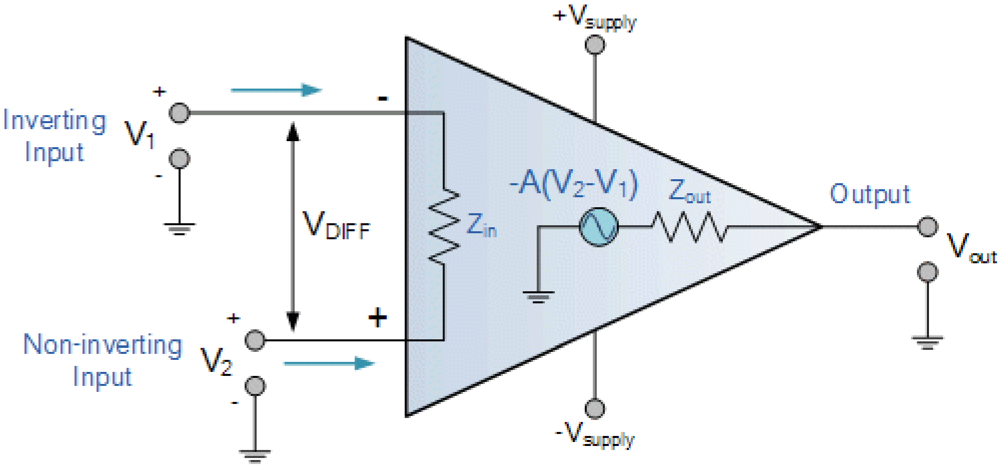
Operational Amplifier Basics



Operational Amplifiers, or **Op-amps** as they are more commonly called, are one of the basic building blocks of Analogue Electronic Circuits.

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 of the inputs is called the **Inverting Input**, marked with a negative or "minus" sign, (–). The other input is called the **Non-inverting Input**, marked with a positive or "plus" sign (+).

A third terminal represents the operational amplifiers output port which can both sink and source either a voltage or a current. In a linear operational amplifier, the output signal is the amplification factor, known as the amplifiers gain (A) multiplied by the value of the input signal and depending on the nature of these input and output signals, there can be four different classifications of operational amplifier gain.

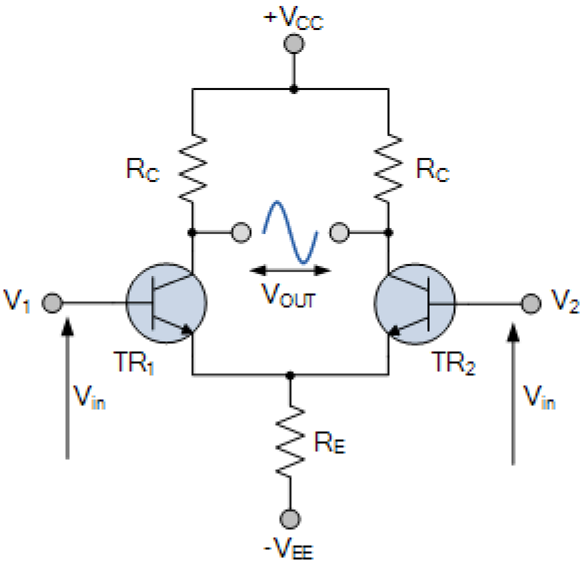
- Voltage – Voltage "in" and Voltage "out"
- Current – Current "in" and Current "out"
- Transconductance – Voltage "in" and Current "out"
- Transresistance – Current "in" and Voltage "out"

Since most of the circuits dealing with operational amplifiers are voltage amplifiers, we will limit the tutorials in this section to voltage amplifiers only, (Vin and Vout).

The output voltage signal from an Operational Amplifier is the difference between the signals being applied to its two individual inputs. In other words, an op-amps output signal is the difference between the two input signals as the input stage of an Operational Amplifier is in fact a differential amplifier as shown below.

Differential Amplifier

The circuit below shows a generalized form of a differential amplifier with two inputs marked V1 and V2. The two identical transistors TR1 and TR2 are both biased at the same operating point with their emitters connected together and returned to the common rail, -Vee by way of resistor Re.



Differential Amplifier

The circuit operates from a dual supply +Vcc and -Vee which ensures a constant supply. The voltage that appears at the output, Vout of the amplifier is the difference between the two input signals as the two base inputs are in *anti-phase* with each other.

So as the forward bias of transistor, TR1 is increased, the forward bias of transistor TR2 is reduced and vice versa. Then if the two transistors are perfectly matched, the current flowing through the common emitter resistor, Re will remain constant.

Like the input signal, the output signal is also balanced and since the collector voltages either swing in opposite directions (anti-phase) or in the same direction (in-phase) the output voltage signal, taken from between the two collectors is, assuming a perfectly balanced circuit the zero difference between the two collector voltages.

This is known as the *Common Mode of Operation* with the **common mode gain** of the amplifier being the output gain when the input is zero.

