Operational amplifier or op-amp, is a very high gain differential amplifier with a high input impedance (typically a few meg-Ohms) and low output impedance (less than 100 Ω).

Note the op-amp has two inputs and one output.
Basic Op-Amp

Symbol

- One of the input terminals (1) is called an inverting input terminal denoted by ‘-’
- The other input terminal (2) is called a non-inverting input terminal denoted by ‘+’
IC Product

741
8-pin DIL (Dual In Line)

- Offset null 1
- Inverting input 2
- Non-inverting input 3
- \(-V\) 4
- 8 not connected
- 7 \(+V\)
- 6 output
- 5 offset null

(viewed from above)

Dual op-amp 1458 device

OUTPUT A
1 input
8 \(V^+\)
7 \(-\text{IN A}\)
6 \(-\text{IN B}\)
3 \(+\text{IN A}\)
2 \(+\text{IN B}\)
4 \(-\text{IN B}\)
5 \(+\text{IN B}\)

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Internal circuitry of LM741.
Op-Amp

Non-inverting
• + terminal : Source
• – terminal : Ground
• 0° phase change

Inverting
• + terminal : Ground
• – terminal : Source
• 180° phase change
Op-Amp Gain

Op-Amps have a very high gain. They can be connected open-loop or closed-loop.

- **Open-loop** refers to a configuration where there is no feedback from output back to the input. In the open-loop configuration the gain can exceed 10,000.

- **Closed-loop** configuration reduces the gain. In order to control the gain of an op-amp it must have feedback. This feedback is a negative feedback. A **negative feedback** reduces the gain and improves many characteristics of the op-amp.
Inverting Op-Amp

- The signal input is applied to the **inverting (–) input**
- The **non-inverting input (+)** is grounded
- The resistor $R_f$ is the **feedback resistor**. It is connected from the output to the negative (inverting) input. This is **negative feedback**.
Inverting Op-Amp Gain

Gain can be determined from external resistors: $R_f$ and $R_1$

$$A_v = \frac{V_o}{V_i} = \frac{-R_f}{R_1}$$

Unity gain—voltage gain is 1

$$R_f = R_1$$

$$A_v = \frac{-R_f}{R_1} = -1$$

The negative sign denotes a $180^\circ$ phase shift between input and output.
Practical Op-Amp Circuits

Inverting amplifier
Noninverting amplifier
Unity follower
Summing amplifier
Integrator
Differentiator
Inverting/Noninverting Op-Amps

**Inverting Amplifier**

\[ V_o = -\frac{R_f}{R_1} V_1 \]

**Noninverting Amplifier**

\[ V_o = (1 + \frac{R_f}{R_1}) V_1 \]
Unity Follower

\[ V_o = V_1 \]
Summing Amplifier

\[ V_o = -\left( \frac{R_f}{R_1} V_1 + \frac{R_f}{R_2} V_2 + \frac{R_f}{R_3} V_3 \right) \]
Integrator

• The output is the integral of the input.
• This circuit is useful in low-pass filter circuits.

\[ v_o(t) = -\frac{1}{RC} \int v_1(t) dt \]
The differentiator takes the derivative of the input.
This circuit is useful in high-pass filter circuits.

\[ v_o(t) = -RC \frac{dv_1(t)}{dt} \]