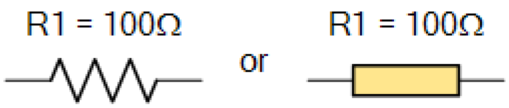
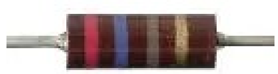
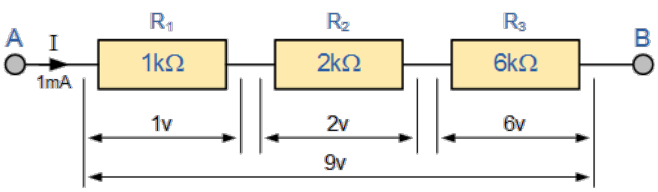
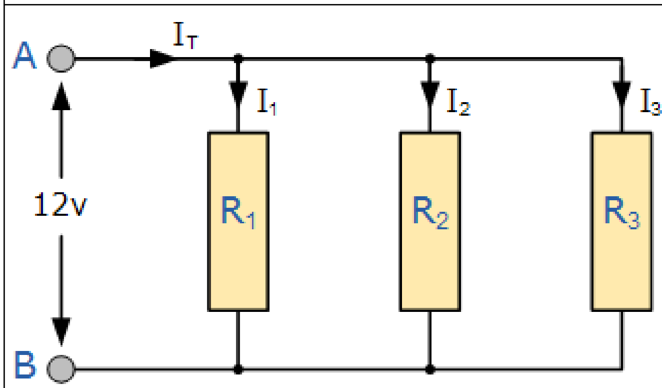
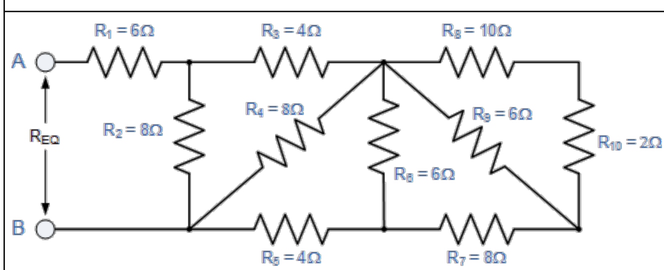
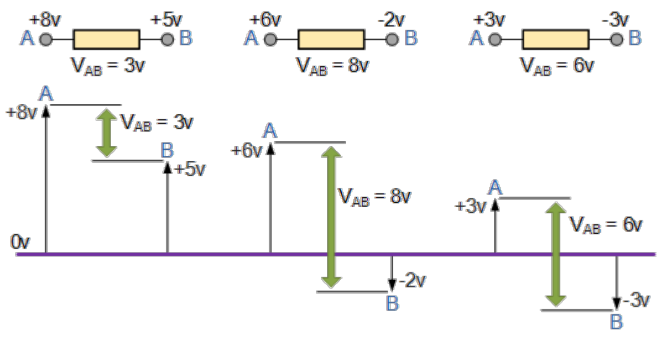
https://www.electronics-tutorials.ws/category/resistor

Resistors (13)

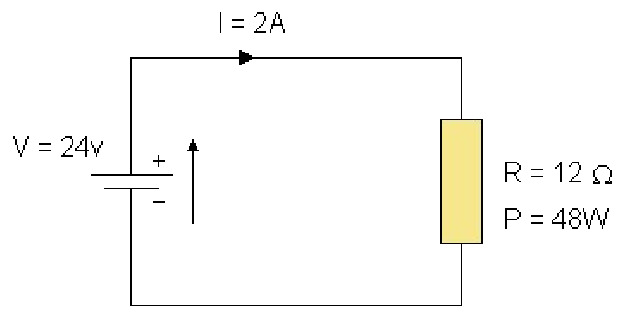
	**Types of Resistor** There are many different Types of Resistor available for the electronics constructor to choose from, from very small surface mount chip resistors up to large wirewound power resistors.
	**Resistor Colour Code** As there are many different types of Resistor available we need a form of resistor colour code system to be able to identify them.
	**Resistors in Series** Individual resistors can be connected together in either a series connection, a parallel connection or combinations of both series and parallel, to produce more complex resistor networks.
	**Resistors in Parallel** Unlike the previous series resistor circuit, in a parallel resistor network the circuit current can take more than one path as there are multiple paths for the current.
	**Resistors in Series and Parallel** In the previous tutorials we have learnt how to connect individual resistors together to form either a Series Resistor Network or a Parallel Resistor

Network and we used Ohms Law to find the various currents and voltages across each resistor combination.



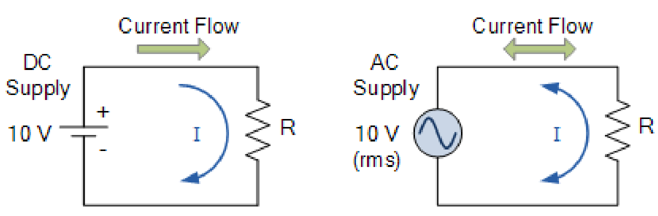
Potential Difference

Unlike current which flows around a closed electrical circuit in the form of electrical charge, potential difference does not move or flow it is applied.



Resistor Power Rating

When an electrical current passes through a resistor due to the presence of a voltage across it, electrical energy is lost by the resistor in the form of heat and the greater this current flow the hotter the resistor will get.

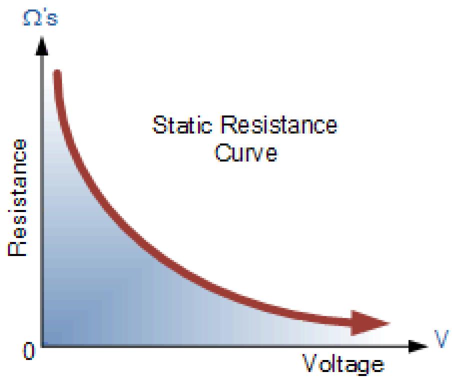


Resistors in AC Circuits

In the previous tutorials we have looked at resistors, their connections and used Ohm's Law to calculate the voltage, current and power associated with them.

Resistor Tutorial Summary

Resistor tutorial summary listing the main points we have learnt through this tutorial section about resistors and resistance.



Varistor Tutorial

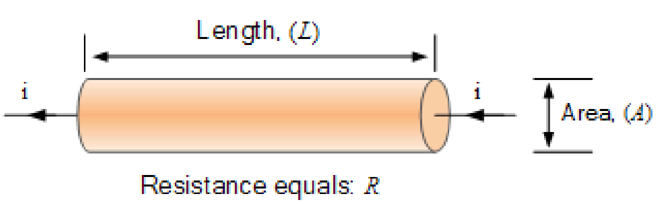
Unlike the fuse or circuit breaker which offers over-current protection, the varistor provides over-voltage protection by means of voltage-clamping in a similar way to the zener diode.

Resistor Colour Code Wheel

This handy and simple resistor colour code wheel can be used as a reference for finding the correct resistor colour code of any 4-band or 5-band resistor.

Potentiometers

Resistors provide a fixed value of resistance that blocks or resists the flow of electrical current around a circuit, as well as producing a voltage drop in accordance with Ohm's law.



Resistivity

Ohms Law states that when a voltage (V) source is applied between two points in a circuit, an electrical current (I) will flow between them encouraged by the presence of the potential difference between these two points.

https://www.electronics-tutorials.ws/resistor/res_1.html

Types of Resistor

There are many different **Types of Resistor** available for the electronics constructor to choose from, from very small surface mount chip resistors up to large wirewound power resistors.

The principal job of a resistor within an electrical or electronic circuit is to "resist" (hence the name **Resistor**), regulate or to set the flow of electrons (current) through them by using the type of conductive material from which they are composed. Resistors can also be connected together in various series and parallel combinations to form resistor networks which can act as voltage droppers, voltage dividers or current limiters within a circuit.

Resistors are what are called "Passive Devices", that is they contain no source of power or amplification but only attenuate or reduce the voltage or current 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.

Then a potential difference is required between the two terminals of a resistor for current to flow. This potential difference balances out the energy lost. When used in DC circuits the potential difference, also known as a resistors voltage drop, is measured across the terminals as the circuit current flows through the resistor.

Most types of resistor are linear devices that produce a voltage drop across themselves when an electrical current flows through them because they obey Ohm's Law, and different values of resistance produces different values of current or voltage. This can be very useful in Electronic circuits by controlling or reducing either the current flow or voltage produced across them we can produce a voltage-to-current and current-to-voltage converter.

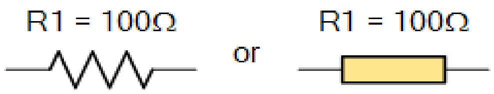
There are many thousands of different **Types of Resistor** and are produced in a variety of forms because their particular characteristics and accuracy suit certain areas of application, such as High Stability, High Voltage, High Current etc, or are used as general purpose resistors where their characteristics are less of a problem.

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

In all Electrical and Electronic circuit diagrams and schematics, the most commonly used symbol for a fixed value resistor is that of a "zig-zag" type line with the value of its resistance given in Ohms, Ω. Resistors have fixed resistance values from less than one ohm, (<1Ω) to well over tens of millions of ohms, (>10MΩ) in value.

Fixed resistors have only one single value of resistance, for example 100Ω, but variable resistors (potentiometers) can provide an infinite number of resistance values between zero and their maximum value.

Standard Resistor Symbols



The symbol commonly used in schematic and electrical drawings for a 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:

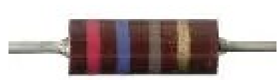
- Carbon Composition Resistor – Made of carbon dust or graphite paste, low wattage values
- Film or Cermet Resistor – Made from conductive metal oxide paste, very low wattage values
- Wire-wound Resistor – Metallic bodies for heatsink mounting, very high wattage ratings
- Semiconductor Resistor – High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

There are a large variety of fixed and variable resistor types with different construction styles available for each group, with each one having its own particular characteristics, advantages and disadvantages compared to the others. To include all types would make this section very large so I shall limit it to the most commonly used, and readily available general purpose types of resistors.

Composition Types of Resistor

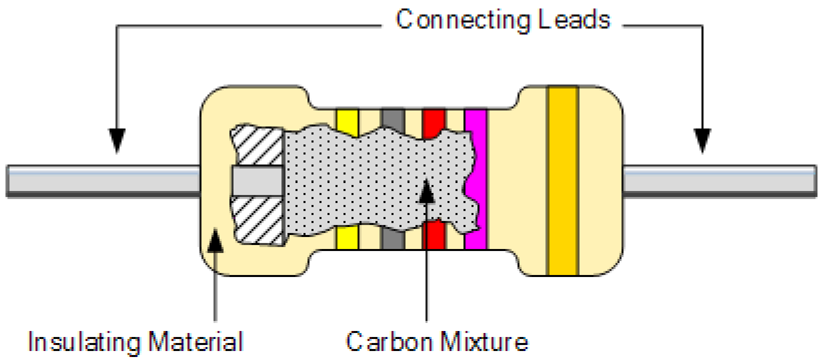
Carbon Resistors are the most common type of **Composition Resistors**. Carbon resistors are a cheap general purpose resistor used in electrical and electronic circuits. Their resistive element is manufactured from a mixture of finely ground carbon dust or graphite (similar to pencil lead) and a non-conducting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

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.



Carbon Composite Type of Resistor

Carbon Resistor

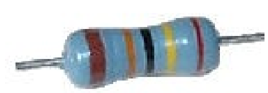


The **Carbon Composite Resistor** is a low to medium type power resistor which has a low inductance making them ideal for high frequency applications but they can also suffer from noise and stability when hot. Carbon composite resistors are generally prefixed with a "CR" notation (eg, CR10kΩ) and are available in E6 (± 20% tolerance (accuracy)), E12 (± 10% tolerance) and E24 (± 5% tolerance) packages with power ratings from 0.250 or 1/4 of a Watt up to 5 Watts.

Carbon composite resistor types 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.



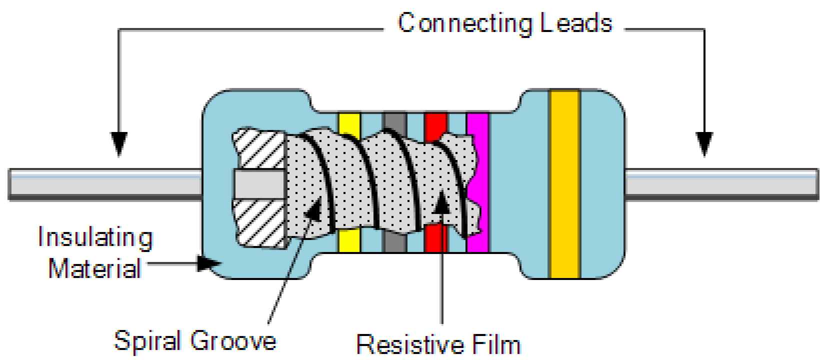
Film Resistor

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.

This method of manufacture allows for much closer tolerance resistors (1% or less) as compared to the simpler carbon composition types. The tolerance of a resistor is the difference between the preferred value (i.e, 100 ohms) and its actual manufactured value i.e, 103.6 ohms, and is expressed as a percentage, for example 5%, 10% etc, and in our example the actual tolerance is 3.6%. Film type resistors also achieve a much higher maximum ohmic value compared to other types and values in excess of 10MΩ (10 Million Ohms) are available.

Film Resistor



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.

Another type of film resistor commonly known as a **Thick Film Resistor** is manufactured by depositing a much thicker conductive paste of **CER**amic and **MET**al, called **Cermet**, onto an alumina ceramic substrate. Cermet resistors have similar properties to metal film resistors and are generally used for making small surface mount chip type resistors, multi-resistor networks in one package for pcb's and high frequency resistors. They have good temperature stability, low noise, and good voltage ratings but low surge current properties.

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 and especially metal film resistors are precision low power components.

Wirewound Types of Resistor

Another type of resistor, called a **Wirewound 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 resistor are generally only available in very low ohmic high precision values (from 0.01Ω 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 Wheatstone bridge type applications.

Wirewound Resistor

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 aluminium heat sink body with fins attached to increase their overall surface area to promote heat loss and cooling.

These special types of resistor are called “Chassis Mounted Resistors” because they are designed to be physically mounted onto heatsinks or metal plates to further dissipate the generated heat. The mounting of the resistor onto a heatsink increases their current carrying capabilities even further.

Another type of wirewound resistor is the **Power Wirewound Resistor**. These are high temperature, high power non-inductive resistor types generally coated with a vitreous or glass epoxy enamel for use in resistance banks or DC motor/servo control and dynamic braking applications. They can even be used as low wattage space or cabinet heaters.

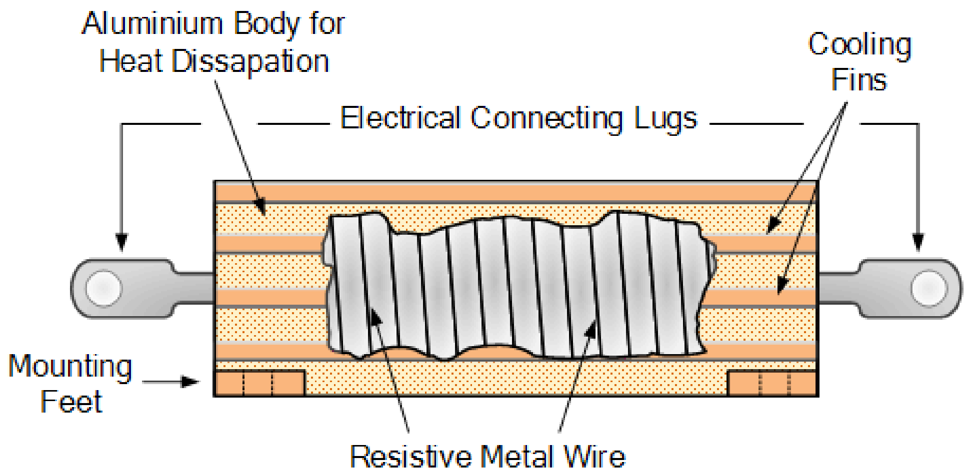
The non-inductive resistance wire is wound around a ceramic or porcelain tube covered with mica to prevent the alloy wires from moving when hot. Wirewound resistors are available in a variety of resistance and power ratings with one main use of power wirewound resistor is in the electrical heating elements of an electric fire which converts the electrical current flowing through it into heat with each element dissipating up to 1000 Watts, (1kW) of energy.

Because the wire of standard wire wound resistors is wound into a coil inside the resistors body, it acts like an inductor causing them to have inductance as well as resistance. This affects the way the resistor behaves in AC circuits by producing a phase shift at high frequencies especially in the larger size resistors. The length of the actual resistance path in the resistor and the leads contributes inductance in series with the “apparent” DC resistance resulting in an overall impedance path of Z Ohms.

Impedance (Z) is the combined effect of resistance (R) and inductance (X), measured in ohms and for a series AC circuit is given as, Z2 = R2 + X2.

When used in AC circuits this inductance value changes with frequency (inductive reactance, XL = $2\pi f$L) and therefore, the overall value of the resistor changes. Inductive reactance increases with frequency but is zero at DC (zero frequency). Then, wirewound resistors must not be designed or used in AC or amplifier type circuits where the frequency across the resistor changes. However, special non-inductive wirewound resistors are also available.

Wirewound Resistor



Wirewound resistor types are prefixed with a “WH” or “W” notation (eg WH10Ω) and are available in the WH aluminium clad package (±1%, ±2%, ±5% and ±10% tolerance) or the W vitreous enamelled package (±1%, ±2% and ±5% tolerance) with power ratings from 1W to 300W or more.

Resistor Types Summary

Then to summarise, there are many different types of resistor available from low cost, large tolerance, general purpose carbon type resistors through to low tolerance, high cost, precision film resistors as well as high power, wirewound ceramic resistors. A resistor regulates, impedes or sets the flow of current through a particular path or it can impose a voltage reduction in an electrical circuit.

The resistive value of a resistor, its ability to limit current flow is measured in Ohm’s (Ω) ranging from less than one Ohm each to many millions of Ohm’s, (Mega-Ohm’s). Resistors can be of a fixed value, for example: 100 Ohms, (100Ω) or variable as in 0 to 100Ω.

A resistor will always have the same resistance value no matter what the frequency of the supply from DC to very high frequencies and all resistors have one thing in common, their resistive value in Ohm’s in a circuit will ALWAYS be positive in nature and never negative.

The uses and applications of a resistor within an electrical or electronic circuit are vast and varied with virtually every electronic circuit ever designed using one or more types of resistor. Resistors are commonly used for purposes such as current limiting, providing appropriate control voltages to semiconductor devices, such as bipolar transistors, protecting LEDs or other semiconductor devices from over current damage, as well as adjusting or limiting the frequency response in an audio or filter circuit.

In digital circuits different types of resistors can be used for pulling up or pulling down the voltage at the input pin of a digital logic chip or by controlling a voltage at a point in a circuit by placing two resistors in series to create a voltage divider network, the list is endless!.

In the next tutorial about Resistors, we will look at the different ways of identifying the resistive value of the different types of fixed resistors with the most common method of identification being the use of Colour Codes and colour bands around the body of the resistor.

https://www.electronics-tutorials.ws/resistor/res_2.html

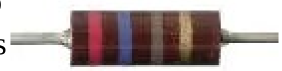
Resistor Colour Code

As there are many different types of **Resistor** available we need to form of resistor colour code system to be able to identify them.

Resistors can be used in both electrical and electronic circuits to control the flow of current or to produce a voltage drop in many different ways. But in order to do this the actual resistor needs to have some form of “resistive” or “resistance” value. Resistors are available in a range of different resistance values from fractions of an Ohm (Ω) to millions of Ohms.

Obviously, it would be impractical to have available resistors of every possible value for example, 1Ω, 2Ω, 3Ω, 4Ω etc, because literally tens of hundreds of thousands, if not tens of millions of different resistors would need to exist to cover all the possible values. Instead, resistors are manufactured in what are called “preferred values” with their resistance value printed onto their body in coloured ink.

The resistance value, tolerance, and wattage rating are generally printed onto the body of the resistor as numbers or letters when the resistors body is big enough to read the print, such as large power resistors. But when the resistor is small such as a 1/4 watt carbon or film type, these specifications must be shown in some other manner as the print would be too small to read.



Resistor Colour Code

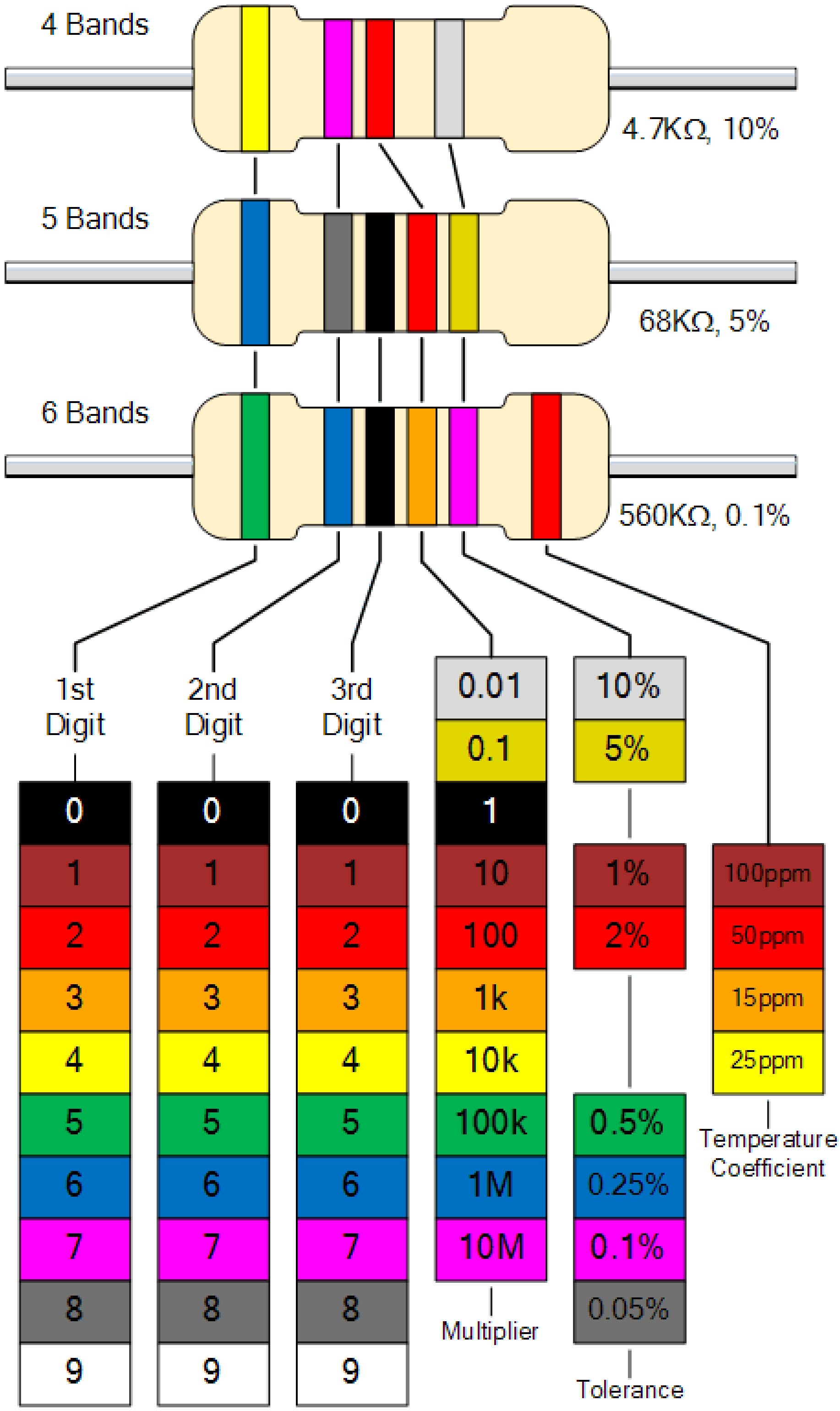
So to overcome this, small resistors use coloured painted bands to indicate both their resistive value and their tolerance with the physical size of the resistor indicating its wattage rating. These coloured painted bands produce a system of identification generally known as a **Resistors Colour Code**.

An international and universally accepted resistor colour code scheme was developed many years ago as a simple and quick way of identifying a resistors ohmic value no matter what its size or condition. It consists of a set of individual coloured rings or bands in spectral order representing each digit of the resistors value.

The resistor colour code markings are always read one band at a time starting from the left to the right, with the larger width tolerance band oriented to the right side indicating its tolerance. By matching the colour of the first band with its associated number in the digit column of the colour chart below the first digit is identified and this represents the first digit of the resistance value.

Again, by matching the colour of the second band with its associated number in the digit column of the colour chart we get the second digit of the resistance value and so on. Then the resistor colour code is read from left to right as illustrated below:

The Standard Resistor Colour Code Chart



The Resistor Colour Code Table

Colour	Digit	Multiplier	Tolerance
Black	0	1	
Brown	1	10	± 1%
Red	2	100	± 2%
Orange	3	1,000	
Yellow	4	10,000	
Green	5	100,000	± 0.5%
Blue	6	1,000,000	± 0.25%
Violet	7	10,000,000	± 0.1%
Grey	8		± 0.05%
White	9		
Gold		0.1	± 5%
Silver		0.01	± 10%
None			± 20%

Then we can summerise the different weighted positions of each coloured band which makes up the resistors colour code above in the following table:

Number of Coloured Bands	3 Coloured Bands (E6 Series)	4 Coloured Bands (E12 Series)	5 Coloured Bands (E48 Series)	6 Coloured Bands (E96 Series)
1st Band	1st Digit	1st Digit	1st Digit	1st Digit
2nd Band	2nd Digit	2nd Digit	2nd Digit	2nd Digit
3rd Band	Multiplier	Multiplier	3rd Digit	3rd Digit
4th Band	–	Tolerance	Multiplier	Multiplier
5th Band	–	–	Tolerance	Tolerance
6th Band	–	–	–	Temperature Coefficient

Calculating Resistor Colour Code Values

The **Resistor Colour Code** system is all well and good but we need to understand how to apply it in order to get the correct value of the resistor. The "left-hand" or the most significant coloured band is the band which is nearest to a connecting lead with the colour coded bands being read from left-to-right as follows:

Digit, Digit, Multiplier = Colour, Colour x $10^{\mathbf{colour}}$ in Ohm's (Ω)

For example, a resistor has the following coloured markings;

Yellow Violet Red = 4 7 2 = 4 7 x 10^2 = 4700Ω or 4k7 Ohm.

The fourth and fifth bands are used to determine the percentage tolerance of the resistor. Resistor tolerance is a measure of the resistors variation from the specified resistive value and is a consequence of the manufacturing process and is expressed as a percentage of its "nominal" or preferred value.

Typical resistor tolerances for film resistors range from 1% to 10% while carbon resistors have tolerances up to 20%. Resistors with tolerances lower than 2% are called precision resistors with the or lower tolerance resistors being more expensive.

Most five band resistors are precision resistors with tolerances of either 1% or 2% while most of the four band resistors have tolerances of 5%, 10% and 20%. The colour code used to denote the tolerance rating of a resistor is given as:

Brown = 1%, Red = 2%, Gold = 5%, Silver = 10 %

If resistor has no fourth tolerance band then the default tolerance would be at 20%.

It is sometimes easier to remember the resistor colour code by using short, easily remembered sentences in the form of expressions, rhymes, and phrases, called an acrostic, which have a separate word in the sentence to represent each of the Ten + Two colours.

The resulting mnemonic matches the first letter of each word to each colour which makes up the resistors colour code by order of increasing magnitude and there are many different mnemonic phrases which can be used. However, these sayings are often very crude but never the less effective for remembering the resistor colours. Here are just a few of the more “cleaner” versions but many more exist:

> Bad Boys Ring Our Young Girls But Vicky Goes Without
>
> Better Be Right Or Your Great Big Venture Goes Wrong
>
> Buster Brown Races Our Young Girls But Vicky Generally Wins (This one indicates the position of Brown
>
> Bad Booze Rots Our Young Guts But Vodka Goes Well (in) Silver Goblets (This one includes the tolerance bands of Gold, Silver)

As an added bonus, why not download and make our handy DIY **Resistor Colour Code Wheel** as a free and handy reference guide to help work out those resistor colour codes.

The British Standard (BS 1852) Code.

Generally on larger power resistors, the resistor colour code systems is not required as the resistance value, tolerance, and even the power (wattage) rating are printed onto the actual body of the resistor instead of using the resistor colour code system. Because it is very easy to “misread” the position of a decimal point or comma especially when the component is discoloured or dirty. An easier system for writing and printing the resistance values of the individual resistance was developed.

This system conforms to the British Standard **BS 1852 Standard** and its replacement, **BS EN 60062**, coding method were the decimal point position is replaced by the suffix letters “K” for thousands or kilohms, the letter “M” for millions or megaohms both of which denotes the multiplier value with the letter “R” used where the multiplier is equal to, or less than one, with any number coming after these letters meaning it’s equivalent to a decimal point.

The BS 1852 Letter Coding for Resistors

BS 1852 Codes for Resistor Values
0.47Ω = R47 or 0R47
1.0Ω = 1R0
4.7Ω = 4R7
47Ω = 47R
470Ω = 470R or 0K47
1.0KΩ = 1K0
4.7KΩ = 4K7
47KΩ = 47K
470KΩ = 470K or 0M47
1MΩ = 1M0

Sometimes depending upon the manufacturer, after the written resistance value there is an additional letter which represents the resistors tolerance value such as 4k7 J and these suffix letters are given as:

Tolerance Letter Coding for Resistors

Tolerance Codes for Resistors (±)
B = 0.1%
C = 0.25%
D = 0.5%
F = 1%
G = 2%
J = 5%
K = 10%
M = 20%

Also, when reading these written codes be careful not to confuse the resistance letter k for kilohms with the tolerance letter K for 10% tolerance or the resistance letter M for Megaohms with the tolerance letter M for 20% tolerance.

Resistor Colour Code for Tolerance, E-series & Preferred Values

Hopefully by now we understand that resistors come in a variety of sizes and resistance values but to have a resistor available of every possible resistance value, literally hundreds of thousands, if not millions of individual resistors would need to exist. Instead, resistors are manufactured in what are commonly known as **Preferred values**.

Instead of sequential values of resistance from 1Ω and upwards, certain values of resistors exist within certain tolerance limits. The tolerance of a resistor is the maximum difference between its actual value and the required value and is generally expressed as a plus or minus percentage value. For example, a 1kΩ ±20% tolerance resistor may have a maximum and minimum resistive value of:

Maximum Resistance Value

$$1k\Omega \text{ or } 1000\Omega + 20\% = 1{,}200\Omega$$

Minimum Resistance Value

$$1k\Omega \text{ or } 1000\Omega - 20\% = 800\Omega$$

Then using our example above, a 1kΩ ±20% tolerance resistor may have a maximum value of 1200Ω and a minimum value of 800Ω resulting in a difference of some 400Ω!! for the same value resistor.

In most electrical or electronic circuits this large 20% tolerance of the same resistor is generally not a problem, but when close tolerance resistors are specified for high accuracy circuits such as filters, oscillators or amplifiers etc, then the correct tolerance resistor needs to be used as a 20% tolerance resistor cannot generally be used to replace 2% or even a 1% tolerance type.

The five and six band resistor colour code is more commonly associated with the high precision 1% and 2% film types while the common garden variety 5% and 10% general purpose types tend to use the four band resistor colour code. Resistors come in a range of tolerances but the two most common are the E12 and the E24 series.

The E12 series comes in twelve resistance values per decade, (A decade representing multiples of 10, i.e. 10, 100, 1000 etc), while the E24 series comes in twenty four values per decade and the E96 series ninety six values per decade. A very high precision E192 series is now available with tolerances as low as ± 0.1% giving a massive 192 separate resistor values per decade.

Resistor Tolerance and E-series Table

E6 Series at ±20% Tolerance – Resistors values in Ω
1.0, 1.5, 2.2, 3.3, 4.7, 6.8
E12 Series at ±10% Tolerance – Resistors values in Ω
1.0, 1.2, 1.5, 1.8, 2.2, 2.7, 3.3, 3.9, 4.7, 5.6, 6.8, 8.2
E24 Series at ±5% Tolerance – Resistors values in Ω
1.0, 1.1, 1.2, 1.3, 1.5, 1.6, 1.8, 2.0, 2.2, 2.4, 2.7, 3.0, 3.3, 3.6, 3.9, 4.3, 4.7, 5.1, 5.6, 6.2, 6.8, 7.2, 8.2, 9.1
E96 Series at ±1% Tolerance – Resistors values in Ω
1.00, 1.02, 1.05, 1.07, 1.10, 1.13, 1.15, 1.18, 1.21, 1.24, 1.27, 1.30, 1.33, 1.37, 1.40, 1.43, 1.47, 1.50, 1.54, 1.58, 1.62, 1.65, 1.69, 1.74, 1.78, 1.82, 1.87, 1.91, 1.96, 2.00, 2.05, 2.10, 2.15, 2.21, 2.26, 2.32, 2.37, 2.43, 2.49, 2.55, 2.61, 2.67, 2.74, 2.80, 2.87, 2.94, 3.01, 3.09, 3.16, 3.24, 3.32, 3.40, 3.48, 3.57, 3.65, 3.74, 3.83, 3.92, 4.02, 4.12, 4.22, 4.32, 4.42, 4.53, 4.64, 4.75, 4.87, 4.99, 5.11, 5.23, 5.36, 5.49, 5.62, 5.76, 5.90, 6.04, 6.19, 6.34, 6.49, 6.65, 6.81, 6.98, 7.15, 7.32, 7.50, 7.68, 7.87, 8.06, 8.25, 8.45, 8.66, 8.87, 9.09, 9.31, 9.53, 9.76

Then by using the appropriate E-series value for the percentage tolerance required for the resistor, adding a multiplication factor to it, any ohmic value of resistance within that series can be found. For example, take an E-12 series resistor, 10% tolerance with a preferred value of 3.3, then the values of resistance for this range are:

Value x Multiplier = Resistance

$$3.3 \times 1 = 3.3\Omega$$

$$3.3 \times 10 = 33\Omega$$

$$3.3 \times 100 = 330\Omega$$

$$3.3 \times 1{,}000 = 3.3k\Omega$$

$$3.3 \times 10{,}000 = 33k\Omega$$

$$3.3 \times 100{,}000 = 330k\Omega$$

$$3.3 \times 1{,}000{,}000 = 3.3M\Omega$$

The mathematical basis behind these preferred values comes from the square root value of the actual series being used. For example, for the E6 20% series there are six individual resistors or steps (1.0 to 6.8) and is given as the sixth root of ten ($^{(1/6)}\sqrt{10}$), so for the E12 10% series there are twelve individual resistors or steps (1.0 to 8.2) and is therefore given as the twelfth root of ten ($^{(1/12)}\sqrt{10}$) and so on for the remaining E-series values.

The tolerance series of **Preferred Values** shown above are manufactured to conform to the British Standard BS 2488 and are ranges of resistor values chosen so that at maximum or minimum tolerance any one resistor overlaps with its neighbouring value. For example, take the E24 range of resistors with a 5% tolerance. It’s neighbouring resistor values are 47 and 51Ω respectively.

$$47\Omega + 5\% = 49.35\Omega, \text{ and } 51\Omega - 5\% = 48.45\Omega, \text{ an overlap of just } 0.9\Omega.$$

Surface Mount Resistors

Surface Mount Resistors or SMD Resistors, are very small rectangular shaped metal oxide film resistors designed to be soldered directly onto the surface, hence their name, of a circuit board. Surface mount resistors generally have a ceramic substrate body onto which is deposited a thick layer of metal oxide resistance.

4.7kΩ SMD Resistor

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.

Surface Mount Resistors are printed with either a 3 or 4-digit numerical code which is similar to that used on the more common axial type resistors to denote their resistive value. Standard SMD resistors are marked with a three-digit code, in which the first two digits represent the first two numbers of the resistance value with the third digit being the multiplier, either x1, x10, x100 etc. For example:

“103” = 10 × 1,000 ohms = 10 kiloΩ

“392” = 39 × 100 ohms = 3.9 kiloΩ

“563” = 56 × 1,000 ohms = 56 kiloΩ

“105” = 10 × 100,000 ohms = 1 MegaΩ

Surface mount resistors that have a value of less than 100Ω are usually written as: “390”, “470”, “560” with the final zero representing a 10 xo multiplier, which is equivalent to 1. For example:

“390” = 39 × 1Ω = 39Ω or 39RΩ

“470” = 47 × 1Ω = 47Ω or 47RΩ

Resistance values below ten have a letter “R” to denote the position of the decimal point as seen previously in the BS1852 form, so that 4R7 = 4.7Ω.

Surface mount resistors that have a “000” or “0000” markings are zero-Ohm (0Ω) resistors or in other words shorting links, since these components have zero resistance.

Then we have seen that the resistor colour code system is used to identify the resistive value of a resistor. Don’t forget to download and make our handy DIY Resistor Colour Code Wheel as a free and handy reference guide to help work out those resistor colour codes.

In the next tutorial about Resistors, we will look at connecting resistors together in a series chain and prove that the total resistance is the sum of all the resistors added together and that the current is common to a series circuit.

https://www.electronics-tutorials.ws/resistor/res_3.html

Resistors in Series

Individual resistors can be connected together in either a series connection, a parallel connection or combinations of both series and parallel, to produce more complex resistor networks. For resistors in series the equivalent resistance is the mathematical combination of the individual resistors connected together in the series string.

A resistor is not only a fundamental electronic component that can be used to convert a voltage to a current or a current to a voltage, but by correctly adjusting its value a different weighting can be placed onto the converted current and/or the voltage allowing it to be used in voltage reference circuits and applications.

Resistors in series or complicated resistor networks can be replaced by one single equivalent resistor, R_{EQ} or impedance, Z_{EQ} and no matter what the combination or complexity of the resistor network is, all resistors obey the same basic rules as defined by *Ohm's Law* and *Kirchhoff's Circuit Laws*.

Resistors in Series

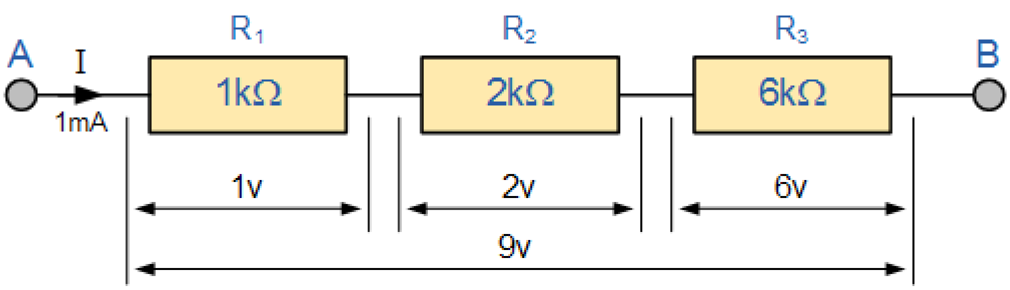
Resistors are said to be connected in "Series", when they are daisy chained together in a single line. Since all the current flowing through the first resistor has no other way to go it must also pass through the second resistor and the third and so on. Then, resistors in series have a **Common Current** 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 will be the same at all points in a series resistor network. For example:

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

In the following example the resistors R1, R2 and R3 are all connected together in series between points A and B with a common current, I flowing through them.

Series Resistor Circuit



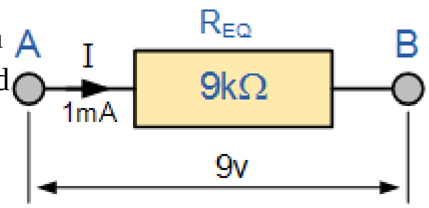
As the resistors are connected together in series the same current passes through each resistor in the chain and the total resistance, R_T of the circuit must be **equal** to the sum of all the individual resistors added together. That is

$$R_T = R_1 + R_2 + R_3$$

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

$$R_{EQ} = R1 + R2 + R3 = 1k\Omega + 2k\Omega + 6k\Omega = 9k\Omega$$

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



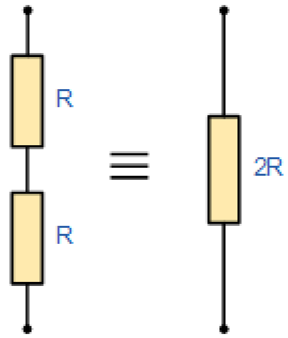
Where four, five or even more resistors are all connected together in a series circuit, the total or equivalent resistance of the circuit, R_T would still be the sum of all the individual resistors connected together and the more resistors added to the series, the greater the equivalent resistance (no matter what their value).

This total resistance is generally known as the **Equivalent Resistance** and can be defined as; « *a single value of resistance that can replace any number of resistors in series without altering the values of the current or the voltage in the circuit* ». Then the equation given for calculating total resistance of the circuit when connecting together resistors in series is given as:

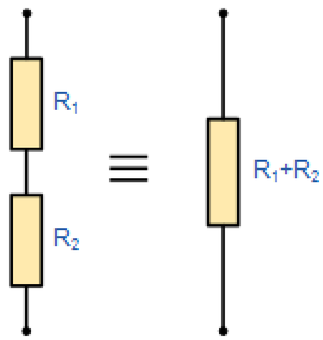
Series Resistor Equation

$$R_{total} = R1 + R2 + R3 + \ldots\ldots R_n$$

Note then that the total or equivalent resistance, R_T has the same effect on the circuit as the original combination of resistors as it is the algebraic sum of the individual resistances.



If two resistances or impedances in series are equal and of the same value, then the total or equivalent resistance, R_T is equal to twice the value of one resistor. That is equal to 2R and for three equal resistors in series, 3R, etc.



If two resistors or impedances in series are unequal and of different values, then the total or equivalent resistance, R_T is equal to the mathematical sum of the two resistances. That is equal to $R_1 + R_2$. If three or more unequal (or equal) resistors are connected in series then the equivalent resistance is: $R_1 + R_2 + R_3 +$..., etc.

One important point to remember about resistors in series networks to check that your maths is correct. The total resistance (R_T) of any two or more resistors connected together in series will always be **GREATER** than the value of the largest resistor in the chain. In our example above $R_T = 9k\Omega$ where as the largest value resistor is only 6kΩ.

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 R1, R2 and R3.

$$V_{AB} = V_{R1} + V_{R2} + V_{R3} = 9V.$$

Using Ohm’s Law, the individual voltage drops across each resistor can be calculated as:

The voltage drop across resistor, R1 is equal to: I*R1 = 1mA x 1kΩ = 1V

The voltage drop across resistor, R2 is equal to: I*R2 = 1mA x 2kΩ = 2V

The voltage drop across resistor, R3 is equal to: I*R3 = 1mA x 6kΩ = 6V

Thus the voltage V_{AB} being the sum of all the individual voltage drops in the resistors in series. That is: (1V + 2V + 6V) = 9V. This is also equal to the value of the supply voltage. Then the sum of the potential differences across all the resistors is equal in value to the total potential difference across the series combination. In this example it 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:

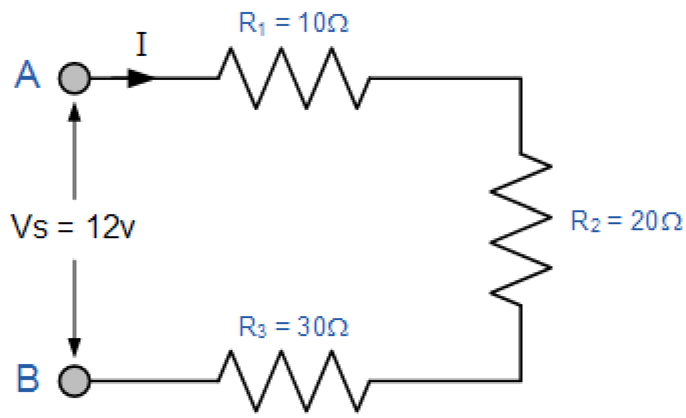
$$V_{Total} = V_{R1} + V_{R2} + V_{R3} + \ldots\ldots + V_N$$

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.

Resistors in Series Example No1

Using Ohms Law, calculate the equivalent series resistance, the series current, voltage drop and power for each resistor in 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
$R_1 = 10\Omega$	$I_1 = 200mA$	$V_1 = 2V$	$P_1 = 0.4W$
$R_2 = 20\Omega$	$I_2 = 200mA$	$V_2 = 4V$	$P_2 = 0.8W$
$R_3 = 30\Omega$	$I_3 = 200mA$	$V_3 = 6V$	$P_3 = 1.2W$
$R_T = 60\Omega$	$I_T = 200mA$	$V_S = 12V$	$P_T = 2.4W$

Then for the circuit above, $R_T = 60\Omega$, $I_T = 200mA$, $V_S = 12V$ and $P_T = 2.4W$

The Voltage Divider Circuit

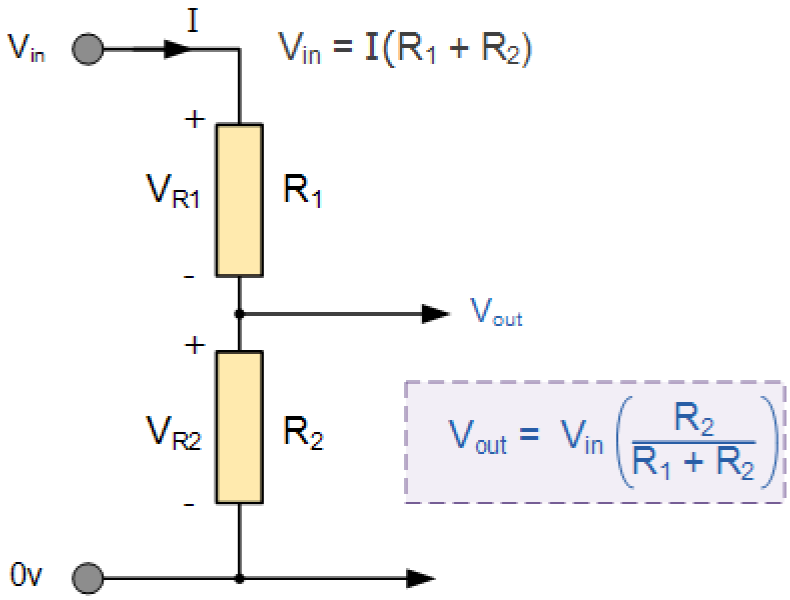
We can see from the above example, that although the supply voltage is given as 12 volts, different voltages, or voltage drops, appear across each resistor within the series network. Connecting resistors in series like this across a single DC supply has one major advantage, different voltages appear across each resistor producing a very handy circuit called a **Voltage Divider Network**.

This simple circuit splits the supply voltage proportionally across each resistor in the series chain with the amount of voltage drop being determined by the resistors value and as we now know, the current through a series resistor circuit is common to all resistors. So a larger resistance will have a larger voltage drop across it, while a smaller resistance will have a smaller voltage drop across it.

The series resistive circuit shown above forms a simple voltage divider network were three voltages 2V, 4V and 6V are produced from a single 12V supply. Kirchhoff's Voltage Law states that "the supply voltage in a closed circuit is equal to the sum of all the voltage drops (I*R) around the circuit" and this can be used to good effect.

The **Voltage Division Rule**, allows us to use the effects of resistance proportionality to calculate the potential difference across each resistance regardless of the current flowing through the series circuit. A typical "voltage divider circuit" is shown below.

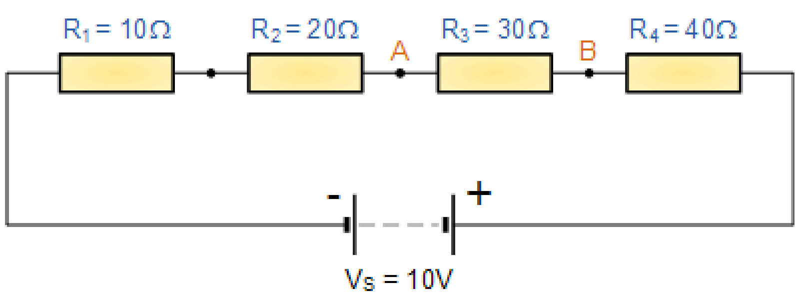
Voltage Divider Network



The circuit shown consists of just two resistors, R1 and R2 connected together in series across the supply voltage V_{in}. One side of the power supply voltage is connected to resistor, R1, and the voltage output, V_{out} is taken from across resistor R2. The value of this output voltage is given by the corresponding formula.

If more resistors are connected in series to the circuit then different voltages will appear across each resistor in turn with regards to their individual resistance R (Ohms Law **I*R**) values providing different but smaller voltage points from one single supply.

So if we had three or more resistances in the series chain, we can still use our now familiar potential divider formula to find the voltage drop across each one. Consider the circuit below.



The *potential divider circuit* above shows four resistances connected together is series. The voltage drop across points A and B can be calculated using the potential divider formula as follows:

$$V_{AB} = V_{R3} = V_S \times \frac{R3}{R1 + R2 + R3 + R4}$$

$$V_{AB} = 10 \times \frac{30}{10+20+30+40} = 10 \times 0.3 = 3V$$

We can also apply the same idea to a group of resistors in the series chain. For example if we wanted to find the voltage drop across both R2 and R3 together we would substitute their values in the top numerator of the formula and in this case the resulting answer would give us 5 volts (2V + 3V).

In this very simple example the voltages work out very neatly as the voltage drop across a resistor is proportional to the total resistance, and as the total resistance, (RT) in this example is equal to 100Ω or 100%, resistor R1 is 10% of RT, so 10% of the source voltage V_S will appear across it, 20% of VS across resistor R2, 30% across resistor R3, and 40% of the supply voltage V_S across resistor R4. Application of Kirchhoff’s voltage law (KVL) around the closed loop path confirms this.

Now lets suppose that we want to use our two resistor potential divider circuit above to produce a smaller voltage from a larger supply voltage to power an external electronic circuit. Suppose we have a 12V DC supply and our circuit which has an impedance of 50Ω requires only a 6V supply, half the voltage.

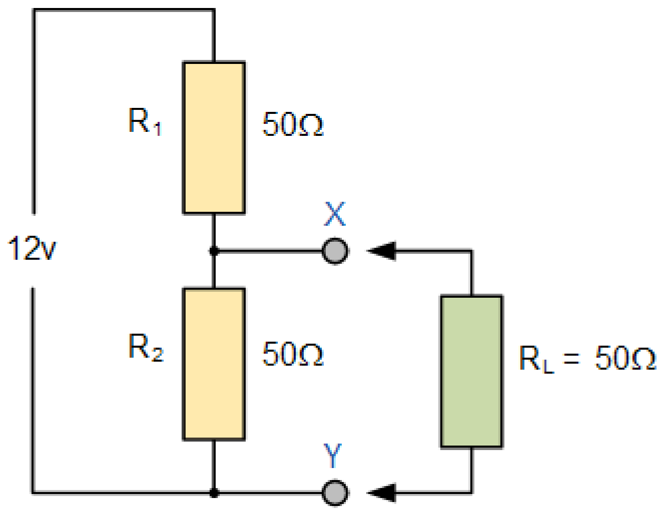
Connecting two equal value resistors, of say 50Ω each, together as a potential divider network across the 12V will do this very nicely until we connect the load circuit to the network. This is because the loading effect of resistor RL connected in parallel across R2 changes the ratio of the two series resistances altering their voltage drop and this is demonstrated below.

Resistors in Series Example No2

Calculate the voltage drops across X and Y

a) Without RL connected

b) With RL connected



a) Without R_L connected

$$R_{X\text{-}Y} = 50\Omega$$

$$V_{out} = V_{in} \times \frac{R_2}{R_1 + R_2}$$

$$V_{out} = 12v \times \frac{50}{50 + 50} = 6.0v$$

b) With R_L connected

$$R_{X\text{-}Y} = 25\Omega \quad \text{(Resistors in Parallel)}$$

$$V_{out} = V_{in} \times \frac{R_2}{R_1 + R_2}$$

$$V_{out} = 12v \times \frac{25}{50 + 25} = 4.0v$$

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 we can see that a loaded voltage divider network changes its output voltage as a result of this loading effect, since the output voltage Vout is determined by the ratio of R1 to R2. However, as the load resistance, RL increases towards infinity (∞) this loading effect reduces and the voltage ratio of V_{out}/V_s becomes unaffected by the addition of the load on the output. Then the higher the load impedance the less is the loading effect on the output.

The effect of reducing a signal or voltage level is known as **Attenuation** so care must be taken when using a voltage divider network. This loading effect could be compensated for by using a potentiometer instead of fixed value resistors and adjusted accordingly. This method also compensates the potential divider for varying tolerances in the resistors construction.

A variable resistor, potentiometer or pot as it is more commonly called, is a good example of a multi-resistor voltage 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.

The **Voltage Divider Circuit** is the simplest way of producing a lower voltage from a higher voltage, and is the basic operating mechanism of the potentiometer.

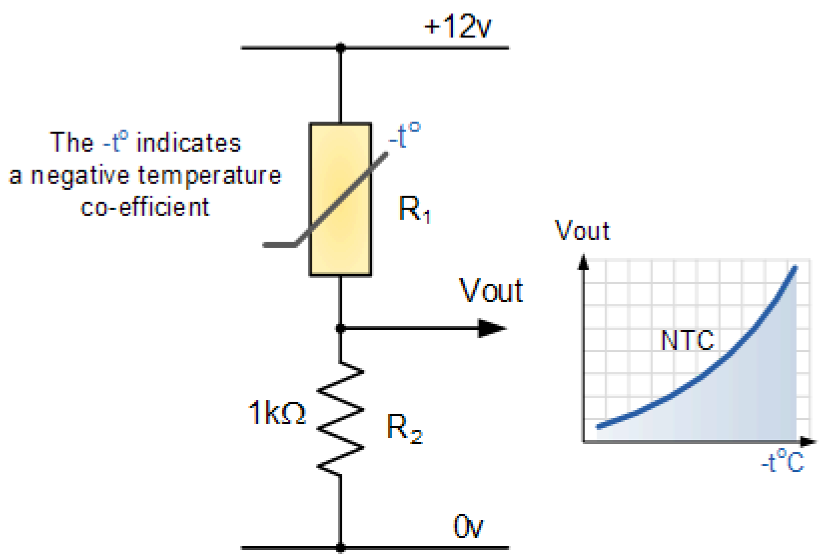
As well as being used to calculate a lower supply voltage, the voltage divider formula can also be used in the analysis of more complex resistive circuits containing both series and parallel branches. The voltage or potential divider formula can be used to determine the voltage drops around a closed DC network or as part of a various circuit analysis laws such as Kirchhoff's or Thevenin's theorems.

Applications of Resistors in Series

We have seen that Resistors in Series 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 dependant 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.

For example, the following thermistor circuit has a resistance of 10KΩ at 25°C and a resistance of 100Ω at 100°C. Calculate the output voltage (V_{out}) for both temperatures.

Thermistor Circuit



At 25°C

$$Vout = \frac{R_2}{R_1 + R_2} \text{ x } Vin = \frac{1{,}000}{10{,}000+1{,}000} \text{ x } 12 = 1.09v$$

At 100°C

$$Vout = \frac{R_2}{R_1 + R_2} x\ Vin = \frac{1{,}000}{100+1{,}000} x\ 12 = 10.9v$$

So by changing the fixed 1KΩ resistor, R2 in our simple circuit above to a variable resistor or potentiometer, a particular output voltage set point can be obtained over a wider temperature range.

Resistors in Series Summary

So to summarise. When two or more resistors are connected together end-to-end in a single branch, the resistors are said to be connected together in series. **Resistors in Series** carry the same current, but the voltage drop across them is not the same as their individual resistance values will create different voltage drops across each resistor as determined by Ohm's Law (V = I*R). Then series circuits are voltage dividers.

In a series resistor network the individual resistors add together to give an 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.

In the next tutorial about Resistors, we will look at connecting resistors together in parallel and show that the total resistance is the reciprocal sum of all the resistors added together and that the voltage is common to a parallel circuit.

https://www.electronics-tutorials.ws/resistor/res_4.html

Resistors in Parallel

Unlike the previous series resistor circuit, in a parallel resistor network the circuit current can take more than one path as there are multiple paths for the current. Then resistors in parallel circuits are classed as current dividers.

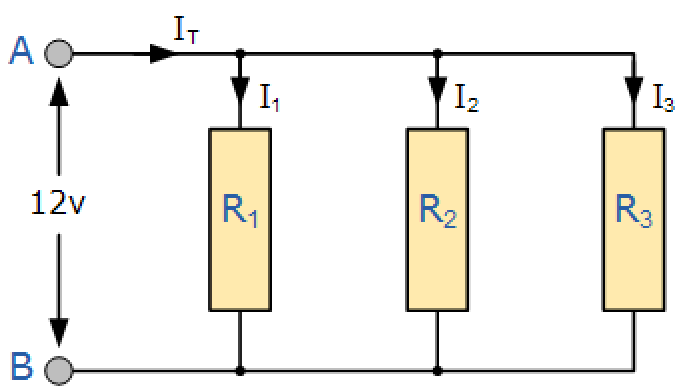
Since there are multiple paths for the supply current to flow through, the current may not be the same through all the branches in the parallel network. However, the voltage drop across all of the resistors in a parallel resistive network IS the same. Then, **Resistors in Parallel** have a **Common Voltage** across them and this is true for all parallel connected elements.

So we can define a parallel resistive circuit as one where the resistors are connected to the same two points (or nodes) and is identified by the fact that it has more than one current path connected to a common voltage source. Then in our parallel resistor example below, the voltage across resistor R1 equals the voltage across resistor R2 which equals the voltage across R3 and which equals the supply voltage. Therefore, for a parallel resistor network this is given as:

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

In the following resistors in parallel circuit the resistors R1, R2 and R3 are all connected together in parallel between the two points A and B as shown.

Parallel Resistor Circuit



In the previous series resistor network we saw that the total resistance, R_T of the circuit was equal to the sum of all the individual resistors added together. For resistors in parallel the equivalent circuit resistance R_T is calculated differently.

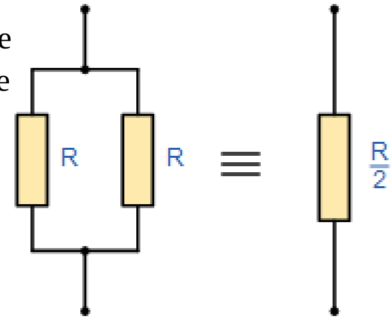
Here, the reciprocal (1/R) value of the individual resistances are all added together instead of the resistances themselves with the inverse of the algebraic sum giving the equivalent resistance as shown.

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.

If the two resistances or impedances in parallel are equal and of the same value, then the total or equivalent resistance, R_T is equal to half the value of one resistor. That is equal to R/2 and for three equal resistors in parallel, R/3, etc.

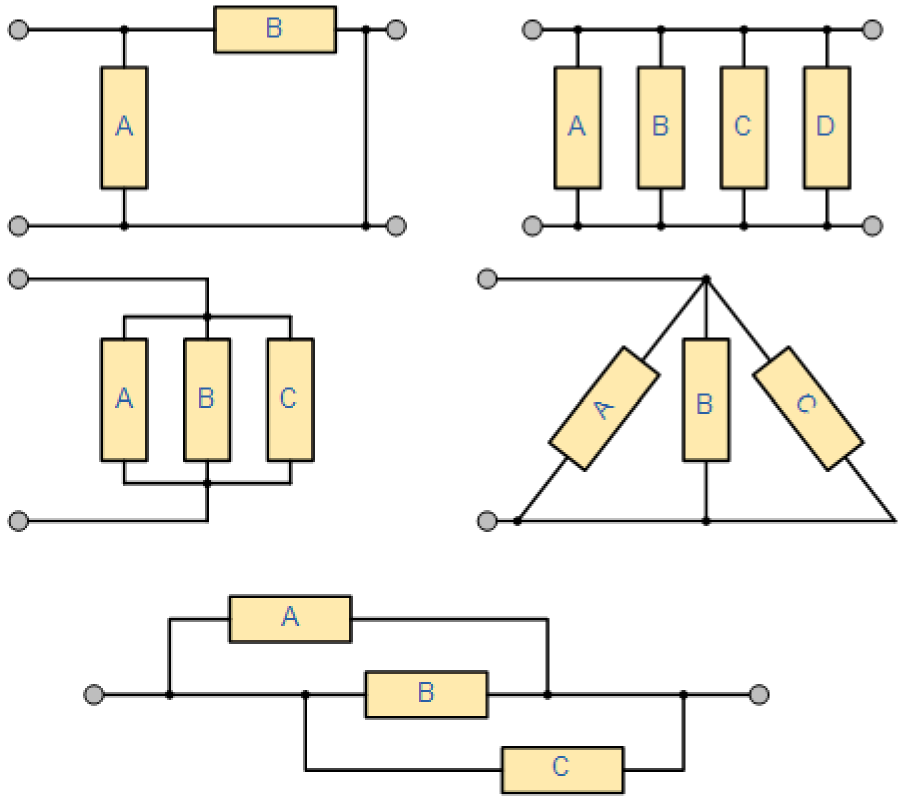


Note that the equivalent resistance is always less than the smallest resistor in the parallel network so the total resistance, R_T will always decrease as additional parallel resistors are added.

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). To convert conductance back into a resistance value we need to take the reciprocal of the conductance giving us then the total resistance, R_T of the resistors in parallel.

We now know that resistors that are connected between the same two points are said to be in parallel. But a parallel resistive circuit can take many forms other than the obvious one given above and here are a few examples of how resistors can be connected together in parallel.

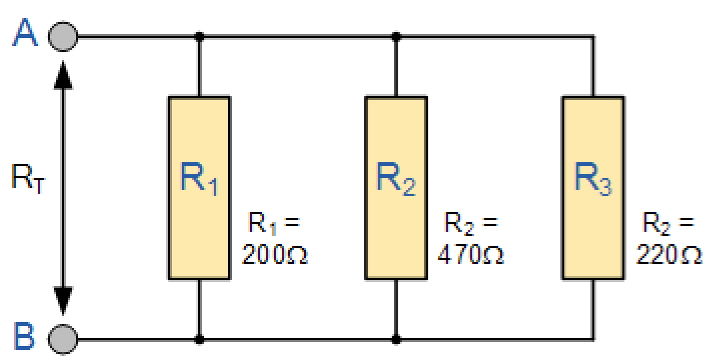
Various Parallel Resistor Networks



The five resistive networks above may look different to each other, but they are all arranged as **Resistors in Parallel** and as such the same conditions and equations apply.

Resistors in Parallel Example No1

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

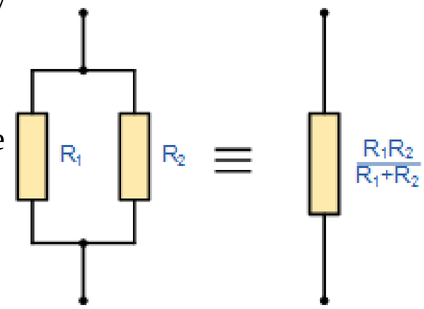


The total resistance R_T across the two terminals A and B is calculated as:

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

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

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



This method of reciprocal calculation can be used for calculating any number of individual resistances connected together within a single parallel network.

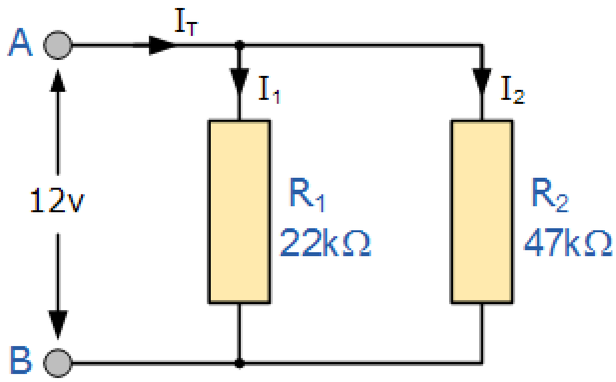
If however, there are only two individual resistors in parallel then we can use a much simpler and quicker formula to find the total or equivalent resistance value, R_T and help reduce the reciprocal maths a little.

This much quicker product-over-sum method of calculating two resistor in parallel, either having equal or unequal values is given as:

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

Resistors in Parallel Example No2

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



Using our formula above for two resistors connected together in parallel we can calculate the total circuit resistance, R_T as:

$$R_T = \frac{22k\Omega \times 47k\Omega}{22k\Omega + 47k\Omega} = 14{,}985\Omega \text{ or } 15k\Omega$$

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 in that combination.

In our example above, the value of the combination was calculated as: R_T = 15kΩ, where as the value of the smallest resistor is 22kΩ, much higher. In other words, the equivalent resistance of a parallel network will always be less than the smallest individual resistor in the combination.

Also, in the case of R1 being equal to the value of R2, that is R1 = R2, 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 = 16.7Ω. But note that this ONLY works for equivalent resistors. That is resistors all having the same value.

Currents in a Parallel Resistor Circuit

The total current, IT entering a parallel resistive circuit is the sum of all the individual currents flowing in all the parallel branches. But the amount of current flowing through each parallel branch may not necessarily be the same, as the resistive value of each branch determines the amount of current flowing 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.

Consider the two resistors in parallel above. The current that flows through each of the resistors (I_{R1} and I_{R2}) connected together in parallel is not necessarily the same value as it depends upon the resistive value of the resistor. However, we do know that the current that enters the circuit at point A must also exit the circuit at point B.

Kirchhoff's Current Laws states that: "*the total current leaving a circuit is equal to that entering the circuit – no current is lost*". Thus, the total current flowing in the circuit is given as:

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

By using *Ohm's Law*, we can calculate the current flowing through each parallel resistor shown in Example No2 above as being:

The current flowing in resistor R1 is given as:

$$I_{R1} = V_S \div R1 = 12V \div 22k\Omega = 0.545mA \text{ or } 545\mu A$$

The current flowing in resistor R2 is given as:

$$I_{R2} = V_S \div R2 = 12V \div 47k\Omega = 0.255mA \text{ or } 255\mu A$$

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

$$I_T = 0.545mA + 0.255mA = 0.8mA \text{ or } 800\mu A$$

and this can also be verified directly using Ohm's Law as:

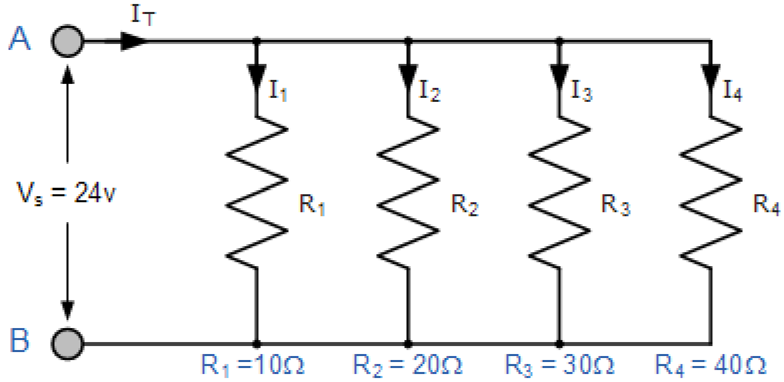
$$I_T = V_S \div R_T = 12 \div 15k\Omega = 0.8mA \text{ or } 800\mu A \text{ (the same)}$$

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:

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

Resistors in Parallel Example No3

Calculate the individual branch currents and total current drawn from the power supply for the following set of resistors connected together in a parallel combination.



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.

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

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

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

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

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

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

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

$$I_T = 5.0 \text{ Amps}$$

This total circuit current value of 5 amperes can also be found and verified by finding the equivalent circuit resistance, R_T of the parallel branch and dividing it into the supply voltage, V_S as follows.

Equivalent circuit resistance:

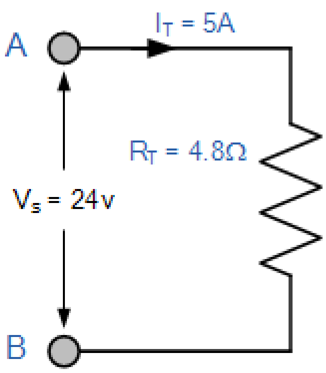
$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

$$\frac{1}{R_T} = \frac{1}{10} + \frac{1}{20} + \frac{1}{30} + \frac{1}{40}$$

$$\frac{1}{R_T} = 0.1 + 0.05 + 0.033 + 0.025$$

$$\therefore R_T = \frac{1}{0.2083} = 4.8\Omega$$

Then the current flowing in the circuit will be:



$$I_T = \frac{V_S}{R_T} = \frac{24}{4.8} = 5 \text{ Amps}$$

Resistors in Parallel Summary

So to summarise. 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 voltage across each resistor within a parallel combination is exactly the same but the currents flowing through them are not the same as this is determined by their resistance value and Ohms Law. Then parallel circuits are current dividers.

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 resistor networks 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.

Thus far we have seen resistor networks connected in either a series or a parallel combination. In the next tutorial about *Resistors*, we will look at connecting resistors together in both a series and parallel combination at the same time producing a mixed or combinational resistor circuit.

https://www.electronics-tutorials.ws/resistor/res_5.html

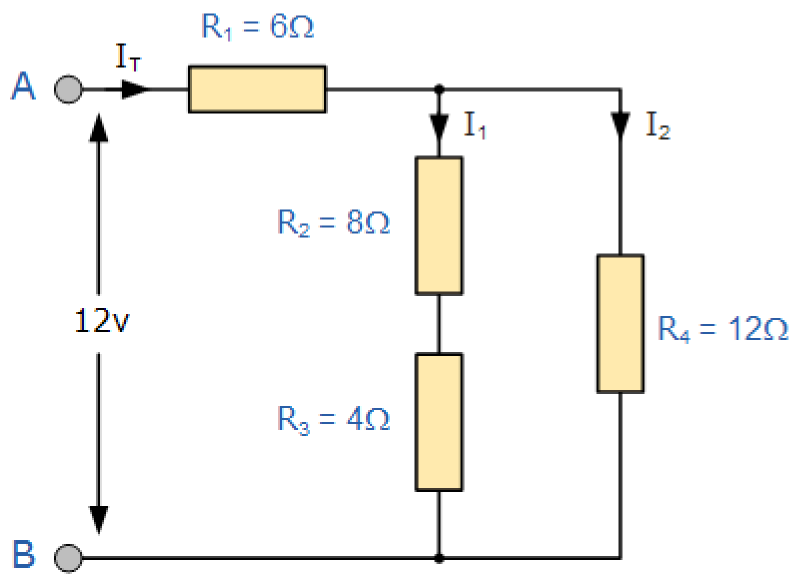
Resistors in Series and Parallel

In the previous tutorials we have learnt how to connect individual resistors together to form either a Series Resistor Network or a Parallel Resistor Network and we used Ohms Law to find the various currents and voltages across each resistor combination. But we can also connect resistors in series and parallel combinations together.

What if we want to connect various resistors together in "BOTH" parallel and series combinations within the same circuit to produce more complex resistive networks, how do we calculate the combined or total circuit resistance, currents and voltages for these resistive combinations.

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

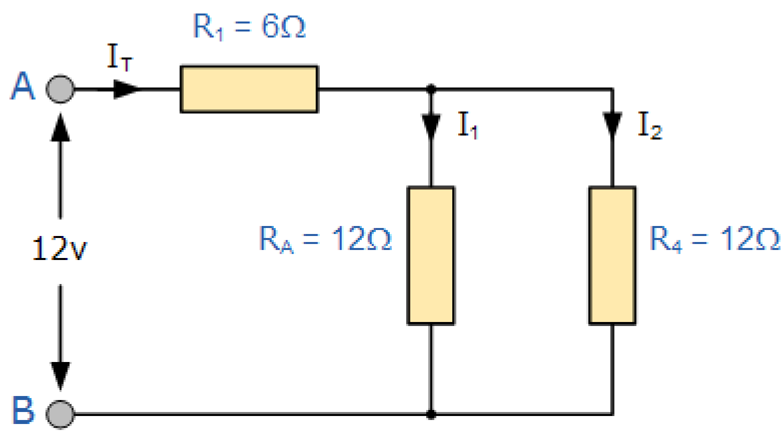
For example, in the following circuit calculate the total current (I_T) taken from the 12v supply.



At first glance this may seem a difficult task, but if we look a little closer we can see that the two resistors, R2 and R3 are actually both connected together in a "SERIES" combination so we can add them together to produce an equivalent resistance the same as we did in the series resistor tutorial. The resultant resistance for this combination would therefore be:

$$R2 + R3 = 8\Omega + 4\Omega = 12\Omega$$

So we can replace both resistor R2 and R3 above with a single resistor of resistance value 12Ω

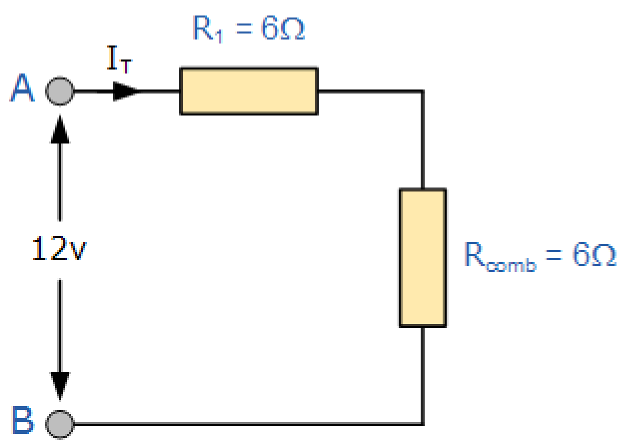


So our circuit now has a single resistor R_A in "PARALLEL" with the resistor R4. Using our resistors in parallel equation we can reduce this parallel combination to a single equivalent resistor value of $R_{(combination)}$ using the formula for two parallel connected resistors as follows.

$$R_{(eq)} = \frac{1}{R_A} + \frac{1}{R_4} = \frac{1}{12} + \frac{1}{12} = 0.1667$$

$$R_{(combination)} = \frac{1}{R_{(eq)}} = \frac{1}{0.1667} = 6\Omega$$

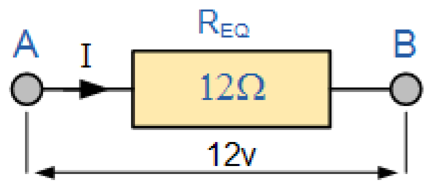
The resultant resistive circuit now looks something like this:



We can see that the two remaining resistances, R1 and R_{comb} are connected together in a "SERIES" combination and again they can be added together (resistors in series) so that the total circuit resistance between points A and B is therefore given as:

$$R_{(ab)} = R_{comb} + R1 = 6\Omega + 6\Omega = 12\Omega$$

Thus a single resistor of just 12Ω can be used to replace the original four resistors connected together in the original circuit above.



By using Ohm's Law, the value of the current (I) flowing around the circuit is calculated as:

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

Then we can see that any complicated resistive circuit consisting of several resistors can be reduced to a simple single circuit with only one equivalent resistor by replacing all the resistors connected together in series or in parallel using the steps above.

We can take this one step further by using Ohms Law to find the two branch currents, I_1 and I_2 as shown.

$$V_{R1} = I*R1 = 1*6 = 6 \text{ volts}$$

$$V_{RA} = V_{R4} = (12 - V_{R1}) = 6 \text{ volts}$$

Thus:

$$I_1 = 6V \div RA = 6 \div 12 = 0.5A \text{ or } 500mA$$

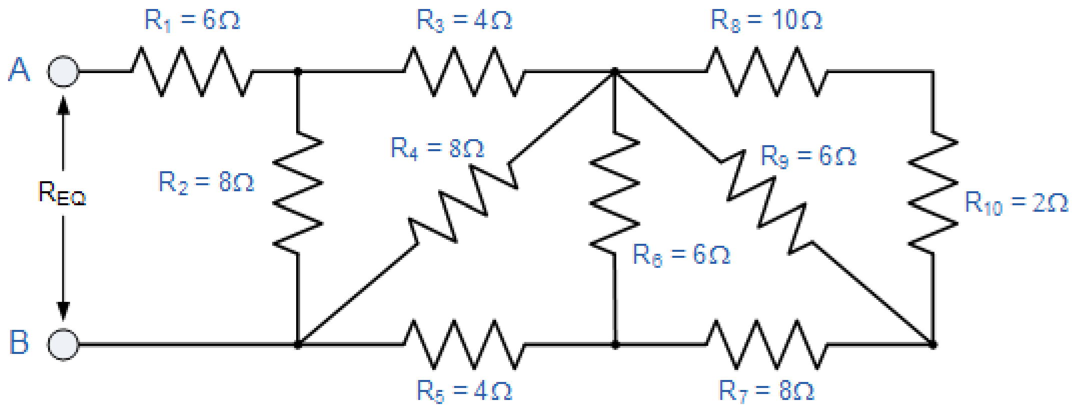
$$I_2 = 6V \div R4 = 6 \div 12 = 0.5A \text{ or } 500mA$$

Since the resistive values of the two branches are the same at 12Ω, the two branch currents of I_1 and I_2 are also equal at 0.5A (or 500mA) each. This therefore gives a total supply current, I_T of: 0.5 + 0.5 = 1.0 amperes as calculated above.

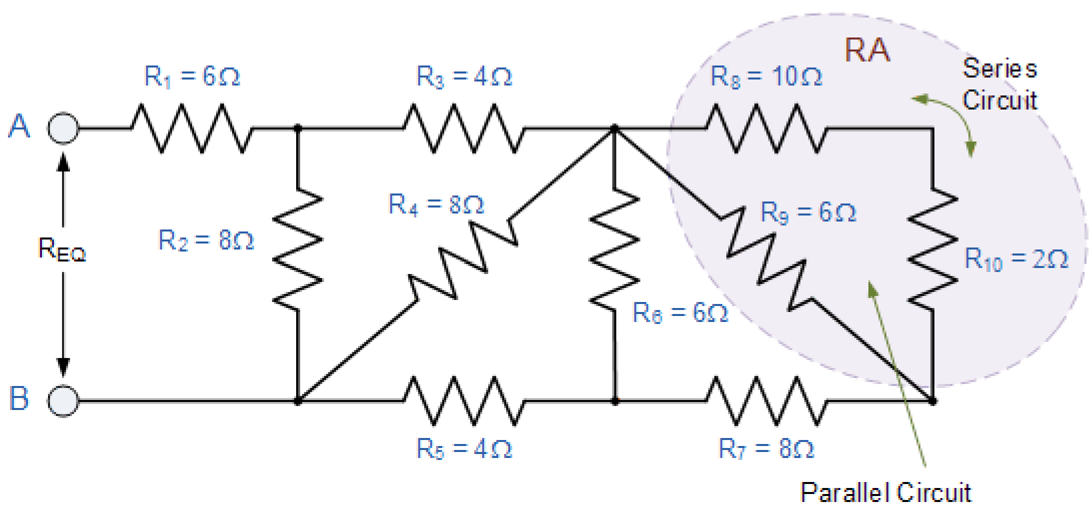
It is sometimes easier with complex resistor combinations and resistive networks to sketch or redraw the new circuit after these changes have been made, as this helps as a visual aid to the maths. Then continue to replace any series or parallel combinations until one equivalent resistance, R_{EQ} is found. Lets try another more complex resistor combination circuit.

Resistors in Series and Parallel Example No2

Find the equivalent resistance, R_{EQ} for the following resistor combination circuit.

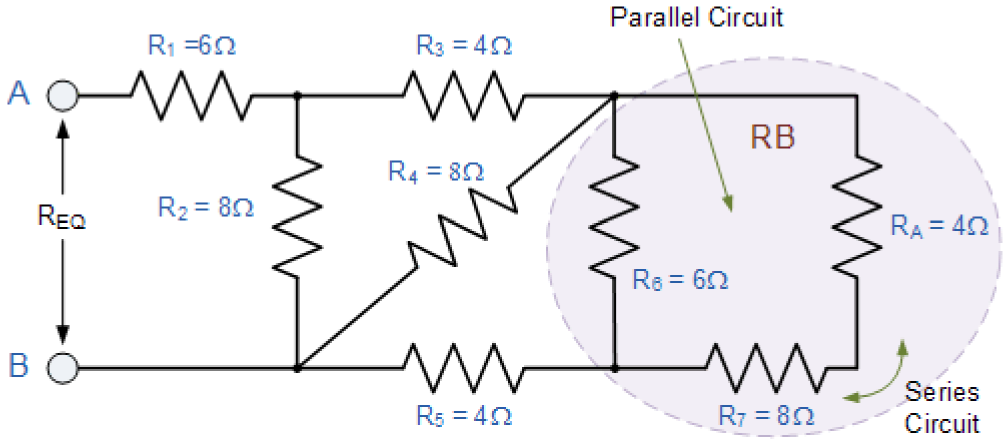


Again, at first glance this resistor ladder network may seem a complicated task, but as before it is just a combination of series and parallel resistors connected together. Starting from the right hand side and using the simplified equation for two parallel resistors, we can find the equivalent resistance of the R8 to R10 combination and call it R_A.



$$R_A = \frac{R_9 \times (R_8 + R_{10})}{R_9 + R_8 + R_{10}} = \frac{6 \times (10 + 2)}{6 + 10 + 2} = 4\Omega$$

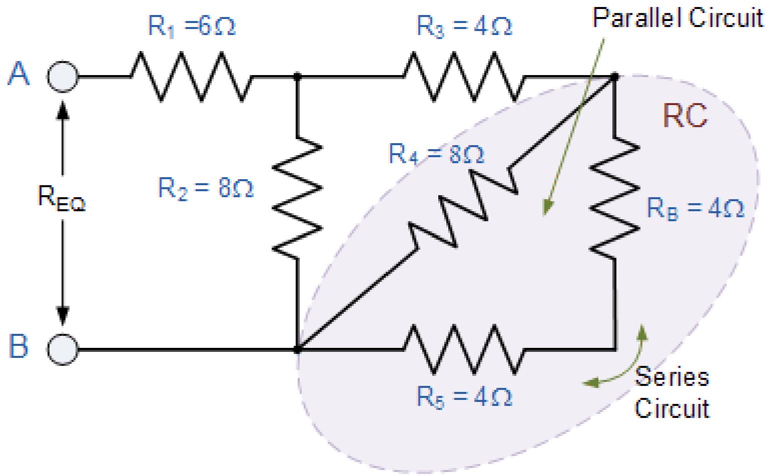
R_A is in series with R7 therefore the total resistance will be R_A + R7 = 4 + 8 = 12Ω as shown.



This resistive value of 12Ω is now in parallel with R6 and can be calculated as R_B.

$$R_B = \frac{R_6 \times (R_A + R_7)}{R_6 + R_A + R_7} = \frac{6 \times (4+8)}{6+4+8} = 4\Omega$$

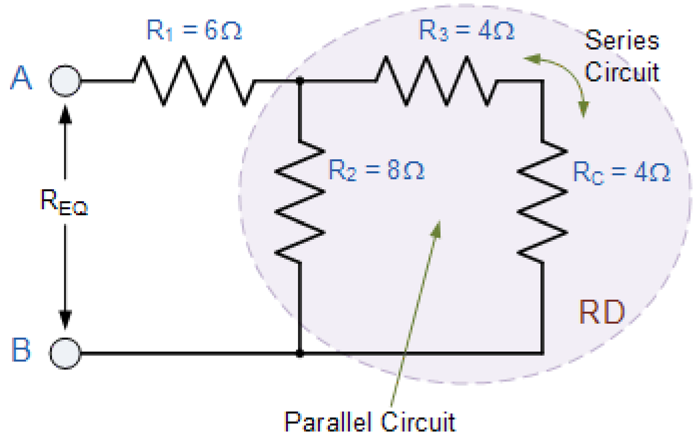
R_B is in series with R5 therefore the total resistance will be R_B + R5 = 4 + 4 = 8Ω as shown.



This resistive value of 8Ω is now in parallel with R4 and can be calculated as R_C as shown.

$$R_C = \frac{R_4 \times (R_B + R_5)}{R_4 + R_B + R_5} = \frac{8 \times (4+4)}{8+4+4} = 4\Omega$$

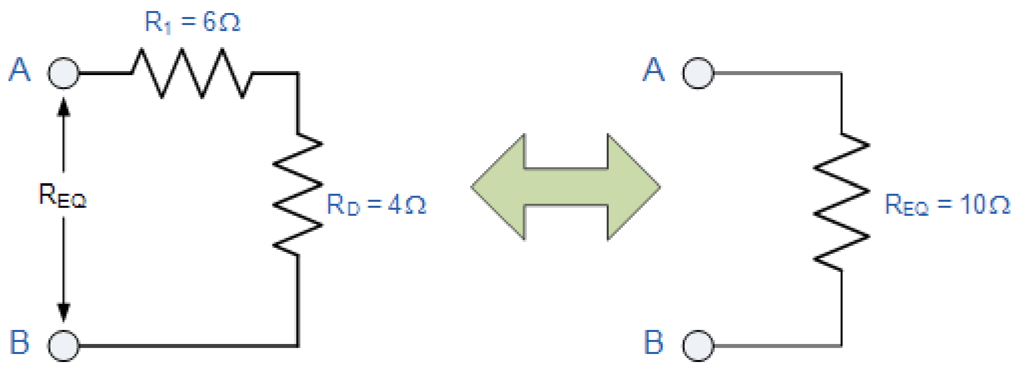
R_C is in series with R3 therefore the total resistance will be R_C + R3 = 8Ω as shown.



This resistive value of 8Ω is now in parallel with R2 from which we can calculated R_D as:

$$R_D = \frac{R_2 \times (R_C + R_3)}{R_2 + R_C + R_3} = \frac{8 \times (4+4)}{8+4+4} = 4\Omega$$

R_D is in series with R1 therefore the total resistance will be R_D + R1 = 4 + 6 = 10Ω as shown.



Then the complex combinational resistive network above comprising of ten individual resistors connected together in series and parallel combinations can be replaced with just one single equivalent resistance (R_{EQ}) of value 10Ω.

When solving any combinational resistor circuit that is made up of resistors in series and parallel branches, the first step we need to take is to identify the simple series and parallel resistor branches and replace them with equivalent resistors.

This step will allow us to reduce the complexity of the circuit and help us transform a complex combinational resistive circuit into a single equivalent resistance remembering that series circuits are voltage dividers and parallel circuits are current dividers.

However, calculations of more complex T-pad Attenuator and resistive bridge networks which cannot be reduced to a simple parallel or series circuit using equivalent resistances require a different approach. These more complex circuits need to be solved using Kirchhoff's Current Law, and Kirchhoff's Voltage Law which will be dealt with in another tutorial.

In the next tutorial about Resistors, we will look at the electrical potential difference (voltage) across two points including a resistor.

https://www.electronics-tutorials.ws/resistor/res_6.html

Potential Difference

Unlike current which flows around a closed electrical circuit in the form of electrical charge, potential difference does not move or flow it is applied.

The unit of potential difference generated between two points is called the **Volt** and is generally defined as being the potential difference dropped across a fixed resistance of one ohm with a current of one ampere flowing through it.

In other words, 1 Volt equals 1 Ampere times 1 Ohm, or commonly 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.

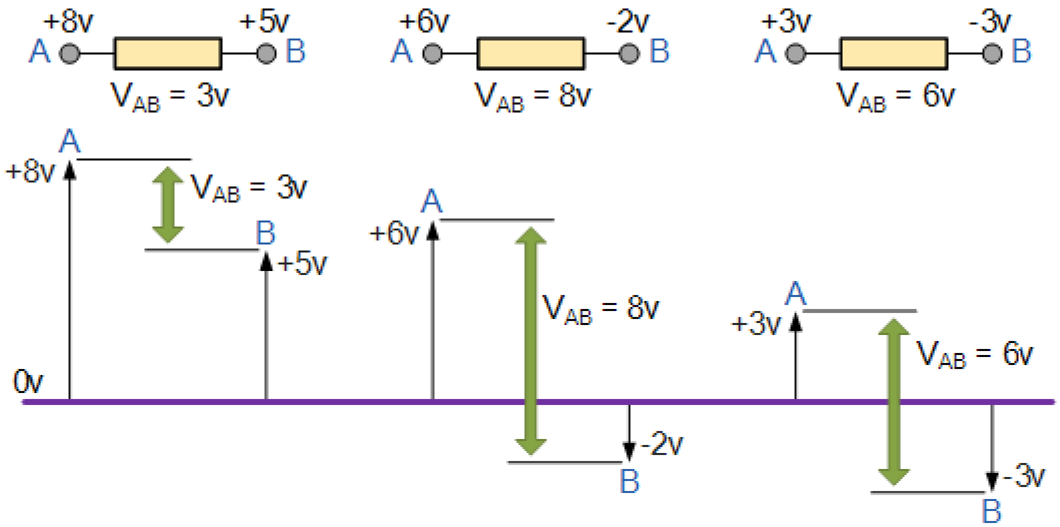
For example, if the voltage at one side of a 10Ω resistor measures 8V and at the other side of the resistor it measures 5V, then the potential difference across the resistor would be 3V (8 – 5) causing a current of 0.3A to flow.

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.

For electrical circuits, the earth or ground potential is usually taken to be at zero volts (0V) and everything is referenced to that common point in a circuit. This is similar in theory to measuring height. We measure the height of hills in a similar way by saying that the sea level is at zero feet and then compare other points of the hill or mountain to that level.

In a very similar way we can call the common point in a circuit zero volts and give it the name of ground, zero volts or earth, then all other voltage points in the circuit are compared or referenced to that ground point. The use of a common ground or reference point in electrical schematic drawings allows the circuit to be drawn more simply as it is understood that all connections to this point have the same potential. For example:

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 as seen in the resistors in parallel tutorial, for example.

For series connected voltages:

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

For parallel connected voltages:

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

Potential Difference Example No1

By using Ohm's Law, the current flowing through a resistor can be calculated as follows:

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:

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

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

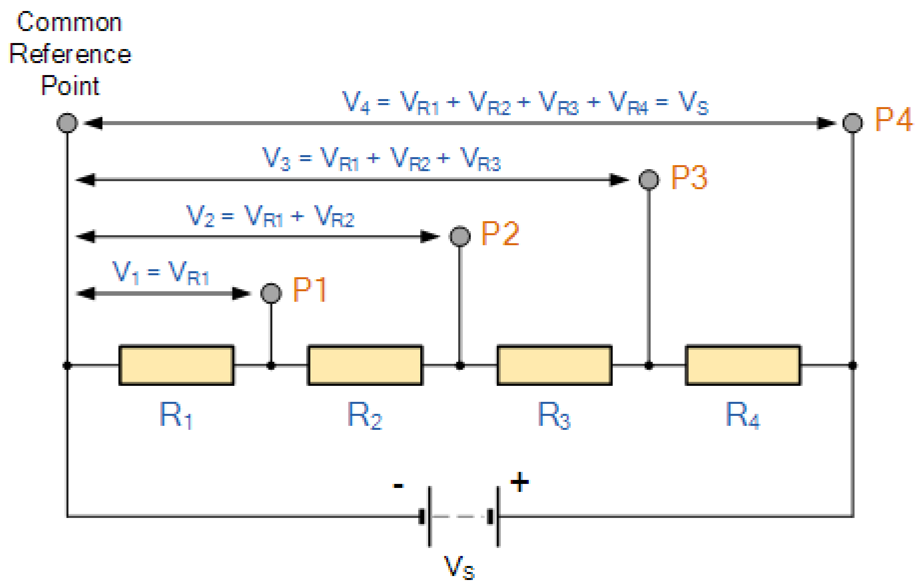
$$I = V_{AB} \div R = 20\text{V} \div 100\Omega = 200\text{mA}$$

Voltage Divider Network

We know from the previous tutorials that by connecting together resistors in series across a potential difference we can produce a voltage divider circuit which will give the ratios of voltages across each resistor with respect to the supply voltage across the total combination.

This produces what is generally called a **Voltage Divider Network** and one which only applies to resistors connected together in series, because as we saw in the Resistors in Parallel tutorial, resistors connected together in parallel produce what is called a current divider network. Consider the series circuit below.

Voltage Division



The circuit shows the principle of a voltage divider circuit where the output voltage drops across each resistor within the series chain, with resistors R1, R2, R3 and R4 being referenced to some common reference point (usually zero volts).

So for any number of resistors connected together in series, dividing the supply voltage VS by the total resistance, RT will give the current flowing through the series branch as: I = VS/RT, (Ohm's Law). Then the individual voltage drops across each resistor can be simply calculated as: V = I*R where R represents the resistance value.

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 Formula

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

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.

Potential Difference Example No2

In the circuit above, four resistors of values, R1 = 10Ω, R2 = 20Ω, R3 = 30Ω and R4 = 40Ω are connected across a 100 volts DC supply. Using the formula above, calculated the voltage drops at points P1, P2, P3 and P4 and also the individual voltage drops across each resistor within the series chain.

1. The voltages at the various points are calculated as:

$$V_{P1} = \frac{R_1}{R_T} \times V_S = \frac{(10)100}{(10+20+30+40)} = 10 \text{ Volts}$$

$$V_{P2} = \frac{R_1 + R_2}{R_T} \times V_S = \frac{(10 + 20)100}{(10+20+30+40)} = 30 \text{ Volts}$$

$$V_{P3} = \frac{R_1 + R_2 + R_3}{R_T} \times V_S = \frac{(10+20+30)100}{(10+20+30+40)} = 60 \text{ Volts}$$

$$V_{P4} = V_S = 100 \text{ Volts}$$

2. The individual voltage drops across each resistor are calculated as:

$$I = \frac{V_S}{R_T} = \frac{100V}{(10+20+30+40)} = \frac{100V}{100\Omega} = 1 \text{ Ampere}$$

$$V_{R1} = I \times R_1 = 1 \times 10 = 10 \text{ Volts}$$

$$V_{R2} = I \times R_2 = 1 \times 20 = 20 \text{ Volts}$$

$$V_{R3} = I \times R_3 = 1 \times 30 = 30 \text{ Volts}$$

$$V_{R4} = I \times R_4 = 1 \times 40 = 40 \text{ Volts}$$

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 Kirchhoff'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 flows through and around a circuit. But there is a third variable we can also apply to resistors and resistor networks. 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.

https://www.electronics-tutorials.ws/resistor/res_7.html

Resistor Power Rating

When an electrical current passes through a resistor due to the presence of a voltage across it, electrical energy is lost by the resistor in the form of heat and the greater this current flow the hotter the resistor will get. This is known as the **Resistor Power Rating**.

Resistors are rated by the value of their resistance and the electrical power given in watts, (W) that they can safely dissipate based mainly upon their size. Every resistor has a maximum power rating which is determined by its physical size as generally, the greater its surface area the more power it can dissipate safely into the ambient air or into a heatsink.

A resistor can be used at any combination of voltage (within reason) and current so long as its “Dissipating Power Rating” is not exceeded with the resistor power rating indicating how much power the resistor can convert into heat or absorb without any damage to itself. The **Resistor Power Rating** is sometimes called the *Resistors Wattage Rating* and is defined as *the amount of heat that a resistive element can dissipate for an indefinite period of time without degrading its performance*.

The power rating of resistors can vary a lot from less than one tenth of a watt to many hundreds of watts depending upon its size, construction and ambient operating temperature. Most resistors have their maximum resistive power rating given for an ambient temperature of +70°C or below.

Electrical power is the rate in time at which energy is used or consumed (converted into heat). The standard unit of electrical power is the **Watt**, symbol **W** and a resistors power rating is also given in Watts. As with other electrical quantities, prefixes are attached to the word “Watt” when expressing very large or very small amounts of resistor power. Some of the more common of these are:

Electrical Power Units

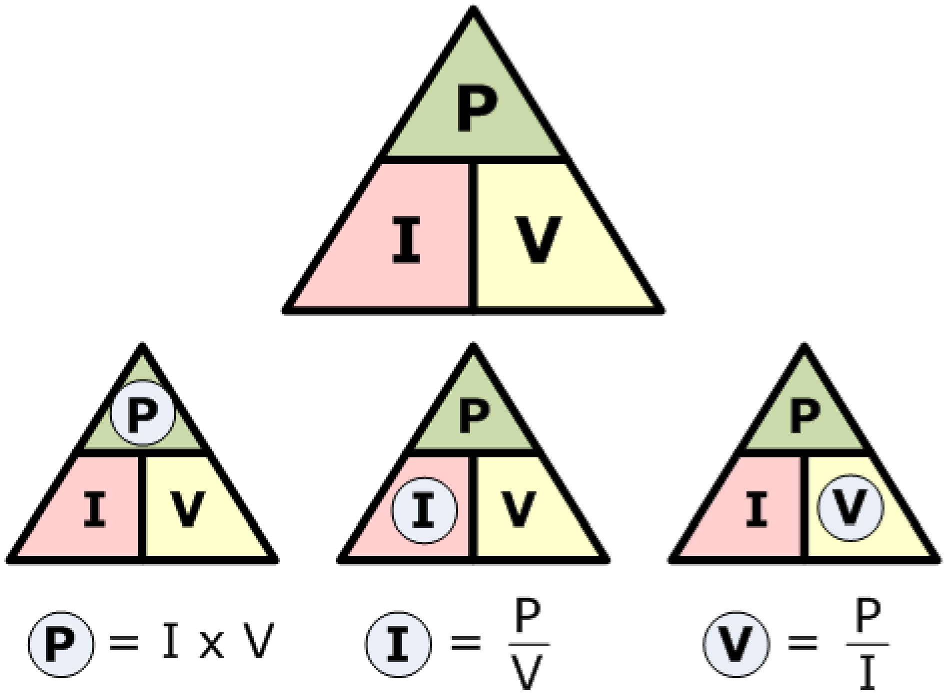
Unit	Symbol	Value	Abbreviation
milliwatt	mW	1/1,000th watt	10^{-3} W
kilowatt	kW	1,000 watts	10^{3} W
megawatt	MW	1,000,000 watts	10^{6} W

Resistor Power (P)

We know from Ohm’s Law that when a current flows through a resistance, a voltage is dropped across it producing a product which relates to power.

