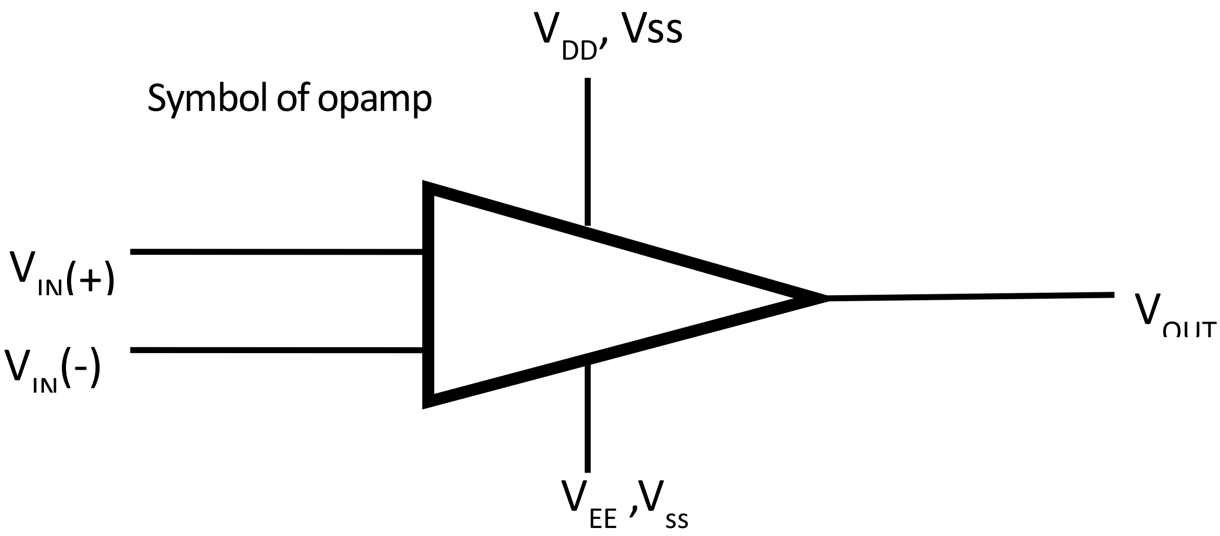
Operational Amplifier(op amp)

- An Operational Amplifier (op amp) is an analog circuit block that takes a differential voltage input and produces a single-ended voltage output.
- An op-amp is so called because it is used for various computational operations such as comparison, addition, subtraction, differentiation, and integral.
- The electronic symbol for op-amps is shown below. An op-amp has five terminals: 1) noninverting input, 2) inverting input, 3) output, 4) positive power supply, and 5) negative power supply. Here, “inverting” and “noninverting” indicate the polarity with respect to the output.

Symbol of opamp



- **V_{IN} (+) ---Non Inverting Input** **V_{IN} (-) --- Inverting Input**
- **V_{OUT} ----- output**
- **V_{DD},V_{CC} – Positive Power Supply**
- **V_{EE}, V_{SS}---Negative power supply**

- The voltage applied to the noninverting input is amplified by a factor of A_V with respect to the inverting input potential. The output has the same phase as the noninverting input.
- The voltage applied to the inverting input is also amplified by a factor of A_V with respect to the noninverting input potential. The output has the opposite phase to the inverting input.
- The output provides a voltage equal to a difference in voltage between the inverting and noninverting inputs multiplied by AV. Therefore, when the inverting and noninverting inputs have the same voltage and phase, the output voltage becomes zero. When the inverting and noninverting inputs have the same voltage and opposite phases, the output has the same phase as the noninverting input and provides a voltage equal to twice the difference between their voltages multiplied by AV.

- Application of op amp
- A wide range of IoT home appliances and other electronic applications, op-amps are used to amplify analog signals from sensors and measuring instruments.

Characteristics of opamp

- **Open-loop gain**

  Open-loop gain: The open-loop gain of an operational amplifier is the measure of the gain achieved when there is no feedback implemented in the circuit.

- **Input Impedance**

 important characteristic of op amps is that they generally have high input impedance. Input impedance is measured between the negative and positive input terminals, and its ideal value is infinity, which minimizes loading of the source.

- **Output impedance**
- An operational amplifier ideally has zero output impedance. However, the output impedance typically has a small value, which determines the amount of current it can drive, and how well it can operate as a voltage buffer.
- **Frequency response and bandwidth (BW)**
- An ideal op amp would have an infinite bandwidth (BW), and would be able to maintain a high gain regardless of signal frequency. However, all operational amplifiers have a finite bandwidth, generally called the "-3dB point," where the gain begins to roll as frequency increases. The gain of the amplifier then decreases at a rate of -20dB/decade while the frequency increases. Op amps with a higher BW have improved performance because they maintain higher gains at higher frequencies; however, this higher gain results in larger power consumption or increased cost.
- **Gain Bandwidth Product(GBP)**

GBP is measured at the frequency point at which the operational amplifier's gain reaches unity. This is useful because it allows the user to calculate the device's open-loop gain at different frequencies

- **Input Offset voltage**

An ideal amplifier gives 0v output when input is 0v,But it gives some output because of imperfect internal balance, if gives that much voltage at the input ,op amp would give 0v at the output, that input voltage called it as input offset voltage .

- **Slew Rate**

It is rate of change of voltage with respect to the time

$S=dV_{out}/dt$

- **CMRR(Common Mode Rejection Ratio)**

CMRR is a measure of the capability of an op-amp to reject a signa l that is common to both inputs.

