Topic 1
INTRODUCTION TO ELECTRONICS

Lesson objectives is to:
By the end of the lesson, the learner should be able to:
(i) Distinguish between electronics and electricity
(ii) Distinguish between analogue circuits and digital circuits
(iii) Describe the different types of resistors
(iv) Describe the different connections of resistors in a circuit
(v) To explain the application of resistors

Definition of terms:

Simple Definition of electronic

- : operating through the use of many small electrical parts (such as microchips and transistors)
- : produced by the use of electronic equipment
- : operating by means of a computer : involving a computer or a computer system

An electronic circuit is a structure that directs and controls electric currents, presumably to perform some useful function. The very name "circuit" implies that the structure is closed, something like a loop. That is all very well, but this answer immediately raises a new question: "What is an electric current?" Again, the name "current" indicates that it refers to some type of flow, and in this case we mean a flow of electric charge, which is usually just called charge because electric charge is really the only kind there is.

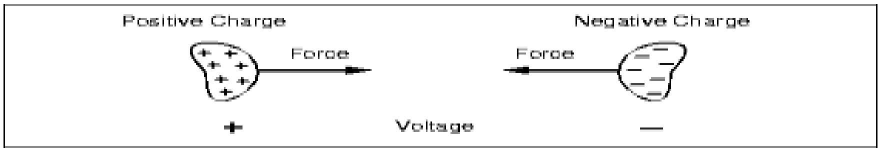
Charge: is an electrical property of the atomic particles of which matter consists, measured in Coulomb's (C) a charge of electron is 1.602×10^{-19} C

$1C = 6.24 \times 10^{18}$ electrons

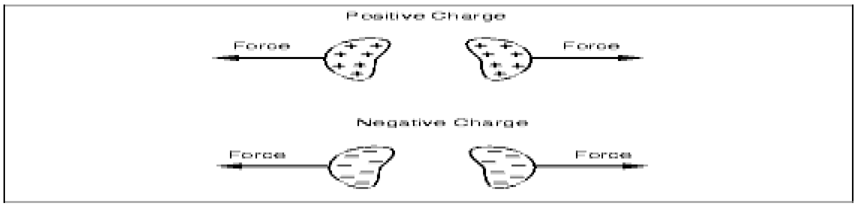
An electric charge exist between two charged objects as a force that we can measure, there are +Ve and –Ve Charges and electric charge can neither be created nor destroyed. Charge is mobile and it can be converted from one form to another.

Voltage (or potential difference) is the energy required to move a unit charge through an element, measured in Volts (V)

Opposite charges exert an attractive force on each other, just like two masses attract. External force is required to hold them apart, and work is required to move them farther apart.



: Like charges exert a repulsive force on each other. External force is required to hold them together, and work is required to push them closer.



Electric Current it's the time rate change of charge (i=dq/dt), measured in Ampheres (A) there is Direct Current (DC) as well as Alternate Current (AC)

Two spheres with opposite charges are connected by a conductor, allowing charge to flow.

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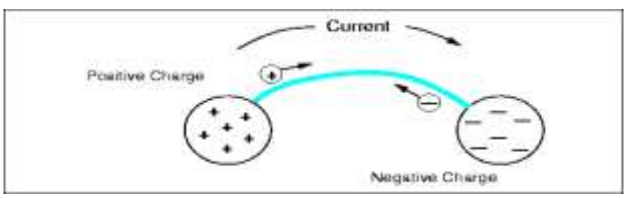


An electric circuit is an interconnection of electric elements

Batteries

Charges can be separated by several means to produce a voltage. A battery uses a chemical reaction to produce energy and separate opposite sign charges onto its two terminals. As the charge is drawn off by an external circuit, doing work and finally returning to the opposite terminal, more chemicals in the battery react to restore the charge difference and the voltage

Difference between Electronic and Electrical Technology:

Electronics is the branch of science and technology that deals with electrical circuits involving active electrical components such as vacuum tubes, transistors, diodes and integrated circuits. The nonlinear behaviour of these components and their ability to control electron flows makes amplification of weak signals possible, and is usually applied to information and signal processing. Electronics is distinct from **electrical** and electro-mechanical science and technology, which deals with the generation, distribution, switching, storage and conversion of electrical energy to and from other energy forms using wires, motors, generators, batteries, switches, relays, transformers, resistors and other passive components.

Today, most electronic devices use semiconductor components to perform electron control. The study of semiconductor devices and related technology is considered a branch of steady state physics, whereas the design and construction of electronic circuits to solve practical problems come under electronics engineering.

Electronic devices and components

An electronic component is any physical entity in an electronic system used to affect the electrons or their associated fields in a desired manner consistent with the intended function of the electronic system. Components are generally intended to be connected together, usually by being soldered to a printed circuit board (PCB), to create an electronic circuit with a particular function (for example an amplifier, radio receiver, or oscillator). Components may be packaged singly or in more complex groups as integrated circuits. Some common electronic components are:

1. Resistors
2. Capacitors
3. Inductors
4. Vacuum Tube (No longer in use)
5. Semiconductors

    - Diodes
    - Transistors
    - Integrated Circuits
    - Thyristors

The first three components are often categorized as passive (e.g. resistors, capacitors and inductors). The other two components (Vacuum Tube and Semiconductors) are called active (e.g. transistors and thyristors). Semiconductors form the bulk of the Electronics unit.

Types of electronic circuits

Circuits and components can be divided into two groups: analog and digital. A particular device may consist of circuitry that has one or the other or a mix of the two types.

