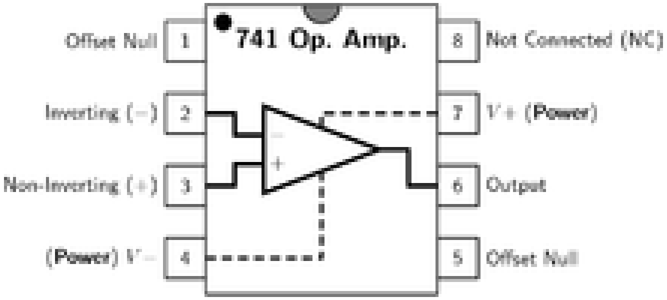
Lecture-1

Basics of Op-amp , Operation of Op-Amp

What is an Op-Amp? – The Surface

- An Operational Amplifier (Op-Amp) is an integrated circuit that uses external voltage to amplify the input through a very high gain.
- We recognize an Op-Amp as a mass-produced component found in countless electronics.

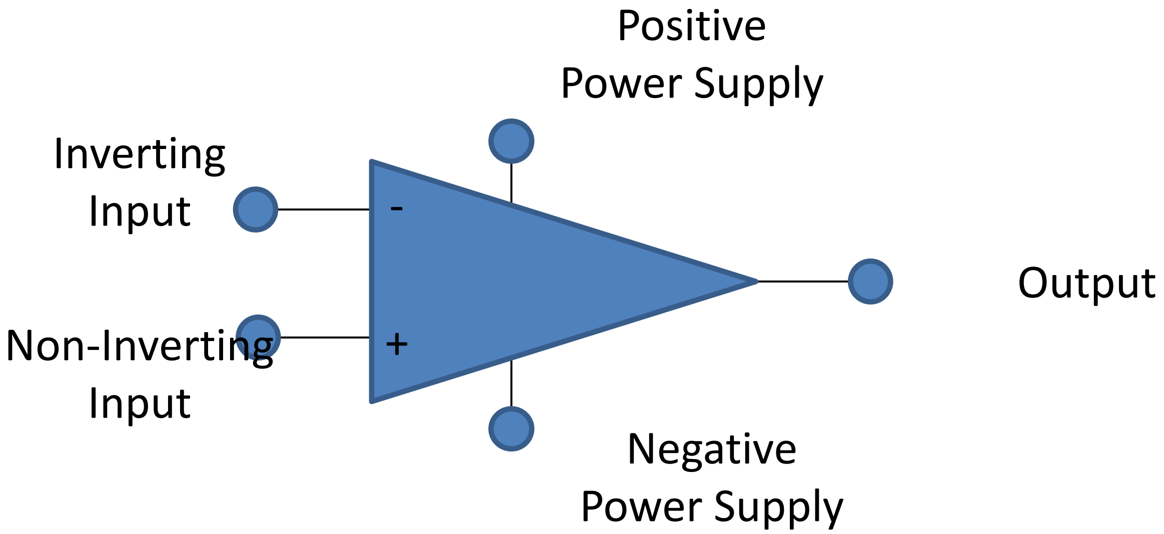
What an Op-Amp looks like to a lay-person



What an Op-Amp looks like to an engineer

What is an Op-Amp? – The Inside

- The actual count varies, but an Op-Amp contains several Transistors, Resistors, and a few Capacitors and Diodes.
- For simplicity, an Op-Amp is often depicted as this:



Mathematics of the Op-Amp

- The gain of the Op-Amp itself is calculated as:

