Fundamentals of Microelectronics II

فصل ۱۴- تنظیم کننده ولتاژ

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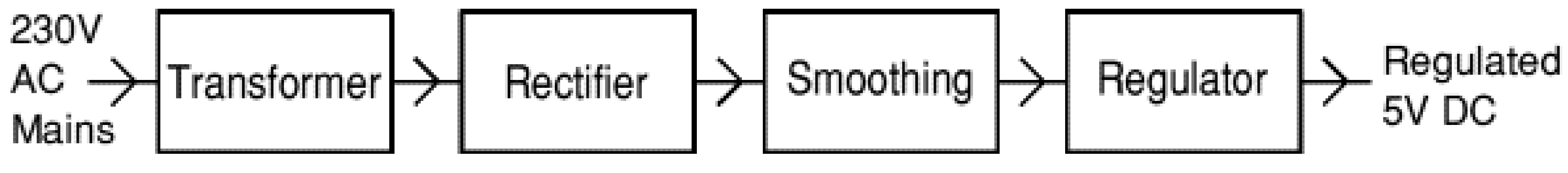
Chapter 14 Voltage Regulator

- **14.1 Power Supplies**
- **14.2 Regulator**
- **14.3 Zener diode regulator**
- **14.4 Basic Series Regulators**
- **11.5 IC Regulators**

Power Supplies

- A reliable method of obtaining DC power is to transform, rectify, filter and regulate an AC line voltage.

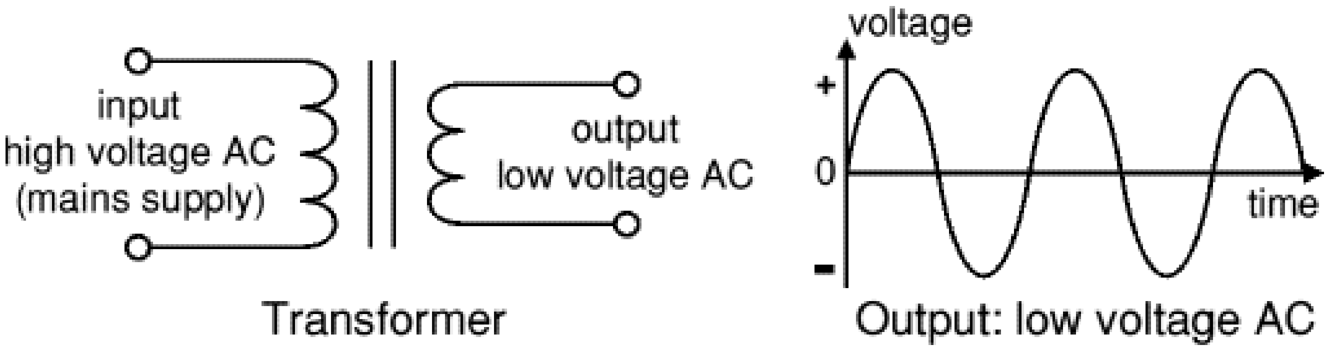
- A power supply can by broken down into a series of blocks, each of which performs a particular function.



Block Diagram of a Regulated Power Supply System

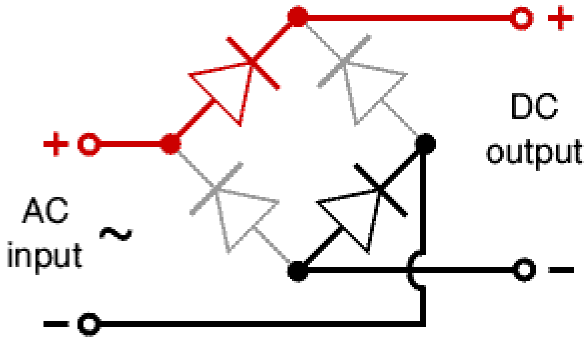
➢ Transformer

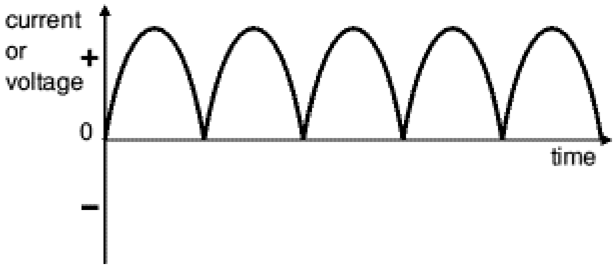
- Transformers convert AC electricity from one voltage to another with little loss of power.
- Transformers work only with AC and this is one of the reasons why mains electricity is AC.
- Step-up transformers increase voltage.
- Step-down transformers reduce voltage.