It is the ratio of differential voltage gain to common –mode voltage gain

CMRR=Avol(dm)/Avol(cm)

$CMRR=20\log_{10}A_{vol}(dm)/A_{vol}(cm)$ (In decibel format)

Characteristics of op amp

- Open loop voltage gain should be very high
- 2Input resistance should be high
- Output resistance should be very low
- full power bandwidth should be wide as much
- Slew rate should be large s possible
- Input offset should be small s possible
- CMRR should be large s possible

Configuration of op-amp

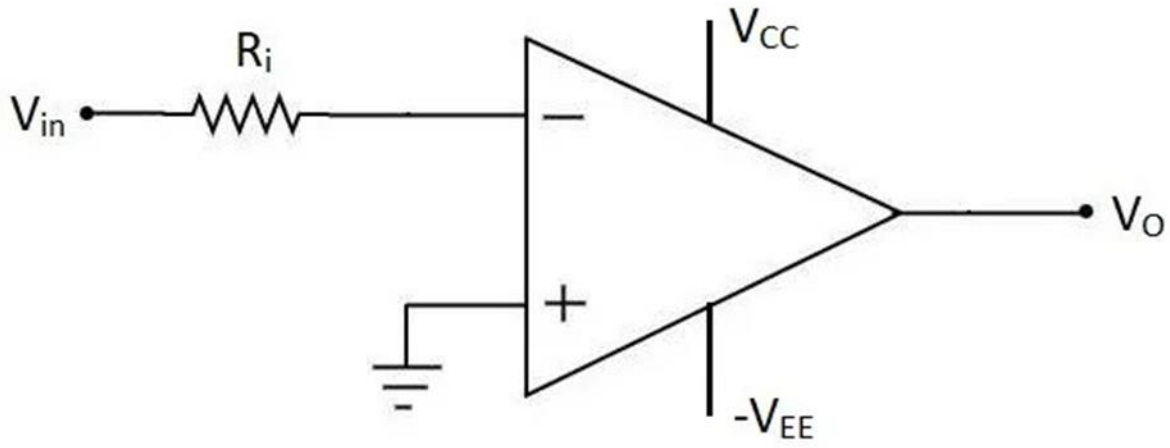
Configuration of op-amp means the ways in which an op-amp is connected in circuit. Based on the connection, the op-amp can work in two different modes.

- 1. Open loop mode
- 2. Closed loop mode

Open Loop Configuration of Op-amp

When no part of output is connected to input, it is known as open loop configuration. It means that there is absolutely no feedback present from output to Input.

Following figure shows an open loop configuration of op-amp.



Input signals V_1 and V_2 are applied to non-inverting and inverting terminal respectively.

Differential Input voltage (Vid) is the difference between the voltages applied at non-inverting and inverting terminals.

Therefore it is,

$V_{id} = (V_1-V_2)$

Output voltage is given by,

$V_o=A_v \cdot V_{id}$

$\therefore$ Vo = Av (V1-V2)

Where,

Av is the open loop gain gain of the op-amp. Ideally open loop gain is infinite but practically it's value is very high.

As AV is very high, a small value of Vid will drive the Op-amp into positive or negative saturation.

∴ $V_o = \pm V_{sat}$

When the output voltage of the circuit exceeds the possible range, the op-amp is said to saturate. It just provides its maximum or minimum possible voltage.

Depending on the polarity of V_{id}, the output voltage is equal to $+V_{sat}$ or $-V_{sat}$.

Means, If V_{id} is positive then the output of op-amp is positive saturation. Also, if V_{id} is negative, the output of op-amp is negative saturation.

A very small value of differential input voltage will drive the op-amp into positive or negative saturation. Therefore the output voltage is not proportional to differential input voltage. **Hence open loop configuration is not used for linear amplification.**

Closed Loop Configuration of Op-amp

When a part of output is connected to (or fed back to) the input, it is called as closed loop configuration. It means that, some kind of feedback is present in the circuit.

Types of feedback

- Positive feedback or regenerative feedback
- Negative feedback or degenerative feedback

Positive Feedback

In positive feedback, the feedback signal and the original input signal are **in phase** with each.

Here, the feedback is present between **non-inverting terminal** (+) through resistor Rf.

It is used in oscillators and Schmitt triggers.

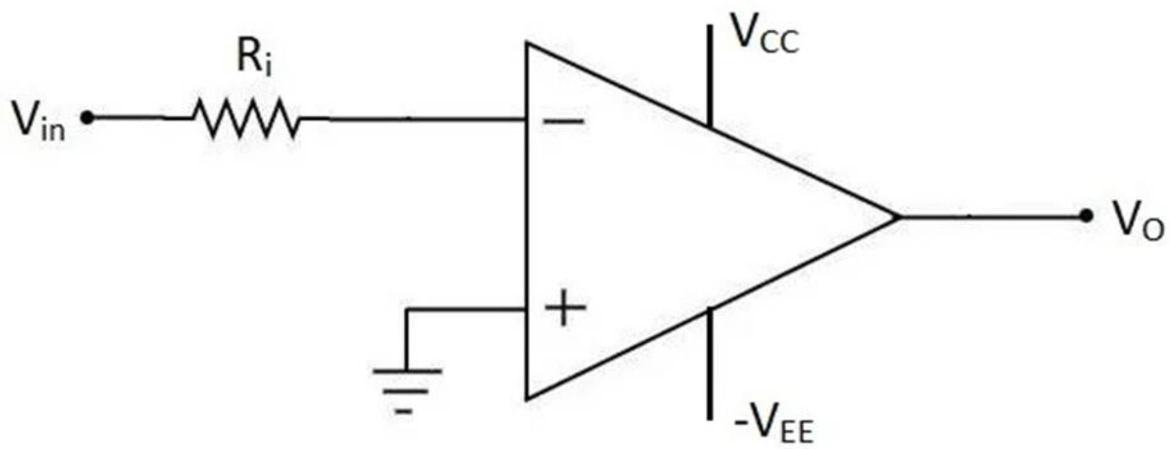
Negative Feedback

If the feedback signal and the original input signal are **180° out of phase**, then it is called as negative feedback.

