

14/12/21

# Voltage Regulators

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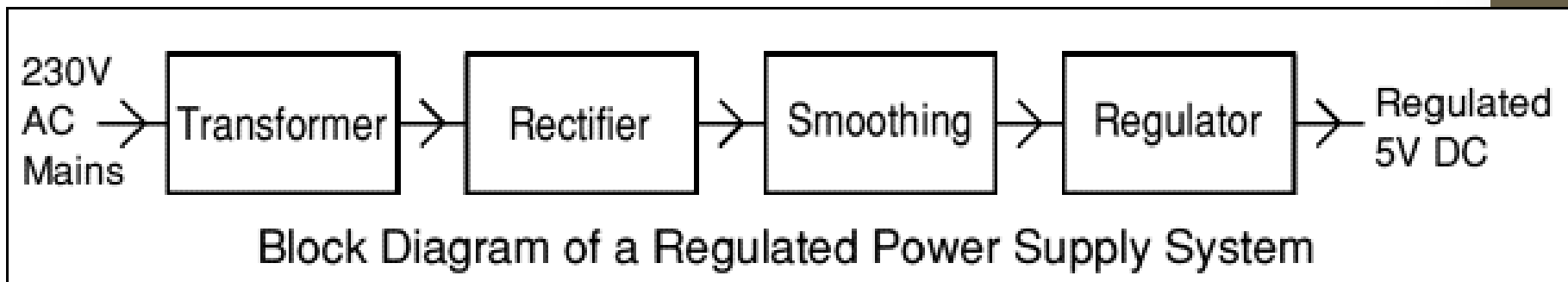
# Introduction

- ◆ 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 be broken down into a series of blocks, each of which performs a particular function.

# Power Supplies

- For example a 5V regulated supply

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

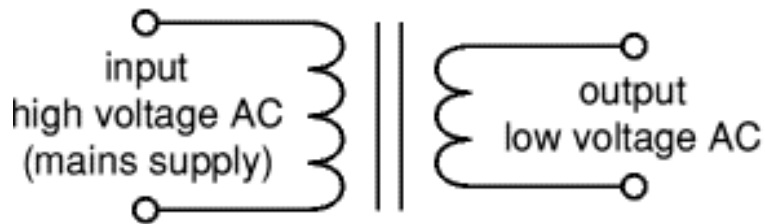


$$\text{Line regulation} = \left( \frac{\Delta V_{\text{OUT}}}{\Delta V_{\text{IN}}} \right) 100\% \quad \text{mV/V}$$

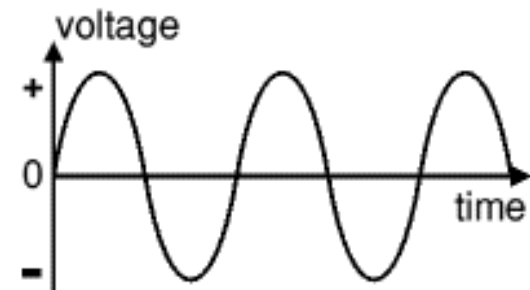
$$\text{Line regulation} = \frac{(\Delta V_{\text{OUT}}/V_{\text{OUT}}) 100\%}{\Delta V_{\text{IN}}} \quad /\text{V}$$

# Power Supplies

- Transformer



Transformer



Output: low voltage AC

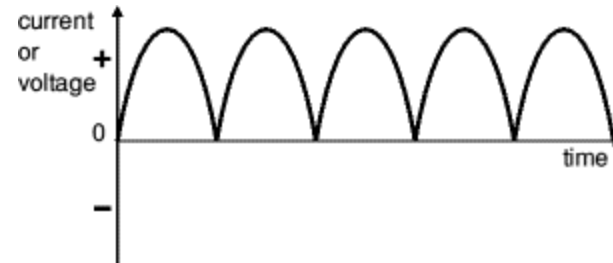
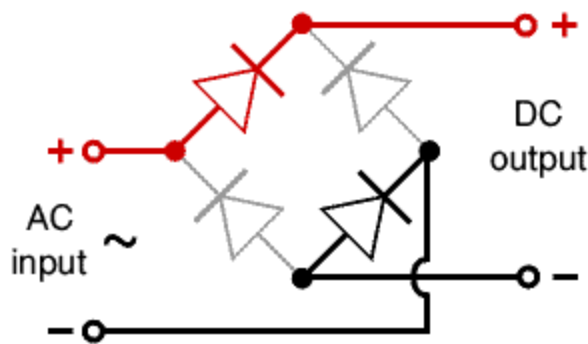
# Power Supplies

- **Transformer**
  - ◆ Transformers convert AC electricity from one voltage to another with little loss of power.
  - ◆ Transformers work only with AC and this is one of the reasons why mains electricity is AC.
  - ◆ Step-up transformers increase voltage.
  - ◆ Step-down transformers reduce voltage.

