K J SOMAIYA COLLEGE OF ENGINEERING, MUMBAI-77

(CONSTITUENT COLLEGE OF SOMAIYA VIDYAVIHAR UNIVERSITY)

Operational Amplifiers

Presented by:

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Operational Amplifiers

Outline of Presentation

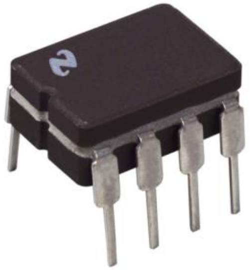
- What is an Op-Amp?
- Characteristics of Ideal and Real Op-Amps
- Common Op-Amp Circuits
- Applications of Op-Amps
- References

What is an Op-Amp?

An Operational Amplifier (known as an “Op-Amp”) is a device that is used to amplify a signal using an external power source

Op-Amps are generally composed of:

Transistors, Resistors, Capacitors



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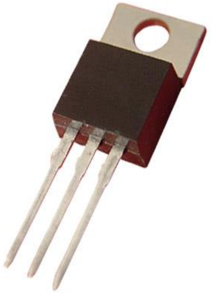

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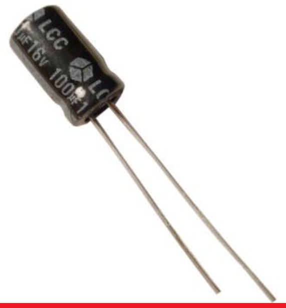
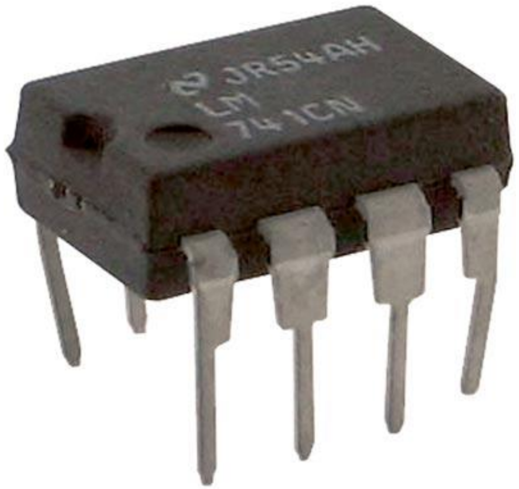
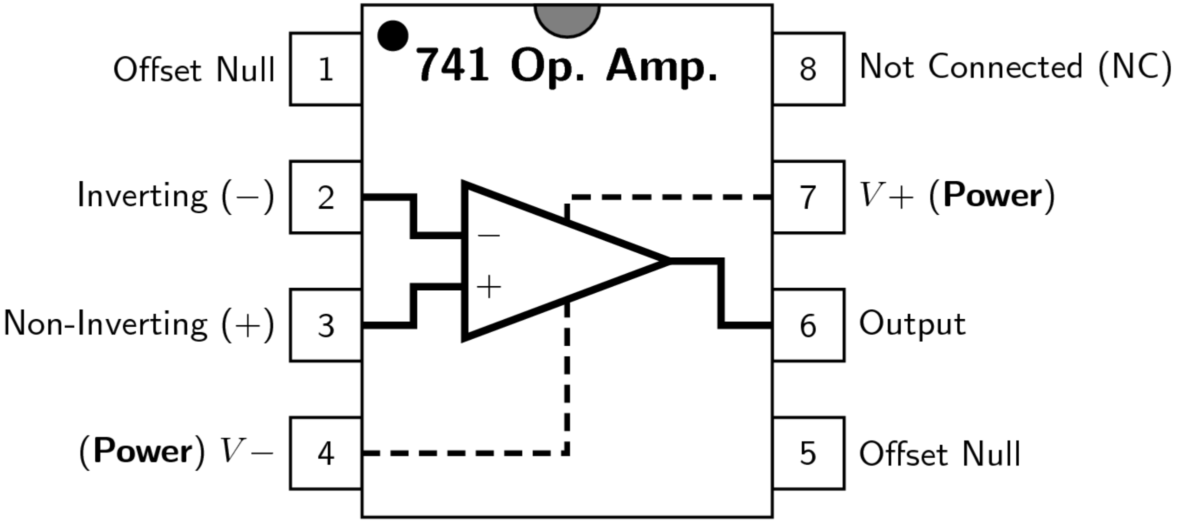


Leading to the advent of the modern IC which is still used even today (1967 – present)



