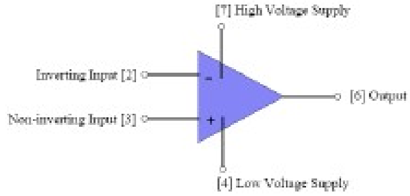
Computer Interfacing

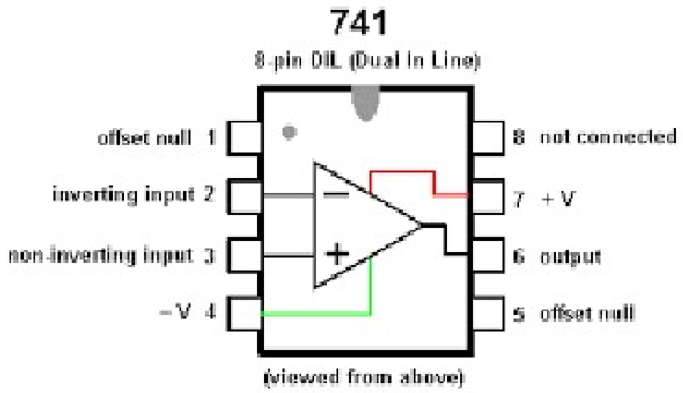
Chapter-3: Operational Amplifiers

Operational Amplifier

Operational amplifiers are linear devices that have all the properties required for nearly ideal DC amplification and are therefore used extensively in signal conditioning, filtering or to perform mathematical operations such as add, subtract, integration and differentiation.



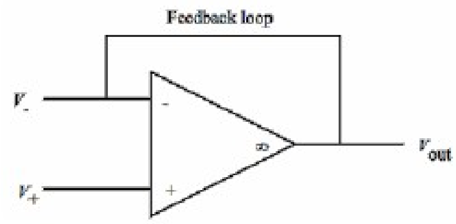
An Operational Amplifier, or op-amp for short, is fundamentally a voltage amplifying device designed to be used with external feedback components such as resistors and capacitors between its output and input terminals. These feedback components determine the resulting function or "operation" of the amplifier and by virtue of the different feedback configurations whether resistive, capacitive or both, the amplifier can perform a variety of different operations, giving rise to its name of "Operational Amplifier".



An Operational Amplifier is basically a three-terminal device which consists of two high impedance inputs, one called the **Inverting Input**, marked with a negative or "minus" sign, (–) and the other one called the **Non-inverting Input**, marked with a positive or "plus" sign (+).

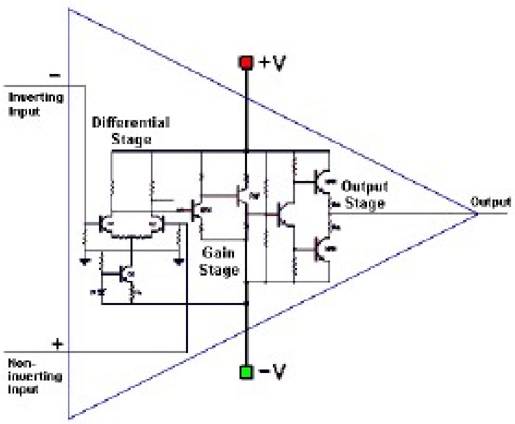
Key Notes:

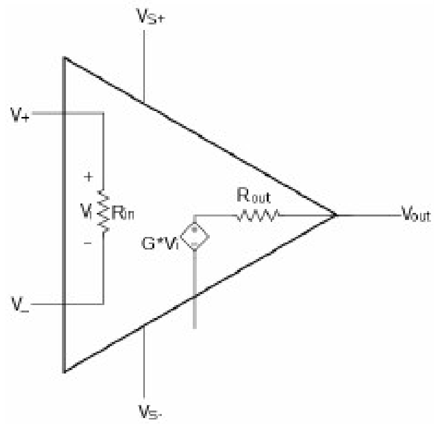
- The output voltage can range from V+ to V-. The positive and negative power supply voltages do not have to be equal. In magnitude, for example, 0V and +3V is fine.
- Output gain is high. Tiny difference in the input voltages result in a very large output voltage.
- Sensor signals are often too weak or too noisy. Op-Amps ideally increase the signal amplitude without affecting its other properties.
- The output attempts to do whatever is necessary to make the voltage difference between the inputs zero.



