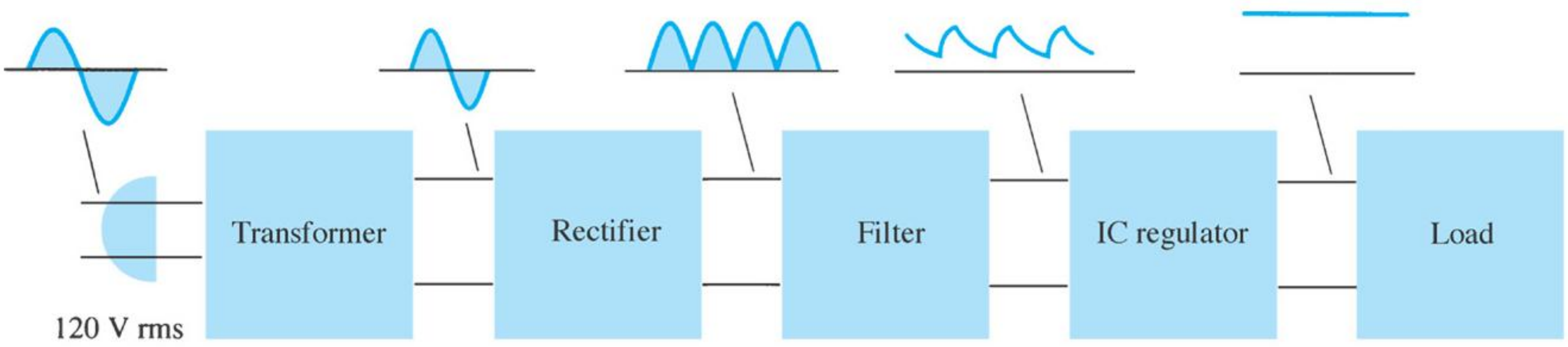
Lecture-4

Voltage Regulators

Introduction

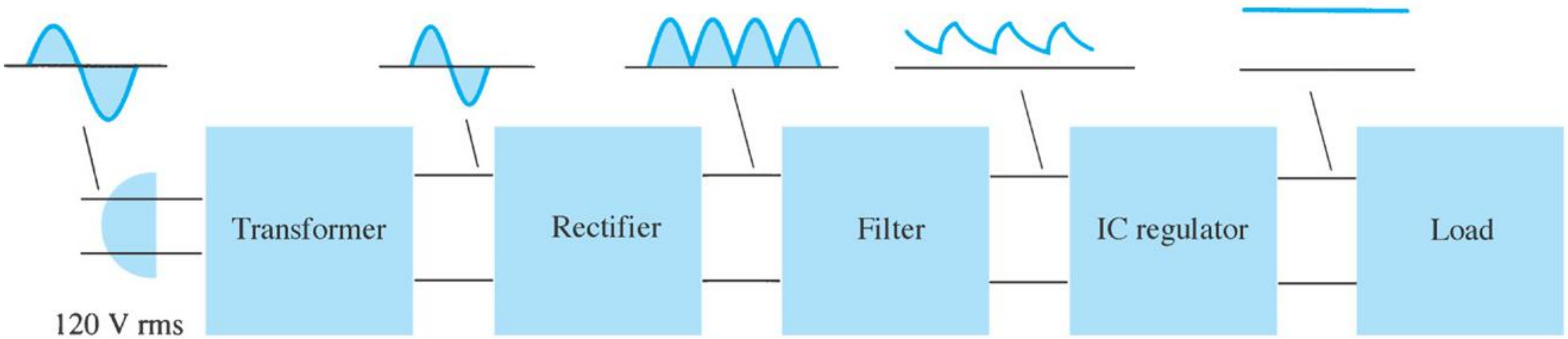
- Batteries are often shown on a schematic diagram as the source of DC voltage but usually the actual DC voltage source is a power supply.
- There are many types of power supply. Most are designed to convert high voltage AC mains electricity to a suitable low voltage supply for electronics circuits and 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



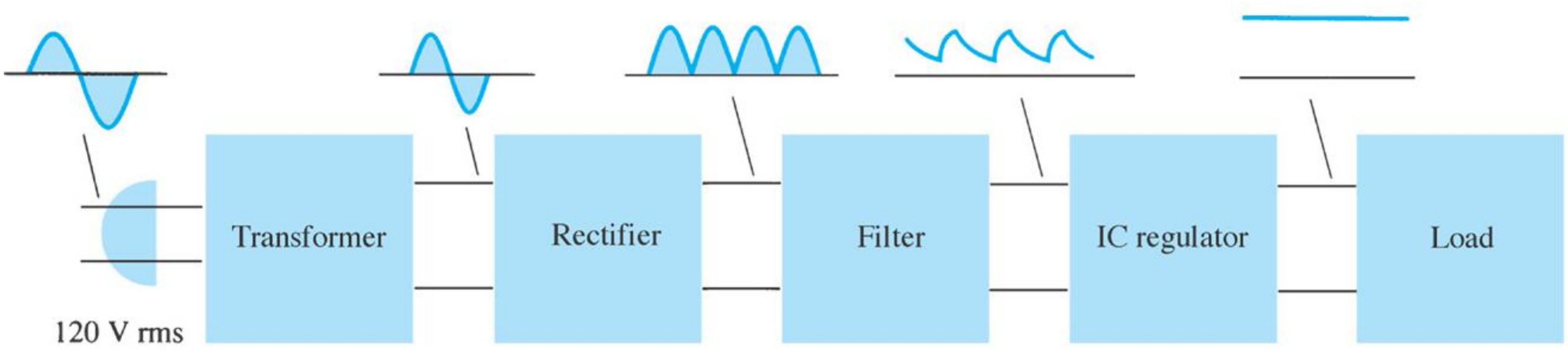
- ***Power supply***: a group of circuits that convert the ***standard ac voltage*** (120 V, 60 Hz) provided by the wall outlet to ***constant dc voltage***
- ***Transformer*** : a device that step up or step down the ***ac voltage*** provided by the wall outlet to a desired amplitude through the *action*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