Here the feedback is present between output and **inverting terminal** (-) through resistor Rf. Negative feedback is used in almost every circuit (except few) using op-amp.

For example, circuits like inverting op-amp, adder, subtractor and integrator use negative feedback.

Following fugure shows the negative feedback through a resistance Rf . It is a closed loop configuration of Op-amp.



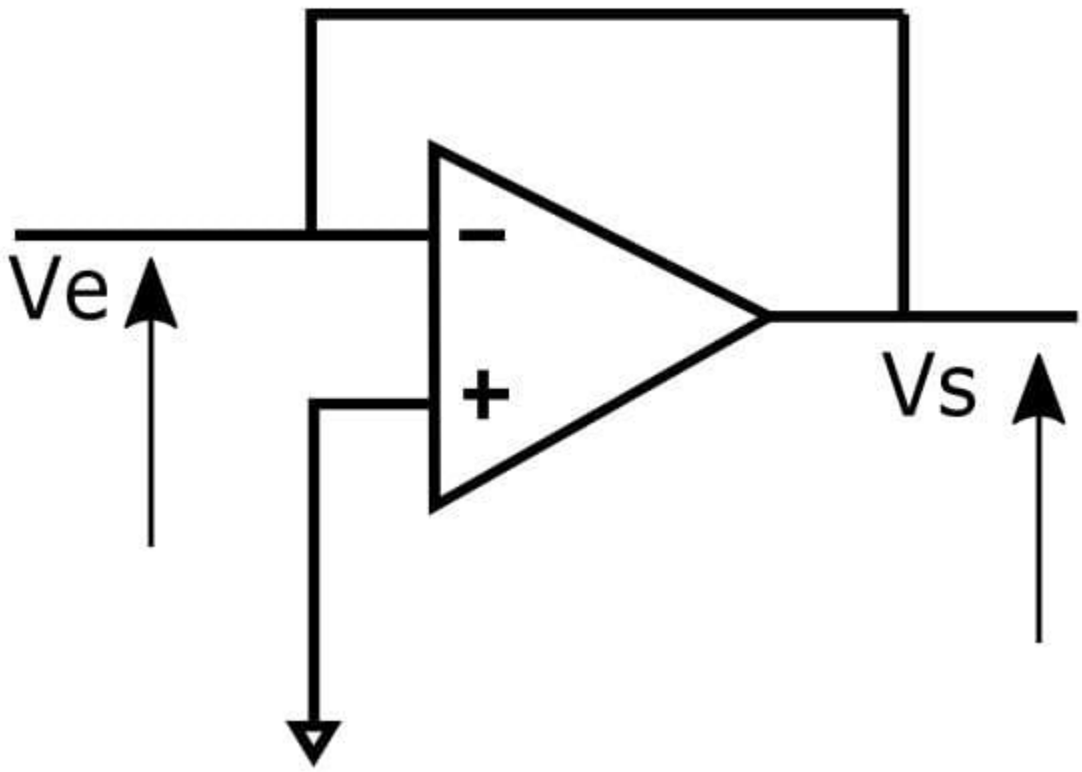
Advantages Of Negative Feedback

1. Reduces the distortion.
2. Reduces and stabilizes the gain.
3. Increases the bandwidth.
4. Changes values of input and output resistance.
5. Reduces the effects of variations in temperature and supply voltage on the output of Op-amp.

Operational Amplifier circuit

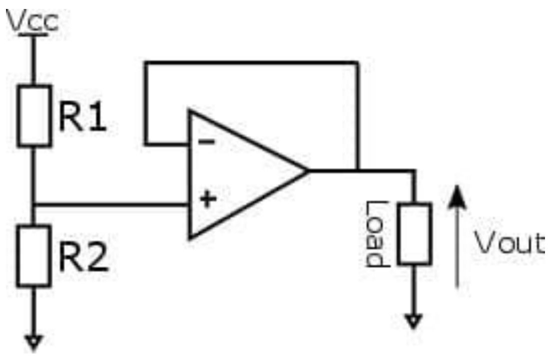
1. Voltage Follower

The most basic circuit is the voltage buffer, as it does not require any external components. As the voltage output is equal to the voltage input, students might become puzzled and wonder whether this kind of circuit has any practical application.



$$V_S = V_e$$

This circuit allows for the creation of a very high impedance input and low impedance output. This is useful to interface logic levels between two components or when a power supply is based on a voltage divider. The figure below is based on a voltage divider, and the circuit cannot function. Indeed, the load impedance can have large variations, so Vout voltage can change dramatically, mainly if the load impedance has a value of the same magnitude as R2.