$$G = V_{out}/(V_+ - V_-)$$

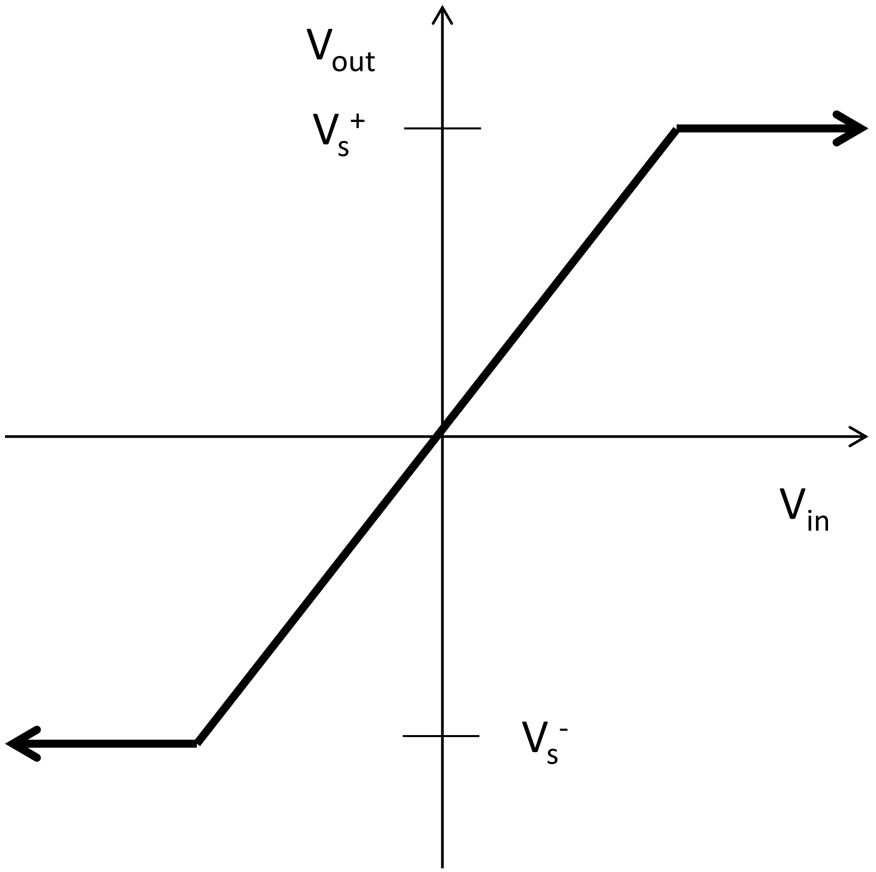
- The maximum output is the power supply voltage

- When used in a circuit, the gain of the circuit (as opposed to the op-amp component) is:

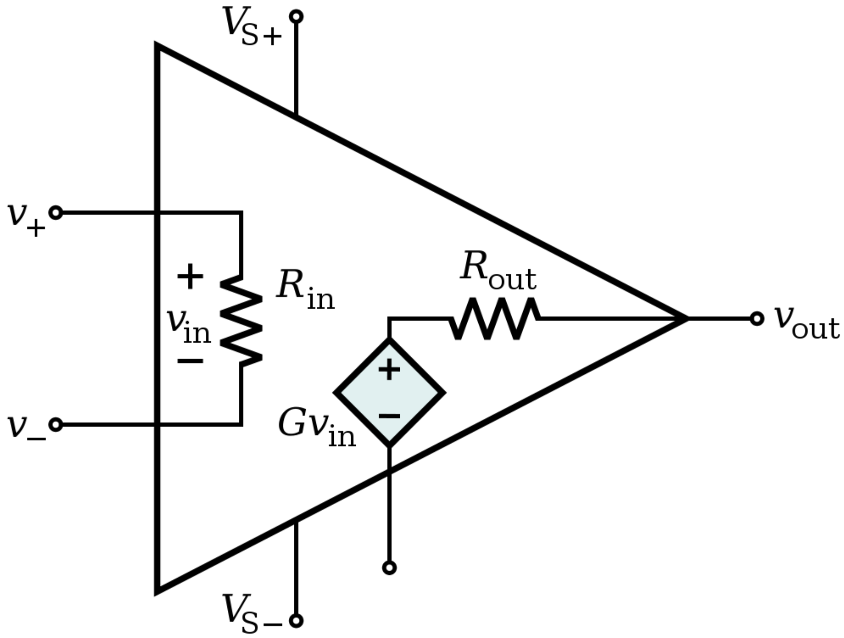
$$A_v = V_{out}/V_{in}$$

Op-Amp Saturation

- As mentioned earlier, the maximum output value is the **supply voltage**, positive and negative.
- The gain (G) is the slope between saturation points.