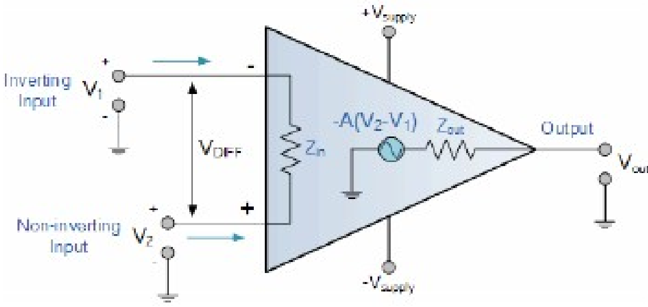
- The inputs draw no current.

Inside of an Op-Amp





Op-amp Parameter and Idealized Characteristics



- **Open Loop Gain, (A_{vo})**

  Infinite – The main function of an operational amplifier is to amplify the input signal and the more open loop gain it has the better. Open-loop gain is the gain of the op-amp without positive or negative feedback and for such an amplifier the gain will be infinite but typical real values range from about 20,000 to 200,000.

- **Input impedance, (Z_{in})**

  Infinite – Input impedance is the ratio of input voltage to input current and is assumed to be infinite to prevent any current flowing from the source supply into the amplifiers input circuitry ($I_{in} = 0$). Real op-amps have input leakage currents from a few pico-amps to a few mille-amps.

- **Output impedance, (Z_{out})**

  Zero – The output impedance of the ideal operational amplifier is assumed to be zero acting as a perfect internal voltage source with no internal resistance so that it can supply as much current as necessary to the load. This internal resistance is effectively in series with the load thereby reducing the output voltage available to the load. Real op-amps have output impedances in the 100-20kΩ range.

- **Bandwidth, (BW)**

  Infinite – An ideal operational amplifier has an infinite frequency response and can amplify any frequency signal from DC to the highest AC frequencies so it is therefore assumed to have an infinite bandwidth. With real op-amps, the bandwidth is limited by the Gain-Bandwidth product (GB), which is equal to the frequency where the amplifiers gain becomes unity.

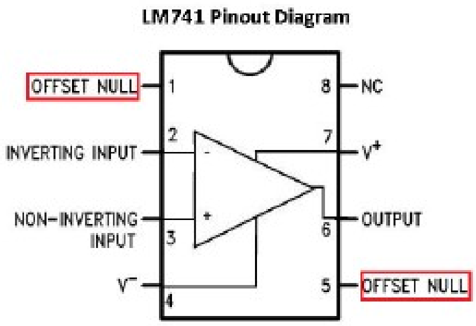
- **Offset Voltage, (V_{io})**

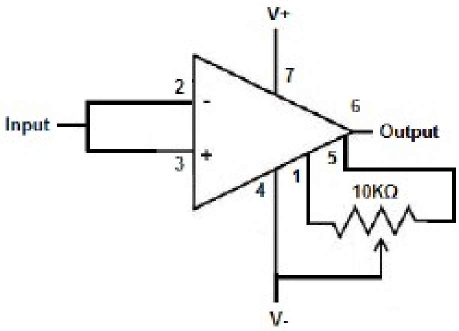
  Zero – The amplifiers output will be zero when the voltage difference between the inverting and the non-inverting inputs is zero, the same or when both inputs are grounded. Real op-amps have some amount of output offset voltage.

