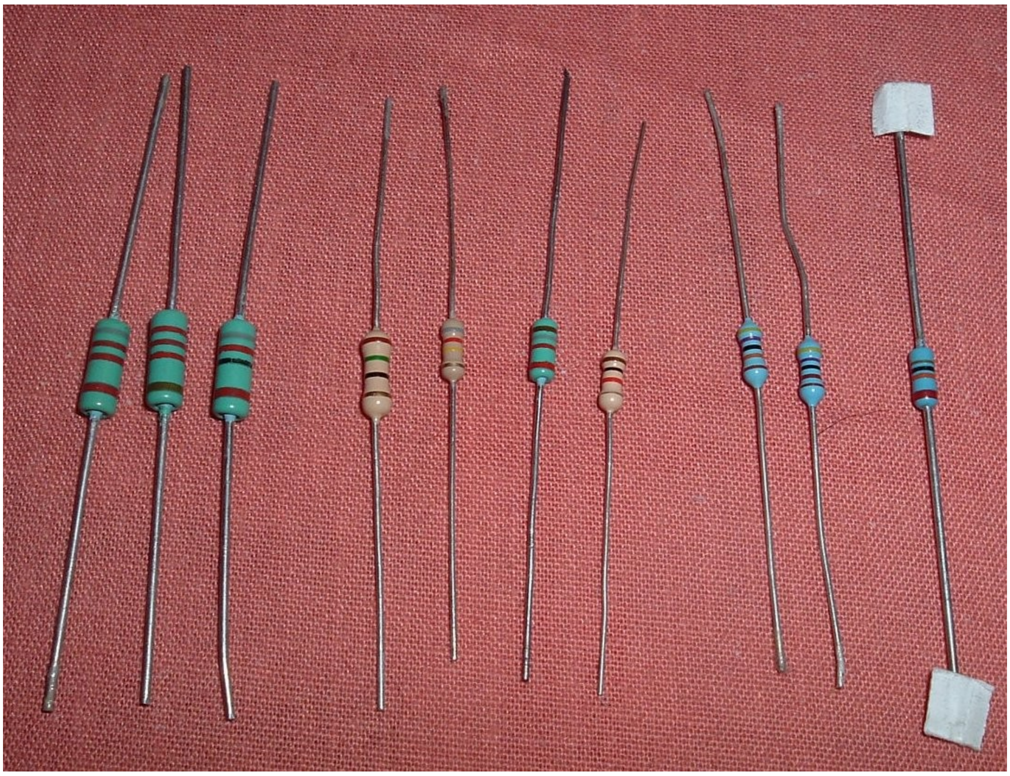
Resistors

The most widely used type of component used are probably resistors. Apart from the different types, each has a different value, marked on the case using a colour code. Even then, some resistors use a four band code whilst others use a 5 band code. Resistors are available in a whole range of fixed "preferred" values, ranging from a fraction of an Ohm, right up to 10 million or more. Variable resistors include rotary action variables, sliders and small trimmer resistors. Some are designed to change their value depending upon temperature, or change their value depending on how much light is falling on the component. These are in common use and are known as Thermistors and Light Dependent Resistors (LDR) respectively. A project demonstrating the LDR is detailed in the projects section



The SI unit of resistance is the Ohm (Ω), and being a small unit, it is not uncommon to see resistors that are measured in millions of Ohms. There is an abbreviation for the number of zero's in the value – K meaning "kilo", or thousand. "M" meaning "meg" or million, and simply "R" for values less than 1,000 Ohms.

Thus, a 10 Ohm resistor could be written on paper as 10R. A resistor with a value of 4,700 Ohms could be written as 4.7K but more usually as 4K7, since it's easy to miss the decimal point and end up reading 47K instead of only 4.7K. 100,000 Ohms would be written as 100K and finally, 2,200,000 Ohms would be written as 2M2

Resistors are never exactly the marked value either, they have a "tolerance" - usually plus or minus 5% of the stated value – although some are within 2% of the marked value, and some are 1%

Resistors are so named because they resist or slow down the flow of an electrical current.

Preferred values

Resistors are made in what are known as "preferred values", and available in several different ranges. The range that almost all the resistor values you will ever use comes from the E12 range. There are other ranges, such as the E24 range for example, but the additional values offered by the E24 range are seldom used by the hobbyist. The E12 range of values is given later towards the end of the resistor section.

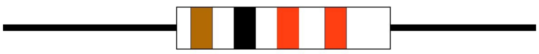
The E12 range extends beyond the the values given in the table given later, resistors of a fraction of an Ohm are available, as are resistors of 10M and more. Take note of how the numbers multiply by a factor of ten as you across the table. These are know as "decade" values.

Inside the ZX Spectrum 48K machine, there are two resistors that are outside the standard E12 range. One is 3K and the other is 5.1K, both at 2%.