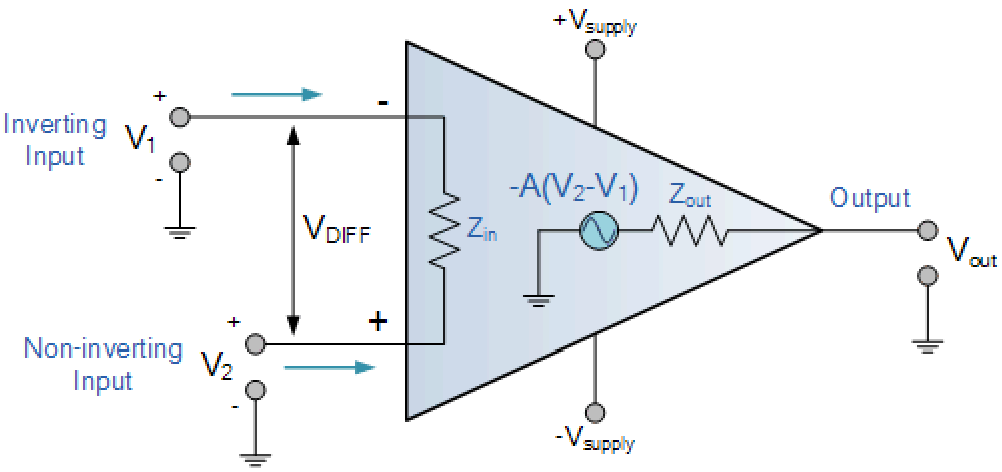
Operational Amplifiers also have one output (although there are ones with an additional differential output) of low impedance that is referenced to a common ground terminal and it should ignore any common mode signals that is, if an identical signal is applied to both the inverting and non-inverting inputs there should no change to the output.

However, in real amplifiers there is always some variation and the ratio of the change to the output voltage with regards to the change in the common mode input voltage is called the **Common Mode Rejection Ratio** or **CMRR** for short.

Operational Amplifiers on their own have a very high open loop DC gain and by applying some form of **Negative Feedback** we can produce an operational amplifier circuit that has a very precise gain characteristic that is dependant only on the feedback used. Note that the term "open loop" means that there are no feedback components used around the amplifier so the feedback path or loop is open.

An operational amplifier only responds to the difference between the voltages on its two input terminals, known commonly as the "*Differential Input Voltage*" and not to their common potential. Then if the same voltage potential is applied to both terminals the resultant output will be zero. An Operational Amplifiers gain is commonly known as the **Open Loop Differential Gain**, and is given the symbol (A_o).

Equivalent Circuit of an Ideal Operational Amplifier



Op-amp Parameter and Idealised Characteristic

- **Open Loop Gain, (Avo)**
    - **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

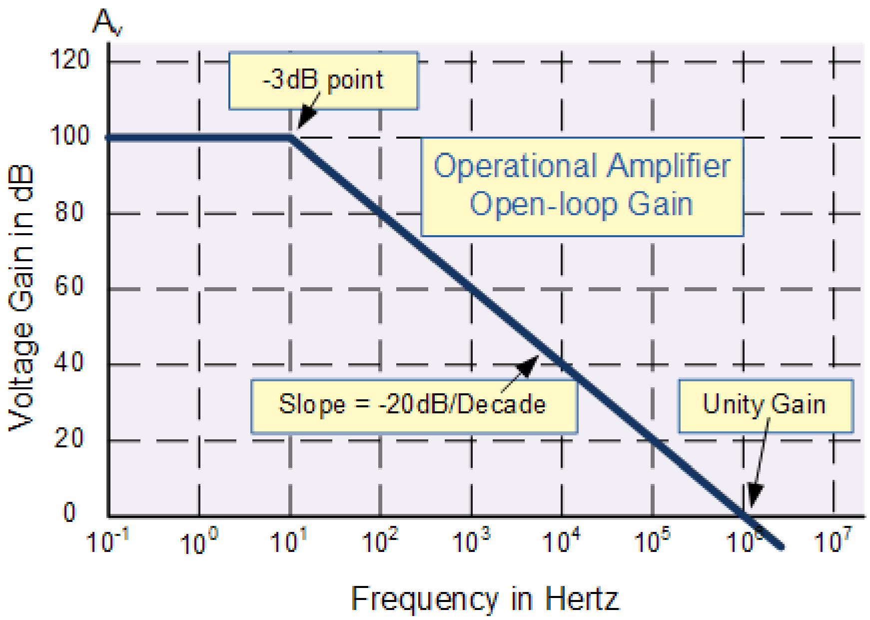
amplifier the gain will be infinite but typical real values range from about 20,000 to 200,000.

- **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 milli-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.

From these "idealized" characteristics above, we can see that the input resistance is infinite, so **no current flows into either input terminal** (the "current rule") and that the **differential input offset voltage is zero** (the "voltage rule"). It is important to remember these two properties as they will help us understand the workings of the **Operational Amplifier** with regards to the analysis and design of op-amp circuits.

However, real **Operational Amplifiers** such as the commonly available **uA741**, for example do not have infinite gain or bandwidth but have a typical "Open Loop Gain" which is defined as the amplifiers output amplification without any external feedback signals connected to it and for a typical operational amplifier is about 100dB at DC (zero Hz). This output gain decreases linearly with frequency down to "Unity Gain" or 1, at about 1MHz and this is shown in the following open loop gain response curve.