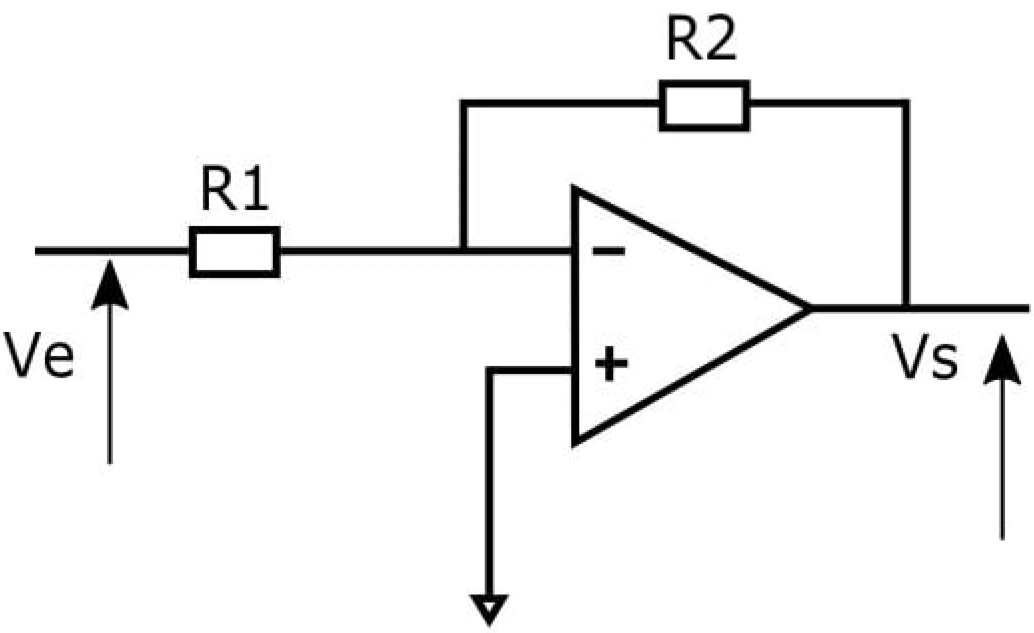


The primary goal of an operational amplifier, as its names states, is to amplify a signal. For instance, the output of a sensor must be amplified in order to have the ADC measure this signal.

2. Inverting Op Amp

In this configuration, the output is fed back to the negative or inverting input through a resistor (R2). The input signal is applied to this inverting pin through a resistor (R1).

The positive pin is connected to ground.



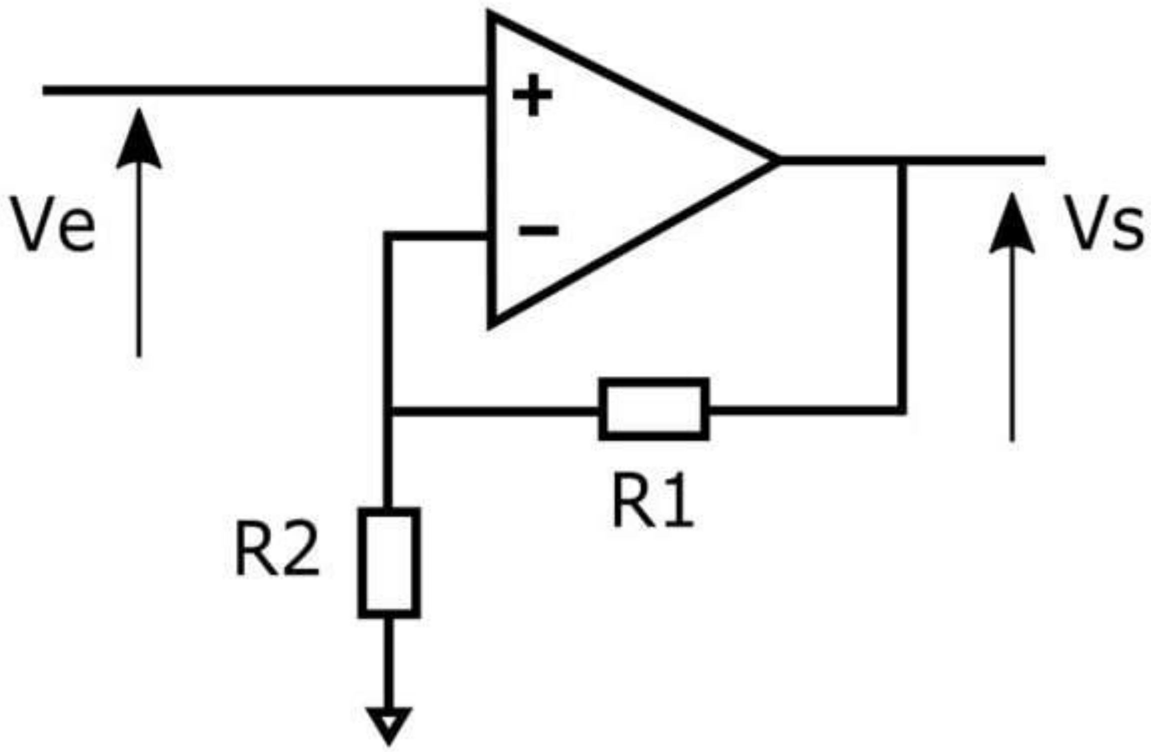
$$V_S = -V_e \frac{R_2}{R_1}$$

This is evident in the special case where R1 and R2 are equal. This configuration allows for the production of a signal that is complementary to the input, as the output is exactly the opposite of the input signal.

Due to the negative sign, the output and input signals are out of phase. If both signals must be in phase, a non-inverting amplifier is used.

3. Non-inverting Op Amp

This configuration is very similar to the inverting operation amplifier. For the non-inverting one, the input voltage is directly to the applied to the non-inverting pin and the end of feedback loop is connected to ground.

