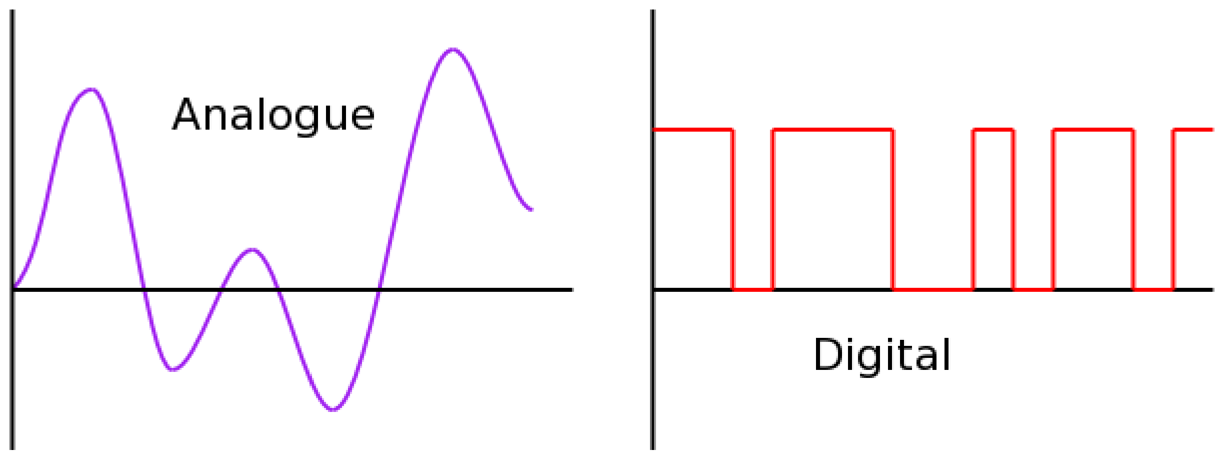
Operational Amplifiers (Op Amps)

Analogue electronics deal with electrical signals which are representations of the physical quantities which produce them. For example, the electrical signals (Voltage and Current) produced by a microphone and displayed on an oscilloscope is the analogue of the sound wave that produced it. The electrical signal changes exactly in phase (step) with the sound wave. Below shows an analogue signal compared to a digital signal.



The basic building block of analogue electronics is the Operational Amplifier called the op-amp for short. A typical op-amp have a very complex internal circuitry and may contain as many as 20 transistors, resistors and capacitors all on one single chip! The op-amp is used widely and can carry out functions such as **Addition**, **Subtraction**, **Multiplication**, **Differentiation**, **Integration**, **Compare and Simplify Voltages**.