➢ Rectifier

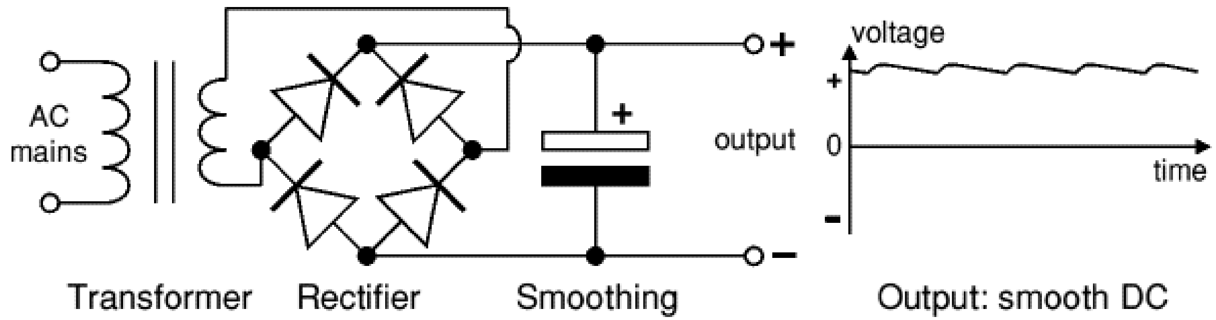
Produces full-wave varying DC.

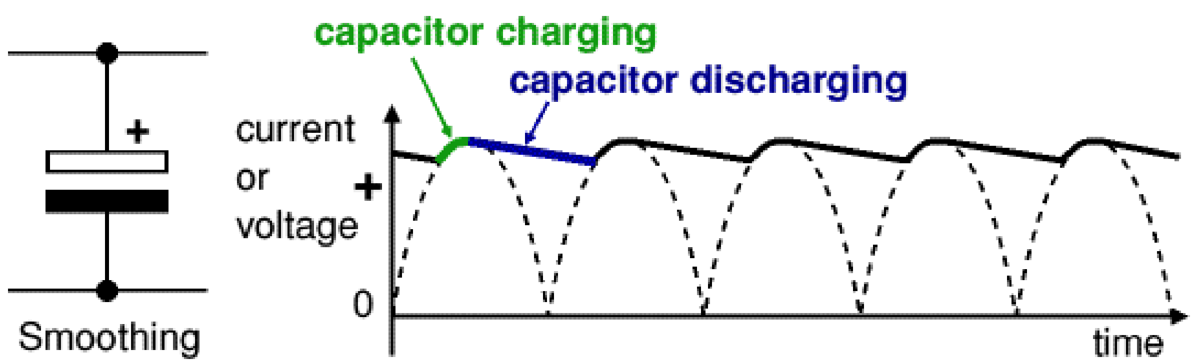




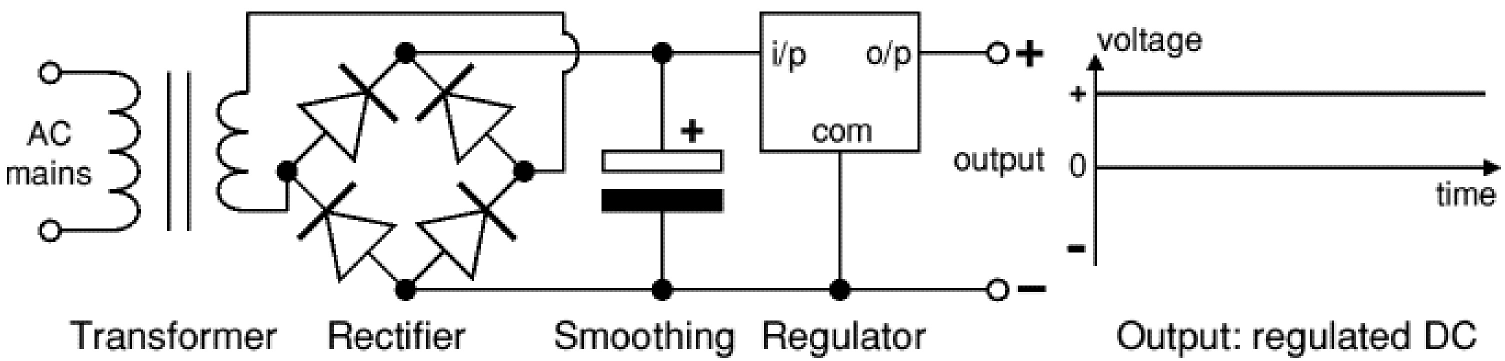
A bridge rectifier can be made using four individual diodes, but it is also available in special packages containing the four diodes required.

