EE2013

NON-LINEAR CIRCUIT ANALYSIS

LECTURE 16: THE OPERATIONAL AMPLIFIER

Instructors: Alex Jaeger, Anthony Wall
Coordinator: Prof. Pádraig Cantillon-Murphy

LECTURE SCHEDULE

Thursdays 11am-1pm
(with short break)

Monday 9am-10am slot not used!

LECTURE NOTES

https://www.jaeger.ie/ee2013/lec16

Uploaded after lecture takes place

QUESTIONS?

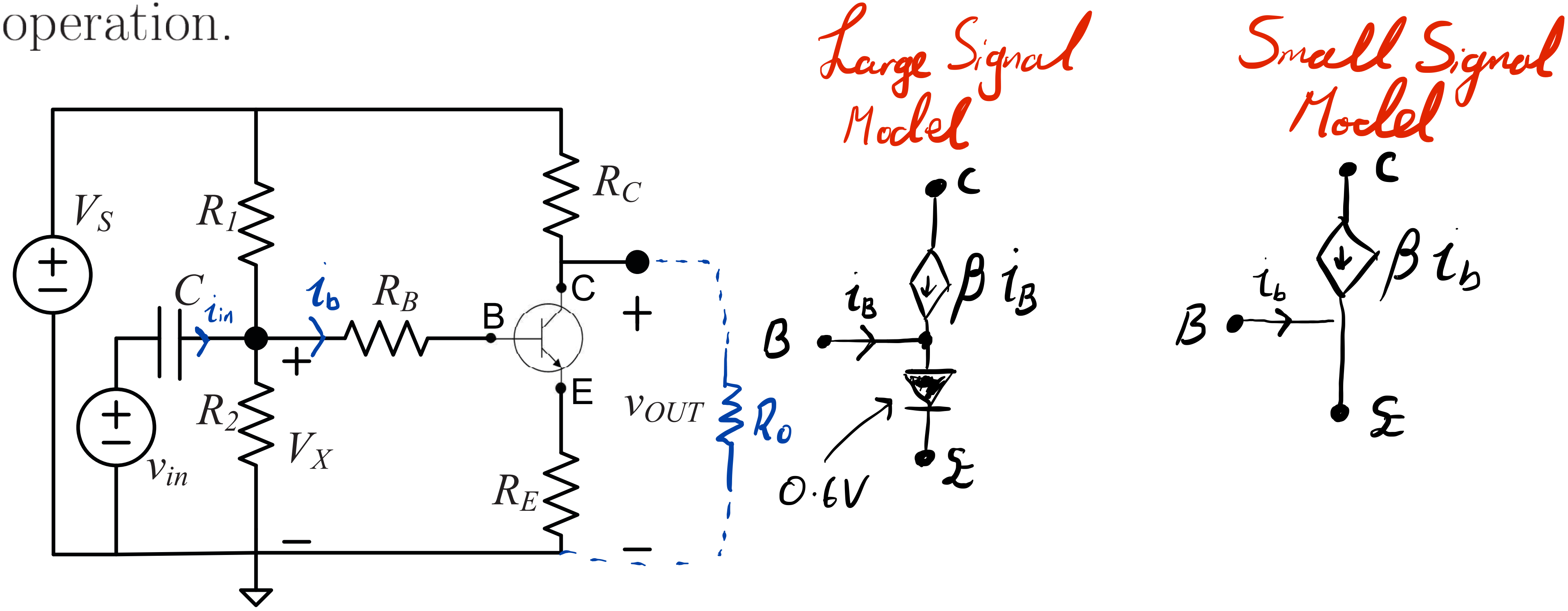
Just ask whenever it comes to you!

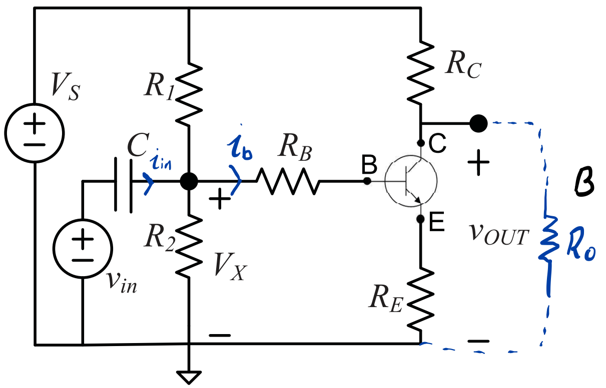
OR:

anthony.wall@mcci.ie on Email, Teams or Canvas

1.1 BJT and DC Bias

The DC biasing resistors in the BJT common emitter amplifier ensure that the circuit remains in the *forward active* region of operation.