Analog circuits

Most analog electronic appliances, such as radio receivers, are constructed from combinations of a few types of basic circuits. Analog circuits use a continuous range of voltage as opposed to discrete levels as in digital circuits.

The number of different analog circuits so far devised is huge, especially because a 'circuit' can be defined as anything from a single component, to systems containing thousands of components.

Analog circuits are sometimes called linear circuits although many non-linear effects are used in analog circuits such as mixers, modulators, etc. Good examples of analog circuits include vacuum tube and transistor amplifiers, operational amplifiers and oscillators.

One rarely finds modern circuits that are entirely analog. These days analog circuitry may use digital or even microprocessor techniques to improve performance. This type of circuit is usually called "mixed signal" rather than analog or digital.

Sometimes it may be difficult to differentiate between analog and digital circuits as they have elements of both linear and non-linear operation. An example is the comparator which takes in a continuous range of voltage but only outputs one of two levels as in a digital circuit. Similarly, an overdriven transistor amplifier can take on the characteristics of a controlled switch having essentially two levels of output.

Digital circuits

Digital circuits are electric circuits based on a number of discrete voltage levels. Digital circuits are the most common physical representation of Boolean algebra and are the basis of all digital computers. To most engineers, the terms "digital circuit", "digital system" and "logic" are interchangeable in the context of digital circuits. Most digital circuits use a binary system involving two voltage levels labeled "Low"(0) and "High"(1). Often "Low" will be near zero volts and "High" will be at a higher level depending on the supply voltage in use. Voltage drop due to resistance is often compensated by checking rounding voltages in the middle to 1. Ternary (with three states) logic has been studied, and some prototype computers made. Digital circuits are also slightly less prone to error and for that reason are used in computers. Computers electronic clocks, and programmable logic controllers (used to control industrial processes) are constructed of digital circuits. Digital Signal Processors are another example.

There is short circuit and open circuit

Resistor

It's an electronic component that limits the amount of current or that produces the desired voltage drop

Applications

They are used in a variety of applications in all types of electronic circuits. The power or wattage rating is related to the resistors physical size; however the resistance of the resistor is not related to the physical size of the resistor. Resistors with high resistance have low wattage that is less current.

Types of Resistors they vary in many ways; from very small surface mount chip resistors up to large wire-wound power resistors.

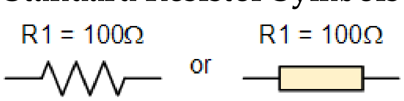
A Typical Resistor

Resistors are "Passive Devices", that is they contain no source of power or amplification. They only attenuate or reduce the voltage signal passing through them. This attenuation results in electrical energy being lost in the form of heat as the resistor resists the flow of electrons through it.

Most resistors are linear devices that produce a voltage drop across themselves when an electrical current flow through them because they obey Ohm's Law, and different values of resistance produces different values of current or voltage.

Some of the common characteristics associated with the humble resistor are; **Temperature Coefficient, Voltage Coefficient, Noise, Frequency Response, Power** as well as **Temperature Rating, Physical Size** and **Reliability**.

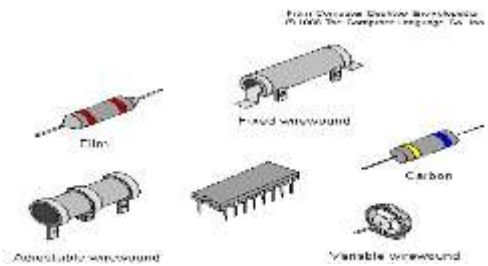
Standard Resistor Symbols



The symbol of Resistor can either be a "zig-zag" type line or a rectangular box.

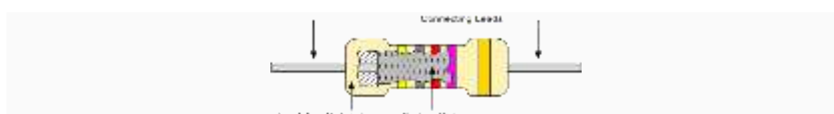
All modern fixed value resistors can be classified into four broad groups;

- Carbon Composition Resistor - Made of carbon dust or graphite paste, low wattage values
- Film or Cermet Resistor - Made from conductive metal oxide paste, very low wattage values
- Wire-wound Resistor - Metallic bodies for heat-sink mounting, very high wattage ratings
- Semiconductor Resistor - High frequency/precision surface mount thin film technology



Composition Type Resistors

Carbon Resistors are the most common type of **Composition Resistors**. Carbon resistors are a cheap general purpose resistor used in electrical and electronic circuits. Their resistive element is manufactured from a mixture of finely ground carbon dust or graphite (similar to pencil lead) and a non-conducting ceramic (clay) powder to bind it all together.



Carbon Resistor

The ratio of carbon dust to ceramic (conductor to insulator) determines the overall resistive value of the mixture and the higher the ratio of carbon, the lower the overall resistance. The mixture is moulded into a cylindrical shape with metal wires or leads are attached to each end to provide the electrical connection as shown, before being coated with an outer insulating material and colour coded markings to denote its resistive value.

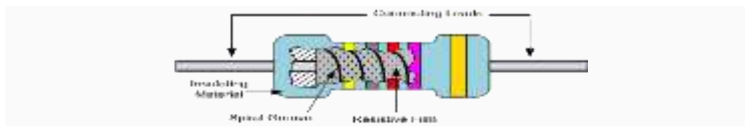
The **Carbon Composite Resistor** is a low to medium type power resistor which has a low inductance making them ideal for high frequency applications but they can also suffer from noise and stability when hot. Carbon composite resistors are generally prefixed with a "CR" notation (eg CR10kΩ) and are available in E6 (±20% tolerance (accuracy)), E12 (±10% tolerance) and E24 (±5% tolerance) packages with power ratings from 0.125 or 1/4 of a Watt up to 2 Watts.

