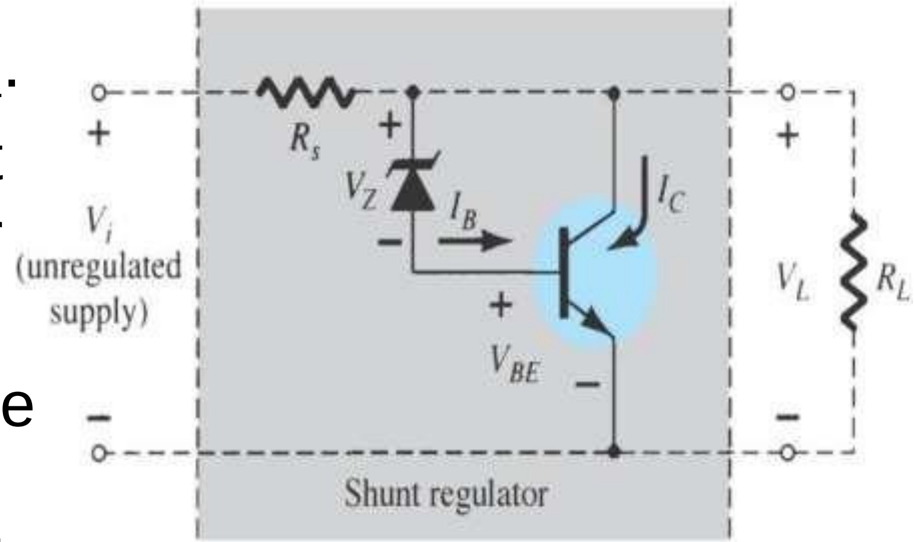
Transistor Shunt Regulator



- The control element is a transistor, in parallel with the load. While, the resistor, R_S, is in series with the load.
- The operation of the transistor shunt regulator is **similar** to that of the transistor series regulator, except that regulation is achieved by **controlling the current through the parallel transistor**

Transistor Shunt Regulator

- Resistor R_S drops the unregulated voltage depends on current supplied to load R_L.
- Voltage across the load is set by zener diode and transistor base-emitter voltage.
- If R_L decrease, a reduced drive current to base of Q1 → shunting less collector current.
- Load current, I_L is larger, maintaining the regulated voltage across load.

