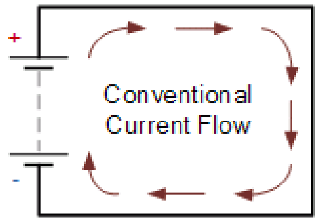


DC Circuit Theory

The fundamental relationship between voltage, current and resistance in an electrical or electronic circuit is called Ohm’s Law.

All materials are made up from atoms, and all atoms consist of protons, neutrons and electrons. Protons, have a positive electrical charge. Neutrons have no electrical charge (that is they are Neutral), while Electrons have a negative electrical charge. Atoms are bound together by powerful forces of attraction existing between the atoms nucleus and the electrons in its outer shell.

When these protons, neutrons and electrons are together within the atom they are happy and stable. But if we separate them from each other they want to reform and start to exert a potential of attraction called a *potential difference*.

Now if we create a closed circuit these loose electrons will start to move and drift back to the protons due to their attraction creating a flow of electrons. This flow of electrons is called an*electrical current*. The electrons do not flow freely through the circuit as the material they move through creates a restriction to the electron flow. This restriction is called *resistance*.

Then all basic electrical or electronic circuits consist of three separate but very much related electrical quantities called: Voltage, (v), Current, (i) and Resistance, (Ω).

Electrical Voltage

Voltage, (V) is the potential energy of an electrical supply stored in the form of an electrical charge. Voltage can be thought of as the force that pushes electrons through a conductor and the greater the voltage the greater is its ability to “push” the electrons through a given circuit. As energy has the ability to do work this potential energy can be described as the work required in joules to move electrons in the form of an electrical current around a circuit from one point or node to another.

Then the difference in voltage between any two points, connections or junctions (called nodes) in a circuit is known as the **Potential Difference**, (p.d.) commonly called the **Voltage Drop**.

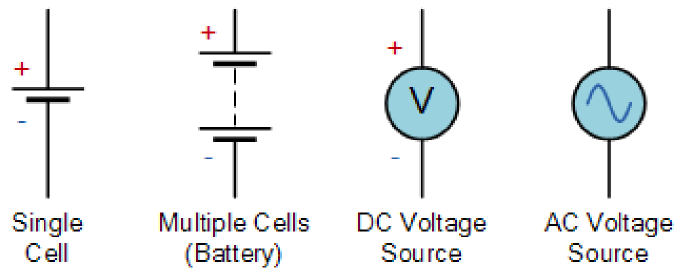
The Potential difference between two points is measured in **Volts** with the circuit symbol V, or lowercase “v“, although **Energy**, E lowercase “e” is sometimes used to indicate a generated emf (electromotive force). Then the greater the voltage, the greater is the pressure (or pushing force) and the greater is the capacity to do work.

A constant voltage source is called a **DC Voltage** with a voltage that varies periodically with time is called an **AC voltage**. Voltage is measured in volts, with one volt being defined as the electrical pressure required to force an electrical current of one ampere through a resistance of one Ohm. Voltages are generally expressed in Volts with prefixes used to denote sub-multiples of the voltage such as **microvolts** ($\mu V = 10^{-6}$ V), **millivolts** ($mV = 10^{-3}$ V) or **kilovolts** ($kV = 10^{3}$ V). Voltage can be either positive or negative.

Batteries or power supplies are mostly used to produce a steady D.C. (direct current) voltage source such as 5v, 12v, 24v etc in electronic circuits and systems. While A.C. (alternating current) voltage sources are available for domestic house and industrial power and lighting as well as power transmission. The mains voltage supply in the United Kingdom is currently 230 volts a.c. and 110 volts a.c. in the USA.

General electronic circuits operate on low voltage DC battery supplies of between 1.5V and 24V dc The circuit symbol for a constant voltage source usually given as a battery symbol with a positive, + and negative, – sign indicating the direction of the polarity. The circuit symbol for an alternating voltage source is a circle with a sine wave inside.

Voltage Symbols



A simple relationship can be made between a tank of water and a voltage supply. The higher the water tank above the outlet the greater the pressure of the water as more energy is released, the higher the voltage the greater the potential energy as more electrons are released.