➢ Smoothing


AC
mains
+
output
voltage
+
0
time
-
Transformer
Rectifier
Smoothing
Output: smooth DC


capacitor charging
capacitor discharging
+
current
or
voltage
+
0
time
Smoothing

➢ Regulator



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

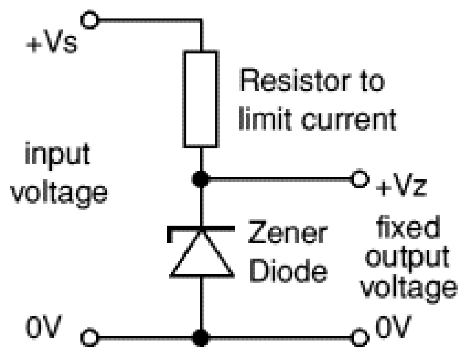
Zener diode regulator

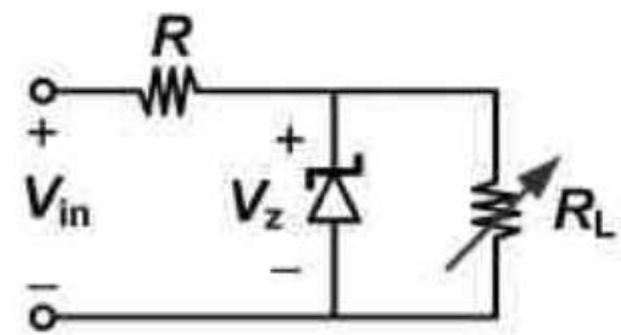
➢ Regulator

- 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 Vz and maximum power Pz (typically 400mW or 1.3W).





$$I = \frac{V_i - V_Z}{R}$$

$$I = I_L + I_Z$$

Voltage stabilization coefficients

$$\Delta V_o = \frac{\partial V_o}{\partial I_L}\Delta I_L + \frac{\partial V_o}{\partial V_i}\Delta V_i + \frac{\partial V_o}{\partial T}\Delta T = S_I\,\Delta I_L + S_V\,\Delta V_i + S_T\,\Delta T$$

$$S_I = \left(\frac{\partial V_o}{\partial I_L}\right)\Bigg|_{\substack{V_i = cte \\ T = cte}}$$

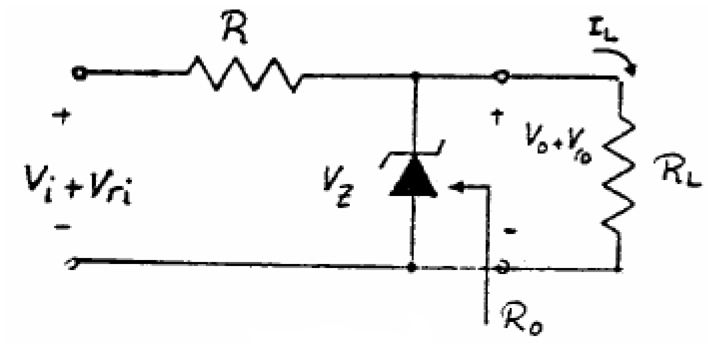
$$S_V = \left(\frac{\partial V_o}{\partial V_i}\right)\Bigg|_{\substack{I_L = cte \\ T = cte}}$$

$$S_T = \left(\frac{\partial V_o}{\partial T}\right)\Bigg|_{\substack{I_L = cte \\ V_i = cte}}$$

Voltage stabilization coefficients

- **Voltage stabilization coefficients**

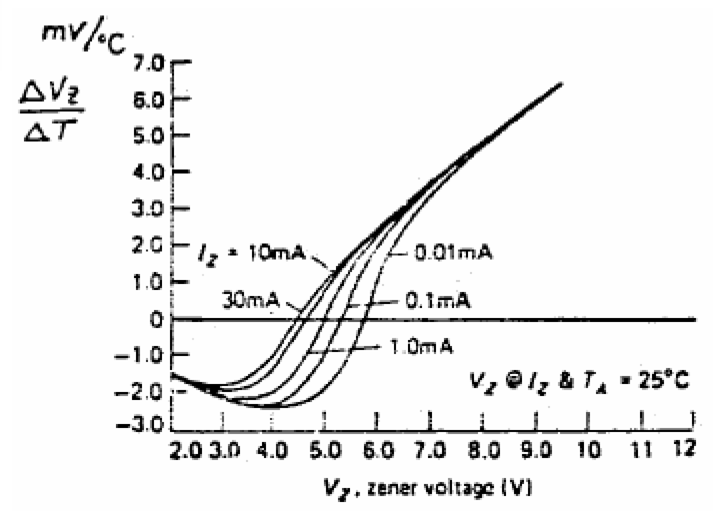
  - Zener diode regulator



$$S_I = \left(\frac{\partial V_o}{\partial I_L}\right)\Bigg|_{\substack{V_i = ct \\ T = ct}} = R_o = r_Z \| R$$