In other words, if a resistance is subjected to a voltage, or if it conducts a current, then it will always consume electrical power and we can superimpose these three quantities of power, voltage and current into a triangle called a **Power Triangle** with the power, which would be dissipated as heat in the resistor at the top, with the current consumed and the voltage across it at the bottom as shown.

The Resistor Power Triangle



The above power triangle is great for calculating the power dissipated in a resistor if we know the values of the voltage across it and the current flowing through it. But we can also calculate the power dissipated by a resistance by using Ohm's Law.

Ohms law allows us to calculate the power dissipation given the resistance value of the resistor. By using Ohms Law it is possible to obtain two alternative variations of the above expression for the resistor power if we know the values of only two, the voltage, the current or the resistance as follows:

[$P = V \times I$] Power = Volts x Amps

[$P = I^2 \times R$] Power = Current^2 x Ohms

[$P = V^2 \div R$] Power = Volts^2 ÷ Ohms

The electrical power dissipation of any resistor in a DC circuit can be calculated using one of the following three standard formulas:

$$\text{Power (P)} = V \times I = I^2R = \frac{V^2}{R}$$

Where:

V is the voltage across the resistor in Volts

I is in current flowing through the resistor in Amperes

R is the resistance of the resistor in Ohm’s (Ω)

As the dissipated resistor power rating is linked to their physical size, a 1/4 (0.250)W resistor is physically smaller than a 1W resistor, and resistors that are of the same ohmic value are also available in different power or wattage ratings. Carbon resistors, for example, are commonly made in wattage ratings of 1/8 (0.125)W, 1/4 (0.250)W, 1/2 (0.5)W, 1W, and 2 Watts.

Generally speaking the larger their physical size the higher its wattage rating. However, it is always better to select a particular size resistor that is capable of dissipating two or more times the calculated power. When resistors with higher wattage ratings are required, wirewound resistors are generally used to dissipate the excessive heat.

Type	Power Rating	Stability
Metal Film	Very low at less than 3 Watts	High 1%
Carbon	Low at less than 5 Watts	Low 20%
Wirewound	High up to 500 Watts	High 1%

Power Resistors

Wirewound power resistors come in a variety of designs and types, from the standard smaller heatsink mounted aluminium body 25 Watt types as we have seen previously, to the larger tubular 1000 Watt ceramic or porcelain power resistors used for heating elements.

The resistance value of wirewound resistors is very low (low ohmic values) compared to the carbon or metal film types. The resistive range of a power resistor ranges from less than 1Ω (R005) up to only 100kΩ as larger resistance values would require fine gauge wire that would easily fail.

Low ohmic, low power value resistors are generally used for current sensing applications were, using ohm’s law the current flowing through the resistance gives rise to a voltage drop across it.

This voltage can be measured to determine the value of the current flowing in the circuit. This type of resistor is used in test measuring equipment and controlled power supplies.

The larger wirewound power resistors are made of corrosion resistant wire wound onto a porcelain or ceramic core type former and are generally used to dissipate high inrush currents such as those generated in motor control, electromagnet or elevator/crane control and motor braking circuits.

Generally these types of resistors have standard power ratings up to 500 Watts and are generally connected together to form what are called “resistance banks”.

Another useful feature of wirewound power resistors is in the use of heating elements like the ones used for electric fires, toaster, irons etc. In this type of application the wattage value of the resistance is used to produce heat and the type of alloy resistance wire used is generally made of Nickel-Chrome (Nichrome) allowing temperatures up to 1200ºC.

All resistors whether carbon, metal film or wirewound obey Ohm´s Law when calculating their maximum power (wattage) value. It is also worth noting that when two resistors are connected in parallel then their overall power rating is increased. If both resistors are of the same value and of the same power rating, then the total power rating is doubled.

Resistor Power Rating Example No1

What is the maximum power rating in watts of a fixed resistor which has a voltage of 12 volts across its terminals and a current of 50 milliamperes flowing through it.

Given that we know the values of the voltage and current above, we can substitute these values into the following equation: P = V*I.

$$\text{Power}\left(\text{P}\right) = \text{Volts}(\text{V}) \times \text{Amperes}(\text{I})$$

$$\therefore \text{P} = \text{V} \times \text{I} = 12 \times 0.05 = 600\text{mW or } 0.6\,\text{Watts}$$

Resistor Power Rating Example No2

Calculate the maximum safe current that can pass through a 1.8KΩ resistor rated at 0.5 Watts.

Again, as we know the resistors power rating and its resistance, we can now substitute these values into the standard power equation of: $P = I^2R$.

$$P = I^2 R$$

$$\text{therefore,} \quad I = \sqrt{\frac{P}{R}}$$

$$= \sqrt{\frac{0.5}{1800}} = 0.016\text{A or } 16\text{mA}$$

All resistors have a **Maximum Dissipated Power Rating**, which is the maximum amount of power it can safely dissipate without damage to itself. Resistors which exceed their maximum power rating tend to go up in smoke, usually quite quickly, and damage the circuit they are connected to. If a resistor is to be used near to its maximum power rating then some form of heatsink or cooling is required.

Resistor power rating is an important parameter to consider when choosing a resistor for a particular application. The job of a resistor is to resist current flow through a circuit and it does this by dissipating the unwanted power as heat. Selecting a small wattage value resistor when high power dissipation is expected will cause the resistor to over heat, destroying both the resistor and the circuit.

Thus far we have considered resistors connected to a steady DC supply, but in the next tutorial about Resistors, we will look at the behaviour of resistors that are connected to a sinusoidal AC supply, and show that the voltage, current and therefore the power consumed by a resistor used in an AC circuit are all in-phase with each other.

https://www.electronics-tutorials.ws/resistor/res_8.html

Resistors in AC Circuits

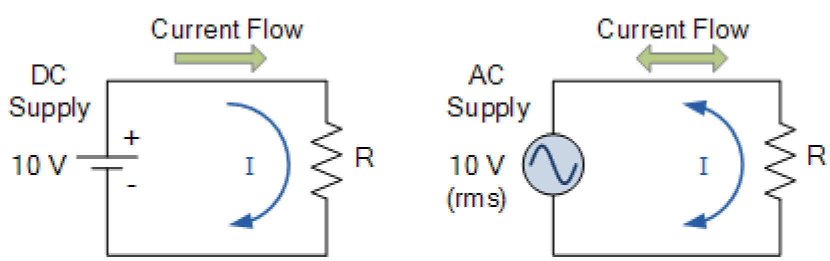
In the previous tutorials we have looked at resistors, their connections and used Ohm's Law to calculate the voltage, current and power associated with them. In all cases both the voltage and current has been assumed to be of a constant polarity, flow and direction, in other words **Direct Current** or **DC**. But we can also use resistors in AC circuits.

But there is another type of supply known as alternating current or **AC** whose voltage switches polarity from positive to negative and back again over time and also whose current with respect to the voltage oscillates back and forth. The oscillating shape of an AC supply follows that of the mathematical form of a "sine wave" which is commonly called a **Sinusoidal Waveform**. Therefore, a sinusoidal voltage can be defined as $V(t) = V_{max} \sin \omega t$.

When using pure resistors in AC circuits that have negligible values of inductance or capacitance, the same principals of Ohm's Law, circuit rules for voltage, current and power (and even Kirchhoff's Laws) apply as they do for DC resistive circuits the only difference this time is in the use of the instantaneous "peak-to-peak" or "rms" quantities.

When working with AC alternating voltages and currents it is usual to use only "rms" values to avoid confusion. The rms or "root mean squared" value of an AC waveform is the effective or DC value equivalent for an AC waveform. Also the schematic symbol used for defining an AC voltage source is that of a "wavy" line as opposed to a battery symbol for DC and this is shown below.

Symbol Representation of DC and AC Supplies

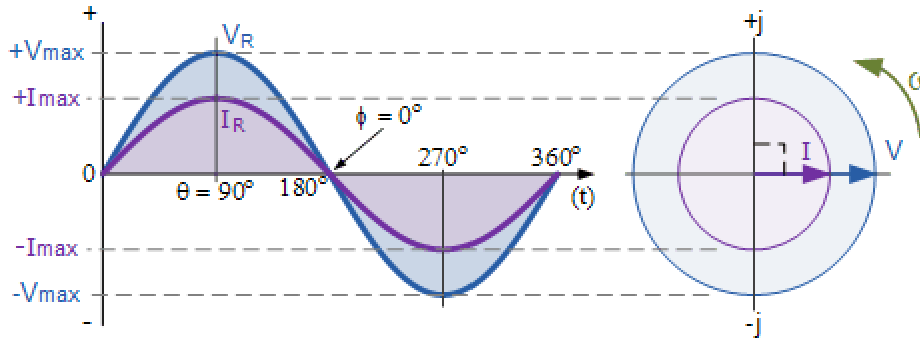


Resistors are "passive" devices, that is they do not produce or consume any electrical energy, but convert electrical energy into heat. In DC circuits the linear ratio of voltage to current in a resistor is called its resistance. However, in AC circuits this ratio of voltage to current depends upon the frequency and phase difference or phase angle (φ) of the supply. So when using resistors in AC circuits the term **Impedance**, symbol **Z** is the generally used and we can say that DC resistance = AC impedance, R = Z.

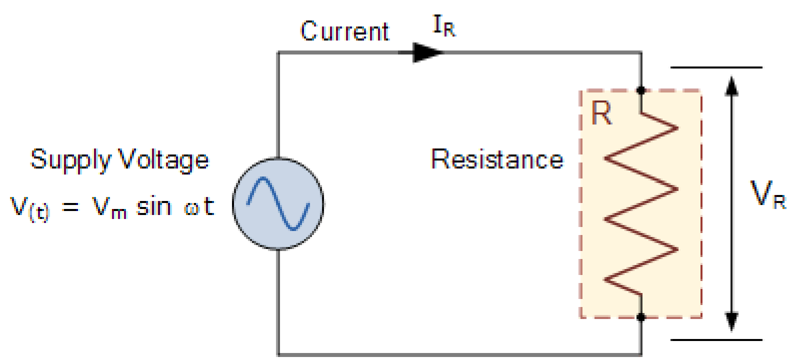
It is important to note, that when used in AC circuits, a resistor will always have the same resistive value no matter what the supply frequency from DC to very high frequencies, unlike capacitor and inductors.

For resistors in AC circuits the direction of the current flowing through them has no effect on the behaviour of the resistor so will rise and fall as the voltage rises and falls. The current and voltage reach maximum, fall through zero and reach minimum at exactly the same time. i.e, they rise and fall simultaneously and are said to be "in-phase" as shown below.

V-I Phase Relationship and Vector Diagram



We can see that at any point along the horizontal axis that the instantaneous voltage and current are in-phase because the current and the voltage reach their maximum values at the same time, that is their phase angle θ is 0º. Then these instantaneous values of voltage and current can be compared to give the ohmic value of the resistance simply by using ohms law. Consider below the circuit consisting of an AC source and a resistor.



The instantaneous voltage across the resistor, V_R is equal to the supply voltage, V_t and is given as:

$$V_R = V_{max} \sin\omega t$$

The instantaneous current flowing in the resistor will therefore be:

$$I_R = \frac{V_R}{R} = \frac{V_{max}}{R}\sin\omega t = I_{max}\sin\omega t$$

As the voltage across a resistor is given as V_R = I.R, the instantaneous voltage across the resistor above can also be given as:

$$V_R = I_{max} R \sin\omega t$$

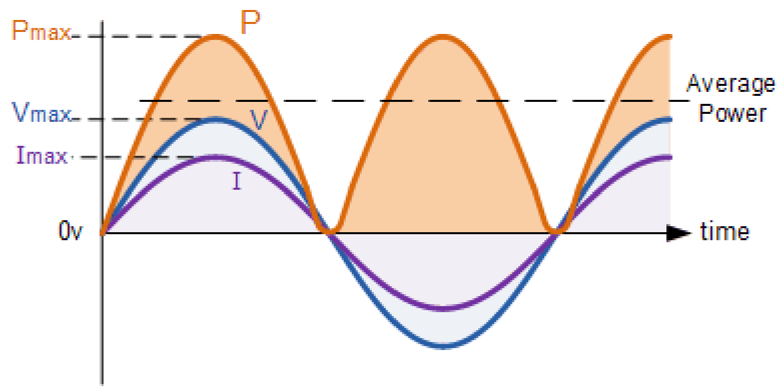
In purely resistive series AC circuits, all the voltage drops across the resistors can be added together to find the total circuit voltage as all the voltages are in-phase with each other. Likewise, in a purely resistive parallel AC circuit, all the individual branch currents can be added together to find the total circuit current because all the branch currents are in-phase with each other.

Since for resistors in AC circuits the phase angle φ between the voltage and the current is zero, then the power factor of the circuit is given as cos 0º = 1.0. The power in the circuit at any instant in time can be found by multiplying the voltage and current at that instant.

Then the power (P), consumed by the circuit is given as P = Vrms I cos Φ in watts. But since cos(Φ) = 1 in a purely resistive circuit, the power consumed is simply given as, P = Vrms I the same as for Ohm’s Law.

This then gives us the “Power” waveform and which is shown below as a series of positive pulses because when the voltage and current are both in their positive half of the cycle the resultant power is positive. When the voltage and current are both negative, the product of the two negative values gives a positive power pulse.

Power Waveform in a Pure Resistance



Then the power dissipated in a purely resistive load fed from an AC rms supply is the same as that for a resistor connected to a DC supply and is given as:

$$P = V_{R(rms)} \times I_{rms} = I_{rms}^2 R = \frac{V_{rms}^2}{R}$$

Where:

P is the average power in Watts

Vrms is the rms supply voltage in Volts

Irms   is the rms supply current in Amps

R is the resistance of the resistor in Ohm’s (Ω) – should really be Z to indicate impedance

The heating effect produced by an alternating current with a maximum value of Imax is not the same as that of a DC current of the same value. To compare the AC heating effect to an equivalent DC the rms values must be used. Any resistive heating element such as Electric Fires, Toasters, Kettles, Irons, Water Heaters etc can be classed as a resistive AC circuit and we use resistors in AC circuits to heat our homes and water.

Resistors in AC Circuits Example No1

A 1000 Watt (1kW) heating element is connected to a 250v AC supply voltage. Calculate the impedance (AC resistance) of the element when it is hot and the amount of current taken from the supply.

$$\text{Current}, I = \frac{P}{V} = \frac{1000W}{250V} = 4 \text{ amps}$$

$$Z = \frac{V}{I} = \frac{250}{4} = 62.5\Omega$$

Resistors in AC Circuits Example No2

Calculate the power being consumed by a 100Ω resistive element connected across a 240v supply.

As there is only one component connected to the supply, the resistor, then VR = VS

$$\text{Current}, I = \frac{V_R}{R} = \frac{240}{100} = 2.4 \text{ amps}$$

$$\text{Power consumed}, P = I^2R = 2.4^2 \times 100 = 576W$$

Then to summarise, in a pure ohmic AC Resistance, the current and voltage are both said to be “in-phase” as there is no phase difference between them. The current flowing through the resistor is directly proportional to the voltage across it with this linear relationship in an AC circuit being called Impedance. As with DC circuits, Ohm’s Law can be used when working with resistors in AC circuits to calculate the resistors voltages, currents and power.

https://www.electronics-tutorials.ws/resistor/res_9.html

Resistor Tutorial Summary

Resistor tutorial summary listing the main points we have learnt through this tutorial section about resistors and resistance.

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 Wirewound are all types of resistors.
- Resistor colour codes are used to identify the resistance and tolerance rating of small resistors.
- The BS1852 Standard uses letters and is used to identify large size resistors.
- Tolerance is the percentage measure of the accuracy of a resistor from its preferred value with the E6 (20%), E12 (10%), E24 (5%) and E96 (1%) series of tolerance values available.

Series Resistor Tutorial

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.

$$I_{total} = I1 = I2 = I3 \ldots. \text{ etc}$$

- The total circuit resistance of series resistors is equal to:

$$R_{total} = R1 + R2 + R3 + \ldots.. Rn$$

- Total circuit voltage is equal to the sum of all the individual voltage drops.

$$V_{total} = V1 + V2 + V3 \ldots. \text{ etc}$$

- The total resistance of a series connected circuit will always be greater than the highest value resistor.

Parallel Resistor Tutorial

- 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.

$$V_S = V1 = V2 = V3 \ldots. \text{ etc}$$

- 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.

$$I_{total} = I1 + I2 + I3 \ldots. \text{ etc}$$

- The total resistance of a parallel circuit will always be less than the value of the smallest resistor.

Resistor Power Rating

- The larger the power rating, the greater the physical size of the resistor to dissipate the heat.
- All resistors have a maximum power rating and if exceeded will result in the resistor overheating and becoming damaged.
- Standard resistor power rating sizes are 1/8 W, 1/4 W, 1/2 W, 1 W, and 2 W.
- Low ohmic value power resistors are generally used for current sensing or power supply applications.
- The power rating of resistors can be calculated using the formula:

$$\text{Power (P)} = V \times I = I^2 R = \frac{V^2}{R}$$

- In AC Circuits the voltage and current flowing in a pure resistor are always “in-phase” producing 0º phase shift.
- When used in AC Circuits the AC impedance of a resistor is equal to its DC Resistance.
- The AC circuit impedance for resistors is given the symbol **Z**.

https://www.electronics-tutorials.ws/resistor/varistor.html

Varistor Tutorial

Unlike the fuse or circuit breaker which offers over-current protection, the varistor provides over-voltage protection by means of voltage-clamping in a similar way to the zener diode.

The word “Varistor” is a combination of the words VARI-able resi-STOR used to describe their mode of operation way back in their early days of development which is a little misleading since a varistor can not be manually varied like a potentiometer or rheostat.

But unlike a variable resistor whose resistance value can be manually varied between its minimum and maximum values, the varistor changes its resistance value automatically with the change in voltage across it making it a voltage-dependant, non-linear resistor or VDR for short.

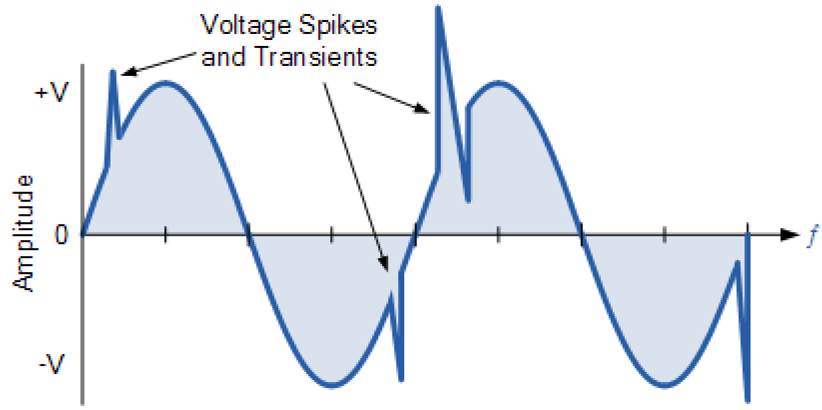
Nowadays the resistive body of a varistor is made from semiconductor material making it a type of semiconductor resistor with a non-ohmic symmetrical voltage and current characteristics suitable for both AC and DC voltage applications.

In many ways the varistor looks similar in size and design to a capacitor and is often confused as being one. However, a capacitor cannot suppress voltage surges in the same way a varistor can. When a high voltage surge is applied to a circuit, the outcome is usually catastrophic to the circuit, therefore the varistor plays an important role in the protection of delicate electronic circuits from switching spikes and over voltage transients.

Transient surges originate from a variety of electrical circuits and sources regardless of whether they operate from an AC or DC supply as they are often generated within the circuit itself or transmitted into the circuit from external sources. Transients within a circuit can rise rapidly increasing the voltage to several thousand volts, and it is these voltage spikes which must be prevented from appearing across delicate electronic circuits and components.

One of the most common sources of voltage transients is the L(di/dt) effect caused by the switching of inductive coils and transformer magnetizing currents, DC motor switching applications and surges from the switching-on of fluorescent lighting circuits or other supply surges.

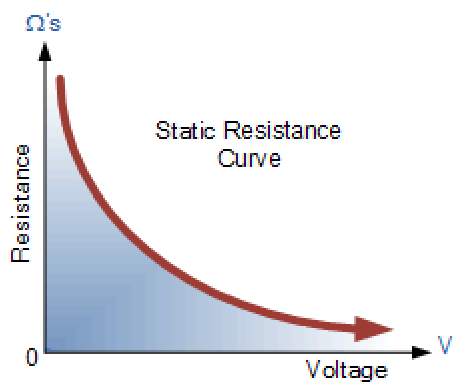
AC Waveform Transients



Varistors are connected in circuits across a mains supply either phase-to-neutral, phase-to-phase for AC operation, or positive-to-negative for DC operation and have a voltage rating to suit their application. A varistor can also be used for DC voltage stabilization and especially for electronic circuit protection against over voltage pulses.

Static Resistance

Under normal operation the varistor has a very high resistance, hence part of its name, operating in a similar way to the zener diode by allowing lower threshold voltages to pass unaffected.

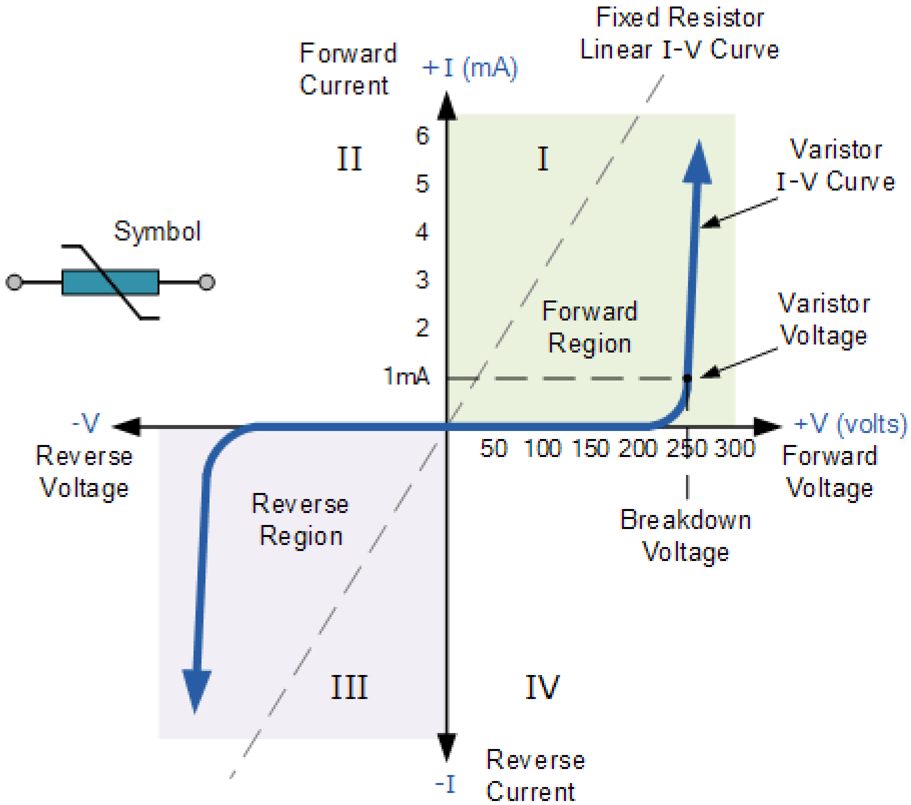


However, when the voltage across the varistor (either polarity) exceeds the varistors rated value, its effective resistance decreases strongly with an increasing voltage as shown.

We know from Ohm’s Law that the current-voltage (I-V) characteristics of a fixed resistor is a straight line provided that R is kept constant. Then the current is directly proportional to the potential difference across the ends of the resistor.

But the I-V curves of a varistor is not a straight line as a small change of voltage causes a significant change of current. A typical normalised voltage versus current characteristics curve for a standard varistor is given below.

Characteristics Curve



We can see from above, that the varistor has symmetrical bi-directional characteristics, that is the varistor operates in both directions (quadrant I and III) of a sinusoidal waveform behaving in a similar way to two zener diodes connected back-to-back. When not conducting, the I-V curve shows a linear relationship as the current flowing through the varistor remains constant and low at only a few micro-amperes of “leakage” current. This is due to its high resistance acting as an open circuit and remains constant until the voltage across the varistor (either polarity) reaches a particular “rated voltage”.

This rated or clamping voltage is the voltage across the varistor measured with the specified DC current of 1mA. That is, the DC voltage level applied across its terminals that allows a current of 1mA to flow through the varistors resistive body which itself is dependant upon the materials used in its construction. At this voltage level, the varistor begins to change from its insulating state into its conducting state.

When the transient voltage across the varistor is equal to or greater than the rated value, the resistance of the device suddenly becomes very small turning the varistor into a conductor due to the avalanche effect of its semiconductor material. The small leakage current flowing through the varistor rapidly rises but the voltage across it is limited to a level just above the varistor voltage.

In other words, the varistor self-regulates the transient voltage across it by allowing more current to flow through it and because of its steep non-linear I-V curve it can pass widely varying currents over a narrow voltage range clipping-off any voltage spikes.

Varistor Capacitance Values

Since the main conducting region of a varistor between its two terminals behaves like a dielectric, below its clamping voltage the varistor acts like a capacitor rather than resistor. Every semiconductor varistor has a capacitance value that depends directly on its area and varies inversely with its thickness.

When used in DC circuits, the capacitance of the varistor remains more or less constant provided that the applied voltage does not increase above the clamping voltage level, and drops off abruptly near towards its maximum rated continuous DC voltage.

However, in AC circuits, this capacitance can affect the body resistance of the device in the non-conducting leakage region of its I-V characteristics. As they are normally connected in parallel with an electric device to protect it against over voltages, the varistors leakage resistance drops rapidly with an increase in frequency.

This relationship is approximately linear with the frequency and the resulting parallel resistance, its AC reactance, XC can be calculated using the usual $1/(2\pi f C)$ as for a normal capacitor. Then as the frequency increases so to does its leakage current.

But as well as the silicon semiconductor based varistor, metal oxide varistors have been developed to overcome some of the limitations associated with their silicon carbide cousins.

Metal Oxide Varistor

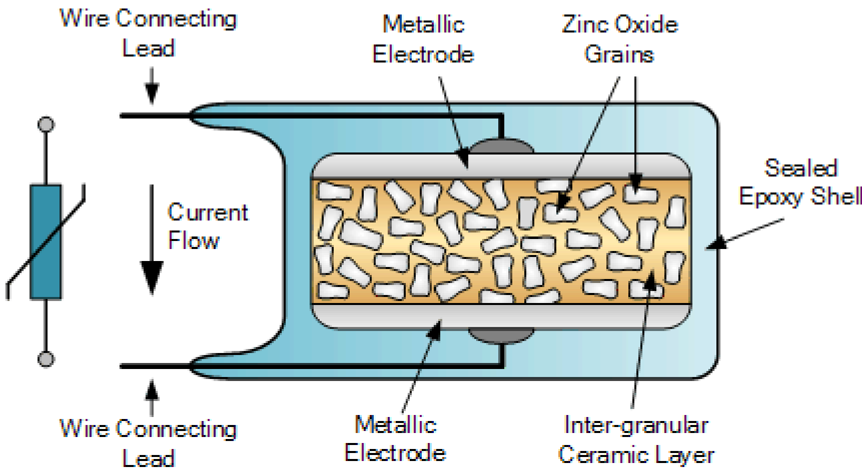
The **Metal Oxide Varistor** or **MOV** for short, is a voltage dependant resistor in which the resistance material is a metallic oxide, primarily zinc oxide (ZnO) pressed into a ceramic like material. Metal oxide varistors consist of approximately 90% zinc oxide as a ceramic base material plus other filler materials for the formation of junctions between the zinc oxide grains.

Metal oxide varistors are now the most common type of voltage clamping device and are available for use at a wide range of voltages and currents. The use of a metallic oxide within their construction means that MOV's are extremely effective in absorbing short term voltage transients and have higher energy handling capabilities.

As with the normal varistor, the metal oxide varistor starts conduction at a specific voltage and stops conduction when the voltage falls below a threshold voltage. The main differences between a standard silicon carbide (SiC) varistor and a MOV type varistor is that the leakage current through the MOV's zinc oxide material is very small current at normal operating conditions and its speed of operation in clamping transients is much faster.

MOV's generally have radial leads and a hard outer blue or black epoxy coating which closely resembles disc ceramic capacitors and can be physically mounted on circuit boards and PCB's in a similar manner. The construction of a typical metal oxide varistor is given as:

MOV Construction



To select the correct MOV for a particular application, it is desirable to have some knowledge of the source impedance and the possible pulse power of the transients. For incoming line or phase borne transients, the selection of the correct MOV is a little more difficult as generally the characteristics of the power supply are unknown. In general, MOV selection for the electrical protection of circuits from power supply transients and spikes is often little more than an educated guess.

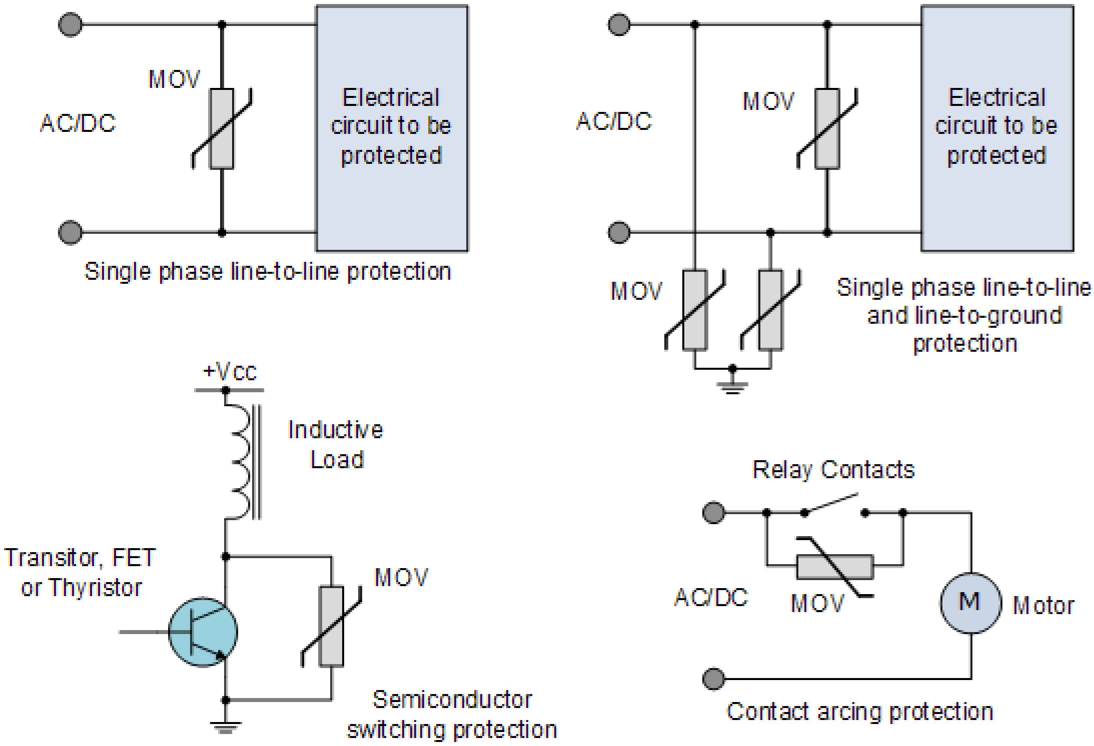
However, metal oxide varistors are available in a wide range of varistor voltages, from about 10 volts to over 1,000 volts AC or DC, so selection can be helped by knowing the supply voltage. For example, selecting a MOV or any silicon varistors for that matter, for voltage, its maximum continuous rms voltage rating should be just above the highest expected supply voltage, say 130 volts rms for a 120 volt supply, and 260 volts rms for a 230 volt supply.

The maximum surge current value that varistors will take depends on the transient pulse width and the number of pulse repetitions. Assumptions can be made upon the width of a transient pulse which are typically 20 to 50 microseconds (μs) long. If the peak pulse current rating is insufficient, then the varistor may overheat and become damaged. So for a varistor to operate without any failure or degradation, it must be able to quickly dissipate the absorbed energy of the transient pulse and return safely to its pre-pulse condition.

Varistor Applications

Varistors have many advantages and can be used in many different types of applications for the suppression of mains borne transients from domestic appliances and lighting to industrial equipment on both AC or DC power lines. Varistors can be connected directly across mains supplies and across semiconductor switches for protection of transistors, MOSFET’s and thyristor bridges.

Varistor Applications



Tutorial Summary

In this tutorial we have seen that the basic function of a **Voltage Dependant Resistor**, or **VDR**, is to protect electronic devices and electrical circuits against voltage surges and spikes, such as those generated by inductive switching transients.

As such varistors are used in sensitive electronic circuits to ensure that if the voltage does suddenly exceeds a predetermined value, the varistor will effectively become a short circuit to protect the circuit that it shunts from excessive voltage as they are able to withstand peak currents of hundreds of amperes.

Varistors are a type of resistor with a non-linear, non-ohmic current voltage characteristic and are a reliable and economical means of providing protection against over voltage transients and surges.

They achieve this by acting as a high resistance blocking device at lower voltages and as a good low resistance conducting device at higher voltages. The effectiveness of a varistor in protecting an electrical or electronic circuit depends on the proper selection of the varistor with regards to voltage, current and energy dissipation.

Metal Oxide Varistors, or MOV's are typically made from a small disk-shaped metal zinc oxide material. They are available in many values for specific voltage ranges. An MOV's voltage rating, called the "varistor voltage" is the voltage across a varistor when a current of 1mA is passed through the device. This varistor voltage level is essentially the point on the I-V characteristic curve when the device starts to conduct. Metal oxide varistors can also be connected in series to increase the clamping voltage rating.

While metal oxide varistors are widely used in many AC power electronics circuits to protect against transient over voltages, there are also other types of solid state voltage suppression devices such as diodes, zener diodes and suppressors which all can be used in some AC or DC voltage suppression applications along with **Varistors**.

https://www.electronics-tutorials.ws/resistor/resistor-colour-code-wheel.html

Resistor Colour Code Wheel

This handy and simple resistor colour code wheel can be used as a reference for finding the correct resistor colour code of any 4-band or 5-band resistor.

Resistor colour codes can sometimes be a little confusing until you understand how they work. But once you get the hang of them it becomes easier to read the values of those simple colour coded bands.

There is a lot of information both online and on this Electronics Tutorials website too, to help you read and understand how resistor colour codes work and this free, simple to use and practical resistor colour code wheel will hopefully help you on your way.

Generally, resistors are too small in size for manufacturers to print numbers and letters on them to indicate their resistive value and tolerance. Luckily for us, some bright spark somewhere invented a resistor colour coding system to make our lives easier and help us to work it out with our free resistor colour code wheel. Fixed resistors have different coloured rings or bands around them to indicate their resistive value with each coloured band having a decimal value associated with it.

There are many clear advantages to using a colour coding system on electrical and electronic components. The main advantage of using coloured rings or bands around a resistors body, is that they can be very easily seen and read no matter what the position or orientation of the resistor on a board. These coloured bands can also be read even if the resistors body is a little dirty or badly burnt.

We saw in our Ohm's Law tutorial that resistors are used to limit the amount of current flowing in a circuit so it is important to know their resistive value and depending upon the type, size and tolerance of the resistor, there can be three, four or five coloured bands used to do this.

Although these coloured bands represent nominal or ideal values, they are a good approximation of the actual resistance value. This is because the actual resistive value can have a percentage variation of resistance either side of the nominal value. This variation is called the "tolerance".

All fixed resistors have a tolerance ranging from less than a tenth of a percent, (0.1%) up to 20% for large carbon types. So a tolerance of 5, 10 and 20 percent, means that the actual value of the resistor can vary from the expected nominal value by as much as ±5, ±10, and ±20%. For example, a 100Ω resistor with a tolerance of ±10% can have a value from 90Ω (-10%) to 110Ω; (+10%). That's a variation of 20Ω and still be in tolerance.

Resistors with just three coloured bands generally have no (none) tolerance band as they have a fixed tolerance of ±20%. The first two coloured bands are the digit or number bands and the third is known as the multiplier. When there are four bands, the first two coloured bands are the digit bands, the third is the “multiplier”, with the fourth band being the “tolerance” value. On resistors with five coloured bands, the first three colours are always digit bands followed by the multiplier and tolerance bands.

Step 1 – Download and Print

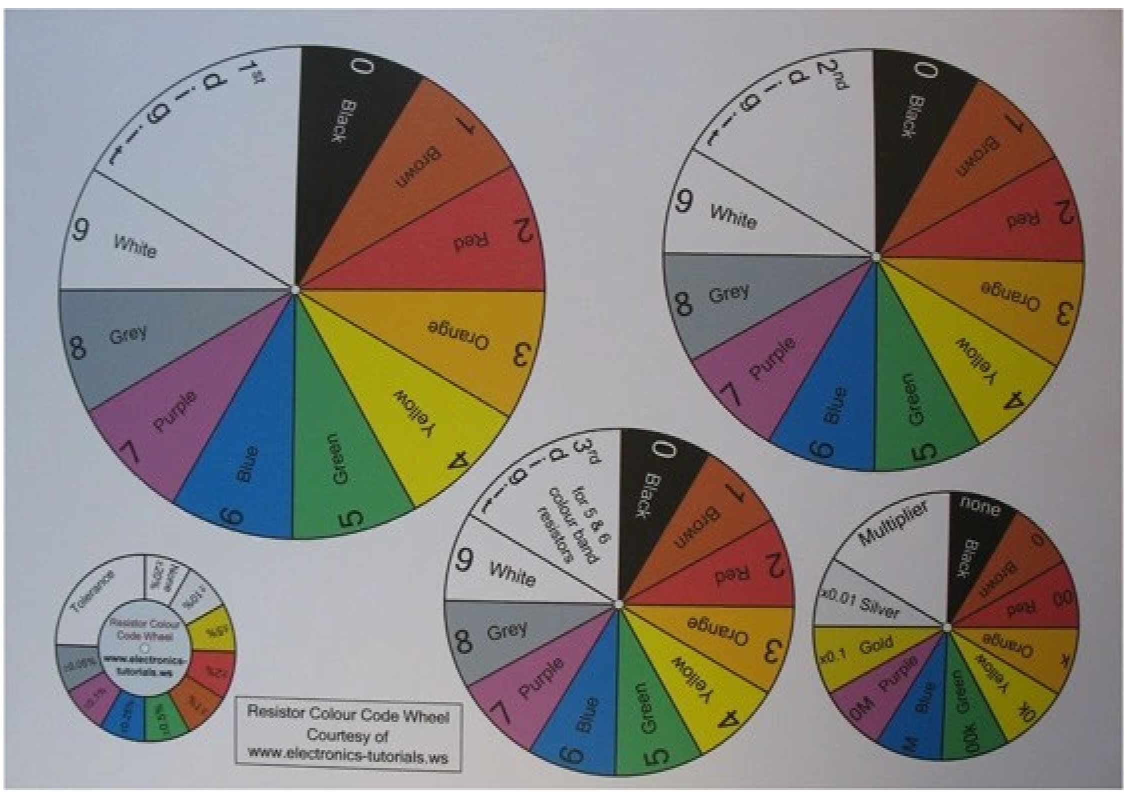
Using our simple and free resistor colour code wheel we can now make sense of all these different coloured bands and what they mean. But first things first. We need to download and print out the **Resistor Colour Code Wheel** template using the download button below. Its completely free!

Please click the button to download the related PDF file.

Note that this is a PDF (Acrobat) Document File. Please make sure that you have an application to open this file type before downloading the resistor colour code wheel template.

After you have download and printed out the resistor colour code wheel template, you should have an A4 sized paper (or whatever size you want to print out) colour wheel template looking like this:

The Resistor Colour Wheel Template

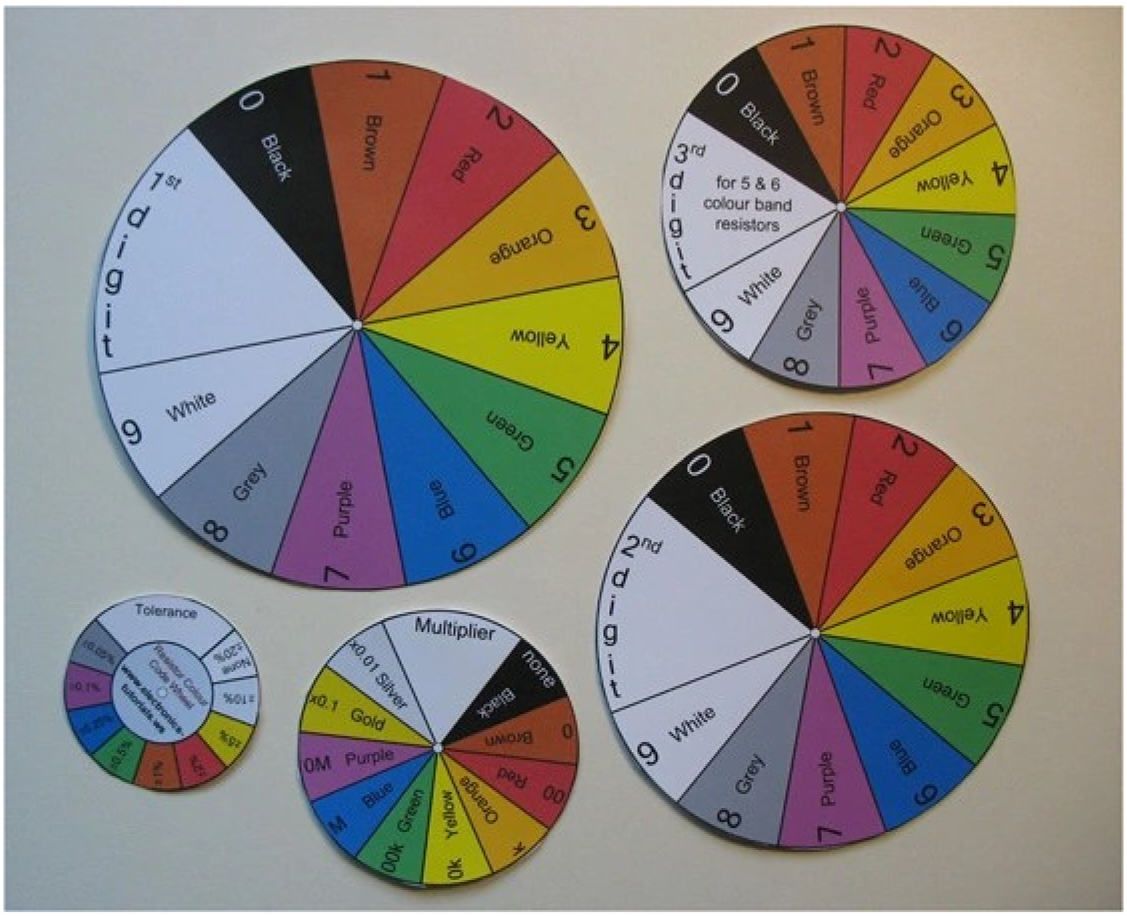


Note that you can print this resistor colour code wheel template onto any size or density (weight) of paper that you want. It all depends upon your printer and what you have. The standard A4 sized printer or office copier paper has a paper density or weight of 80 g/m^2. This standard printer paper is fine and can be used to make the resistor colour wheel.

However, being thin printing paper it can easily be torn or damaged with constant use. Then using a paper with a density of 150g/m^2 or greater, or using thin card would be a better choice and more durable. It would also be possible to laminate the template sheet after printing to both strengthen and prolong its life, the choice is yours. Anyway once you have the resistor colour code wheel template downloaded to your hard drive, you can print it out as many times as you want.

Step 2 – Cut Out the Discs

Having printed out our resistor colour code wheel template from the link above on to suitable paper, we now need to carefully cut out the five coloured discs as shown using scissors or a sharp knife.



Once we have our five coloured discs cut out we can now start to assemble them together to form the finished colour wheel design.

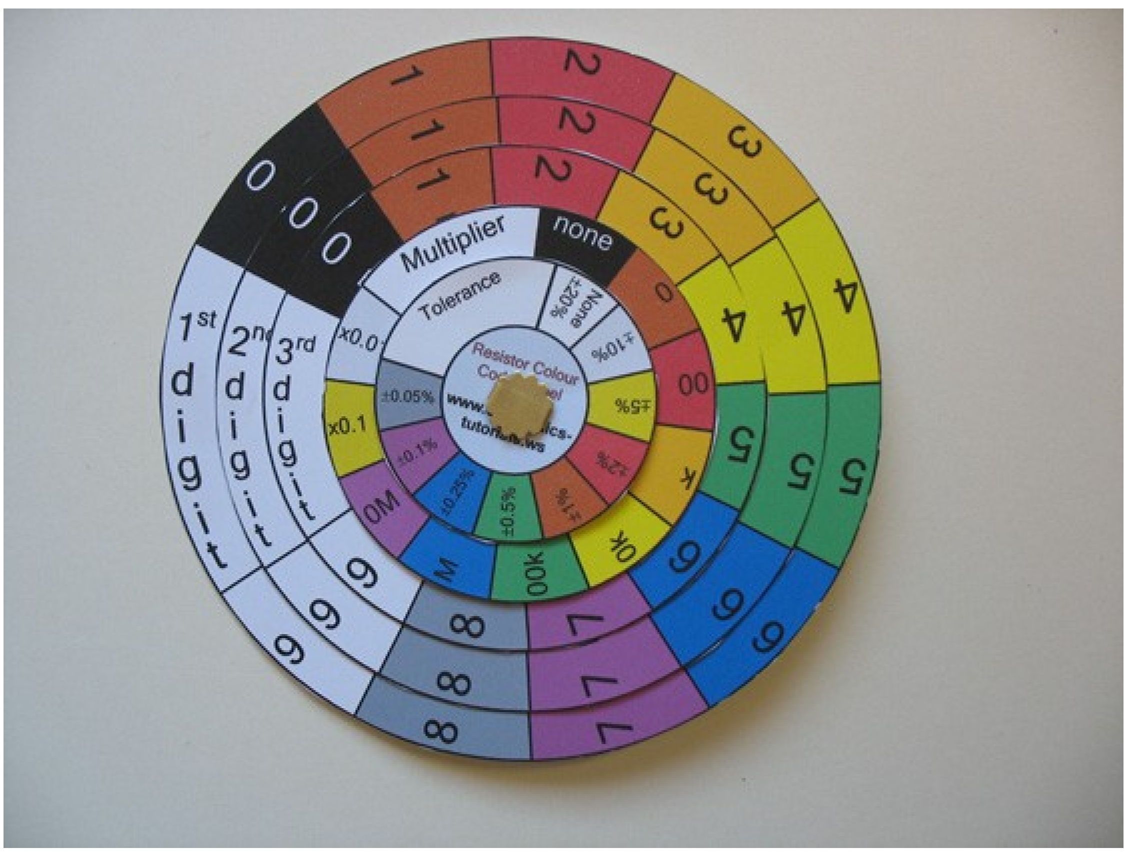
Step 3 – Assemble the Discs

In order to assemble our five individual coloured discs together to create the finished resistor colour code wheel, we need to use a brass paper fastener like the ones shown or something similar that you may have easily available.

Carefully poke or make a hole through the center of each wheel using a pin, needle, compass point, knife or any other sharp object you have, being careful not to cut yourself in the process. The hole you make needs to be the same diameter as the brass paper fasteners. Make sure that the hole you make is big enough to both insert and rotate the paper fastener, or whatever you decide to use. In my case the hole was about 4mm (5/32″) in diameter.

Insert the paper fastener through each hole in turn, starting with the smallest disc and working upwards making sure that each disc is free to rotate as you assemble. Once complete bend the fasteners tabs over at the back of the larger disc. You should now have an assembled resistor colour code wheel that looks something like this.

Assembled Resistor Colour Code Wheel



Step 4 – Using the Colour Wheel

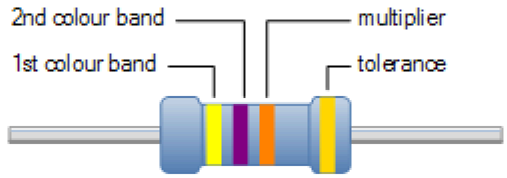
Now that we have assembled our *resistor colour code wheel* its time to start using it. In the following examples we are going to use it to find the values of a 4-band and a 5-band resistor. But first we will define what each coloured disc is in relationship to the meaning of the coloured bands on a resistors body.

- Disc One (1st Digit) – This is for the first coloured band closest to the end of the resistor on the left hand side and represents the first digit of the resistors value.
- Disc Two (2nd Digit) – This is for the second coloured band along representing the second digit of the resistors value.
- Disc Three (3rd Digit) – This is used for metal film resistors which use a five and six-band colour code for more precise values. In this case the first three coloured bands indicate the first three numerical digits. For a three or four band colour coded resistor this 3rd digit can be ignored.
- Disc Four (the multiplier) – The next coloured band is the mathematical multiplier which represents the number of zeros to be added to the first two (or three) digits. If the third colour, for a 4-band resistor or the fourth colour, for a 5-band resistor, is either gold or silver, this represents a fractional decimal multiplier as the resistive value is less than 10Ω. If the coloured band is Gold, multiply the first two or three digits by 0.1 (divide-by 10) and if the coloured band is Silver multiply by 0.01 (divide-by 100).
- Disc Five (the tolerance) – The final coloured band represents the tolerance of the resistor. A Gold band indicates a tolerance of ±5% while a Silver band indicates a tolerance of ±10%. If there is no coloured band as in a three band resistor, then the tolerance is ±20%.

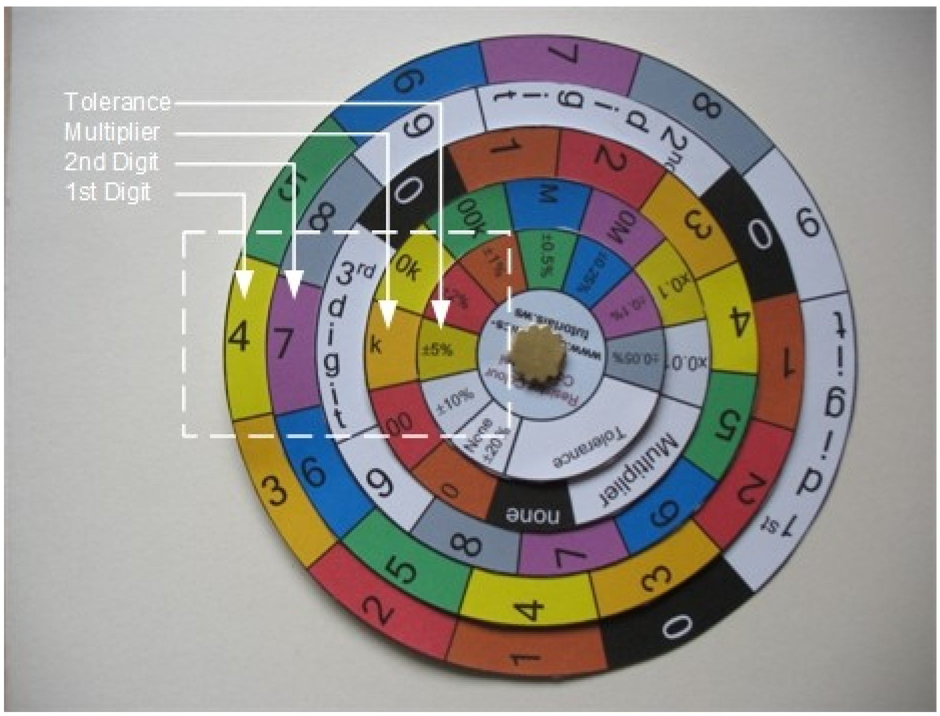
Note that a resistor can have 3, 4 or 5 coloured bands to indicate its resistive value. The coloured bands that are grouped, or closer together on one side of the resistors body indicate the resistive value of the resistor and you should start here reading from left to right. A single coloured band separate from the group and on its own will be the tolerance value.

In this first example, we are going to use the resistor colour code wheel we have just made to find the resistive value of the following 4-band resistor which is used for most resistors.

4-band Resistor Colour Code



The coloured bands are shown as: YELLOW , VIOLET, ORANGE and GOLD. Then the resistance using the colour wheel is found as:



As this is a 4-band resistor and the resistor colour code wheel can be used to find the resistive values of 5-band resistors, then the 3rd digit wheel is not used in this case. Then the colour code wheel shows:

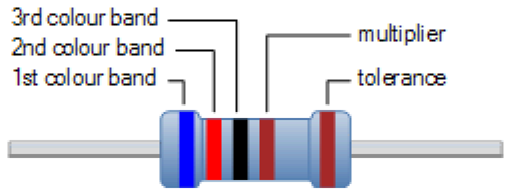
The first colour band (Yellow) gives the first digit value of 4. The second colour band (Violet) gives the second digit value of 7. This gives a two digit value of 47. Multiply this by the value of the third band. In this case, Orange which has a value of 1000 or 1k, so the resistor has a resistive value of 47,000 ohms (47 × 1000 = 47000) or 47kΩ. The last band gives the resistors tolerance value and Gold equals a tolerance range of ±5%.

Then using the resistor colour wheel, the resistor has the following resistance:

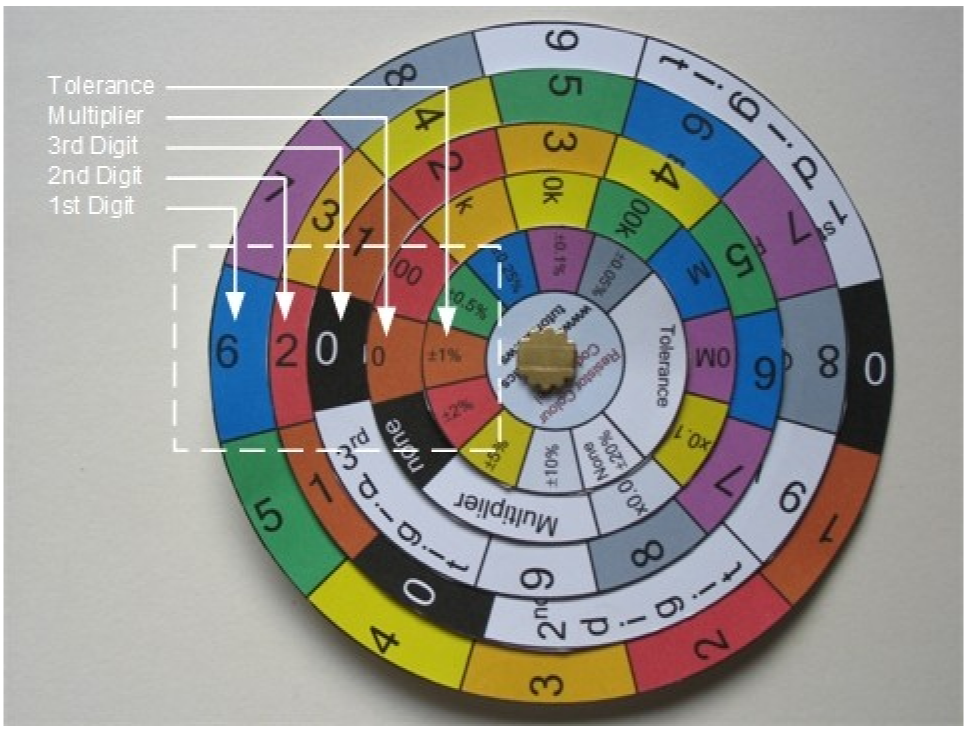
Yellow Violet Orange = 4 7 3 = 4 7 x 103 = 47000Ω or 47kΩ ±5%.

In this second example, we will use it to find the value of the following 5-band resistor. Five band colour codes are used to provide more precise values in precision metal-film resistors with lower tolerances.

5-band Resistor Colour Code



The coloured bands are shown as: BLUE, RED, BLACK, BROWN and BROWN. Then the resistance using the colour wheel is found as:



As this is a 5-band resistor, all the discs of the resistor colour code wheel can be used to find the resistive value. Then the colour code wheel shows:

The first colour band (Blue) gives the first digit value of 6. The second colour band (Red) gives the second digit value of 2. The third colour band (Black) gives the third digit value of 0. This gives a three digit value of 620. We now multiply this by the value of the fourth band, Brown which has a value of 10. So the resistor has a resistive value of 6200 ohms (620 × 10 = 6200) or 6k2Ω. The last band gives the resistors tolerance value and Brown equals a tolerance range of ±1%.

Then using the resistor colour wheel, the resistor has the following resistance:

Blue Red Black Brown = 6 2 0 0 = 6 2 0 x 10 = 6200Ω or 6k2Ω ±1%.

So there you have it, a fun little project to do at home for use at school or the science lab, just download, print and cut out to give you a very useful reference tool for finding the resistive values of 4 or 5-band resistors using this free and simple **Resistor Colour Code Wheel**.

This resistor colour code wheel is simple to use, just position the colours of the discs and read off the number its that easy and simple, and for checking the value of more resistors, just rotate the coloured discs and you will get another colour scheme. But remember, if you are still unsure of a resistors value, you can always find its resistance using a multimeter or check out our **Resistor Colour Codes** tutorial.

You can still download the related PDF file here:

Have fun making it, using it and sharing it, and let me know what you think. Enjoy https://www.electronics-tutorials.ws/resistor/potentiometer.html

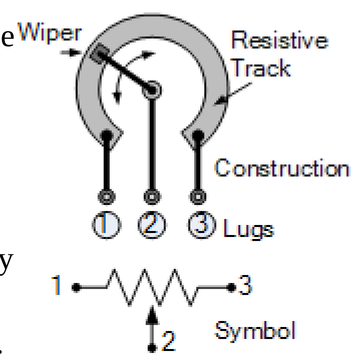
Potentiometers

Resistors provide a fixed value of resistance that blocks or resists the flow of electrical current around a circuit, as well as producing a voltage drop in accordance with Ohm's law. Resistors can be manufactured to have either a fixed resistive value in Ohms or as a potentiometer which can be adjusted by some external means.

The **potentiometer**, commonly referred to as a "pot", is a three-terminal mechanically operated rotary analogue device which can be found and used in a large variety of electrical and electronic circuits. They are passive devices, meaning they do not require a power supply or additional circuitry in order to perform their basic linear or rotary position function.

Variable potentiometers are available in a variety of different mechanical variations allowing for easy adjustment to control a voltage, current, or the biasing and gain control of a circuit to obtain a zero condition.

The name "potentiometer" is a combination of the words *Potential Difference* and *Metering*, which came from the early days of electronics development. It was thought then that adjusting large wirewound resistive coils metered or measured out a set amount of potential difference making it a type of *voltage-metering device*.



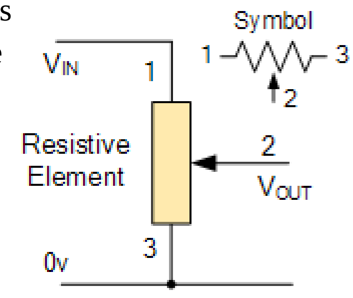
Today, potentiometers are much smaller and much more accurate than those early large and bulky variable resistances, and as with most electronic components, there are many different types and names ranging from variable resistor, preset, trimmer, rheostat and of course variable potentiometer.

But whatever their name, these devices all function in exactly the same way in that their output resistance value can be changed or varied by the movement of a mechanical contact or wiper given by some external action.

Variable resistors in whatever format, are generally associated with some form of control, whether that is adjusting the volume of a radio, the speed of a vehicle, the frequency of an oscillator or accurately setting the calibration of a circuit, single-turn and multiple-turn potentiometers, trim-pots and rheostats find many uses in everyday electrical items.

The term potentiometer and variable resistor are often used together to describe the same component, but it is important to understand that the connections and operation of the two are different. However, both share the same physical properties in that the two ends of an internal resistive track are brought out to contacts, in addition to a third contact connected to a moveable contact called the "slider" or "wiper".

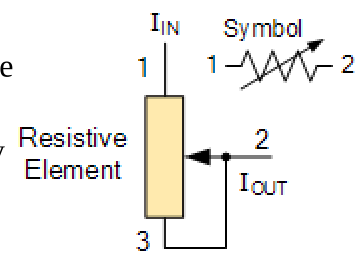
Potentiometer



When used as a potentiometer, connections are made to both ends as well as the wiper, as shown. The position of the wiper then provides an appropriate output signal (pin 2) which will vary between the voltage level applied to one end of the resistive track (pin 1) and that at the other (pin 3).

The potentiometer is a three-wire resistive device that acts as a voltage divider producing a continuously variable voltage output signal which is proportional to the physical position of the wiper along the track.

Variable Resistor



When used as a variable resistor, connections are made to only one end of the resistive track (either pin 1 or pin 3) and the wiper (pin 2) as shown. The position of the wiper is used to vary or change the amount of effective resistance connected between itself, the movable contact, and the stationary fixed end.

Sometimes it is appropriate to make an electrical connection between the unused end of the resistive track and the wiper to prevent open-circuit conditions.

Then a variable resistor is a two-wire resistive device that provides an infinite number of resistance values controlling the current offered to the connected circuit in proportion to the physical position of the wiper along the track. Note that a variable resistor used to control very high circuit currents found in lamp or motor loads are called Rheostats.

Potentiometer Types

Variable potentiometers are an analogue device consisting basically of two main mechanical parts:

1. An electrical part that consists of a fixed or stationary resistive element, track or wire coil which defines the potentiometers resistive value, such as 1kΩ (1000 ohms), 10kΩ (10000 ohms), etc.
2. A mechanical part which allows a wiper or contact point to move along the whole length of the resistive track from one end to the other changing its resistive value as it moves.

There are many different ways to move the wiper across the resistive track either mechanically or electrically.

But as well as the resistive track and wiper, potentiometers also comprise of a housing, a shaft, slider block, and a bush or bearing. The movement of the sliding wiper or contact can itself be a rotatory (angular) action or a linear (straight) action. There are four basic groups of variable potentiometer.

Rotary Potentiometer

Rotary potentiometer (the most common type) vary their resistive value as a result of an angular movement. Rotating a knob or dial attached to the shaft causes the internal wiper to sweep around a curved resistive element. The most common use of a rotary potentiometer is the volume-control pot.

Carbon rotary potentiometers are designed to be mounted onto the front panel of a case, enclosure or printed circuit board (PCB) using a ring nut and locking washer. They can also have one single resistive track or multiple tracks, known as a ganged potentiometer that all rotate together using one single shaft. For example, a dual-gang pot to adjust the left and right volume control of a radio or stereo amplifier at the same time. Some rotary pots include on-off switches.

Rotary potentiometers can produce a linear or logarithmic output with tolerances of typically 10 to 20 percent. As they are mechanically controlled, they can be used to the measure the rotation of a shaft, but a single-turn rotary potentiometer normally offers less than 300 degrees of angular movement from minimum to maximum resistance. However, multi-turn potentiometers, called trimmers, are available that allow for a higher degree of rotational accuracy.

Multi-turn potentiometers allow for a shaft rotation of more than 360 degrees of mechanical travel from one end of the resistive track to the other. Multi-turn pots are more expensive, but very stable with high precision used mainly for trimming and precision adjustments. The two most common multi-turn potentiometers are the 3-turn (1080^o) and 10-turn (3600^o), but 5-turn, 20-turn and higher 25-turn pots are available in a variety of ohmic values.

Slider Potentiometer

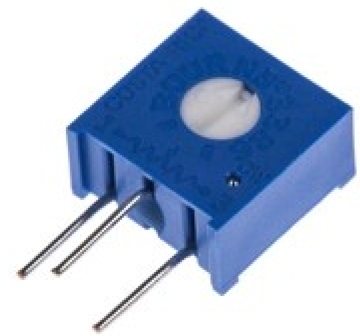
Slider potentiometers, or slide-pots, are designed to change the value of their contact resistance by means of a linear motion and as such there is a linear relationship between the position of the slider contact and the output resistance.

Slide potentiometers are mainly used in a large range of professional audio equipment such as studio mixers, faders, graphic equalizers and audio tone control consoles allowing the users to see from the position of the plastic square knob or finger-grip the actual setting of the slide.

One of the main disadvantages of a slider potentiometer is that they have a long open slot to allow the wiper lug to move freely up and down along the full length of the resistive track. This open slot makes the resistive track inside susceptible to contamination from dust and dirt, or by sweat and grease from the users hands. Slotted felt covers and screens can be used to minimise the effects of resistive track contamination.

As the potentiometer is one of the simplest ways of converting a mechanical positional into a proportional voltage, they can also be used as resistive position sensors, also known as a linear displacement sensor. Sliding carbon track potentiometers measure a precise linear (straight) motion with the sensor part of a linear sensor being the resistive element attached to a sliding contact. This contact is in turn attached via a rod or shaft to the mechanical mechanism to be measured. Then the position of the slide changes with respect to the quantity being sensed (the measurand) which in turn changes the resistive value of the sensor.

Presets and Trimmer’s



Preset or trimmer potentiometers are small “set-and-forget” type potentiometers that allow for very fine or occasional adjustments to be easily made to a circuit, (e.g. for calibration). Single-turn rotary preset potentiometers are miniature versions of the standard variable resistor designed to be mounting directly on a printed circuit board and are adjusted by means of a small bladed screwdriver or similar plastic tool.

Generally, these linear carbon track preset pots are of an open skeleton design or of a closed square shape that once the circuit is adjusted and factory set, are then left at this setting, being only adjusted again if some changes occur to the circuit settings.

Being of an open construction, skeleton preset’s are prone to mechanical and electrical degradation affecting the performance and accuracy so are therefore not suitable for continuous use, and as such, preset pots are only mechanically rated for a few hundred operations. However, their low cost, small size and simplicity makes them popular in non-critical circuit applications.

Presets can be adjust from its minimum to maximum value within a single turn, but for some circuits or equipment this small range of adjustment may be too coarse to allow for very sensitive adjustments. Multi-turn variable resistors however, operate by moving the wiper arm using a small screwdriver some number of turns, ranging from 3 turns to 20 turns enabling very fine adjustments.

Trimmer potentiometers or “trim pots” are multi-turn rectangular devices with linear tracks that are designed to be installed and soldered directly onto a circuit board either through-hole or as surface-mount. This gives the trimmer both electrical connections and mechanical mounting and encasing the track within a plastic housing avoids the problems of dust and dirt during use associated with skeleton presets.

Rheostats

Rheostats are the big boys of the potentiometer world. They are two connection variable resistors configured to provide any resistive value within their ohmic range to control the flow of current through them.

While in theory, any variable potentiometer can be configured to operate as a rheostat, generally rheostats are large high wattage, wire-wound variable resistors, used in high current applications as the main advantage of the rheostat is their higher power rating.

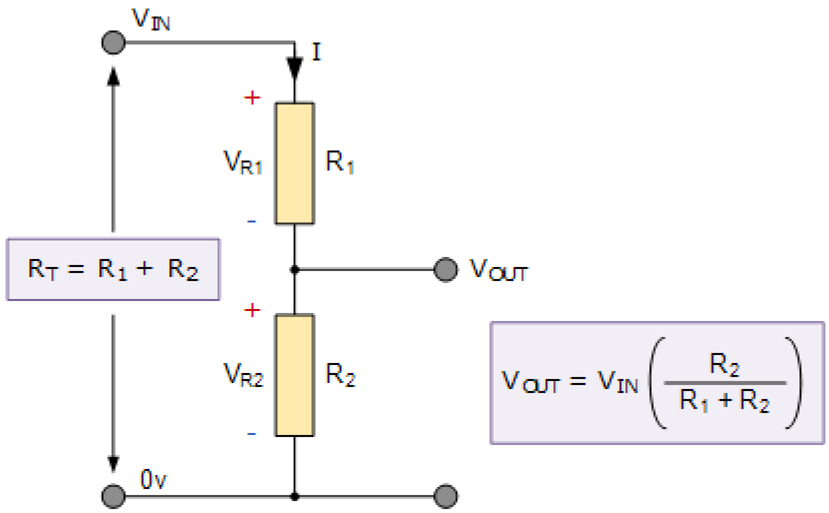
When a variable resistor is used as a two-terminal rheostat, only the portion of the total resistive element that is in between the end terminal and the movable contact will be dissipating power. Also, unlike the potentiometer configured as a voltage divider, all the current flowing through the rheostats resistive element also passes through the wiper circuit. Then the contact pressure of the wiper on this conductive element must be capable of carrying the same current.

Potentiometers are available in various technologies such as: carbon film, conductive plastic, cermet, wirewound, etc. The rating or “resistive” value of a potentiometer or variable resistor relates to the resistive value of the entire stationary resistance track from one fixed terminal to the other. So a potentiometer with a rating of 1kΩ will have a resistive track equal to the value of a 1kΩ fixed resistor.

In its simplest form, the electrical operation of a potentiometer can be considered the same as for two resistors in series with the sliding contact varying the values of these two resistors allowing it to be used as a voltage divider.

In our tutorial about Resistors in Series, we saw that the same current flows through the series circuit, since there is only one path for the current to follow, and that we can apply Ohm’s Law to find the voltage drops across each resistor in the series chain. Then a series resistive circuit acts as a voltage divider network as shown.

Voltage Divider Series Circuit

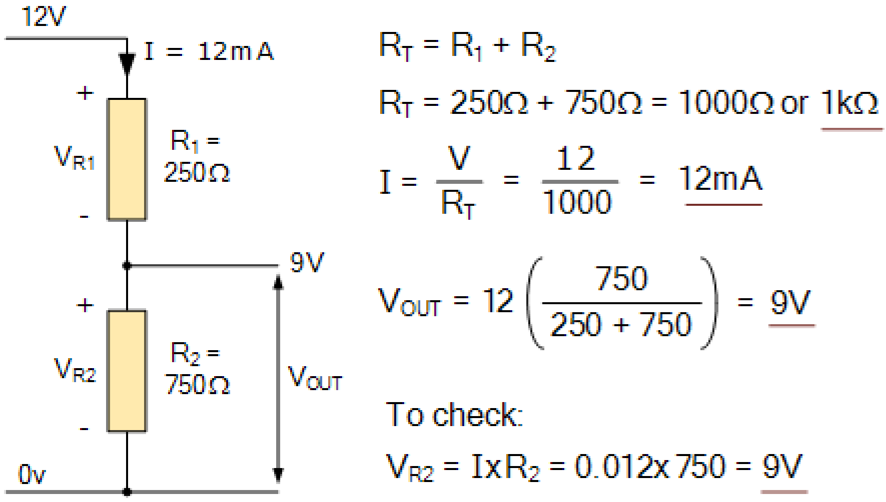


In this example above, the two resistors are connected together in series across the supply. As they are in series, the equivalent or total resistance, RT is therefore equal to the sum of the two individual resistors, that is: R1 + R2.

Also being a series network, the same current flows through each resistor as it has nowhere else to go. However, the voltage drop given across each resistor will be different due to the different ohmic values of the resistors. These voltage drops can be calculated using Ohm's Law with their sum equal to the supply voltage across the series chain. So here in this example, VIN = VR1 + VR2.

Potentiometer Example No1

A resistor of 250 ohms is connected in series with a second resistor of 750 ohms so that the 250 ohm resistor is connected to a supply of 12 volts and the 750 ohm resistor is connected to ground (0v). Calculate the total series resistance, the current flowing through the series circuit and the voltage drop across the 750 ohm resistor.

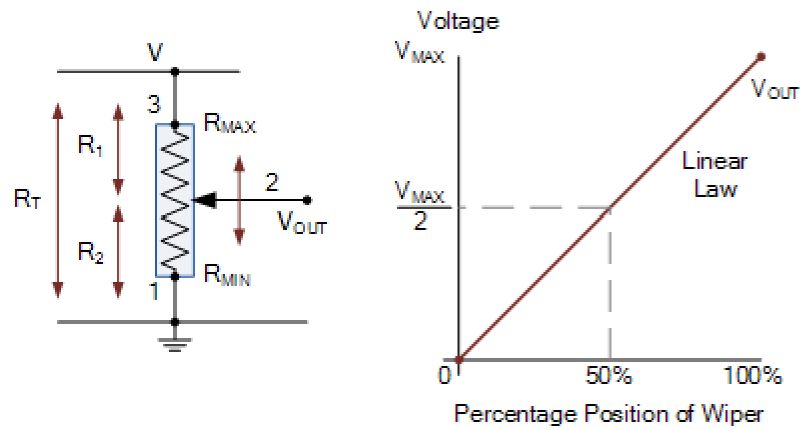


In this simple voltage divider example, the voltage developed across R2 was found to be 9 volts. But by changing the value of any one of the two resistors, the voltage can in theory be any value between 0V and 12V. This idea of a two resistor series circuit in which we can change the value of either resistor to obtain a different voltage output is the basic concept behind the operation of the potentiometer.

The difference this time with the potentiometer is that to obtain different voltages at the output, the total resistance, RT value of the potentiometer resistive track does not change, only the ratio of the two resistances formed either side of the wiper as it moves.

Thus the potentiometers movable wiper provides an output which varies between the voltage at one end of the track and that at the other, usually between maximum and zero respectively as shown.

Potentiometer as a Voltage Divider



When the potentiometer resistance is decreased (the wiper moves downwards) the output voltage from pin 2 decreases producing a smaller voltage drop across R2. Likewise, when the potentiometer resistance is increased (the wiper moves upwards) the output voltage from pin 2 increases producing a larger voltage drop. Then the voltage at the output pin depends upon the position of the wiper with this voltage drop value subtracted from the supply voltage.

Potentiometer Example No2

A 270o single-turn 1.5kΩ carbon track rotary potentiometer is required to provide a 6 volt supply from a 9 volt battery. Calculate, 1. the angular position of the wiper on the track in degrees and, 2. the values of the resistances either side of the wiper.

1. Angular position of pots wiper:

$$\theta = \frac{V_{OUT}}{V_{IN}} = \frac{6}{9} = 0.667$$

$$\therefore\ 270^{o} \times 0.667 = 180^{o}$$

Then the wipers angular position is 180^{o} or $2/3^{rds}$ rotation.

2. Potentiometer Resistance Values:

$$R_T = 1.5k\Omega \quad \text{and} \quad \theta = 0.667$$

$$\therefore R_2 = R_T \times \theta = 1500 \times 0.667 = 1000\Omega$$

$$R_1 = R_T - R_2 = 1500 - 1000 = 500\Omega$$

Then the resistive values either side of the wiper are R1 = 500Ω and R2 = 1000Ω. We can also confirm that these values are correct by using the voltage divider formula from above:

$$V_{OUT} = V_{IN}\left(\frac{R_2}{R_1 + R_2}\right)$$

$$V_{OUT} = 9\left(\frac{1000}{500 + 1000}\right) = 6\ \text{Volts}$$

Then we can see that when used as a variable voltage divider, the output voltage will be some percentage value of the input voltage with the amount of output voltage being proportional to the physical position of the movable wiper with respect to one end terminal. So for example, if the resistance from one end terminal to the wiper is 30% of the total, then the output voltage at the wiper pin across that section will be 30% of the voltage across the potentiometer, and this condition will always be true for linear potentiometers.

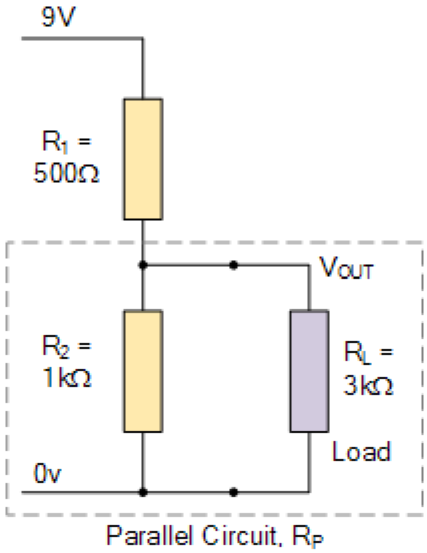
Loading the Wiper

In the simple voltage divider example above, we have calculated the values for R1 and R2 as 500Ω and 1000Ω respectively, to produce a voltage at the wiper terminal (pin 2) of 6 volts with a wiper angular position of 180o. We have assumed here that the potentiometer is unloaded and producing a linear straight line output, so V_{OUT} = θVIN.

However, if we were to load the wiper terminal by connecting a resistive load, RL, the output voltage would no longer be 6 volts as the load resistor, RL is effectively in parallel with R2, the lower 1000Ω part, and thus affects the total resistive value of the load part of the voltage divider network.

Consider what would happen if we connected a 3kΩ load resistance to the wipers output terminals.

Loaded Potentiometer Wiper



$$R_P = \frac{R_2 \times R_L}{R_2 + R_L}$$

$$R_P = \frac{1000 \times 3000}{1000 + 3000} = \underline{750\Omega}$$

$$V_{OUT} = 9\left(\frac{750}{500 + 750}\right) = \underline{5.4V}$$

So we can see that by connecting a load across the terminals of the potentiometers output, the voltage has decreased in this example, from the required 6 volts to just 5.4 volts as the loading effect of the 3kΩ resistor gives a parallel equivalent resistance, R_P of 750Ω instead of the original 1kΩ.

Obviously, the higher or lower the resistance of the connected load the greater or lesser the loading effect on the wiper. So a load resistance in the mega-ohms range would have very little effect compared to one that was just a few ohms in value. Thus, to return the output voltage back to the original 6 volts would require a small adjustment of the potentiometer wiper position (18º in this case) as now R_T is equal to 1250Ω (500 + 750).

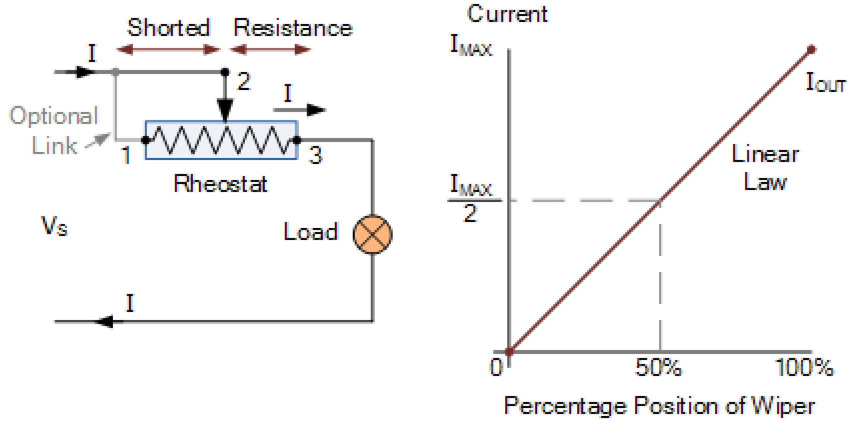
The Rheostat

Thus far we have seen that a variable resistor can be configured to operate as a voltage divider circuit which is given the name of potentiometer. But we can also configure a variable resistor to regulate a current, and this type of configuration is commonly known as a **Rheostat**.

Rheostats are two-terminal variable resistors which are configured to use one end terminal and the wiper terminal only. The unused end terminal can be either left unconnected or connected directly to the wiper. They are wirewound devices which contain tight coils of heavy duty enamelled wire that changes resistance in step-like increments. By changing the position of the wiper on the resistive element, the amount of resistance can be increased or decreased thereby controlling the amount of current.

Then the rheostat is used to control a current by changing the value of its resistance making it a true variable resistor. The classic example of the use of a rheostat is in the speed control of a model train set or Scalextric were the amount of current that passes through the rheostat is governed by Ohm’s Law. Then rheostats are defined not only by their resistive values but also by their power handling capabilities as $P = I^2 * R$.

Rheostat as a Current Regulator



In the diagram above, the effective resistance of the rheostat is between end terminal pin 3 and the wiper at pin 2. If pin 1 is left unconnected, the resistance of the track between pin 1 and pin 2 is open-circuited and has no effect on the value of the load current. Conversely, if pin 1 and pin 2 are connected together, then that part of the resistive track is short-circuited, and again has no effect on the value of the load current.

As rheostats control a current, then by definition they should be suitably rated to handle that continuous load current. It is possible to configure a three-terminal potentiometer as a two-terminal rheostat, but the carbon based resistive track may not be able to pass the load current. Also the wiper contact of a potentiometer is normally the weakest point so its best to draw as little current through the wiper as possible.

Note however that the rheostat is not suitable for controlling a load current if the load resistance, R_L is much higher than the full value of the rheostat resistance. That is $R_L >> R_{RHEO}$. The resistive value of the load resistance must be much lower than that of the rheostat to allow load current to flow.

Generally rheostats are high-wattage electro-mechanical variable resistors used for power applications and whose resistance element is usually made of thick resistance wire suitable to carry the maximum current, I when its resistance, R is minimum.

Wirewound rheostats are mainly used in power control applications such as in lamp, heater or motor control circuits to regulate the field currents for speed control or the starting current of DC motors, etc. There are many types of rheostat but the most common are the rotary toroidal types which use an open construction for cooling, but enclosed types are also available.

Slider Rheostat

Tubular slider rheostats are of the types found in physics labs and science laboratories in schools and colleges. These linear or slide types use resistive wire wound around an insulating tubular former or cylinder. The sliding contact (pin 2) mounted above, is manually adjusted left or right to increase or decrease the rheostats effective resistance as shown.

As with rotary potentiometers, multi-gang type slider rheostats are also available. In some types, fixed electrical connections are made to the resistive wire to give a fixed value of resistance between any two terminals. Such intermediate connections are generally known as “tappings”, the same name as those used on transformers.

Linear or Logarithmic Potentiometers

The most popular type of variable resistor and potentiometer is the linear type, or linear taper, whose resistive value at pin 2 varies linearly when adjusted producing a characteristics curve that represents a straight line. That is the resistive track has the same change of resistance per angle of rotation along the whole length of the track.

So if the wiper is rotated 20% of its total travel, then its resistance is 20% of maximum, or minimum. This is mainly because their resistive track element is made from carbon composites, ceramic-metal alloys or conductive plastics type materials which have a linear characteristic across their whole length.

But the resistance element of a potentiometer may not always produce a straight line characteristic or have a linear change in resistance across its whole range of travel as the wiper is adjusted, but instead can produce what is called a logarithmic change in resistance.

Logarithmic potentiometers are basically very popular non-linear or non-proportional types of potentiometers whose resistance that varies logarithmically. Logarithmic or “log” potentiometers are commonly used as volume and gain controls in audio applications where the attenuation changes as a logarithmic ratio in decibels. This is because the sensitivity to sound levels of human ear has a logarithmic response and is therefore non-linear.

If we where to use a linear potentiometer to control the volume, it would give the impression to the ear that most of the volume adjustment was restricted to one end of the pots track. The logarithmic potentiometer however, gives the impression of a more even and balanced volume adjustment across the full rotation of the volume control.

So the operation of a logarithmic potentiometers when adjusted is to produce an output signal which closely matches the nonlinear sensitivity of the human ear making the volume level sound as though it is increasing linearly. However, some cheaper logarithmic potentiometers are more exponential in resistance changes rather than logarithmic but are still called logarithmic because their resistive response is linear on a log scale. As well as logarithmic potentiometers, there are also anti-logarithmic potentiometers in which their resistance quickly increases initially but then levels off.

All potentiometers and rheostats are available in a choice of different resistive tracks or patterns, known as laws, being either linear, logarithmic, or anti-logarithmic. These terms are more commonly abbreviated to lin, log, and anti-log, respectively.

The best way to determine the type, or law of a particular potentiometer is to set the pots shaft to the center of its travel, that is about half way, and then measure the resistance across each half from wiper to end terminal. If each half has more or less equal resistance, then it’s a Linear Potentiometer. If the resistance appears to be split at about 90% one way and 10% the other then chances are it’s a Logarithmic Potentiometer.

Potentiometer Summary

In this tutorial about potentiometers, we have seen that a potentiometer or variable resistor basically consists of a resistive track with a connection at either end and a third terminal called the wiper with the position of the wiper dividing the resistive track. The position of the wiper on the track is adjusted mechanically by rotating a shaft or by using a screwdriver.

Variable resistors can be categorised into one of two operational modes – the variable voltage divider or the variable current rheostat. The potentiometer is a three terminal device used for voltage control, while the rheostat is a two terminal device used for current control.

We can summarise this in the following table:

Type	Potentiometer	Rheostat
Number of Connections	Three Terminals	Two Terminals
Number of Turns	Single and Multi-turn	Single-turn Only
Connection Type	Connected Parallel with a Voltage Source	Connected in Series with the Load
Quantity Controlled	Controls Voltage	Controls Current
Type of Taper Law	Linear and Logarithmic	Linear Only

Then the potentiometer, trimmer and rheostat are electromechanical devices designed so that their resistance values can be easily changed. They can be designed as single-turn pots, presets, slider pots, or as multi-turn trimmers. Wirewound rheostats are mainly used to control an electrical current.

Potentiometers and rheostats are also available as multi-gang devices and can be classified as having either a linear taper or a logarithmic taper.

Either way, potentiometers can provide highly precise sensing and measurement for linear or rotary movement as their output voltage is proportional to the wipers position. The advantages of potentiometers include low cost, simple operation, lots of shapes, sizes and designs and can be used in a vast array of different applications.

However as mechanical devices, their disadvantages include eventual wear-out of the sliding contact wiper and/or track, limited current handling capabilities (unlike Rheostats), electrical power restrictions and rotational angles that are limited to less than 270 degrees for single turn pots.

https://www.electronics-tutorials.ws/resistor/resistivity.html

Resistivity

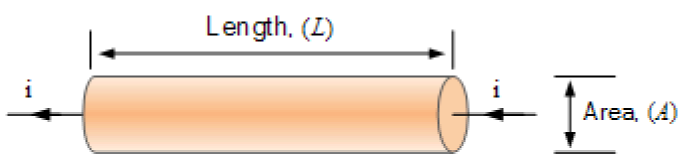
Ohms Law states that when a voltage (V) source is applied between two points in a circuit, an electrical current (I) will flow between them encouraged by the presence of the potential difference between these two points. The amount of electrical current which flows is restricted by the amount of resistance (R) present. In other words, the voltage encourages the current to flow (the movement of charge), but it is resistance that discourages it.

We always measure electrical resistance in Ohms, where Ohms is denoted by the Greek letter Omega, Ω. So for example: 50Ω, 10kΩ or 4.7MΩ, etc. Conductors (e.g. wires and cables) generally have very low values of resistance (less than 0.1Ω), so for circuit analysis calculations we can assume that wires have zero resistance and neglect them from our calculations.

Insulators (e.g. plastic or air) on the other hand generally have very high values of resistance (greater than 50MΩ), therefore we can ignore them also for circuit analysis as their value is far too high.

But the electrical resistance between two points can depend on many factors such as the conductors length, its cross-sectional area, the temperature, as well as the actual material from which it is made. For example, let's assume we have a piece of wire (a conductor) that has a length *L*, a cross-sectional area *A* and a resistance *R* as shown.

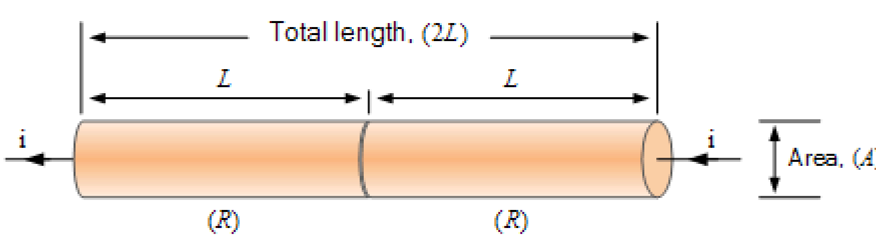
A Single Conductor



Resistance equals: *R*

The electrical resistance, R of this simple conductor is a function of its length, L and the conductors area, A. Ohms law tells us that for a given resistance R, the current flowing through the conductor is proportional to the applied voltage as I = V/R. Now suppose we connect two identical conductors together in a series combination as shown.

Doubling the Length of a Conductor



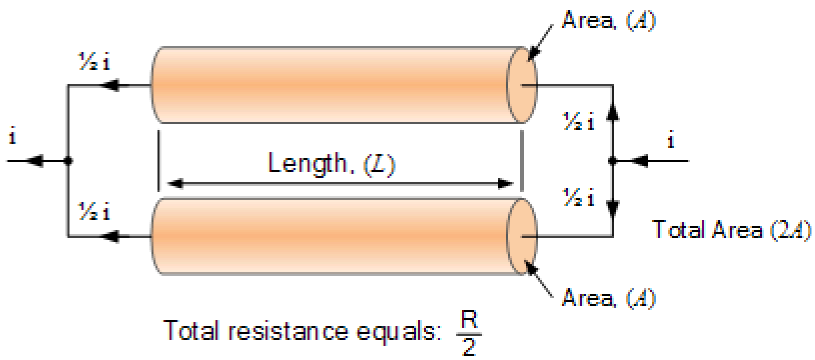
Total resistance equals: 2*R*

Here by connecting the two conductors together in a series combination, that is end to end, we have effectively doubled the total length of the conductor (2L), while the cross-sectional area, A remains exactly the same as before. But as well as doubling the length, we have also doubled the total resistance of the conductor, giving 2R as: 1R + 1R = 2R.

Therefore we can see that the resistance of the conductor is proportional to its length, that is: $R \propto L$. In other words, we would expect the electrical resistance of a conductor (or wire) to be proportionally greater the longer it is.

Note also that by doubling the length and therefore the resistance of the conductor (2R), to force the same current, i to flow through the conductor as before, we need to double (increase) the applied voltage as now I = (2V)/(2R). Next suppose we connect the two identical conductors together in parallel combination as shown.

Doubling the Area of a Conductor



Here by connecting the two conductors together in a parallel combination, we have effectively doubled the total area giving 2A, while the conductors length, L remains the same as the original single conductor. But as well as doubling the area, by connecting the two conductors together in parallel we have effectively halved the total resistance of the conductor, giving 1/2R as now each half of the current flows through each conductor branch.

Thus the resistance of the conductor is inversely proportional to its area, that is: R $1/\propto$ A, or $R \propto 1/A$. In other words, we would expect the electrical resistance of a conductor (or wire) to be proportionally less the greater is its cross-sectional area.

Also by doubling the area and therefore halving the total resistance of the conductor branch (1/2R), for the same current, i to flow through the parallel conductor branch as before we only need half (decrease) the applied voltage as now I = (1/2V)/(1/2R).

So hopefully we can see that the resistance of a conductor is directly proportional to the length (L) of the conductor, that is: $R \propto L$, and inversely proportional to its area (A), $R \propto 1/A$. Thus we can correctly say that resistance is:

Proportionality of Resistance

$$R \propto \frac{L}{A}$$

But as well as length and conductor area, we would also expect the electrical resistance of the conductor to depend upon the actual material from which it is made, because different conductive materials, copper, silver, aluminium, etc all have different physical and electrical properties.

Thus we can convert the proportionality sign ($\propto$) of the above equation into an equals sign simply by adding a “proportional constant” into the above equation giving:

Electrical Resistivity Equation

$$R = \rho\left(\frac{L}{A}\right)\ \Omega$$

Where: R is the resistance in ohms (Ω), L is the length in metres (m), A is the area in square metres (m^2), and where the proportional constant ρ (the Greek letter “rho”) is known as **Resistivity**.

Electrical Resistivity

The electrical resistivity of a particular conductor material is a measure of how strongly the material opposes the flow of electric current through it. This resistivity factor, sometimes called its “specific electrical resistance”, enables the resistance of different types of conductors to be compared to one another at a specified temperature according to their physical properties without regards to their lengths or cross-sectional areas. Thus the higher the resistivity value of ρ the more resistance and vice versa.

For example, the resistivity of a good conductor such as copper is on the order of 1.72×10^{-8} ohm metre (or 17.2 nΩm), whereas the resistivity of a poor conductor (insulator) such as air can be well over 1.5×10^{14} or 150 trillion Ωm.

Materials such as copper and aluminium are known for their low levels of resistivity thus allowing electrical current to easily flow through them making these materials ideal for making electrical wires and cables. Silver and gold have much low resistivity values, but for obvious reasons are more expensive to turn into electrical wires.

Then the factors which affect the resistance (R) of a conductor in ohms can be listed as:

- The resistivity (ρ) of the material from which the conductor is made.
- The total length (L) of the conductor.
- The cross-sectional area (A) of the conductor.
- The temperature of the conductor.

Resistivity Example No1

Calculate the total DC resistance of a 100 metre roll of 2.5mm2 copper wire if the resistivity of copper at 20ºC is 1.72×10^{-8} Ω metre.

Data given: resistivity of copper at 20ºC is 1.72×10^{-8}, coil length L = 100m, the cross-sectional area of the conductor is $2.5mm^2$ which is equivalent to a cross-sectional area of: $A = 2.5 \times 10^{-6}$ $metres^2$.

$$R = \rho\frac{L}{A}\ \Omega$$

$$R = \frac{\left(1.72\times10^{-8}\right)\times100}{2.5\times10^{-6}} = 688m\Omega$$

That is 688 milli-ohms or 0.688 Ohms.

We said previously that resistivity is the electrical resistance per unit length and per unit of conductor cross-sectional area thus showing that resistivity, ρ has the dimensions of ohms metre, or Ωm as it is commonly written. Thus for a particular material at a specified temperature its electrical resistivity is given as:

Electrical Resistivity, Rho

$$\rho = \frac{R\times A}{L} = \frac{ohms\times meters^2}{meters} = \Omega.m$$

Electrical Conductivity

While both the electrical resistance (R) and resistivity (or specific resistance) ρ, are a function of the physical nature of the material being used, and of its physical shape and size expressed by its length (L), and its sectional area (A), **Conductivity**, or specific conductance relates to the ease at which electric current can flow through a material.

Conductance (G) is the reciprocal of resistance (1/R) with the unit of conductance being the siemens (S) and is given the upside down ohms symbol mho, ℧. Thus when a conductor has a conductance of 1 siemens (1S) it has a resistance is 1 ohm (1Ω). So if its resistance is doubled, the conductance halves, and vice-versa as: siemens = 1/ohms, or ohms = 1/siemens.

While a conductors resistance gives the amount of opposition it offers to the flow of electric current, the conductance of a conductor indicates the ease by which it allows electric current to flow. So metals such as copper, aluminium or silver have very large values of conductance meaning that they are good conductors.

Conductivity, σ (Greek letter sigma), is the reciprocal of the resistivity. That is 1/ρ and is measured in siemens per metre (S/m). Since electrical conductivity σ = 1/ρ, the previous expression for electrical resistance, R can be rewritten as:

Electrical Resistance as a Function of Conductivity

$$R = \rho\frac{L}{A} \quad \text{and} \quad \sigma = \frac{1}{\rho}$$

$$\therefore R = \frac{L}{\sigma A}\ \Omega$$

Then we can say that conductivity is the efficiency by which a conductor passes an electric current or signal without resistive loss. Therefore a material or conductor that has a high conductivity will have a low resistivity, and vice versa, since 1 siemens (S) equals 1Ω-1. So copper which is a good conductor of electric current, has a conductivity of 58.14 x 10^6 siemens per metre.

Resistivity Example No2

A 20 metre length of cable has a cross-sectional area of $1mm^2$ and a resistance of 5 ohms. Calculate the conductivity of the cable.

Data given: DC resistance, R = 5 ohms, cable length, L = 20m, and the cross-sectional area of the conductor is $1mm^2$ giving an area of: A = 1 x 10^{-6} $metres^2$.

$$R = \frac{L}{\sigma A} \quad \therefore \sigma = \frac{L}{RA}$$

$$\sigma = \frac{L}{RA} = \frac{20}{5\times1\times10^{-6}} = 4MS/m$$

That is 4 mega-siemens per metre length.

Resistivity Summary

We have seen in this tutorial about resistivity, that resistivity is the property of a material or conductor that indicates how well the material conducts electrical current. We have also seen that the electrical resistance (R) of a conductor depends not only on the material from which the conductor is made from, copper, silver, aluminium, etc. but also on its physical dimensions.

The resistance of a conductor is directly proportional to its length (L) as $R \propto L$. Thus doubling its length will double its resistance, while halving its length would halve its resistance. Also the resistance of a conductor is inversely proportional to its cross-sectional area (A) as $R \propto 1/A$. Thus doubling its cross-sectional area would halve its resistance, while halving its cross-sectional area would double its resistance.

We have also learnt that the resistivity (symbol: ρ) of the conductor (or material) relates to the physical property from which it is made and varies from material to material. For example, the resistivity of copper is generally given as: 1.72×10^{-8} Ωm. The resistivity of a particular material is measured in units of Ohm-Metres (Ωm) which is also affected by temperature.

Depending upon the electrical resistivity value of a particular material, it can be classified as being either a “conductor”, an “insulator” or a “semiconductor”. Note that semiconductors are materials where its conductivity is dependent upon the impurities added to the material.

Resistivity is also important in power distribution systems as the effectiveness of the earth grounding system for an electrical power and distribution system greatly depends on the resistivity of the earth and soil material at the location of the system ground.

Conduction is the name given to the movement of free electrons in the form of an electric current. Conductivity, σ is the reciprocal of the resistivity. That is $1/\rho$ and has the unit of siemens per metre, S/m. Conductivity ranges from zero (for a perfect insulator) to infinity (for a perfect conductor). Thus a super conductor has infinite conductance and virtually zero ohmic resistance.