UNIT 3

OPERATIONAL AMPLIFIER

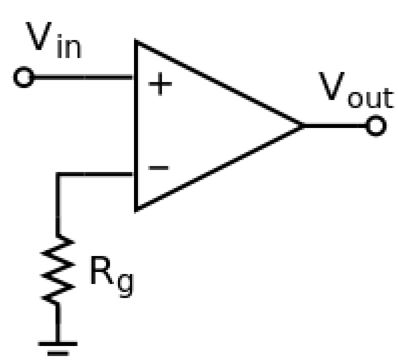
An operational amplifier (often op-amp or opamp) is a DC-coupled high-gain electronic voltage amplifier with a differential input and, usually, a single-ended output.

In this configuration, an op-amp produces an output potential (relative to circuit ground) that is typically hundreds of thousands of times larger than the potential difference between its input terminals. Operational amplifiers had their origins in analog computers, where they were used to perform mathematical operations in many linear, non-linear, and frequency-dependent circuits.

The popularity of the op-amp as a building block in analog circuits is due to its versatility. By using negative feedback, the characteristics of an op-amp circuit, its gain, input and output impedance, bandwidth etc. are determined by external components and have little dependence on temperature coefficients or engineering tolerance in the op-amp itself.

The amplifier's differential inputs consist of a non-inverting input (+) with voltage V_+ and an inverting input (–) with voltage V_-; ideally the op-amp amplifies only the difference in voltage between the two, which is called the differential input voltage. The output voltage of the op-amp V_{out} is given by the equation

$$V_{\text{out}} = A_{\text{OL}}(V_+ - V_-)$$



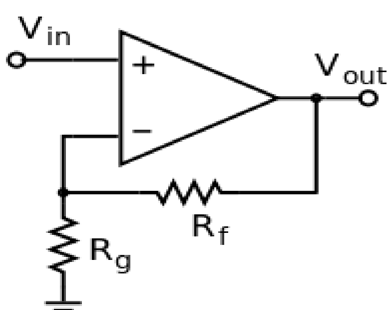
OPEN-LOOP AMPLIFIER

The magnitude of A_{OL} is typically very large (100,000 or more for integrated circuit op-amps), and therefore even a quite small difference between V_+ and V_- drives the amplifier output nearly to the supply voltage. Situations in which the output voltage is equal to or greater than the supply voltage are referred to as *saturation* of the amplifier. The magnitude of A_{OL} is not well controlled by the manufacturing process, and so it is impractical to use an open-loop amplifier as a stand-alone differential amplifier.

Without negative feedback, and perhaps with positive feedback for regeneration, an op-amp acts as a comparator. If the inverting input is held at ground (0 V) directly or by a resistor R_g, and the input voltage V_{in} applied to the non-inverting input is positive, the output will be maximum positive; if V_{in} is negative, the output will be maximum negative. Since there is no feedback from the output to either input, this is an *open-loop* circuit acting as a comparator.

CLOSED-LOOP AMPLIFIER

If predictable operation is desired, negative feedback is used, by applying a portion of the output voltage to the inverting input. The *closed-loop* feedback greatly reduces the gain of the circuit. When negative feedback is used, the circuit's overall gain and response becomes determined mostly by the feedback network, rather than by the op-amp characteristics.



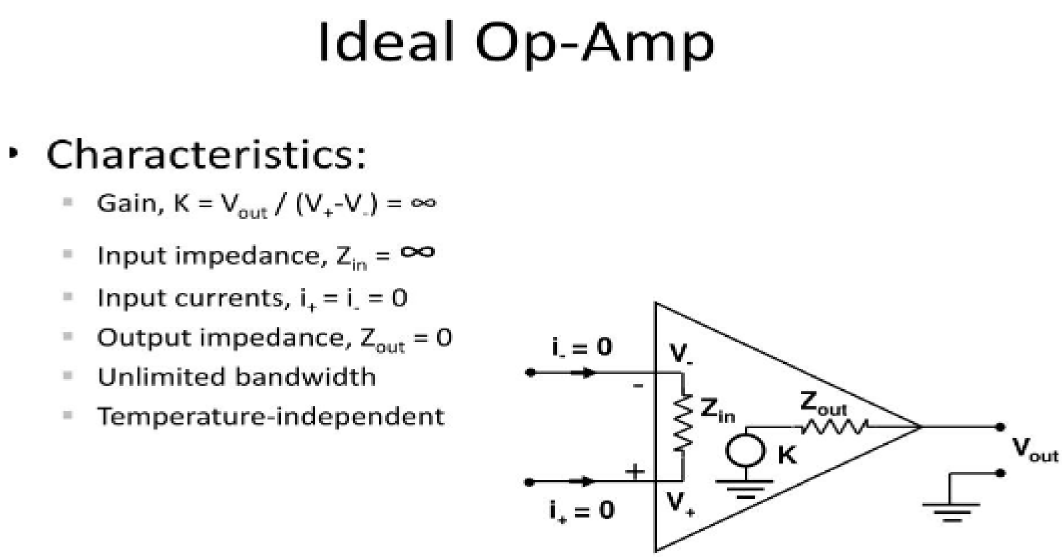
If the feedback network is made of components with values small relative to the op amp's input impedance, the value of the op-amp's open-loop response A_{OL} does not seriously affect the circuit's performance. The response

