Lecture Five

Amplifiers and Signal Processing, P1

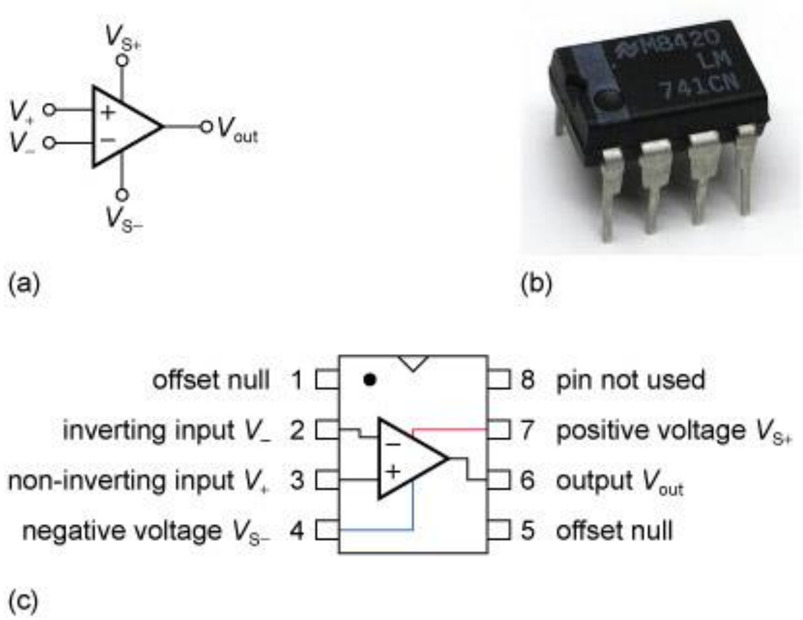
Introduction

Operational amplifiers (op amps) are a staple in modern electronics. Found in everything from industrial flow metering to ultrasound imaging, versatility is their appeal. This building block is unique in that no other single integrated circuit (IC) can be used in so many different applications and configurations.

Today's consumer can purchase a wide variety of home healthcare electronics including automatic blood pressure monitors, fingertip pulse oximeters, digital thermometers, and blood glucose monitors. Op amps, used in medical platforms that include diagnostics, therapy, monitoring, imaging, and instrumentation, can be found in almost any block diagram. In the main signal path, secondary circuits and power supplies, their uses are countless.

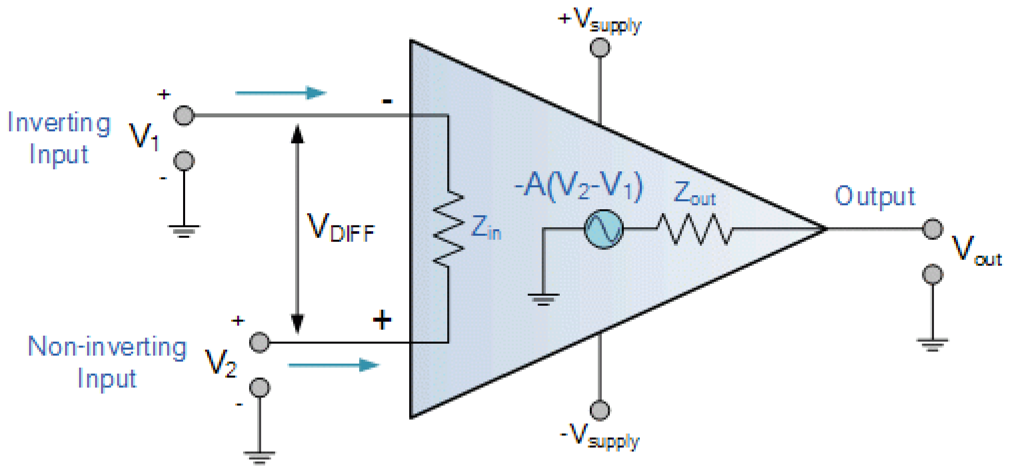
Operational Amplifier Basics

Operational Amplifiers, or Op-amps 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 op-amp 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.

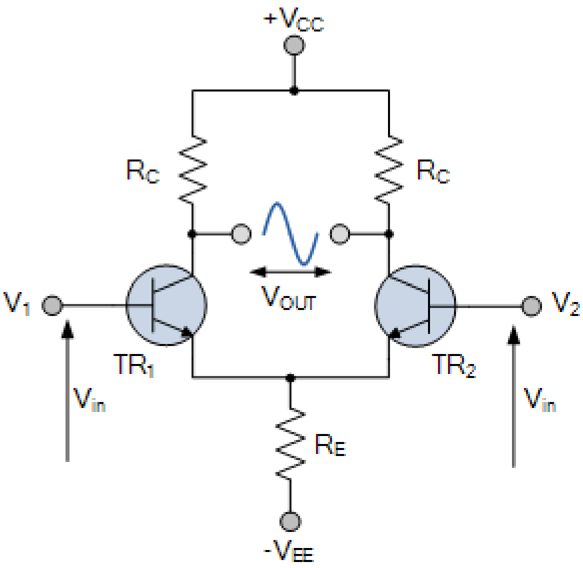


- Voltage: Voltage "in" and Voltage "out"
- Current: Current "in" and Current "out"
- Transconductance: Voltage "in" and Current "out"
- Transresistance: Current "in" and Voltage "out"

Since most of the circuits dealing with operational amplifiers are voltage amplifiers, we will limit our discussion to voltage amplifiers only, (V_{in} and V_{out}). The output voltage signal from an Operational Amplifier is the difference between the signals being applied to its two individual inputs.