# Power Supplies

- **Rectifier**

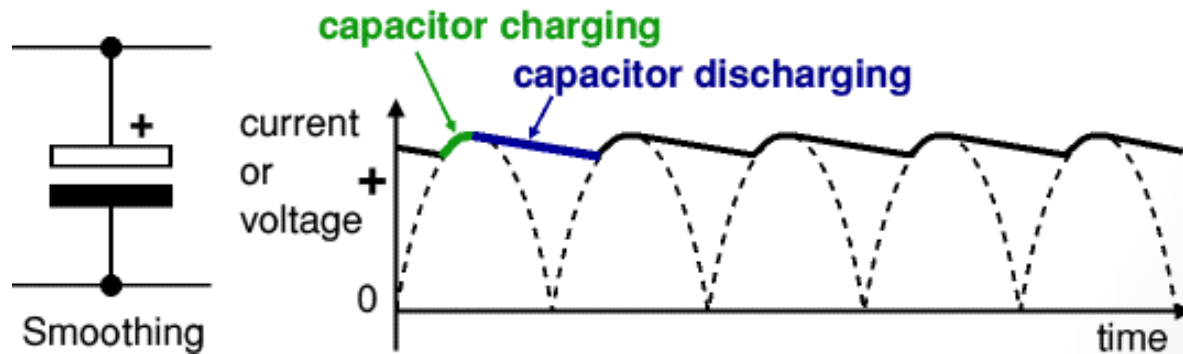
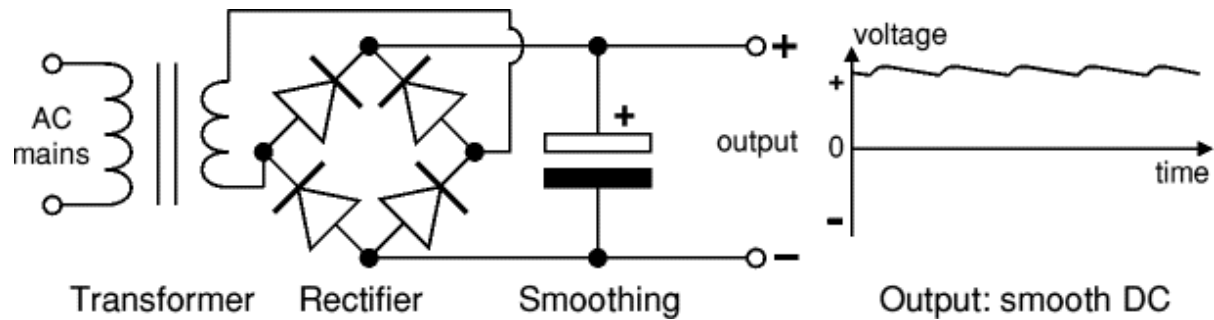
Produces full-wave varying DC.



A bridge rectifier can be made using four individual diodes, but it is also available in special packages containing the four diodes required.

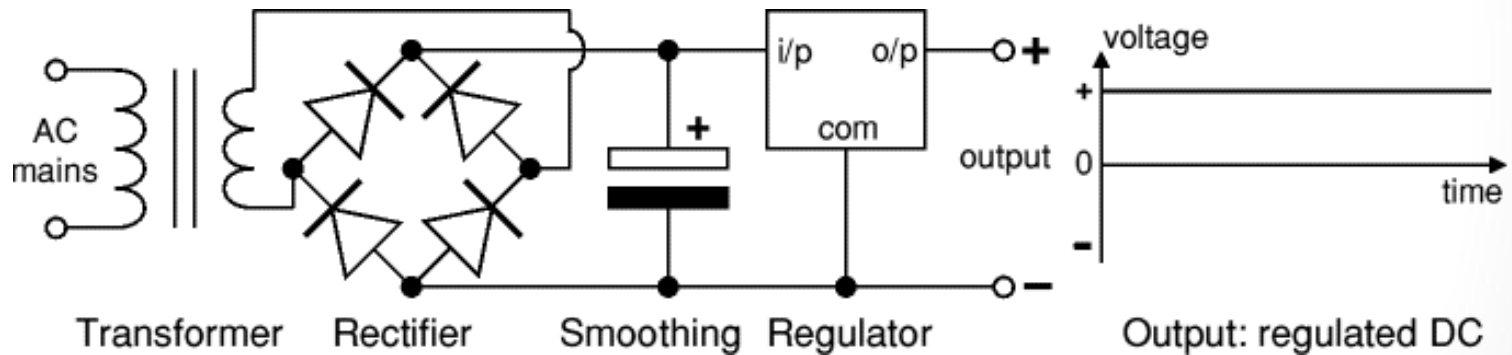
# Power Supplies

- Smoothing



# Power Supplies

- Regulator



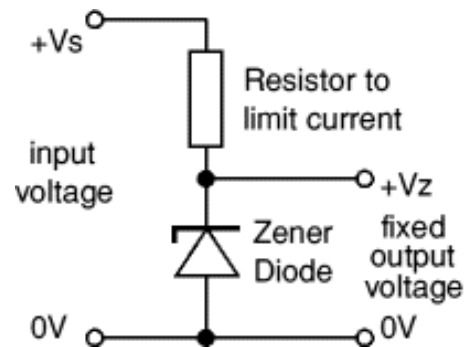
Voltage regulator ICs are available with fixed (typically 5, 12 and 15V) or variable output voltages.

# Power Supplies

- **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 as shown in the diagram.

Zener diodes are rated by their breakdown voltage  $V_z$  and maximum power  $P_z$  (typically 400mW or 1.3W).



# Voltage Regulation

**Line regulation** is the maintenance of a specific output voltage despite changes in input voltage.

How well a regulator performs line regulation can be determined by the formula below.

$$\text{Line Regulation} = \left( \frac{\Delta V_{out}}{\Delta V_{in}} \right) 100\%$$

# Voltage Regulation

**Load regulation** is the maintenance of a precise output voltage despite changes in load resistance.

How well a regulator performs load regulation can be determined by the formula below.

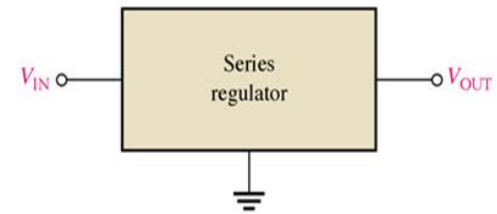
$$\text{Load Regulation} = \left( \frac{V_{NL} - V_{FL}}{V_{FL}} \right) 100\%$$