Open-loop Frequency Response Curve



From this frequency response curve we can see that the product of the gain against frequency is constant at any point along the curve. Also that the unity gain (0dB) frequency also determines the gain of the amplifier at any point along the curve. This constant is generally known as the **Gain Bandwidth Product** or **GBP**. Therefore:

GBP = Gain x Bandwidth = A x BW

For example, from the graph above the gain of the amplifier at 100kHz is given as 20dB or 10, then the gain bandwidth product is calculated as:

GBP = A x BW = 10 x 100,000Hz = 1,000,000.

Similarly, the operational amplifiers gain at 1kHz = 60dB or 1000, therefore the GBP is given as:

GBP = A x BW = 1,000 x 1,000Hz = 1,000,000. **The same!**.

The **Voltage Gain** (A_V) of the operational amplifier can be found using the following formula:

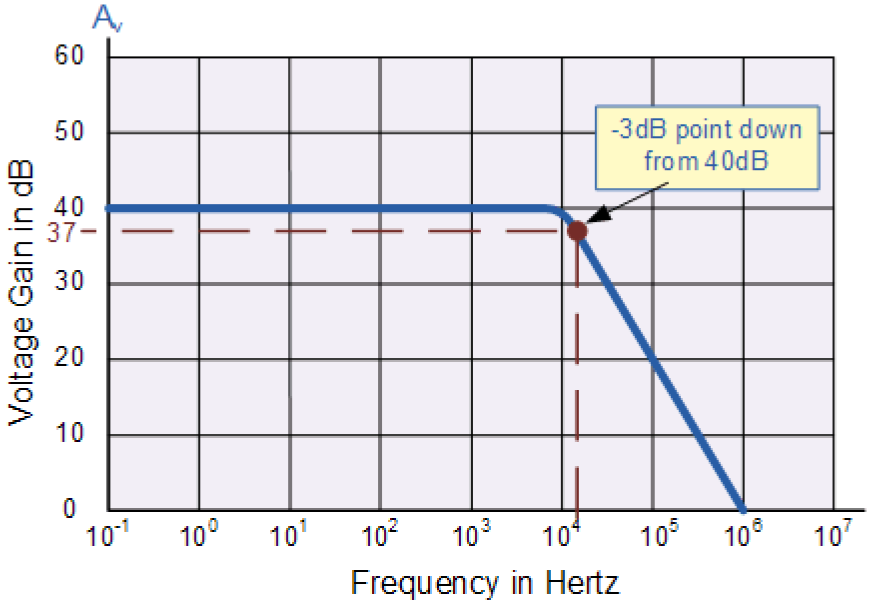
$$\text{Voltage Gain, (A)} = \frac{V_{out}}{V_{in}}$$

and in **Decibels** or (dB) is given as:

$$20\log(A) \text{ or } 20\log\frac{V_{out}}{V_{in}} \textit{ in dB}$$

An Operational Amplifiers Bandwidth

The operational amplifiers bandwidth is the frequency range over which the voltage gain of the amplifier is above **70.7%** or **-3dB** (where 0dB is the maximum) of its maximum output value as shown below.



Here we have used the 40dB line as an example. The -3dB or 70.7% of Vmax down point from the frequency response curve is given as **37dB**. Taking a line across until it intersects with the main GBP curve gives us a frequency point just above the 10kHz line at about 12 to 15kHz. We can now calculate this more accurately as we already know the GBP of the amplifier, in this particular case 1MHz.

Operational Amplifier Example No1.

Using the formula 20 log (A), we can calculate the bandwidth of the amplifier as:

37 = 20 log (A)   therefore, A = anti-log (37 ÷ 20) = 70.8

GBP ÷ A = Bandwidth, therefore, 1,000,000 ÷ 70.8 = 14,124Hz, or 14kHz

Then the bandwidth of the amplifier at a gain of 40dB is given as **14kHz** as previously predicted from the graph.

Operational Amplifier Example No2.

If the gain of the operational amplifier was reduced by half to say **20dB** in the above frequency response curve, the -3dB point would now be at 17dB. This would then give the operational amplifier an overall gain of 7.08, therefore **A = 7.08**.

If we use the same formula as above, this new gain would give us a bandwidth of approximately **141.2kHz**, ten times more than the frequency given at the 40dB point. It can therefore be seen that by reducing the overall “open loop gain” of an operational amplifier its bandwidth is increased and visa versa.

In other words, an operational amplifiers bandwidth is inversely proportional to its gain, (A 1/∞ BW). Also, this -3dB corner frequency point is generally known as the “half power point”, as the output power of the amplifier is at half its maximum value as shown:

$$\text{Power, } P = \left[\frac{V^2}{R}\right] = \left[I^2 \times R\right]$$

$$\text{At } f_C \text{ V or I} = 70.71\% \text{ of maximum}$$

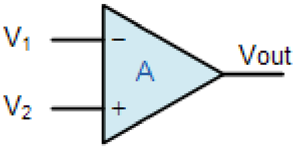
$$\text{If } R = 1 \quad \text{and} \quad \text{V or I} = 0.7071\text{max}$$

$$\text{Then: } P = \left[\frac{(0.7071 \times V)^2}{1}\right] = \left[(0.7071 \times I)^2 \times 1\right]$$

$$\therefore P = 0.5V \quad \text{or} \quad 0.5I \quad \text{(half power)}$$

Operational Amplifiers Summary

We know now that an **Operational amplifiers** is a very high gain DC differential amplifier that uses one or more external feedback networks to control its response and characteristics. We can connect external resistors or capacitors to the op-amp in a number of different ways to form basic “building Block” circuits such as, Inverting, Non-Inverting, Voltage Follower, Summing, Differential, Integrator and Differentiator type amplifiers.