Ideal Op-Amp VS Typical Op Amp

Topic	Ideal Op-Amp	Typical Op-Amp
Input Resistance	infinite	10^6 Ω (bipolar) 10^5 to 10^9 (FET)
Input Current	0	10^{-12} to 10^{-8}
Output Resistance	0	100 to 1000 Ω
Operational Gain	Infinite	10^5 to 10^9
Common Mode Gain	0	10^{-5}
Bandwidth	Infinite	Attenuates and phases at high frequencies
Temperature	Independent	Depends of bandwidth and gain

OFFSET NULL Pin





An op amp is a differential amplifier. This means it amplifies the difference in voltage between the two input pins. Because of this fact, its output should be 0V when there is no difference between its inputs, in other words, when its inputs are at equal voltages. In a perfect ideal op amp, this should be the case when there is no voltage connected to the 2 pins. However, in real life op amps, the output is only 0V when the inputs differ by a small amount known as the input offset voltage. Normally, op amps come with offset, so that voltage must be applied to one terminal in order for the voltages to be equal and, thus, for there to be 0 output.

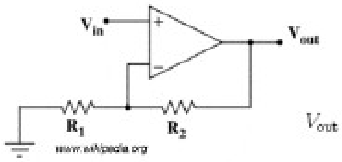
This is why op amps have offset null terminals.

To make the voltages exactly equal, you apply the same voltage to both pins and place a potentiometer to one of the pins and change the resistance until the output is 0V.

Op-Amp Applications

- Comparator
- Voltage follower
- Signal Modulation
- Mathematical Operations
- Filters
- Voltage-Current signal conversion

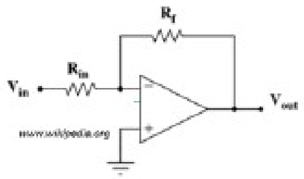
Non-inverting Op-Amp



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

Uses: Amplify…straight up

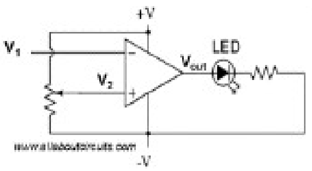
Inverting Op-Amp



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

Uses: Analog inverter

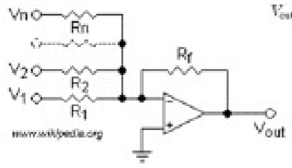
Comparator



$$V_{out} = \begin{cases} V_{S+} & V_1 > V_2 \\ V_{S-} & V_1 < V_2 \end{cases}$$

Uses: Low-voltage alarms, night light controller

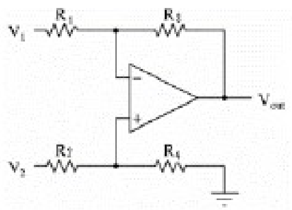
Summation



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

Uses: Add multiple sensors inputs until a threshold is reached.

Difference

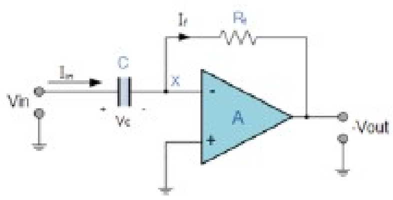


$$V_{out} = \frac{V_2(R_3 + R_1)R_4}{(R_4 + R_2)R_1} - \frac{V_1 R_3}{R_1}$$

If all resistors are equal:

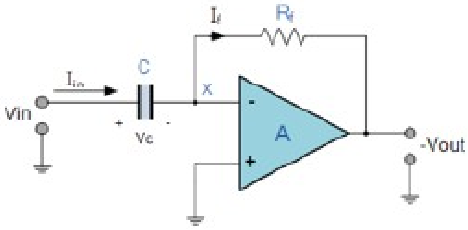
$$V_{out} = V_2 - V_1$$

Differentiating Op-Amp



$$V_{out} = -RC\left(\frac{dV_{in}}{dt}\right)$$

Differentiating Op-Amp



$$V_{\text{out}} = -RC\left(\frac{dV_{\text{in}}}{dt}\right)$$