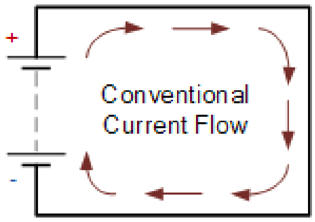
Voltage is always measured as the difference between any two points in a circuit and the voltage between these two points is generally referred to as the "**Voltage drop**". Note that voltage can exist across a circuit without current, but current cannot exist without voltage and as such any voltage source whether DC or AC likes an open or semi-open circuit condition but hates any short circuit condition as this can destroy it.

Electrical Current

Electrical Current, (I) is the movement or flow of electrical charge and is measured in **Amperes**, symbol **i**, for *intensity*). It is the continuous and uniform flow (called a drift) of electrons (the negative particles of an atom) around a circuit that are being "pushed" by the voltage source. In reality, electrons flow from the negative (–ve) terminal to the positive (+ve) terminal of the supply and for ease of circuit understanding conventional current flow assumes that the current flows from the positive to the negative terminal.

Generally in circuit diagrams the flow of current through the circuit usually has an arrow associated with the symbol, I, or lowercase i to indicate the actual direction of the current flow. However, this arrow usually indicates the direction of conventional current flow and not necessarily the direction of the actual flow.

Conventional Current Flow

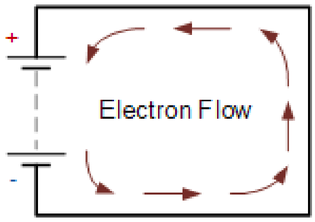


Conventionally this is the flow of positive charge around a circuit, being positive to negative. The diagram at the left shows the movement of the positive charge (holes) around a closed circuit flowing from the positive terminal of the battery, through the circuit and returns to the negative terminal of the battery. This flow of current from positive to negative is generally known as conventional current flow.

This was the convention chosen during the discovery of electricity in which the direction of electric current was thought to flow in a circuit. To continue with this line of thought, in all circuit diagrams and schematics, the arrows shown on symbols for components such as diodes and transistors point in the direction of conventional current flow.

Then **Conventional Current Flow** gives the flow of electrical current from positive to negative and which is the opposite in direction to the actual flow of electrons.

Electron Flow



The flow of electrons around the circuit is opposite to the direction of the conventional current flow being negative to positive.The actual current flowing in an electrical circuit is composed of electrons that flow from the negative pole of the battery (the cathode) and return back to the positive pole (the anode) of the battery.

This is because the charge on an electron is negative by definition and so is attracted to the positive terminal. This flow of electrons is called **Electron Current Flow**. Therefore, electrons actually flow around a circuit from the negative terminal to the positive.

Both *conventional current flow* and *electron flow* are used by many textbooks. In fact, it makes no difference which way the current is flowing around the circuit as long as the direction is used consistently. The direction of current flow does not affect what the current does within the circuit. Generally it is much easier to understand the conventional current flow – positive to negative.

In electronic circuits, a current source is a circuit element that provides a specified amount of current for example, 1A, 5A 10 Amps etc, with the circuit symbol for a constant current source given as a circle with an arrow inside indicating its direction.

Current is measured in **Amps** and an amp or ampere is defined as the number of electrons or charge (Q in Coulombs) passing a certain point in the circuit in one second, (t in Seconds).

Electrical current is generally expressed in Amps with prefixes used to denote **micro amps** ($\mu A = 10^{-6} A$) or **milliamps** ($mA = 10^{-3} A$). Note that electrical current can be either positive in value or negative in value depending upon its direction of flow around the circuit.

Current that flows in a single direction is called **Direct Current**, or **D.C.** and current that alternates back and forth through the circuit is known as **Alternating Current**, or **A.C.**. Whether AC or DC current only flows through a circuit when a voltage source is connected to it with its “flow” being limited to both the resistance of the circuit and the voltage source pushing it.

Also, as alternating currents (and voltages) are periodic and vary with time the “effective” or “RMS”, (Root Mean Squared) value given as I_{rms} produces the same average power loss equivalent to a DC current $I_{average}$. Current sources are the opposite to voltage sources in that they like short or closed circuit conditions but hate open circuit conditions as no current will flow.