The Resistor Colour Code – Four Band

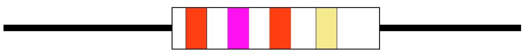
Colour	Band 1	Band 2	Band 3 - Multiplier
Black	0	0	1
Brown	1	1	10
Red	2	2	100
Orange	3	3	1,000
Yellow	4	4	10,000
Green	5	5	100,000
Blue	6	6	1,000,000
Violet	7	7	10,000,000
Grey	8	8	100,000,000
White	9	9	-
Gold	-	-	0.1
Silver	-	-	0.01
Forth band - Tolerance (accuracy)			
None 20% Silver 10%	Gold 5%	Red 2%	Brown 1%

Some examples



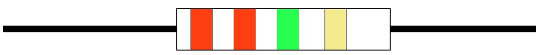
Brown	1
Black	0
Red	multiply by 100
Red	Tolerance = 2%

10x100=1000 or 1K Ohms at 2%



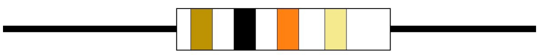
Red	2
Violet	7
Red	Multiply by 100
Gold	Tolerance = 5%

27x10=2700 or 2K7 Ohms at 5%



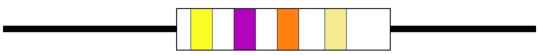
Red	2
Red	2
Green	Multiply by 100,000
Gold	Tolerance = 5%

22x100,000=2,200,000 or 2M2 at 5%



Brown	1
Black	0
Orange	Multiply by 1,000
Gold	Tolerance = 5%

10x1,000=10,000 or 10K at 5%



Yellow	4
Violet	7
Orange	Multiply by 1,000
Gold	Tolerance = 5

47x1,000=47,000 or 47K at 5%

Yellow	4
Violet	7
Black	Multiply by 1
Gold	Tolerance = 5%

47x1=47, or 47R at 5%

The Resistor Colour Code – Five band

Colour	Band 1	Band 2	Band 3	Multiplier
Black	0	0	0	1
Brown	1	1	1	10
Red	2	2	2	100
Orange	3	3	3	1,000
Yellow	4	4	4	10,000
Green	5	5	5	100,000
Blue	6	6	6	1,000,000
Violet	7	7	7	10,000,000
Grey	8	8	8	100,000,000
White	9	9	9	
Fifth band - Tolerance (accuracy) Gold 5% Red 2% Brown 1%				

Five band resistor colour codes are very similar to the four band codes. The only real difference is that band three isn't a multiplier band but instead, represents a third digit. The fifth band is the tolerance indicator instead. If your resistor has a sixth band, it's probably black or brown and indicates the temperature coefficient – it can be ignored usually.

To use a 220K resistor as an example

The four band codes are:

Red	2
Red	2
Yellow	Multiply by 10,000
Red	Tolerance =2%

22x10,000 = 220K at 2%

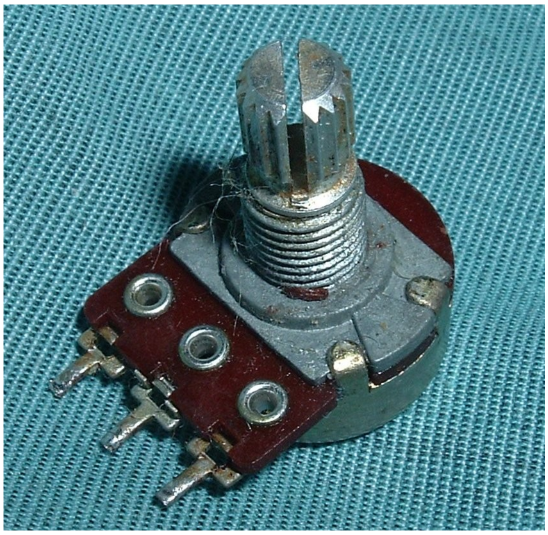
The five band codes are:

Red	2
Red	2
Black	0
Orange	Multiply by 1,000
Brown	Tolerance = 1%

220x1000 = 220,000 or 220K at 1%

Variable Resistors

Resistors are also available in what are known as “variable”, or to give them their proper name, potentiometers (or “pots” - Photograph below right). They are not fixed in value like the resistors discussed so far but are infinitely variable, from almost zero, all the way up to the total value of the device. Examples of which are level and volume controls etc, where the level of resistance needs to be altered in order to turn up, or turn down a signal level into an amplifier. Sometimes in a circuit you may need a variable resistance to perhaps tune (or “trim”) an oscillator to a certain frequency, such as in a guitar tuner or similar device. Other uses of variable resistors are for example, when you need a resistor of a certain value that isn't available as a fixed value. This is known as a “preset” resistor or a “trimmer resistor”. See photograph left.