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, $-V_{ee}$ by way of resistor R_e.



The circuit operates from a dual supply $+V_{cc}$ and $-V_{ee}$ which ensures a constant supply. The voltage that appears at the output, V_{out} 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, R_e 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.

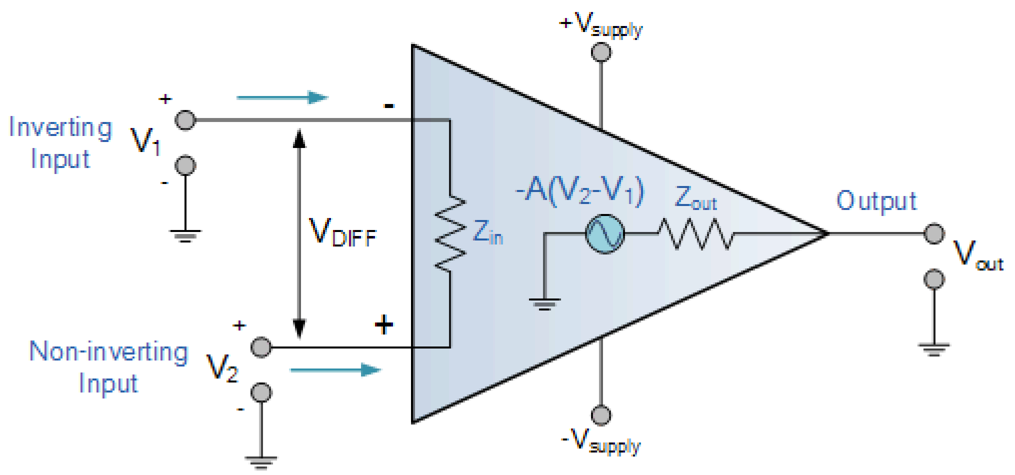
This is known as the *Common Mode of Operation* with the **common mode gain** of the amplifier being the output gain when the input is zero.

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 dependent 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



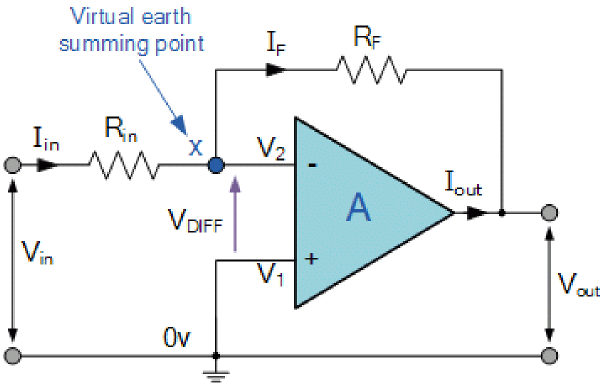
Op-amp Parameter and Idealized Characteristic

- 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 from 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 amplifier's gain becomes unity.
- Offset Voltage, (V_{IO}): **Zero** – The amplifier's 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 regard to the analysis and design of op-amp circuits.

Inverting Operational Amplifier

The Inverting Operational Amplifier configuration is one of the simplest and most commonly used op-amp topologies.



As mentioned before, the **Open Loop Gain**, (A_{VO}) of an operational amplifier can be very high, as much as 1,000,000 (120dB) or more. However, this very high gain is of no real use as it makes the amplifier both unstable and hard to control as the smallest of input signals, just a few micro-volts, (μV) would be enough to cause the output voltage to saturate and swing towards one or the other of the voltage supply rails losing complete control of the output.

As the open loop DC gain of an operational amplifier is extremely high, we can therefore afford to lose some of this high gain by connecting a suitable resistor across the amplifier from the output terminal back to the inverting input terminal to both reduce and control the overall gain of the amplifier. This then produces and effect known commonly as Negative Feedback, and thus produces a very stable Operational Amplifier based system.