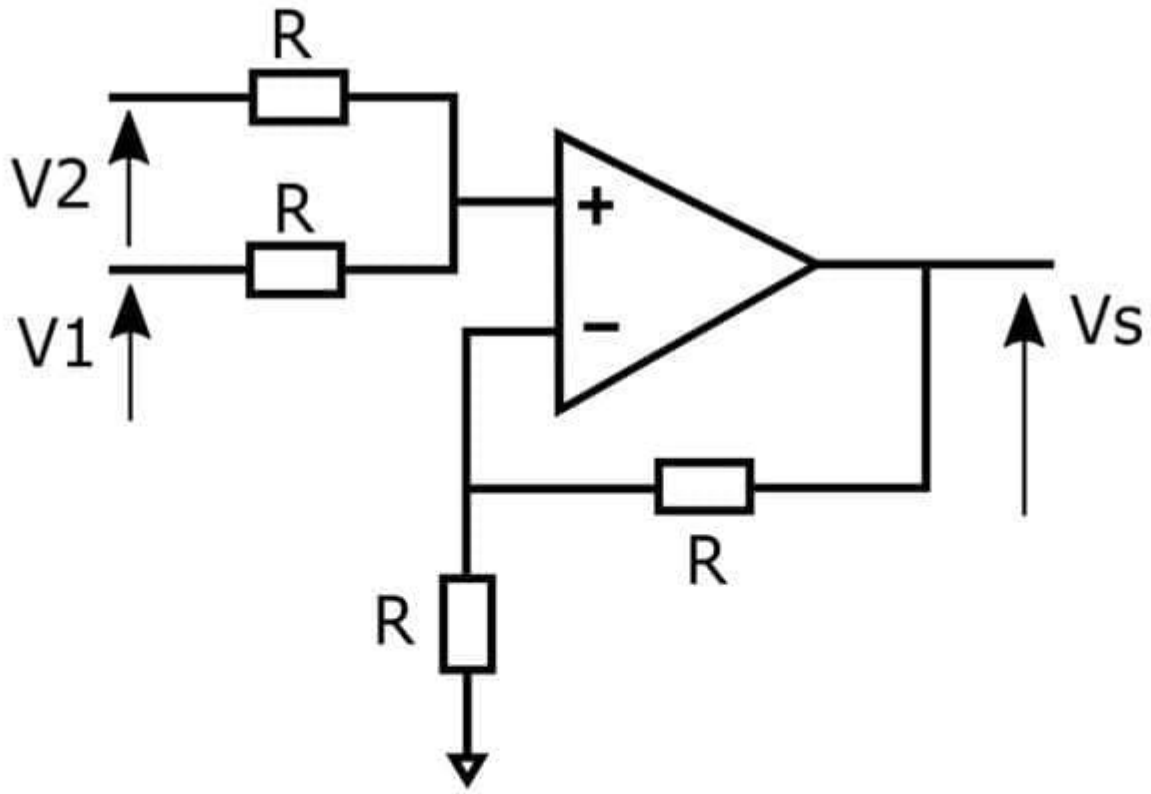


$$V_S = Ve\,(1 + \frac{R_1}{R_2})$$

These configurations allow amplification of one signal. It's possible to amplify several signals by using summing amplifiers.

4. Non-inverting Summing Amplifier

To add 2 voltages, only 2 resistors can be added on the positive pin to the non-inverting operational amplifier circuit.



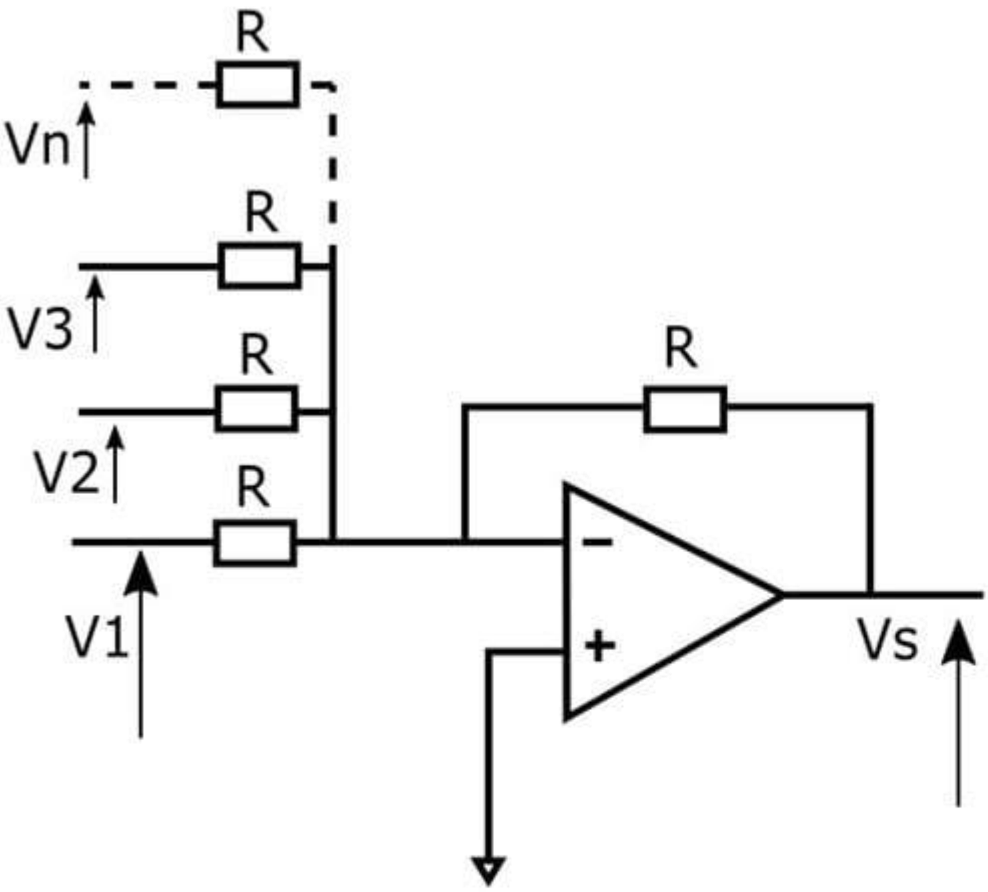
$$V_S = V_1 + V_2$$

It is worth noticing that adding several voltages is not a very flexible solution. Indeed, if a 3rd voltage is added with exactly the same resistances, the formula would be Vs = 2/3 ($V_1 + V_2 + V_3$).

