Voltage Regulators

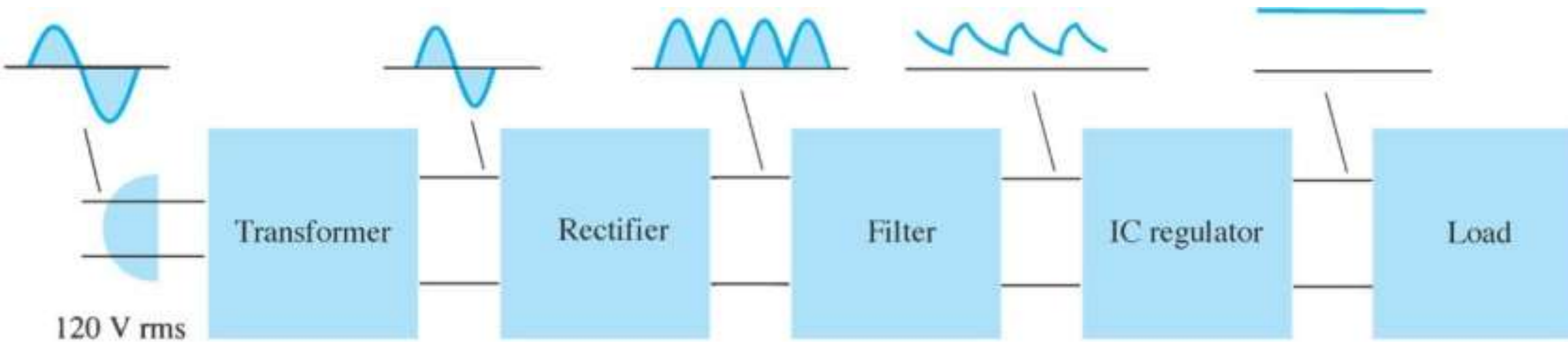
Outline

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

Introduction

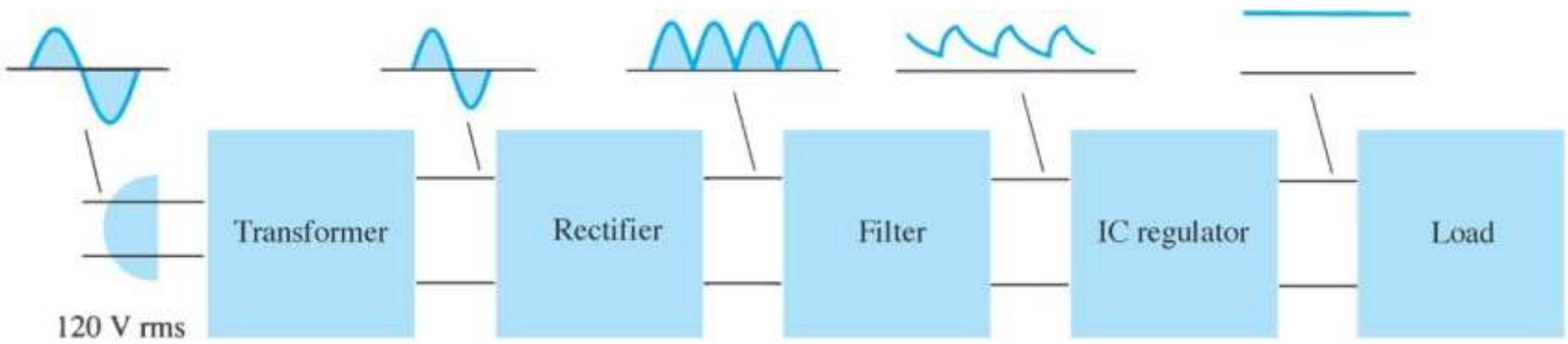
- Batteries are often shown on a schematic diagram as the source of DC voltage but usually the actual DC voltage source is a power supply.
- There are many types of power supply. Most are designed to convert high voltage AC mains electricity to a suitable low voltage supply for electronics circuits and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



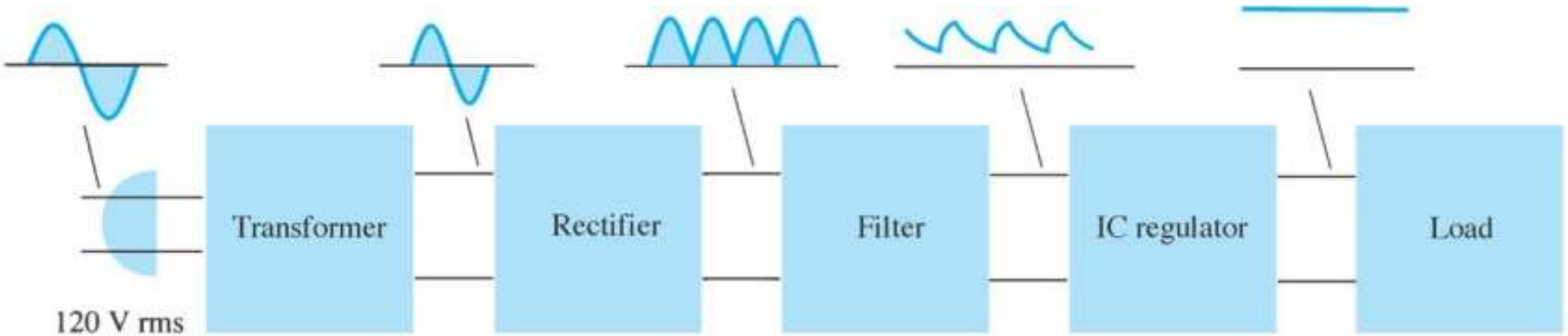
- ***Power supply***: a group of circuits that convert the ***standard ac voltage*** (120 V, 60 Hz) provided by the wall outlet to ***constant dc voltage***
- ***Transformer*** : a device that step up or step down the ***ac voltage*** provided by the wall outlet to a desired amplitude through the *action*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

Introduction



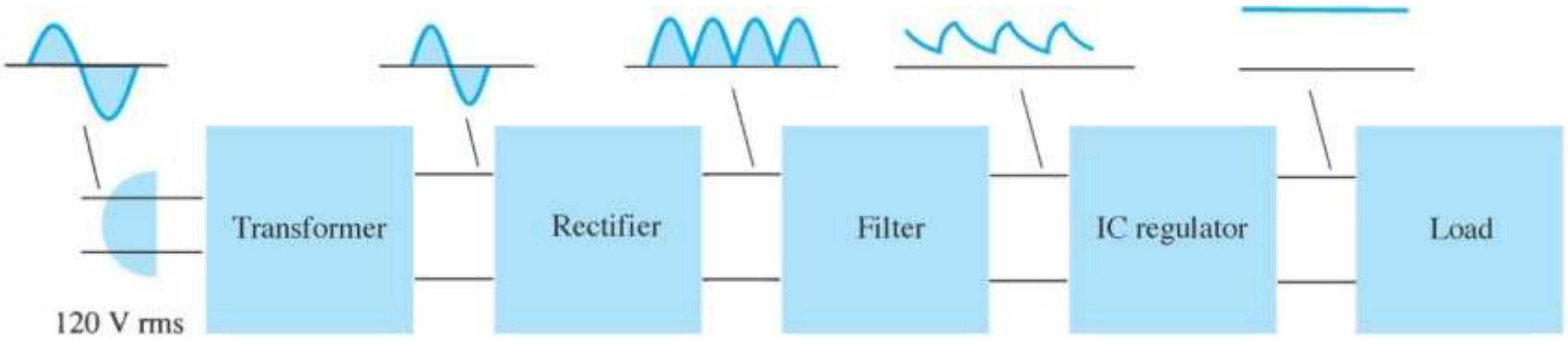
- ***Rectifier***: a diode circuits that converts the ***ac input voltage*** to a ***pulsating dc voltage***
- The pulsating dc voltage is **only suitable** to be used as a battery charger, but **not good enough** to be used as a dc power supply in a radio, stereo system, computer and so on.