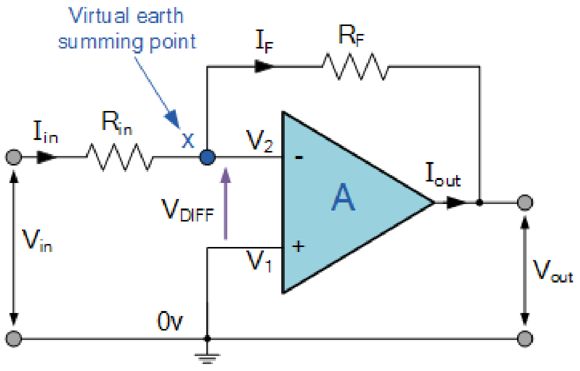
Negative Feedback is the process of "feeding back" a fraction of the output signal back to the input, but to make the feedback negative, we must feed it back to the negative or "inverting input" terminal of the op-amp using an external **Feedback Resistor** called Rf. This feedback connection between the output and the inverting input terminal forces the differential input voltage towards zero.

This effect produces a closed loop circuit to the amplifier resulting in the gain of the amplifier now being called its **Closed-loop Gain**. Then a closed-loop inverting amplifier uses negative feedback to accurately control the overall gain of the amplifier, but at a cost in the reduction of the amplifiers gain.

This negative feedback results in the inverting input terminal having a different signal on it than the actual input voltage as it will be the sum of the input voltage plus the negative feedback voltage giving it the label or term of a *Summing Point*. We must therefore separate the real input signal from the inverting input by using an **Input Resistor**, Rin.

As we are not using the positive non-inverting input, this is connected to a common ground or zero voltage terminal as shown below, but the effect of this closed-loop feedback circuit results in the voltage potential at the inverting input being equal to that at the non-inverting input producing a *Virtual Earth* summing point because it will be at the same potential as the grounded reference input. In other words, the op-amp becomes a "differential amplifier".

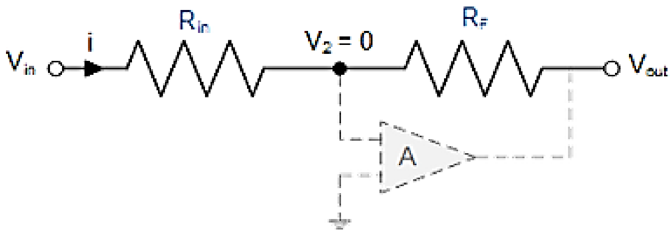
Inverting Operational Amplifier Configuration



In this **Inverting Amplifier circuit,** the operational amplifier is connected with feedback to produce a closed-loop operation. When dealing with operational amplifiers, there are two very important rules to remember about inverting amplifiers, these are: "*No current flows into the input terminal,*" and "*V_1 always equals V_2*". However, in real-world op-amp circuits, both of these rules are slightly broken.

This is because the junction of the input and feedback signal (X) is at the same potential as the positive (+) input which is at zero volts or ground then, the junction is a **"Virtual Earth"**. Because of this virtual earth node, the input resistance of the amplifier is equal to the value of the input resistor, Rin and the closed loop gain of the inverting amplifier can be set by the ratio of the two external resistors. by using the two previously mentioned rules:

- No Current Flows into the Input Terminals
- The Differential Input Voltage is Zero as $V_1 = V_2 = 0$ (Virtual Earth)



we can derive the equation for calculating the closed-loop gain of an inverting amplifier, using first principles.

Current (i) flows through the resistor network as shown.

$$i = \frac{Vin - Vout}{Rin + Rf}$$

$$\text{therefore, } i = \frac{Vin - V2}{Rin} = \frac{V2 - Vout}{Rf}$$

$$i = \frac{Vin}{Rin} - \frac{V2}{Rin} = \frac{V2}{Rf} - \frac{Vout}{Rf}$$

$$\text{so, } \frac{Vin}{Rin} = V2\left[\frac{1}{Rin} + \frac{1}{Rf}\right] - \frac{Vout}{Rf}$$

$$\text{and as, } i = \frac{Vin - 0}{Rin} = \frac{0 - Vout}{Rf} \qquad \frac{Rf}{Rin} = \frac{0 - Vout}{Vin - 0}$$

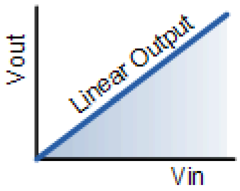
$$\text{the Closed Loop Gain (Av) is given as, } \frac{Vout}{Vin} = -\frac{Rf}{Rin}$$

Then, the **Closed-Loop Voltage Gain** of an Inverting Amplifier is given as.

$$\text{Gain (Av)} = \frac{V_{out}}{V_{in}} = -\frac{R_f}{R_{in}}$$

and this can be transposed to give Vout as:

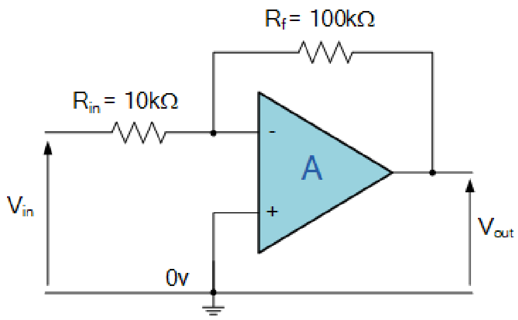
$$\text{Vout} = -\frac{\text{Rf}}{\text{Rin}} \times \text{Vin}$$



The negative sign in the equation indicates an inversion of the output signal with respect to the input as it is 180° out of phase. This is due to the feedback being negative in value. The equation for the output voltage Vout also shows that the circuit is linear in nature for a fixed amplifier gain as Vout = Vin x Gain. This property can be very useful for converting a smaller sensor signal to a much larger voltage.