Symbol for an Op-amp

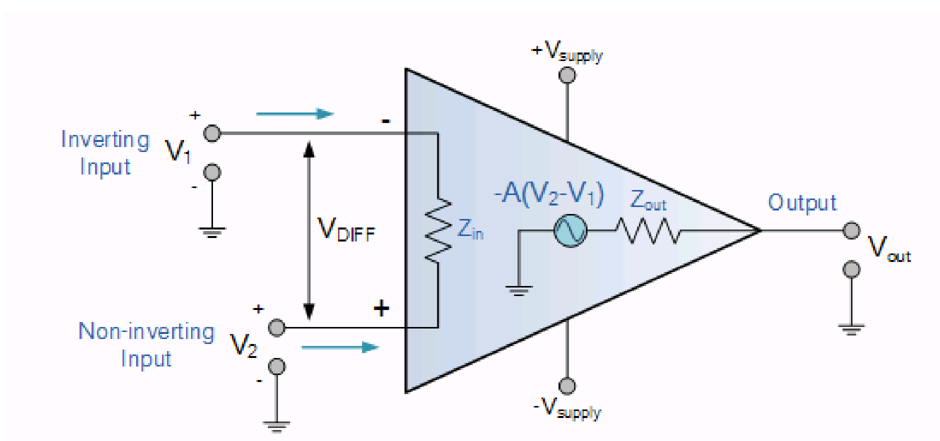


Figure 2: The Op Amp

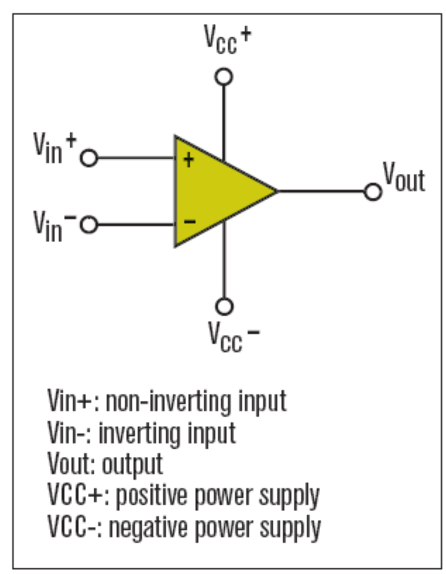


Figure 1. The Op Amp

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

a) Show the Input Voltage on non-Inverting input

b) Show the Input Voltage on Inverting input

The third terminal represents the op-amps 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.

The output Voltage or potential difference is proportional to the difference between the p.d of the input terminals, provided that the op-Amp does not reach saturation. Saturation refers to the Op – Amp voltage reaching the supply voltage.

$V_{out} = A\,(V_{non\text{-}inverting} - V_{inverting})$

$$V_o = A\,(V_+ - V_-)$$

Where A Is the Gain of the Amplifier circuit. Which is given by :

$$Gain\ (A) = \frac{V_0}{V_i}$$

Properties of an Ideal Op-Amp

PARAMETER	REAL CHARACTERISTIC	IDEALIZED CHARACTERISTIC
Open Loop Gain, (Avo)	10^5	**Infinite** – This means that a small difference at the input terminals will cause saturation of the Op-Amp
Input impedance, (Z_{in})	Between $10^6\Omega$ and $10^{12}\,\Omega$	**Infinite** – No current flows into the Op-Amp
Output impedance, (Z_{out})	100Ω	**Zero** – The Op-Amp can supply power to any device since no power is used by the Op-Amp during amplification.
Bandwidth, (BW)	**Finite**	**Infinite** – all frequencies are amplified by the same amount.
Slew Rate	**Finite**	**Infinite** - The amplifiers responds to changes to input signal instantaneously

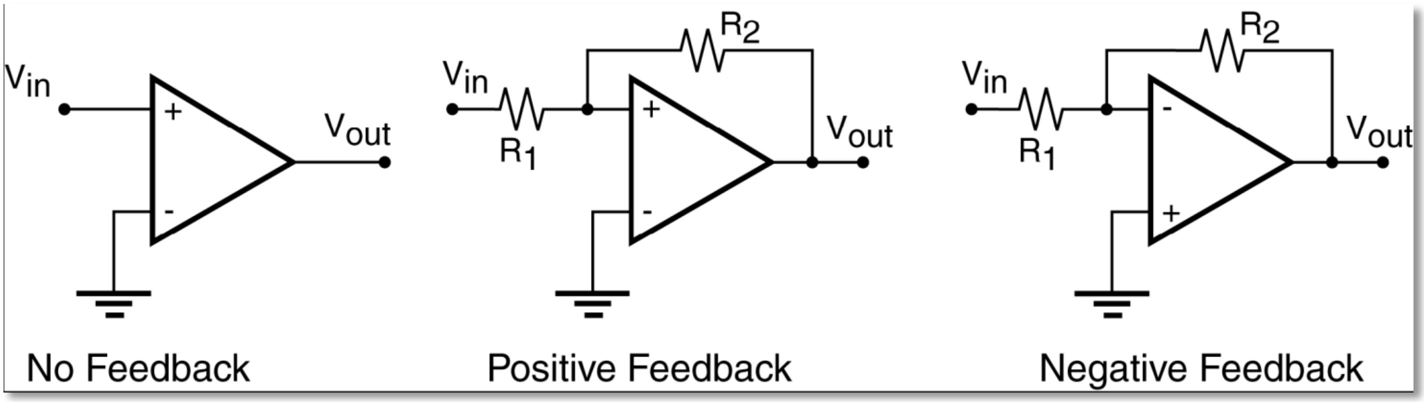
From these "idealized" characteristics above, we can see that the input resistance is infinite, so **no current flows into either input terminal** (the "current rule") and that the **differential input offset voltage is zero** (the "voltage rule"). It is important to remember these two properties as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

Feed Back

Feed back is the process of returning to the input, a portion of the output. Negative feedback returns a portion of the output such that it is in antiphase with the input. Positive feedback occurs when the returned portion is in phase with the input. The portion which is fed back can be done through resistors, capacitors etc.