The resistors would need to be changed to get Vs = $V_1 + V_2 + V_3$, or a 2nd option is to use an inverting summer amplifier.

5. Inverting Summing Amplifier

By adding resistors in parallel on the inverting input pin of the inverting operation amplifier circuit, all the voltages are summed.



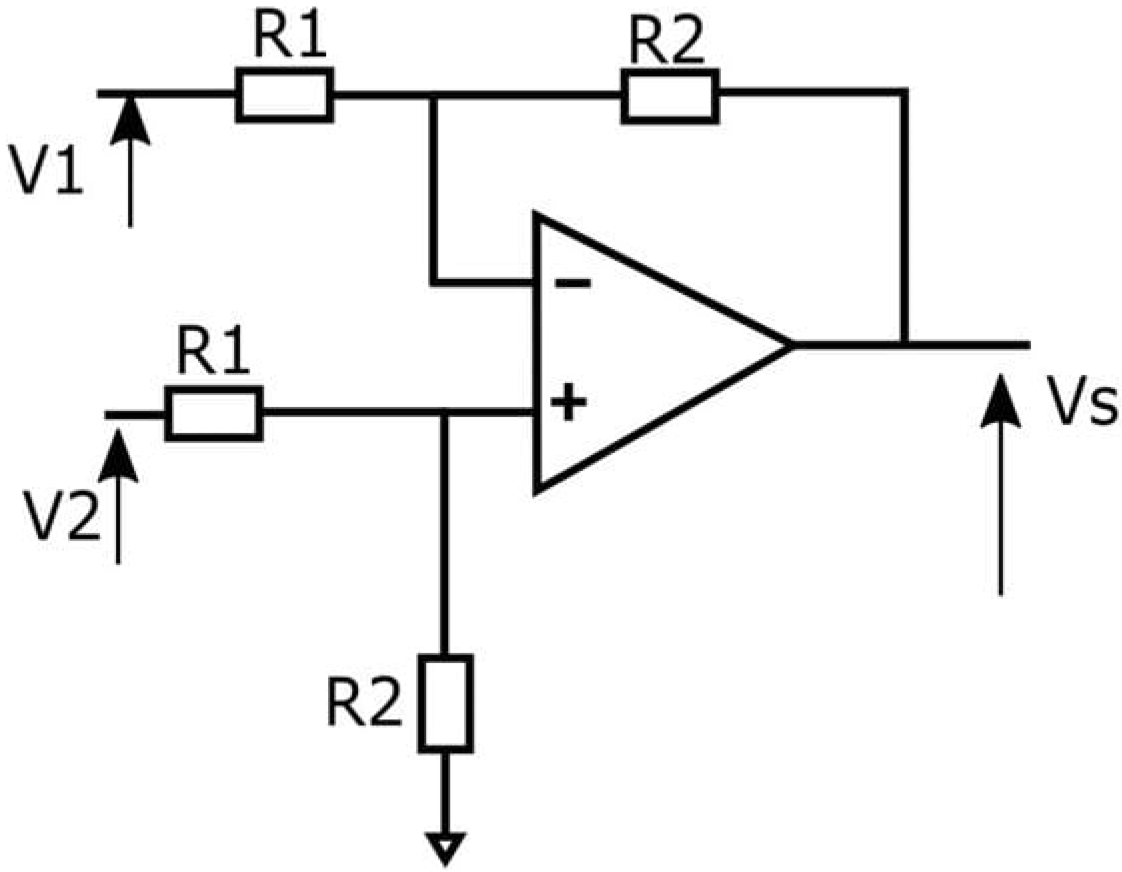
$$V_S = -(V_1 + V_2 + V_3 + \cdots + V_n)$$

Unlike the non-inverting summing amplifier, any number of voltages can be added without changing resistor values.

6. Differential Amplifier

The inverting operational amplifier (see circuit number 2) amplified a voltage that was applied on the inverting pin, and the output voltage was out of phase. The non-inverting pin is connected to ground with this configuration.

If the above circuit is modified by applying a voltage through a voltage divider on the non-inverting, we end up with a differential amplifier as shown below.