Inverting Op-amp Example.

Find the closed loop gain of the following inverting amplifier circuit.



Using the previously found formula for the gain of the circuit

$$\text{Gain (Av)} = \frac{V_{out}}{V_{in}} = -\frac{R_f}{R_{in}}$$

we can now substitute the values of the resistors in the circuit as follows,

Rin = 10kΩ and Rf = 100kΩ

and the gain of the circuit is calculated as: -Rf/Rin = 100k/10k = -10

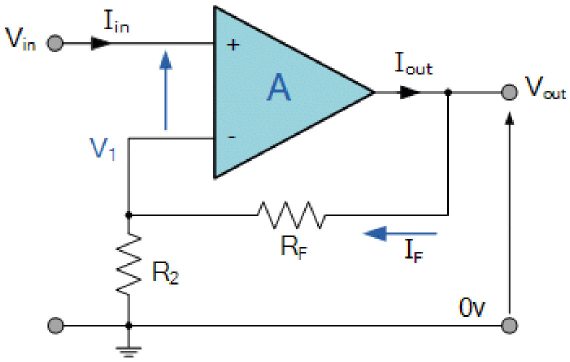
Therefore, the closed-loop gain of the inverting amplifier circuit above is given:

-10 or **20dB** (20log(10)).

Note: in the inverting amplifier, if the two resistors are of equal value, Rin = Rf then the gain of the amplifier will be **-1** producing a complementary form of the input voltage at its output as Vout = -Vin. This type of inverting amplifier configuration is generally called a **Unity Gain Inverter** or simply an *Inverting Buffer*.

Non-inverting Operational Amplifier

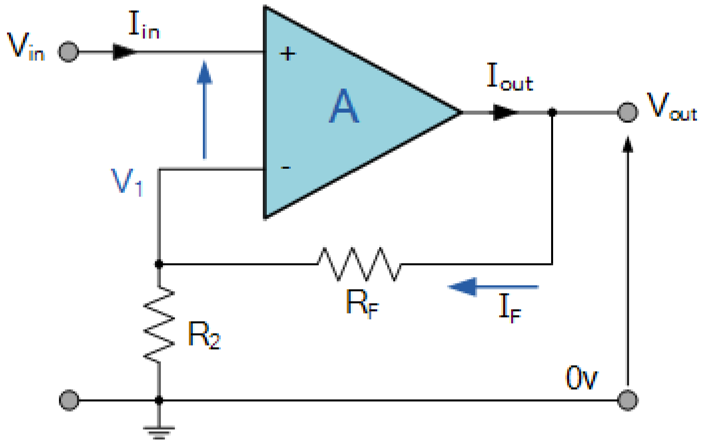
The second basic configuration of an operational amplifier circuit is that of a **Non-inverting Operational Amplifier** design.



In this configuration, the input voltage signal, (V_{IN}) is applied directly to the non-inverting (+) input terminal which means that the output gain of the amplifier becomes “Positive” in value in contrast to the “Inverting Amplifier” circuit whose output gain is negative in value. The result of this is that the output signal is “in-phase” with the input signal.

Feedback control of the non-inverting operational amplifier is achieved by applying a small part of the output voltage signal back to the inverting (-) input terminal via an R_f – R_2 voltage divider network, again producing negative feedback. This closed-loop configuration produces a non-inverting amplifier circuit with very good stability, a very high input impedance, Rin approaching infinity, as no current flows into the positive input terminal, (ideal conditions) and a low output impedance.

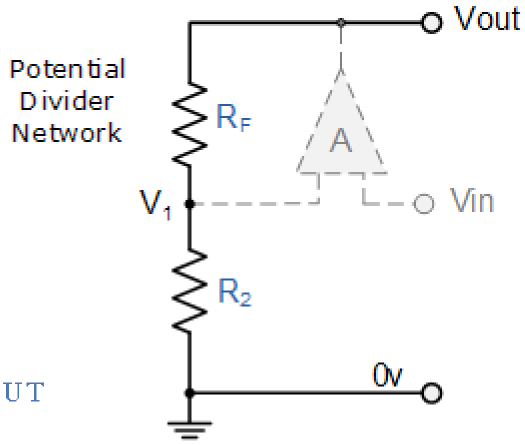
Non-inverting Operational Amplifier Configuration



In the inverting amplifier, we said that for an ideal op-amp, "No current flows into the input terminal" of the amplifier and that "V_1 always equals V_2". This was because the junction of the input and feedback signal (V_1) are at the same potential. In other words, the junction is a "virtual earth" summing point. Because of this virtual earth node, the resistors, R_f and R_2 form a simple potential divider network across the non-inverting amplifier, with the voltage gain of the circuit being determined by the ratios of R_2 and R_f.