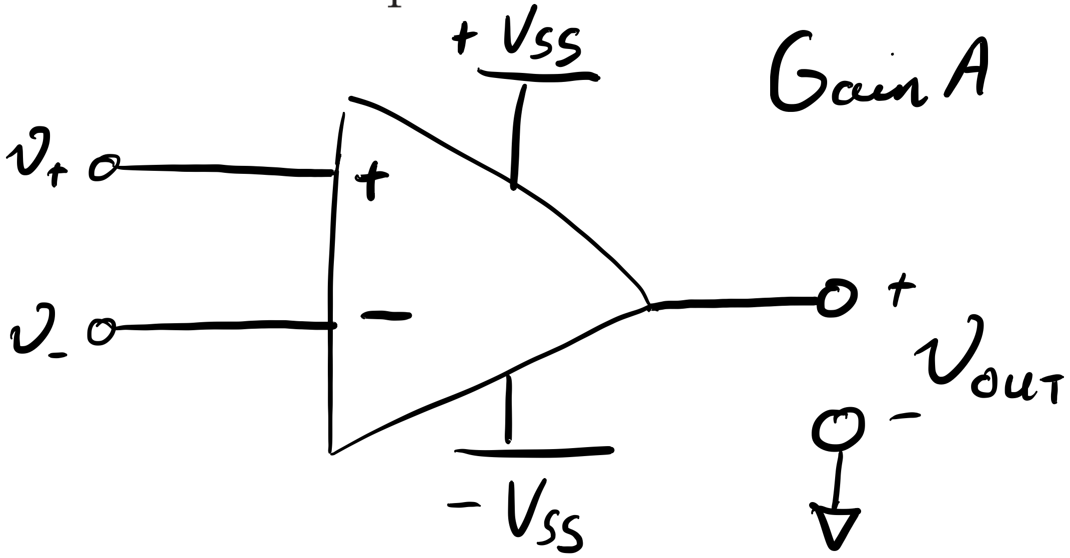
1.2 Small Signal Parameters for BJT Common Emitter Amplifier

Parameter	Value for BJT CE Amplifier
Small signal voltage gain	$A_v = -R_C / R_E$
Small signal input resistance	$r_{in} = (R_1 // R_2) // (R_B + (\beta+1) R_E)$
Small signal output resistance	$R_o \simeq R_C$
Small signal current gain	$A_i = \frac{i_{out}}{i_b} \cdot \frac{i_b}{i_{in}} = \beta\left(\frac{R_o}{R_c + R_o}\right) \cdot \frac{(R_1 // R_2)}{r_{in}' + (R_1 // R_2)}$
Small signal power gain	$\lvert A_v \rvert \lvert A_i \rvert$

2 The Operational-Amplifier

Today, we look at a new device: the operational amplifier, commonly termed the *op-amp*.

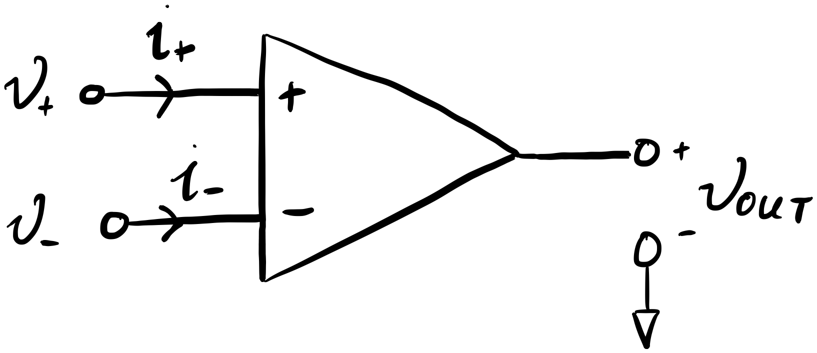
The integrated-circuit operational-amplifier is the fundamental building block for many electronic circuits. An op-amp is simply a very high gain electronic amplifier with a pair of differential inputs. Its functionality comes about through the use of *feedback* around the amplifier as we will show.



The op-amp has the following characteristics:

- Op-amps are typically powered by two DC voltage levels, $+V_{SS}$ and $-V_{SS}$. A typical value for V_{SS} is 15 V. In circuit diagrams, these connections are almost always ignored and not included as it's assumed that the op-amp is powered on during operation.