Draw in the space below using only one input line:

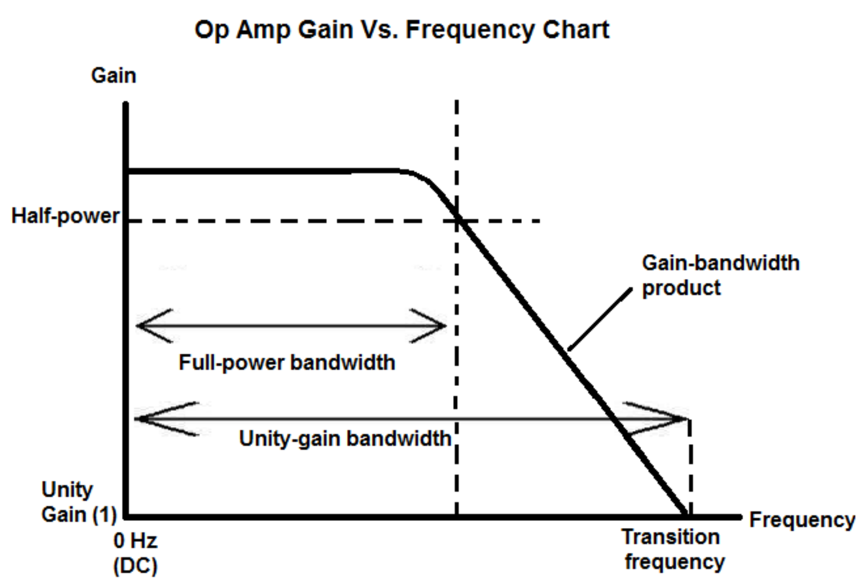
a) no feedback   b) negative feedback



Gain vs Frequency

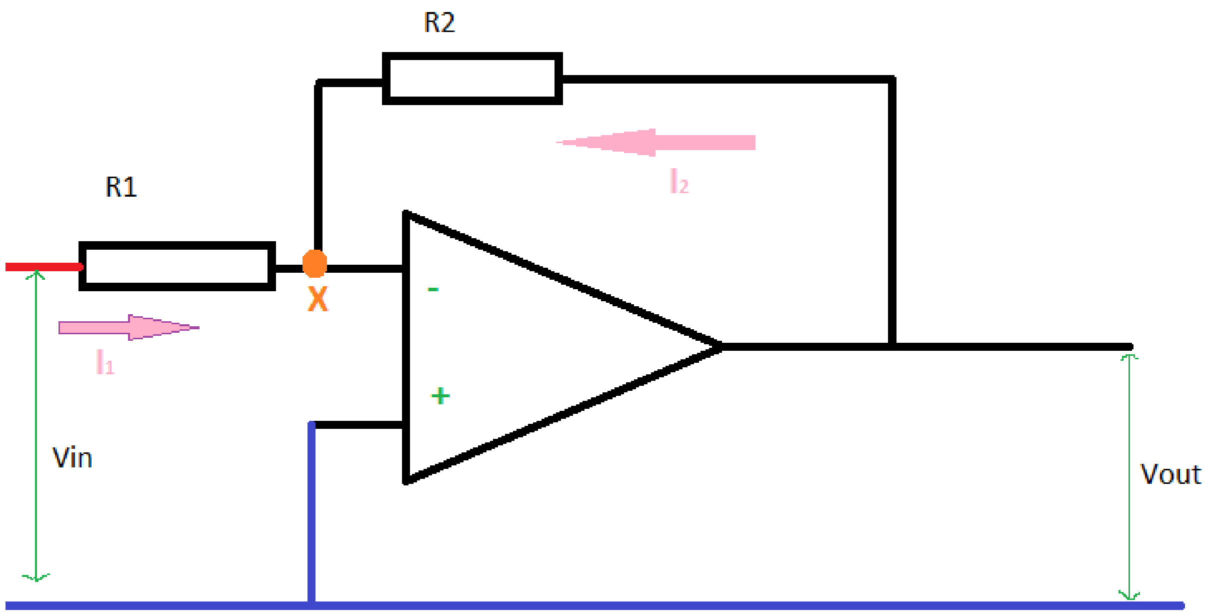
The open loop gain of an op-amp depends on its operating frequency and is not constant for all input frequencies. **The use of negative feedback stabilizes the gain and makes it constant over a wide range of frequencies**. However the negative feedback reduces the gain of the op-amp. The graph below shows how the gain of the op-amp varies with frequency.