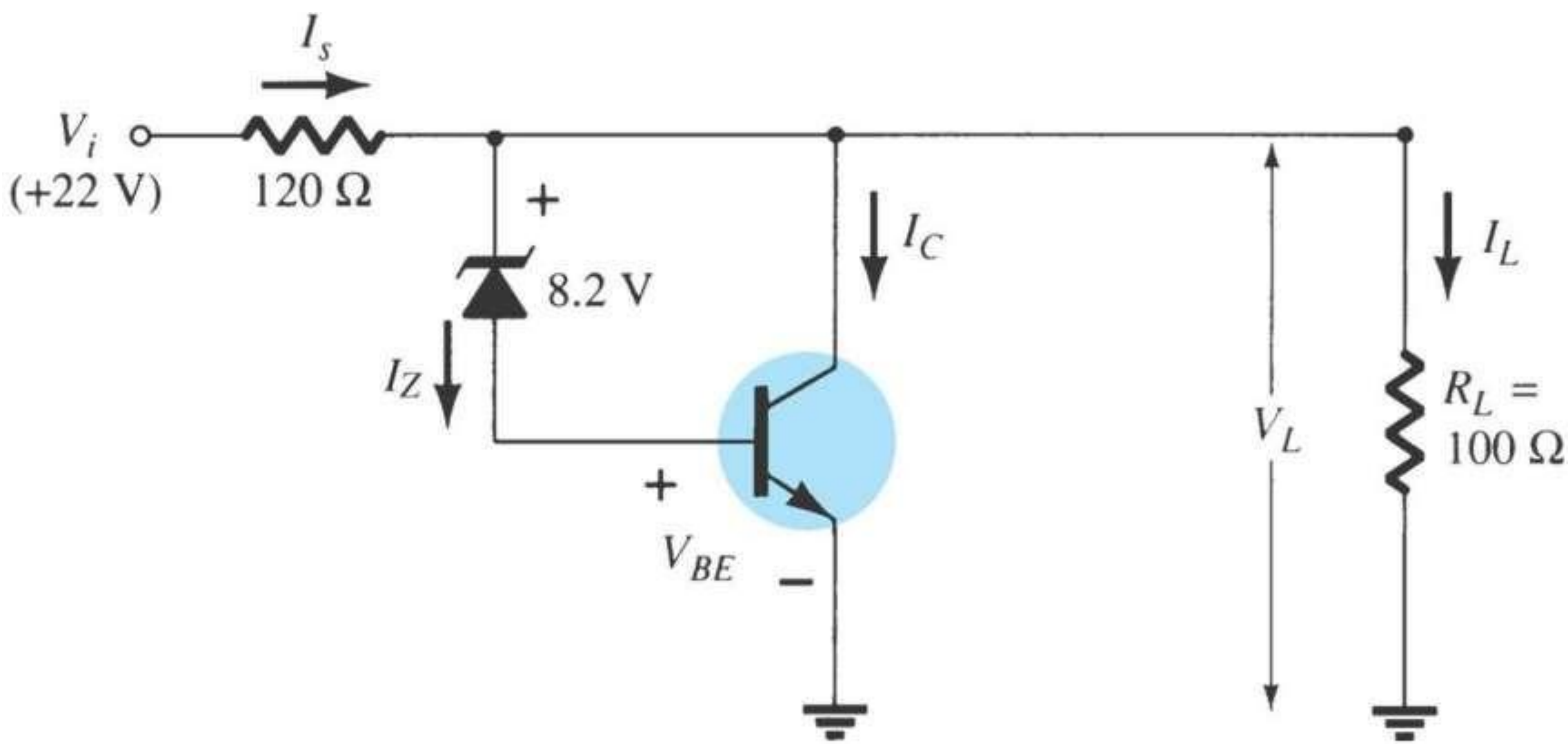


Transistor Shunt Regulator

- The output voltage to the load is: $V_o = V_L = V_Z + V_{BE}$
- voltage across the load is set by the Zener diode voltage and the transistor base-emitter voltage.
- If the load resistance decreases, the load current will be larger at a value of: $I_L = \frac{V_L}{R_L}$
- The increase in load current causes the collector current shunted by the transistor is to be less: $I_C = I_S - I_L$
- The current through R_S: $I_S = \frac{V_i - V_L}{R_S}$

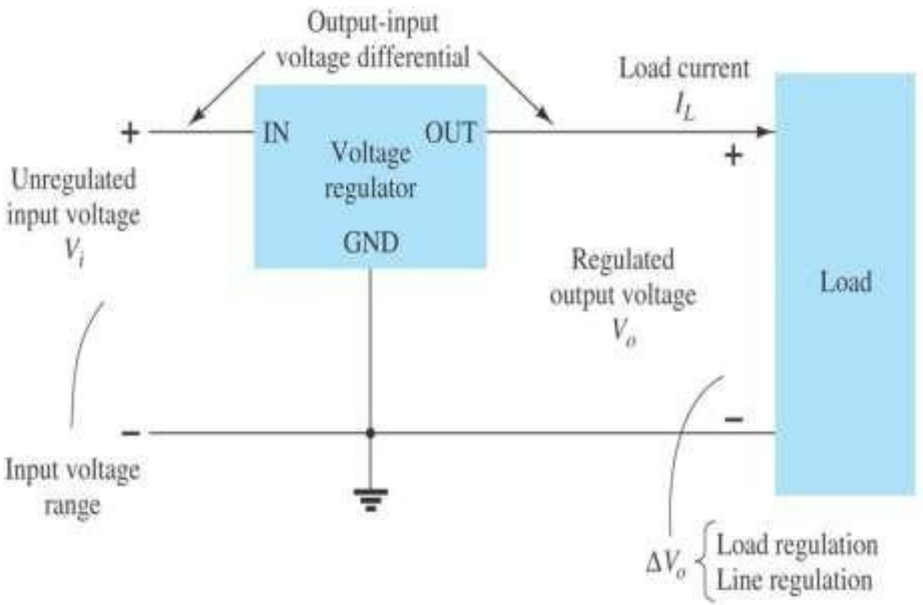
Example

- Determine the regulated voltage, V_L and circuit currents. (Solution: V_L=8.9 V; I_L=89 mA; I_S=109 mA; I_C=20 mA)



Switching Regulator

- The switching regulator is a type of regulator circuit which its efficient transfer of power to the load is greater than series and shunt regulators because the transistor is not always conducting.
- The switching regulator passes voltage to the load in pulses, which then filtered to provide a smooth dc voltage.