Equivalent Potential Divider Network

Then using the formula to calculate the output voltage of a potential divider network, we can calculate the closed-loop voltage gain (A_V) of the **Non-inverting Amplifier** as follows:



$$V_1 = \frac{R_2}{R_2 + R_F} \times V_{OUT}$$

$$\text{Ideal Summing Point: } V_1 = V_{IN}$$

$$\text{Voltage Gain, } A_{(V)} \text{ is equal to: } \frac{V_{OUT}}{V_{IN}}$$

$$\text{Then, } A_{(V)} = \frac{V_{OUT}}{V_{IN}} = \frac{R_2 + R_F}{R_2}$$

$$\text{Transpose to give: } A_{(V)} = \frac{V_{OUT}}{V_{IN}} = 1 + \frac{R_F}{R_2}$$

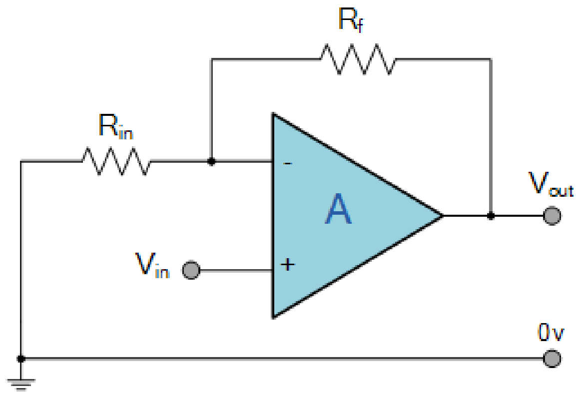
Then the closed-loop voltage gain of a **Non-inverting Operational Amplifier** will be given as:

$$A_{(v)} = 1 + \frac{R_F}{R_2}$$

We can see from the equation above, that the overall closed-loop gain of a non-inverting amplifier will always be greater but never less than one (unity), it is positive in nature and is determined by the ratio of the values of Rf and R2.

If the value of the feedback resistor Rf is zero, the gain of the amplifier will be exactly equal to one (unity). If resistor R2 is zero the gain will approach infinity, but in practice it will be limited to the operational amplifiers open-loop differential gain, (A_O).

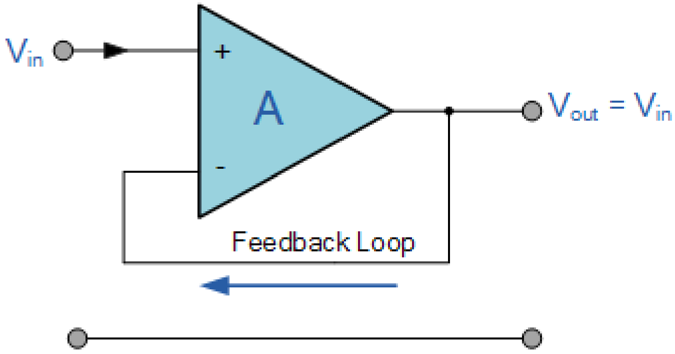
We can easily convert an inverting operational amplifier configuration into a non-inverting amplifier configuration by simply changing the input connections as shown.



Voltage Follower (Unity Gain Buffer)

If we made the feedback resistor, R_f equal to zero, ($R_f = 0$), and resistor R_2 equal to infinity, ($R_2 = \infty$), then the resulting circuit would have a fixed gain of "1" (unity) as all the output voltage is fed back to the inverting input terminal (negative feedback). This configuration would produce a special type of the non-inverting amplifier circuit called a **Voltage Follower**, also known as a "unity gain buffer".

Non-inverting Voltage Follower



The output is connected directly back to the negative inverting input, so the feedback is 100%, and Vin is exactly equal to V_{out}, giving it a fixed gain of 1 or unity. As the input voltage, Vin, is applied to the non-inverting input, the voltage gain of the amplifier is therefore given as:

$$V_{out} = A(V_{in})$$

$$(V_{in} = V+) \text{ and } (V_{out} = V-)$$

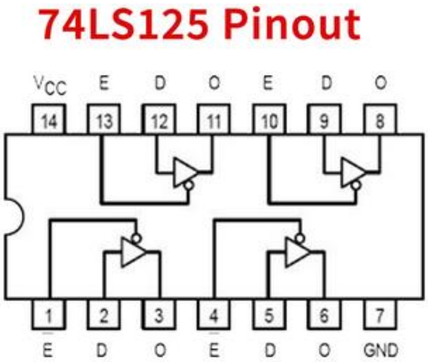
$$\text{therefore Gain, } (A_V) = \frac{V_{out}}{V_{in}} = +1$$

Since no current flows into the non-inverting input terminal, the input impedance is infinite (ideal conditions), so zero current will flow through the feedback loop. Thus, any value of resistance may be placed in the feedback loop without affecting the characteristics of the circuit as no current flows through it, so there is zero voltage drop across it, resulting in zero power loss.