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

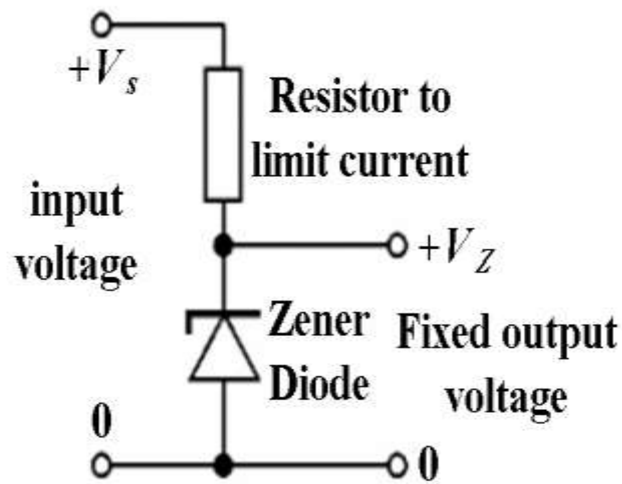


- ***Filter***: a circuit used to reduce the fluctuation in the rectified output voltage or ripple. This provides a ***steadier*** dc voltage.
- ***Regulator***: a circuit used to produces a ***constant*** dc output voltage by reducing the ripple to negligible amount. One part of power supply.

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)

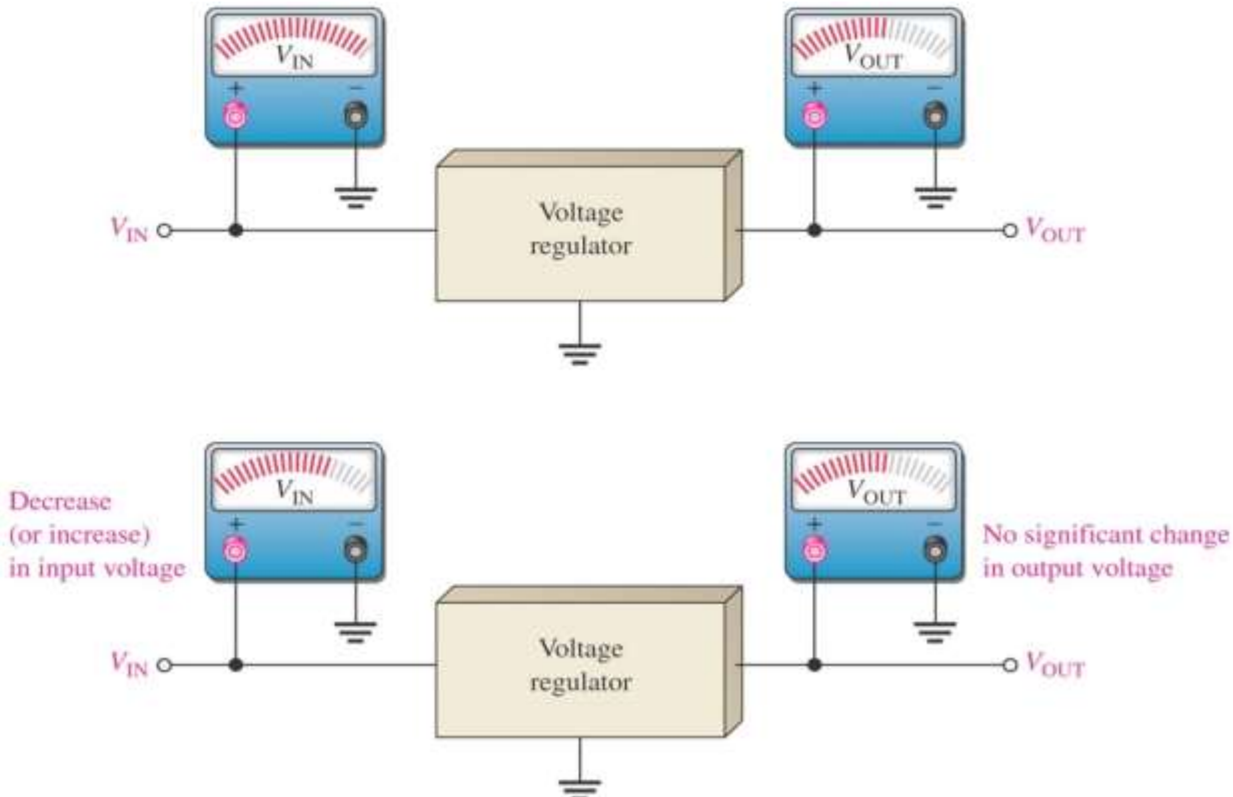


Voltage Regulation

- Two basic categories of voltage regulation are:
  - θline regulation
  - θload 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.

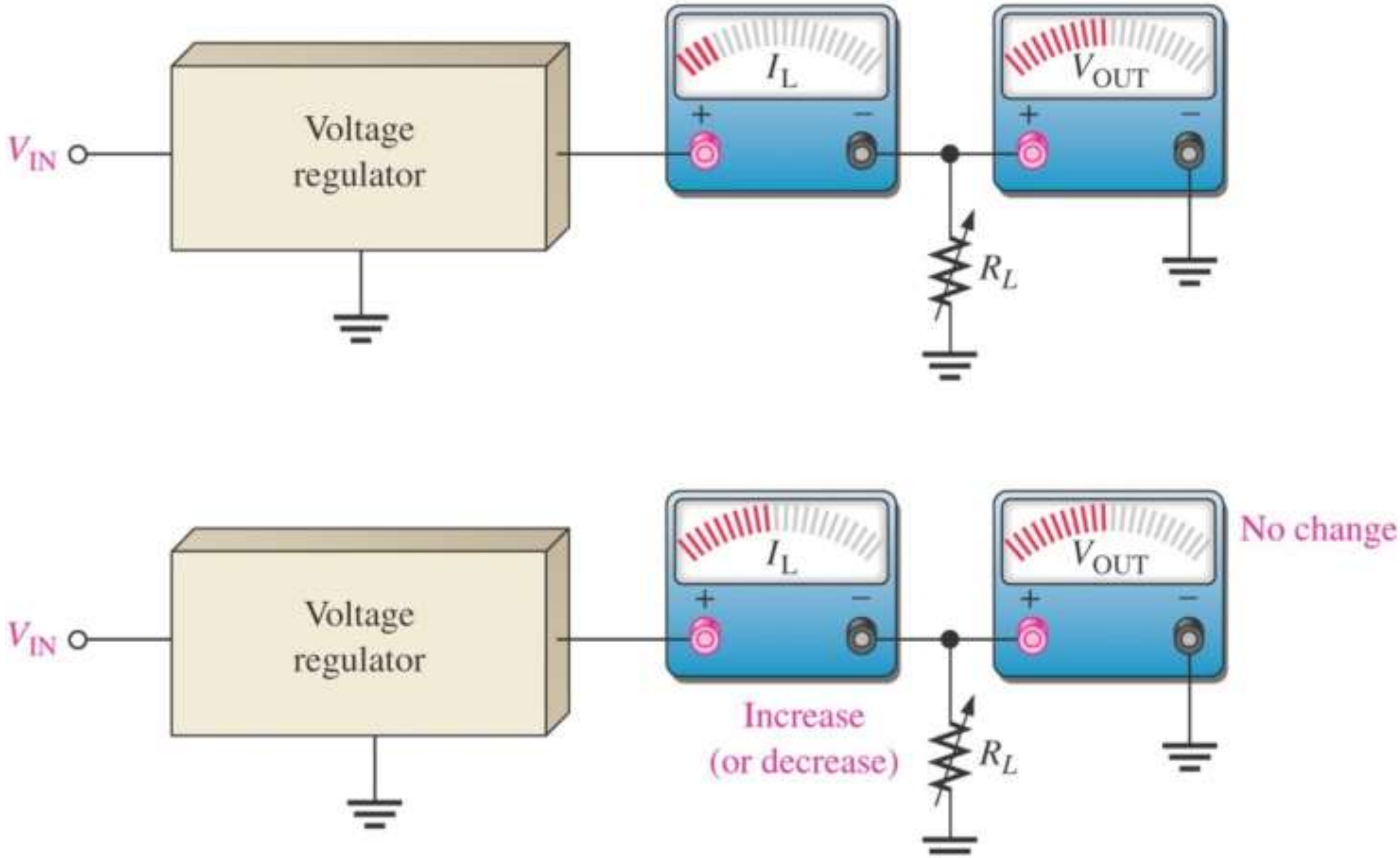
$$Line\ regulation = \left(\frac{\Delta V_{OUT}}{\Delta V_{IN}} \right) \times 100\%$$

Δ means "a change in"

- Line regulation can be calculated using the following formula:

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

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).

