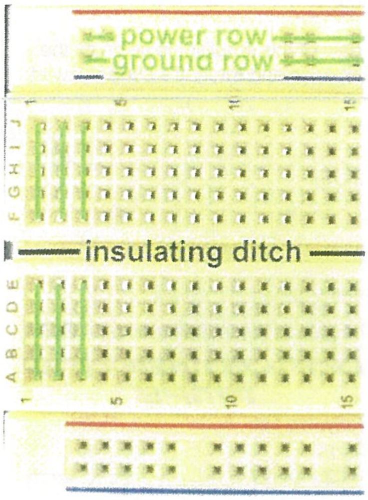
# QUICK START GUIDE TO ELECTRONICS

## BREADBOARDS

Breadboards provide a convenient way to prototype circuits quickly.

Rows of sockets along the long edges of the breadboard are connected together. These are typically used for ground and power connections.




Sockets in the middle of the breadboard are connected together in columns of five. There is no electrical connection between columns above and below the 'ditch' that runs along the length of the board.

## MULTIMETERS

Multimeters allow us to measure voltage, resistance and current with a simple twist of a dial.

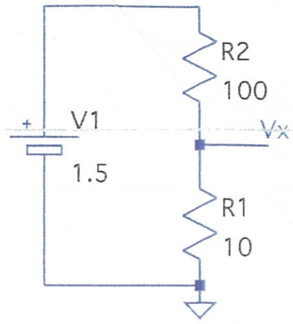
**To measure voltage**: Plug two probes into the **COM** and **V** sockets on the multimeter. Connect the COM probe to a ground point on your circuit. Connect the V probe to the point in the circuit that has the voltage you want to measure.

**To measure resistance:** use the same connections as for voltage measurement, but place the probes on either side of the resistance you are measuring. It does not matter which way round the probes go.

**To measure current:** Plug two probes between the **COM** and **A** sockets (some multimeters have more than one A socket, depending on the size of the current you want to measure). **Break** your circuit and connect the probes to each side of the break

## POWER SUPPLIES

We can use common batteries to produce a range of voltages: most often 1.5 V or 9 V. To produce smaller voltages, we can connect a **voltage divider** – two resistors in series – across our battery:



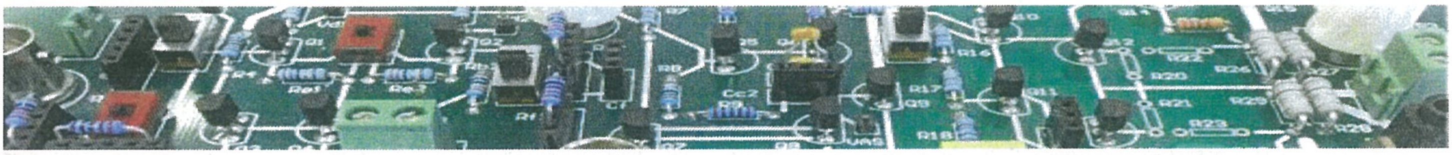

The voltage Vx relative to ground is given by the voltage of the battery, V1, and the ratio of the resistors, R1 and R2:

$$\mathrm{Vx} = \mathrm{V1}\frac{\mathrm{R1}}{\mathrm{R1+R2}}$$

In the example above,

$$\mathrm{Vx} = 1.5\ \mathrm{V}\frac{10\,\Omega}{10\,\Omega + 100\,\Omega}$$
$$= 136\ \mathrm{mV}$$

Voltage dividers are also useful for creating a bipolar (positive and negative) power supply from a single battery.



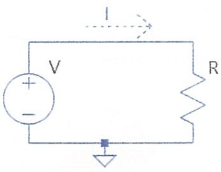
# ELECTRICAL QUANTITIES

## VOLTAGE

Voltage (V, in units of volts, V) is the energy of a bunch of charge carriers – it tells us how hard an electron can push through a resistance.

$$1\ \mathrm{V} = 1\ \mathrm{J/C}$$
$$= 1\ \mathrm{J}/6.242 \times 10^{18}\ \text{charge carriers}$$

Typically we look at the voltage difference between two points in a circuit. Often, one of these points is ground (⏚), which has a voltage of 0 V.




## CURRENT

Current (I, in units of amps, A) is a measure of how fast charge carriers in a circuit are moving:

$$1\ \mathrm{A} = 1\ \mathrm{C/s}$$

Current *flows through* components when those components form a complete circuit. Breaking the circuit stops the current.