As the input impedance is extremely high, the unity gain buffer (voltage follower) can be used to provide a large power gain as the extra power comes from the op-amp supply rails and through the output of the op-amp to the load and not directly from the input. However, in most real unity gain buffer circuits, there are leakage currents, and parasitic capacitances present, so a low value (typically 1kΩ) resistor is required in the feedback loop to help reduce the effects of these leakage currents providing stability, especially if the operational amplifier is of a current feedback type.

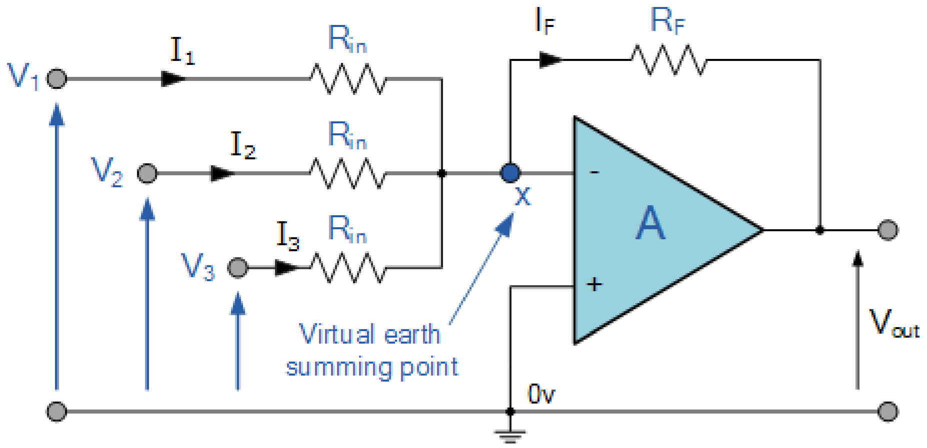
The voltage follower or unity gain buffer is a special and very useful type of **Non-inverting amplifier** circuit that is commonly used in electronics to isolated circuits from each other, especially in High-order state variable or Sallen-Key type active filters to separate one filter stage from the other. Typical digital buffer IC's available are the 74LS125 Quad 3-state buffer or the more common 74LS244 Octal buffer.

One final thought, the closed loop voltage gain of a voltage follower circuit is "1" or **Unity**. The open loop voltage gain of an operational amplifier with no feedback is **Infinite**. Then by carefully selecting the feedback components we can control the amount of gain produced by a non-inverting operational amplifier anywhere from one to infinity.



The Summing Amplifier

The summing amplifier is another type of operational amplifier circuit configuration that is used to combine the voltages present on two or more inputs into a single output voltage. If we add more input resistors to the input of the inverting operational amplifier, each equal in value to the original input resistor, (Rin) we end up with another operational amplifier circuit called a **Summing Amplifier**, "*summing inverter*" or even a "*voltage adder*" circuit as shown.



In this simple summing amplifier circuit, the output voltage, (V_{out}) now becomes proportional to the sum of the input voltages, V_1, V_2, V_3, etc. Then we can modify the original equation for the inverting amplifier to take account of these new inputs thus:

$$I_F = I_1 + I_2 + I_3 = -\left[\frac{V1}{Rin} + \frac{V2}{Rin} + \frac{V3}{Rin}\right]$$

$$\text{Inverting Equation: } Vout = -\frac{Rf}{Rin} \times Vin$$

$$\text{then, } -Vout = \left[\frac{R_F}{Rin}V1 + \frac{R_F}{Rin}V2 + \frac{R_F}{Rin}V3\right]$$

However, if all the input impedances, (R_{IN}) are equal in value, we can simplify the above equation to give an output voltage of:

$$-Vout = \frac{R_F}{R_{IN}}\left(V1 + V2 + V3 \ldots .etc\right)$$

We now have an operational amplifier circuit that will amplify each individual input voltage and produce an output voltage signal that is proportional to the algebraic "SUM" of the three individual input voltages V_1, V_2 and V_3.

Note that when the summing point is connected to the inverting input of the op-amp the circuit will produce the negative sum of any number of input voltages. Likewise, when the summing point is connected to the non-inverting input of the op-amp, it will produce the positive sum of the input voltages.