Carbon composite resistors are very cheap to make and are therefore commonly used in electrical circuits. However, due to their manufacturing process carbon type resistors have very large tolerances so for more precision and high value resistances, **film type resistors** are used instead.

Film Type Resistors

The generic term "**Film Resistor**" consist of *Metal Film*, *Carbon Film* and *Metal Oxide Film* resistor types, which are generally made by depositing pure metals, such as nickel, or an oxide film, such as tin-oxide, onto an insulating ceramic rod or substrate.

Film Resistor



The resistive value of the resistor is controlled by increasing the desired thickness of the deposited film giving them the names of either "thick-film resistors" or "thin-film resistors". Once deposited, a laser is used to cut a high precision spiral helix groove type pattern into this film. The cutting of the film has the effect of increasing the conductive or resistive path, a bit like taking a long length of straight wire and forming it into a coil.

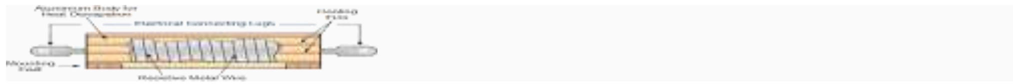
Metal Film Resistors have much better temperature stability than their carbon equivalents, lower noise and are generally better for high frequency or radio frequency applications. **Metal Oxide Resistors** have better high surge current capability with a much higher temperature rating than the equivalent metal film resistors.

Metal Film Resistors are prefixed with a "MFR" notation (eg MFR100kΩ) and a CF for Carbon Film types. Metal film resistors are available in E24 (±5% & ±2% tolerances), E96 (±1% tolerance) and E192 (±0.5%, ±0.25% & ±0.1% tolerances) packages with power ratings of 0.05 (1/20th) of a Watt up to 1/2 Watt. Generally speaking Film resistors are precision low power components.

Wire wound Type Resistors

Another type of resistor, called a **Wire wound Resistor**, is made by winding a thin metal alloy wire (Nichrome) or similar wire onto an insulating ceramic former in the form of a spiral helix similar to the film resistor above. These types of resistors are generally only available in very low ohmic high precision values (from 0.01 to 100kΩ) due to the gauge of the wire and number of turns possible on the former making them ideal for use in measuring circuits and Whetstone bridge type applications.

They are also able to handle much higher electrical currents than other resistors of the same ohmic value with power ratings in excess of 300 Watts. These high power resistors are moulded or pressed into an aluminum heat sink body with fins attached to increase their overall surface area to promote heat loss and cooling.



Wire wound resistor types
are prefixed with a "WH" or "W" notation (eg WH10Ω) and are available in the WH aluminum cladded package (±1%, ±2%, ±5% & ±10% tolerance) or the W vitreous enameled package (±1%, ±2% & ±5% tolerance) with power ratings from 1W to 300W or more.

Surface Mount Resistors

4.7kΩ SMD Resistor

Surface Mount Resistors or SMD Resistors, are very small rectangular shaped metal oxide film resistor. They have a ceramic substrate body onto which is deposited a thick layer of metal oxide resistance. The resistive value of the resistor is controlled by increasing the desired thickness, length or type of deposited film being used and highly accurate low tolerance resistors, down to 0.1% can be produced. They also have metal terminals or caps at either end of the body which allows them to be soldered directly onto printed circuit boards.

Resistor Colour Code

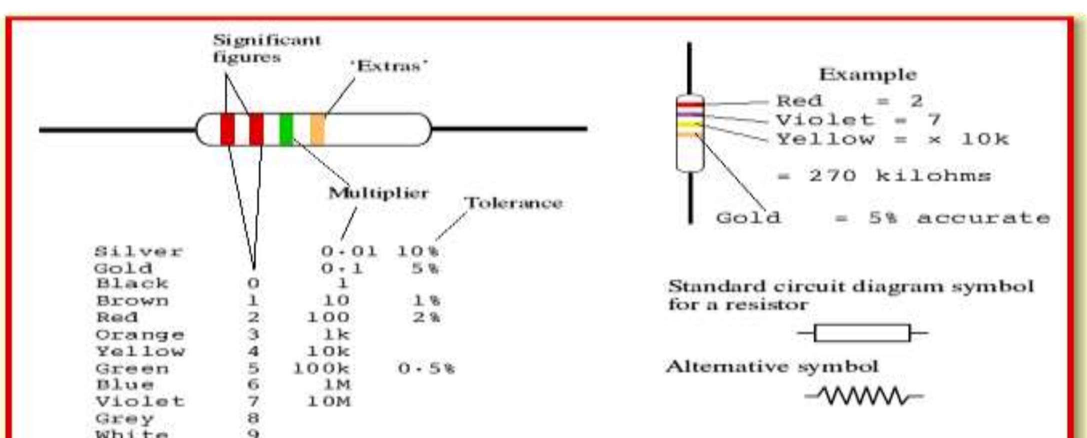


Figure 2.3 Resistor Colour Code & Circuit Symbols.