of the op-amp circuit with its input, output, and feedback circuits to an input is characterized mathematically by a transfer function; designing an op-amp circuit to have a desired transfer function is in the realm of electrical engineering. The transfer functions are important in most applications of op-amps, such as in analog computers. High input impedance at the input terminals and low output impedance at the output terminal(s) are particularly useful features of an op-amp.

OPERATIONAL AMPLIFIER: THE IDEAL op amp is an amplifier with infinite input impedance, infinite open-loop gain, zero output impedance, infinite bandwidth, and zero noise. It has positive and negative inputs which allow circuits that use feedback to achieve a wide range of functions.
Using op amps, it's easy to make amplifiers, comparators, log amps, filters, oscillators, data converters, level translators, references, and more. Mathematical functions like addition, subtraction, multiplication, and integration can be easily accomplished.

Practical, real-world op amps have finite characteristics but in most applications, are close enough to the ideal to make a huge range of inexpensive, high-performance analog applications possible. They are the building block for analog design.

One key to op amp design is nodal analysis. Since the input impedance is infinite, the current in and out of the + and - input nodes defines the circuit's behavior.



Inverting & Non-Inverting Amplifier Basics

An "ideal" or perfect operational amplifier is a device with certain special characteristics such as infinite open-loop gain, infinite input resistance, zero output resistance, infinite bandwidth and zero offset. Operational amplifiers are used extensively in signal conditioning or perform mathematical operations as they are nearly ideal for DC amplification. It is fundamentally a voltage amplifying device used with external feedback components such as resistors and capacitors between its output and input terminals. An operational amplifier is basically a three-terminal device consisting of two high impedance inputs, one called the inverting input (–) and the other one called the non-inverting input (+). The third terminal represents the operational amplifiers output port which can both sink and source either a voltage or a current.

Negative feedback

While on the one hand, operational amplifiers offer very high gain, it makes the amplifier unstable & hard to control. Some of this gain can be lost by connecting a resistor across the amplifier from the output terminal back to the inverting input terminal to control the final gain of the amplifier. This is commonly known as negative feedback and produces a more stable op-amp.

Negative feedback is the process of feeding a part of the output signal back to the input. But to make the feedback negative, it is fed to the negative or "inverting input" terminal of the op-amp using a resistor. This effect produces a closed loop circuit resulting in Closed-loop Gain. A closed-loop inverting

amplifier uses negative feedback to accurately control the overall gain of the amplifier, but causes a reduction in the amplifiers gain.

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 we saw in the last tutorial 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 a R*ƒ* – R2 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, Rout as shown below.

In the previous Inverting Amplifier tutorial, we said that for an ideal op-amp "No current flows into the input terminal" of the amplifier and that "V1 always equals V2". This was because the junction of the input and feedback signal (V1) 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*ƒ* and R2 form a simple potential divider network across the non-inverting amplifier with the voltage gain of the circuit being determined by the ratios of R2 and R*ƒ* as shown below.

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:**

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

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

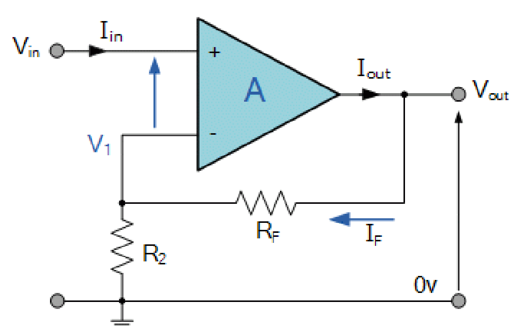
$$\text{Voltage Gain, } A_{(V)} \text{ is equal to:} \quad \frac{V_{OUT}}{V_{IN}}$$