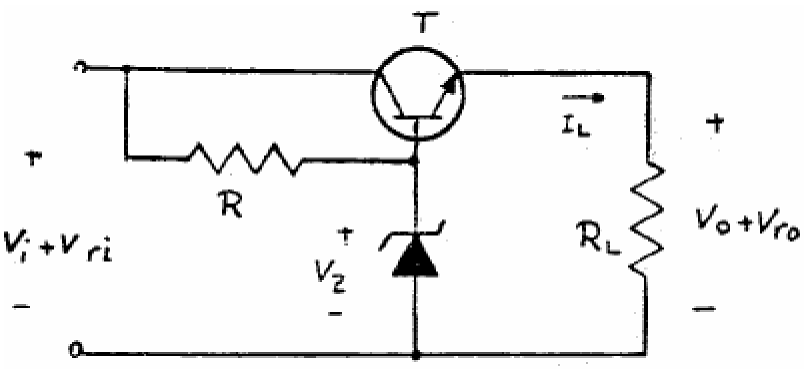
$$S_V = \frac{v_{ro}}{v_{ri}} = \frac{r_Z \| R_L}{r_Z \| R_L + R} \Rightarrow \boxed{S_V \simeq \frac{r_Z}{r_Z + R}}$$

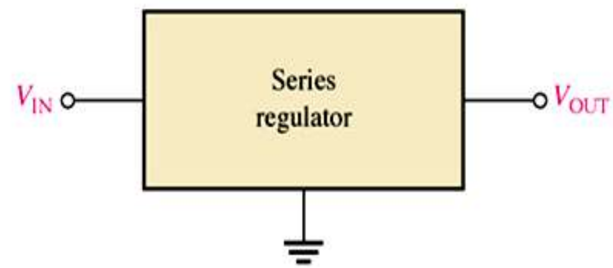
$$S_T = \left(\frac{\partial V_o}{\partial T}\right)\Bigg|_{\substack{V_i = ct \\ I_L = ct}} = \frac{\Delta V_Z}{\Delta T}$$



Basic Series Regulators

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





(a)

$$S_I = \left(\frac{\partial V_o}{\partial I_L}\right)\Bigg|_{\substack{V_i = cte \\ T = cte}} = \frac{R \| r_Z + h_{ie}}{1+\beta} \qquad S_I \simeq \frac{h_{ie}}{1+\beta} \simeq \frac{\beta}{\beta+1}\frac{V_T}{I_L} \simeq \frac{V_T}{I_L}$$

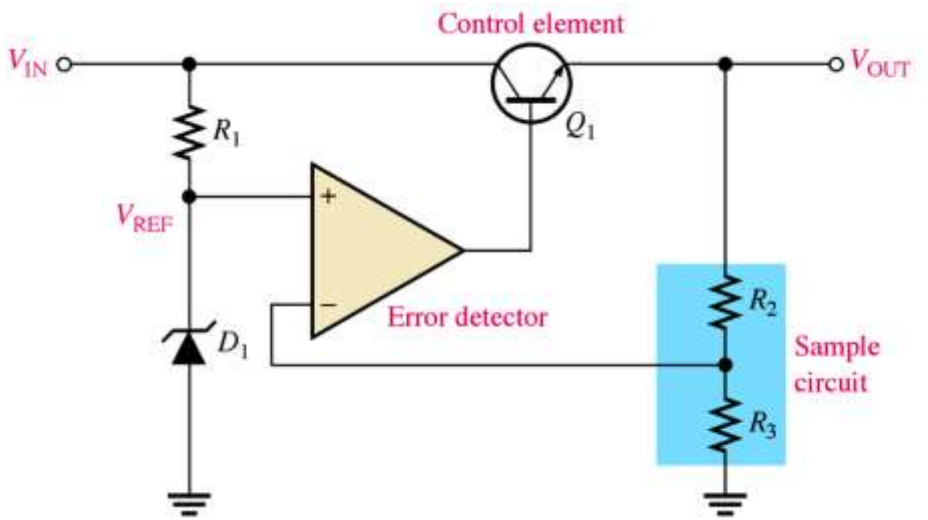
$$S_V = \left(\frac{\partial V_o}{\partial V_i}\right)\Bigg|_{\substack{I_L = cte \\ T = cte}} = \frac{\partial V_o}{\partial V_Z}\frac{\partial V_Z}{\partial V_i} = \frac{(1+\beta)R_L}{h_{ie} + (1+\beta)R_L} \times \frac{r_Z \| (h_{ie} + (1+\beta)R_L)}{r_Z \| [h_{ie} + (1+\beta)R_L] + R} \simeq \frac{r_Z}{r_Z + R}$$