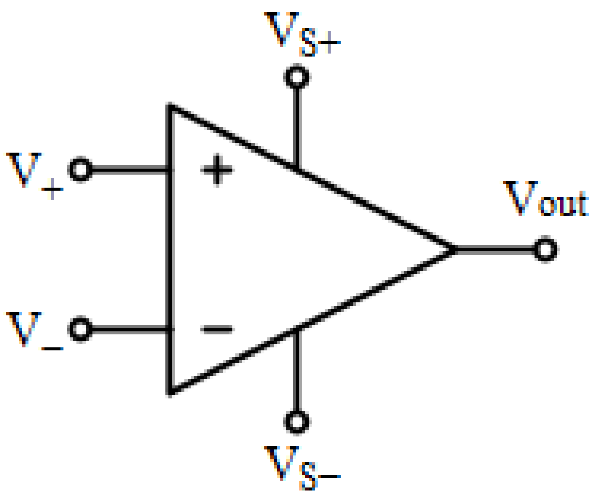
Fairchild µA741



Electrical Schematic of µA741

Op-Amps and their Math

A traditional Op-Amp:



V_+ : non-inverting input
V_- : inverting input
V_{out} : output
V_{s+} : positive power supply
V_{s-} : negative power supply

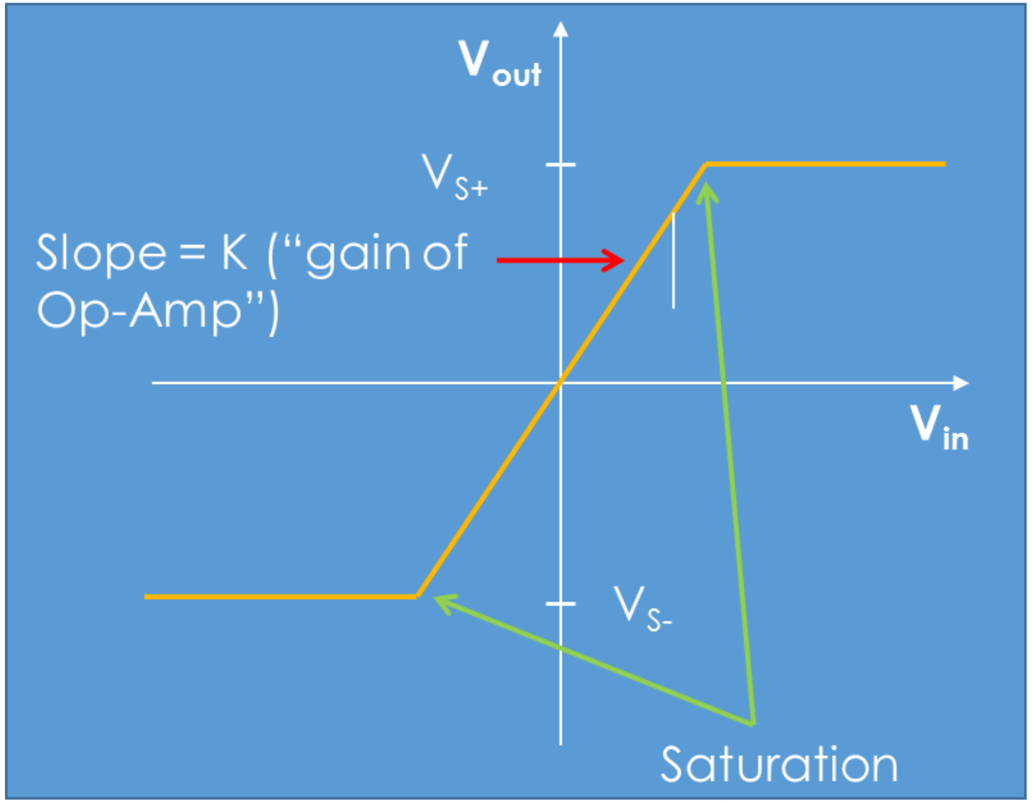
$$V_{out} = K\,(V_+ - V_-)$$

- The difference between the two inputs voltages (V_+ and V_-) multiplied by the gain (K, “amplification factor”) of the Op-Amp gives you the output voltage

- The output voltage can only be as high as the <u>difference</u> between the power supply (V_{s+} / V_{s-})and ground (0 Volts)

Saturation

Saturation is caused by increasing/decreasing the input voltage to cause the output voltage to equal the power supply's voltage*