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

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

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

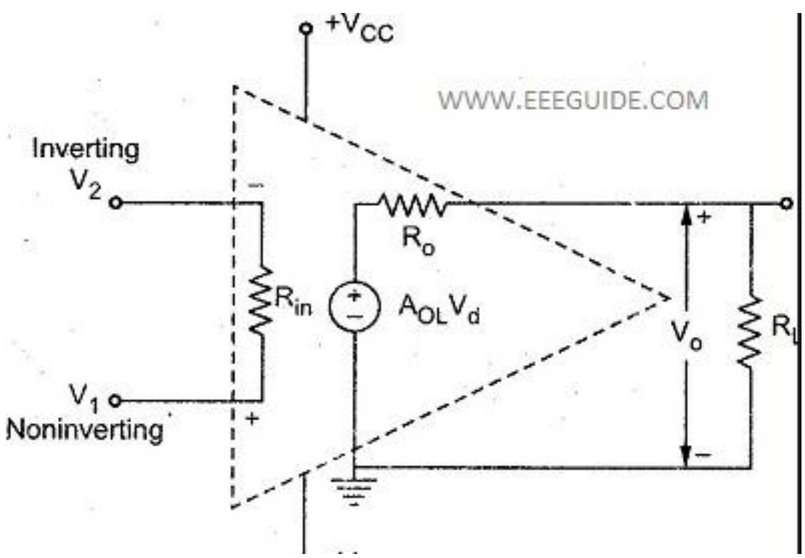
$$A_{(v)} = 1 + \frac{R_F}{R_2}$$



Inverting amplifier

In an inverting amplifier circuit, the operational amplifier inverting input receives feedback from the output of the amplifier. Assuming the op-amp is ideal and applying the concept of virtual short at the input terminals of op-amp, the voltage at the inverting terminal is equal to non-inverting terminal. The non-inverting input of the operational amplifier is connected to ground. As the gain of the op amp itself is very high and the output from the amplifier is a matter of only a few volts, this means that the difference between the two input terminals is exceedingly small and can be ignored. As the non-inverting input of the operational amplifier is held at ground potential this means that the inverting input must be virtually at earth potential.

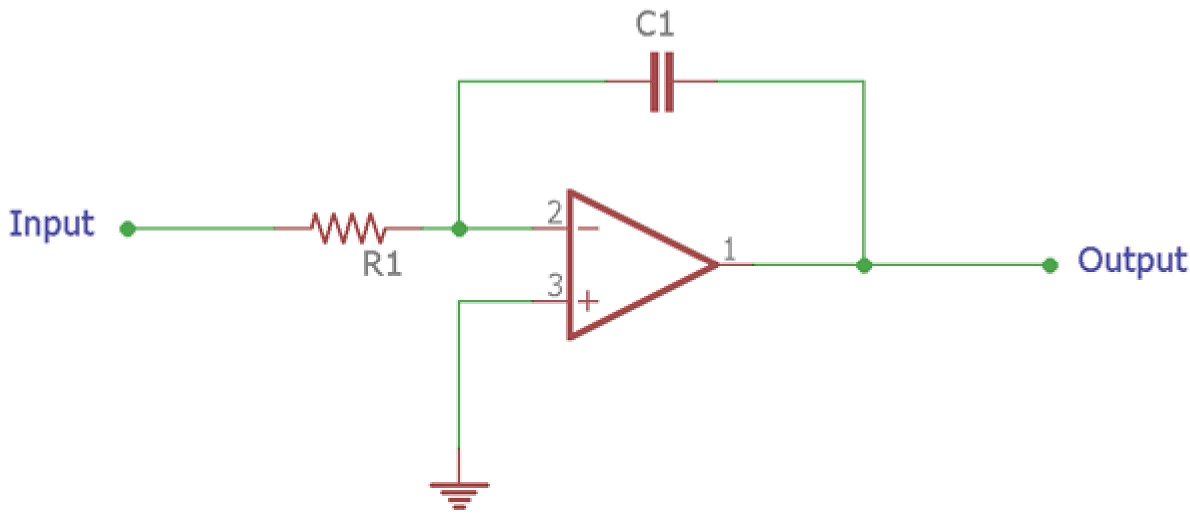
Equivalent Circuit model OPAMP



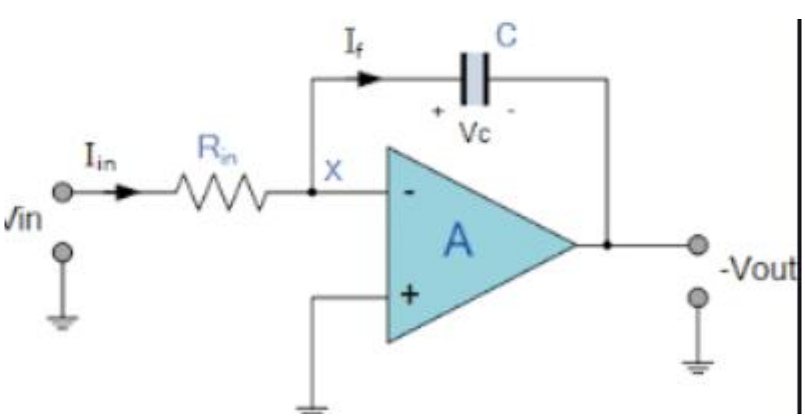
OP AMP APPLICATION IN INTEGRATION

Construction and Working of Op-amp Integrator Circuit

Op-amp is very widely used component in Electronics and is used to build many useful amplifier circuits.