Resistors in Series

Connecting Resistors Together

Individual resistors can be connected together in a series connection, a parallel connection or combinations of both series and parallel together, to produce more complex networks whose equivalent resistance is a combination of the individual resistors. Then complicated networks of resistors or impedances can be replaced by a single equivalent resistor or impedance. Whatever the combination or complexity of the circuit, all resistors obey *Ohm's Law* and *Kirchoff's Circuit Laws.*

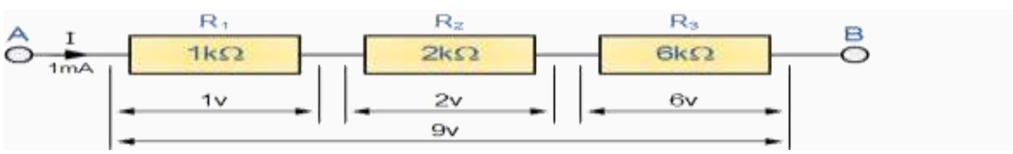
Resistors in Series.

Resistors are said to be connected in "**Series**", when they are daisy chained together in a single line. Resistors in series have a **Common Current** flowing through them as the current that flows through one resistor must also flow through the others as it can only take one path. Then the amount of current that flows through a set of resistors in series is the same at all points in a series circuit. For example:

$$I_{R1} = I_{R2} = I_{R3} = I_{AB} = 1mA$$

Resistors R_1, R_2 and R_3 are all connected together in series between points A and B.

Series Resistor Circuit

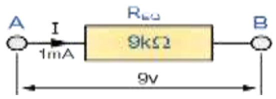


As the resistors are connected together in series the same current passes through each resistor in the chain and the total resistance, R_T of the circuit must be **equal** to the sum of all the individual resistors added together. That is

$$R_T = R_1 + R_2 + R_3$$

by taking the individual values of the resistors in our simple example above, the total equivalent resistance, R_{EQ} is therefore given as:

$$R_{EQ} = R_1 + R_2 + R_3 = 1k\Omega + 2k\Omega + 6k\Omega = 9k\Omega$$



So we can replace all three individual resistors above with just one single equivalent resistor which will have a value of 9kΩ.

Series Resistor Equation

$$R_{total} = R_1 + R_2 + R_3 + \ldots\ldots R_n \text{ etc.}$$

Series Resistor Voltage

The voltage across each resistor connected in series follows different rules to that of the series current. We know from the above circuit that the total supply voltage across the resistors is equal to the sum of the potential differences across
R_1 , R_2 and R_3 , $V_{AB} = V_{R1} + V_{R2} + V_{R3} = 9V$.

Using *Ohm's Law*, the voltage across the individual resistors can be calculated as:

$$\text{Voltage across } R_1 = IR_1 = 1mA \times 1k\Omega = 1V$$

$$\text{Voltage across } R_2 = IR_2 = 1mA \times 2k\Omega = 2V$$

$$\text{Voltage across } R_3 = IR_3 = 1mA \times 6k\Omega = 6V$$

giving a total voltage V_{AB} of (1V + 2V + 6V) = 9V which is equal to the value of the supply voltage. Then the sum of the potential differences across the resistors is equal to the total potential difference across the combination and in our example this is 9V.

The equation given for calculating the total voltage in a series circuit which is the sum of all the individual voltages added together is given as:

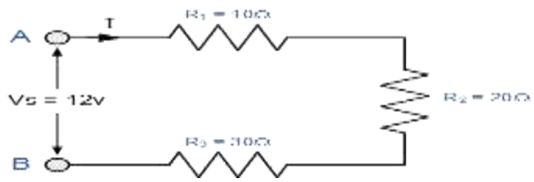
$$V_{total} = V_{R1} + V_{R2} + V_{R3} \ldots\ldots + VRn$$

Then series resistor networks can also be thought of as "voltage dividers" and a series resistor circuit having *N* resistive components will have N-different voltages across it while maintaining a common current.

By using *Ohm's Law* either the voltage, current or resistance of any series connected circuit can easily be found and resistor of a series circuit can be interchanged without affecting the total resistance, current, or power to each resistor.

Example No1

Calculate the equivalent resistance, series current, voltage drop and power for each resistor of the following resistors in series circuit.



All the data can be found by using *Ohm's Law*, and to make life a little easier we can present this data in tabular form.

Resistance	Current	Voltage	Power
$R_1 = 10\Omega$	$I_1 = 200mA$	$V_1 = 2V$	$P_1 = 0.4W$
$R_2 = 20\Omega$	$I_2 = 200mA$	$V_2 = 4V$	$P_2 = 0.8W$
$R_3 = 30\Omega$	$I_3 = 200mA$	$V_3 = 6V$	$P_3 = 1.2W$
$R_T = 60\Omega$	$I_T = 200mA$	$V_S = 12V$	$P_T = 2.4W$

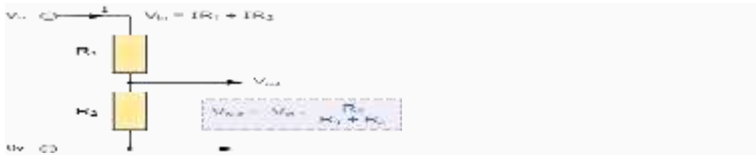
The Potential Divider Circuit

Connecting resistors in series like this across a single DC supply voltage has one major advantage; different voltages appear across each resistor with the amount of voltage being determined by the resistors value only because as we now know, the current through a series circuit is common. This ability to generate different voltages produces a circuit called a **Potential** or **Voltage Divider Network**.

The series circuit shown above is a simple potential divider where three voltages 1V, 2V and 6V are produced from a single 9V supply. *Kirchoff's voltage laws* states that "*the supply voltage in a closed circuit is equal to the sum of all the voltage drops (IR) around the circuit*" and this can be used to good effect as this allows us to determine the voltage levels of a circuit without first finding the current.

The basic circuit for a potential divider network (also known as a voltage divider) for resistors in series is shown below.