The slope is normally much steeper than it is shown here. Potentially just a few milli-volts (mV) of change in the difference between V_+ and V_- could cause the op-amp to reach the saturation level

* Note that saturation level of traditional Op-Amp is 80% of supply voltage with exception of CMOS op-amp which has a saturation at the power supply's voltage

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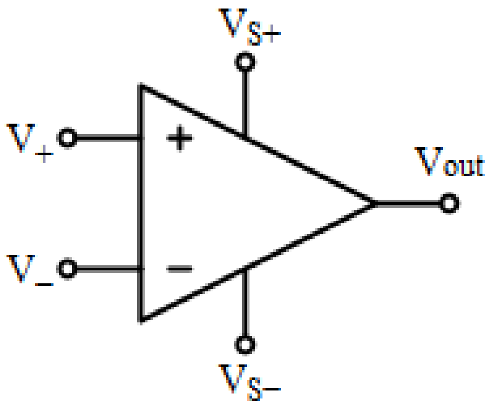
An Ideal Op-Amp Characteristics

- Infinite voltage gain
- Infinite input impedance
- Zero output impedance
- Infinite bandwidth
- Zero input offset voltage (i.e., exactly zero out if zero in).
- Slew Rate(SR):The slew rate of an op amp or any amplifier circuit is the rate of change in the output voltage caused by a step change on the input. It is measured as a voltage change in a given time - typically V / µs or V / ms. A typical general purpose device may have a slew rate of 10 V / microsecond.

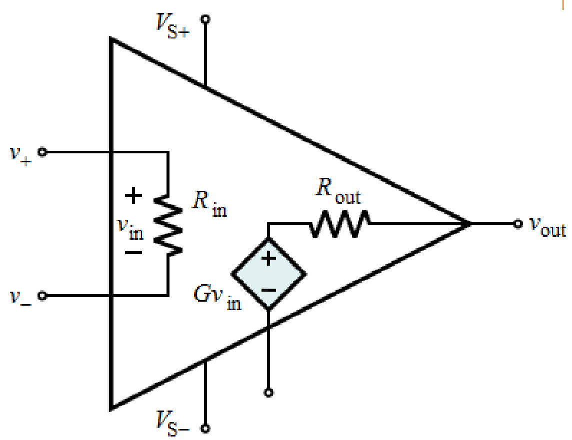
Ideal versus Real Op-Amps

Parameter	Ideal Op-Amp	Real Op-Amp
Differential Voltage Gain	∞	10^5 - 10^9
Gain Bandwidth Product (Hz)	∞	1-20 MHz
Input Resistance (R)	∞	10^6 - 10^{12} Ω
Output Resistance (R)	0	100 - 1000 Ω



Ideal

Real



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Basic Op-Amp Circuits

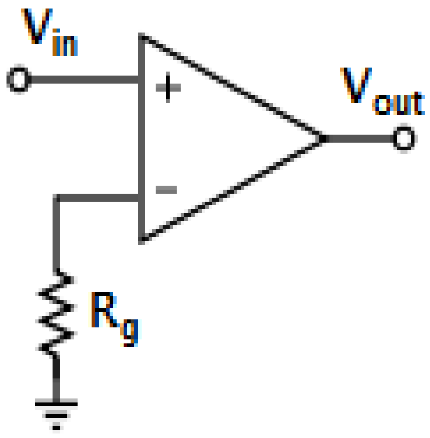
- An op-amp amplifies the difference of the inputs V_+ and V_- (known as the differential input voltage)
- This is the equation for an *open loop* gain amplifier:

$$V_{out} = K(V_+ - V_-)$$

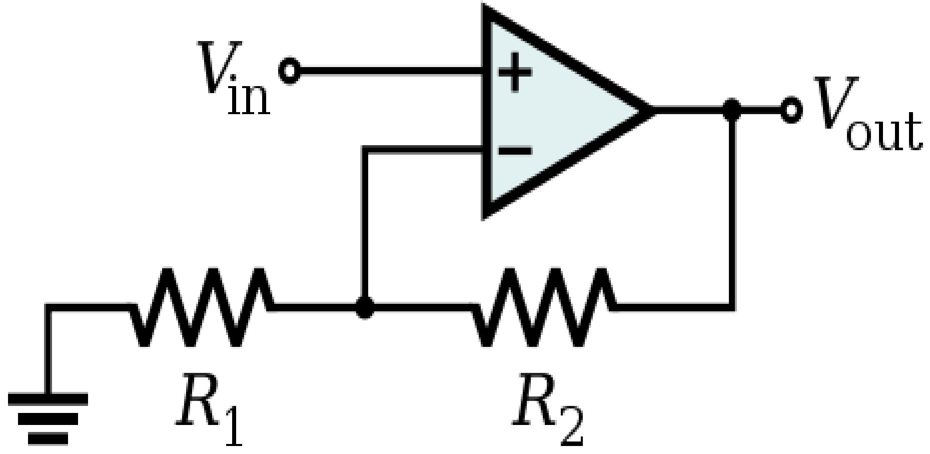
- K is typically very large – at around 10,000 or more for IC Op-Amps
- This equation is the basis for all the types of amps we will be discussing