$$S_T = \left(\frac{\partial V_o}{\partial T}\right)\Bigg|_{\substack{V_i = cte \\ I_L = cte}} = \frac{\partial (V_Z - V_{BE})}{\partial T} = \frac{\partial V_Z}{\partial T} - \frac{\partial V_{BE}}{\partial T}$$

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.

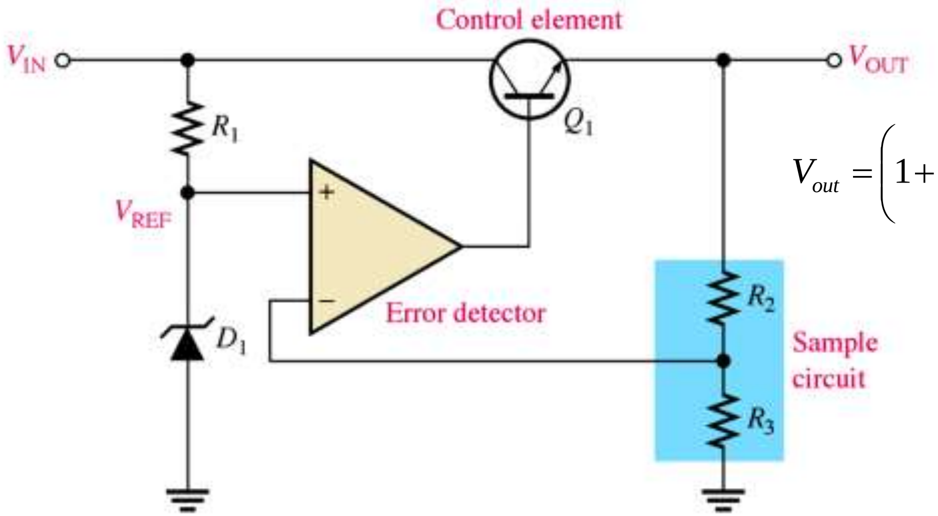


$$V_{out} = \left(1 + \frac{R_2}{R_3}\right) V_{REF}$$

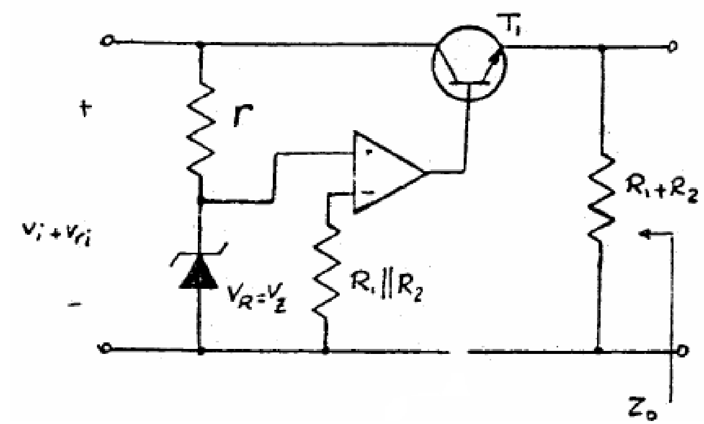
$$V_o' = \left(V_Z - \frac{R_2}{R_1+R_2} V_o\right) A_d \quad , \quad V_o = v_o' + V_{BE}$$

$$v_o - V_{BE} = \left(V_Z - \frac{R_2}{R_1+R_2} V_o\right) A_d \Rightarrow V_o = \frac{A_d V_Z}{1 + \frac{A_d R_2}{R_1+R_2}} + \frac{V_{BE}}{1 + \frac{A_d R_2}{R_1+R_2}} \xrightarrow{A_d \gg 1} v_o \simeq \left(1 + \frac{R_1}{R_2}\right) V_Z$$