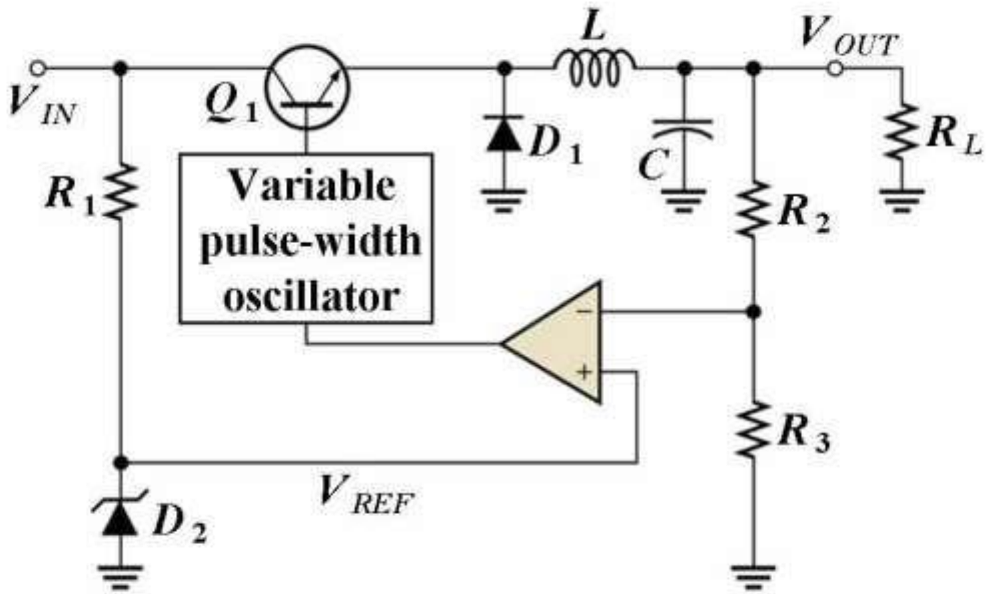
Switching Regulator

- The switching regulator is **more efficient** than the linear series or shunt type.
- This type regulator is ideal for high current applications since less power is dissipated.
- Voltage regulation in a switching regulator is achieved by the on and off action limiting the amount of current flow based on the varying line and load conditions.
- With switching regulators 90% efficiencies can be achieved.

Switching Regulator

Step-Down Configuration

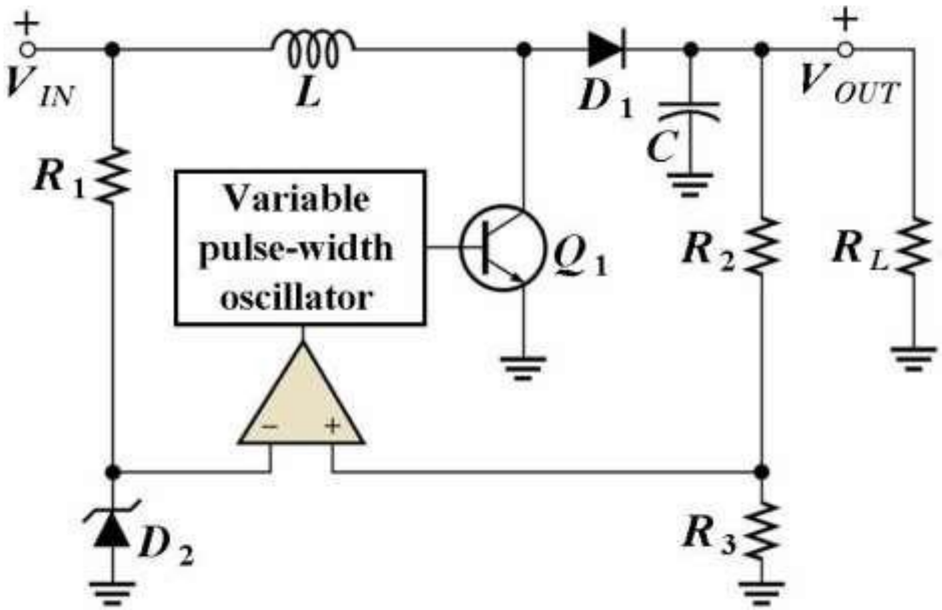
- With the step-down (output is less than the input) configuration the control element Q_1 is pulsed on and off at variable rate based on the load current.
- The pulsations are filtered out by the LC filter.



