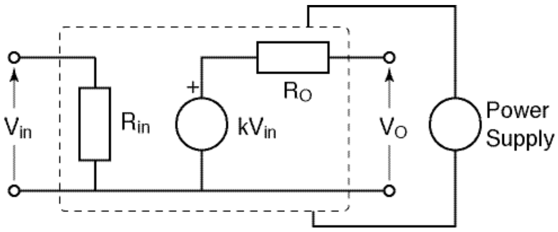
§n Operational Amplifiers

A previous example has already indicated how we might model an amplifier using passive components and voltage sources. A simpler model is shown below.

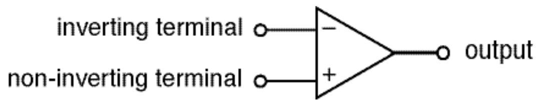


The input is modelled by a single resistor and the output is modelled by a dependant generator (which gives a voltage $k{\times}V_{in}$) and associated output resistance.

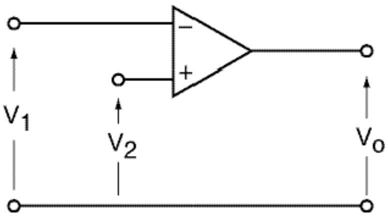
In drawing diagrams to represent an amplifier, the power supply is often left out for clarity, although it is always necessary because the basis of amplifier operation is that the (small) input signal controls the flow of power from the power supply to the load.

To determine the gain of such a system we would have to redraw the circuit diagram to show details of both the signal source which has to be amplified, and the details of the load.

In this course we will concentrate on the (ideal) integrated circuit operational amplifier (op-amp), shown in the diagram below.



If we now draw the op-amp with its ground reference we have;



The basic relationship for the op-amp is:

$$V_O = -AV_i$$

where A is typically 10^6 and $V_i = V_1 - V_2$

If $V_2 = 0$, then $V_O = -AV_1$; this is the reason for labelling the upper terminal as the inverting input. Similarly if $V_1 = 0$, then $V_O = -A(-V_2)$ i.e. $V_O = +AV_2$ in justification of the non-inverting label.

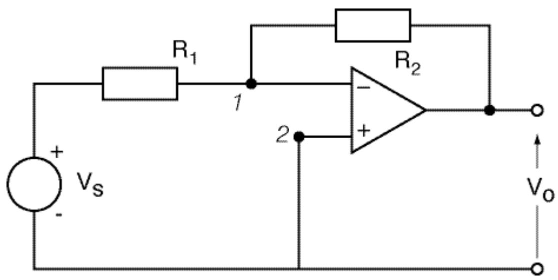
In many cases the real op-amp may be modelled as an ideal op-amp which has the following characteristics;

$I_1 = I_2 = 0$ (input impedance large > 1MΩ)

$A \Rightarrow \infty$, $V_1 - V_2 = V_i \Rightarrow 0$ (if the gain is very large and the output voltage remains moderate, then V_i must be small, $V_i \Rightarrow 0$).

One problem with op-amps is that the gain A is non-reproducable, i.e. the manufacturer can produce chips which all have large gains, but the parameter A varies from chip to chip. Consequently, op-amp designs attempt to ensure that the circuit gain is determined by the comp-onents surrounding the op-amp and not by A.

Inverting Op-amp design :



Voltage at non-inverting (+) input is 0, i.e. $V_+ = 0$. The very high gain demands that $V_+ = V_-$ and so therefore $V_- = 0$ also.

The large input impedance means that $I_1 = 0$, i.e. no current will flow into the amplifier.

The current flowing through $R_1 = (V_S - 0) / R_1$

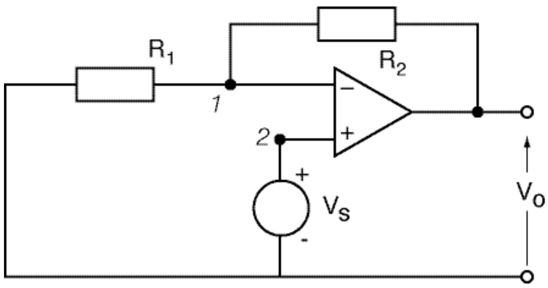
The current flowing through $R_2 = (0 - V_O) / R_2$

Since no current flows into the amplifier terminal these two currents must be equal.

$$\frac{V_S - 0}{R_1} = \frac{0 - V_O}{R_2} \Rightarrow \frac{V_S}{R_1} = -\frac{V_O}{R_2} \Rightarrow \frac{R_2}{R_1} = -\frac{V_O}{V_S}$$

The magnitude of the voltage ratio is determined by the ratio of the resistors while the sign is –ve, hence the circuit is called an inverting amplifier.