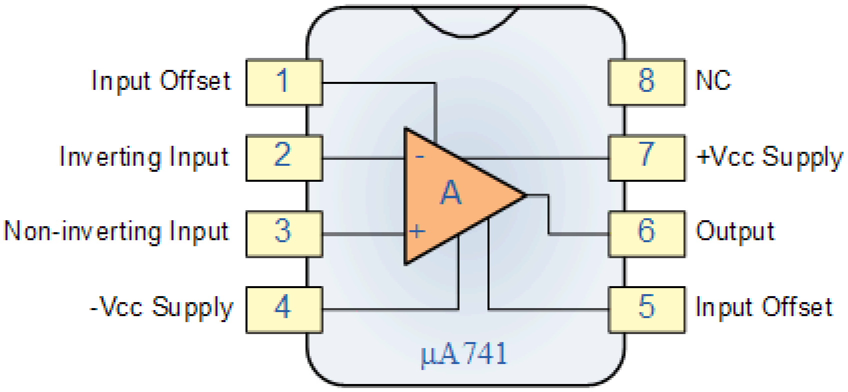


Op-amp Symbol

An “ideal” or perfect operational amplifier is a device with certain special characteristics such as infinite open-loop gain A_O, infinite input resistance R_{IN}, zero output resistance R_{OUT}, infinite bandwidth 0 to ∞ and zero offset (the output is exactly zero when the input is zero).

There are a very large number of operational amplifier IC’s available to suit every possible application from standard bipolar, precision, high-speed, low-noise, high-voltage, etc, in either standard configuration or with internal Junction FET transistors.

Operational amplifiers are available in IC packages of either single, dual or quad op-amps within one single device. The most commonly available and used of all operational amplifiers in basic electronic kits and projects is the industry standard **µA-741**.



What are Operational Amplifiers?

Operational amplifiers are the basic building blocks of Analogue electronic circuits. They are linear devices with all properties of a DC amplifier. We can use external resistors or capacitors to the Op Amp is many different ways to make them different forms of amplifies such as Inverting amplifier, Non inverting amplifier, Voltage follower, Comparator, Differential amplifier, Summing amplifier, Integrator etc. OPAMPs may be single, dual, quad etc. OPAMPs like CA3130, CA3140, TL0 71, LM311 etc have excellent performance with very low input current and voltage. The ideal Op Amp has three important terminals in addition to other terminals. The input terminals are Inverting input and Non inverting input. The third terminal is the output which can sink and source current and voltage. The output signal is the amplifiers gain multiplied by the value of the input signal.

5 Ideal characters of an Op Amp:

1. Open Loop gain

Open loop gain is the gain of the Op Amp without a positive or negative feedback. An ideal OP Amp should have an infinite open loop gain but typically it range between 20,000 and 2, 00000.

2. Input impedance

It is the ratio of the input voltage to input current. It should be infinite without any leakage of current from the supply to the inputs. But there will be a few Pico ampere current leakages in most Op Amps.

3. Output impedance

The ideal Op Amp should have zero output impedance without any internal resistance. So that it can supply full current to the load connected to the output.

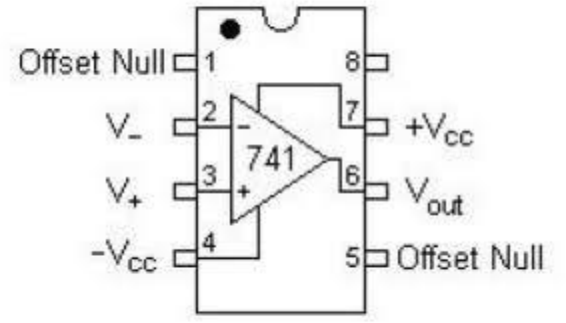
4. Band width

The ideal Op Amp should have an infinite frequency response so that it can amplify any frequency from DC signals to the highest AC frequencies. But most Op Amps have limited bandwidth.

5. Offset

The output of the Op Amp should be zero when the voltage difference between the inputs is zero. But in most Op Amps, the output will not be zero when off but there will be a minute voltage from it.

OPAMP Pin Configuration:



In a typical Op Amp there will be 8 pins. These are

Pin1 – Offset Null

Pin2 – Inverting input INV

Pin3 – Non inverting input Non-INV

Pin4 – Ground- Negative supply

Pin5 – Offset Null

Pin6 – Output

Pin7 – Positive supply

Pin8 – Strobe

4 types of gain in OPAMPs:

Voltage gain – Voltage in and voltage out

Current gain – Current in and Current out

Transconductance – Voltage in and Current out

Trans resistance – Current in and voltage out

Working of an Operational Amplifier:

Here we used an operational amplifier of LM358. Usually a non-inverting input has to be given to a biasing and the inverting input is the real amplifier; connected this to a feedback of 60k resister from output to the input. And a resister 10k is connected in series with a capacitor and a supply of 1V sine wave is given to the circuit, now we will see how gain will be governed by R2/R1=60k/10k=6 gain, then the output is 6V. If we change the gain by 40 then the output is 4V of sine wave.