# Types of Regulator

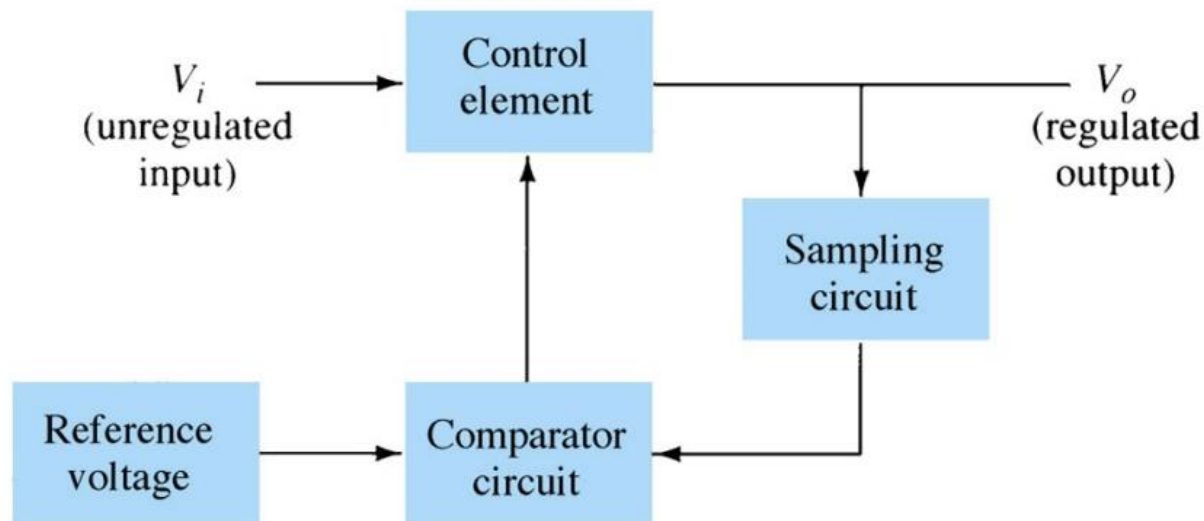
- **Linear Regulator**
  - Series Regulator
  - Shunt Regulator
- **Switching Regulator**

# Basic Series Regulators

With series regulation the control element is in series with the input and output.



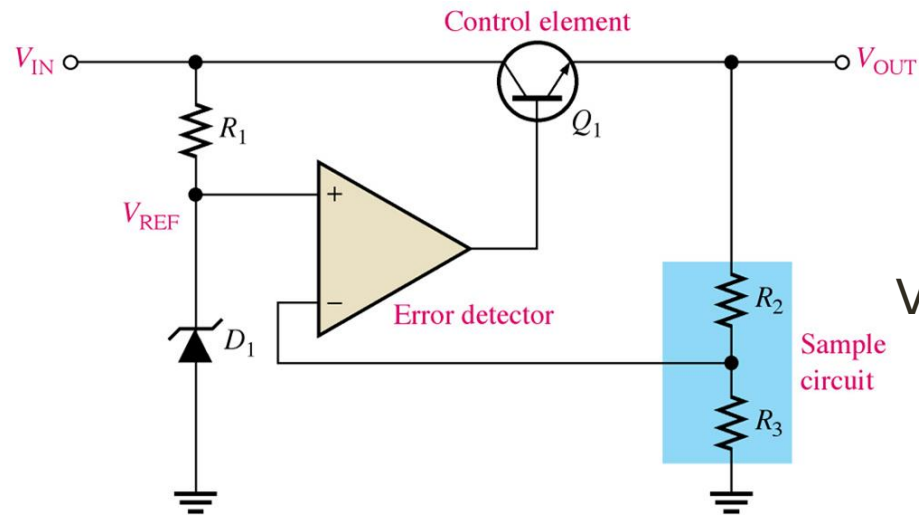
(a)



# Basic Series Regulators

The zener diode sets the reference voltage for the noninverting input of the op-amp. Any changes in the output are fed back to the inverting input of the op-amp.

The difference voltage output of the op-amp biases the transistor to correct the output voltage for the overall circuit.



$$V_{R3} = V_{out} * R3 / (R2 + R3)$$

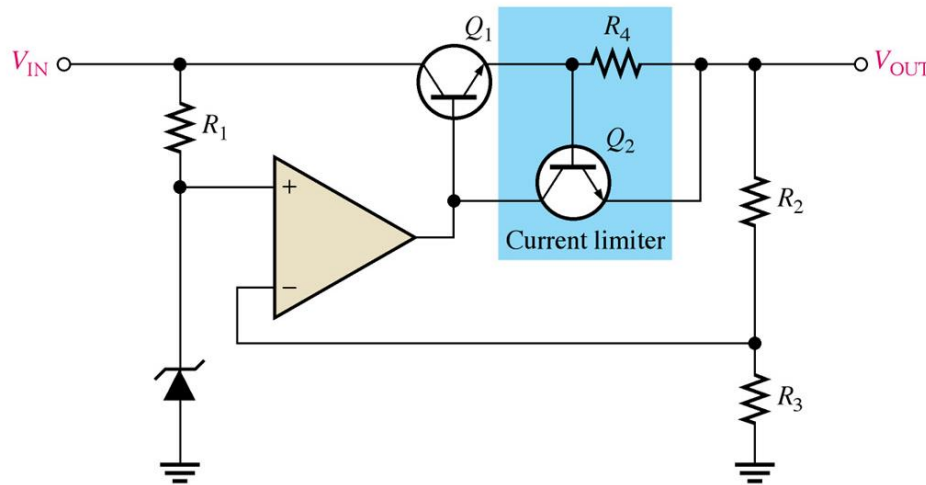
$$V_{REF} (1 + R3/R2) = V_{out}$$

# Basic Series Regulators

Overload protection for a series regulator protects the control element in the case of a short.

$Q_2$  is biased by the voltage drop across  $R_4$ .

When load current exceeds the predetermined level,  $Q_2$  diverts current from the base of  $Q_1$  causing  $Q_1$  to conduct less.