Basic Series Regulators



$$V_{out} = \left(1 + \frac{R_2}{R_3}\right) V_{REF}$$



$$S_I = Z_{out} = \frac{Z_o}{1 + af} = \frac{(R_1 + R_2) \,\|\, \left(\frac{h_{ie_1} + R_o}{1 + \beta_1}\right)}{1 + A_d f} = \frac{(R_1 + R_2) \,\|\, \left(\frac{h_{ie_1} + R_o}{1 + \beta_1}\right)}{1 + A_d \left(\frac{R_1}{R_1 + R_2}\right)}$$

$$S_V = \frac{V_{ro}}{V_{ri}} = \frac{V_{ro}}{V_3} \frac{V_3}{V_{ri}} = \frac{A_d}{1 + A_d f} \times \frac{r_3}{r_3 + r} = \frac{A_d}{1 + A_d \left(\frac{R_1}{R_1 + R_2}\right)} \times \frac{r_3}{r_3 + r}$$

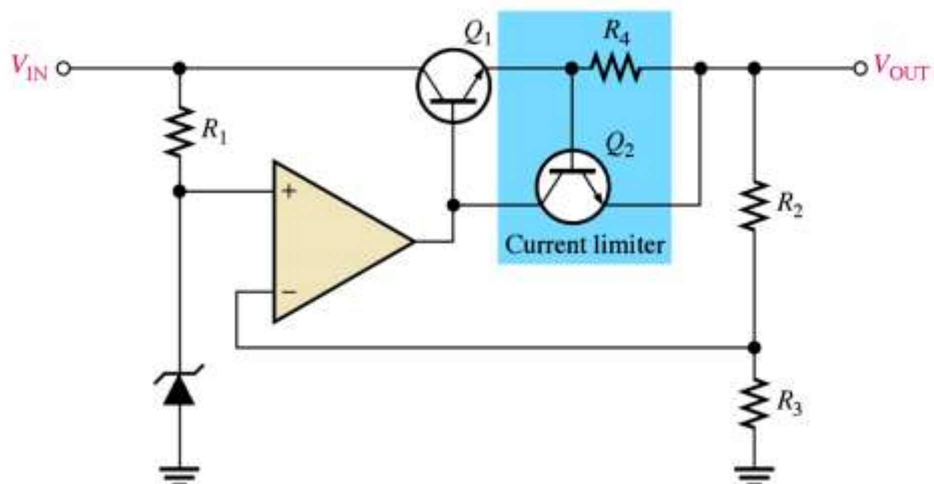
$$S_T = \frac{\partial V_o}{\partial T} = \left(1 + \frac{R_1}{R_2}\right) \frac{\partial V_3}{\partial T}$$

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.