A **Scaling Summing Amplifier** can be made if the individual input resistors are "NOT" equal. Then the equation would have to be modified to:

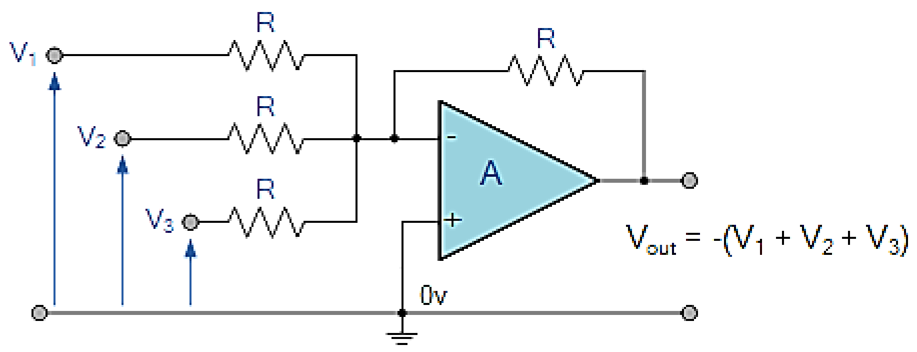
$$-V_{OUT} = V_1\left(\frac{R_f}{R_1}\right) + V_2\left(\frac{R_f}{R_2}\right) + V_3\left(\frac{R_f}{R_3}\right) \text{....etc}$$

To make the math's a little easier, we can rearrange the above formula to make the feedback resistor R*f* the subject of the equation giving the output voltage as:

$$-V_{OUT} = R_f\left(\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}\right) \text{....etc}$$

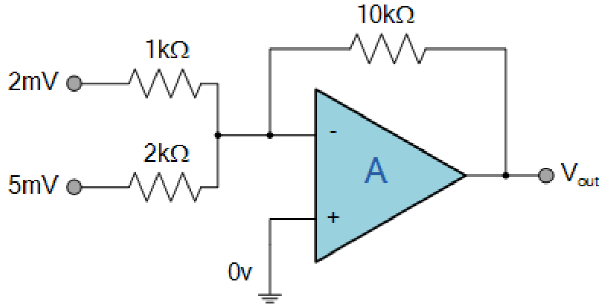
This allows the output voltage to be easily calculated if more input resistors are connected to the amplifiers inverting input terminal. The input impedance of each individual channel is the value of their respective input resistors, ie, R_1, R_2, R_3 … etc.

Sometimes we need a summing circuit to just add together two or more voltage signals without any amplification. By putting all of the resistances of the circuit above to the same value R, the op-amp will have a voltage gain of unity and an output voltage equal to the direct sum of all the input voltages as shown:



Summing Amplifier Example

Find the output voltage of the following *Summing Amplifier* circuit.



Using the previously found formula for the gain of the circuit:

$$\text{Gain (Av)} = \frac{V_{out}}{V_{in}} = -\frac{R_f}{R_{in}}$$

We can now substitute the values of the resistors in the circuit as follows:

$$A_1 = \frac{10k\Omega}{1k\Omega} = -10$$

$$A_2 = \frac{10k\Omega}{2k\Omega} = -5$$

We know that the output voltage is the sum of the two amplified input signals and is calculated as:

$$V_{out} = (A_1 \times V_1) + (A_2 \times V_2)$$

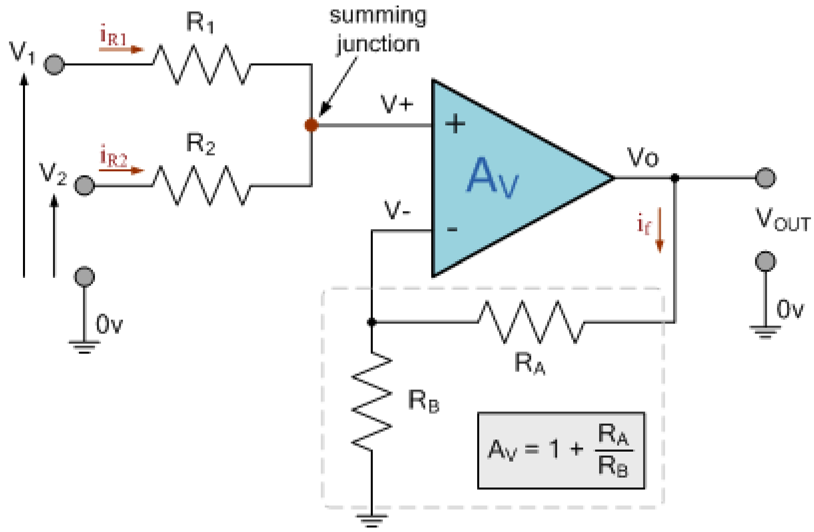
$$V_{out} = (-10(2mV)) + (-5(5mV)) = -45mV$$

Then the output voltage of the **Summing Amplifier** circuit above is given as **-45 mV** and is negative as its an inverting amplifier.

