

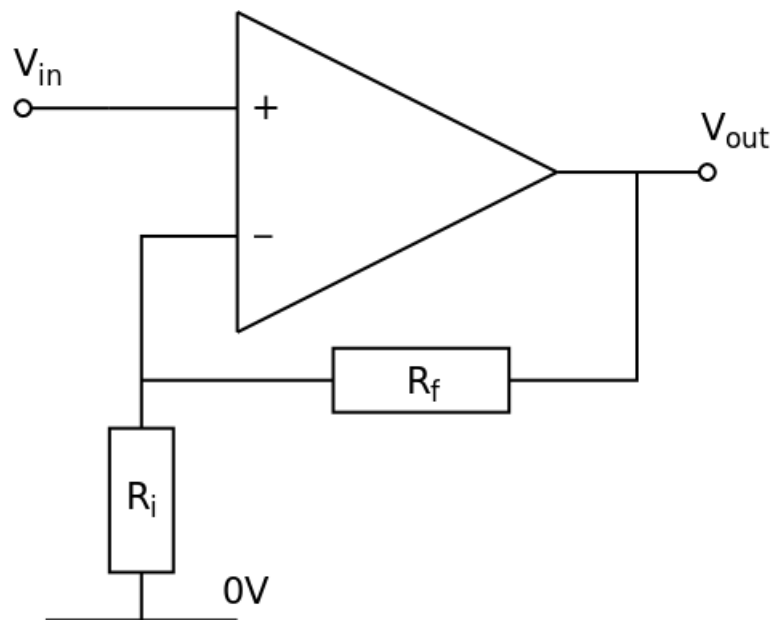
Non-Inverting Amplifier

Introduction

A Non-Inverting amplifier is an analogue circuit. The output voltage (V_{out}) of the circuit depends on the input voltage (V_{in}) and the Gain (A_v) of the circuit.

For all the circuits shown below, the amplifier is assumed to have a positive and a negative power supply, usually $\pm 15\text{ V}$, so that the output voltage can be both positive and negative.

Basic Non-Inverting Amplifier Circuit



The Op-Amp needs to have $\pm$ power supplies (assumed to be $\pm 15\text{ V}$)

The input, V_{in} , is connected directly to the non-inverting input

The circuit uses a feedback resistor (R_f) and an input resistor (R_i) to feedback a fraction of the output voltage to the inverting input. R_f and R_i form a potential divider

R_i is not the actual input resistor but the same naming convention is used to be consistent with the inverting amplifier

Voltage gain (A_v) is determined by R_i and R_f . The voltage gain is given by:

$$A_v = 1 + \frac{R_f}{R_i}$$

Note: R_i and R_f should both be $> 1\text{ k}\Omega$ and $< 10\text{ M}\Omega$

Note: The voltage gain of the Non-Inverting amplifier cannot be less than unity (1) and so this amplifier cannot be used to attenuate signals

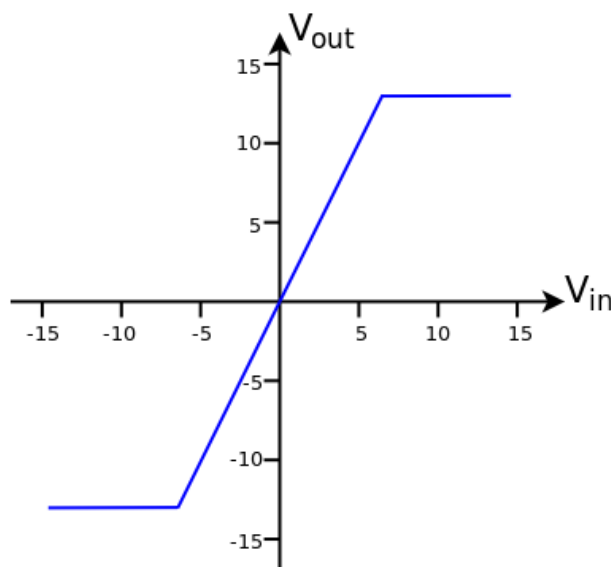
Function of the Non-Inverting Amplifier

The output voltage is directly proportional to the input voltage (as long as the output is not saturated) such that:

$$V_{out} = A_v \times V_{in}$$

If the input voltage is positive, the output voltage is also positive

If the input voltage is negative, the output voltage is also negative



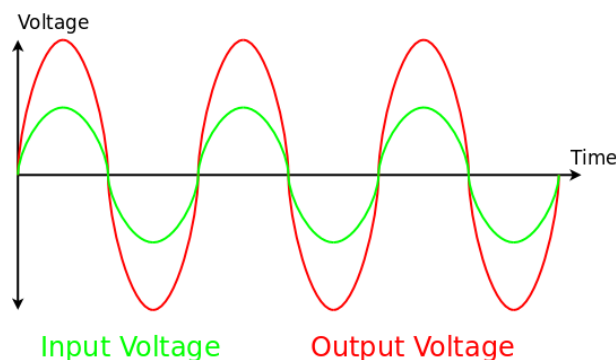
The graph shows the transfer characteristics (Input Voltage and Output Voltage) for a Non-Inverting amplifier with a voltage Gain of +2

When $V_{in} = +5$ V then $V_{out} = +10$ V and when $V_{in} = -5$ V then $V_{out} = -10$ V

The Output Voltage is limited to ± 13 V by the power supply of the amplifier.