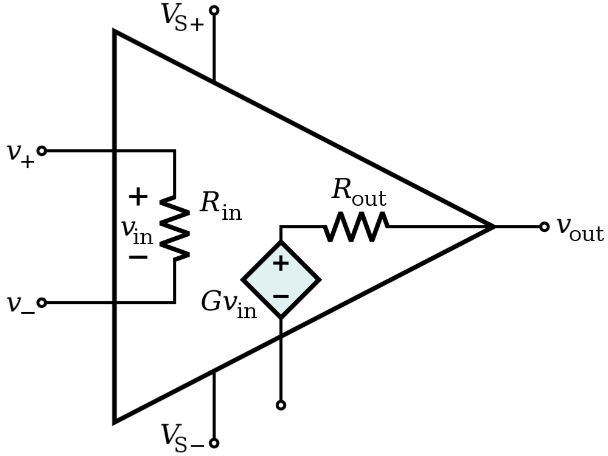


Op-Amp Characteristics



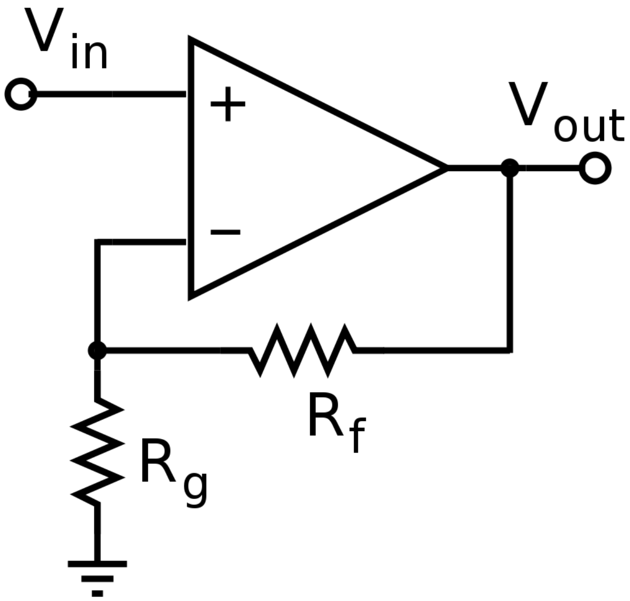
- Open-loop gain G is typically over 9000
  - But closed-loop gain is much smaller
- R_{in} is very large (MΩ or larger)
- R_{out} is small (75Ω or smaller)
  - Effective output impedance in closed loop is very small

Ideal Op-Amp Characteristics



- Open-loop gain G is infinite
- R_{in} is infinite
  - Zero input current
- R_{out} is zero