$i_+ \simeq i_- \simeq 0$



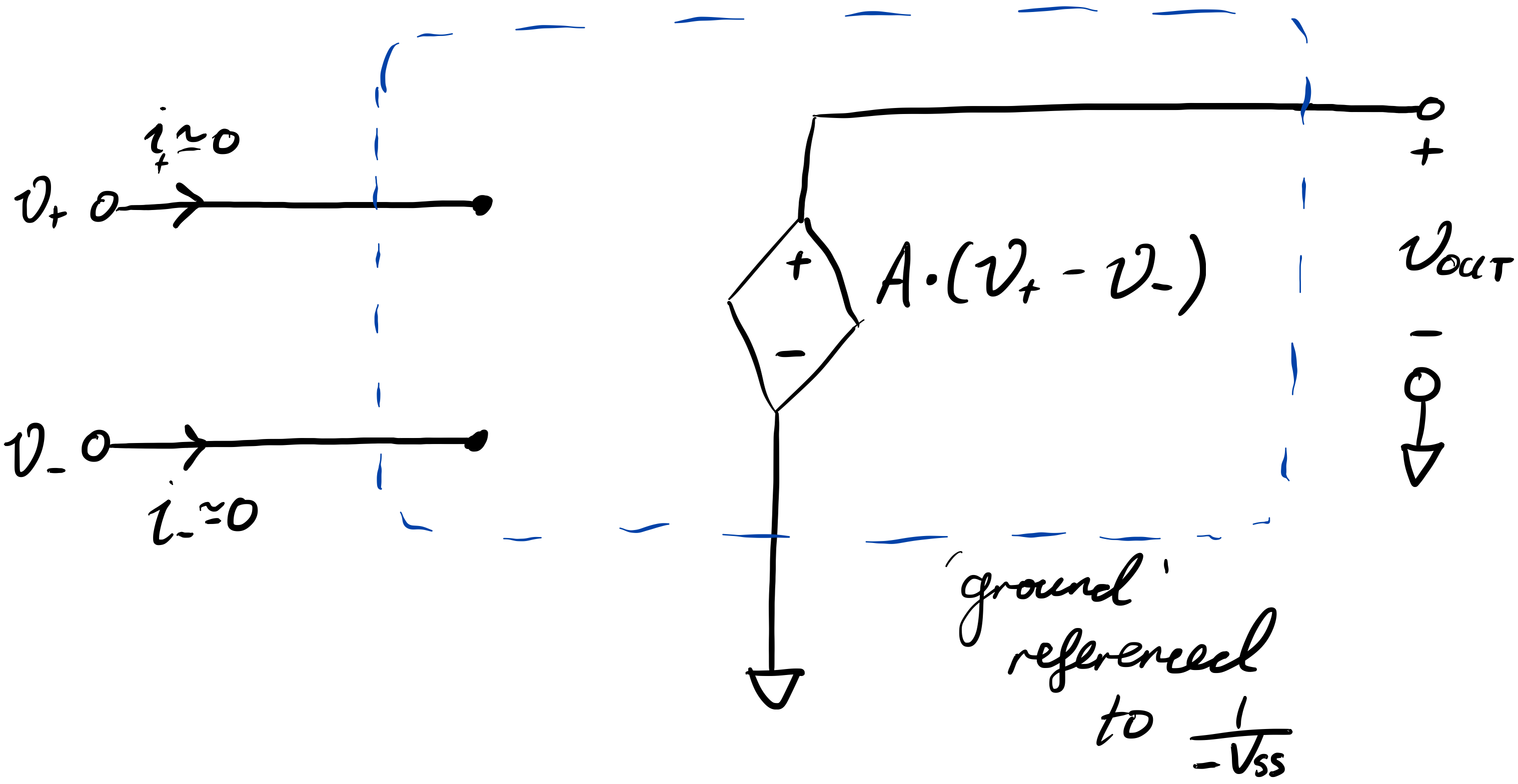
- The op-amp is basically a "three terminal" signal amplifier with two inputs and an output. It is a differential amplifier with very high gain, A, (typically 10^4 to 10^5). The two inputs are known as the non-inverting (v^+) and inverting (v^-) inputs respectively. In the ideal op-amp we assume that the gain A is infinite.

Very Large !

$$v_{out} = A(v^+ - v^-)$$

- In an ideal op-amp no current flows into either input, that is to say, they are voltage-controlled and have infinite input resistance. In a practical op-amp the input current is in the order of pico-amps (10^{-12}) amps, or less.