Open Loop vs Closed Loop Circuit

- A closed loop op-amp has feedback from the output to the input, an open loop op-amp does not



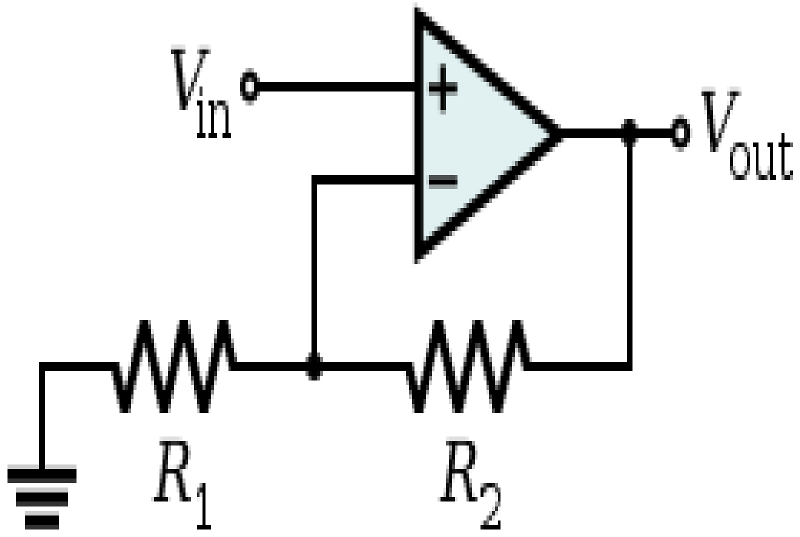
Open Loop



Closed Loop

Op-Amp as Non-Inverting Amplifier

- Amplifies the input voltage by a constant
- Closed loop op-amp
- Voltage input connected to non-inverting input
- Voltage output connected to inverting input through a feedback resistor
- Inverting input is also connected to ground
- Non-inverting input is only determined by voltage output



Op-Amp as Non-Inverting Amplifier

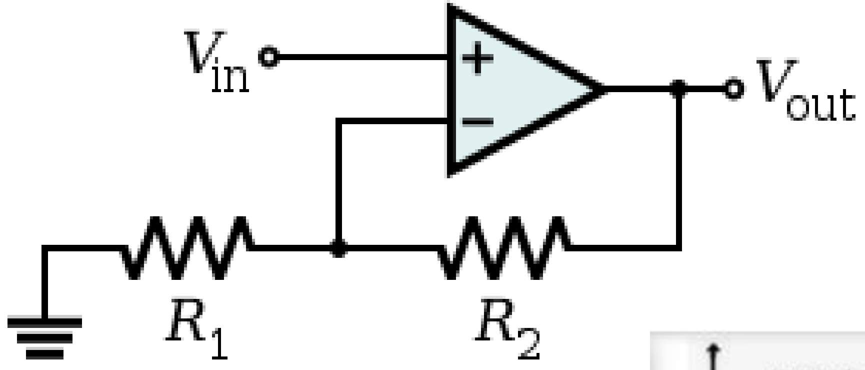
$$V_{non} = V_{inv}$$

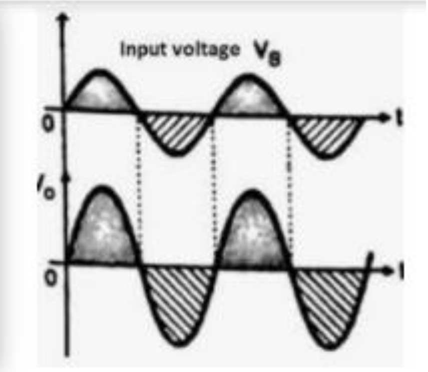
But $V_{non} = V_{in}$, so $V_{inv} = V_{in}$