Op-amp Graph Explained



Amplifier Circuits

Inverting Amplifier



Note:

- R2 is called the feedback resistor
- The feedback is negative since the feedback resistor is connected t the inverting input terminal

To Solve the Op-Amp circuit above, two principles are used:

1. The current into the Op-Amp is Zero
2. The potential at the inverting terminal is equal to the non inverting terminal
   ie:

$$V_- = V_+$$

Solution:

$V_- = 0$

Since $V_+ = 0$ (As it is connected directly to ground)

Also note that in this solution, The point x is called a virtual ground

Definition of Virtual Ground

Note that the current flowing into the op amp is vanishingly small compared to the current flowing through the resistors. Also, note that the input voltage is very small compared to the other voltages. That's why we say that the top (-) input of the op-amp and is at "virtual ground".

Therefore the current flowing into Resistor 1 is:

$$I_1 = \frac{V_i - 0}{R_1}$$

$$\therefore \; I_1 = \frac{V_i}{R_1}$$

AND the current fed back through resistor 2 is:

$$I_2 = \frac{V_0 - 0}{R_2}$$

$$\therefore\ I_2 = \frac{V_0}{R_2}$$

NOW, Since no current flows through the Op-Amp, then theoretically; $\mathbf{I_1 = - I_2}$

HENCE:

$$\frac{V_i}{R_2} = -\frac{V_0}{R_2}$$

FINALLY:

$$\frac{V_0}{V_i} = -\frac{R_2}{R_1}$$

Thus we now have a second formula for Gain:

$$A = -\frac{R_2}{R_1}$$

Notice the –ve sign on the ration of the feedback and input resistor. This sign indicates a 180 degree phase change between input and output. Note also that the gain above is referred to as the closed loop gain.

Example:

1. For the amplifier circuit below, calculate;
   a. Gain of amplifier
   b. The Output Voltage

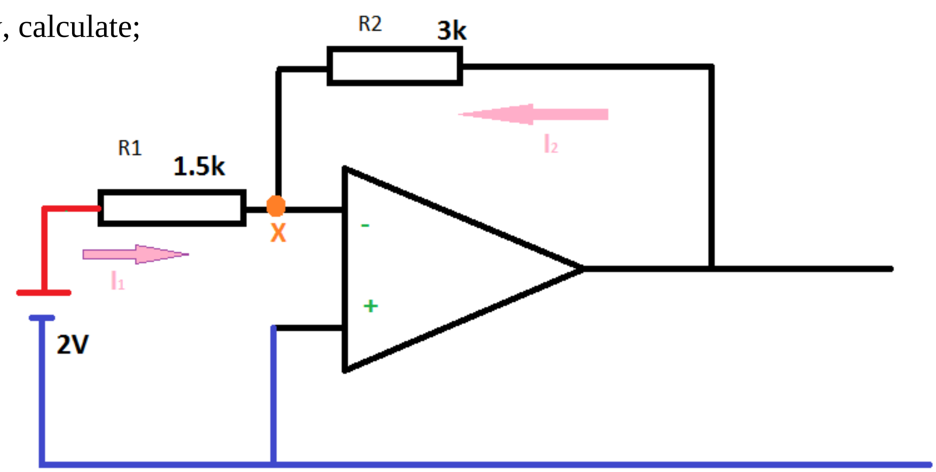
Solution

a) Gain (A) = - Rf/Ri

   A = - 3000/1500 = -2

b) Output Voltage (V_0) = A(V_+ - V_-)