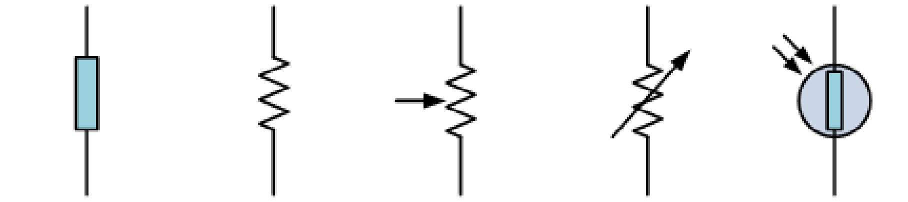
Using the tank of water relationship, current is the equivalent of the flow of water through the pipe with the flow being the same throughout the pipe. The faster the flow of water the greater the current. Note that current cannot exist without voltage so any current source whether DC or AC likes a short or semi-short circuit condition but hates any open circuit condition as this prevents it from flowing.

Resistance

Resistance, (R) is the capacity of a material to resist or prevent the flow of current or, more specifically, the flow of electric charge within a circuit. The circuit element which does this perfectly is called the “Resistor”.

Resistance is a circuit element measured in **Ohms**, Greek symbol (**Ω**, Omega) with prefixes used to denote **Kilo-ohms** ($k\Omega = 10^3\Omega$) and **Mega-ohms** ($M\Omega = 10^6\Omega$). Note that resistance cannot be negative in value only positive.

Resistor Symbols



The amount of resistance a resistor has is determined by the relationship of the current through it to the voltage across it which determines whether the circuit element is a “good conductor” – low resistance, or a “bad conductor” – high resistance. Low resistance, for example 1Ω or less implies that the circuit is a good conductor made from materials such as copper, aluminium or carbon while a high resistance, 1MΩ or more implies the circuit is a bad conductor made from insulating materials such as glass, porcelain or plastic.

A “semiconductor” on the other hand such as silicon or germanium, is a material whose resistance is half way between that of a good conductor and a good insulator. Hence the name “semi-conductor”. Semiconductors are used to make Diodes and Transistors etc.

Resistance can be linear or non-linear in nature, but never negative. Linear resistance obeys Ohm’s Law as the voltage across the resistor is linearly proportional to the current through it. Non-linear resistance, does not obey Ohm’s Law but has a voltage drop across it that is proportional to some power of the current.

Resistance is pure and is not affected by frequency with the AC impedance of a resistance being equal to its DC resistance and as a result can not be negative. Remember that resistance is always positive, and never negative.

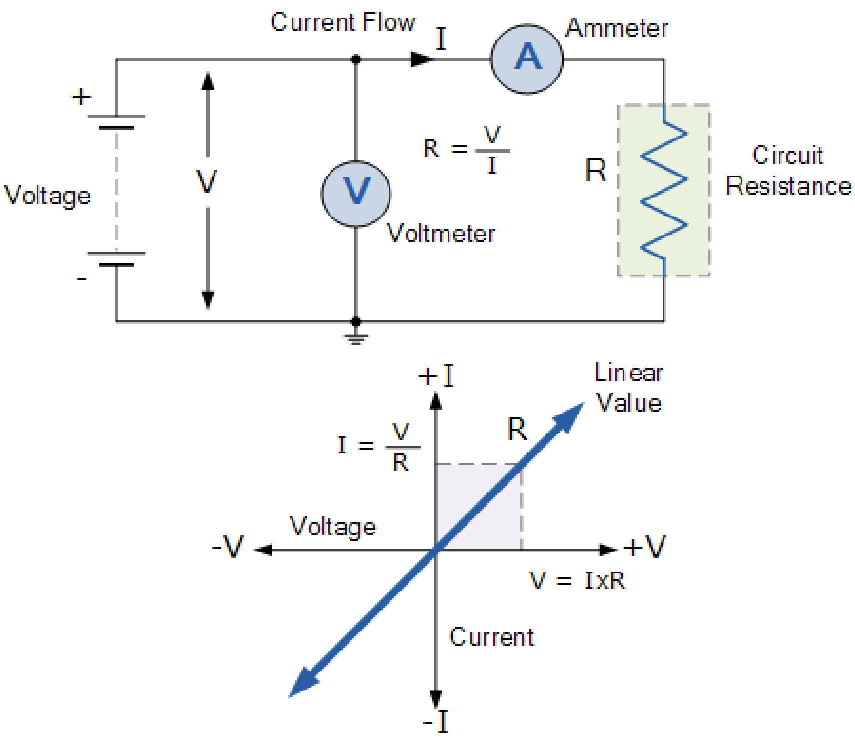
A resistor is classed as a passive circuit element and as such cannot deliver power or store energy. Instead resistors absorbed power that appears as heat and light. Power in a resistance is always positive regardless of voltage polarity and current direction.