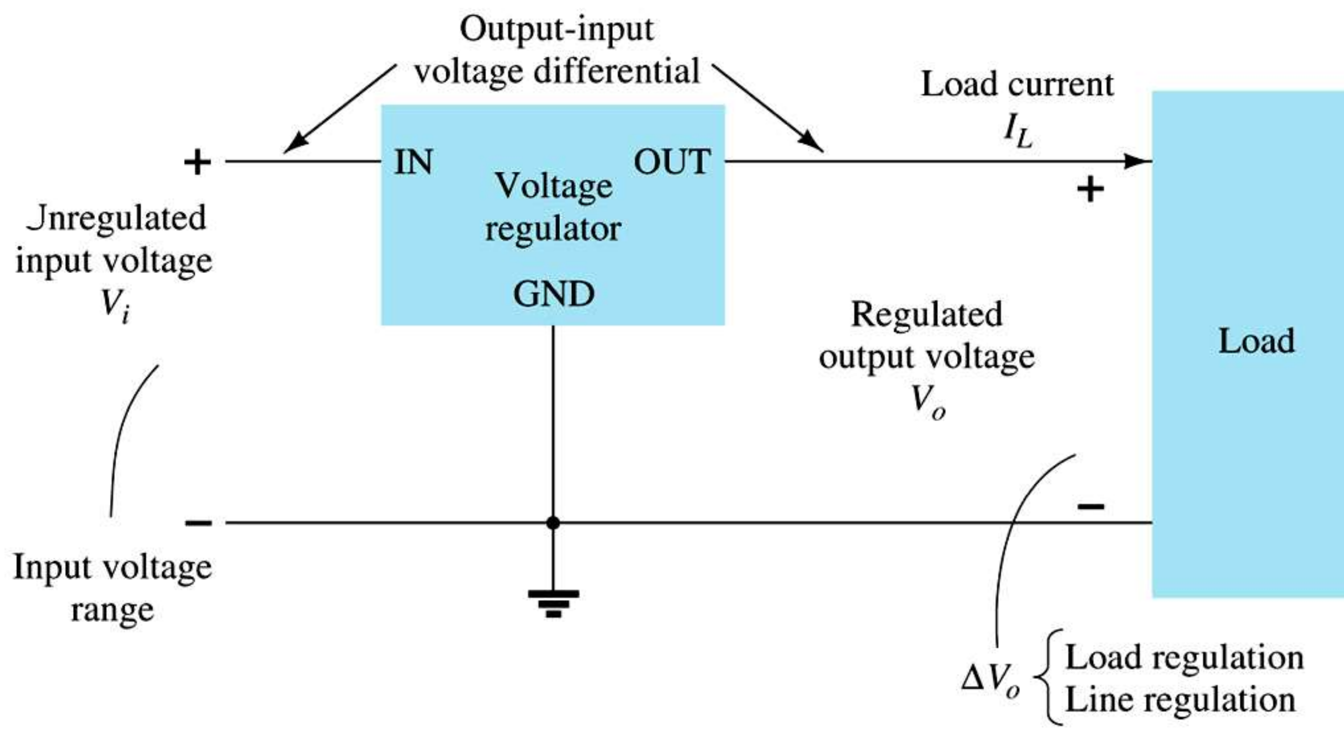


IC Regulators

- Regulation circuits in integrated circuit form are widely used.
- Their operation is no different but they are treated as a single device.
- These are generally three terminal devices that provide a positive or negative output.
- Some types are have variable voltage outputs.

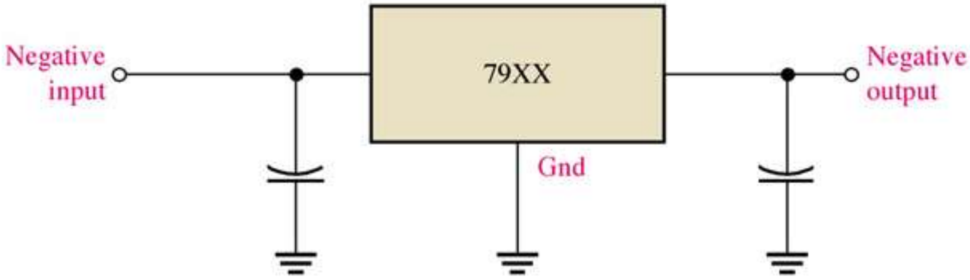
  Fixed IC regulators

  Adjustable IC regulators



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.



(a) Standard configuration

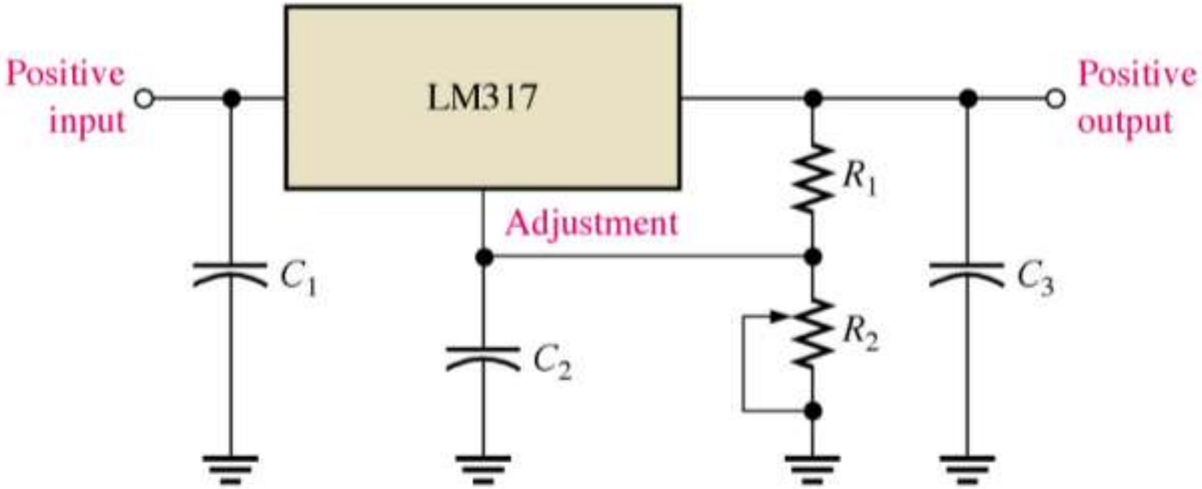
Type number	Output voltage
7905	–5.0 V
7905.2	–5.2 V
7906	–6.0 V
7908	–8.0 V
7912	–12.0 V
7915	–15.0 V
7918	–18.0 V
7924	–24.0 V