Therefore, when $V_{in} > +6.5$ V then V_{out} saturates at +13 V and when $V_{in} < -6.5$ V then V_{out} saturates at -13 V

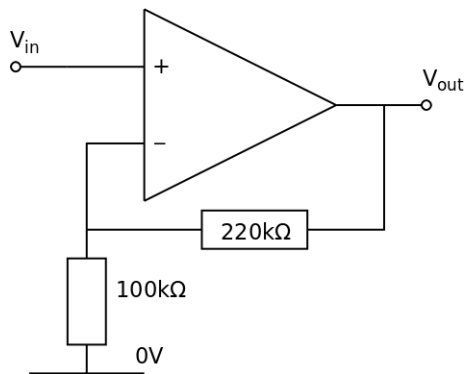
The saturated output is shown by the horizontal lines on the graph.



The graph shows the relationship between the Input Voltage and Output Voltage of a Non-Inverting amplifier with a voltage Gain of +2 when the input is an A.C. voltage

At all times $V_{out} = +2 \times V_{in}$

Example Circuits

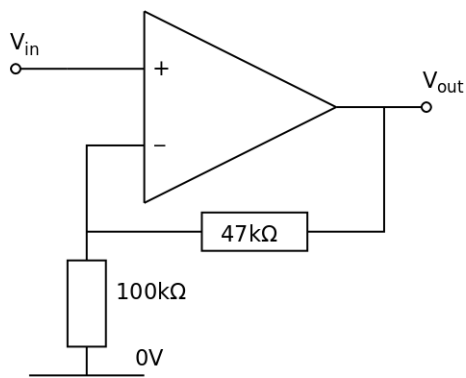


The voltage gain is:

$$A_v = 1 + (220 \times 10^3 / 100 \times 10^3) = +3.2$$

If $V_{in} = +1.0\text{ V}$ then $V_{out} = +3.2\text{ V}$

The Input Voltage has been amplified (made bigger)

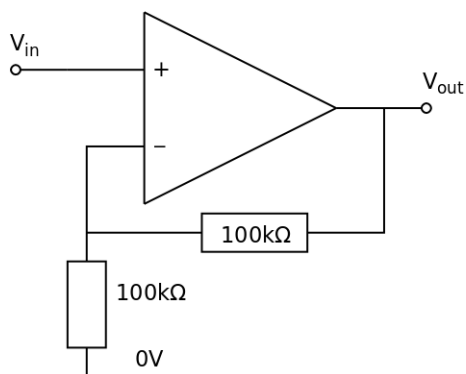


The voltage gain is:

$$A_v = 1 + (47 \times 10^3 / 100 \times 10^3) = +1.47$$

If $V_{in} = +1.0\text{ V}$ then $V_{out} = +1.47\text{ V}$

The Input Voltage has been amplified even though R_f is smaller than R_i

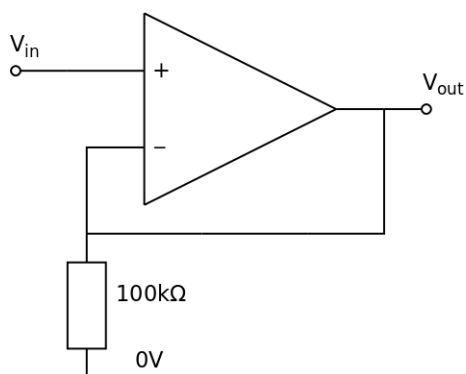


The voltage gain is:

$$A_v = 1 + (100 \times 10^3 / 100 \times 10^3) = +2.0$$

If $V_{in} = +1.0\text{ V}$ then $V_{out} = +2.0\text{ V}$

The Input Voltage has been amplified by a factor of two



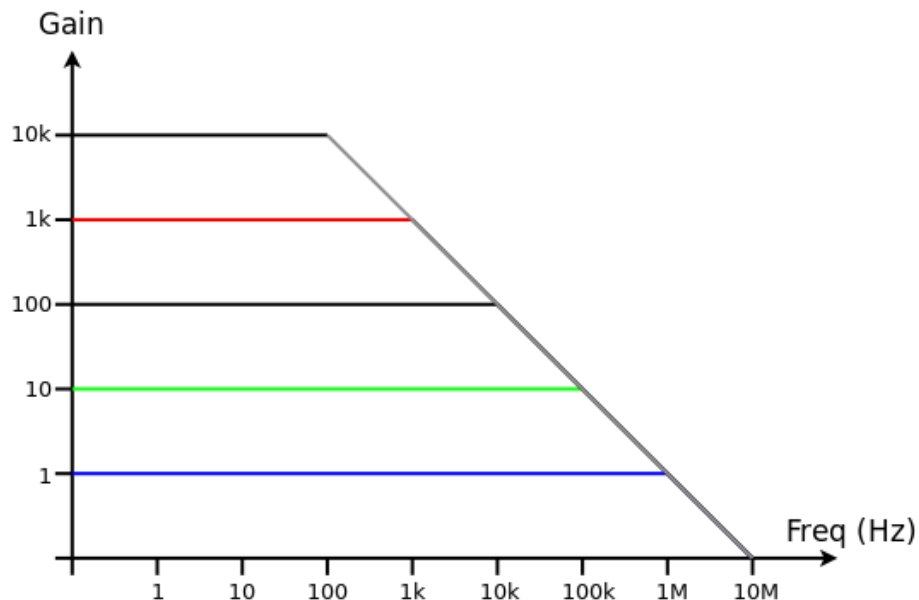
The voltage gain is:

$$A_v = 1 + 0 / 100 \times 10^3 = +1.0$$

This is a unit gain amplifier. The Output Voltage has the same amplitude as the Input Voltage. This amplifier is a buffer as the input takes almost no current from the voltage source but provides a reasonable current to the subsequent circuits

Gain and Bandwidth

The two main parameters of the Inverting Amplifier are the gain and the bandwidth. Increasing the gain reduces the bandwidth and vice versa.



For a Non-Inverting amplifier based on a standard Op-Amp the relationship between gain and bandwidth is approximately:

$$\text{gain} \times \text{bandwidth} = 10^6$$

The graph shows that as gain increases, bandwidth decreases. Note that both scales are logarithmic

When the gain is $\times 1$ (blue line) the amplifier works effectively up to frequencies of 1 MHz.

If the gain is increased to $\times 10$ (green line) the amplifier only works effectively up to about 100 kHz (still okay for audio)

At a gain of $\times 1000$ (red line) the amplifier only works effectively up to a frequency of 1 kHz before the gains starts to reduce and the Output Voltage starts to decrease

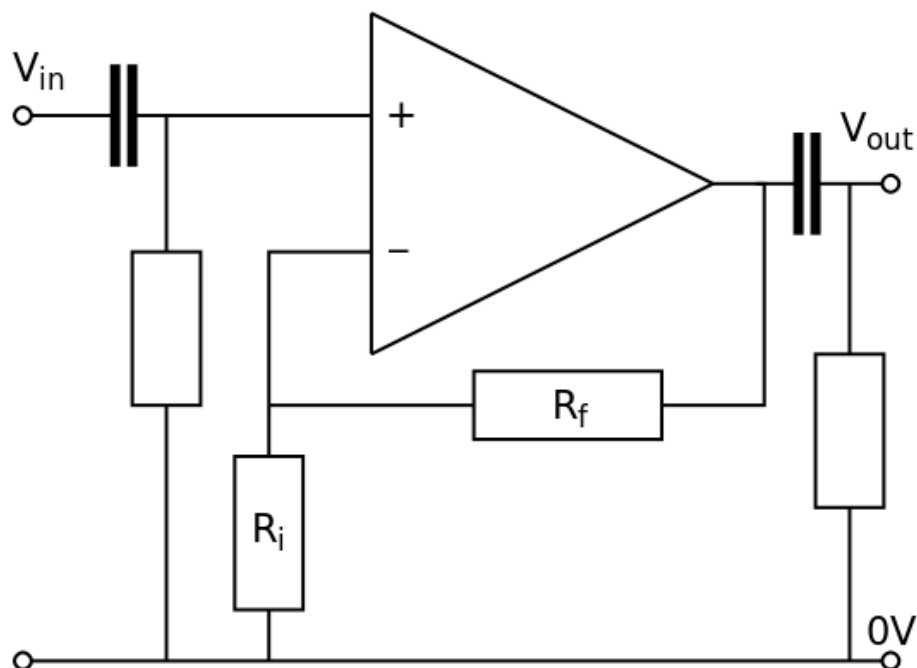
Example: If the gain is +100, the bandwidth is 10 kHz

Example: If a bandwidth of 40 kHz is required, the maximum gain is +25

Better Non-Inverting Amplifier Circuit

When used in reality, amplifiers are often decoupled which means that the input and output are connected through capacitors to stop any spurious D.C. signals compromising the performance of the amplifier.