Potential Divider Network



In this circuit the two resistors are connected in series across V_{in}, which is the power supply voltage connected to the resistor, R_1, where the output voltage V_{out} is the voltage across the resistor R_2 which is given by the formula. If more resistors are connected in series to the circuit then different voltages will appear across each resistor with regards to their individual resistance R (Ohms law IxR) providing different voltage points from a single supply. However, care must be taken when using this type of network as the impedance of any load connected to it can affect the output voltage. For example,

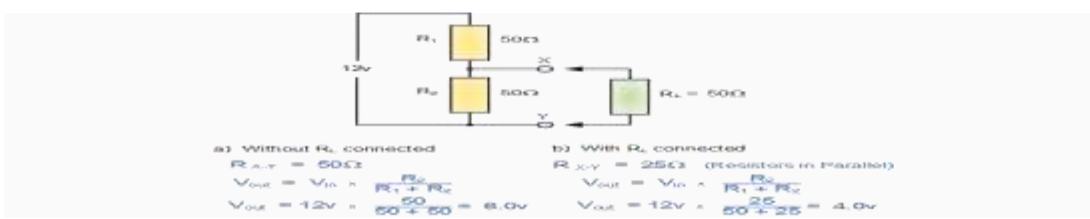
Suppose you only have a 12V DC supply and your circuit which has an impedance of 50Ω requires a 6V supply. Connecting two equal value resistors, of say 50Ω each, together as a potential divider network across the 12V will do this very nicely until you connect your load circuit to the network. The loading effect of two resistances connected together in parallel changes the ratio of the two resistances altering the voltage drop and this is demonstrated below.

Example No2

Calculate the voltage across X and Y.

a) Without R_L connected

b) With R_L connected



As you can see from above, the output voltage V_{out} without the load resistor connected gives us the required output voltage of 6V but the same output voltage at V_{out} when the load is connected drops to only 4V, (*Resistors in Parallel*). Then the output voltage V_{out} is determined by the ratio of V_1 to V_2 with the effect of reducing the signal or voltage level being known as **Attenuation** so care must be taken when using a potential divider networks. The higher the load impedance the less is the loading effect on the output.

A variable resistor, potentiometer or pot as it is more commonly called, is a good example of a multi-resistor potential divider within a single package as it can be thought of as thousands of mini-resistors in series. Here a fixed voltage is applied across the two outer fixed connections and the variable output voltage is taken from the wiper terminal. Multi-turn pots allow for a more accurate output voltage control.

Resistors in Series Applications

Series resistors can be used to produce different voltages across themselves and this type of resistor network is very useful for producing a voltage divider network. If we replace one of the resistors in the voltage divider circuit above with a *Sensor* such as a thermistor, light dependent resistor (LDR) or even a switch, we can convert an analogue quantity being sensed into a suitable electrical signal which is capable of being measured.

Resistors in Series Summary

When two or more resistors are connected together end-to-end in a single branch they are said to be connected together in series. **Resistors in Series** carry the same current, but the potential differences across them are not the same. In a series circuit the individual resistors add together to give the equivalent resistance, (R_T) of the series combination. The resistors in a series circuit can be interchanged without affecting the total resistance, current, or power to each resistor or the circuit.

Resistors in Parallel

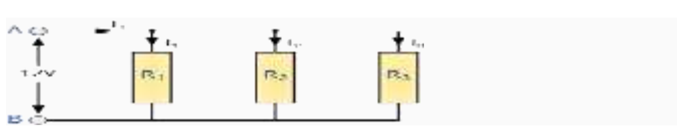
Resistors are said to be connected together in "**Parallel**" when both of their terminals are respectively connected to each terminal of the other resistor or resistors. Unlike in series circuit, in parallel circuits the current can take more than one path and because there are multiple paths the current is not the same at all points in a parallel circuit. However, the voltage drop across all of the resistors in a parallel circuit is the same. Then, **Resistors in Parallel** have a **Common Voltage** across them and is true for all parallel elements.

The voltage across resistor R_1 equals the voltage across resistor R_2 which equals the voltage across R_3 and all equal the supply voltage and is therefore given as:

$$V_{R1} = V_{R2} = V_{R3} = V_{AB} = 12V$$

In the following resistors in parallel circuit the resistors R_1, R_2 and R_3 are all connected together in parallel between the two points A and B as shown.

Parallel Resistor Circuit



Here, the reciprocal (1/R) value of the individual resistances are all added together instead of the resistances themselves with the inverse of the algebraic sum giving the equivalent resistance as shown.

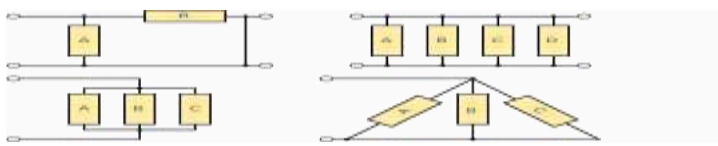
Parallel Resistor Equation

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \;\ldots\ldots + \frac{1}{R_n} \text{ etc}$$

Then the inverse of the equivalent resistance of two or more resistors connected in parallel is the algebraic sum of the inverses of the individual resistances. The equivalent resistance is always less than the smallest resistor in the parallel network so the total resistance, R_T will always decrease as additional parallel resistors are added.

Parallel resistance gives us a value known as **Conductance**, symbol **G** with the units of conductance being the **Siemens**, symbol **S**. Conductance is the reciprocal or the inverse of resistance, (G = 1/R).

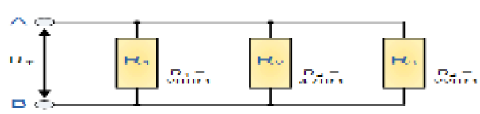
Various Parallel Resistor Circuits



All the above are parallel resistor circuits.