For very low values of resistance, for example milli-ohms, ($m\Omega$) it is sometimes much easier to use the reciprocal of resistance ($1/R$) rather than resistance (R) itself. The reciprocal of resistance is called **Conductance**, symbol (**G**) and represents the ability of a conductor or device to conduct electricity.

In other words the ease by which current flows. High values of conductance implies a good conductor such as copper while low values of conductance implies a bad conductor such as wood. The standard unit of measurement given for conductance is the **Siemen**, symbol (**S**).

The unit used for conductance is mho (ohm spelt backward), which is symbolized by an inverted Ohm sign ℧. Power can also be expressed using conductance as: $p = i^2/G = v^2G$.

The relationship between Voltage, (v) and Current, (i) in a circuit of constant Resistance, (R) would produce a straight line i-v relationship with slope equal to the value of the resistance as shown.



Voltage, Current and Resistance Summary

Hopefully by now you should have some idea of how electrical Voltage, Current and Resistanceare closely related together. The relationship between **Voltage**, **Current** and **Resistance** forms the basis of Ohm's law. In a linear circuit of fixed resistance, if we increase the voltage, the current goes up, and similarly, if we decrease the voltage, the current goes down. This means that if the voltage is high the current is high, and if the voltage is low the current is low.

Likewise, if we increase the resistance, the current goes down for a given voltage and if we decrease the resistance the current goes up. Which means that if resistance is high current is low and if resistance is low current is high.

Then we can see that current flow around a circuit is directly proportional (∝) to voltage, (V↑ causes I↑) but inversely proportional (1/∝) to resistance as, (R↑ causes I↓).

A basic summary of the three units is given below.

- Voltage or potential difference is the measure of potential energy between two points in a circuit and is commonly referred to as its " **volt drop** ".

- When a voltage source is connected to a closed loop circuit the voltage will produce a current flowing around the circuit.
- In DC voltage sources the symbols +ve (positive) and −ve (negative) are used to denote the polarity of the voltage supply.
- Voltage is measured in **Volts** and has the symbol V for voltage or E for electrical energy.
- Current flow is a combination of electron flow and hole flow through a circuit.
- Current is the continuous and uniform flow of charge around the circuit and is measured in **Amperes** or **Amps** and has the symbol I.
- Current is Directly Proportional to Voltage ($I \propto V$)
- The effective (rms) value of an alternating current has the same average power loss equivalent to a direct current flowing through a resistive element.
- Resistance is the opposition to current flowing around a circuit.
- Low values of resistance implies a conductor and high values of resistance implies an insulator.
- Current is Inversely Proportional to Resistance ($I\ 1/\propto R$)
- Resistance is measured in **Ohms** and has the Greek symbol Ω or the letter R.

Quantity	Symbol	Unit of Measure	Abbreviation
Voltage	V *or* E	Volt	V
Current	I	Ampere	A
Resistance	R	Ohms	Ω

In the next tutorial about DC Circuits we will look at Ohms Law which is a mathematical equation explaining the relationship between Voltage, Current, and Resistance within electrical circuits and is the foundation of electronics and electrical engineering. **Ohm's Law** is defined as: $V = I*R$.