Depending on what the amplifier is attached to, a resistor may also be needed on the output down to 0 V. The input resistance of the Op-Amp is very high, meaning that small currents can become relatively large voltages ($V=I \times R$) at the input, increasing the random noise of the amplifier. To avoid this, an input resistor is often connected to ground to lower the effective input resistance of the amplifier.



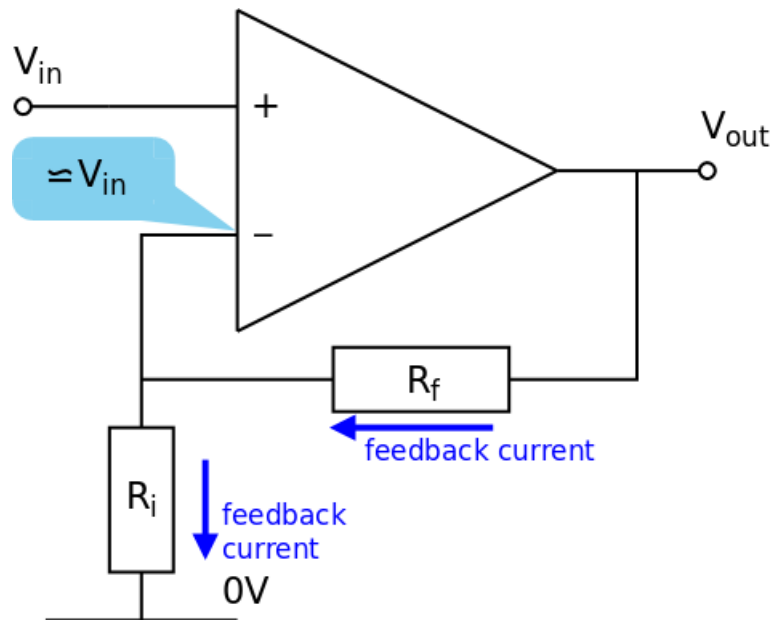
The capacitor on the input is usually a non-electrolytic type, nominally 1 μF or less. The capacitor on the output is ideally a non-electrolytic type but sometimes larger value electrolytic capacitors need to be used if the amplifier is providing significant current to the next stage.

The addition of capacitors and resistors to the input and output can reduce the bandwidth of the amplifier.

How the Non-Inverting Amplifier works (Advanced)

When considering amplifiers made from Op-Amps there are two basic assumptions:

- The open loop gain (A_0) of the Op-Amp is very large
- No current flows into the inverting and non-inverting inputs



Negative Feedback

- Recall that $V_{out} = A_0 \times (V_+ - V_-)$ where $A_0 = 10^6$ and so a difference between V_+ and V_- of more than a few μV will result in a large (saturated) output voltage
- The feedback resistor ensures that voltage at the inverting input is very similar (within a few microvolts) to the voltage at the non-inverting input
- As the non-inverting input is connected directly to the Input Voltage (V_{in}) then the inverting input must also be very close to the Input Voltage - within a few μV or so
- R_f and R_i form a potential divider with V_{out} at one end, 0 V at the other end and the inverting input at approximately V_{in} in the middle
- The feedback works because if V_{in} is positive and rises, the voltage at the output rises very rapidly as a consequence because there is a difference between the inverting and non-inverting inputs which causes V_{out} to change. As the non-inverting input is bigger than the inverting input in this case then V_{out} becomes more positive. As V_{out} becomes more positive, the voltage at the inverting input also rises until it is approximately V_{in} once more. Therefore a change in the Input Voltage causes a corresponding change in the Output Voltage to keep the inverting input at (or very close to) the non-inverting input

Gain Equation

- Assume V_{in} is positive (as shown in the diagram above)
- The feedback current in the input resistor is given by $I = V_{in} / R_i$ because the voltage at the inverting input is V_{in} due to the negative feedback and so this is the potential difference across the resistor
- As no current flows into the inverting input, the current in the input resistor also flows through the feedback resistor
- To make current flow through the feedback resistor as shown, V_{out} must be greater than V_{in}
- The potential difference across the feedback resistor is therefore $V_{out} - V_{in}$
- Therefore, $I = (V_{out} - V_{in}) / R_f$
- Equating the currents leads to the gain equation
- Recall, gain is defined as: $\text{Gain} = V_{out} / V_{in}$

We have

$$I = \frac{V_{in}}{R_i} = \frac{(V_{out} - V_{in})}{R_f}$$

and therefore

$$\text{Gain} = \frac{V_{out}}{V_{in}} = 1 + \left(\frac{R_f}{R_i} \right)$$

Website

https://www.electronicsteaching.com/Electronics_Resources/DocumentIndex.html

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August 2022



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