$$R_4 = 0.7V / 0.1A = 0.7$$

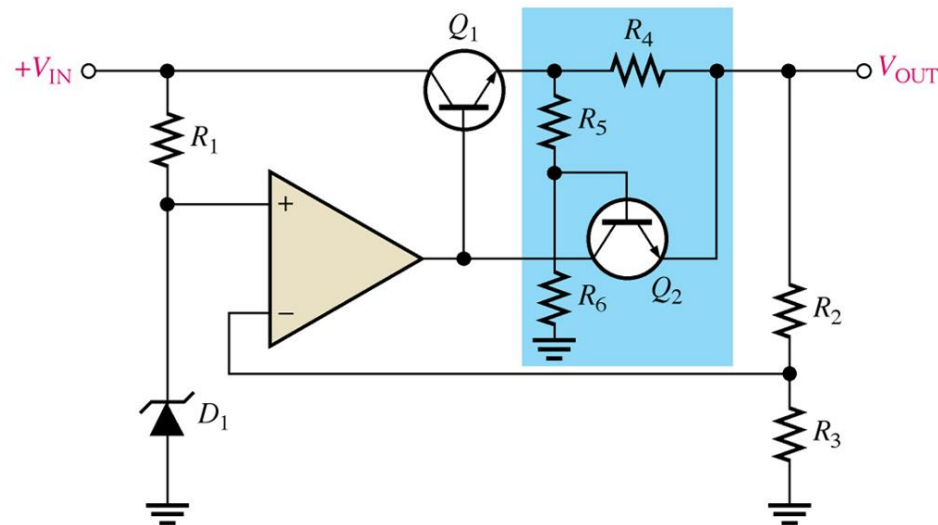
## Regulator with Fold-Back Current Limiting

# Basic Series Regulators

Fold-back current limiting allows operation up to peak load current.

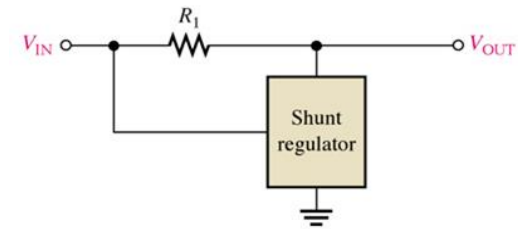
With a shorted output the current is dropped to a lower value (folded back).

$V_{R5} + V_{BE}$  must be overcome before  $Q_2$  conducts to limit current.

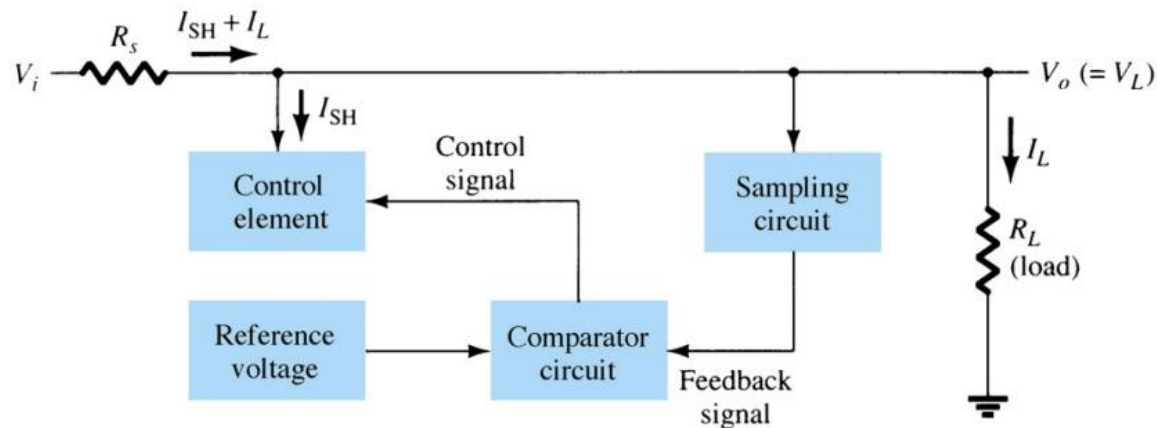


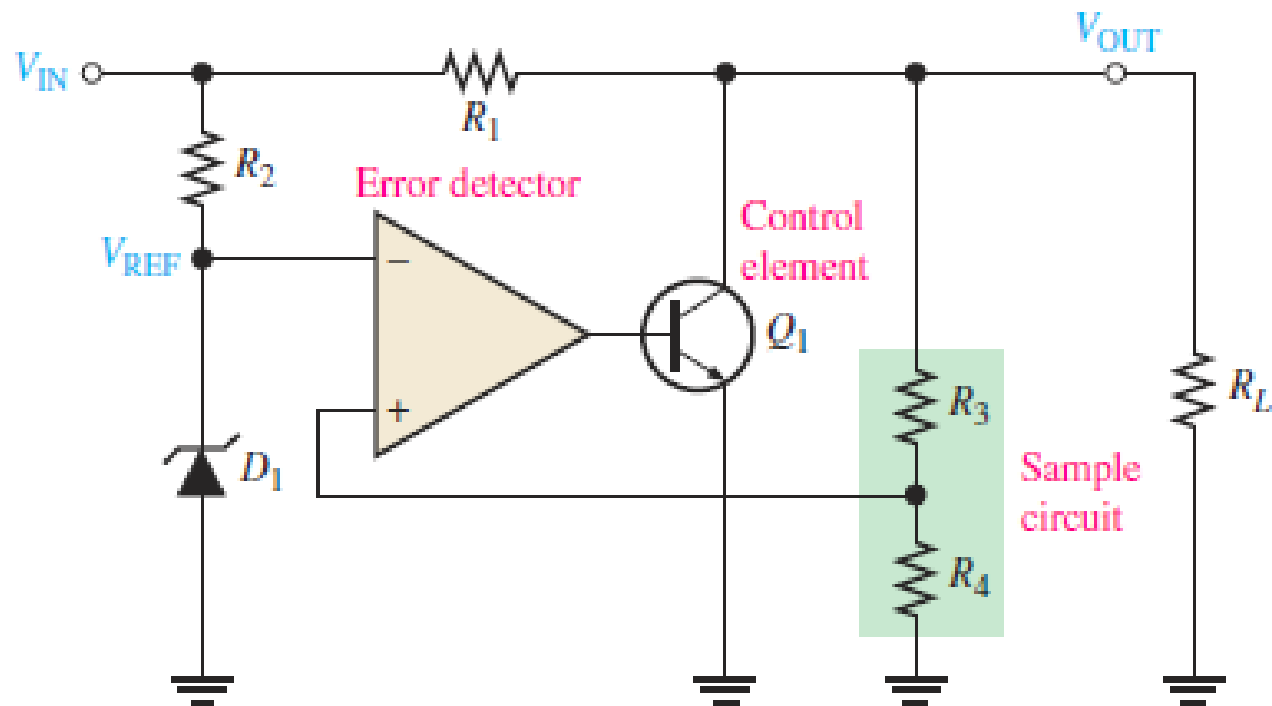
# Basic Shunt Regulators

In **shunt regulation** the control element is in parallel with the load.