Switching Regulator

Step-up configuration

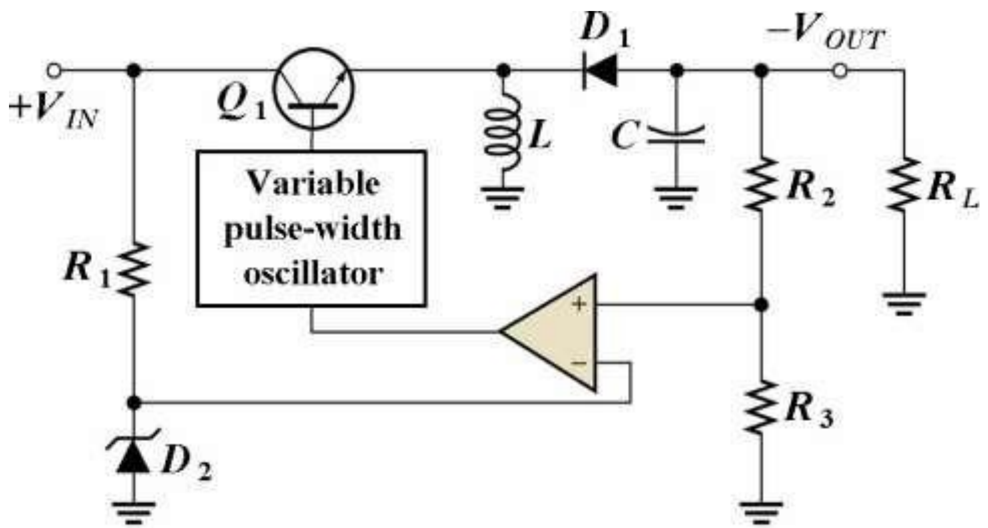
- The difference is in the placement of the inductor and the fact that Q_1 is shunt configured.
- During the time when Q_1 is off the V_L adds to V_C stepping the voltage up by some amount.



Switching Regulator

Voltage-inverter configuration

- output voltage is of opposite polarity of the input.
- This is achieved by V_L forward-biasing reverse-biased diode during the off times producing current and charging the capacitor for voltage production during the off times.
- With switching regulators 90% efficiencies can be achieved.



IC Voltage Regulators

- Regulation circuits in integrated circuit form are widely used.
- Their operation is no different but they are treated as a single device with associated components.
- These are generally three terminal devices that provide a positive or negative output.
- Some types have variable voltage outputs.
- A typical 7800 series voltage regulator is used for positive voltages.
- The 7900 series are negative voltage regulators.
- These voltage regulators when used with heatsinks can safely produce current values of 1A and greater.
- The capacitors act as line filtration.

IC Voltage Regulators

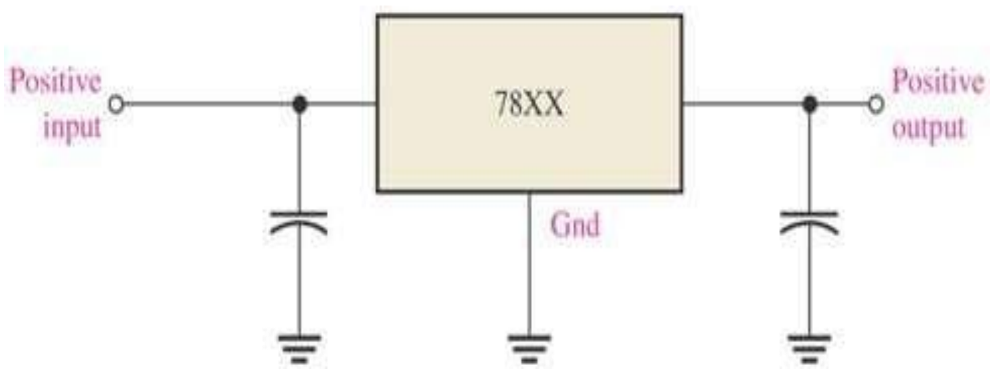
- Several types of both linear (series and shunt) and switching regulators are available in integrated circuit (IC) form.
- Single IC regulators contain the circuitry for:
  (1) reference source
  (2) comparator amplifier
  (3) control device
  (4) overload protection
- Generally, the linear regulators are three-terminal devices that provides either positive or negative output voltages that can be either fixed or adjustable.