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

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

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



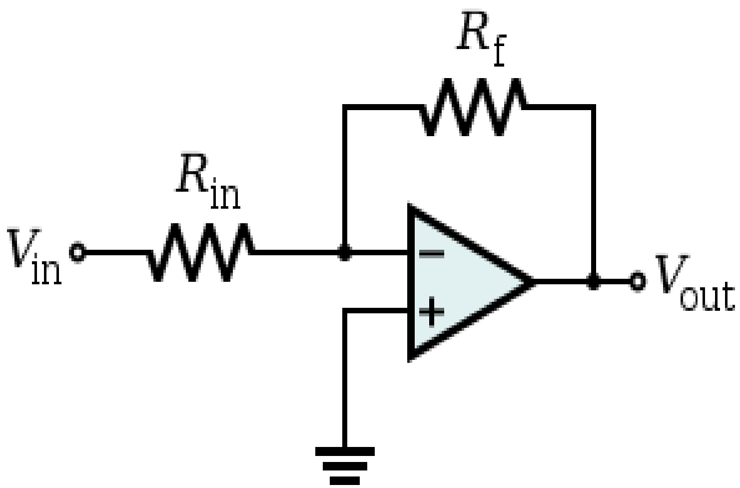


Non-Inverting Op-Amp : Circui...

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

Op-Amp as Inverting Amplifier

- Amplifies and inverts the input voltage
- Closed loop op-amp
- Non-inverting input is determined by *both* voltage input and output
- The polarity of the output voltage is opposite to that of the input voltage
- Input Voltage is connected to inverting terminal
- Output Voltage is fedback to inverting input through a feedback resistor
- Non-inverting input is grounded



Op-Amp as Inverting Amplifier

$$I_f + I_{in} = 0$$

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

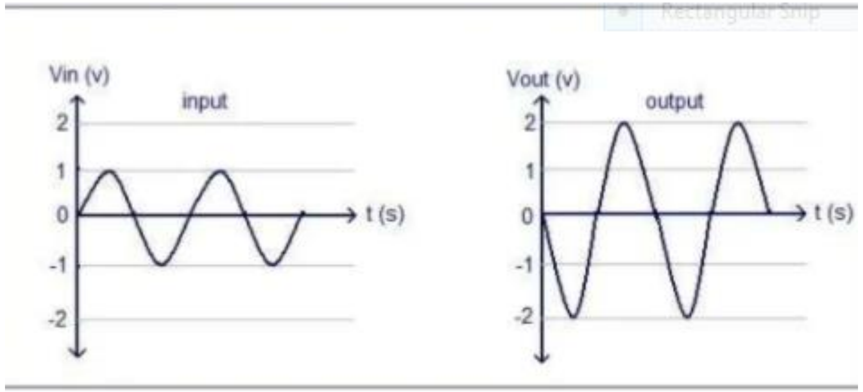
$$A_f = \frac{V_{out}}{V_{in}} = \frac{-R_f}{R_{in}}$$

Apply KCL at inverting node of OPAMP

$$I_f + I_{in} = 0$$

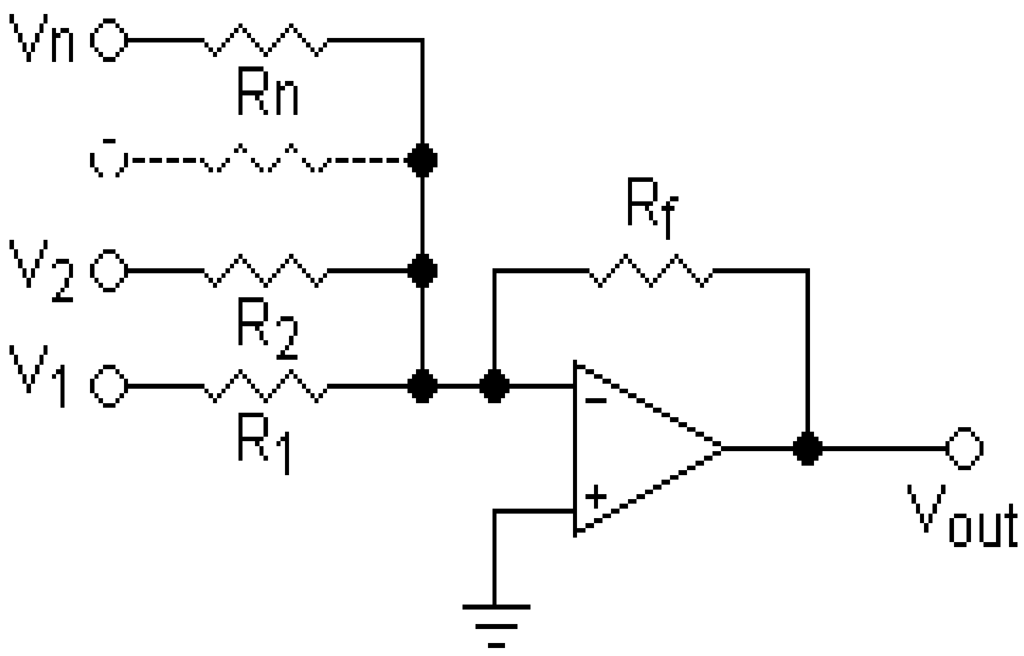
$$\frac{V_{out}}{R_F} = -\frac{V_{in}}{R_{in}}$$