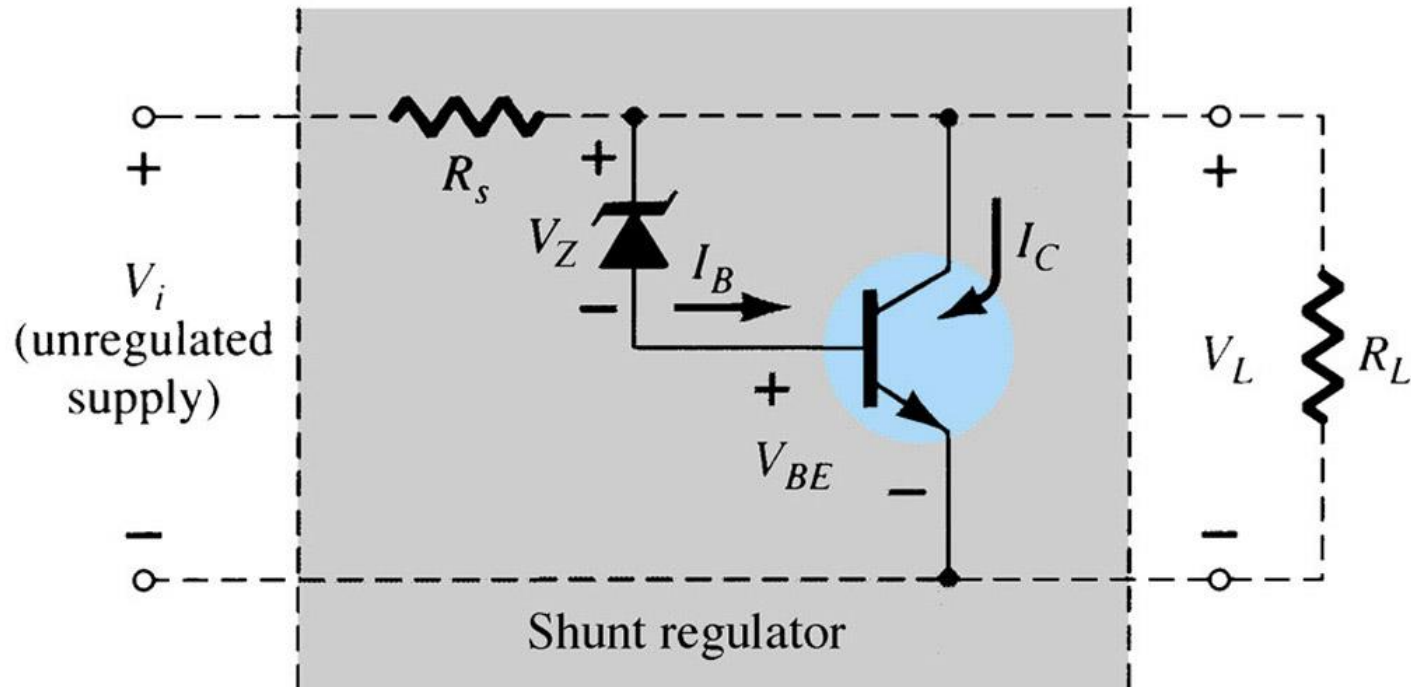
(a)





# Basic Shunt Regulators

In **shunt regulation** the control element is in parallel with the load.



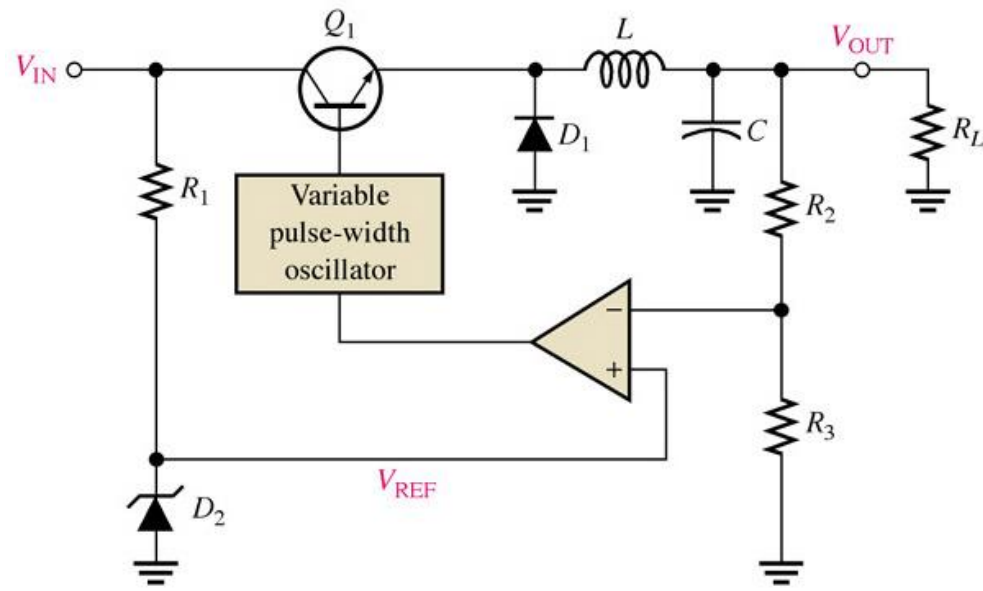
# Basic Switching Regulators

- ◆ 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.

# Basic Switching Regulators

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.