## RESISTANCE

Resistance (R, in units of ohms, Ω) describes how much charge carriers are impeded as they move around a circuit.

$$1\,\Omega = 1\ \mathrm{V/A}$$

Resistance also relates current to voltage, as described by Ohm's law: $R = V/I$

## SERIES RESISTANCE

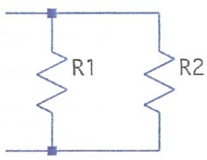
Series resistances add together:

$$R_{series} = R_1 + R_2$$


## PARALLEL RESISTANCE

The parallel combination of two resistances is always less than either of the resistances on their own. This is because adding another path through a circuit always makes it easier for charge carriers to flow:

$$R_{parallel} = \frac{R_1 R_2}{R_1 + R_2} < R_1 \text{ or } R_2$$




## POWER

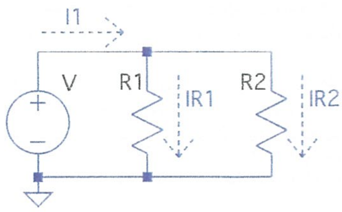
$$P = V \times I$$

Power (P, in units of watts, W) is a measure of the work done in a circuit: it is the amount of heat dissipated by a resistance or kinetic energy delivered to a motor.

## KIRCHOFF'S CURRENT LAW

The sum of currents entering a node is always equal to the sum of currents leaving the node. We can use this law to find unknown voltages.

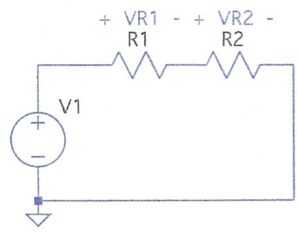
$$\Sigma I_{in} = \Sigma I_{out}$$
$$I_1 = I_{R_1} + I_{R_2}$$




## KIRCHOFF'S VOLTAGE LAW

The sum of voltages around a circuit is zero. We can use this law to find the current flowing in a circuit.

$$\Sigma V = 0$$
$$V_1 - V_{R_1} - V_{R_2} = 0$$

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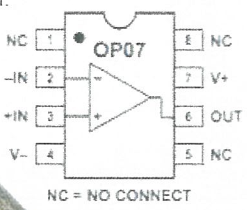
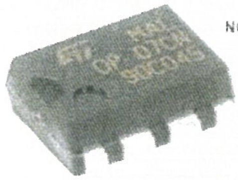
# OP AMP CIRCUITS

## OP AMPS

Operational amplifiers (op amps) are used throughout electronics for a range of applications. Compared to transistors they are stable, reliable, and much easier to analyse.

Different models have different pin arrangements and connections, but all have the following pins:
**Vcc+** positive power supply.
**Vcc-** negative power supply. This is often ground.
**IN+** non-inverting input.
**IN-** inverting input.
**OUT** output.



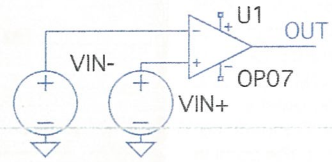



Note that pin 1 is always denoted with an indented circle or half-moon shape to help orient the chip correctly.

## COMPARATORS

With signals connected to IN+ and IN-, the op amp performs a simple task: it determines which input signal is more positive.

**If $V_{IN+} > V_{IN-}$, $V_{OUT}$ is HIGH, i.e. ≈ $V_{cc+}$**
**If $V_{IN+} < V_{IN-}$, $V_{OUT}$ is LOW, i.e. ≈ $V_{cc-}$**




## AMPLIFIERS

If there is a feedback path between OUT and IN- the op amp's behaviour takes on a new dimension: it adjusts $V_{OUT}$ to make $V_{IN-}$ equal to $V_{IN+}$. This means that $V_{OUT}$ changes in proportion to $V_{IN}$, i.e. we have a *linear amplifier*.

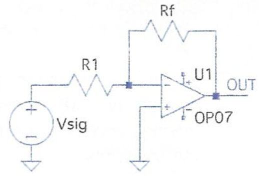
## GOLDEN RULES

We can use Kirchoff's laws to calculate the currents and voltages flowing at any point in an op amp circuit, provided we remember two golden rules:

1. No current flows into IN+ or IN-, i.e.
   **$I_{IN+} = I_{IN-} = 0$**
2. When there is a feedback path between OUT and IN-, $V_{OUT}$ changes to make $V_{IN-}$ equal to $V_{IN+}$:
   **$V_{IN+} = V_{IN-}$**

## INVERTING AMPS

A feedback resistor, Rf, is placed between OUT and IN-. An input signal is applied through a resistor, R1, to IN-. IN+ is connected to ground.