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



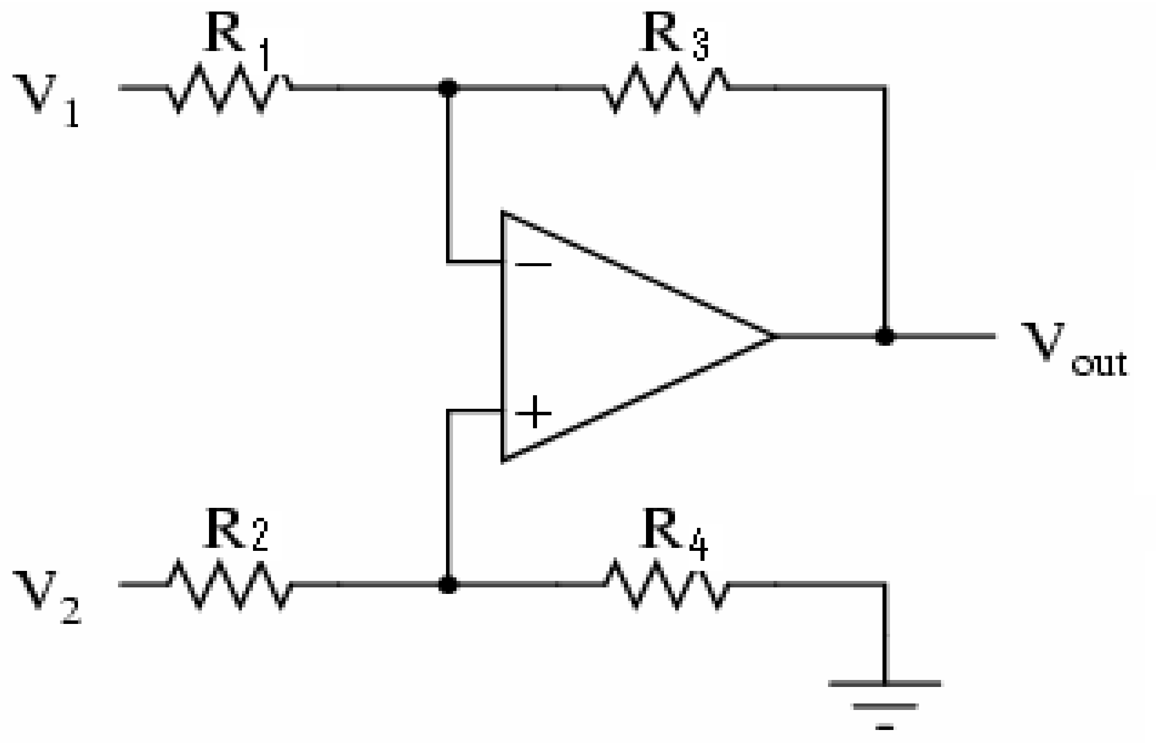
$$V_{out} = -V_{in} * (R_f/R_{in})$$

Op-Amp as Adder/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 as Subtractor



$$V_{out} = \frac{V_2(R_3 + R_1)R_4}{(R_4 + R_2)R_1} - \frac{V_1 R_3}{R_1}$$

If all resistors are equal:

$$V_{out} = V_2 - V_1$$

References

- **Op-amps and Linear Integrated Circuits**

  By Ramakant A Gaikwad

  Publication: Pearson Education

- **Linear Integrated Circuits**

  By Choudhary D. Roy & Shail B. Jain

  Publication: New Age International

Thank you