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

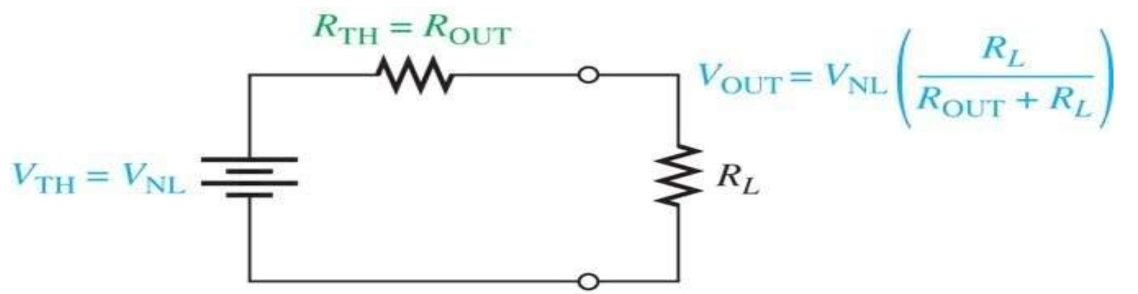
- Where:

  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:

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

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

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

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

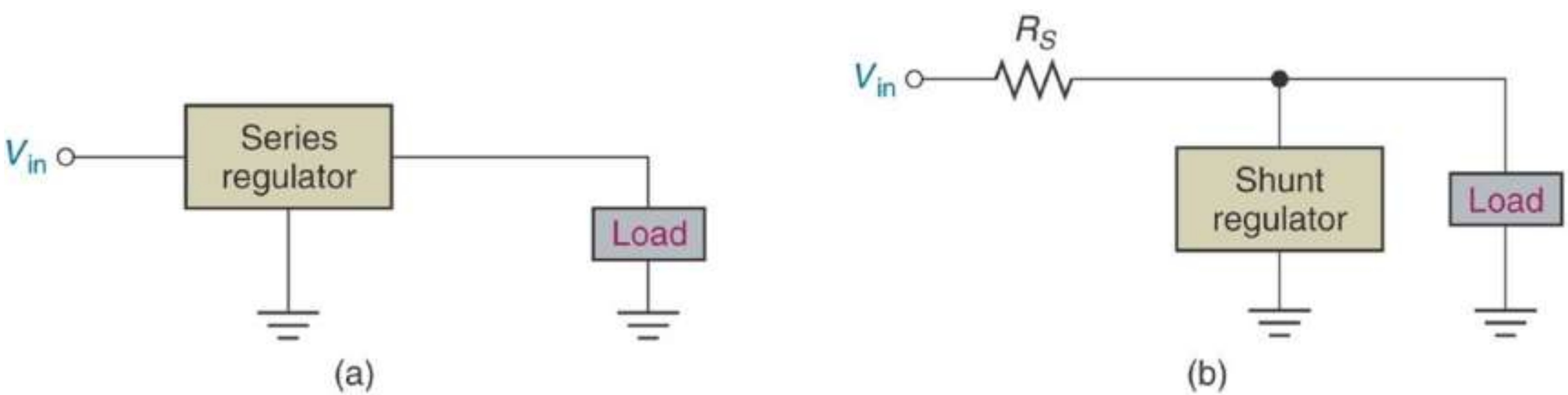
Example

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)

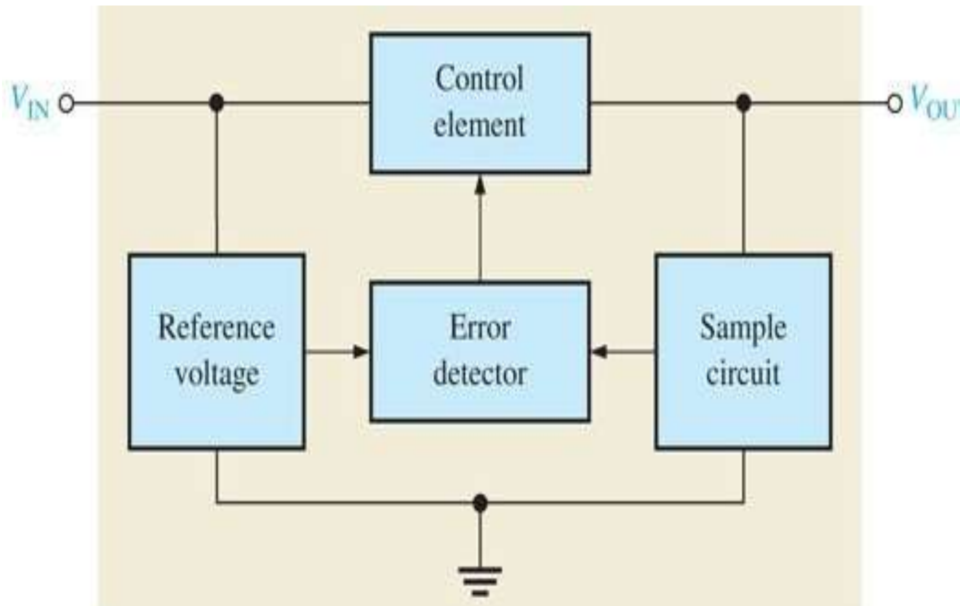
Types of Regulator

- 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.

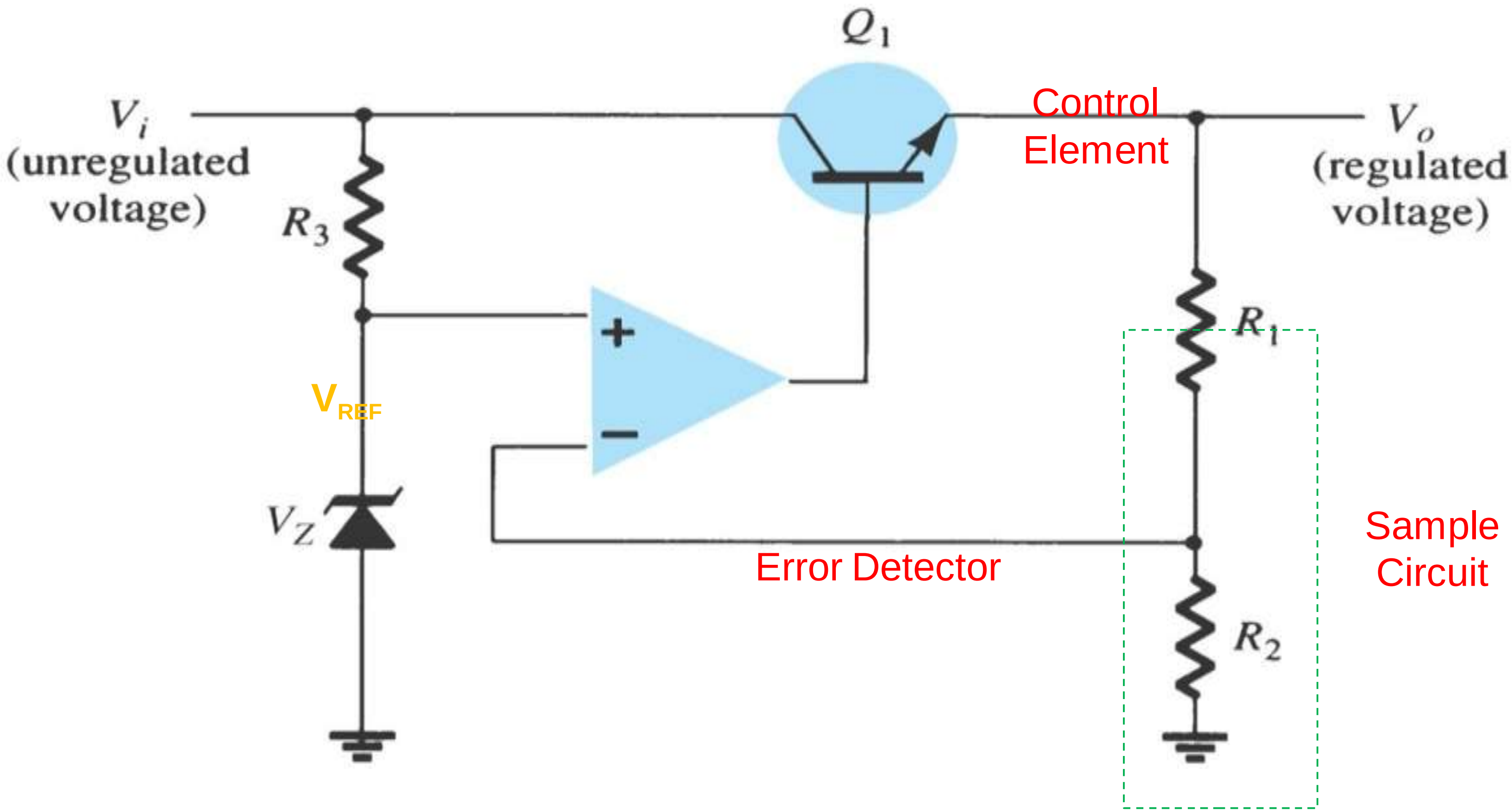


Series Regulator Circuit

- **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

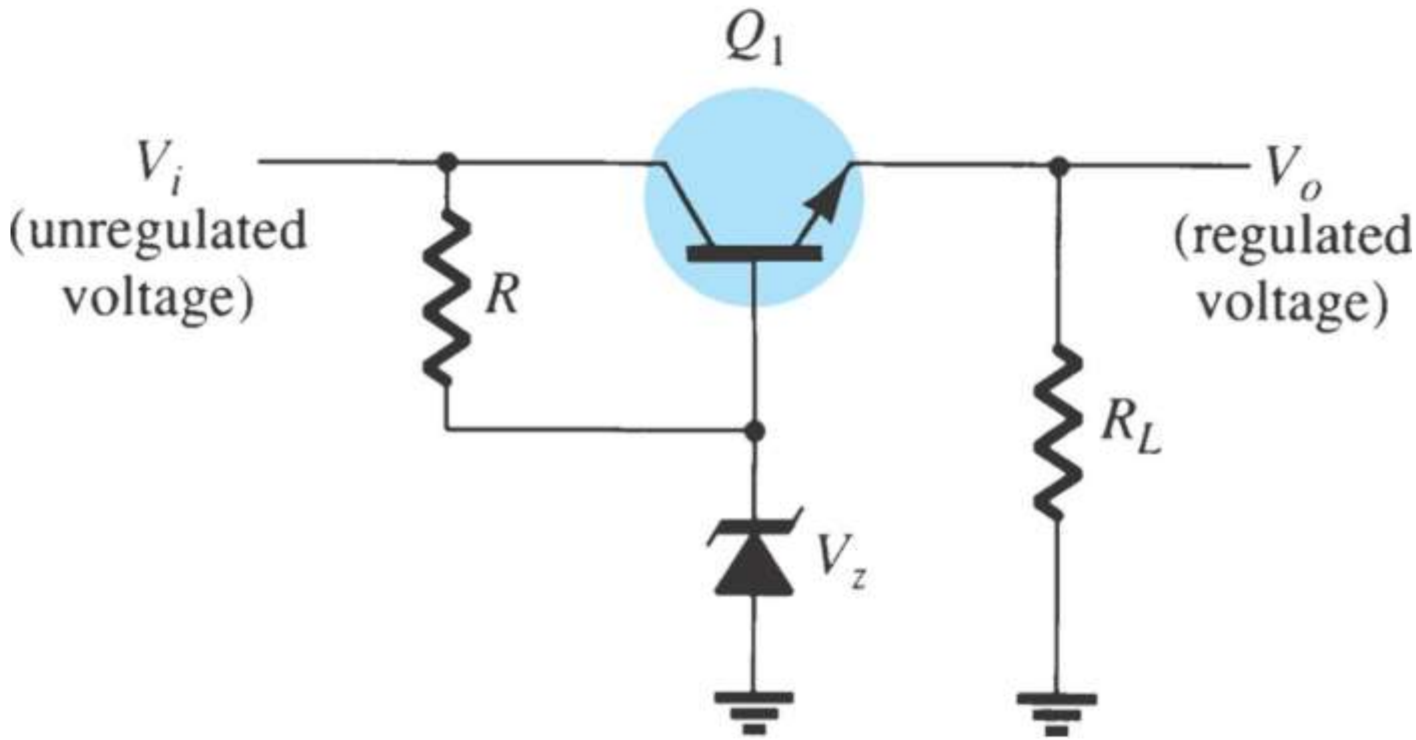


Op-Amp Series Regulator

- 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

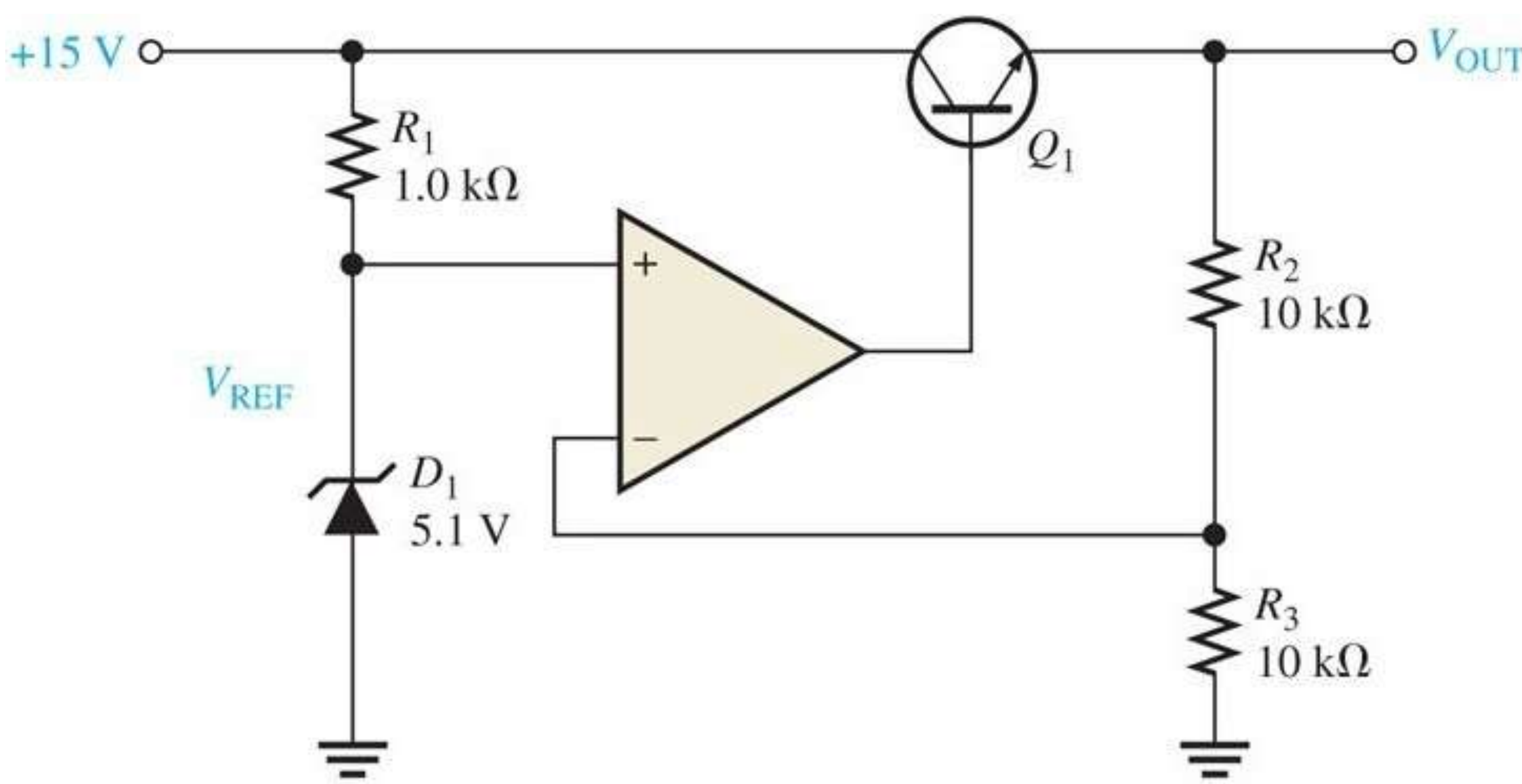
- Since Q_1 is an npn transistor, V_o is found as:

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

- 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

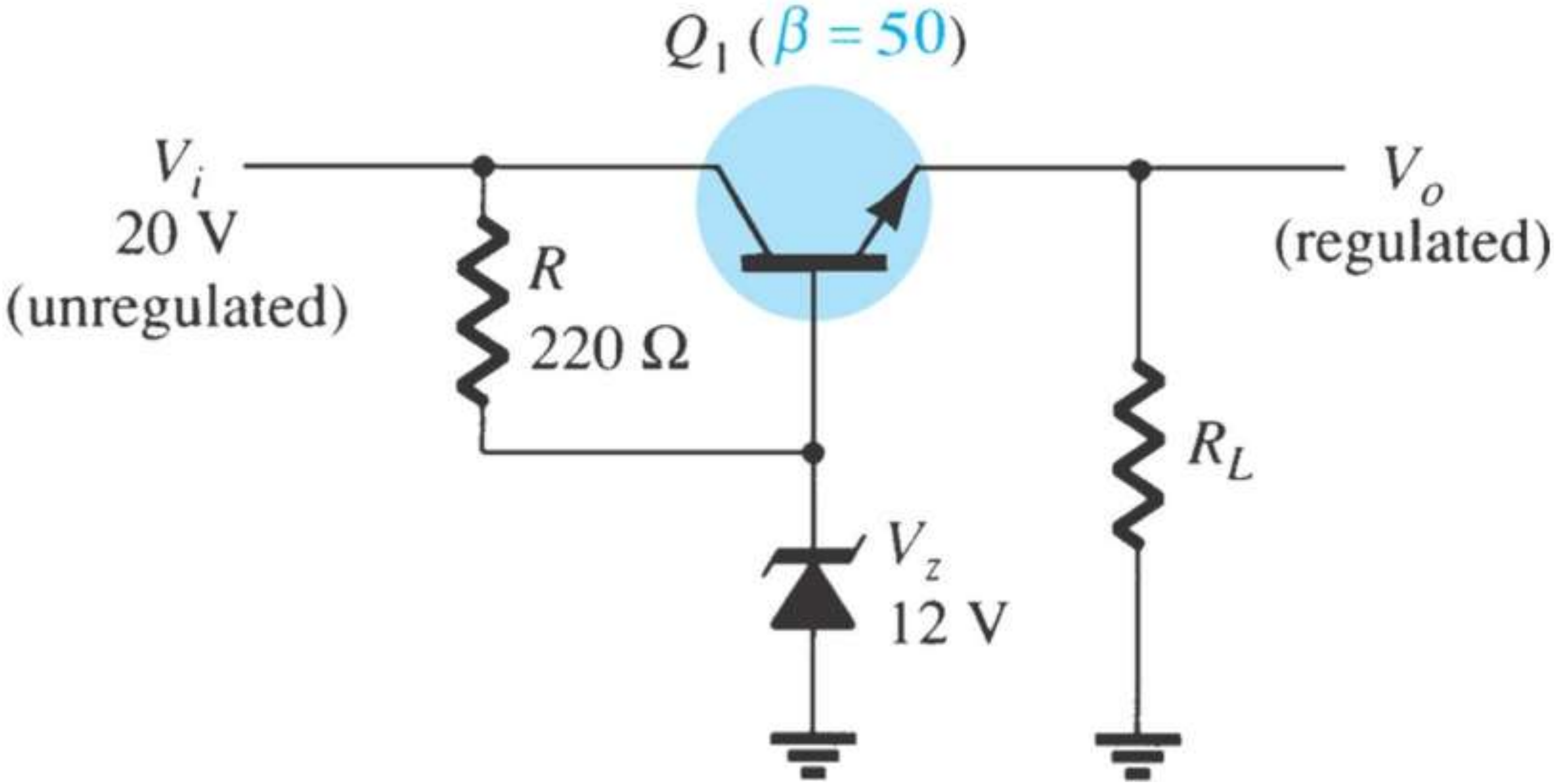
- Determine the output voltage for the regulator below. (Solution: 10.2 V)



Example

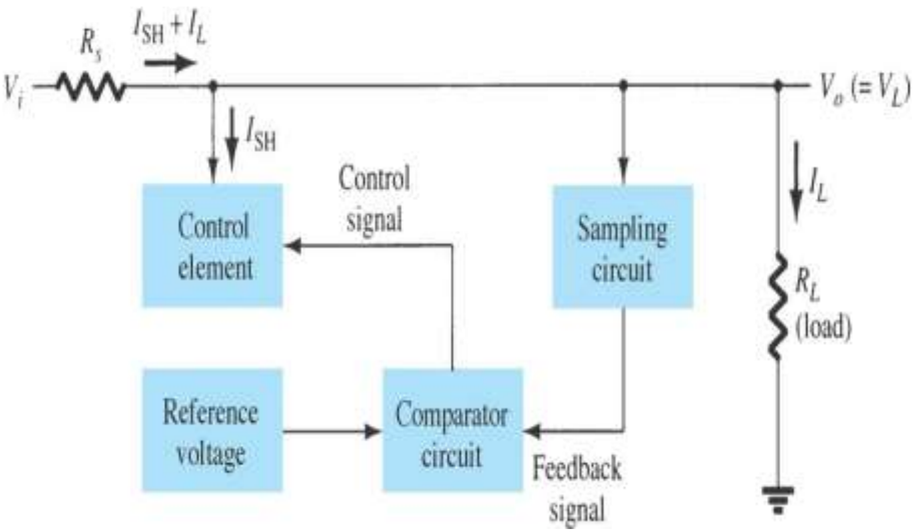
- Calculate the output voltage and Zener current for R_L=1kΩ.

  (Solution: V_o=11.3 V; I_z≈36 mA)

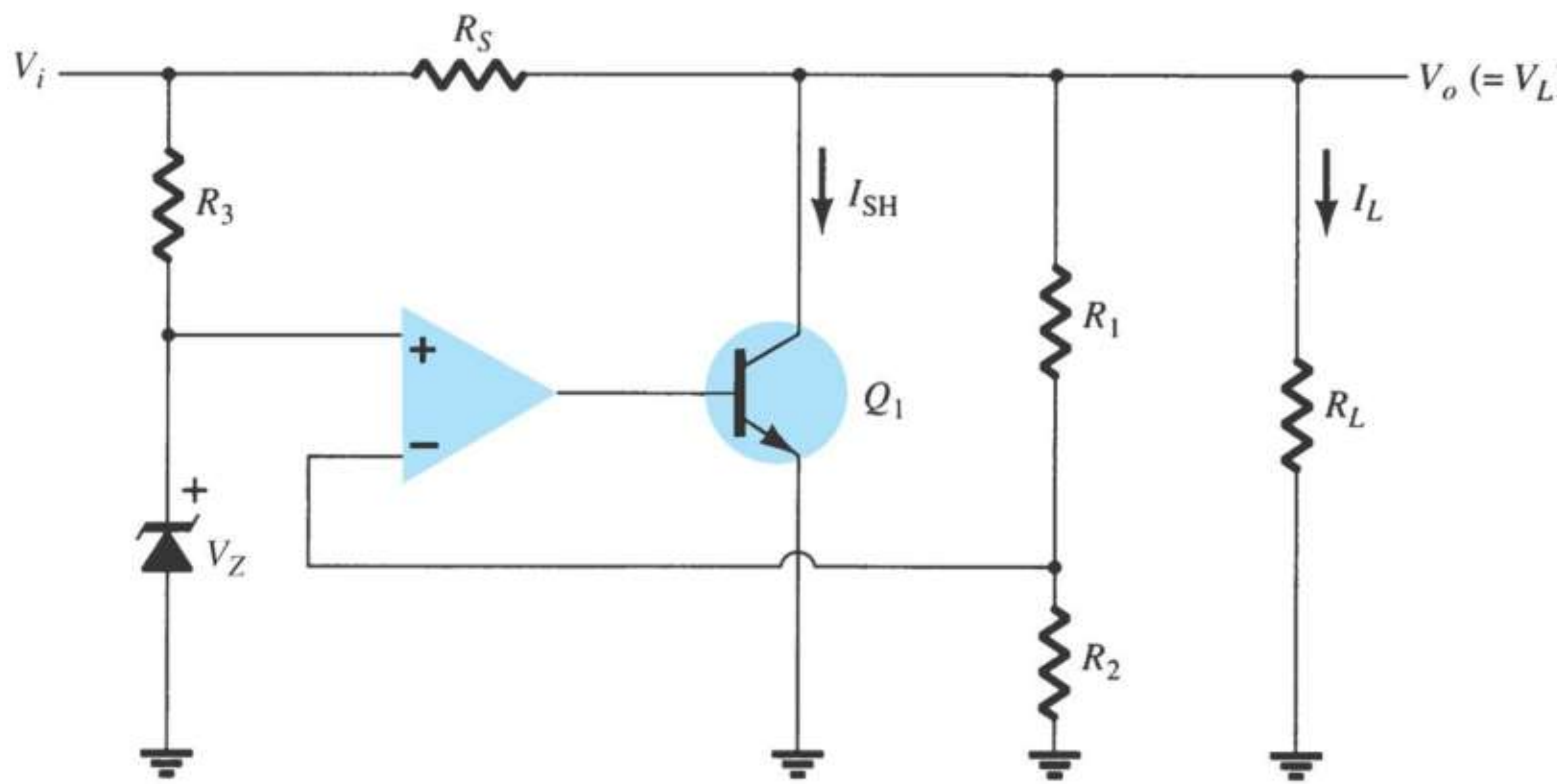


Shunt Regulator Circuit

- 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 vary the amount of the current signal to shunted away from the load to maintain the regulated output voltage across the load.



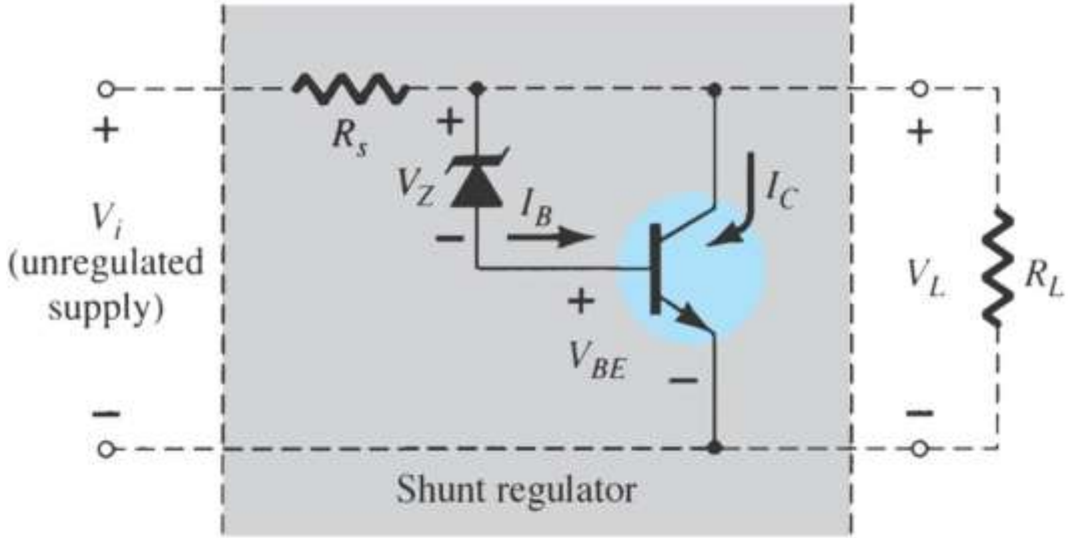
Op-Amp Shunt Regulator



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.

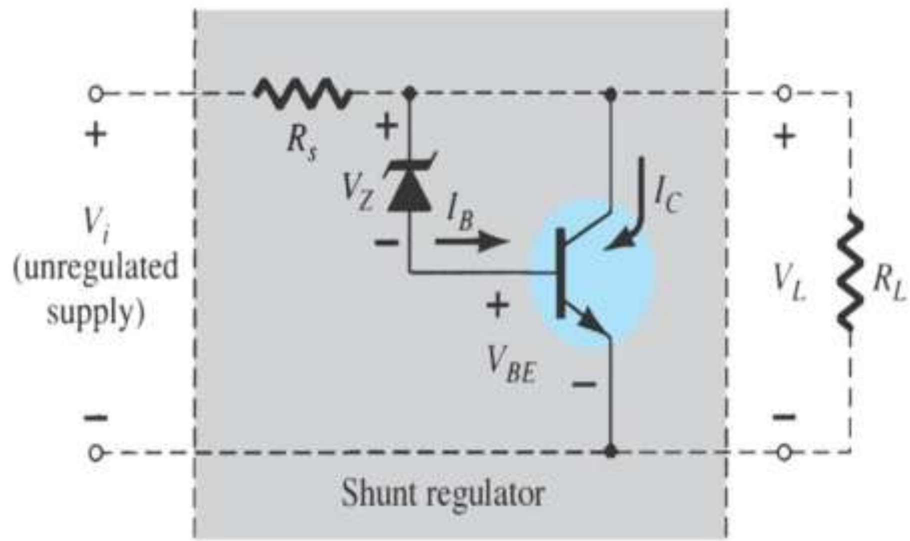
Transistor Shunt Regulator



- 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
- 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.

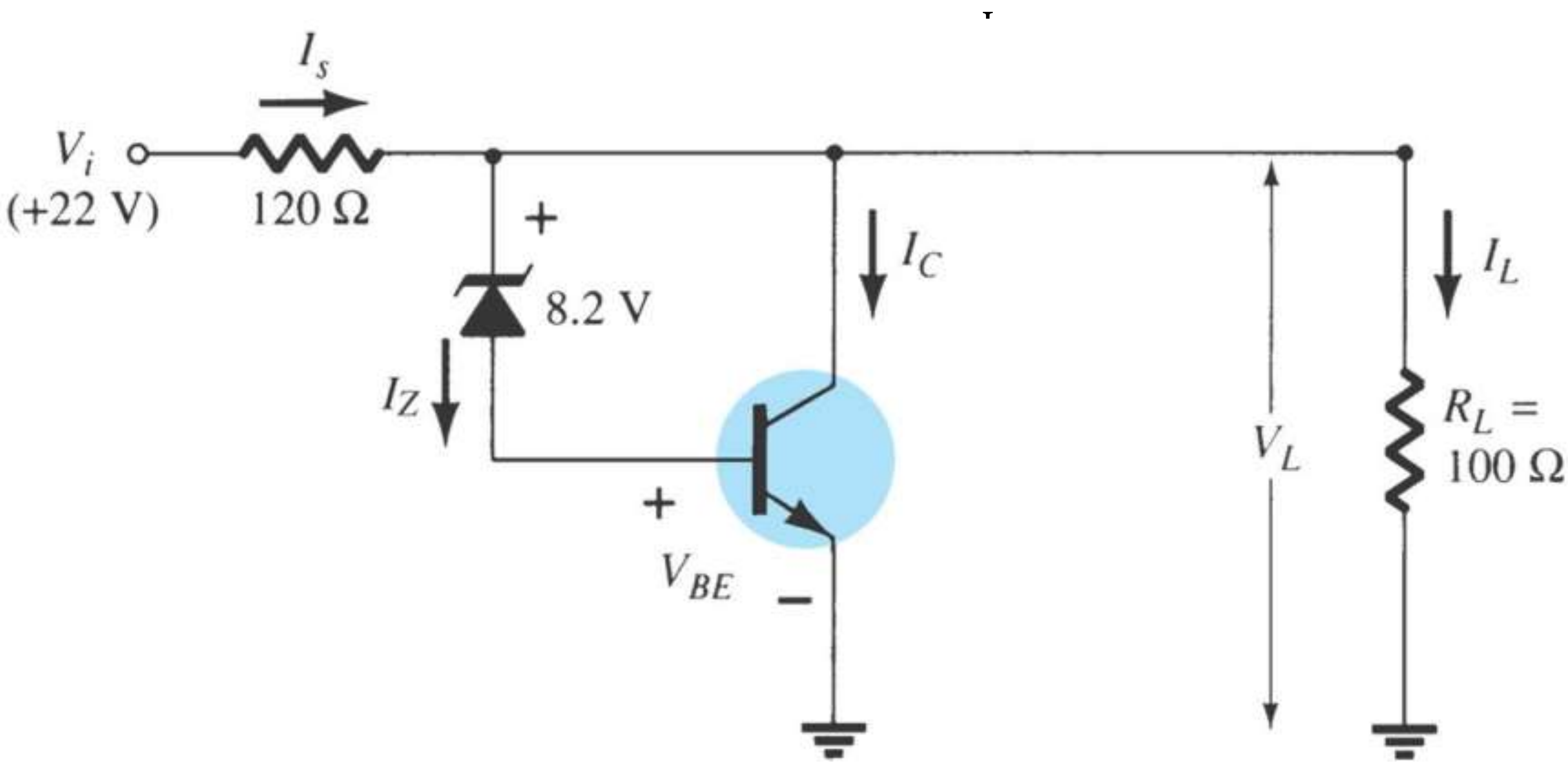


Transistor Shunt Regulator

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

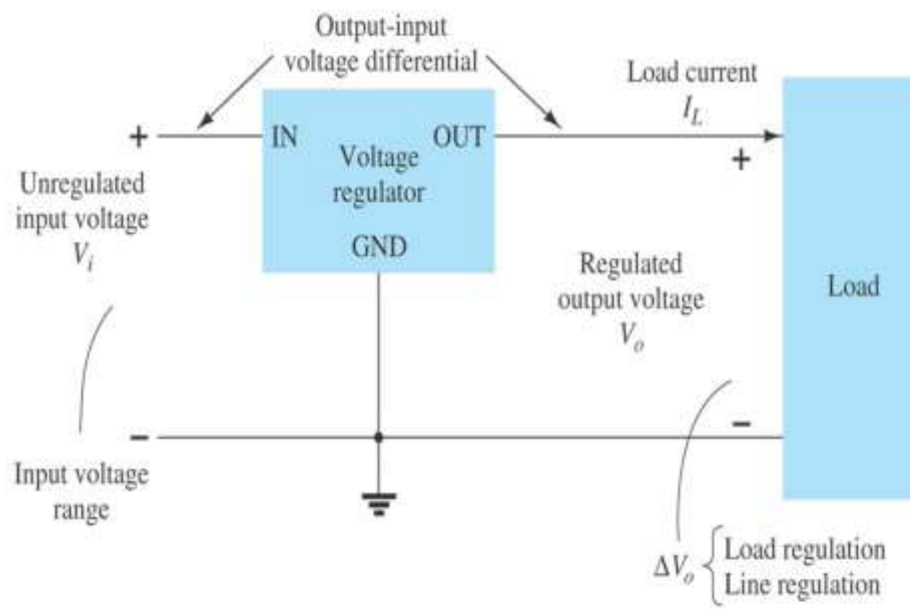
Exampl
e

- Determine the regulated voltage, V and circuit currents.



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.



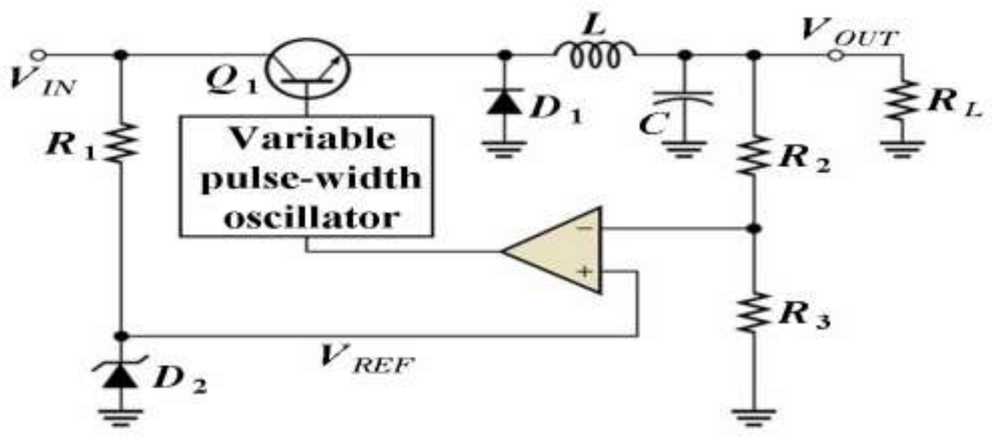
Switching Regulator

- 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

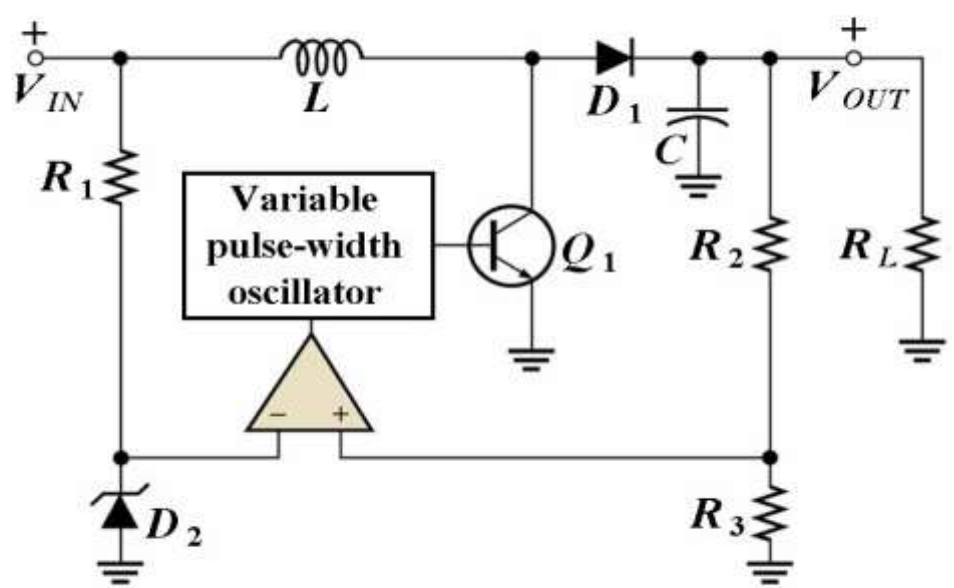
- With the step-down (output is less than the input) configuration the control element Q_1 is pulsed on and off at variable rate based on the load current.
- The pulsations are filtered out by the LC filter.



Switching Regulator

Step-up configuration

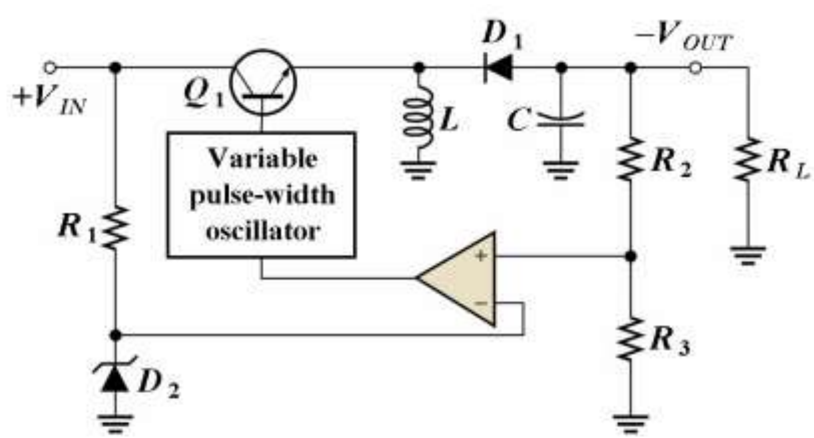
- The difference is in the placement of the inductor and the fact that Q_1 is shunt configured.
- During the time when Q_1 is off the V_L adds to V_C stepping the voltage up by some amount.