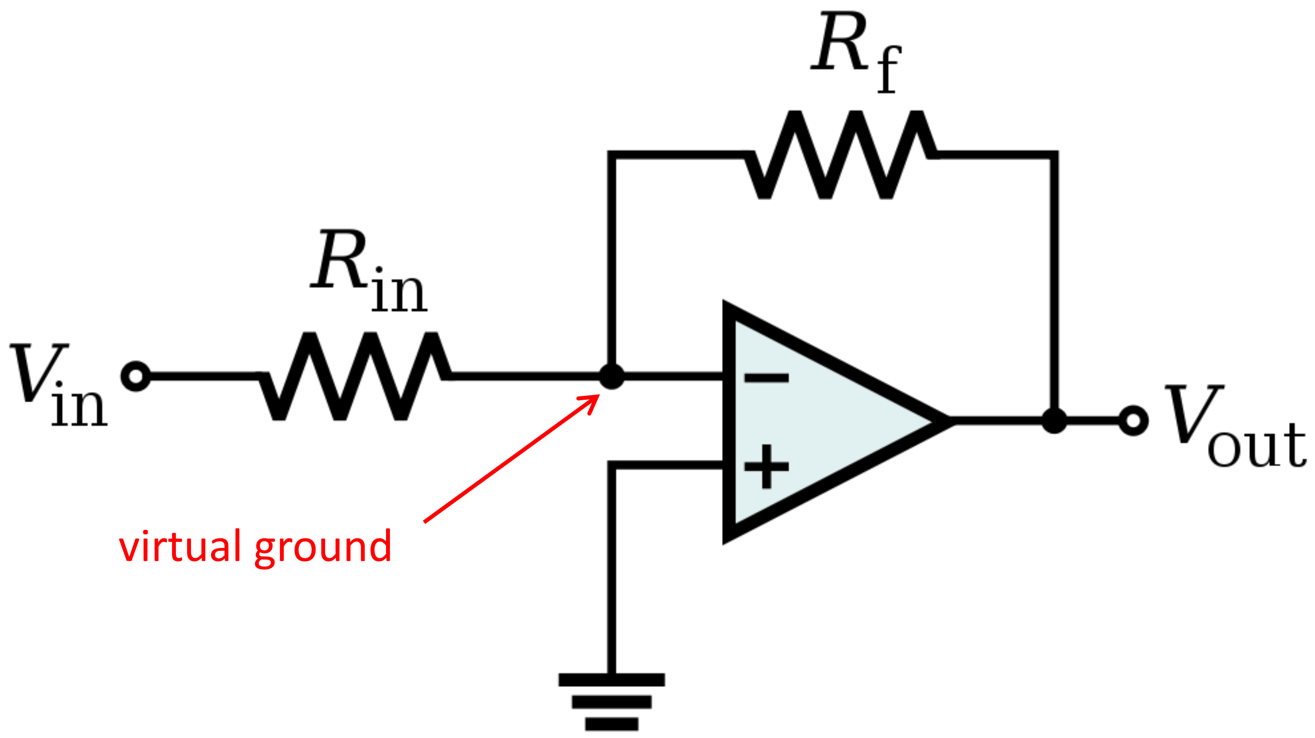
Ideal Op-Amp Analysis



To analyze an op-amp feedback circuit:

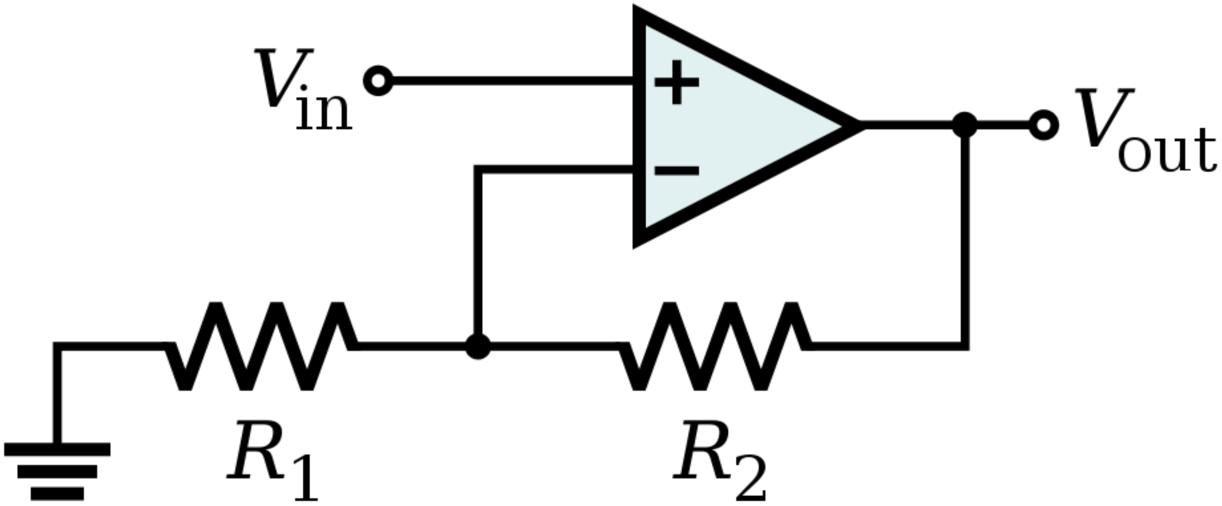
- Assume no current flows into either input terminal
- Assume no current flows out of the output terminal
- Constrain: $V_+ = V_-$

Inverting Amplifier Analysis



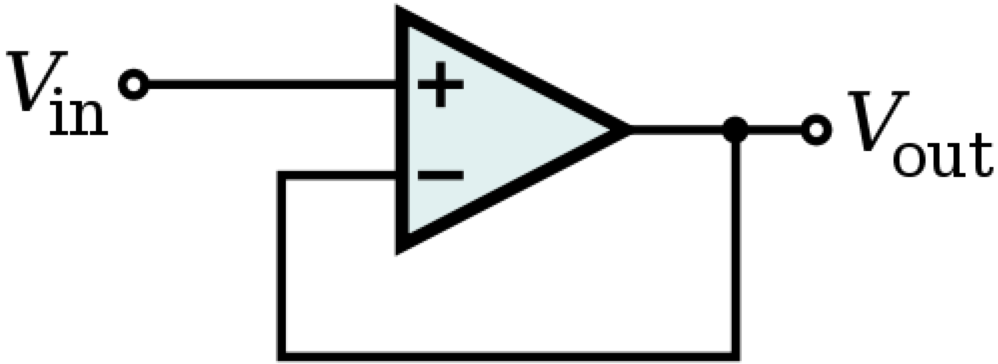
$$V_{out} = -\frac{R_f}{R_{in}} V_{in}$$

