

## Operational Amplifiers Explained (part 2)

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*The article Operational Amplifiers Explained (part 1) should be read before proceeding. The following article explains some further theory behind the function of an operational amplifier.*

If you have any suggestions for improving this application note, please drop us a line at: [enquiries@electronworks.co.uk](mailto:enquiries@electronworks.co.uk)

The operational amplifier is often taught by examining an 'ideal' part. Many amplifiers today are so good that an ideal part can sometimes be assumed in circuit design, thus greatly simplifying the theory behind how an op amp circuit works.

This is best explained by referring to a typical non inverting configuration shown in FIG 1.

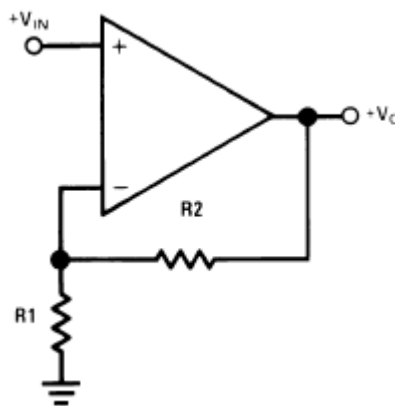


FIG 1

In an ideal op amp the following are true:

- The input connections (+) and (-) have infinite input resistance hence take zero current from the surrounding components.
- The output can provide enough current to power any load.
- The part has infinite gain when amplifying the input voltage difference at the input (the voltage between the inputs (+) and (-)), thus:

$$V_o = A(V_{(+)} - V_{(-)}) \quad \text{where A is infinite.}$$

Point 3 is often tricky to understand. It can be considered in another way: If the amplification (or gain) is infinite then for any output, the voltage difference at the inputs is theoretically zero. This definition is more applicable to how op amps are used in practical circuits.

In practice, we apply a voltage to one of the inputs and then feed a fraction of the output voltage back to the *inverting* input. This has the effect of allowing the output voltage to adjust itself to make sure the two input terminals are at the same voltage, thus adhering with point 3 above. If the output is too high, the fraction fed back to the inverting input tells the amplifier to reduce the output. Thus we have a self correcting action happening.

Consider again FIG 1. Let's apply a voltage ( $V_{in}$ ) of 1V to the non inverting pin (+). If the inverting pin (-) is at zero, the difference between the input pins is 1V. If the gain of the amplifier is infinite, the output voltage of the op amp rises (on its way to infinity). This causes a current to flow in R2 and R1. This current, by Ohm's Law, is represented by:

$$i = \frac{V_o}{R_2 + R_1}$$

From our ideal op amp model, if the resistance of the inputs is infinite, then no current flows into the (-) input, hence all of the current from the output flows through R2 and R1.

The voltage developed across R1, again from Ohm's Law is:

$$V = ixR_1$$

Or

$$V = \frac{(V_o)x(R_1)}{R_2 + R_1}$$

Now, we know that the output adjusts itself to make the two inputs equal. From FIG 1 we can see that the voltage across R1 is the same as the voltage at the (-) pin of the op amp. If the output adjusts itself then the voltage at the (-) pin is the same as the voltage at the (+) pin, or the input voltage.

In fact, rearranging the above equation, we can see that

$$V_{in} = \frac{(V_o)x(R_1)}{R_2 + R_1}$$

or

$$V_o = \left( \frac{R_1 + R_2}{R_1} \right) V_{in}$$

or

$$V_o = \left( 1 + \frac{R_2}{R_1} \right) V_{in}$$

This is our original gain equation for a non inverting op amp as shown in Operational Amplifiers Explained (part 1).

The method of applying a small amount of the output voltage back to the inverting input is called 'Negative feedback' and is a trick used in nearly all op amp circuits. The benefits to the circuit are that it ensures the gain of the circuit is dependent purely on the external components around the amplifier and not on the gain of the amplifier itself.

Just for the sake of completion, let's do the same for the inverting op amp configuration shown in FIG 2.

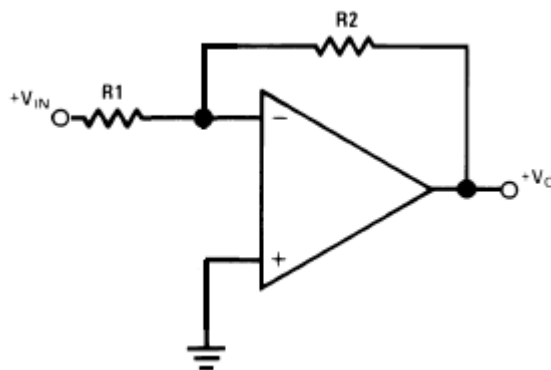


FIG 2

We can see that the (+) input is at 0V. With negative feedback, we know that the (-) input will also be at 0V.

Applying a voltage ( $V_{in}$ ) as shown of 1V causes a current to flow in R1 (from left to right). If the input resistance to the (-) pin is infinite, no current flows into this pin, hence all the current from R1 flows into R2. The output voltage adjusts itself to make sure both input pins are at the same voltage (in this case 0V). To ensure the current continues to flow from left to right, the output voltage has to go negative with respect to the voltage at the (-) pin which is 0V.

If the input voltage is  $V_{in}$  then the input current, from Ohm's Law, is represented by:

$$i = \frac{V_{in} - V_{(-)}}{R1}$$

This current has to flow in R2 and flows from left to right. This current is represented by:

$$i = \frac{V_{(-)} - V_o}{R2} = \frac{-V_o}{R2}$$

Therefore, equating the current through R1 with the current through R2

$$\frac{-V_o}{R2} = \frac{V_{in}}{R1}$$

So

$$\frac{V_o}{V_{in}} = \frac{-R2}{R1}$$

Hence

$$V_o = -V_{in} \left( \frac{R2}{R1} \right)$$

This is the equation for an inverting op amp circuit as shown in Operational Amplifiers Explained (part 1).

In conclusion, we have now shown how the inverting and non inverting gain equations are derived. In fact, if you consider all the currents flowing into and out of each circuit node in any op amp circuit, the gain equation (how the output responds to a given input) can be determined.