Voltage References/Regulators

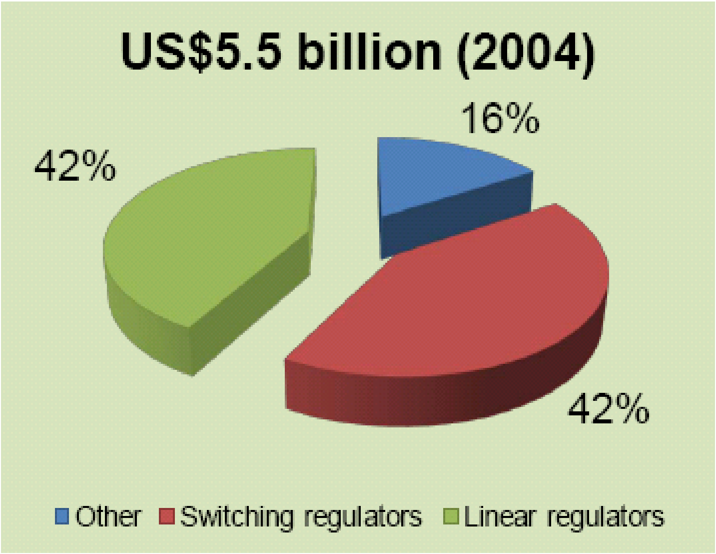
PART 1

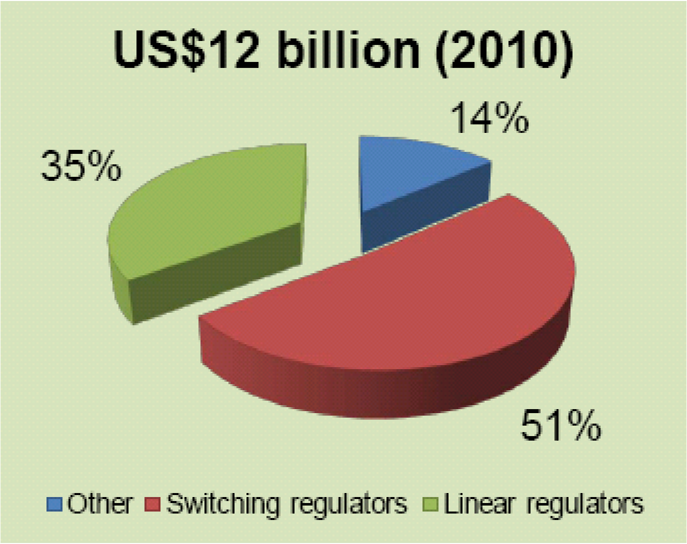
ECEN 457: Op-Amps and Applications
Analog & Mixed-Signal Center
Texas A&M University