Variable resistors are generally available in two types – Logarithmic law and Linear Law, or just “LOG” and “LIN”. The LOG law variable is designed so as you turn the spindle, the resistance rises rapidly at first, then levels out. Some 75% of the total resistance range being covered in perhaps the first 25% of arc, and then the remaining 25% resistance spread out over the remaining 75% of arc.

The LIN law variable is designed so that 10% (for example) of the device's value corresponds to 10% of arc.

Also available are Anti-log law variables, but they are not generally available.

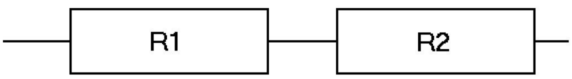
Most variable resistors are made using a small circular element coated with a carbon composite material. Connection is made to either end of the track, and a moveable contact (a “wiper”) is then put in contact with this track so that the resistance between the wiper contact and either end of the track varies, depending on the position of this wiper.

Some potentiometers are made by wrapping resistance wire around a non conductive circular former (like a Polo mint). Contact via a wiper is then made in a similar fashion to that of a carbon potentiometer. Wire-wound variables are always Linear law devices since the resistance wire used in their construction is linear law itself (ie, the resistance over (say) 100 mm of wire is half that of the resistance over 200mm of the same length of wire).

The Light Dependent Resistor (or LDR) is a special type of variable resistor. The LDR is a light sensitive device, and as such, it's value depends upon the amount of light it can “see”. A small project is detailed later in the project section to demonstrate the properties of the LDR.

Resistors is Series and Parallel

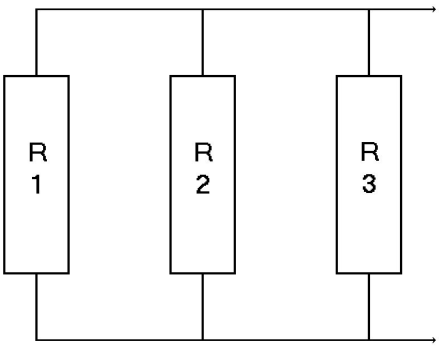
Resistors in Series



$R_T = R1 + R2......$

Resistors in series simply add up. Total resistance (R_T) is equal to:

$R_T = R1+R2+R3.......$



Resistors in Parallel

$$R_T = \frac{1}{\frac{1}{R1}+\frac{1}{R2}+\frac{1}{R3}}$$

Resistors in Parallel follow the formula

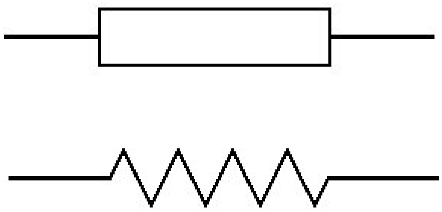
$R_T =$ 1/(1/R1)+(1/R2)+(1/R3)

For two resistors in parallel, use the formula:

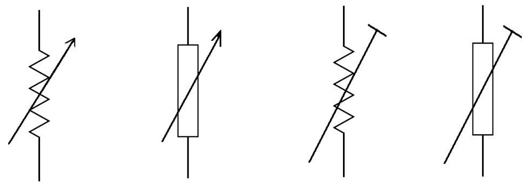
R_T= (R1 x R2) / (R1 + R2)

Symbols

Resistors are represented by the below symbols in circuit diagrams. Nowadays, the rectangular box symbol is more often used, but the older zig-zag symbol is still very common, especially in the USA and Japan



Resistor - Circuit diagram symbols



Circuit diagram symbols for variable and preset resistors respectively

Power Rating

The SI unit of power is the Watt (W). It is important that a resistor can handle the power flowing through it. Resistors have a finite amount of current they can conduct before they overheat and let the magic smoke escape. Generally speaking, most modern circuits use 0.25W resistors, although there are smaller (and much larger) ones available (0.125W - 25W+). The power handling value isn't actually marked on the resistor's body normally, the only way to tell is to look at the physical size of the component. High Wattage resistors are often used in equipment such as power supplies and high powered amplifiers.

To determine the power flowing through a resistor we use the formulae $P = V \times I$ and $P = I^2 \times R$, where P = power, V is the voltage (or potential difference) and I is the current in Amperes.

As an example, 9 Volts at a current of 1 Amp is equal to 9 Watts.

V = 9, Current (I) = 1 Amp. 9(V) x 1(I) = 9 Watts

A current of 2 Amps through a resistor of 10 Ohms would be a power of 40 Watts and would be at a potential of 20V. That is to say, 20 volts flowing through a 10R resistor would have a current flow of 2 Amperes, and the resistor would need to handle 40W of power. In other words, a normal 0.25W resistor would probably explode after glowing red hot for a brief moment.