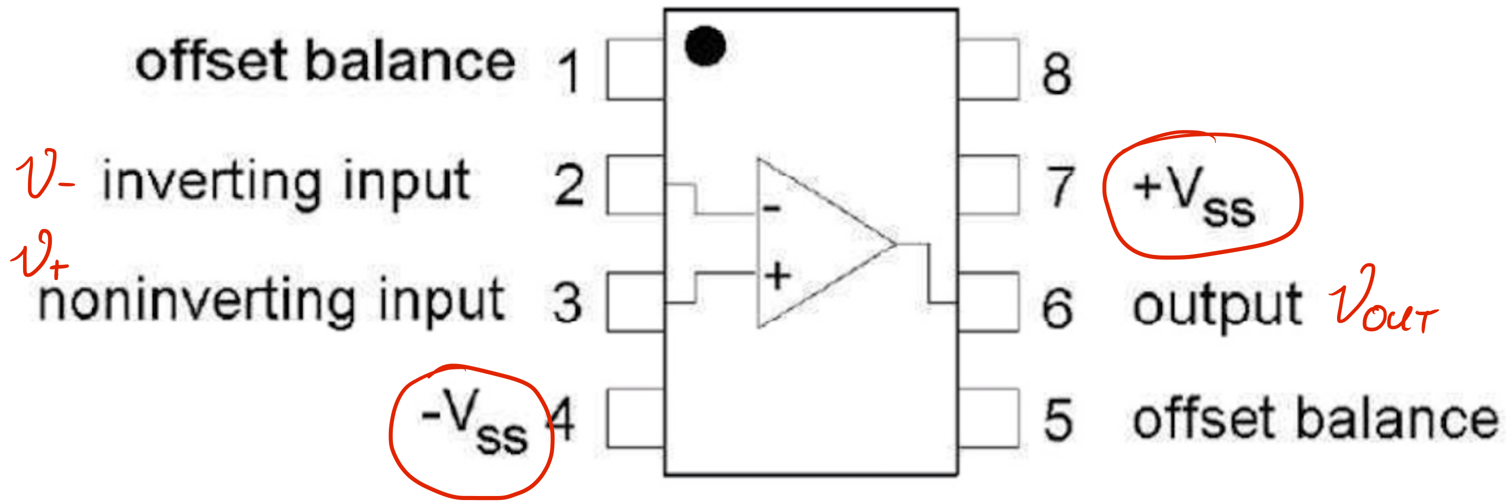
- The output acts as a voltage source, so that it can be modelled as a Thevenin source with a very low source resistance.

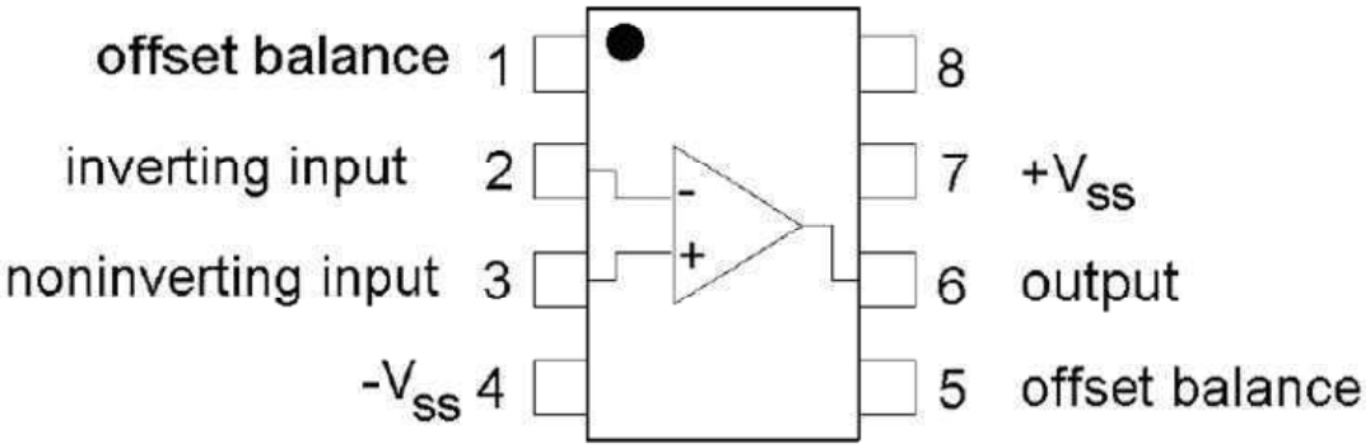


3 Characteristics of Op-amps

Op-amps come in many forms and with a bewildering array of specifications. They range in cost from a few cents upwards, depending on the characteristics. These specifications include input impedance, input bias current, output offset voltage, external power requirements *etc.* Higher grade amplifiers are known as precision, or instrumentation amplifiers. The LM741 is the industry standard 741 op-amp wherever possible. Although it was a major step forward in its day, by today's standards it is not a high performance amplifier. Its major advantage is that it costs about $0.30!

Op-amps come in a variety of "packages". For our laboratory assignment, we will be using the common discrete 8 pin DIP (dual inline package) form. Many op-amps use the same common pin-out for this package as shown below:

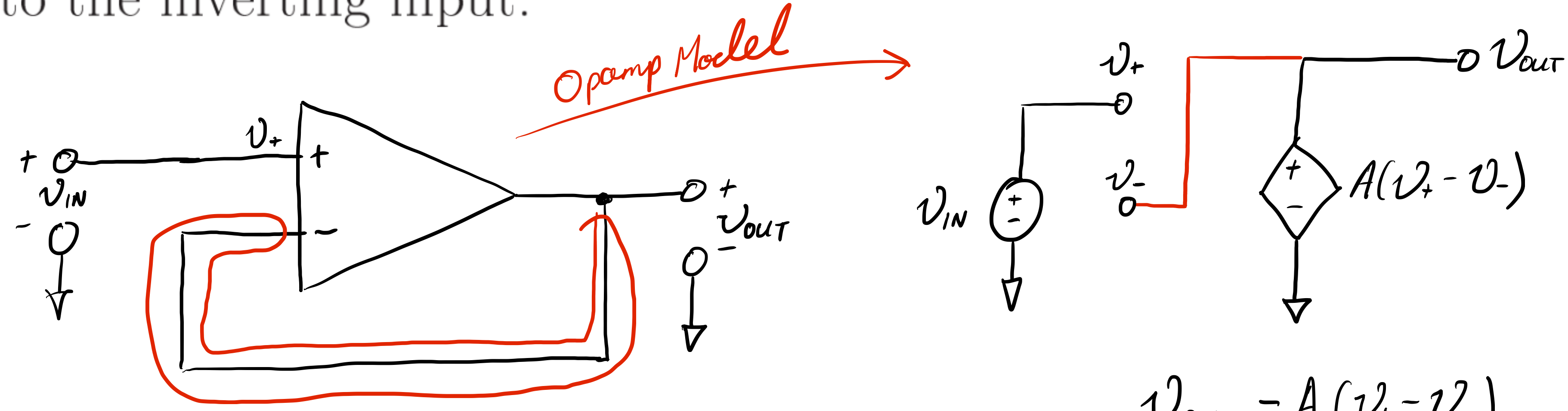




The pins are numbered counter-clockwise from the top left as shown above. (Note that pin 1 is identified by a notch at the top or a dot beside it.) The basic amplifier is connected between pins 2, 3 and 6. The amplifier requires a pair of external supply voltages to operate, typically ±15 V, as already mentioned. These connections are made to pins 7 (positive) and 4 (negative). Pins 1 and 5 are usually used for optional external offset nulling circuitry - the actual connection is dependent on the type. We will not use this feature in this module.

4 The Unity Gain Buffer

The simplest circuit configuration of the op-amp is as a unity gain "buffer" amplifier where the output is connected directly to the inverting input.



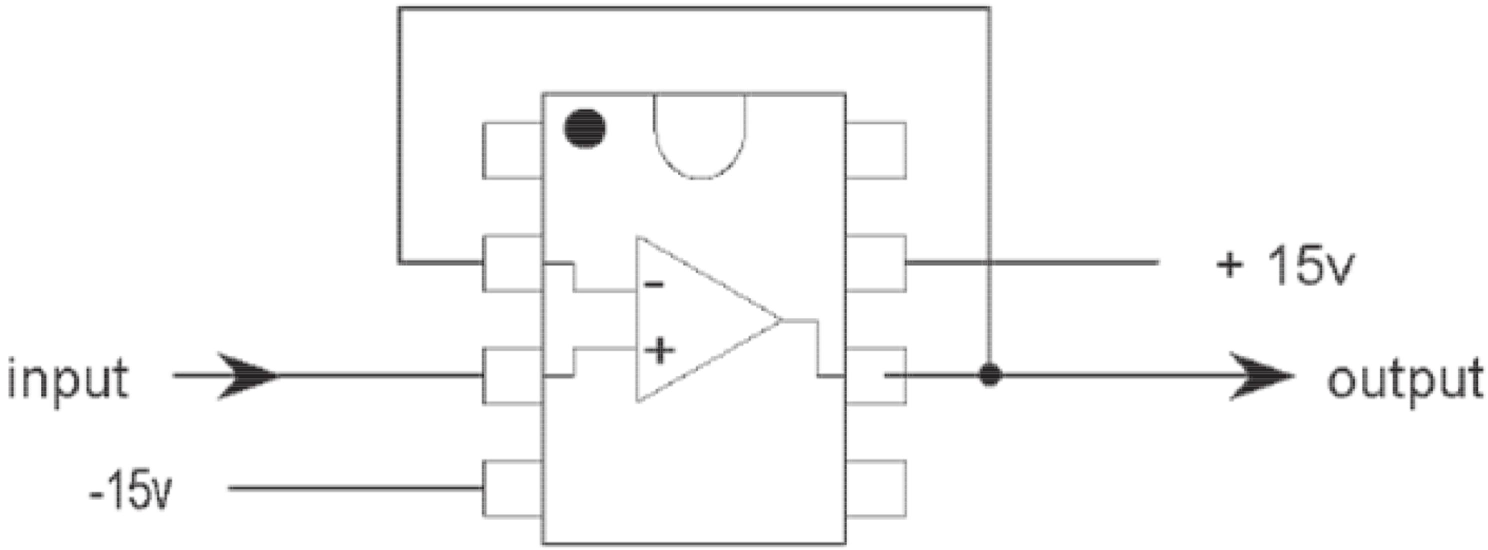
$$v_{OUT} = A(v_+ - v_-)$$

Since A is typically 10^4 or higher the transfer relation simplfies as follows:

$$v_{OUT} = A(v_{IN} - v_{OUT})$$

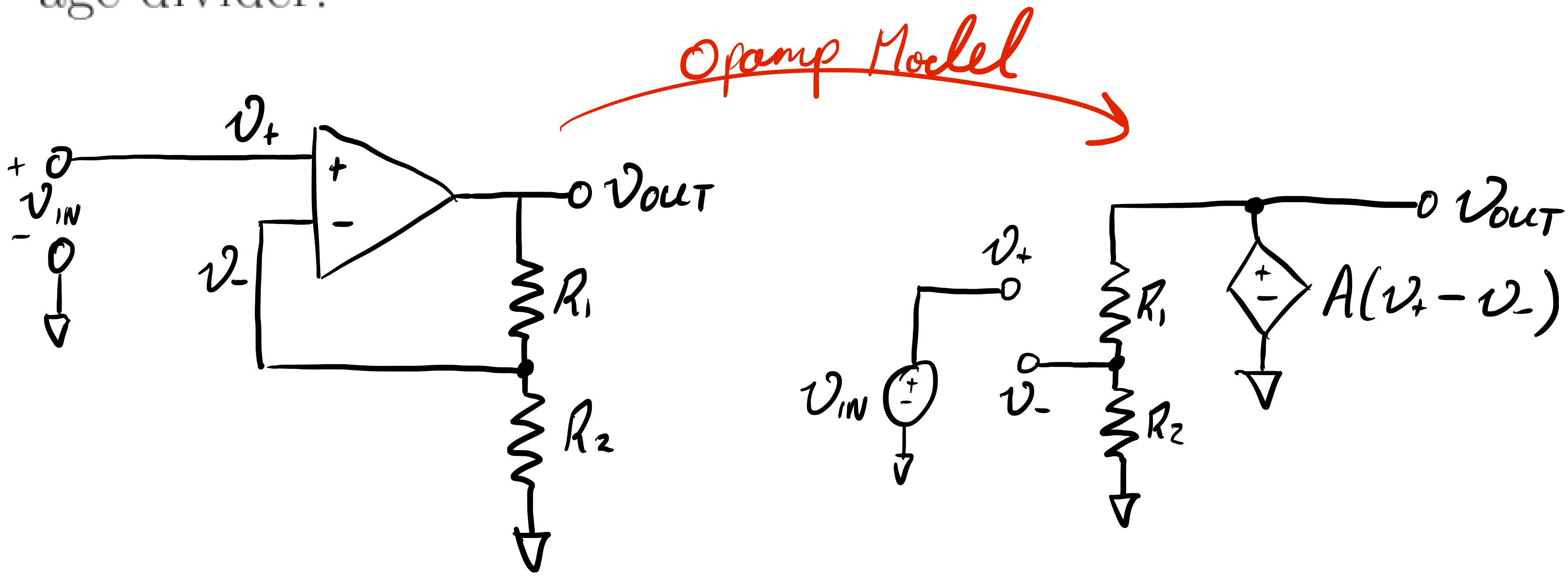
$$v_{OUT} = v_{IN}\,\frac{A}{1+A} \simeq v_{IN}$$

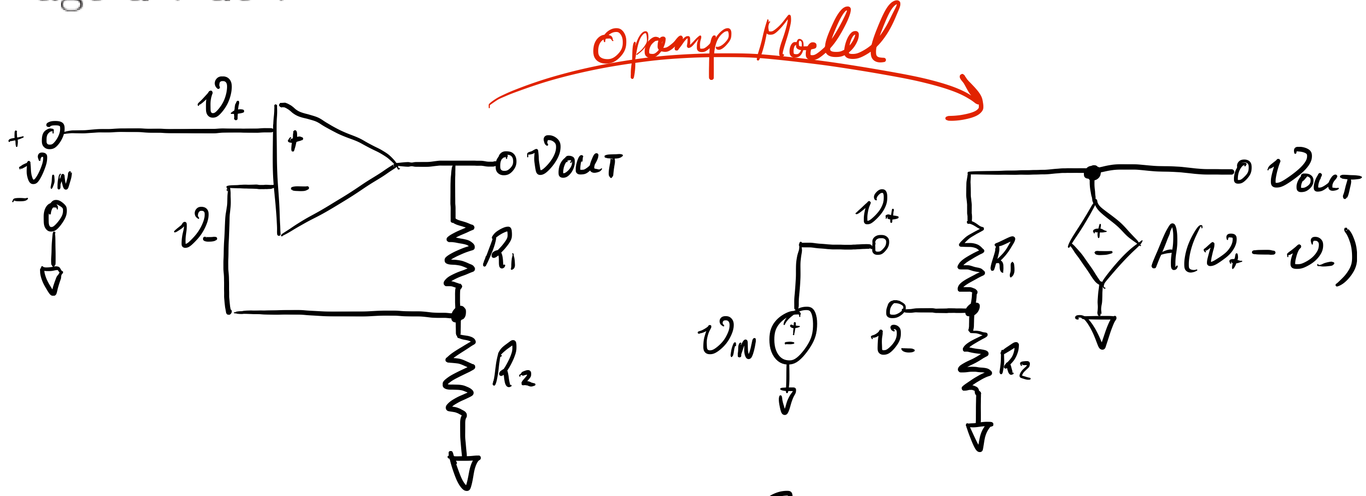
The unity gain amplifier is used commonly to minimize loading on a circuit because it draws no current yet provides a low output resistance output...a highly desireable feature for many circuits.