Agenda

- Motivation
- Important Definitions

Voltage Regulator Market



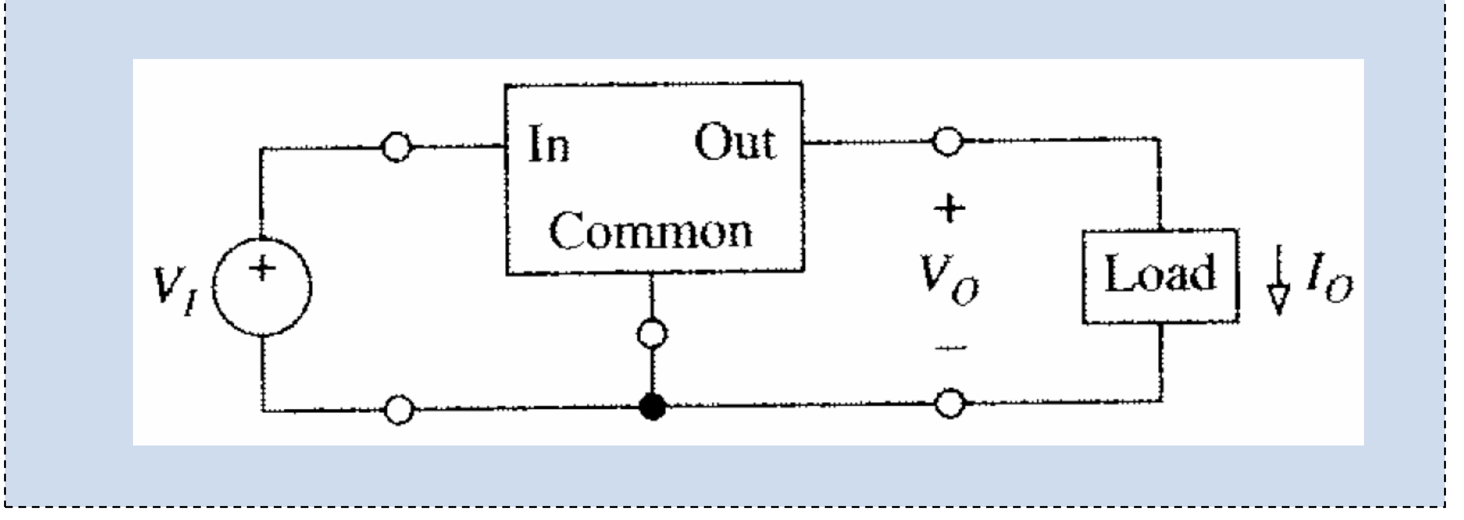


Major Companies:

- ✓ Texas Instruments
- ✓ STMicroelectronics
- ✓ Toshiba
- ✓ Maxim
- ✓ Linear Technologies

Voltage References/Regulators

- The function of a voltage reference/regulator:
  - Provide stable dc voltage V_o starting from a less stable voltage V_i



Basic connection of a voltage reference/regulator

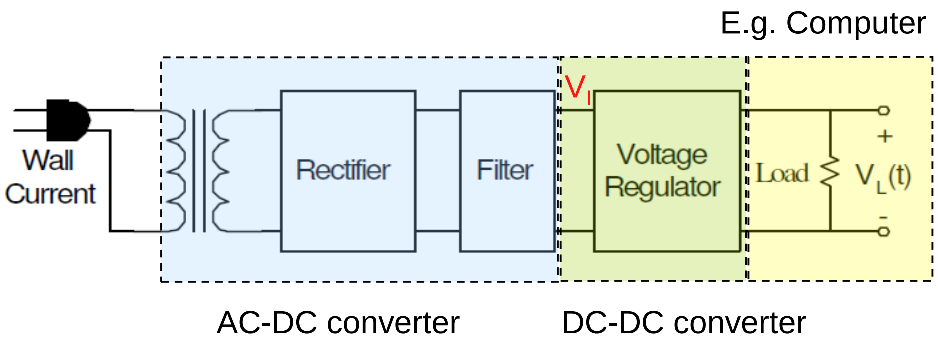
Voltage References

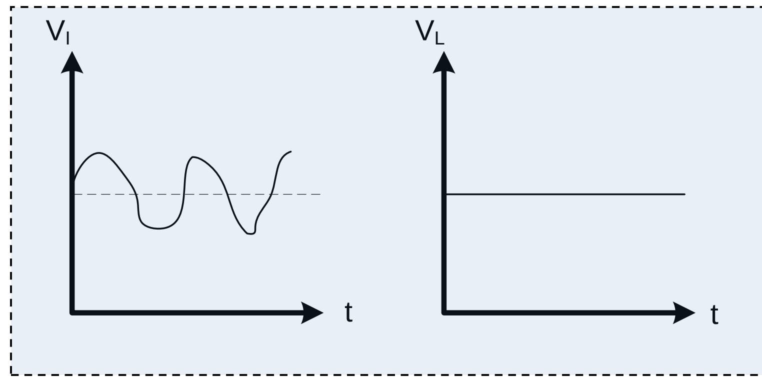
- **Voltage reference:**
  - Provides an even more stable V_o to serve as a standard for other circuits.
  - **Application:**
    - Digital multimeter: the full-scale accuracy is set by the internal voltage of suitable quality.

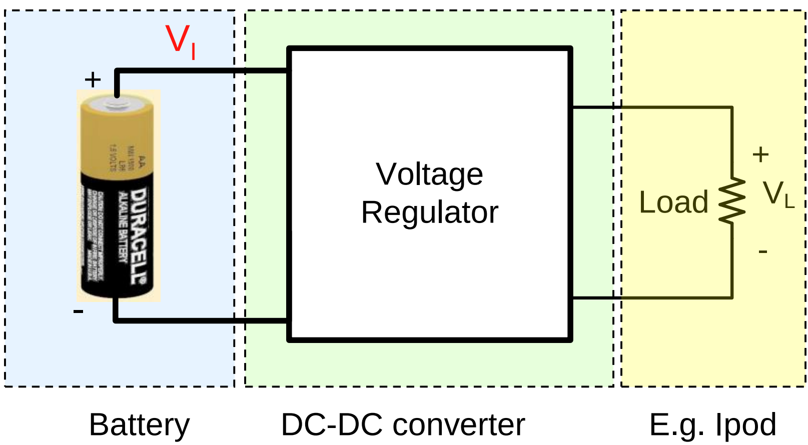
  - **Other applications:**
    - Power supplies
    - AD/DA converters
    - V-F / F-V converters
  - **Main requirements:**
    - Accuracy
    - Stability
  - **To minimize errors due to self-heating:**
    - Modest output-capabilities (few mA)

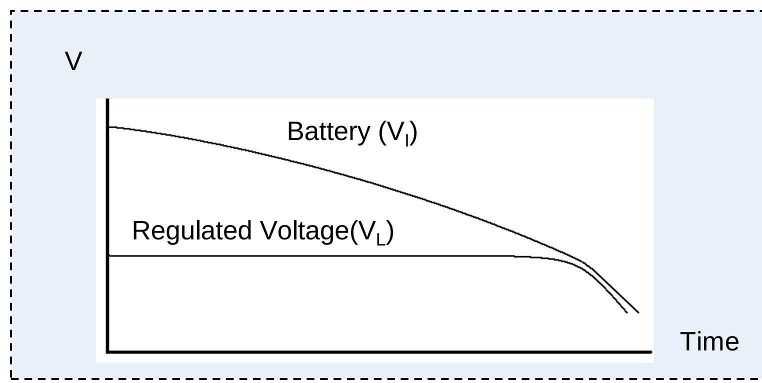
Voltage Regulators

- V_I is usually a poorly specified voltage







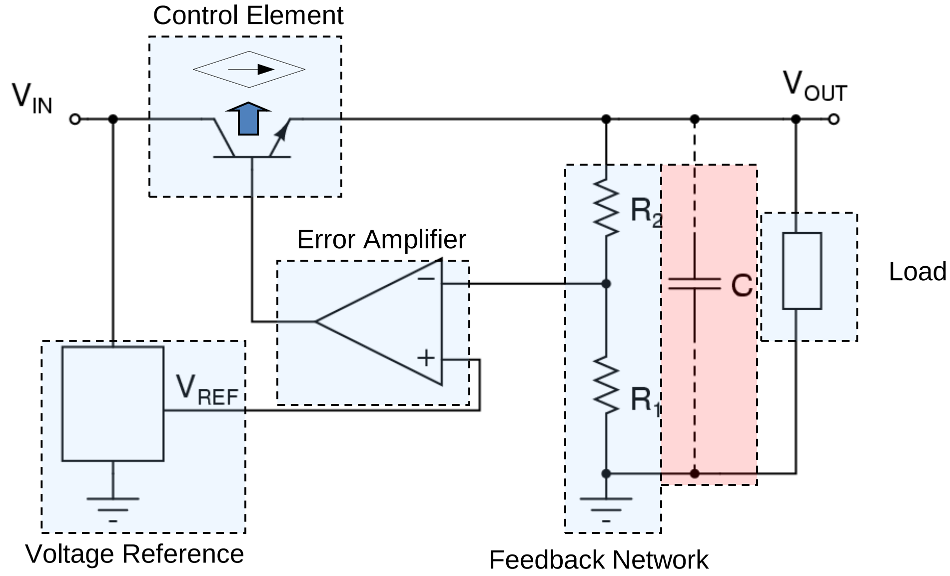


Requirements:

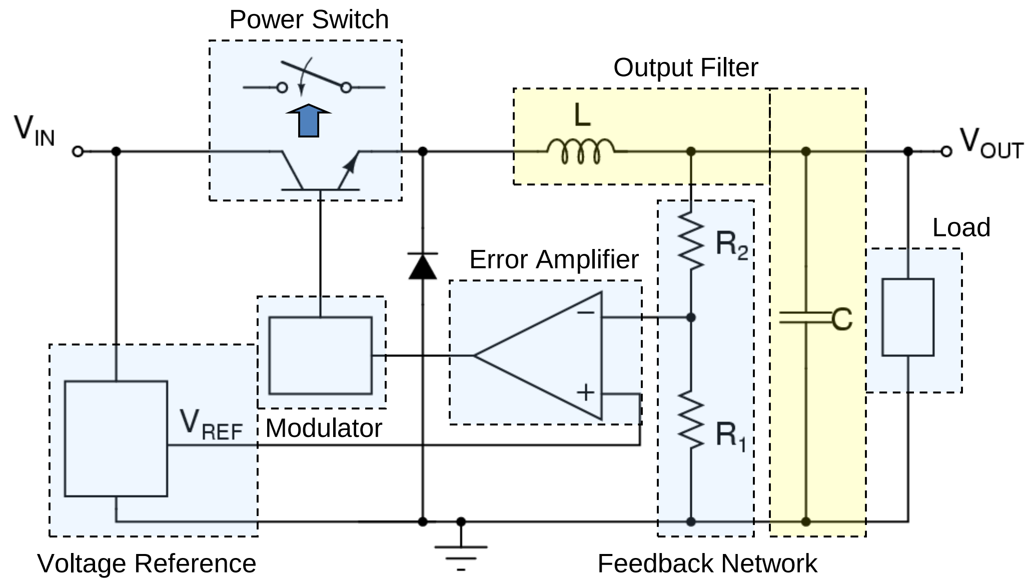
- Similar to voltage references but less stringent
- Output current capabilities are much higher (100mA-10A)

Voltage Regulators

- **Two Types:**
  - **Linear regulators**
    - Simple
    - Low noise
    - Poor Efficiency



  - **Switching regulators**
    - High efficiency
    - Output voltage can be:
      - » Negative
      - » Higher than V_I
    - Complex
    - Require inductors
    - Noisier

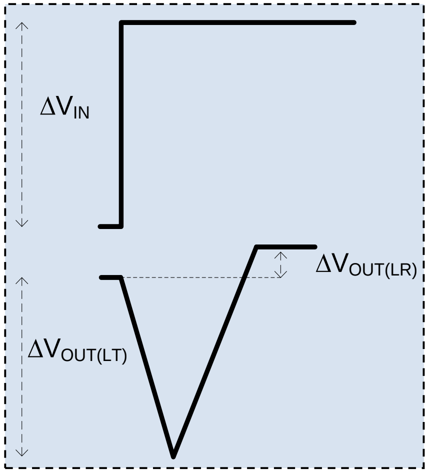


Important Definitions

- Line Regulation:

$$Line-regulation = \frac{\Delta V_o}{\Delta V_I}$$

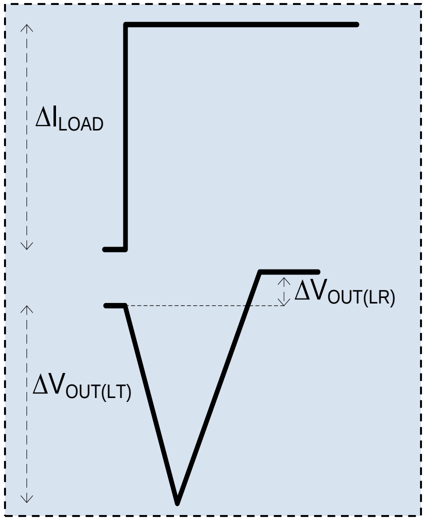
$$Line-regulation(\%) = \frac{\Delta V_o}{\Delta V_I} \cdot \frac{100}{V_o}$$



- Load Regulation:

$$Load-regulation = \frac{\Delta V_o}{\Delta I_o}$$

$$Load-regulation(\%) = 100\frac{\Delta V_o / V_o}{\Delta I_o}$$



More Definitions

- Ripple (power supply) rejection ratio (RRR) (PSR):

$$RRR_{dB} = 20\log_{10}\left(\frac{\Delta V_{ri}}{\Delta V_{ro}}\right)$$

- Dropout Voltage:
  - The minimum difference between V_I and V_o for which the circuit still operates properly.

Example 11.1

- The data sheets of the uA7805 5-V voltage regulator (Fairchild) indicate that V_o typically changes by 3mV when V_I is varied from 7 V to 25 V, and by 5 mV when I_o is varied from 0.25 A to 0.75 A. Moreover, RRR_{dB} = 78dB at 120 Hz.
  - Estimate the typical line and load regulation of this device. What is the output impedance of the regulator?

$$\frac{\Delta V_o}{\Delta V_I} = \frac{3\times 10^{-3}}{(25-7)} = 0.17 mV/V \qquad \frac{\Delta V_o}{\Delta V_I}(\%) = \frac{0.17 mV/V}{5V} x100 = 0.0033\%/V$$

$$\frac{\Delta V_o}{\Delta I_o} = \frac{5\times 10^{-3}}{(0.75-0.25)} = 10 mV/A$$

  - Estimate the amount of output ripple V_{ro} for every volt of V_{ri}.

$$V_{ro} = \frac{V_{ri}}{10^{(78/20)}} = 0.126\times 10^{-3}\times V_{ri}$$

For 1-V at 120Hz ripple at the input: $V_{ro} = 0.126\times 10^{-3}\times 1 = 126 mV$

More Definitions

- Thermal Coefficient of V_o:

$$TC(V_o) = \frac{\Delta V_o}{\Delta T}$$

$$TC(V_o)(\%) = \frac{\Delta V_o}{\Delta T} \cdot \frac{100}{V_o}$$

$$TC(V_o) - in - ppm = \frac{\Delta V_o}{\Delta T} \cdot \frac{10^6}{V_o}$$

ppm = parts per million

Example 11.2

- The data sheets of the REF101KM 10-V precision voltage reference (Burr-Brown) give a typical line regulation of 0.001%/V, a typical load regulation of 0.001%/mA , and a maximum TC of 1 ppm/C. Find the variation in Vo brought about by: (a) a change of V_I from 13.5 V to 35V; (b) a $\pm$10mA change in I_o; (c) a temperature change from 0 C to 70 C.
  - (a)

$$0.001\%/V = \frac{100}{(35-13.5)}\left(\frac{\Delta V_o}{10}\right)$$

$$\Delta V_o = 2.15mV$$

  - (b)

$$0.001\%/mA = \frac{100}{(\pm 10mA)}\left(\frac{\Delta V_o}{10}\right)$$

$$\Delta V_o = \pm 1mV$$

  - (c)

$$1ppm/C = \frac{10^6}{(70^\circ C)}\left(\frac{\Delta V_o}{10}\right)$$

$$\Delta V_o = 0.7mV$$

More Definitions

- Efficiency

$$\eta \equiv \frac{P_{OUT}}{P_{IN}} = \frac{V_{OUT} I_{OUT}}{V_{IN}(I_{Q} + I_{OUT})}$$

If $I_Q << I_{LOAD}$ $$\eta \approx \frac{V_{OUT}}{V_{IN}} = \frac{V_{IN} - V_{DO}}{V_{IN}} = 1 - \frac{V_{DO}}{V_{IN}}$$

Example: A 3.3 V linear regulator with 3.7 V < V_{IN} < 4.7 V, I_Q = 100 µA 1 mA < I_o < 100 mA. What is the minimum drop-out voltage? What is the maximum efficiency? What is the minimum efficiency?

$$\eta_{\max} = \frac{100mA \times 3.3}{(100mA + 100\mu A) \times 3.7} \times 100 = 89.1\%$$

or

$$\eta_{\max} \approx \left(1 - \frac{0.4V}{3.7}\right) \times 100 = 89.2\%$$

$$\eta_{\min} = \frac{1mA \times 3.3}{(1mA + 100\mu A) \times 4.7} \times 100 \cong 63.8\%$$

Next Class

- Bandgap voltage reference
- Voltage regulators
  - Shunt voltage regulators
  - Linear regulators