

Sensing

Electric Current

Current is the rate of flow of charge, and can be positive or negative (negative electrons in wires).

$$I = Q/t$$

Where I is current (Amperes), Q is charge (Coulombs), and t is time (s).

$$\text{The amount of charge in one electron} = 1.6 \times 10^{-19} \text{ C}$$

Hence the number of electrons in one Coulomb = $1 / 1.6 \times 10^{-19} = 6.25 \times 10^{18}$

Potential Difference

For charge to flow, energy is needed. The potential difference is the energy given to charges to make them flow, i.e. the energy per unit of charge:

$$V = J/Q$$

Where V is the potential difference (volts), J is the electrical energy (Joules), and Q is charge (Coulombs).

The positive end of a battery is said to be the high energy end (i.e. where the electrons are). This is because in conventional current, the current is said to go from + to - (even though we know that the electrons go from - to +). There is a potential difference between the high energy and the low energy end, which means a current will flow.

Resistance

Resistance, measured in Ohms (Ω), is the capability of a material to hinder the flow of charge. Resistance is caused because of positive nuclei in the atoms attracting the electrons, and also because the electrons get in each others way, especially when heated.

Ohm's Law

“The potential difference is directly proportional to the current in a resistor, providing the resistance is constant”

$$V = IR$$

Where V is the potential difference (V), I is the current (A), and R is the resistance (Ω).

- We can think of I as the resultant because we can control V , and R is the property of the circuit.
- Ohmic conductors are where the resistance is constant.
- Non-ohmic conductors are where R is not constant. It usually increased due to heat exciting electrons, hence I decreases.

Conductance

Conductance is the measurement of the ease by which a material allows charge to flow. It is

measured in a unit called *Siemens*.

$$G = 1/R$$

Where G is the conductance (S), and R is the resistance (Ω).

Resistors in circuits

Adding another resistor in **series** in a circuit always decreases the current. This means that the effective resistance in the circuit has increased.

$$R_T = r_1 + r_2 + r_3$$

$$1/G_T = 1/G_1 + 1/G_2 + 1/G_3$$

When an additional resistor is added in **parallel** to a circuit, the current always increases. The additional resistor opens up another current path, without affecting the current in any of the existing paths. This results in less resistance in the circuit.

$$1/R_T = 1/r_1 + 1/r_2 + 1/r_3$$

$$G_T = G_1 + G_2 + G_3$$

Electrical Power

Power is the energy used per second ($J s^{-1}$):

$$\text{Power (W)} = \text{Energy (J)}/\text{Time (s)}$$

Hence by substituting in:

$$P = IV$$

$$P = I^2R$$

$$P = V^2/R$$

Potential Dividers

Potential dividers are a means of dividing up potential differences of any energy source (e.g. batteries, power packs etc.) using resistances.

The resistors will divide up the p.d. equally if they are of equal size.

e.g. A 10V potential difference is split up using two $1k\Omega$ resistors. Hence the reading across each of the resistors will be 5V. If there were three resistors, there would each have a share in 3.3V etc.

The potential difference is divided up in proportion to the relative sizes of the resistors:

$$R_1/R_2 = V_1/V_2$$

Potential dividers are used in sensing circuits. The output to a sensor is usually taken across one of the resistances.

e.g. When a thermistor is cold it has a high resistance, which means the potential difference across it is also high. As the temperature increases, the p.d. decreases and so does the resistance.

We can participate in some experiments in order to calibrate the sensor. We can then draw up a **calibration table** to find the relationship between the temperature and potential difference of such a circuit. From the calibration table, we can plot a **calibration curve** so that the temperature can accurately be calculated, given a certain p.d.

Linearity

The output across a resistance is not always linear. More often, the output is non-linear, which will give a curve when plotted. Because most outputs are non-linear, they need to have a calibration table and curve so that the output has some meaningful information. For a linear relationship, a fixed resistor must be much larger than the maximum resistance of the thermistor.

Electromotive Force (E.M.F.)

When a power source, such as a battery, is used, the battery tends to heat up. This must mean that there is resistance inside the battery. This resistance is called the **internal resistance**, which is the current being dissipated as heat, and hence acts as an extra resistor in series with the rest of the circuit. Due to Ohm's law, there must be a p.d. inside the battery and this p.d. reduces the voltage produced by the battery.

The E.M.F. of a supply is the work done per coulomb if there was no internal resistance present, i.e. the maximum amount of energy that a power source can give to a coulomb of charge.

Measuring the E.M.F. is very difficult due to internal resistance.

$$V = \mathcal{E} - IR_{\text{INTERNAL}}$$

Where V is the potential difference across the load (V), \mathcal{E} is the E.M.F. (V), I is the current (A) and R_{INTERNAL} is the internal resistance (Ω) of the power source.

High internal resistance sensors need to have their output voltage measured by high resistance voltmeters, e.g. a C.R.O. This will split the voltage up so it is more measurable.

Definitions

Resolution – Smallest change detectable by a sensor.

Sensitivity – The ratio of the change of output for the change of input.

Response time – The time it takes to respond to a change in input; speed of response.

Systematic error – Errors which are inherent in the measuring device; avoided by calibrating the instrument.

Random error – Spontaneous errors in results; this can be minimised by repeating and averaging.

Linearity – If the results are linear. If not, a calibration table is needed.