Non-Inverting Amplifier Analysis

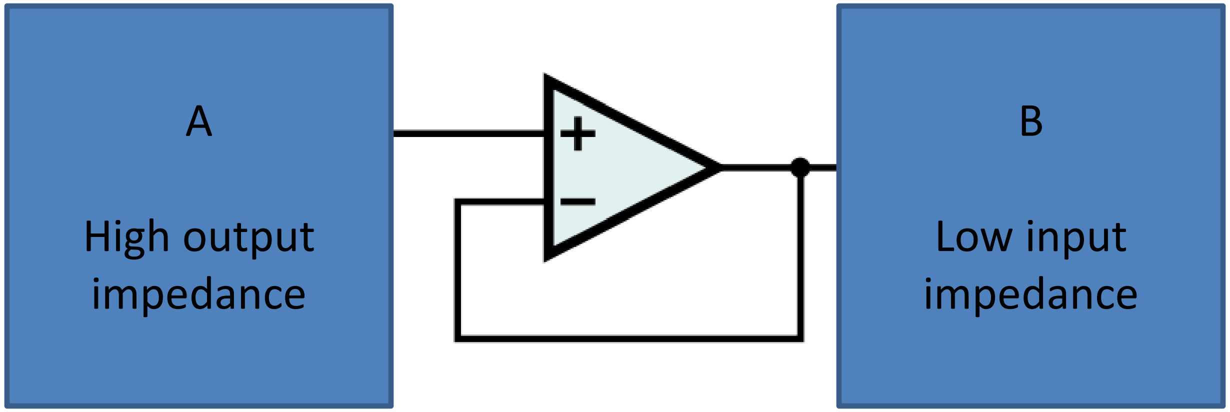


$$V_{\text{out}} = V_{\text{in}} \left(1 + \frac{R_2}{R_1} \right)$$

Op-Amp Buffer