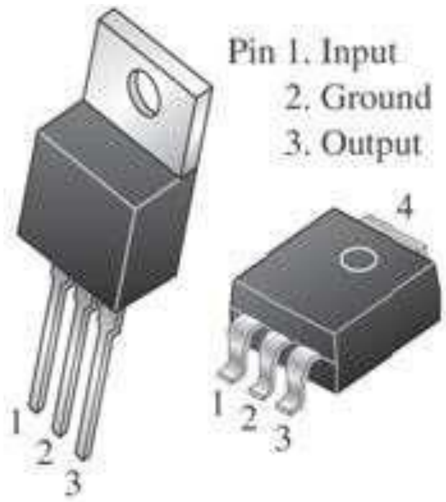
Fixed Voltage Regulator

- The fixed voltage regulator has an unregulated dc input voltage V_i applied to one input terminal, a regulated output dc voltage V_o from a second terminal, and the third terminal connected to ground.

Fixed-Positive Voltage Regulator

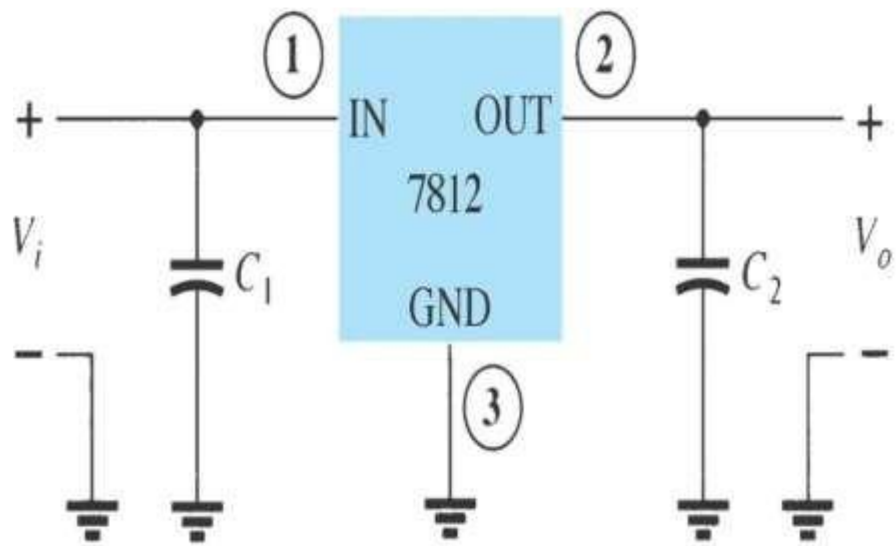
- The series 78XX regulators are the three-terminal devices that provide a fixed positive output voltage.





Fixed Voltage Regulator

- An unregulated input voltage V_i is filtered by a capacitor C_1 and connected to the IC's IN terminal.
- The IC's OUT terminal provides a regulated +12 V, which is filtered by capacitor C_2.
- The third IC terminal is connected to ground (GND)



Fixed Voltage Regulator

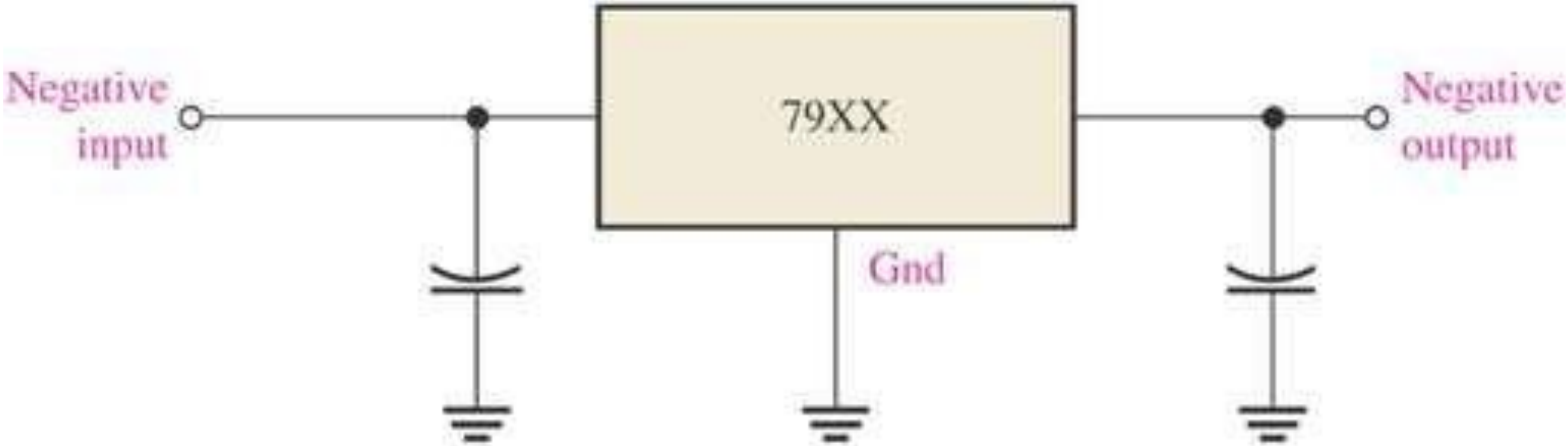
Positive-Voltage Regulators in the 78XX Series