(b) The 7900 series

IC Regulators

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

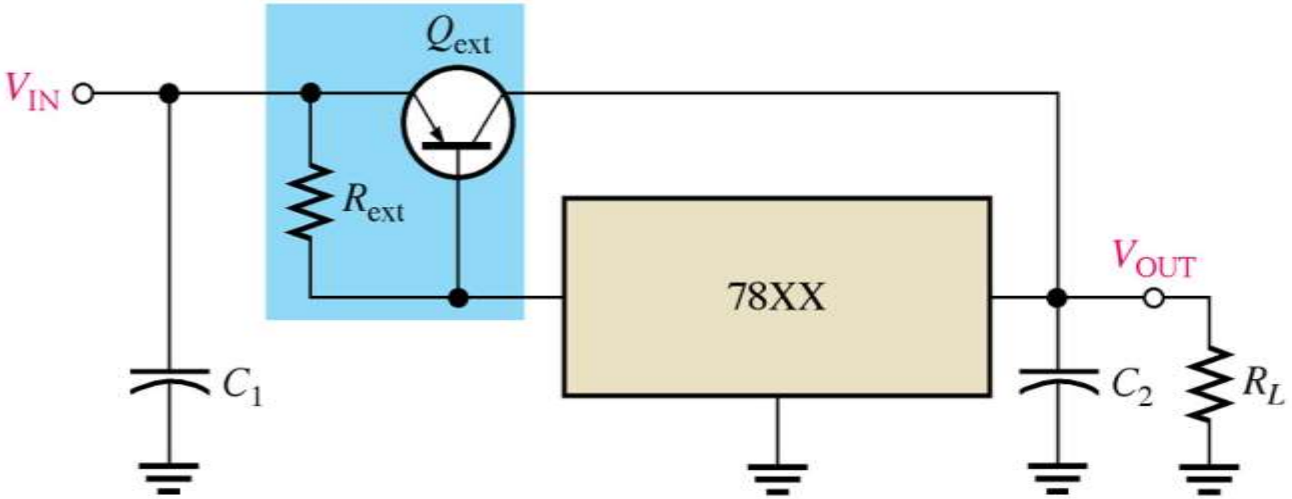
- They can be set to produce a specific voltage by way of an external reference voltage divider network.



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

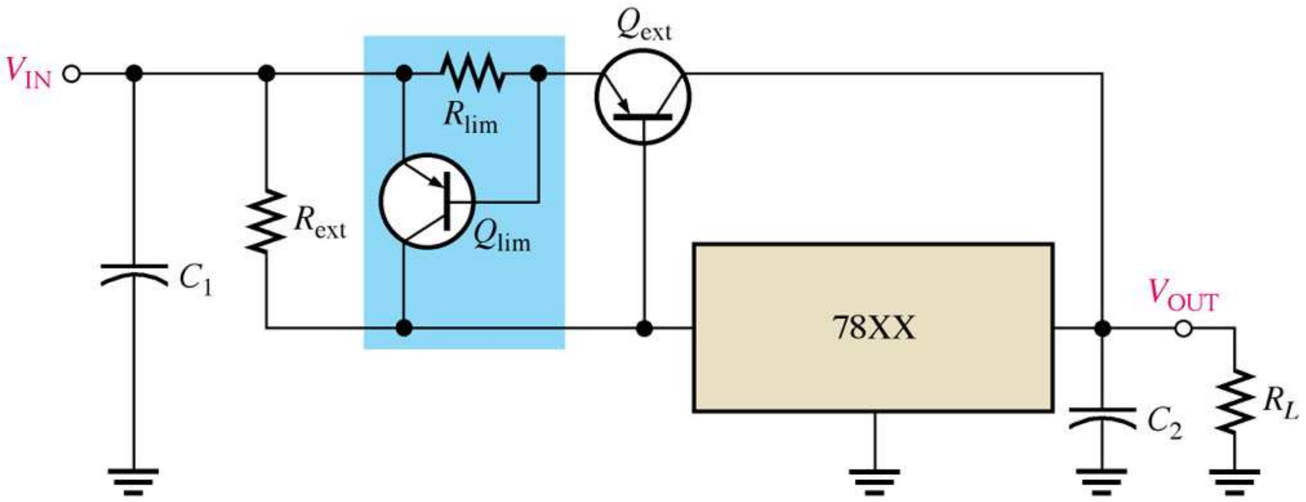
IC Regulators

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



IC Regulators

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



IC Regulators