Vout = Vin
Isolates loading effects



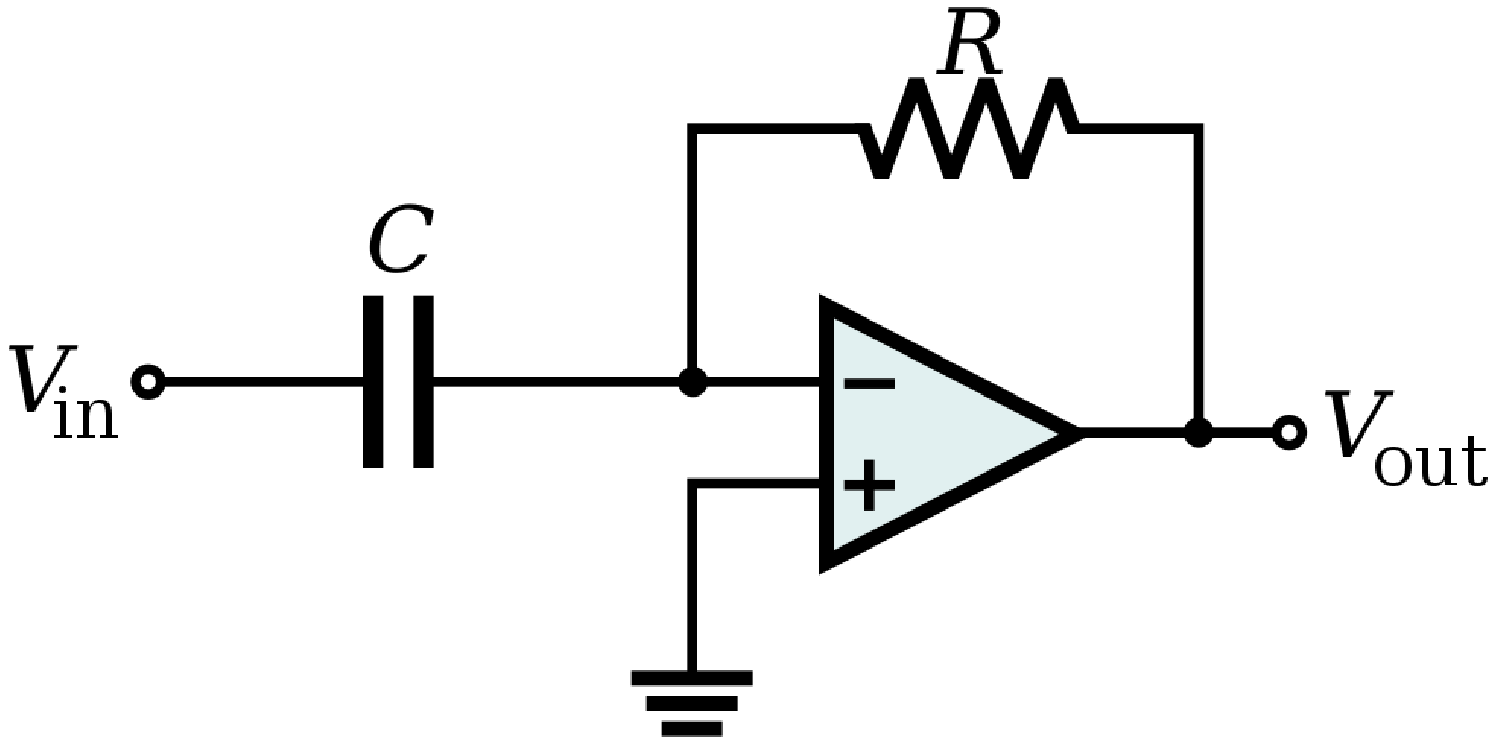
A

High output impedance

B

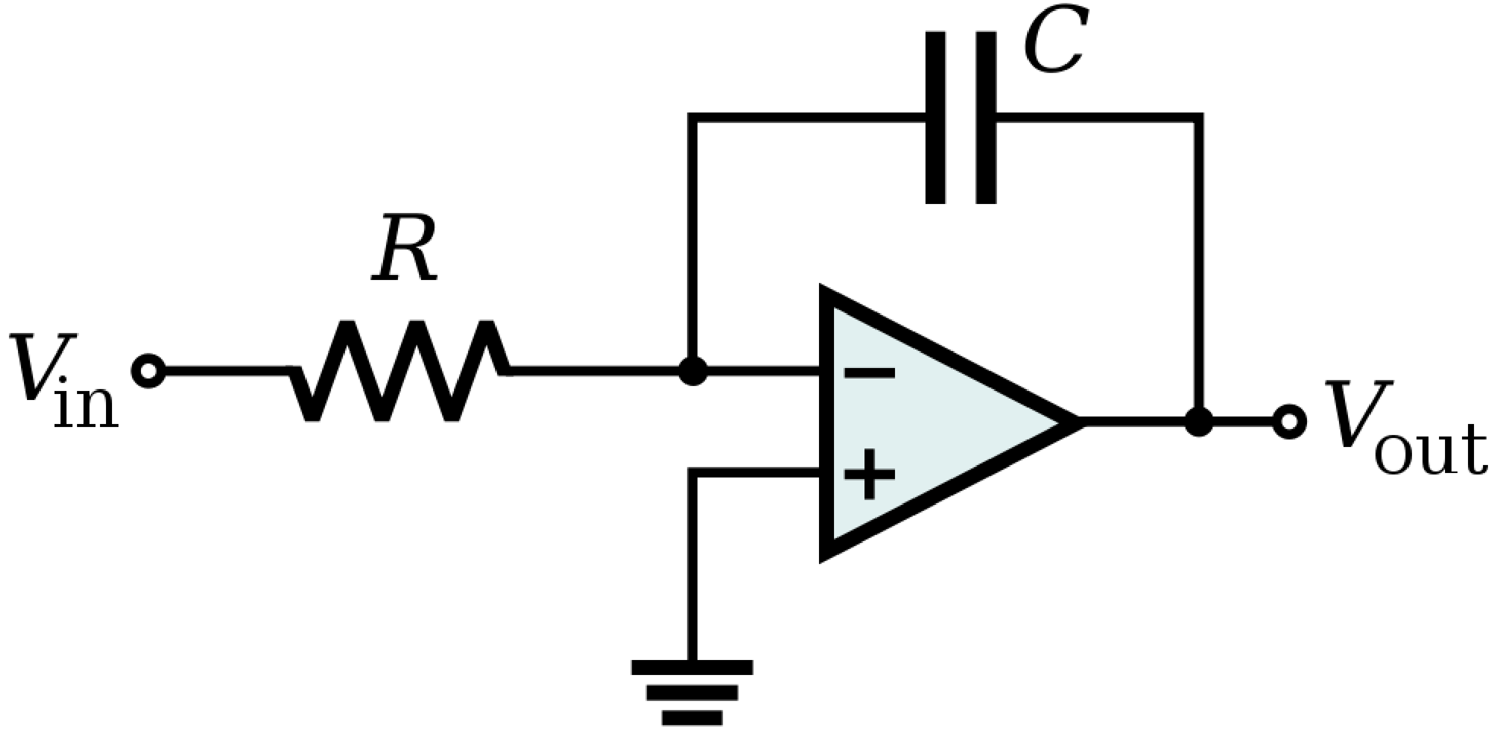