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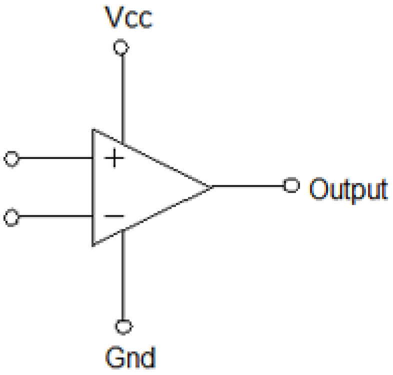
3 OPAMP applications:

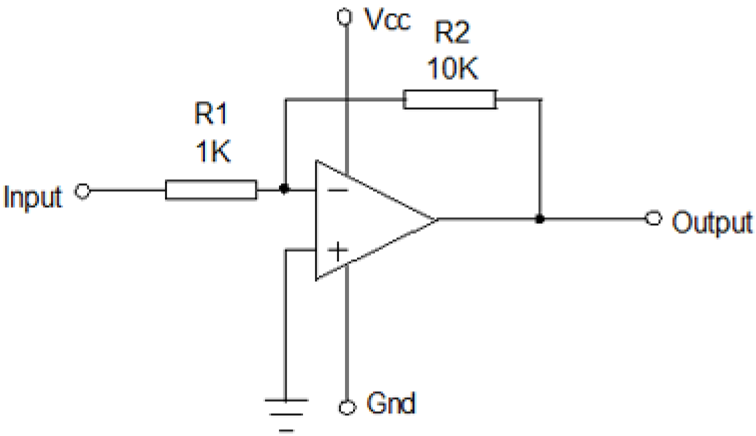
1. Amplification

The amplified output signal from the Op Amp is the difference between the two input signals.



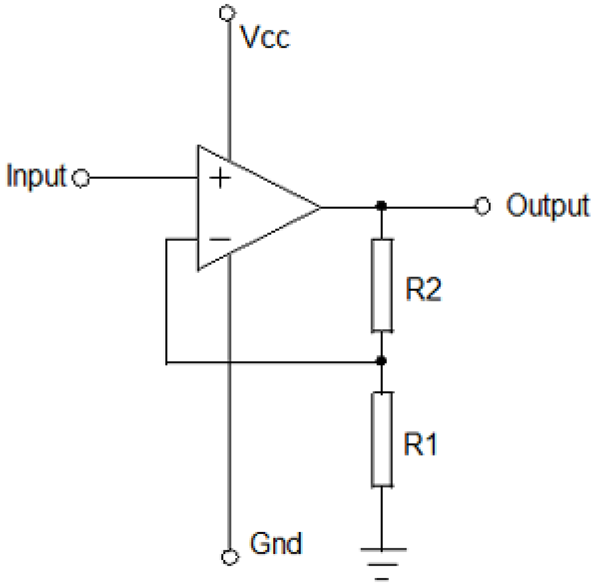
The diagram shown above is the Op Amp simple connection. If both the inputs are supplied with the same voltage, the Op Amp will then takes the difference between the two voltages and it will be 0. The Op Amp will multiply this with its gain 1,000,000 so the output voltage is 0. When 2 volts is given to one input and 1 volt in the other, then the Op Amp will takes its difference and multiply with the gain. That is 1 volt x 1,000,000. But this gain is very high so to reduce the gain, feedback from the output to the input is usually done through a resistor.

Inverting Amplifier:



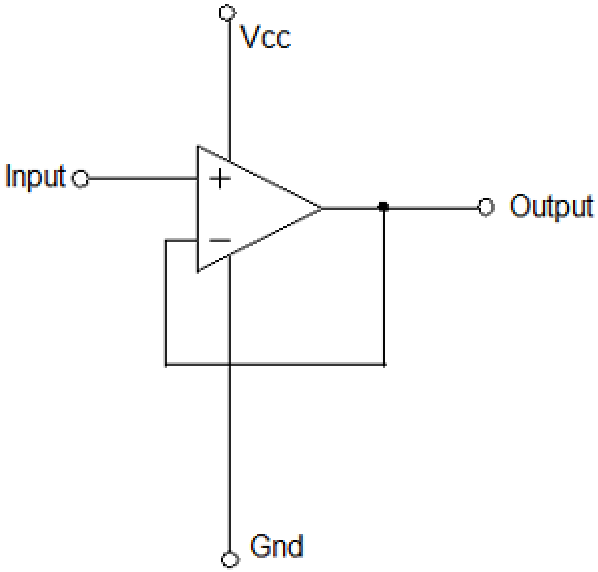
The circuit shown above is an inverting amplifier with the Non inverting input connected to the ground. Two resistors R1 and R2 are connected in the circuit in such a fashion that R1 feeds the input signal while R2 returns the output to the Inverting input. Here when the input signal is positive the output will be negative and vice versa. The voltage change at the output relative to the input depends on the ratio of the resistors R1 and R2. R1 is selected as 1K and R2 as 10K. If the input receives 1 volt, then there will be 1 mA current through R1 and the output will have to become – 10 volts in order to supply 1 mA current through R2 and to maintain zero voltage at the Inverting input. Therefore the voltage gain is R2/R1. That is 10K/1K = 10

Non-inverting Amplifier:



The circuit shown above is a Non inverting amplifier. Here the Non inverting input receives the signal while the Inverting input is connected between R2 and R1. When the input signal moves either positive or negative, the output will be in phase and keeps the voltage at the inverting input same as that of Non inverting input. The voltage gain in this case will be always higher than 1 so (1+R2/R1).