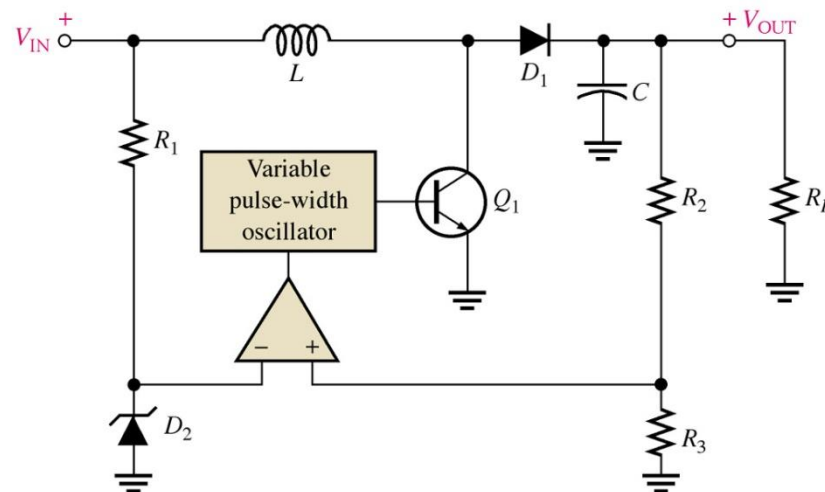
(a) Typical circuit

# Basic Switching Regulators

The step-up configuration works much the same as the step-down.

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.

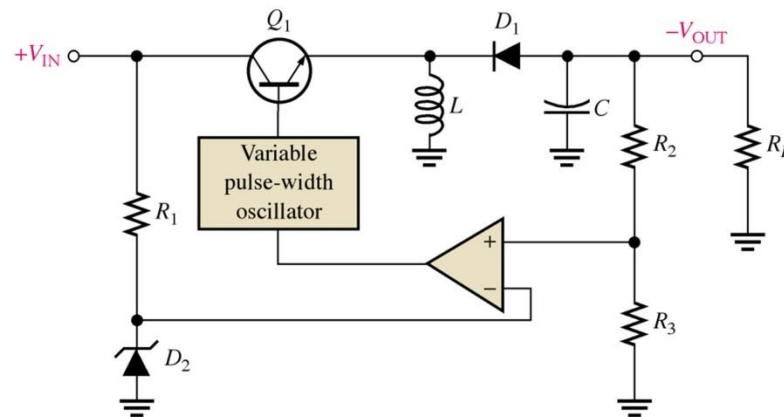


# Basic Switching Regulators

With the voltage-inverter configuration the output voltage output is of opposite polarity of the input.

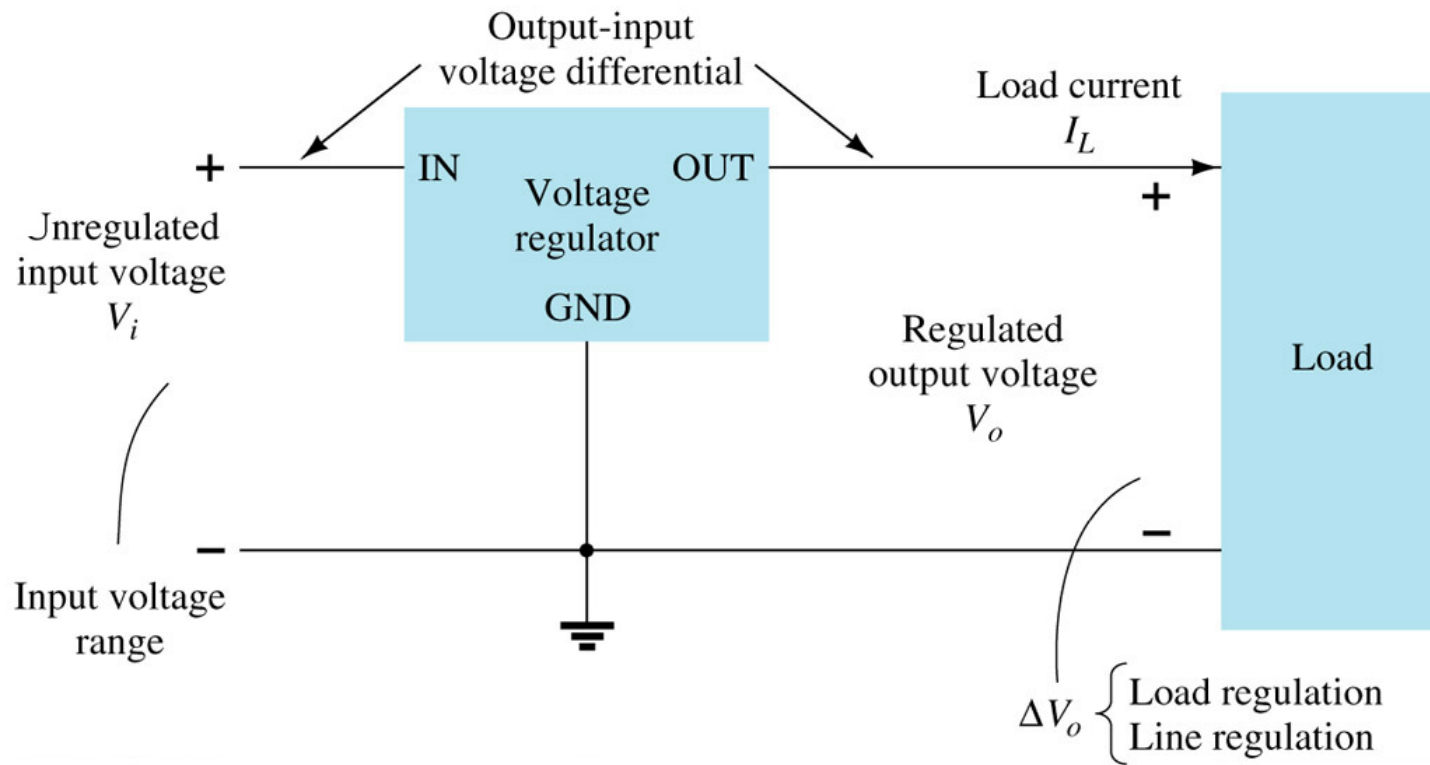
This is achieved by  $V_L$  forward-biasing reverse-biased diode during the off times producing current and charging the capacitor for voltage production during the off times.

With switching regulators 90% efficiencies can be achieved.