5 The Non-Inverting Amplifier

The op-amp buffer circuit may be modified to feedback only a fraction of the output voltage by including a two resistor voltage divider.





$$v_- = v_{OUT} \frac{R_2}{R_1+R_2}$$

$$v_{OUT} = A\left(v_{IN} - v_{OUT} \frac{R_2}{R_1+R_2}\right)$$

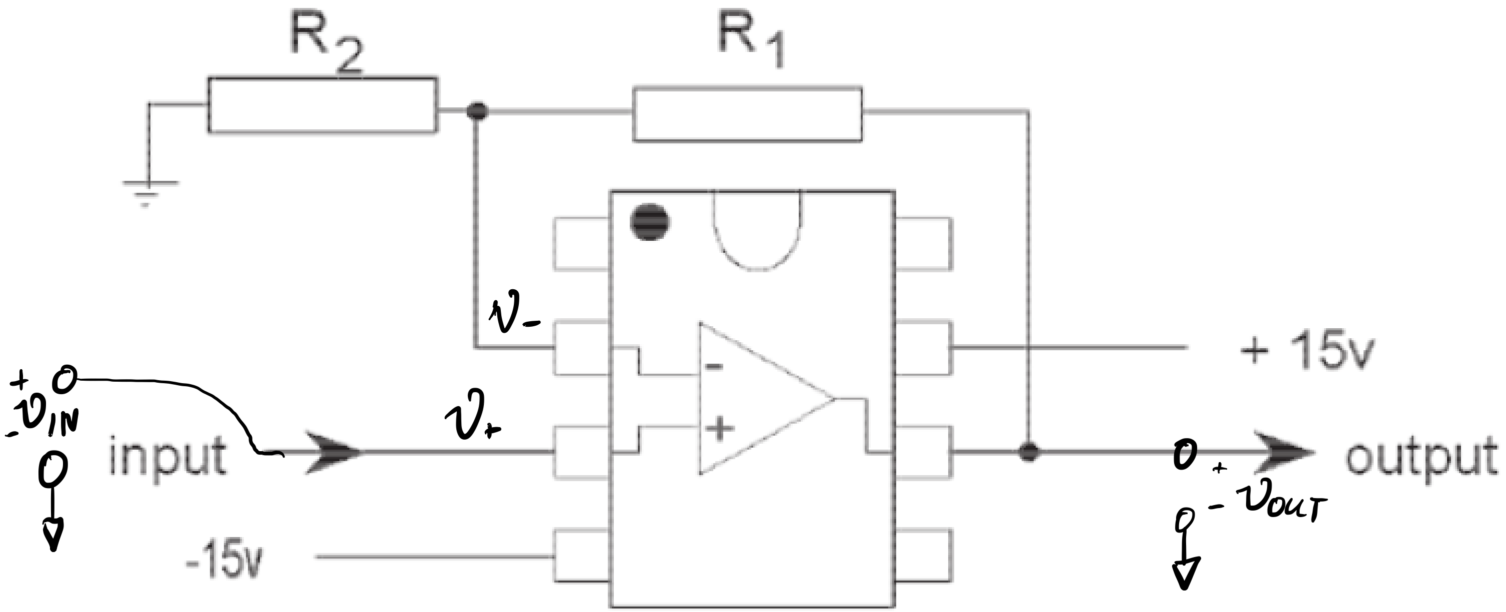
$$v_{OUT} = \frac{A(R_1+R_2)\, v_{IN}}{R_1+R_2+AR_2} \simeq v_{IN} \frac{A(R_1+R_2)}{A R_2}$$