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	+14.5
7815	+15	+17.7
7818	+18	+21.0
7824	+24	+27.1

Fixed Voltage Regulator

Fixed-Negative Voltage Regulator

- The series 79XX regulators are the three-terminal IC regulators that provide a fixed negative output voltage.
- This series has the same features and characteristics as the series 78XX regulators except the pin numbers are different.



Fixed Voltage Regulator

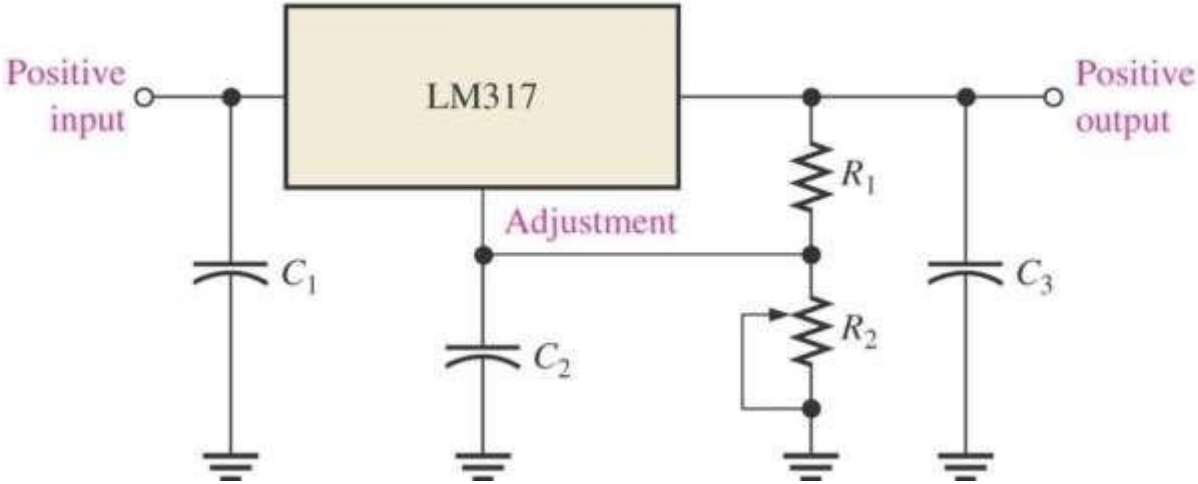
Negative-Voltage Regulators in the 79XX Series

IC Part	Output Voltage (V)	Minimum V_i (V)
7905	-5	-7.3
7906	-6	-8.4
7908	-8	-10.5
7909	-9	-11.5
7912	-12	-14.6
7915	-15	-17.7
7918	-18	-20.8
7924	-24	-27.1

Fixed Voltage Regulator

Adjustable-Voltage Regulator

- Voltage regulators are also available in circuit configurations that allow to set the output voltage to a desired regulated value.
- The LM317 is an example of an adjustable-voltage regulator, can be operated over the range of voltage from 1.2 to 37 V.



Summary

- Voltage regulators keep a constant dc output despite input voltage or load changes.
- The two basic categories of voltage regulators are linear and switching.
- The two types of linear voltage regulators are series and shunt.
- The three types of switching are step-up, step-down, and inverting.

Summary

- Switching regulators are more efficient than linear making them ideal for low voltage high current applications.
- IC regulators are available with fixed positive or negative output voltages or variable negative or positive output voltages.
- Both linear and switching type regulators are available in IC form.
- Current capacity of a voltage regulator can be increased with an external pass transistor.