# IC Regulators

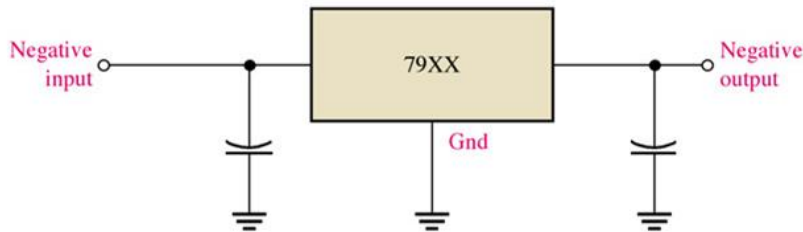


# IC Regulators

- ◆ 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 are have variable voltage outputs.

# IC Regulators

- ◆ 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.



(a) Standard configuration

Type number	Output voltage
7905	-5.0 V
7905.2	-5.2 V
7906	-6.0 V
7908	-8.0 V
7912	-12.0 V
7915	-15.0 V
7918	-18.0 V
7924	-24.0 V

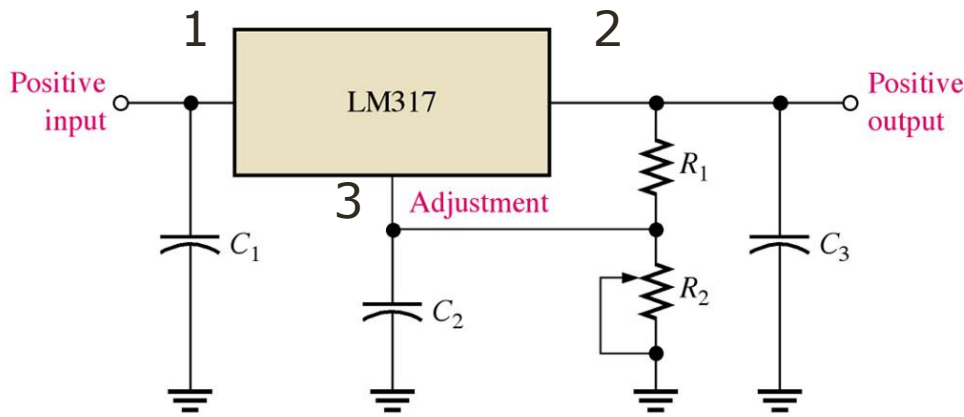
(b) The 7900 series

# IC Regulators

Adjustable IC regulators are available with either positive or negative output.

They can be set to produce a specific voltage by way of an external reference voltage divider network.

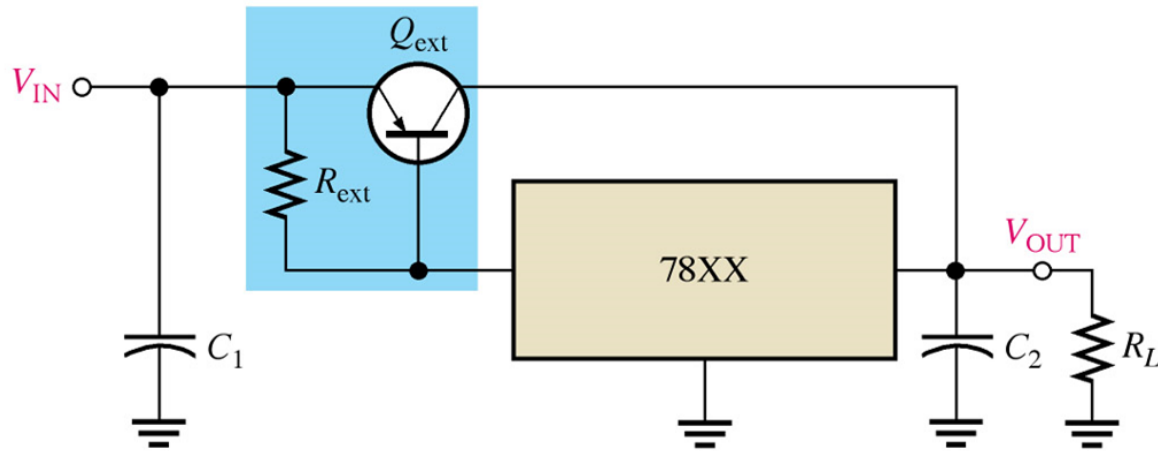
Switching regulators are also available in IC form.