   V_0 = -2 x 2 = 4V

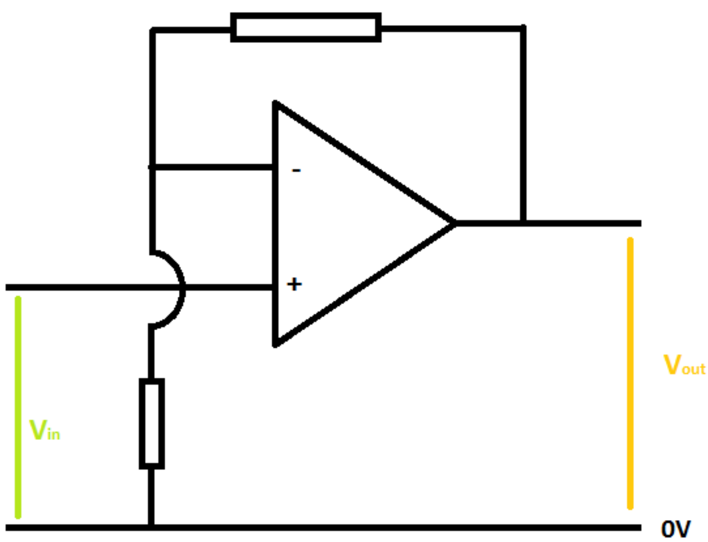


Example 2:

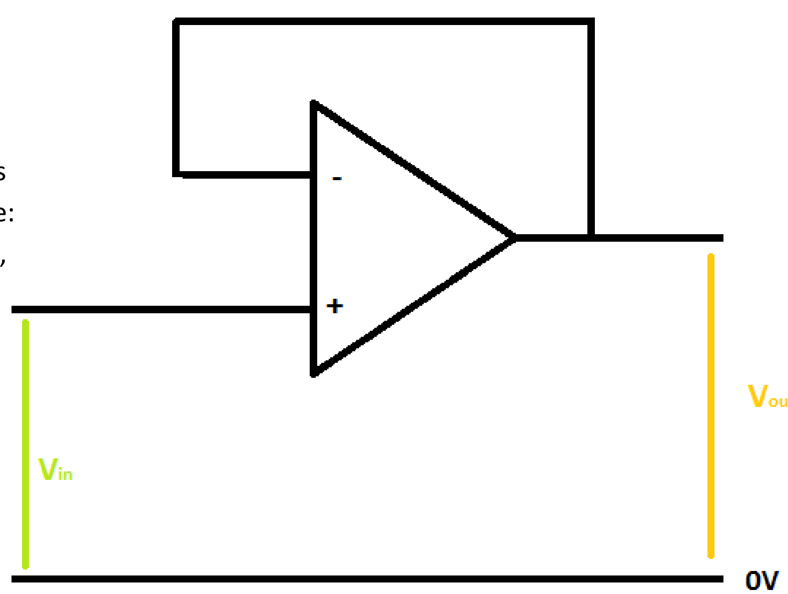
Calculate the value of R2 below if the gain of the amplifier is 10. What is the input for an output of -0.8V? The diagram will be drawn on the board, copy it below.

Voltage Follower

A voltage follower is a non-inverting amplifier circuit where the feedback resistor is Zero in value (like a piece of wire) and the other resistor is infinite. The output of a voltage follower is the same as the input. A typical Non-Inverting Op-Amp is shown below:



The above circuit can be redrawn as follows:



PURPOSE OF VOLTAGE DIVIDER

The Voltage divider is used to match two currents whose resistances are very different. For example: Measuring the emf (Electromotive force) of a cell, which has a large internal resistance. Using a cheap voltage meter would lead to inaccurate values, since these cheap meters usually have small resistances.