Low input impedance

Op-Amp Differentiator



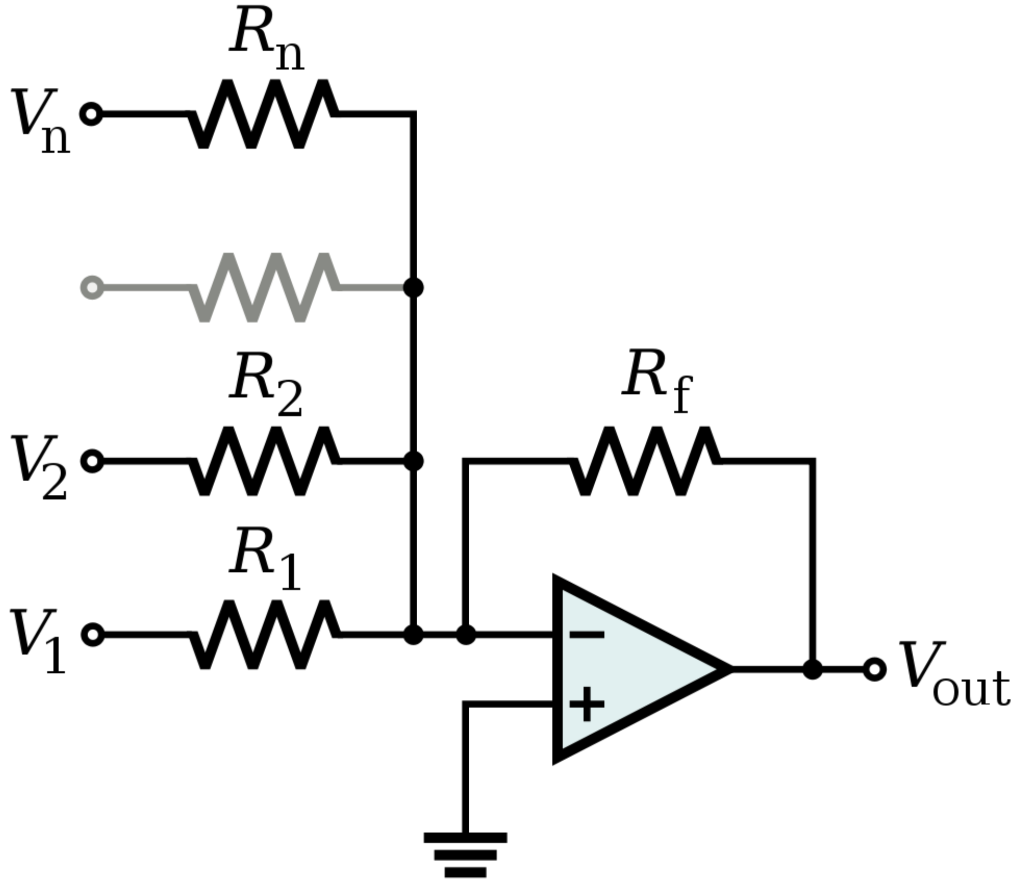
$$V_{\text{out}} = -RC\,\frac{\mathrm{d}V_{\text{in}}}{\mathrm{d}t}$$