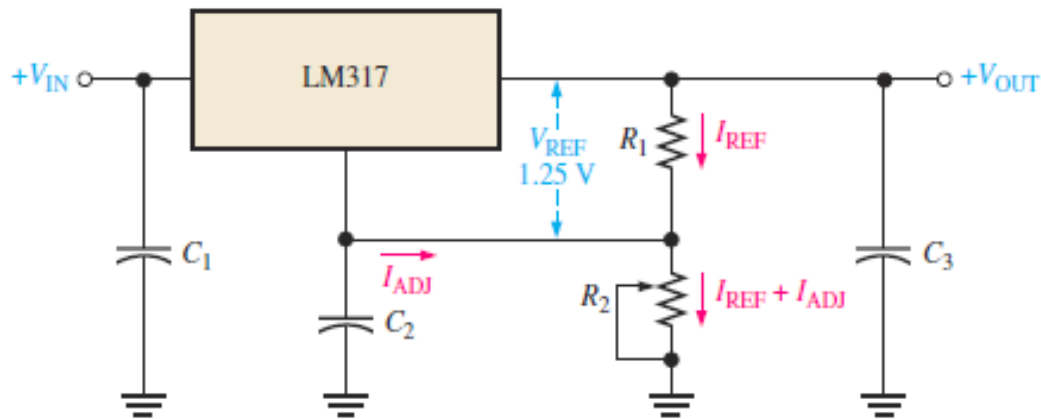


$$I_{\text{REF}} = \frac{V_{\text{REF}}}{R_1} = \frac{1.25 \text{ V}}{R_1}$$

# IC Regulators

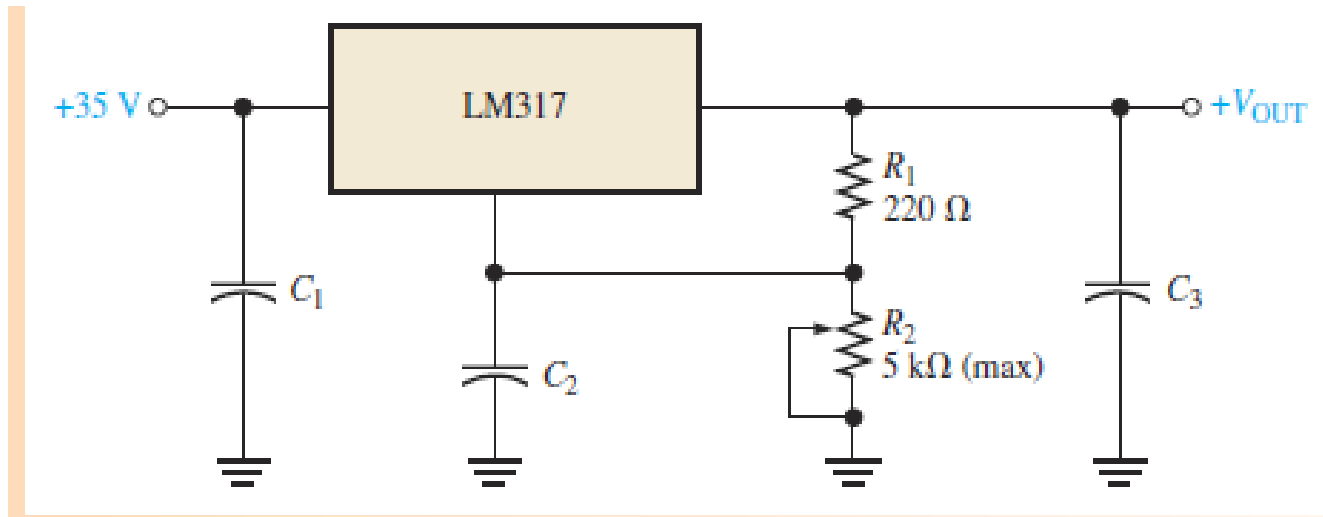
To increase the current capability of an IC regulator an external pass transistor can be used.





$$\begin{aligned}
 V_{\text{OUT}} &= V_{R1} + V_{R2} = I_{\text{REF}}R_1 + I_{\text{REF}}R_2 + I_{\text{ADJ}}R_2 \\
 &= I_{\text{REF}}(R_1 + R_2) + I_{\text{ADJ}}R_2 = \frac{V_{\text{REF}}}{R_1}(R_1 + R_2) + I_{\text{ADJ}}R_2
 \end{aligned}$$

$$V_{\text{OUT}} = V_{\text{REF}} \left( 1 + \frac{R_2}{R_1} \right) + I_{\text{ADJ}}R_2$$



$$I_{adj} = 50 \times 10^{-6} \text{ A}$$

LM337

$$V_{R1} = V_{REF} = 1.25 \text{ V}$$

When  $R_2$  is set at its minimum of  $0 \Omega$ ,

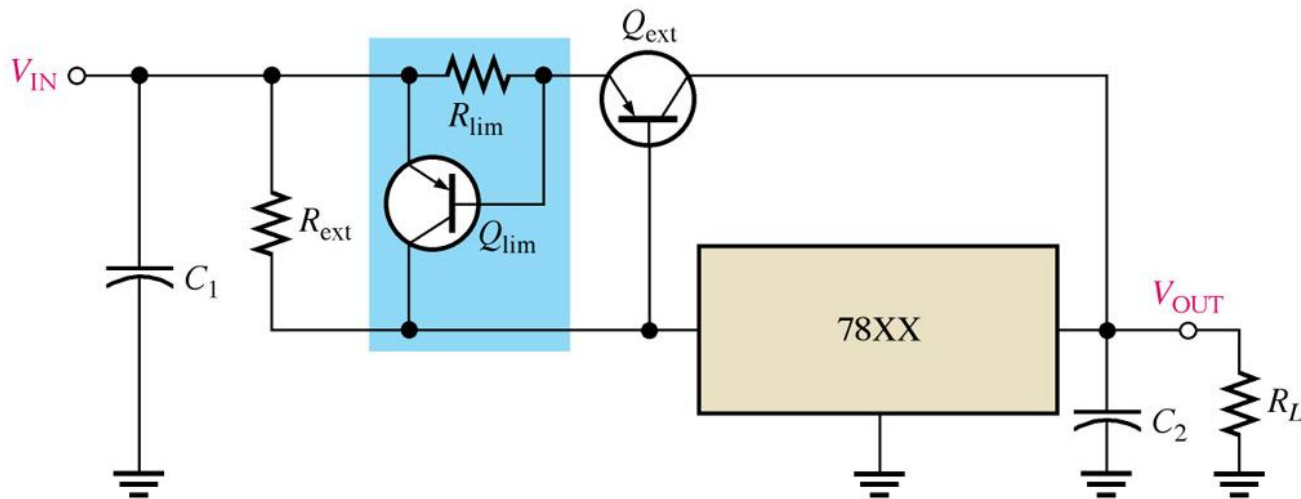
$$V_{OUT(\min)} = V_{REF} \left( 1 + \frac{R_2}{R_1} \right) + I_{ADJ} R_2 = 1.25 \text{ V}(1) = 1.25 \text{ V}$$

When  $R_2$  is set at its maximum of  $5 \text{ k}\Omega$ ,

$$\begin{aligned} V_{OUT(\max)} &= V_{REF} \left( 1 + \frac{R_2}{R_1} \right) + I_{ADJ} R_2 = 1.25 \text{ V} \left( 1 + \frac{5 \text{ k}\Omega}{220 \Omega} \right) + (50 \mu\text{A}) 5 \text{ k}\Omega \\ &= 29.66 \text{ V} + 0.25 \text{ V} = 29.9 \text{ V} \end{aligned}$$

# IC Regulators

A current limiting circuit similar to the one discussed earlier can be used to protect the external pass transistor.



# 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.
- Switching regulators are more efficient than linear making them ideal for low voltage high current applications.

# Summary

- 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.