Non-inverting Summing Amplifier

But as well as constructing inverting summing amplifiers, we can also use the non-inverting input of the operational amplifier to produce a *non-inverting summing amplifier*. We have seen above that an inverting summing amplifier produces the negative sum of its input voltages then it follows that the non-inverting summing amplifier configuration will produce the positive sum of its input voltages.

As its name implies, the non-inverting summing amplifier is based around the configuration of a non-inverting operational amplifier circuit in that the input (either ac or dc) is applied to the non-inverting (+) terminal, while the required negative feedback and gain are achieved by feeding back some portion of the output signal (V_{OUT}) to the inverting (-) terminal as shown.



Besides the most obvious fact that the output voltage of the op-amp (V_{OUT}) is in phase with its input, and the output voltage is the weighted sum of all its inputs which themselves are determined by their resistance ratios, the biggest advantage of the non-inverting summing amplifier is that because there is no virtual earth condition across the input terminals, its input impedance is much higher than that of the standard inverting amplifier configuration.

Also, the input summing part of the circuit is unaffected if the op-amps closed-loop voltage gain is changed. However, there is more math involved in selecting the weighted gains for each individual input at the summing junction, especially if there are more than two inputs, each with a different weighting factor. Nevertheless, if all the inputs have the same resistive values, then the math involved will be a lot less.

If the closed-loop gain of the non-inverting operational amplifier is made equal to the number of summing inputs, then the op-amps output voltage will be exactly equal to the sum of all the input voltages. That is for a two-input non-inverting summing amplifier, the op-amp's gain is equal to 2; for a three-input summing amplifier, the op-amp's gain is 3, and so on. This is because the currents which flow in each input resistor are a function of the voltage at all its inputs. If the input resistances are made all equal, ($R_1 = R_2$), then the circulating currents cancel out as they cannot flow into the high impedance non-inverting input of the op-amp and the v output voltage becomes the sum of its inputs.

For a 2-input non-inverting summing amplifier, the currents flowing into the input terminals can be defined as:

$$I_{R1} + I_{R2} = 0 \quad (KCL)$$

$$\frac{V_1 - V+}{R_1} = \frac{V_2 - V+}{R_2} = 0$$

$$\therefore \left(\frac{V_1}{R_1} - \frac{V+}{R_1}\right) + \left(\frac{V_2}{R_2} - \frac{V+}{R_2}\right) = 0$$

If we make the two input resistances equal in value, then $R_1 = R_2 = R$.

$$V+ = \frac{\frac{V_1}{R} + \frac{V_2}{R}}{\frac{1}{R} + \frac{1}{R}} = \frac{\frac{V_1 + V_2}{R}}{\frac{2}{R}}$$

$$\text{Thus} \quad V+ = \frac{V_1 + V_2}{2}$$

The standard equation for the voltage gain of a non-inverting summing amplifier circuit is given as:

$$A_V = \frac{V_{OUT}}{V_{IN}} = \frac{V_{OUT}}{V+} = 1 + \frac{R_A}{R_B}$$

$$\therefore \quad V_{OUT} = \left[1 + \frac{R_A}{R_B}\right] V+$$

$$\text{Thus:} \quad V_{OUT} = \left[1 + \frac{R_A}{R_B}\right] \frac{V_1 + V_2}{2}$$

The non-inverting amplifier closed-loop voltage gain A_V is given as 1 + R_A/R_B. If we make this closed-loop voltage gain equal to 2 by making $R_A = R_B$, then the output voltage V_O becomes equal to the sum of all the input voltages, as shown.

$$V_{OUT} = \left[1 + \frac{R_A}{R_B}\right]\frac{V_1 + V_2}{2}$$

$$\text{If } R_A = R_B$$

$$V_{OUT} = [1+1]\frac{V_1 + V_2}{2} = \not{2}\,\frac{V_1 + V_2}{\not{2}}$$

$$\therefore V_{OUT} = V_1 + V_2$$

Thus, for a 3-input non-inverting summing amplifier configuration, setting the closed-loop voltage gain to 3 will make V_{OUT} equal to the sum of the three input voltages, V_1, V_2, and V_3. Likewise, for a four-input summer, the closed-loop voltage gain would be 4, and 5 for a 5-input summer, and so on. Note also that if the amplifier of the summing circuit is connected as a unity follower with R_A equal to zero and R_B equal to infinity, then with no voltage gain, the output voltage V_{OUT} will equal the average value of all the input voltages. That is $V_{OUT} = (V_1 + V_2)/2$.

Summing Amplifier Applications

So what can we use summing amplifiers for, either inverting or non-inverting? If the input resistances of a summing amplifier are connected to potentiometersthe , input signals can be mixed in varying amounts.

For example, measuring temperature, you could add a negative offset voltage to make the output voltage or display read “0” at the freezing point or produce an audio mixer for adding or mixing individual waveforms (sounds) from different source channels (vocals, instruments, etc.) before sending them combined to an audio amplifier.