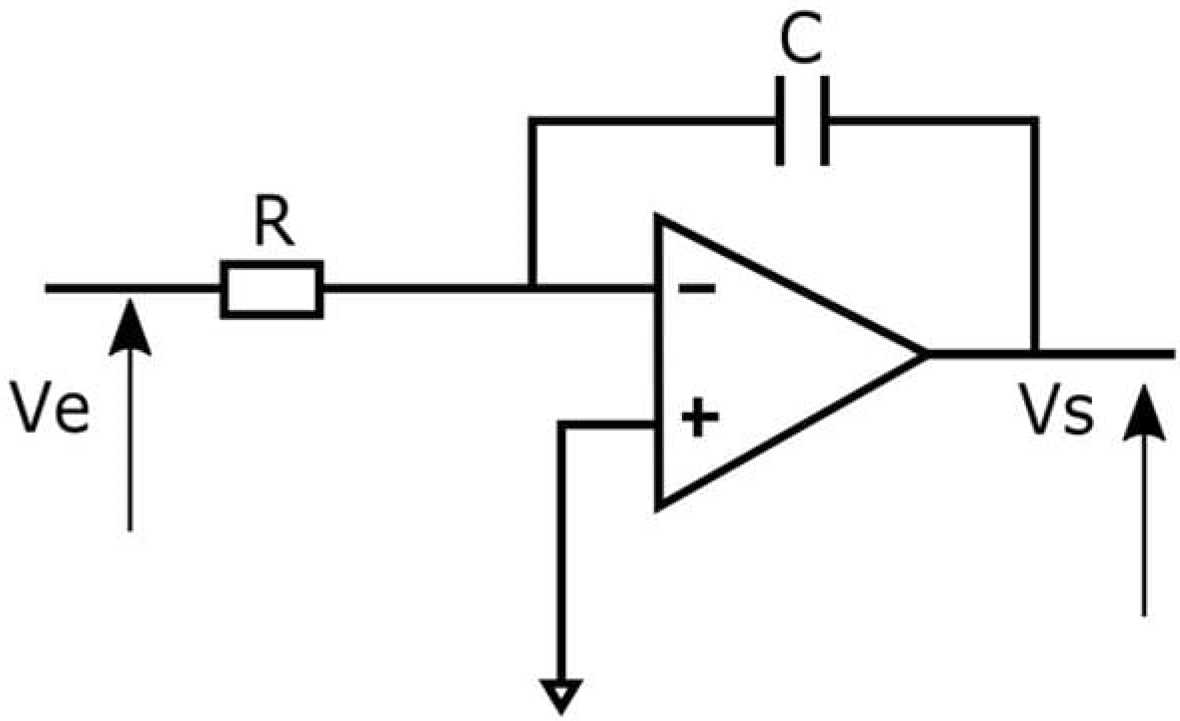


$$V_S = \frac{R_2}{R_1}(V_2 - V_1)$$

An amplifier is useful not just because it lets you add, subtract, or compare voltages. Many circuits allow you to modify signals. Let’s see the most basic ones.

7. Integrator

A square wave is very easy to generate, by just toggling a GPIO of a microcontroller for example. If a circuit needs a triangle waveform, a good way to do it is just integrating the square wave signal. With an Operation Amplifier, a capacitor on the inverting feedback path, and a resistor on the input inverting pin as shown below, the input signal is integrated.

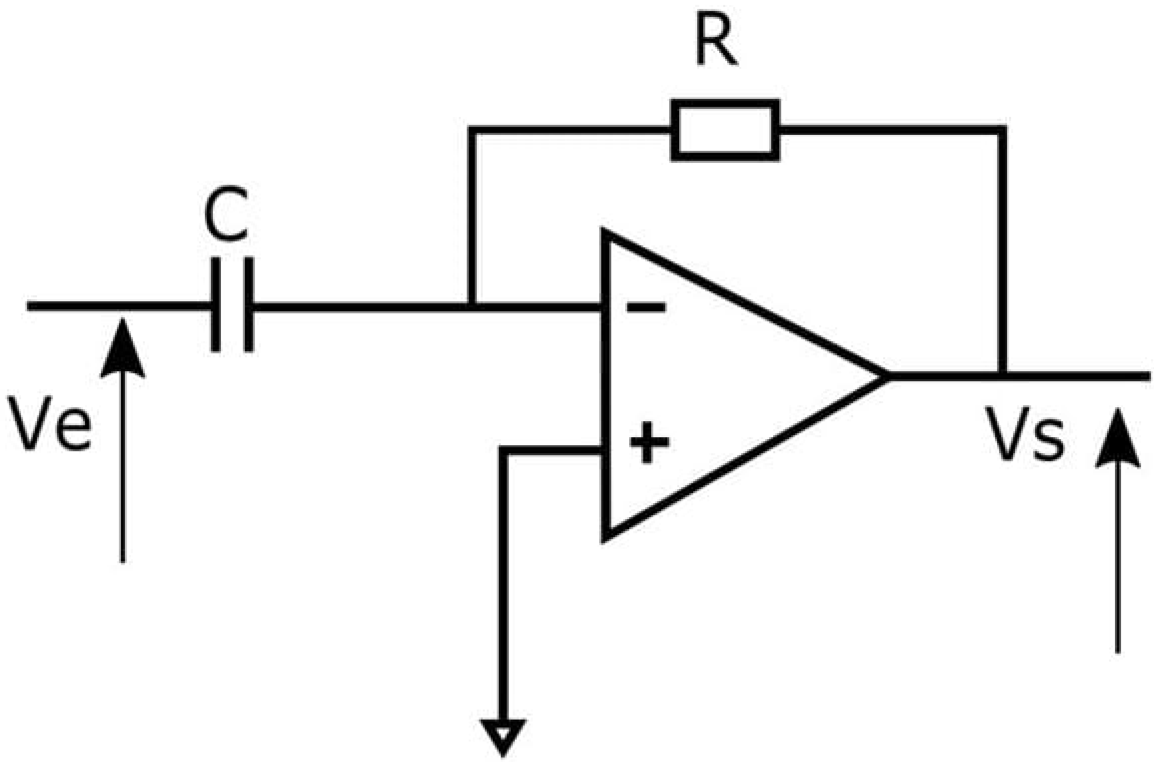


$$V_S = -\frac{1}{RC}\int V_e \, dt$$

Be aware that a resistor is often connected in parallel to the capacitor for saturation issues. Indeed, if the input signal is a very low frequency sine wave, the capacitor acts like an open circuit and blocks feedback voltage. The amplifier is then like a normal open-loop amplifier that has very high open-loop gain, and the amplifier is saturated. Thanks to a resistor in parallel of the capacitor, the circuit behaves like an inverting amplifier with a low frequency, and saturation is avoided.

8. Op Amp Differentiator

The differentiator works similarly to the integrator by swapping the capacitor and the resistor.