Introduction



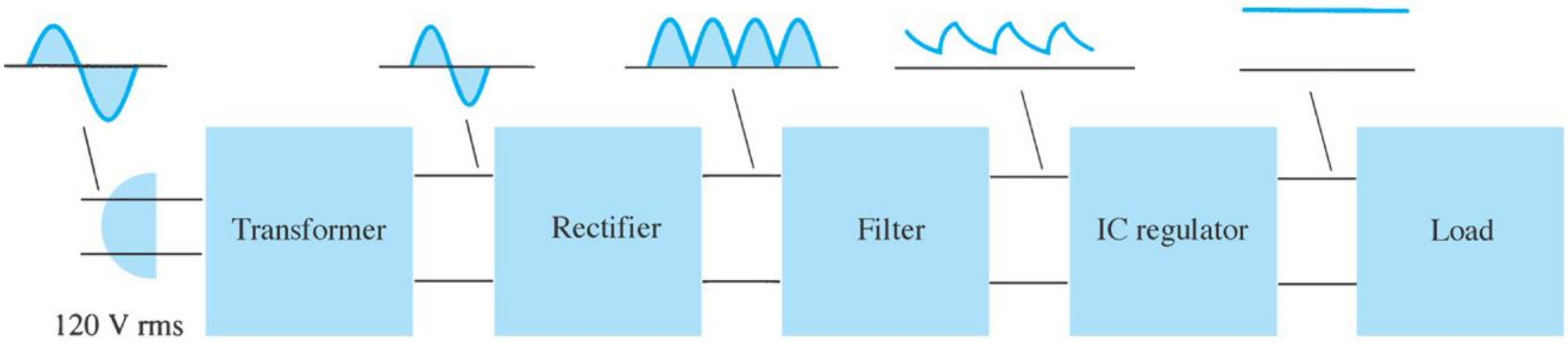
- ***Rectifier***: a diode circuits that converts the ***ac input voltage*** to a ***pulsating dc voltage***
- The pulsating dc voltage is **only suitable** to be used as a battery charger, but **not good enough** to be used as a dc power supply in a radio, stereo system, computer and so on.

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

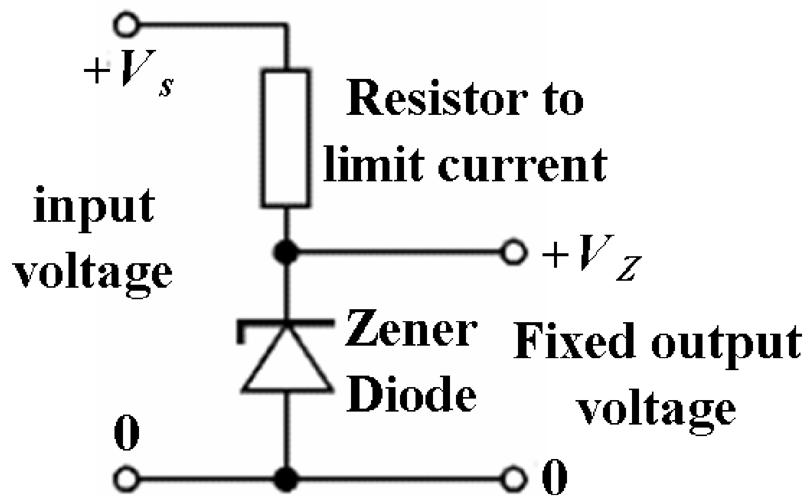


- ***Filter***: a circuit used to reduce the fluctuation in the rectified output voltage or ripple. This provides a ***steadier*** dc voltage.
- ***Regulator***: a circuit used to produces a ***constant*** dc output voltage by reducing the ripple to negligible amount. One part of power supply.

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)

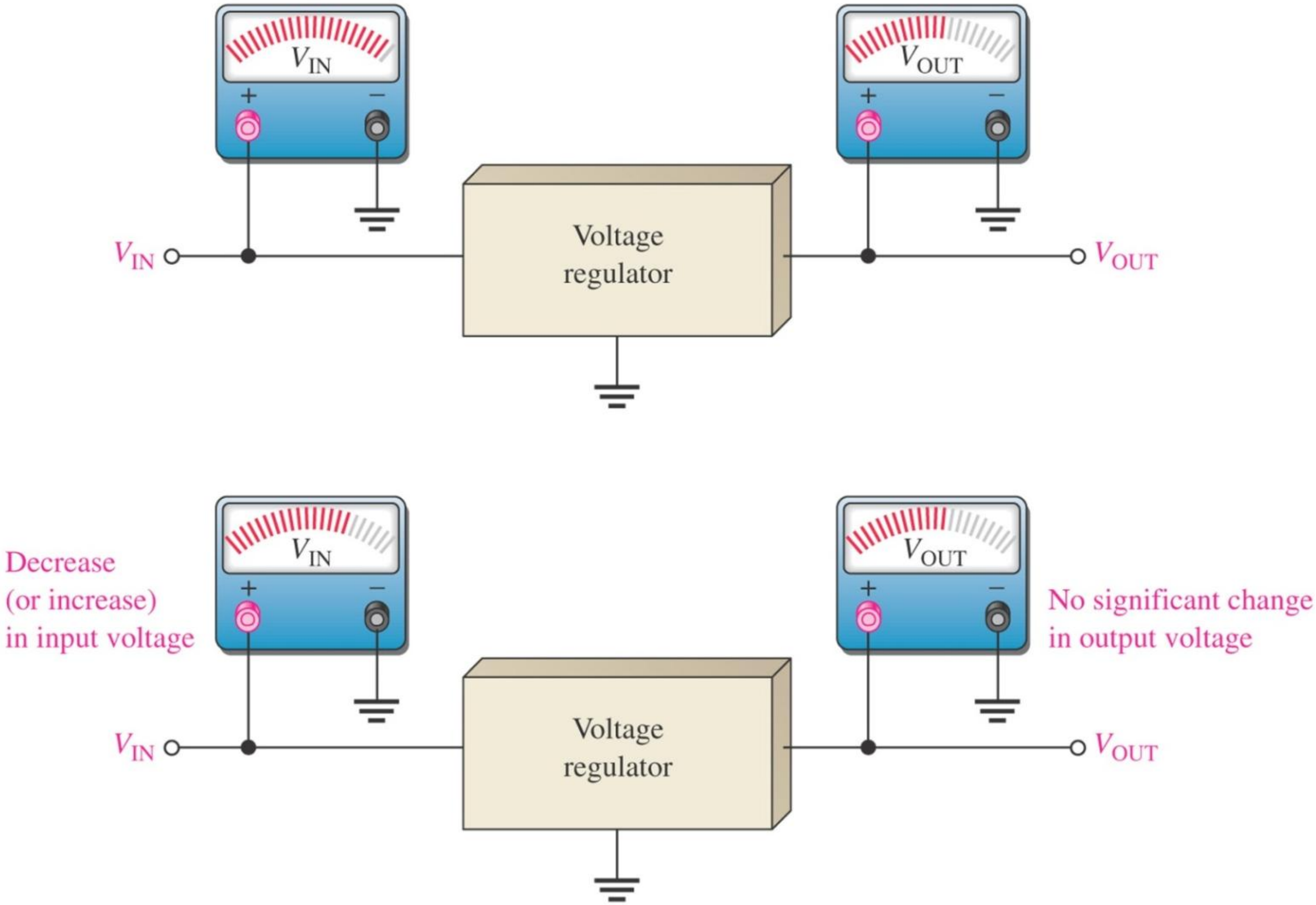


Voltage Regulation

- 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.