The gain of this amplifier is given by the golden rules and Kirchoff's current law at IN-:

$$I_{R1} = I_{Rf} + I_{IN-}$$

$$\frac{(V_{sig} - V_{IN-})}{R1} = \frac{(V_{IN-} - V_{OUT})}{Rf} + 0$$

Golden Rule $I_{IN-} = 0$

$$\frac{V_{sig}}{R1} = -\frac{V_{OUT}}{Rf}$$

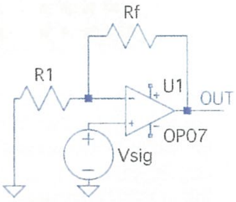
Golden Rule $V_{IN-} = V_{IN+}$. Here $V_{IN+}$ is connected to ground (0 V)

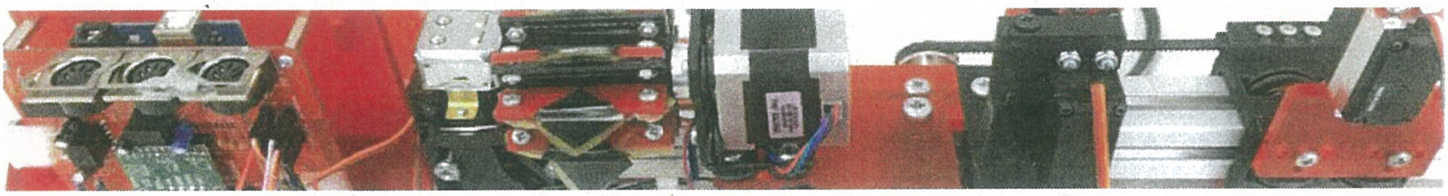
Rearranging: $$\frac{V_{OUT}}{V_{IN}} = \frac{-Rf}{R1}$$

So the gain of the inverting amp is **-Rf/R1**.

## NON-INVERTING AMPS

Similarly, we can build a non-inverting amp by connecting $V_{sig}$ to $V_{IN+}$ instead, and connecting R1 to ground. Using the same analysis, we find the gain to be **1 + Rf/R1**.



# ELECTRONICS PATHWAYS

## DIGITAL ELECTRONICS

The binary output produced by a comparator circuit is the key to the digital electronics that drives computers, mobile phones and the internet.

These topics are covered in the BE and BSc degrees in Electronic and Computer Systems at Victoria University of Wellington.

Graduates of these degrees have used their knowledge of digital electronics to work on 5G mobile systems at Spark and Vodafone and to build internet-of-things devices at Imagination Technologies.

## ANALOGUE ELECTRONICS

Linear amplifiers are the backbone of analogue systems such as hi-fis, electric motors and robotic sensors, which are also covered in the BE and BSc degrees in Electronic and Computer Systems at Victoria University of Wellington.

VUW graduates who studied analogue electronics have gained jobs designing tree felling robots at Waratah, forklifts at crown, human interface systems at Apple, and health care devices at Fisher & Paykel Healthcare.

## UNIVERSITY PREREQUISITES

Studying Electronic and Computer Systems at Victoria University of Wellington requires credits in Mathematics with Calculus and Physics at NCEA Level 3.

The differentiation and integration skills covered in Mathematics with Calculus are used by engineers throughout their work, including when they design electrical circuits driven by alternating current. Meanwhile, the electrical and mechanical systems content in Physics provides an introduction to the sorts of applications that engineers often work on.

## CAREERS

**Eden**, ME
Learnt analogue electronics by designing digital synthesisers at VUW before taking a job at Waratah designing automated tree-felling systems.


**Holly**, BE
After studying digital and analogue electronics, Holly founded a startup, Formalytics, that trains footballers to improve their speed and accuracy.

**Gareth**, BE
Used his final-year project to build a hydration monitor for neonatal intensive care units. Now works for Fisher & Paykel Healthcare.

**Will**, BE
Studied digital electronics and communications engineering. Now works for Spark developing 5G mobile networks.