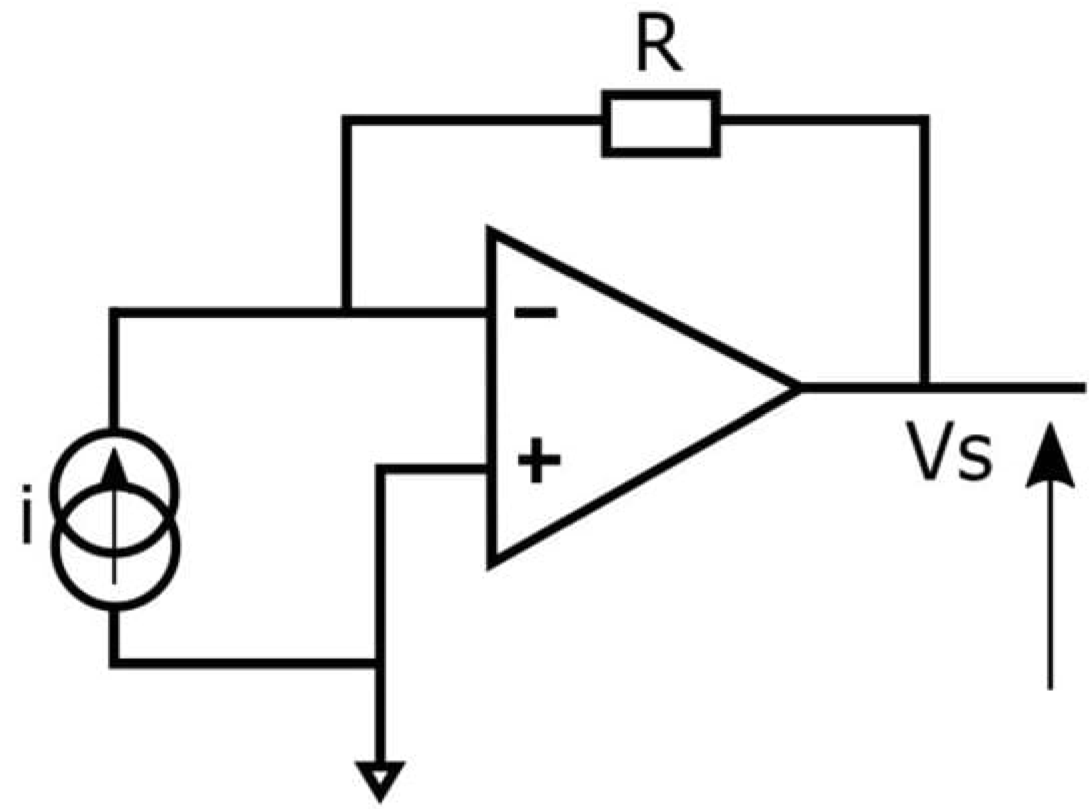


$$V_s = -RC\frac{dV_e}{dt}$$

All the configurations that were presented up to now.

9. Converter current – voltage

A photodetector_converts light into current. To convert the current into voltage, a simple circuit with an operational amplifier, a feedback loop through a resistor on the non-inverting, and the diode connected between the two input pins allows you to get an output voltage proportional to current generated by the photodiode, which is evident by the light characteristics.

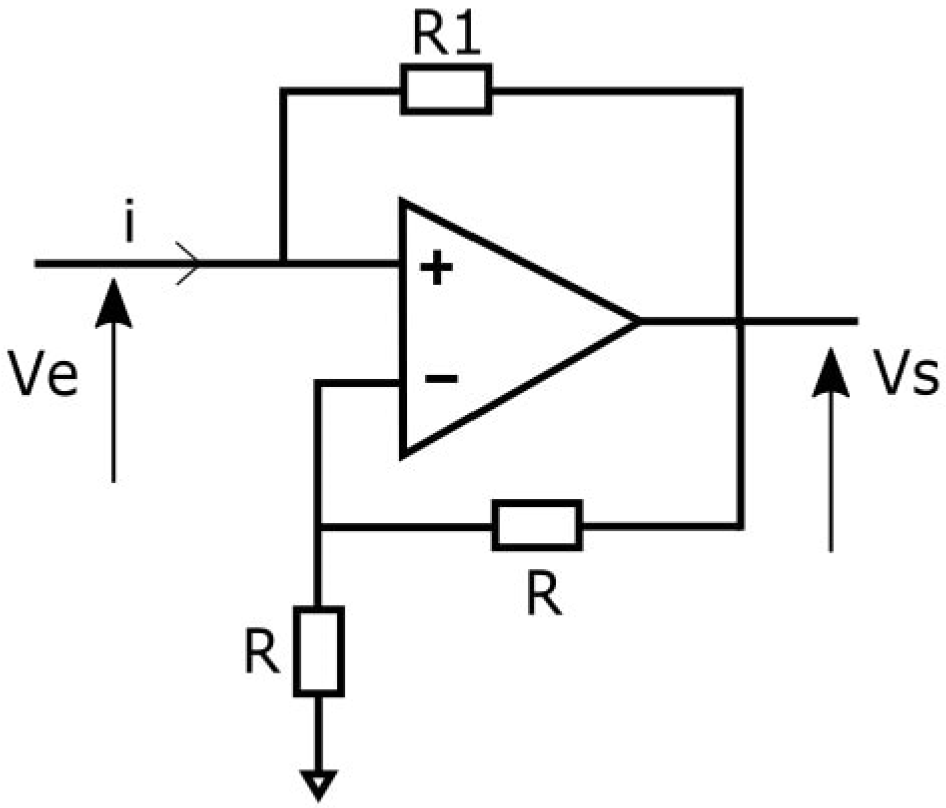


$$V_s = R\,I$$

The above circuit applies Ohm’s law with the fundamental formula: voltage is equal to resistance multiplied by current. The resistance is in Ohms and is always positive. But thanks to operational amplifiers, a negative resistance can be designed!

10. Negative resistance

A feedback on the inverting pin forces the output voltage to be the double of the input voltage. As the output voltage is always higher than the input voltage, the positive feedback through the R1 resistor on the non-inverting pin simulates a negative resistance.



$$V_e = -R_1\, I$$