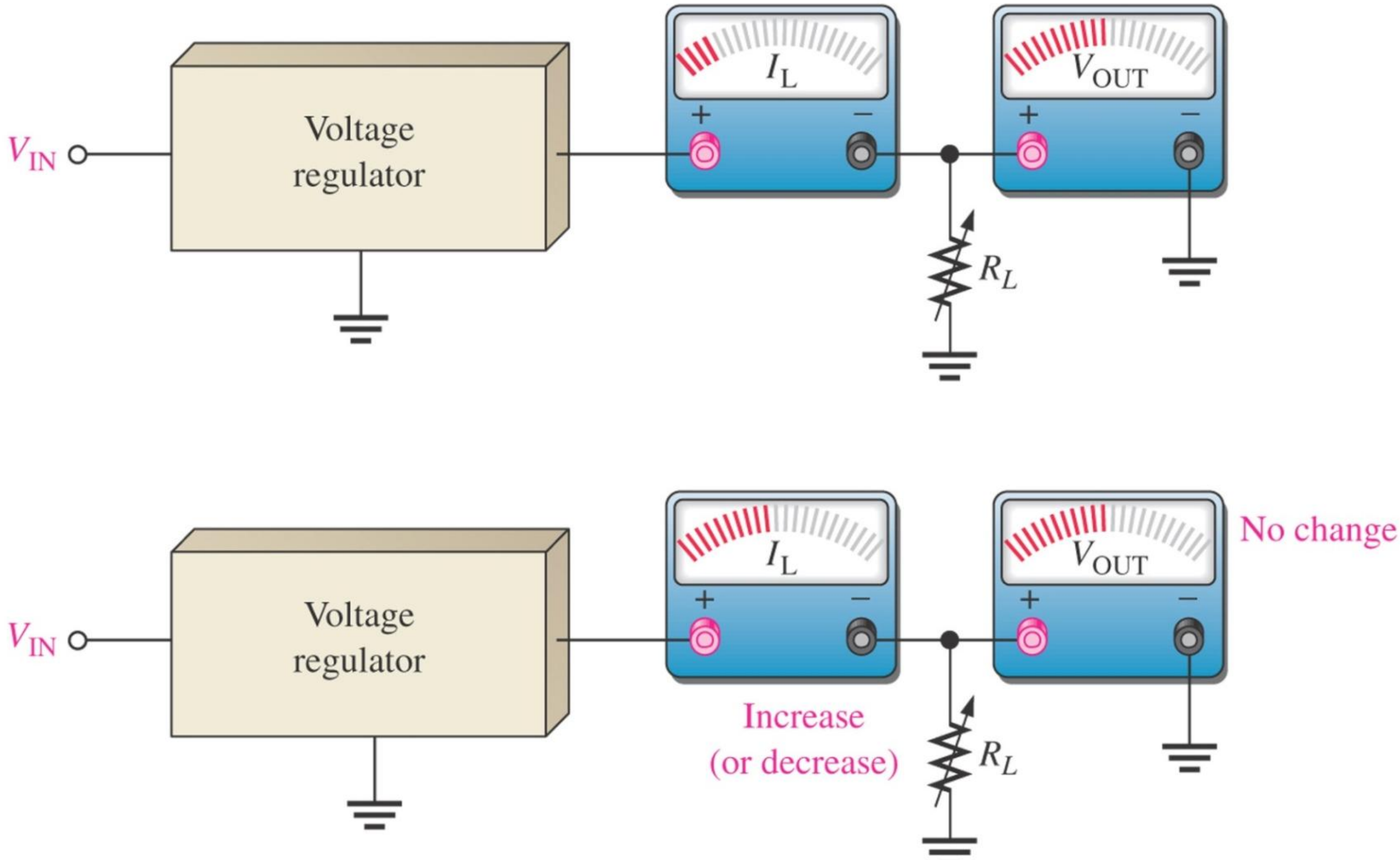
$$Line\ regulation = \left(\frac{\Delta V_{OUT}}{\Delta V_{IN}}\right) \times 100\%$$

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).

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

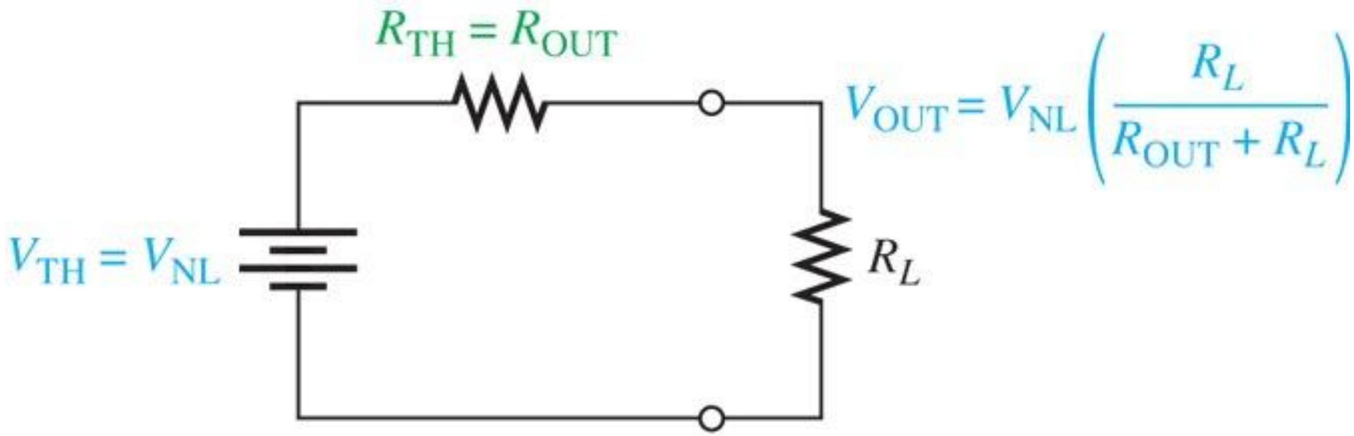
- Where:

  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:

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

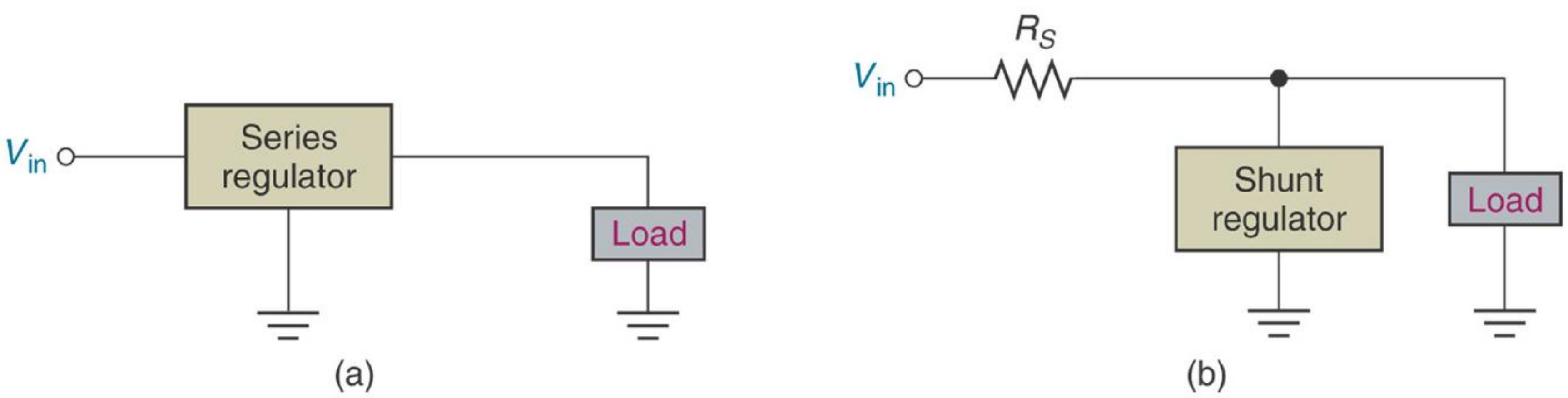
$$Load\ regulation = \frac{V_{FL}\left(\frac{R_{OUT} - R_{FL}}{R_{FL}}\right) - V_{FL}}{V_{FL}} \times 100\%$$

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

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

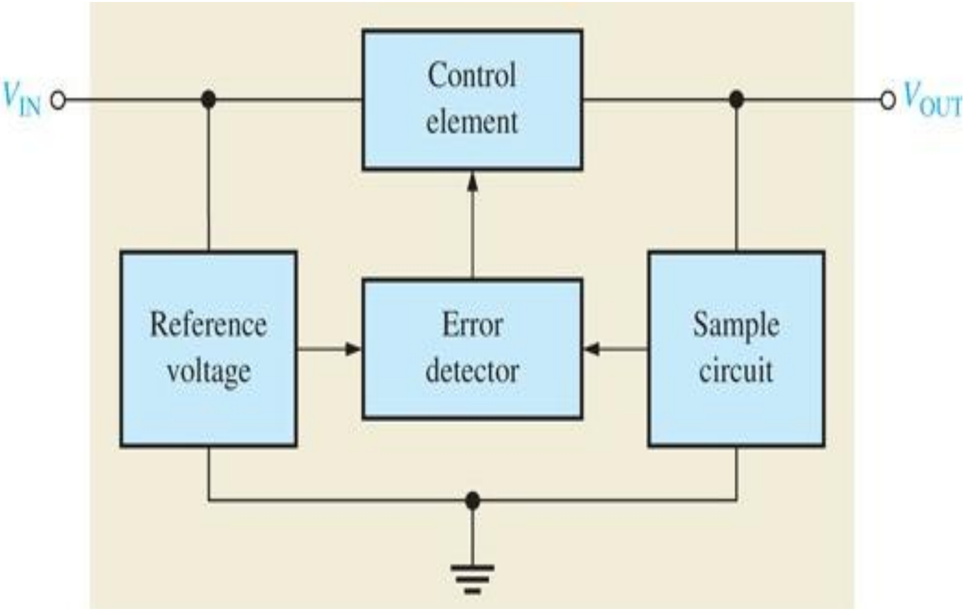
Types of Regulator

- 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.