Op-Amp Integrator



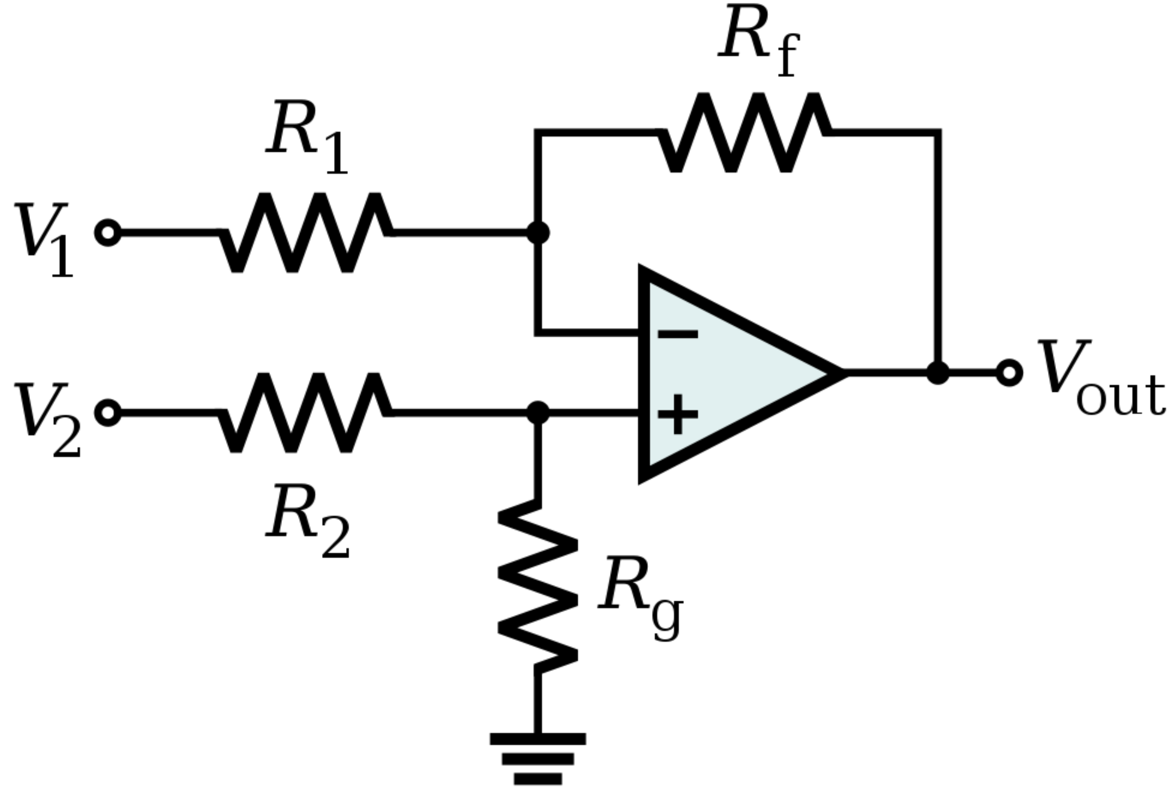
$$V_{\text{out}} = -\int_0^t \frac{V_{\text{in}}}{RC}\,\mathrm{d}t + V_{\text{initial}}$$

Op-Amp Summing Amplifier



$$V_{\text{out}} = -R_{\text{f}}\left(\frac{V_1}{R_1} + \frac{V_2}{R_2} + \cdots + \frac{V_n}{R_n}\right)$$

Op-Amp Differential Amplifier



$$V_{\text{out}} = \frac{(R_f + R_1)\,R_g}{(R_g + R_2)\,R_1} V_2 - \frac{R_f}{R_1} V_1$$

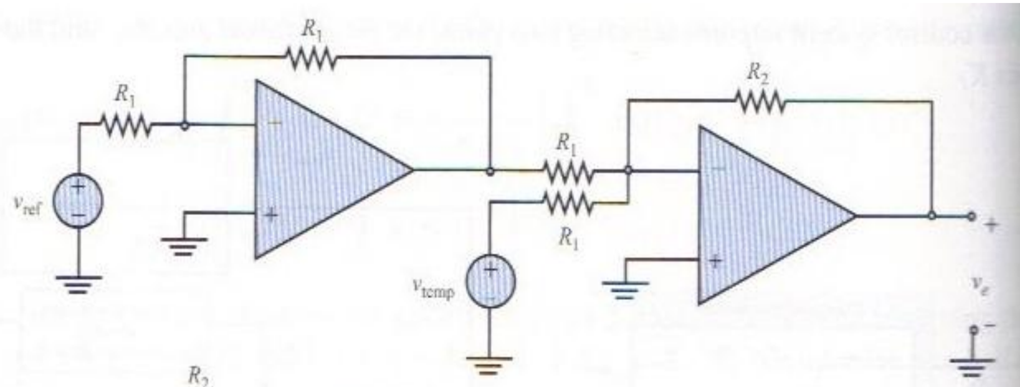
If $R_1 = R_2$ and $R_f = R_g$:

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

Applications of Op-Amps

- Example of PI Control: Temperature Control

- Voltage Error Circuit:



- Proportional-Integral Control Circuit: