Op. Feedback and Op. Amps

- **Operational Feedback**
  - **Current versus voltage feedback**
- **Op Amp**
  - **Properties**
  - **Common Op-Amp-based setups**

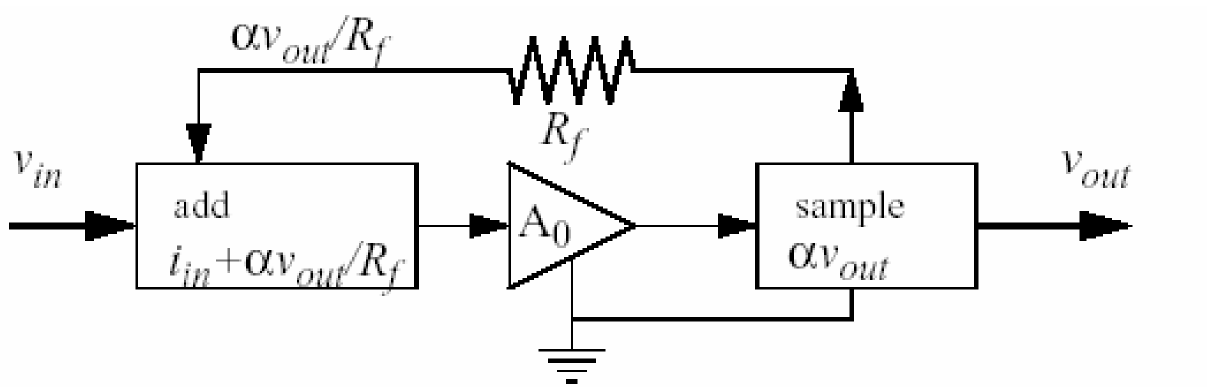
- Op-Amps.

Type of feedback

- Convention for voltage and current feedback:

Sample output	Type of input	Name
Voltage	Voltage	Voltage feedback
Current	Voltage	Current feedback
Voltage	Current	Operational voltage feedback
Current	Current	Operational current feedback

Operational Voltage feedback



- Input impedance of A0 very large, no current can flow into the amplifier
- Input must cancel the feedback

$$i_{in} = -\frac{\alpha V_{out}}{R_f}$$

- Input resistor sets V_{in}

$$i_{in} = \frac{v_{in} - v_A}{R_i}$$

- Input current must all go through the feedback resistor

$$i_{in} = \frac{v_A - v_{out}}{R_f}$$

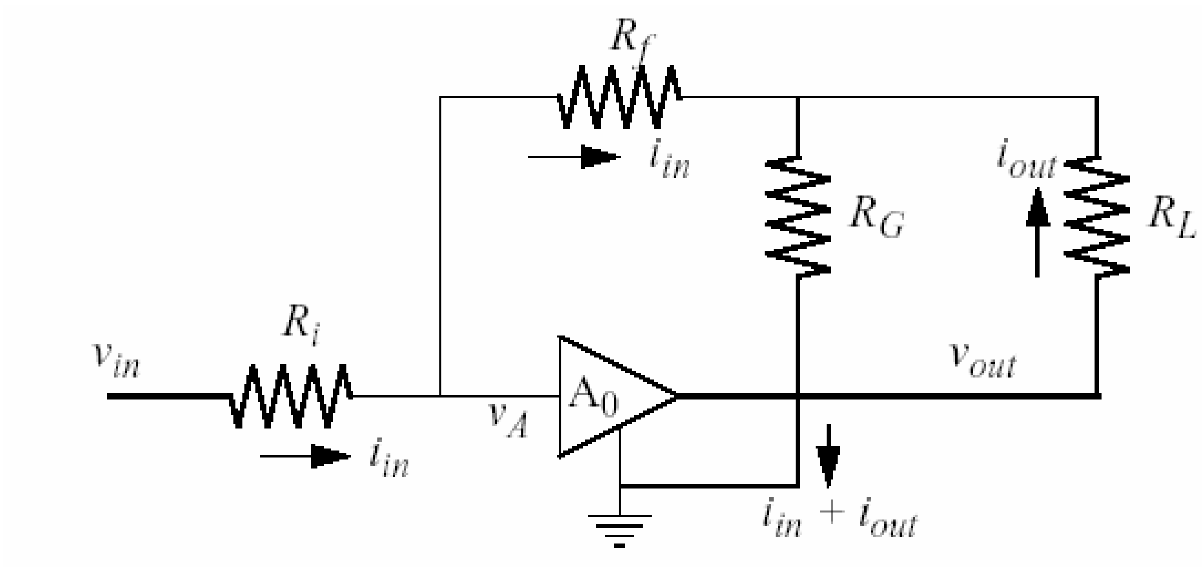
- Amplifier gain is

$$\frac{v_{in} - v_{out}/A_0}{R_i} = \frac{v_{out}/A_0 - v_{out}}{R_f}$$

- So

$$A = \frac{v_{out}}{v_{in}} = \frac{1}{(R_i/R_f)(1/A_0 - 1) + 1/A_0}$$

Operational Current feedback

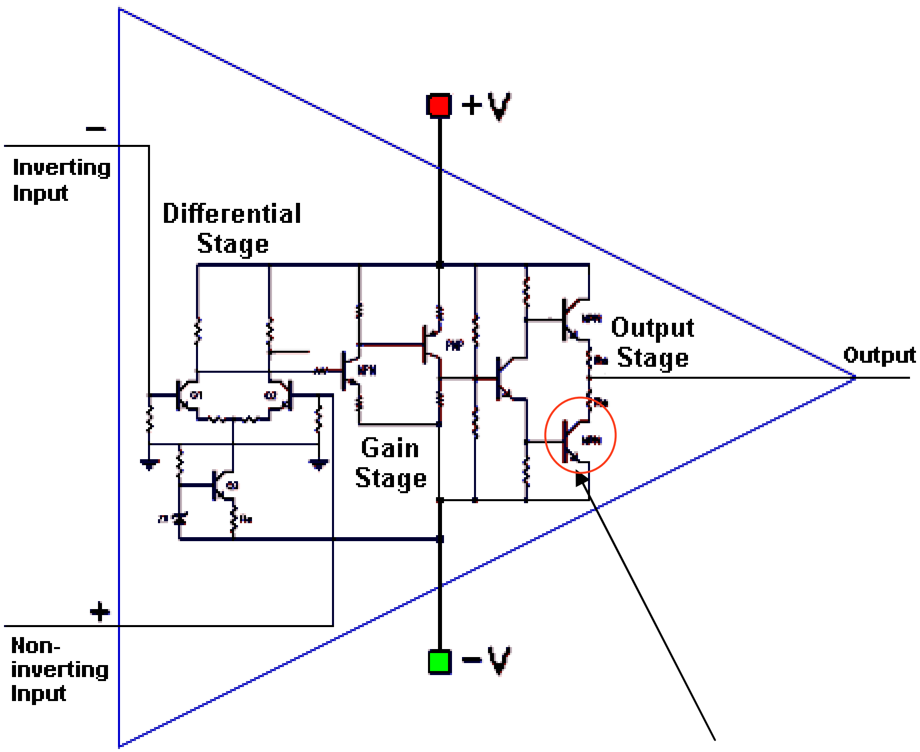


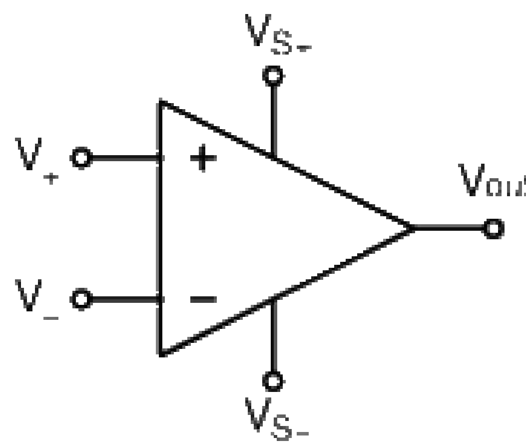
- Resistor is used to sample the output current

$$i_{in} R_f = -(i_{in} + i_{out}) R_G$$

$$i_{out} / i_{in} = -(R_f + R_G) / R_G$$

Operational Amplifier (Op. Amp.)





Transistors (we will learn about these later)

Ideal Operational Amplifier

- **The ideal op-amp is characterized by 7 properties**
  - Knowledge of these properties is sufficient to design and analyze a large number of useful circuits
- **Basic op-amp properties**
  - Infinite open-loop voltage gain
  - Infinite input impedance
  - Zero output impedance
  - Zero noise contribution
  - Zero DC output offset
  - Infinite bandwidth
  - Differential inputs that "stick together"

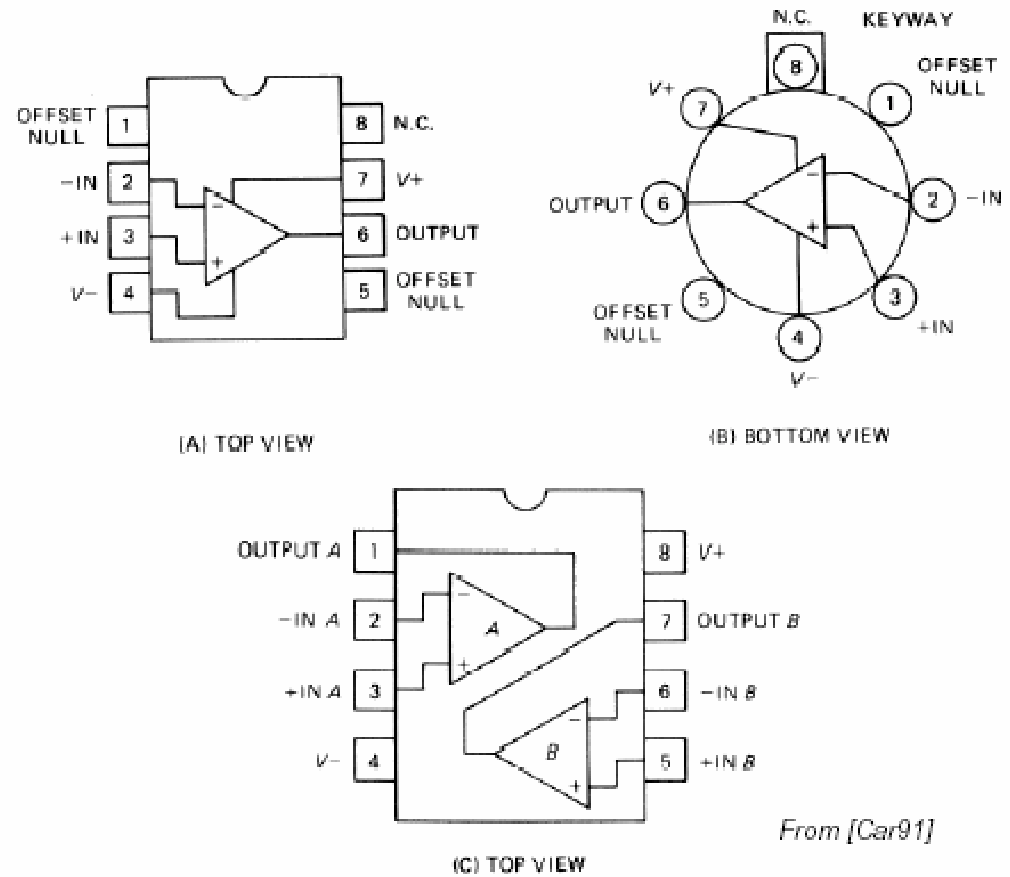


Fig. 12-6 Packaging for industry standard op-amp (741) in (A) DIP and (B) metal can packages; (C) dual op-amp such as 1458 device.

Ideal Op. Amp. Properties

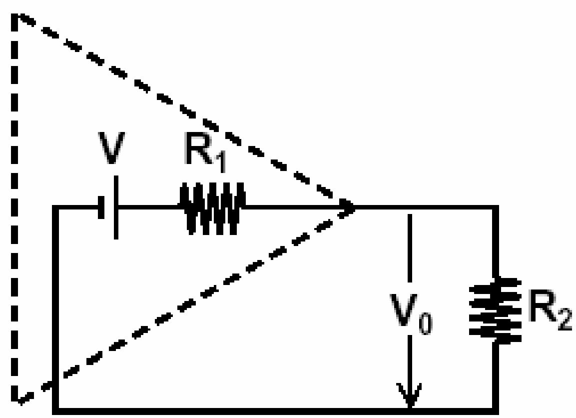
- **Property No.1: Infinite Open-Loop Gain**
  - Open-Loop Gain A_{vol} is the gain of the op-amp without positive or negative feedback
  - In the ideal op-amp A_{vol} is infinite
    - Typical values range from 20,000 to 200,000 in real devices
- **Property No.2: Infinite Input Impedance**
  - Input impedance is the ratio of input voltage to input current

$$Z_{in} = \frac{V_{in}}{I_{in}}$$

  - When Z_{in} is infinite, the input current $I_{in}=0$
    - High-grade op-amps can have input impedance in the TΩ range
      - Some low-grade op-amps, on the other hand, can have mA input currents

Ideal Op. Amp. Properties

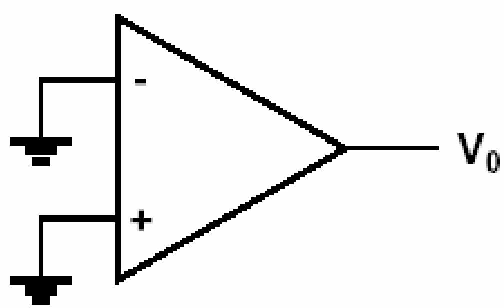
- **Property No. 3: Zero Output Impedance**
  - The ideal op-amp acts as a perfect internal voltage source with no internal resistance
    - This internal resistance is in series with the load, reducing the output voltage available to the load
    - Real op-amps have output-impedance in the 100-20Ω range
  - Example



$$V_0 = \frac{VR_2}{R_1 + R_2}$$

Ideal Op. Amp. Properties

- **Property No.4: Zero Noise Contribution**
  - In the ideal op-amp, zero noise voltage is produced internally
    - This is, any noise at the output must have been at the input as well
  - Practical op-amp are affected by several noise sources, such as resistive and semiconductor noise
    - These effects can have considerable effects in low signal-level applications
- **Property No. 5: Zero output Offset**
  - The output offset is the output voltage of an amplifier when both inputs are grounded
  - The ideal op-amp has zero output offset, but real op-amps have some amount of output offset voltage



Ideal Op. Amp. Properties

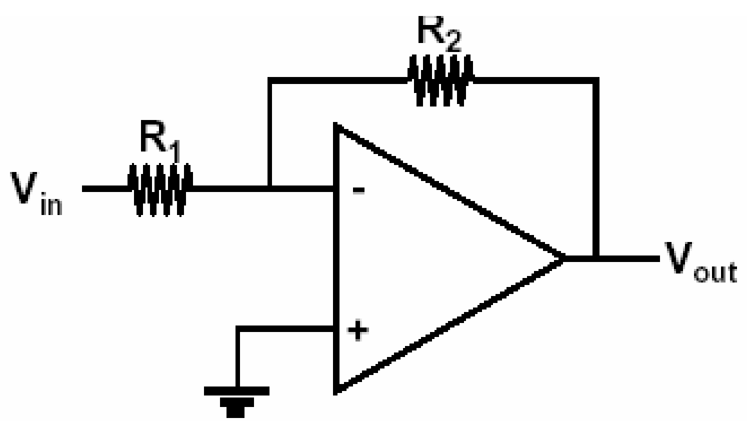
- **Property No. 6: Infinite Bandwidth**
  - The ideal op-amp will amplify all signals from DC to the highest AC frequencies
  - In real opamps, the bandwidth is rather limited
    - This limitation is specified by the Gain-Bandwidth product (GB), which is equal to the frequency where the amplifier gain becomes unity
    - Some op-amps, such as the 741 family, have very limited bandwidth of up to a few KHz
- **Property No. 7: Differential Inputs Stick Together**
  - In the ideal op-amp, a voltage applied to one input also appears at the other input

Op. Amps Rules: The Golden Rules

- **(I) The output attempts to do whatever is necessary to make the voltage difference between the two inputs zero.**

- **(II) The inputs draw no current**

- **This golden rules obscure what is really going on but they greatly**
  simplify the analysis of circuit based on Op. Amps.



1. (+) is grounded so Rule **I** implies (-) is also grounded,
2. So the voltage across R_2 is V_{out} and the voltage across R_1 is V_{in}
3. So rule **II** implies:

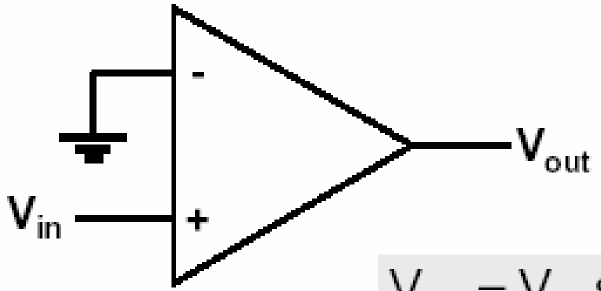
$$V_{out}/R_2 = -V_{in}/R_1$$

Or gain is

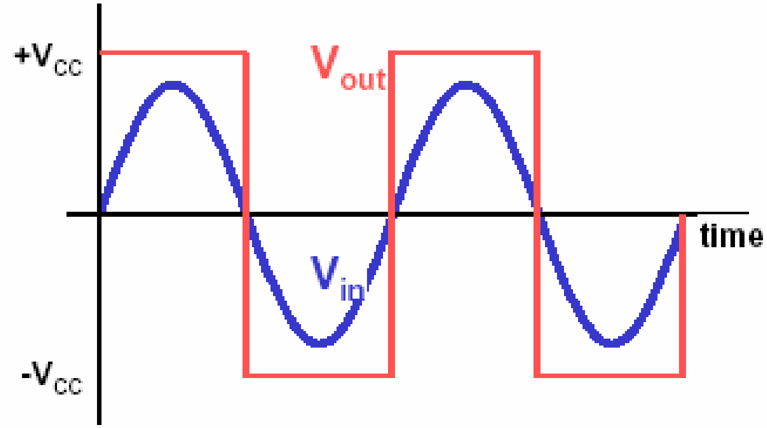
$$A = -R_2/R_1$$

Examples of Op. Amp. applications

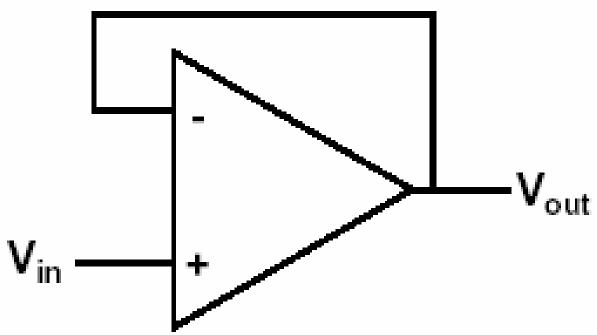
- **Voltage comparator**



$$V_{out} = V_{CC}\,\mathrm{sign}(V_{in})$$



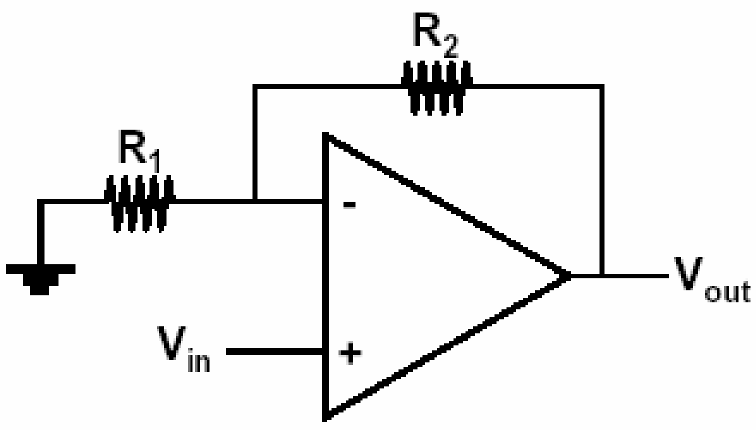
- **Voltage follower**
  - What is the main use of this circuit?
    - Buffering



$$V_{out} = V_{in}$$

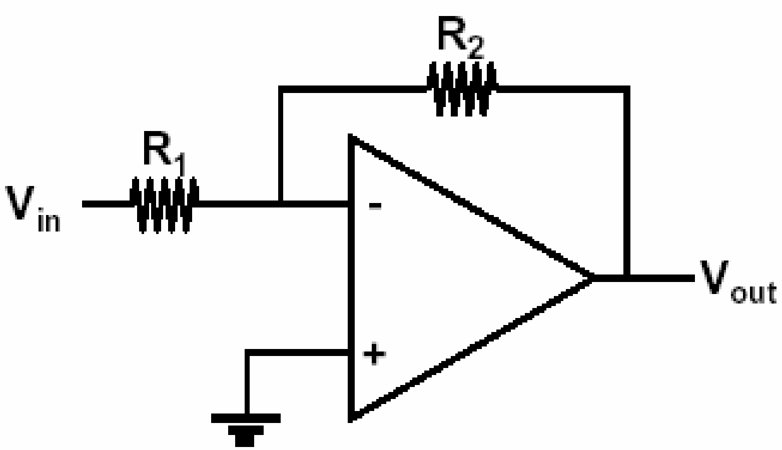
Examples of Op. Amp. applications

- **Non-inverting amplifier**



$$V_{out} = \left(1 + \frac{R_2}{R_1}\right) V_{in}$$

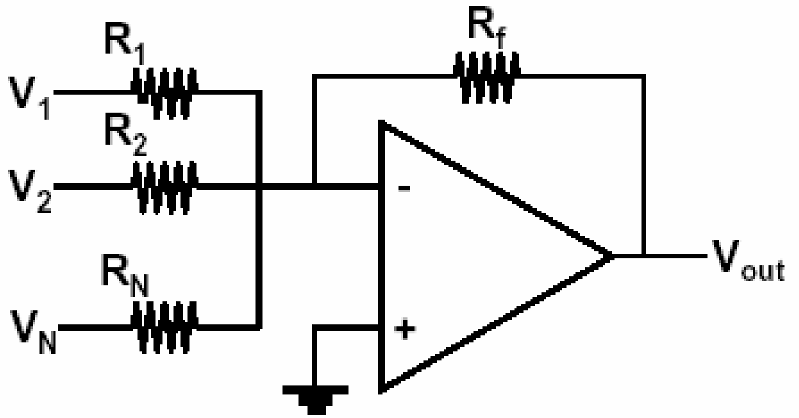
- **Inverting amplifier**



$$V_{out} = -\frac{R_2}{R_1} V_{in}$$

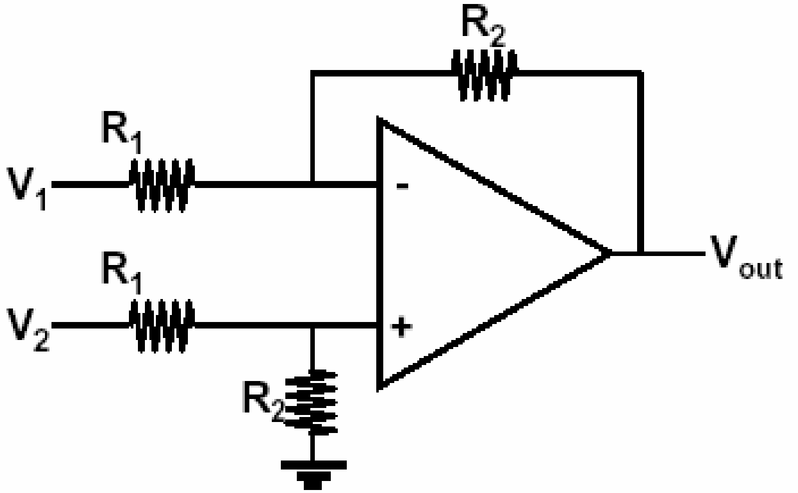
Examples of Op. Amp. applications

- **Summing amplifier**



$$V_{out} = -\left(V_1 \frac{R_f}{R_1} + V_2 \frac{R_f}{R_2} + \cdots + V_N \frac{R_f}{R_N} \right)$$