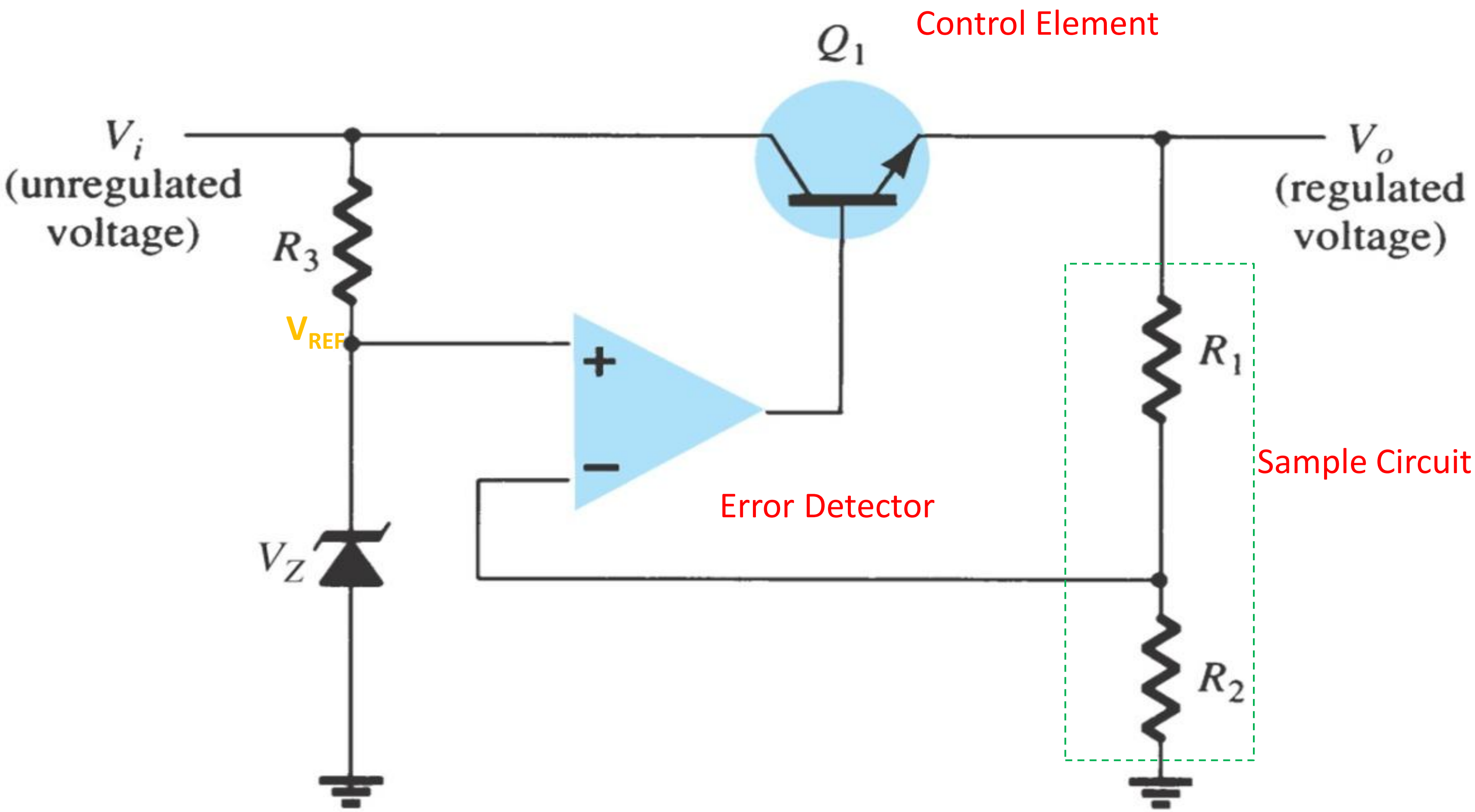


Series Regulator Circuit

- **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

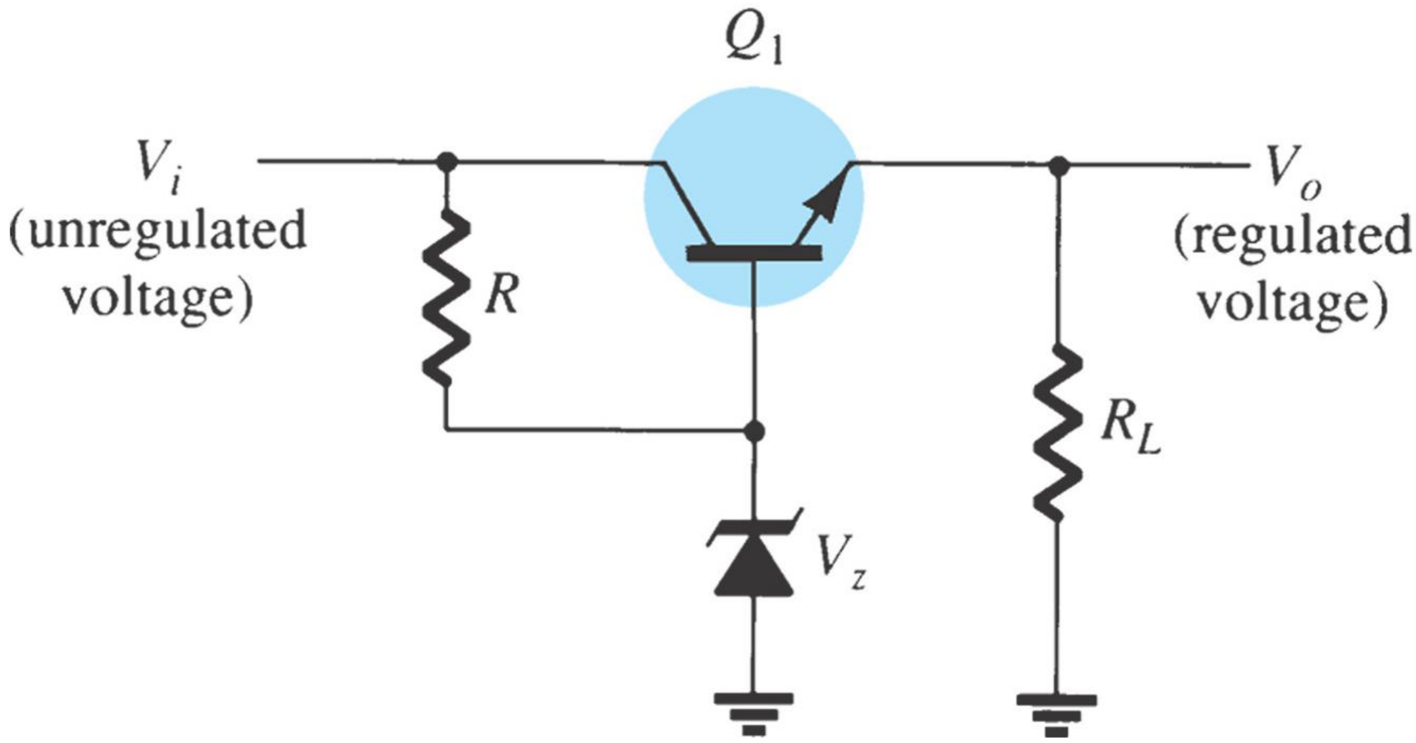


Op-Amp Series Regulator

- 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

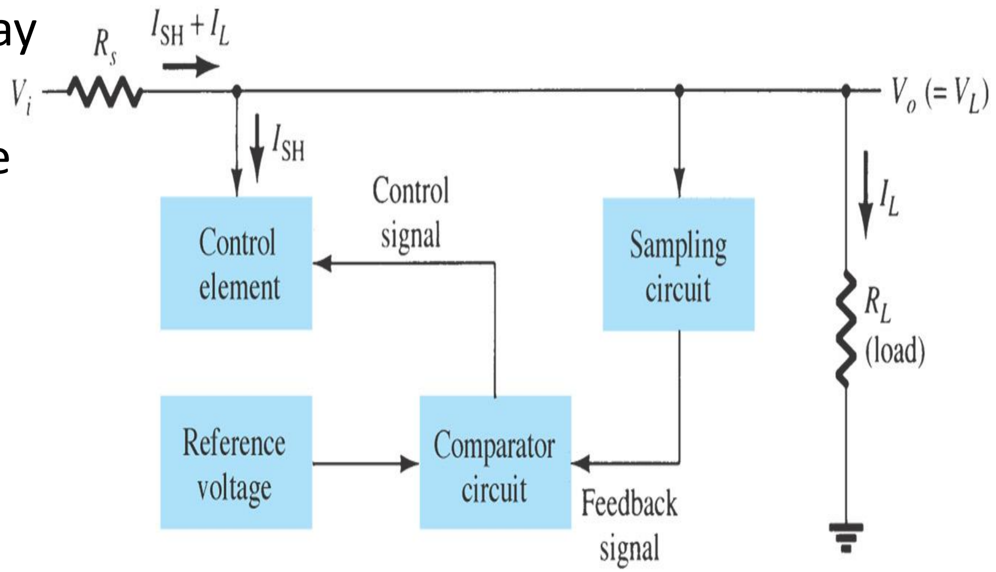
- Since Q_1 is an npn transistor, V_o is found as:

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