2. Voltage Follower



The circuit above is a voltage follower. Here it provides high input impedance, low output impedance .When the input voltage changes, the output and the inverting input will change equally.

3. Comparator

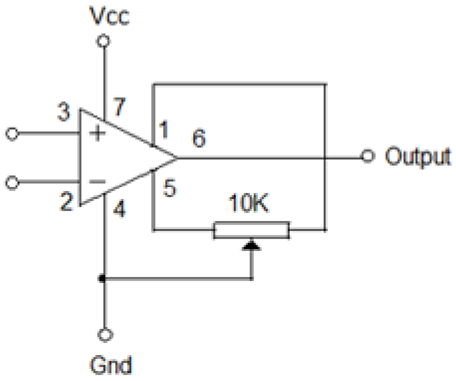
Operational amplifier compares the voltage applied at one input to the voltage applied at the other input. Any difference between the voltages ever if it is small drives the op-amp into saturation. When the voltages supplied to both the inputs are of the same magnitude and the same polarity, then the op-amp output is 0Volts.

A comparator produces limited output voltages which can easily interface with digital logic, even though compatibility needs to be verified.

3 Requirements for OPAMPs:

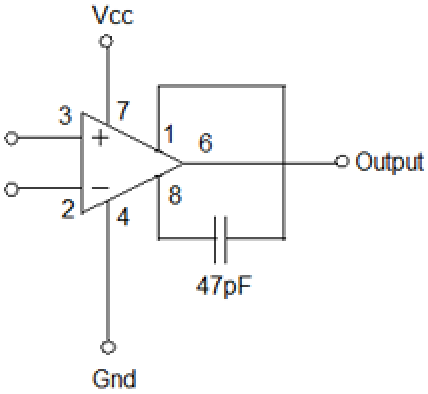
1. Offset Nulling

Most of the OPAMP has an Offset voltage at the output even if the input voltages are same. To make the output to zero voltage, the offset nulling method is used. In most Op-Amps there is a small offset because of their inherent property and results from the mismatches in the input bias arrangement. So a small output voltage is available at the output of some Op-amps even if the input signal is zero. This drawback can be rectified by providing a small offset voltage to the inputs. This is known as the Input Offset voltage. To remove or Null the Offset, most Op-Amps have two pins to enable the offset nulling. For this, a Pot or Preset with a typical value of 100K should be connected between the pins 1 and 5 with its Wiper to the ground. By adjusting the preset, output can be set at Zero voltage.



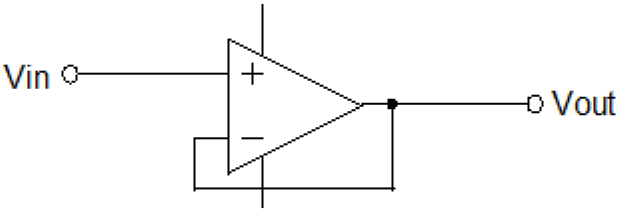
2. Strobing or Phase compensation

Op-Amps may become unstable sometimes and to make them stable for the entire frequency bands a Cap is usually connected between its Strobe pin 8 and pin1. Usually a 47pF disc capacitor is added for phase compensation so that the OpAmp will remain stable. This is most important if the OpAmp is used as a sensitive Amplifier.



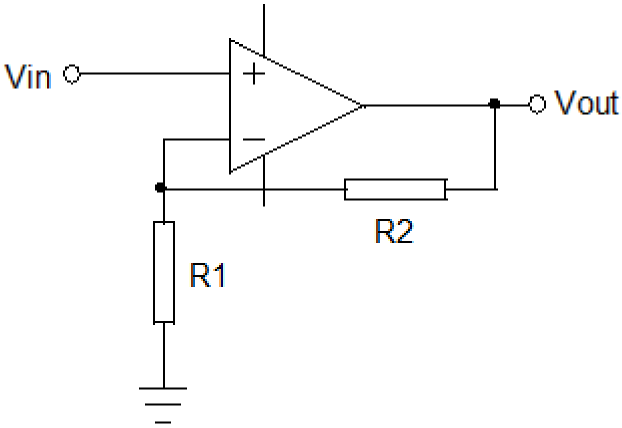
3. Feedback

As you know, the Op-Amp has very high level of amplification typically around 1,000,00 times. Suppose the Op-Amp has 10,000 gain, then the Op-Amp will amplify the difference of voltage in its Non inverting input (V+) and Inverting input (V-). So the output voltage V out is
10,000 x (V+ – V-)



In the diagram, the signal is applied to the Non inverting input and in Inverting input is connected to the output. So V+ = V in and V- = Vout. Therefore Vout = 10,000 x (Vin – Vout). Hence the output voltage is almost equal to the input voltage.

Now let us see how the Feedback works. Simply adding a resistor between the inverting input and the output will reduce the gain considerably. By taking a fraction of the output voltage to the inverting input can reduce the amplification considerably.