Example No1

Find the total resistance, R_T of the following resistors in parallel network.



The total resistance R_T across the two terminals A and B is calculated as:

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

$$\frac{1}{R_T} = \frac{1}{200} + \frac{1}{470} + \frac{1}{220} = 0.0117$$

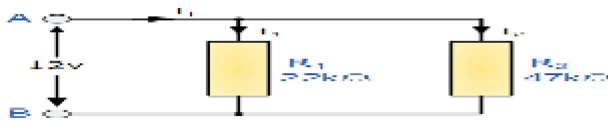
$$\text{therefore, } R_T = \frac{1}{0.0117} = 85.67\Omega$$

This method of calculation can be used for calculating any number of individual resistances connected together within a single parallel network. If however, there are only two individual resistors in parallel then a much simpler and quicker formula can be used to find the total resistance value, and this is given as:

$$R_T = \frac{R_1 \times R_2}{R_1 + R_2}$$

Example No2

Consider the following circuit with only two resistors in a parallel combination.



Using our two resistor formula above we can calculate the total circuit resistance, R_T as:

$$R_T = \frac{22k\Omega \times 47k\Omega}{22k\Omega + 47k\Omega} = 14{,}985\Omega \text{ or } 14{,}9k\Omega$$

One important point to remember about resistors in parallel, is that the total circuit resistance (R_T) of any two resistors connected together in parallel will always be **LESS** than the value of the smallest resistor and in our example above $R_T = 14.9k\Omega$ were as the value of the smallest resistor is only 22kΩ. In other words, the equivalent resistance of a parallel network is always less than the smallest individual resistor in the combination.

Also, in the case of R_1 being equal to the value of R_2, that is $R_1 = R_2$, the total resistance of the network will be exactly half the value of one of the resistors, R/2. Likewise, if three or more resistors each with the same value are connected in parallel, then the equivalent resistance will be equal to R/n where R is the value of the resistor and n is the number of individual resistances in the combination.

For example, six 100Ω resistors are connected together in a parallel combination. The equivalent resistance will therefore be: $R_T = R/n = 100/6 = 16.7\Omega$.

Currents in a Parallel Resistor Circuit

The total current, I_T in a parallel resistor circuit is the sum of the individual currents flowing in all the parallel branches. The amount of current flowing in each parallel branch is not necessarily the same as the value of the resistance in each branch determines the current within that branch. For example, although the parallel combination has the same voltage across it, the resistances could be different therefore the current flowing through each resistor would definitely be different as determined by Ohms Law.

The current that enters the circuit at point A must also exit the circuit at point B. *Kirchoff's Current Laws,* states that "*the total current leaving a circuit is equal to that entering the circuit - no current is lost*". The total current in the circuit is given as:

$$I_T = I_{R1} + I_{R2}$$

Then by using *Ohm's Law*, the current flowing through each resistor can be calculated as:

$$\text{Current flowing in } R_1 = V/R_1 = 12V \div 22k\Omega = 0.545mA$$

$$\text{Current flowing in } R_2 = V/R_2 = 12V \div 47k\Omega = 0.255mA$$

giving us a total current I_T flowing around the circuit as:

$$I_T = 0.545mA + 0.255mA = 0.8mA \text{ or } 800uA.$$

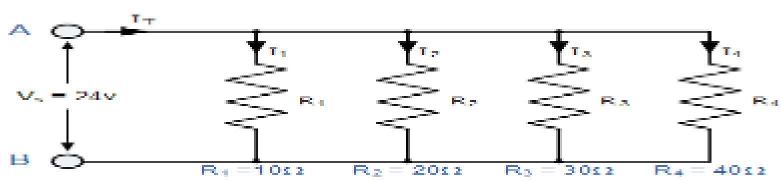
The equation given for calculating the total current flowing in a parallel resistor circuit which is the sum of all the individual currents added together is given as:

$$I_{total} = I_1 + I_2 + I_3 \ldots.. + I_n$$

Then parallel resistor networks can also be thought of as a "current divider" because the current splits or divides between the various branches and a parallel resistor circuit having *N* resistive networks will have N-different current paths while maintaining a common voltage. Parallel resistors can also be interchanged without changing the total resistance or the total circuit current.

Example No3

Calculate the individual branch currents for the following resistors in parallel circuit.



As the supply voltage is common to all the resistors in a parallel circuit, we can use Ohms Law to calculate the individual branch current as follows.

$$I_1 = \frac{V_S}{R_1} = \frac{24V}{10\Omega} = 2.4amps$$

$$I_2 = \frac{V_S}{R_2} = \frac{24V}{20\Omega} = 1.2amps$$

$$I_3 = \frac{V_S}{R_3} = \frac{24V}{30\Omega} = 0.8amps$$

$$I_4 = \frac{V_S}{R_4} = \frac{24V}{40\Omega} = 0.6amps$$

Then the total circuit current, I_T flowing into the parallel resistor combination will be:

$$I_T = I_1 + I_2 + I_3 + I_4$$

$$I_T = 2.4 + 1.2 + 0.8 + 0.6$$

$$I_T = 5.0amps$$

This total circuit current value of 5 amperes can also be found and verified by finding the equivalent circuit resistance and dividing it into the supply voltage (V/R_T).

Resistors in Parallel Summary

Then to summarize. When two or more resistors are connected so that both of their terminals are respectively connected to each terminal of the other resistor or resistors, they are said to be connected together in parallel. The potential difference across each resistor in the parallel combination is the same but the currents flowing through them are not the same.