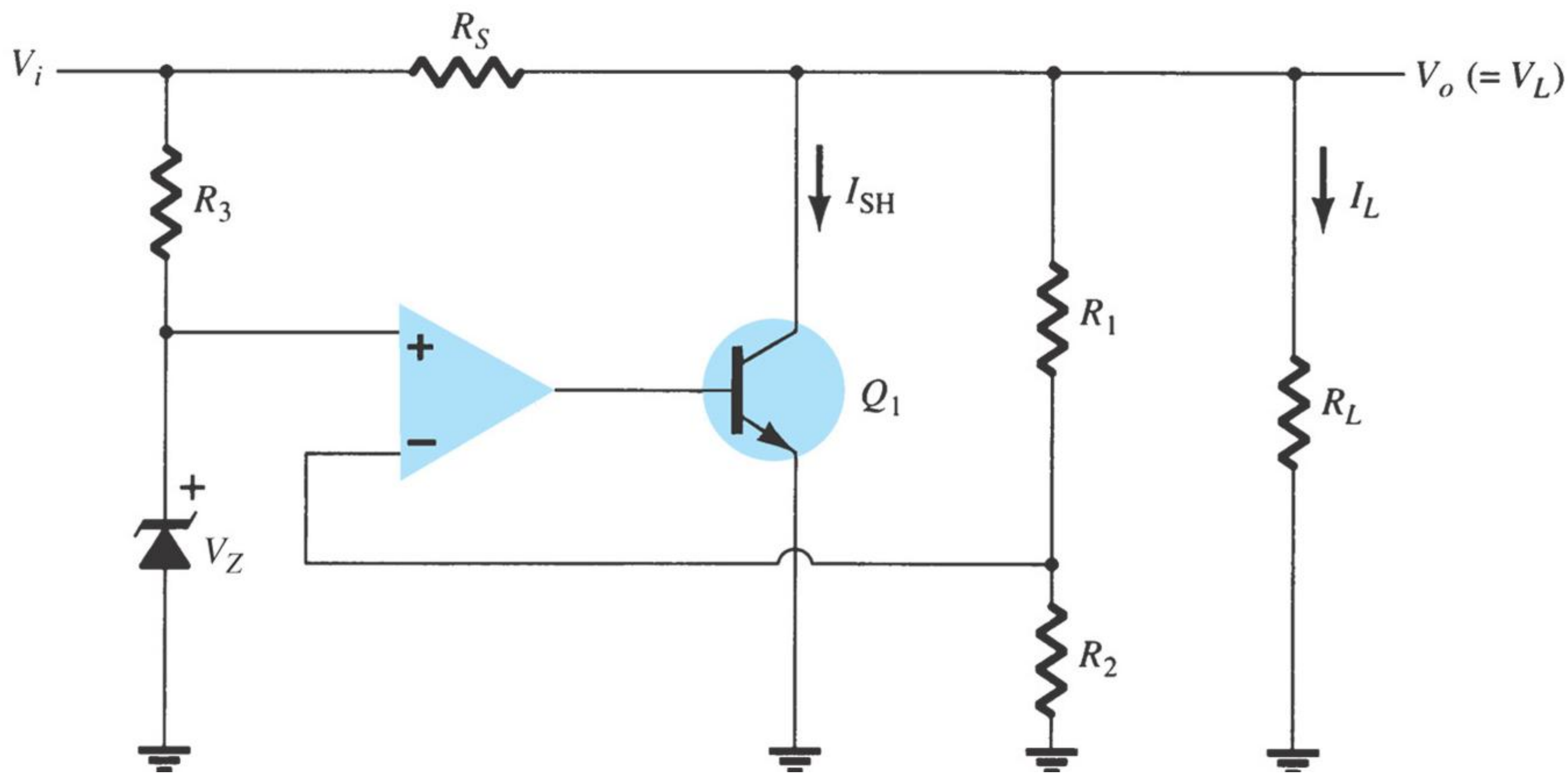
- the response of the pass-transistor to a change in load resistance as follows:
  - If load resistance increases, load voltage also increases.
  - Since the Zener voltage is constant, the increase in V_o causes V_{BE} to decrease.
  - The decrease in V_{BE} reduces conduction through the pass- transistor,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