Consider the case of $A \gg 1$

$$v_{OUT} = \frac{R_1+R_2}{R_2} v_{IN} = (1 + \frac{R_1}{R_2}) v_{IN}$$

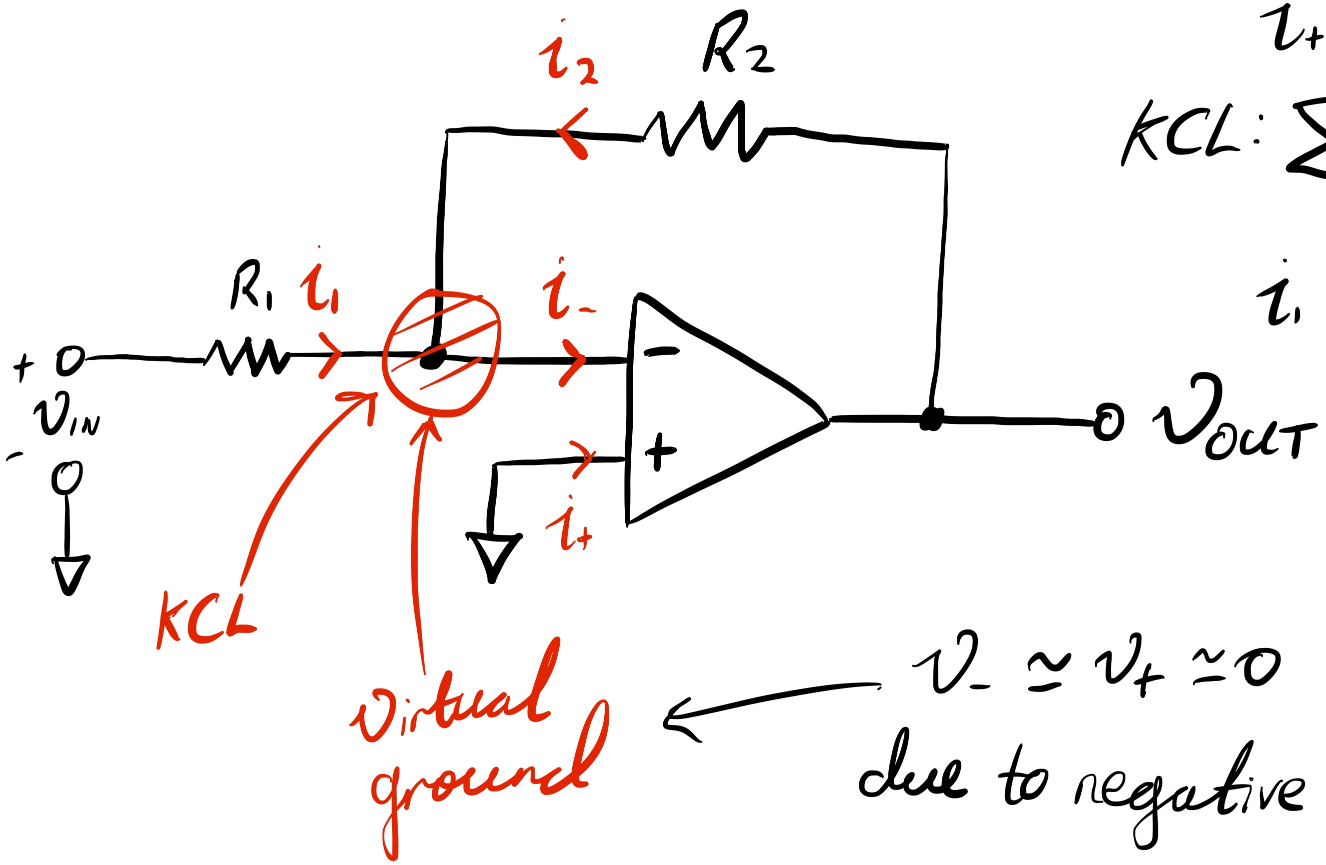
If $R_1 = 47$ kΩ, and $R_2 = 10$ kΩ, the voltage gain is 5.7.

The amplifier pinout arrangement is shown here for the 8-pin DIP:



6 Inverting Amplifier

The inverting amplifier has a configuration as shown below:



$i_+ \simeq i_- \simeq 0$

KCL: $\sum i_{IN} - \sum i_{OUT} = 0$

$\downarrow$

$i_1 + i_2 = 0$

$v_- \simeq v_+ \simeq 0$

due to negative feedback

The non-inverting input is connected to ground and a pair of resistors, R_1 and R_2 (the feedback resistor) is used to define the gain. To simplify the analysis we make the following assumptions:

- The gain A is very high and we let it tend to infinity. Because $v_{OUT} = A(v^+ - v^-)$ and $v^+ = 0$, this means that v^- tends to $\frac{v_{OUT}}{A} \to 0$ if $A \to \infty$. In other words, the inverting input voltage is so small that we declare it to be a "virtual ground" (*i.e.*, $v^- = 0$).

$$V_{OUT} = A(\downarrow - V_-)$$

$$V_{OUT} = A\downarrow - A V_-$$

$$V_- = \downarrow - \frac{V_{OUT}}{A} \simeq \downarrow$$

$A >> 1$

- No current flows into the inputs. This allows us to apply KCL at the junction of the resistors:

$$i_1 + i_2 = 0$$

$$\frac{V_{IN}}{R_1} + \frac{V_{OUT}}{R_2} = 0$$

$$V_{OUT} = -\frac{R_2}{R_1} V_{IN} \rightarrow \frac{V_{OUT}}{V_{IN}} = -\frac{R_2}{R_1}$$

Inversion!