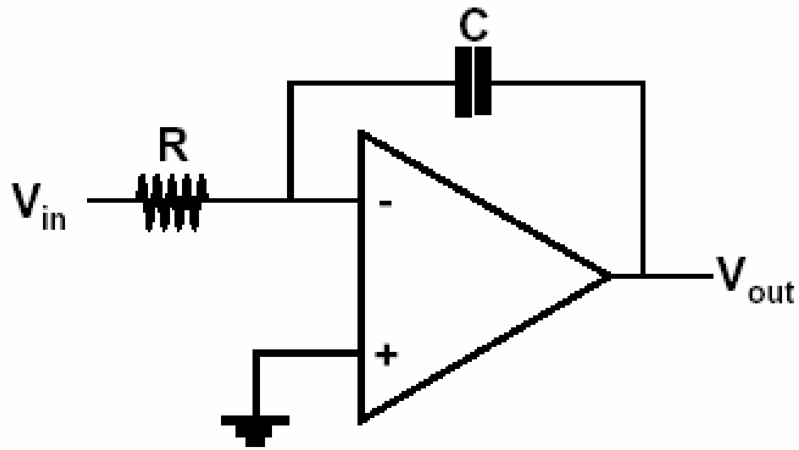
- **Differential amplifier**



$$V_{out} = \frac{R_2}{R_1}(V_2 - V_1)$$

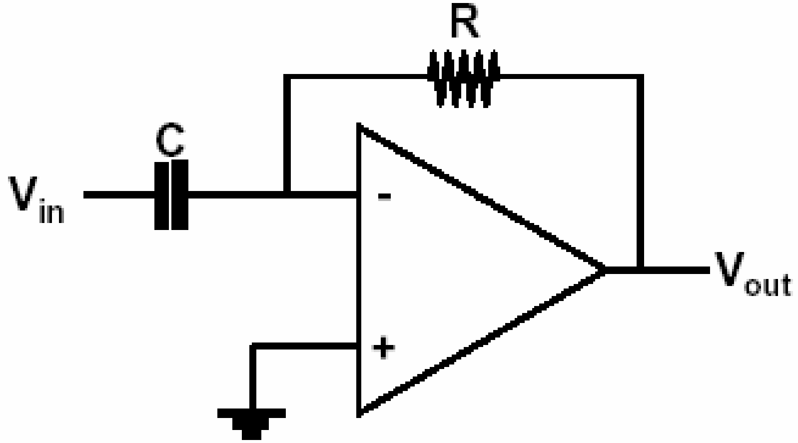
Examples of Op. Amp. applications

- **Integrating amplifier**



$$V_{out} = -\frac{1}{j\omega CR} V_{in} = -\frac{1}{RC}\int V_{in} dt$$

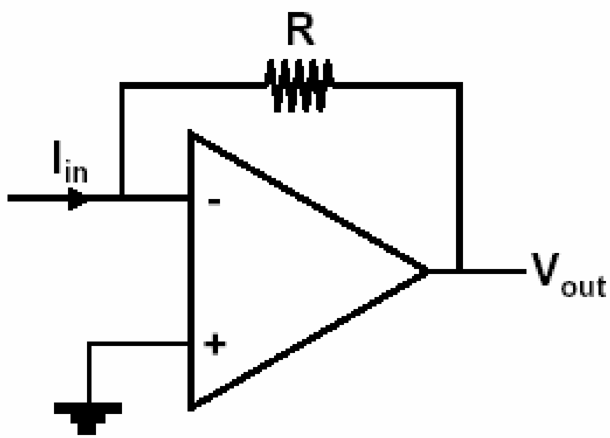
- **Differentiating amplifier**



$$V_{out} = -\frac{R}{\frac{1}{j\omega C}} V_{in} = -RC\frac{dV_{in}}{dt}$$

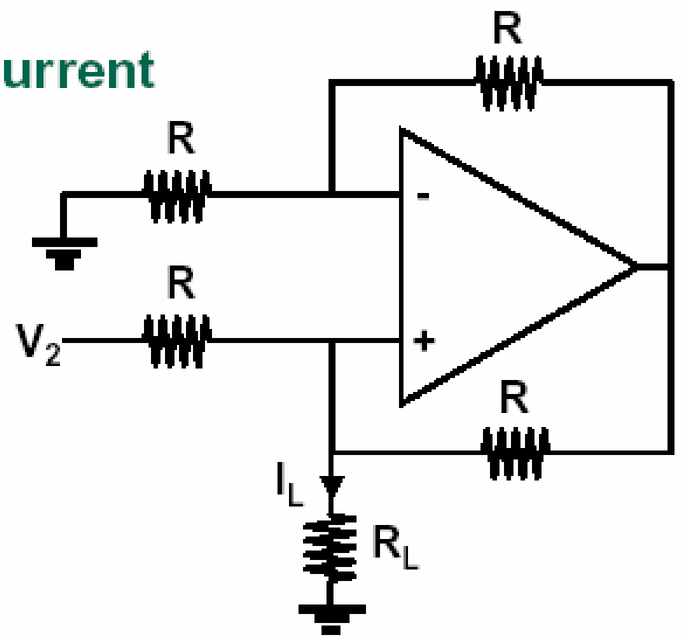
Examples of Op. Amp. applications

- **Current-to-voltage**



$$V_{out} = -I_{in}R$$

- **Voltage to current**



$$I_L = \frac{V_{in}}{R}$$