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.



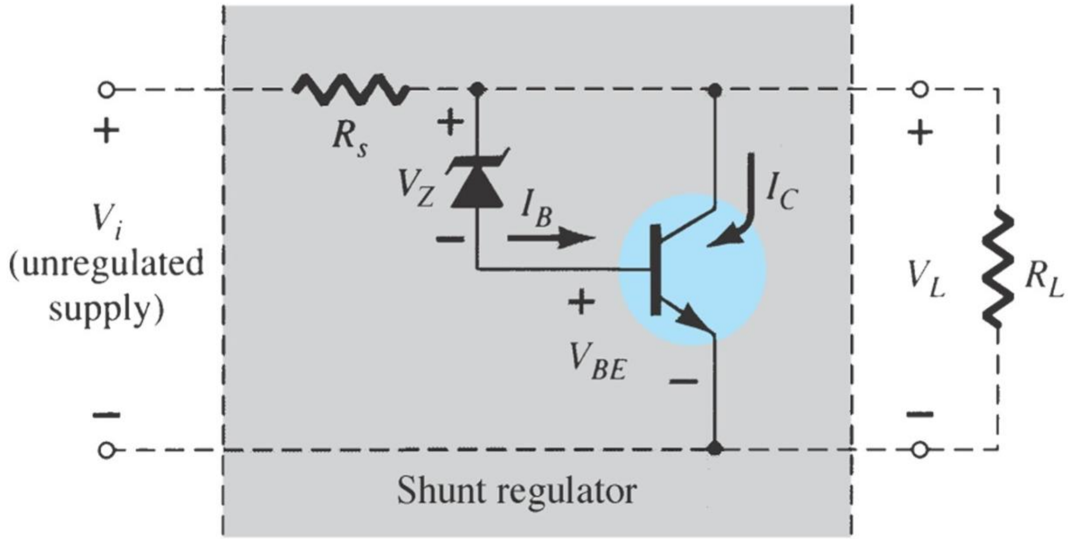
Op-Amp Shunt Regulator



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.

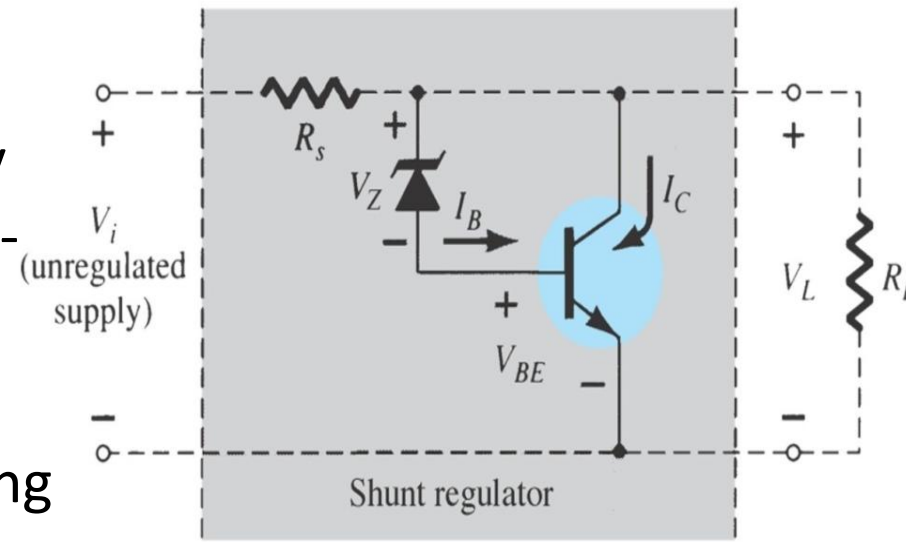
Transistor Shunt Regulator



- 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 … auses the collector current shunted by the transistor is to be less:

$$I_C = I_S - I_L$$

- The current through R_S:

$$I_S = \frac{V_i - V_L}{R_S}$$

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.