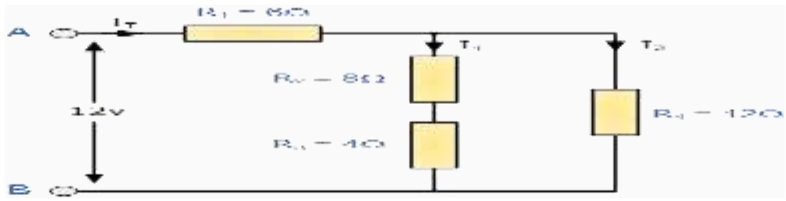
The equivalent or total resistance, R_T of a parallel combination is found through reciprocal addition and the total resistance value will always be less than the smallest individual resistor in the combination. Parallel resistors can be interchanged within the same combination without changing the total resistance or total circuit current. Resistors connected together in a parallel circuit will continue to operate even though one resistor may be open-circuited.

Resistor Combinations

Resistors can be connected together in "BOTH" parallel and series combinations within the same circuit to produce more complex circuits that use resistor combinations, we calculate the combined circuit resistance, currents and voltages.

Resistor circuits that combine series and parallel resistors circuits together are generally known as **Resistor Combination** or mixed circuits and the method of calculating their equivalent resistance is the same as that for any individual series or parallel circuit and we now know that resistors in series carry exactly the same current and that resistors in parallel have exactly the same voltage across them.

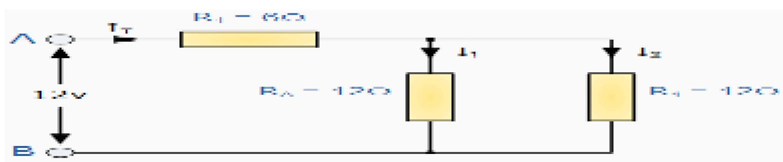
For example, Calculate the total current (I) taken from the 12v supply.



The two resistors, R_2 and R_3 are both connected together in a "SERIES" combination so we can add them together. The resultant resistance for this combination would therefore be,

$$R_2 + R_3 = 8\ \Omega + 4\ \Omega = 12\ \Omega$$

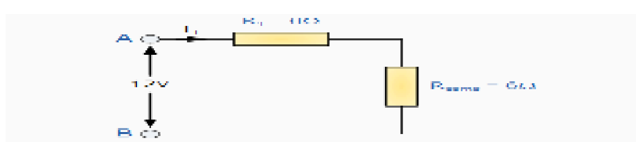
So now we can replace both the resistors R_2 and R_3 with a single resistor of resistance value 12 Ω



Now we have single resistor R_A in "PARALLEL" with the resistor R_4, (resistors in parallel) and again we can reduce this combination to a single resistor value of $R_{(combination)}$ using the formula for two parallel connected resistors as follows.

$$R_{(combination)} = \frac{1}{R_A} + \frac{1}{R_4} = \frac{1}{12} + \frac{1}{12} = \frac{1}{R_{(com)}} = 6\Omega$$

The resultant circuit now looks something like this:



The two remaining resistances, R_1 and $R_{(comb)}$ are connected together in a "SERIES" combination and again they can be added together so the total circuit resistance between points A and B is therefore given as:

$$R_{(A-B)} = R_{comb} + R_1 = 6\ \Omega + 6\ \Omega = 12\ \Omega.$$

and a single resistance of just 12 Ω can be used to replace the original 4 resistor combinations circuit above.

Now by using *Ohm´s Law*, the value of the circuit current (I) is simply calculated as:

$$\text{Circuit Current (I)} = \frac{V}{R} = \frac{12}{12} = 1 \text{ Ampere}$$

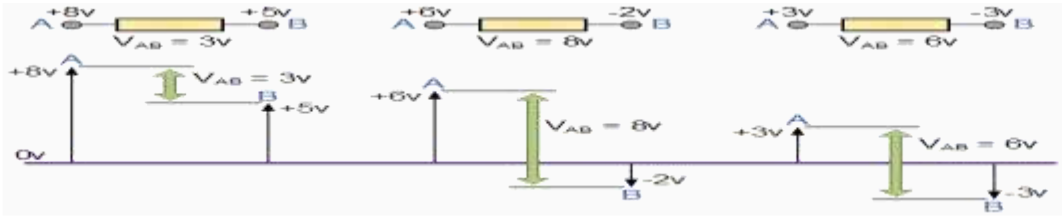
So any complicated circuit consisting of several resistors can be reduced to a simple circuit with only one equivalent resistor by replacing the resistors in series or in parallel using the steps above. It is sometimes easier with complex resistor combinations to sketch or redraw the new circuit after these changes have been made as a visual aid to the calculations. Then continue to replace any series or parallel combinations until one equivalent resistance is found.

Potential Difference

The voltage difference between any two points in a circuit is known as the **Potential Difference**, **pd** or **Voltage Drop** and it is the difference between these two points that makes the current flow. Unlike current which flows around a circuit in the form of electrical charge, potential difference does not move it is applied. The unit of potential difference is the **volt** and is defined as the potential difference across a resistance of one ohm carrying a current of one ampere. In other words, V = I.R

Ohm's Law states that for a linear circuit the current flowing through it is proportional to the potential difference across it so the greater the potential difference across any two points the bigger will be the current flowing through it. For example, if the voltage at one side of a 10Ω resistor measures 8V and at the other side of the resistor it measures 5V, then the potential difference across the resistor would be 3V (8 - 5) causing a current of 0.3A to flow. If however, the voltage on one side was increased from 8V to say 40V, the potential difference across the resistor would now be 40V - 5V = 35V causing a current of 3.5A to flow. The voltage at any point in a circuit is always measured with respect to a common point, generally 0V.