As per the earlier equation, V out = 10,000 x (V+ – V-). But here a feedback resistor is added. So Here V+ is Vin and V- is R1.R1+R2 x V out. Therefore V out is 10,000 x (Vin – R1.R1+R2xVout). So V out = R1+R2.R1x Vin

Negative Feedback:

Here the output of the Op-Amp is connected to its Inverting (–) input, thus the output is fed back to the input so as to reach an equilibrium. Thus the input signal at the Non Inverting (+) input will be reflected at the output. The Op-amp with the negative feedback will drive its output to level necessary and hence the voltage difference between its inverting and non inverting inputs will be almost zero.

Positive Feedback:

Here the output voltage is fed back to the Non inverting (+) input. The input signal is fed to the Inverting input. In positive feedback design, if the Inverting input is connected to ground, then the output voltage from the Op-amp will depends on the magnitude and polarity of voltage at the Non inverting input. When the input voltage is positive, then the output of the Op-Amp will be positive and this positive voltage will be fed to the Non inverting input resulting in a full positive output. If the input voltage is negative, then the condition will be reversed.

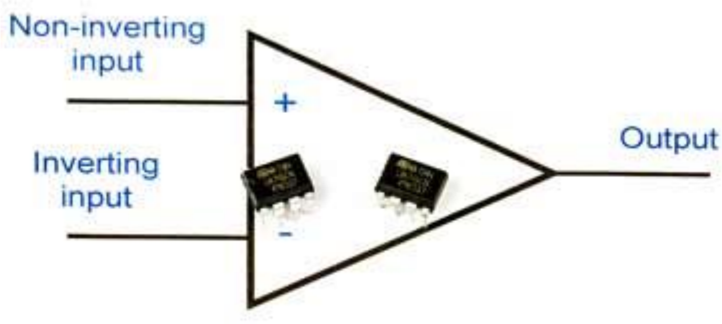
Basics of Op-Amp

Integrated circuits, ICs have made a huge impact on the electronics scene – both analogue and digital circuits have changed the face of electronics.

Within the analogue electronics arena, none has made more difference than the operational amplifier, or op-amp. The op-amp is a differential amplifier and it is a very high performance amplifier circuit block it enables many different electronic amplifier circuits to be designed with the addition of just a handful of other components.

The operational amplifier can form the basis of a host of other circuits ranging from filters to timers, and oscillators to comparators and astables. As such the operational amplifier is one of the most versatile building blocks available to the analogue electronics circuit design engineer and hobbyist.

One of the advantages of using op amp circuits is that the electronic circuit design is often very easy whilst still yielding high performance finished circuits.



Operational amplifier circuit symbol with ICs

Op-amp development

Although the term operational amplifier has now become totally integrated into today's electronics terminology, it may not be realised that it dates back to a paper published in 1947. This described work that was undertaken using these amplifiers in analogue computers of the day.

However it was not until the 1960s that the concept of these amplifiers could be fully realised with the widespread introduction of integrated circuit technology.
In 1963, the first monolithic integrated circuit op amp was introduced. It was the µA702 from Fairchild Semiconductor which had been designed by their engineer Bob Widlar.

Later in 1965 a refinement of the µA702 was launched. Again produced by Fairchild, it was the µA709 and it was the first op amp to become widely used. It worked well, overcoming some of the issues of the ¶micro;A702, although it was necessary to externally compensate the amplifier to prevent it breaking into oscillation.

In 1968 the very famous µA741 was first introduced. This operational amplifier solved the instability issues by incorporating a small 30pF capacitor into the chip within the die. This meant that no external compensation components were required. This difference enabled the 741 to be used particularly widely, and in fact it is still manufactured by some companies to this day. Also the pin configuration has also been carried over to many current day operational amplifier chips.

Since then, many operational amplifier chips have been luched offering improved performance in terms of input impedance, low offsets, low noise and the like, and they have become embedded in analogue electronics circuit design.

Now operational amplifiers have become a fundamental building block used throughout the electronics industry. Even though they have been around for some time, there seems to be little likelihood of their use falling.

What is an Op-Amp? The Basics

An operational amplifier is a very close approximation to a perfect amplifier which has infinite gain, infinite input impedance and zero output impedance. In reality op-amps do not quite attain perfection, but with gains often in the region of 100 000 or more, input impedance levels of Megohms and more and very low output impedance levels, they come sufficiently close to enable the imperfections to be ignored in most cases.

The operational amplifier has two inputs. One is called the inverting input and is marked with a "-" sign on circuit schematic diagrams. The other is the non-inverting input and this is marked with a "+" sign.

The op amp is basically a differential amplifier because the output is proportional to the difference in voltage between the two inputs.

Non-inverting input: The operational amplifier non-inverting input is marked by a "+" sign on the circuit diagram. It is found that a positive voltage applied to the non-inverting input will produce a positive swing at the output. If a changing waveform, such as a sine wave is applied to the non-inverting input, then it will appear in the same sense at

the output. It has not been inverted. Signal applied to the non-inverting input appears at the output in the same senseBy applying an input signal to the non-inverting input and negative feedback to the investing input, it is possible to design a circuit that does not invert the sense of the input signal.