Non-Inverting Op-amp Design :



Start with the input terminal the voltage of which we are able to write down immediately. Here;

$V_+ = V_S$

So $V_- = V_S$ since the op-amp cannot sustain any voltage difference between its terminals.

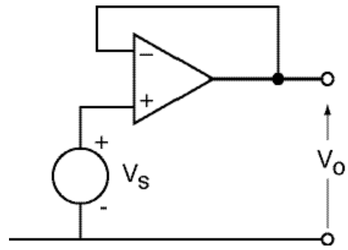
Current through $R_1 = (O - V_S) / R_1$
Current through $R_2 = (V_S - V_O) / R_2$

No current can flow into the terminal of the amplifier and so;

$$\frac{0 - V_S}{R_1} = \frac{V_S - V_O}{R_2} \Rightarrow -\frac{R_2}{R_1} = \frac{V_S - V_O}{V_S} = 1 - \frac{V_O}{V_S}$$

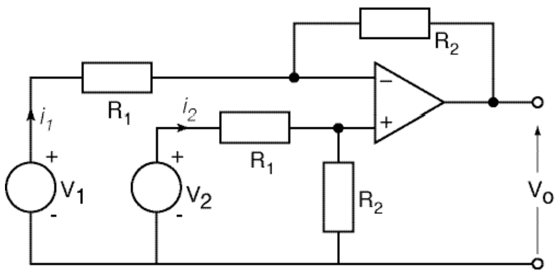
$$\therefore \quad \frac{V_O}{V_S} = 1 + \frac{R_2}{R_1}$$ non-inverting amplifier

Consider a special case of the non-inverting amplifier,



We have $V_+ = V_S$, so $V_- = V_S$, but because of the wire in place of the feedback resistor we also have $V_- = V_O$, therefore $V_O = V_S$.
The obvious question is "why not connect the input to the output". The answer is 'isolation' but this very important subject may be dealt with in more detail next year.

Differential Amplifier Design:



Firstly we find the voltage at the non-inverting input.

$V_2 = I_2R_1 + I_2R_2 = I_2(R_1+R_2)$
(high input impedance, no current to op-amp)

$$\frac{V_+}{V_2} = \frac{I_2R_2}{I_2(R_1 + R_2)} = \frac{R_2}{R_1 + R_2}$$

(or we could have used potential divider rule immediately).

Again, since no current flows in the inverting terminal of the op-amp,

$$\frac{V_- - V_O}{V_1 - V_O} = \frac{R_2}{R_1 + R_2}$$

from the potential divider rule. Alternatively,

$V_1 = I_1R_1 + I_1R_2 + V_O \Rightarrow V_1 - V_O = I_1(R_1+R_2)$
$V_- = I_2R_2 + V_O \Rightarrow V_- - V_O = I_2R_2$

Giving as before, on division,

$$\frac{V_- - V_O}{V_1 - V_O} = \frac{R_2}{R_1 + R_2}$$

The large gain of the op-amp will ensure that $V_- = V_+ = V_2R_2/(R_1+R_2)$ which can be substituted into the equation above to give,

$$\frac{\frac{R_2}{R_1 + R_2}V_2 - V_O}{V_1 - V_O} = \frac{R_2}{R_1 + R_2}$$

$$\frac{R_2}{R_1 + R_2}V_2 - V_O = \frac{R_2}{R_1 + R_2}V_1 - \frac{R_2}{R_1 + R_2}V_O$$

$$\frac{R_2}{R_1 + R_2}(V_2 - V_1) = \left(1 - \frac{R_2}{R_1 + R_2}\right)V_O$$

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

$$V_O = \frac{R_2}{R_1}(V_2 - V_1)$$ i.e. output proportional to the difference in input voltages.