Potential Difference



As the units of measure for **Potential Difference** are volts, potential difference is mainly called **voltage**. Individual voltages connected in series can be added together to give us a "total voltage" sum of the circuit as seen in the resistors in series tutorial. Voltages across components that are connected in parallel will always be of the same value

for series connected voltages,

$$V_T = V_1 + V_2 + V_3 \ \ldots \text{etc}$$

for parallel connected voltages,

$$V_T = V_1 = V_2 = V_3 \ \ldots \text{etc}$$

Example No1

By using *Ohm's Law* the current flowing through a resistor can be calculated. For example, calculate the current flowing through a 100Ω resistor that has one of its terminals connected to 50 volts and the other terminal connected to 30 volts.

Voltage at terminal A is equal to 50v and the voltage at terminal B is equal to 30v. Therefore, the voltage across the resistor is given as:

$$V_A = 50v,\ V_B = 30v,\ \text{therefore},\ V_A - V_B = 50 - 30 = 20v$$

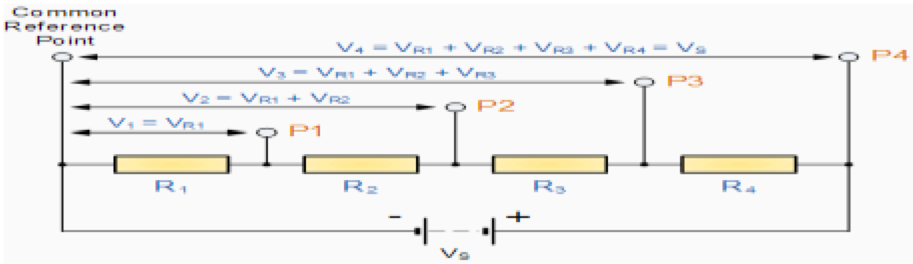
The voltage across the resistor is 20v, then the current flowing through the resistor is given as:

$$I = V_{AB} \div R = 20V \div 100\Omega = 200mA$$

Voltage Divider

We can produce a voltage divider circuit giving ratios of voltages with respect to the supply voltage across the series combination. This then produces a **Voltage Divider** network that only applies to resistors in series as parallel resistors produce a *current divider network*. Consider the circuit below.

Voltage Division



The circuit shows the principal of a voltage divider circuit where the output voltage drops across each resistor, R1, R2, R3 and R4 are referenced to a common point. For any number of resistors connected together in series the total resistance, RT of the circuit divided by the supply voltage Vs will give the circuit current as I = Vs/RT, Ohm's Law. Then the individual voltage drops across each resistor can be simply calculated as: V = IxR.

The voltage at each point, P1, P2, P3 etc increases according to the sum of the voltages at each point up to the supply voltage, Vs and we can also calculate the individual voltage drops at any point without firstly calculating the circuit current by using the following formula.

Voltage Divider Equation

$$V_{(x)} = \frac{R_{(x)}}{R_T} V_S$$

Where, $V_{(x)}$ is the voltage to be found, $R_{(x)}$ is the resistance producing the voltage, R_T is the total series resistance and V_S is the supply voltage.

Then by using this equation we can say that the voltage dropped across any resistor in a series circuit is proportional to the magnitude of the resistor and the total voltage dropped across all the resistors must equal the voltage source as defined by *Kirchoff's Voltage Law* So by using the **Voltage Divider Equation**, for any number of series resistors the voltage drop across any individual resistor can be found.

Thus far we have seen that voltage is applied to a resistor or circuit and that current flow through and around a circuit. But there is a third variable we can apply to resistors. Power is a product of voltage and current and the basic unit of measurement of power is the watt. In the next tutorial about Resistors, we will examine the power dissipated (consumed) by resistance in the form of heat and that the total power dissipated by a resistive circuit, whether it is series, parallel, or a combination of the two, we simply add the powers dissipated by each resistor.

Resistor Summary

- The job of a **Resistor** is to limit the current flowing through an electrical circuit.
- Resistance is measured in **Ohm's** and is given the symbol Ω
- Carbon, Film and Wire wound are all types of resistors.
- Resistor colour codes are used to identify the resistance and tolerance rating of small resistors.

Series Resistor

- Resistors that are daisy chained together in a single line are said to be connected in **SERIES**.
- Series connected resistors have a common **Current** flowing through them.
- $I_{total} = I_1 = I_2 = I_3$ .... etc
- The total circuit resistance of series resistors is equal to.

$R_{total} = R_1 + R_2 + R_3 + \ldots.. R_n$ etc.

- Total circuit voltage is equal to the sum of all the individual voltage drops.
- $V_{total} = V1 + V2 + V3$ .... etc
- The total resistance of a series connected circuit will always be greater than the highest value resistor.

Parallel Resistor

- Resistors that have both of their respective terminals connected to each terminal of another resistor or resistors are said to be connected in **PARALLEL**.
- Parallel resistors have a common **Voltage** across them.
- $V_S = V1 = V2 = V3$ .... etc
- Total resistance of a parallel circuit is equal to.

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \ldots\ldots + \frac{1}{R_n} \text{ etc}$$

- Total circuit current flow is equal to the sum of all the individual branch currents added together.
- $I_{total} = I_1 + I_2 + I_3$ .... etc
- The total resistance of a parallel circuit will always be less than the value of the smallest resistor.

http://www.merriam-webster.com/dictionary/electronic

https://www.clear.rice.edu/elec201/Book/basic_elec.html