- ***Inverting input:*** The operational amplifier inverting input is marked by a "-" sign on the circuit diagram. A positive voltage applied to the inverting input will produce a negative swing at the output. Thus a sine was applied to the inverting input, will appear inverted at the output. Signal applied to the inverting input appears at the output in the opposite senseBy applying the signal and negative feedback to the inverting input of an operational amplifier, it is possible to design a circuit where the output signal is the inverse of the input.

If the same voltage is applied to both inputs together then there should be no change at the output. In fact the output is proportional to the difference between the inverting and non-inverting inputs. It is for this reason that these amplifiers are often called differential amplifiers.

Like any electronics circuit design, those using operational amplifiers need to have a power supply. Normally op-amps are supplied using dual, i.e. positive and negative supplies. Additionally the supply lines are often not shown as they add confusion to the circuit diagram.

In most cases the operational amplifier will only need five connections for its operation - inverting, non-inverting, output and the two power rails. Very occasionally a further three may be used. These are usually for the "offset null" capability. This is used to reduce any DC offsets that may be present, and for most applications these can be ignored and left disconnected.

Operational amplifier characteristics

Operational amplifiers, op-amps have a number of basic features some of which provide advantages, others limit their performance:

Operational amplifier characteristics

- ***Very high gain:*** One of the key attributes of operational amplifiers is their very high gain. Typical figures extend from around 10 000 upwards – figures of 100 000 and more are common. Although an open loop amplifier with a level of gain of this order would be of little use, op-amps are able to harness the advantages of the very high gain levels by using negative feedback. In this way the gain levels are very controllable and distortion levels can be kept very low.

  The use of negative feedback is key to unlocking the power of operational amplifiers. The high gain of the op-amp combined with clever use of negative feedback means that the negative feedback network is able to control the overall performance of the op-amp circuit block, enables it to perform many different functions.
- ***High input impedance:*** A high input impedance is another key aspect of op-amps. In theory their input resistance should be infinite, and the op-amps in use today come very close to this with impedances anywhere from 0.25MΩ upwards. Some using MOSFET input stages have an impedance of hundreds of MΩ.
- ***Low output impedance:*** The op-amp output impedance is also important. As may be expected this should be low. In the ideal amplifier this should be zero, but in reality many amplifiers have an output impedance of less than a hundred ohms, and many very

much less than this. That said, the drive capability of many IC based op-amps is naturally limited.

- ***Common mode rejection:*** Another important feature of the op-amp is its common mode rejection. This refers to the situation where the same signal is applied to both inputs. For an ideal differential amplifier no output should be seen at the output under these circumstances, however the amplifier will never be perfect.

  The actual common mode rejection ratio, CMMR, is the ratio between the output level when the signal is applied to both inputs compared to the output when it is applied to just one. This figure is expressed in decibels and is typically upwards of 70dB or so.

  By using the common mode rejection of an operational amplifier it is possible to design a circuit that reduces the level of interference on a low level signal. The signal and return lines are applied to the two inputs and only differential signals are amplified, any noise or interference picked up and appearing on both lines will be rejected. This is often used within instrumentation amplifiers.
- ***Limited bandwidth:*** The bandwidth of an op-amp can vary quite widely. An ideal amplifier would have an infinite bandwidth but as one may imagine this would be impossible create, and also very difficult to use and tame in practise. In reality op-amps have a limited bandwidth. Many of the chips used for audio applications may only exhibit their full gain over a relatively small bandwidth, after this the gain falls. Despite this most circuits act to reduce the gain, and enable this smaller level of gain to be maintained over a larger bandwidth.

Basic op-amp circuits

Although operational amplifiers are widely used as amplifiers, they can also be as the basis of many other circuits.

As op amp circuits place feedback around the amplifier, changing this changes the properties of the overall circuit. Not only can changing the feedback alter the level of gain, but it can change the function of the circuit - it is possible to make differentiators, integrators, filters, oscillators, astable, multivibrators, and many more circuits simply by changing the feedback levels and configuration.

There are many different circuits based around op amps. These are generally easy to design and construct.

Operational amplifier varieties

Like any other form of electronic component, operational amplifiers are available in many varieties.Op amps are available in many IC packages. Early op-amps like the µA709 were available in the circular 8 pin metal cans, whilst later op-amps were available in 8 pin dual in line packages. Multiple op-amps were also available in 14 pin DIL packages - there were even dual op-amps available in 8 pin DILs although there was no access to offset null capabilities as there were insufficient pins on the package.

As electronic components moved to surface mount pages, op amps were available in the low count packages, making them easy to drop into different circuits where required.

Operational amplifiers are also available with a wide variety of performance parameters. Part from those offering general performance characteristics, there are others that provide low noise performance, low offset, high input impedance, high frequency performance and a variety of other enhanced areas as well.

Accordingly it is possible to obtain these electronic components on formats and with performance to suit almost every requirement.

The operational amplifier is a very useful building block for analogue electronics. Being a differential amplifier circuit, it lends itself to very many areas or analogue electronics circuit design. In view of the widespread use, chips are very cheap and can be used for a wide variety of functions.

In view of their performance, easy of use and the variety of different circuits in which they can be used, operational amplifiers are used in a huge number of circuits, both as integrated circuits in the own right, and also as circuit blocks within integrated circuit chips that contain large amounts of analogue functionality.