The construction of simple Integrator circuit using op-amp **requires two passive components and one active component. The two passive components are resistor and capacitor. The Resistor and the Capacitor form a first-order low pass filter across the active component Op-Amp. Integrator circuit is exactly opposite of Op-amp differentiator circuit.**



A simple Op-amp configuration consists of two resistors, which creates a feedback path. In the case of Integrator amplifier, the feedback resistor is changed with a capacitor.The resistor R1 and capacitor C1 is connected across the amplifier. The amplifier is in Inverting configuration.

Op-amp gain is Infinite, therefore the Inverting input of the amplifier is a virtual ground. When a voltage is applied across the R1, the current start to flow through the resistor as the capacitor has very low resistance. The capacitor is connected in the feedback position and the resistance of the capacitor is insignificant.

At this situation, if the amplifier gain ratio is calculated, the result will be less than the unity. This is because the gain ratio, X_C/R_1 **is too small. Practically, the capacitor has very low resistance between the plates and whatever the value R1 holds, the output result of** X_C/R_1 **will be very low.**

The capacitor begins to charge up by the input voltage and in the same ratio, the capacitor impedance also starts to increase. The charging rate is determined by the RC - time constant of R1 and C1. The op-amp virtual earth now hampered and the negative feedback will produce an output voltage across the op-amp to maintain the virtual earth condition across the input.

The Op-amp produce a ramp output till the capacitor gets fully charged. The capacitor charges current decreases by the influence of the potential difference between the Virtual earth and the negative output.

$$\frac{Vin - 0}{R1} = C1\frac{d(0 - V_{out})}{dt}$$

$$=> \frac{Vin}{R1} = -C1\frac{dV_{out}}{dt}$$

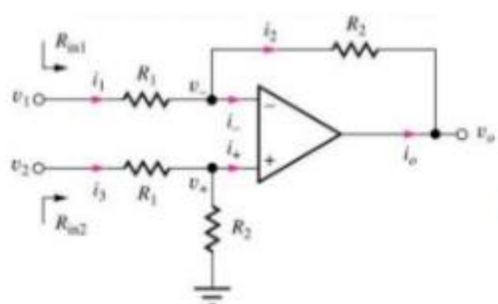
Now, integrating both sides,

$$=> \int_0^t \frac{Vin}{R1} = -\int_0^t C1\frac{dV_{out}}{dt}$$

Or the **ideal output voltage of op-amp integrator is**

$$V_{out} = -\frac{1}{R1C1}\int_0^t Vin\,dt = -\int_0^t Vin\,\frac{dt}{R1\,C1}$$

The Difference Amplifier



$$v_o = v_- - i_2R_2 = v_- - i_1R_2$$

$$= v_- - \frac{R_2}{R_1}(v_1 - v_-) = \left(\frac{R_1+R_2}{R_1}\right)v_- - \frac{R_2}{R_1}v_1$$

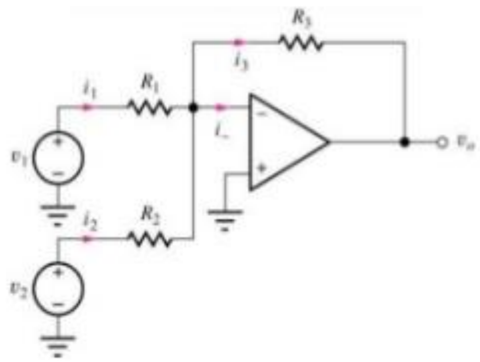
Also, $v_+ = \frac{R_2}{R_1+R_2}v_2$

Since $v_- = v_+$ $\quad v_o = -\frac{R_2}{R_1}(v_1 - v_2)$

For $R_2 = R_1$ $\quad v_o = -(v_1 - v_2)$

- This circuit is also called a differential amplifier, since it amplifies the difference between the input signals.
- R_{in2} is series combination of R_1 and R_2 because i_+ is zero.
- For v_2=0, R_{in1}= R_1, as the circuit reduces to an inverting amplifier.
- For general case, i_1 is a function of both v_1 and v_2.

The Summing Amplifier



Since the negative amplifier input is at virtual ground,

$$i_1 = \frac{v_1}{R_1} \quad i_2 = \frac{v_2}{R_2} \quad i_3 = -\frac{v_o}{R_3}$$

Since $i_- = 0$, $i_3 = i_1 + i_2$,

$$\therefore v_o = -\frac{R_3}{R_1}v_1 - \frac{R_3}{R_2}v_2$$

- Scale factors for the 2 inputs can be independently adjusted by the proper choice of R_2 and R_1.
- Any number of inputs can be connected to a summing junction through extra resistors.
- This circuit can be used as a simple digital-to-analog converter. This will be illustrated in more detail, later