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 off the capacitor for voltage production during the 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

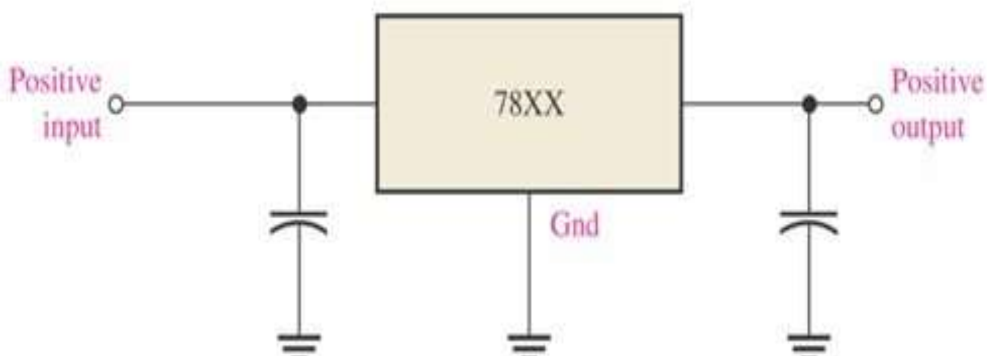
- Generally, the linear regulators are three-terminal devices that provides either positive or negative output voltages that can be either fixed or adjustable.

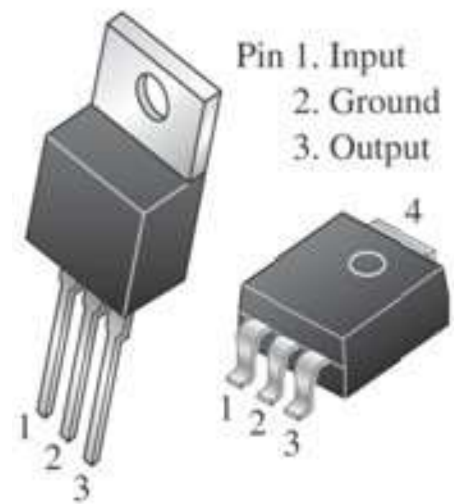
Fixed Voltage Regulator

- 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

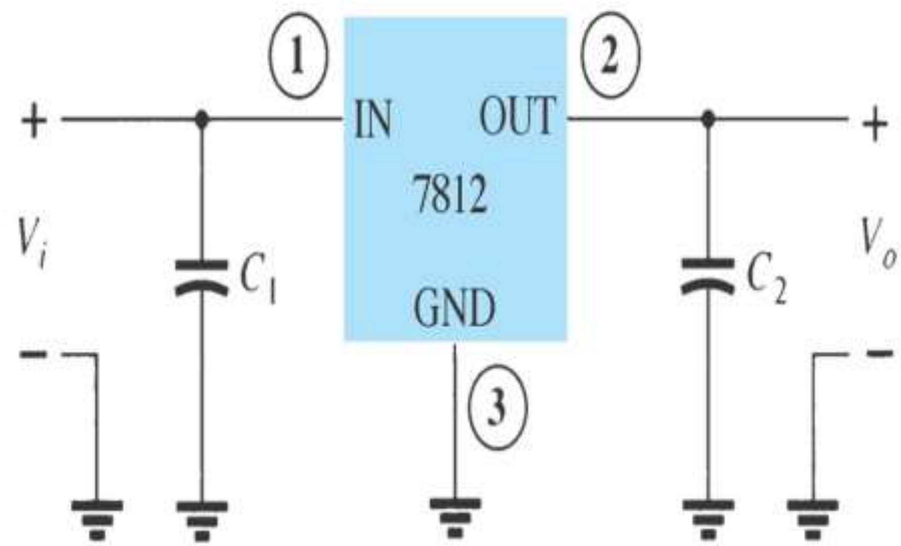
- The series 78XX regulators are the three-terminal devices that provide a fixed positive output voltage.





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

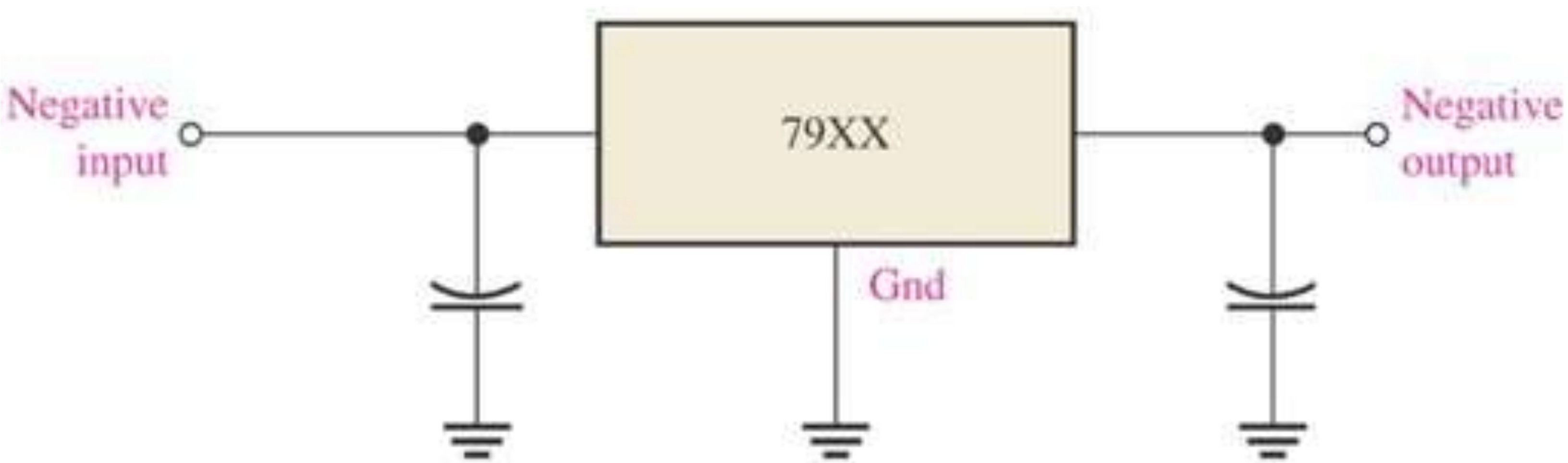
Positive-Voltage Regulators in the 78XX Series

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

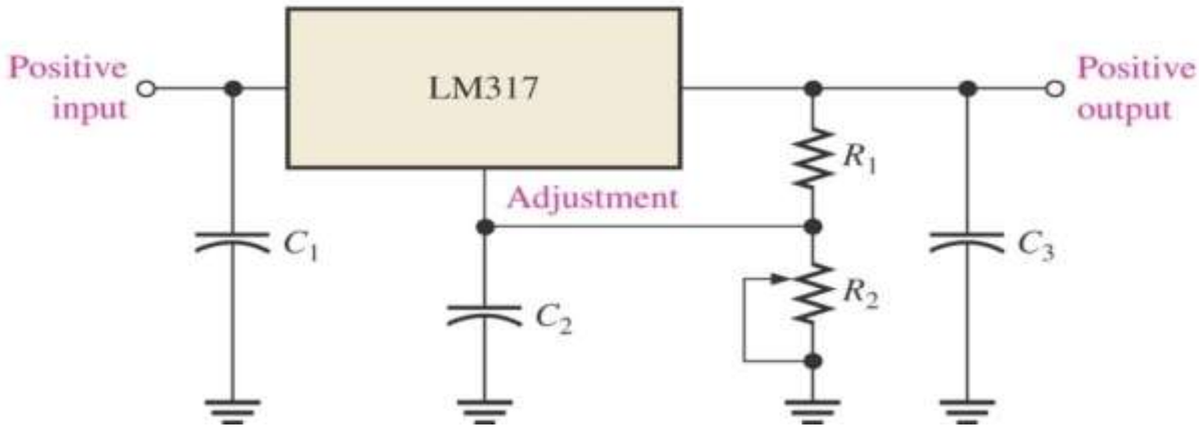
Negative-Voltage Regulators in the 79XX Series

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

IC 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.