I = 2 Amps, R = 10 Ohms. $I^2 = 4$, multiplied by 10 Ohms, = 40 Watts. I=2 Amps multiplied by 10 Ohms, = 20 volts

Ohm's Law

Ohms law is the name given to the formula used to define and calculate the relationship between Voltage (V), current (I) and resistance (R). If you learn no other formula, this one is a must. Voltage is the engine or pump that moves electrons around a circuit, and current is the rate at which they flow. A resistor is a device that slows down the flow of electrons and thus limits current flow. If you think of a water tank with a pipe leading from it, flowing through a turbine and then returning to the tank in a circuit, the amount of water in the system would equate to the voltage, the flow rate down the pipe to the turbine would equate to the current, and the diameter of the pipe would equate to the resistor. As the water flows down the pipe and through the turbine, the turbine spins at a certain speed. Now, If the downpipe was (say) 15 centimetres in diameter, water would flow at a quicker rate than if the downpipe was only 10 centimetres in diameter – there would be a resistance to the flow and the turbine wouldn't be able to spin as fast. The narrower the downpipe, the less flow there is, and the slower the turbine would spin. It stands to reason that a small volume of water (or voltage) wouldn't be able to drive a large turbine (as a small battery wouldn't be able to power a domestic light bulb). Regardless of how quickly it flowed past the turbine, there just wouldn't be enough power to make the turbine spin.

The formula is: $V = I \times R$ $I = V / R$ $R = V / I$

Where V = Volts, I = current (in Amperes) and R = resistance (in Ohms).

When we use Ohms law, we must use the correct units. 5K6 should be expressed at 5,600 Ohms, 100 millivolts should be expressed at 0.1 Volts and 200 milliamps should be expressed as 0.2 Amperes.

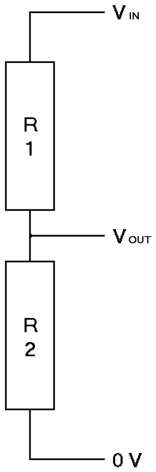
The E12 range of available values

Resistors in the E12 range						
1R	**10R**	**100R**	**1K**	**10K**	**100K**	**1M**
1R2	**12R**	**120R**	**1K2**	**12K**	**120K**	**1M2**
1R5	**15R**	**150R**	**1K5**	**15K**	**150K**	**1M5**
1R8	**18R**	**180R**	**1K8**	**18K**	**180K**	**1M8**
2R2	**22R**	**220R**	**2K2**	**22K**	**220K**	**2M2**
2R7	**27R**	**270R**	**2K7**	**27K**	**270K**	**2M7**
3R3	**33R**	**330R**	**3K3**	**33K**	**330K**	**3M3**
3R9	**39R**	**390R**	**3K9**	**39K**	**390K**	**3M9**
4R7	**47R**	**470R**	**4K7**	**47K**	**470K**	**4M7**
5R6	**56R**	**560R**	**5K6**	**56K**	**560K**	**5M6**
6R8	**68R**	**680R**	**6K8**	**68K**	**680K**	**6M8**
8R2	**82R**	**820R**	**8K2**	**82K**	**820K**	**8M2**

Various abbreviations used

Abbreviations		
Ampere	**Amp or A**	**SI unit of electrical current**
Resistance	**R**	
Farad	**F**	**SI unit of capacitance**
Volt	**V**	**SI unit of voltage**
Ohm	**Ω**	**SI unit of resistance**
Power	**P**	
Current	**I**	
Watt	**W**	**SI unit of power**
Kilo	**k**	**A thousand of Multiply by 1,000 A kilovolt is a thousand (kV) Volts A kilohm is a thousand Ohms (kΩ)**
Meg	**M**	**A million of Multiply by 1,000,000 A Megawatt (MW) is a million Watts A Megohm (MΩ) is a million Ohms**
Milli	**m**	**A thousandth part of Multiply by 0.001 A milliwatt (mW)is a thousandth of a Watt A millivolt (mV) is a thousandth of a Volt**
Micro	**µ**	**A millionth part of Multiply by 0.000 001 A microvolt (µV) is a millionth of a Volt. A microfarad (µF)is a millionth of a Farad**
Pico	**p**	**A million millionth part of Multiply by 0.000,000,000,001 A picofarad (pF) is a million millionth part of a Farad**

Potential/Voltage Division



$$V_{OUT} = V_{IN} \times \left(\frac{R2}{R1 + R2}\right)$$

Resistors can be used to divide a voltage. This is known as a "Potential divider" and the basic circuit is pictured left. The following example assumes the use of fixed resistors, but it is perfectly acceptable to use a potentiometer. V_{OUT} is then taken from the wiper (usually the centre terminal on most potentiometers).

When R1 is equal to R2, V_{OUT} is exactly half of V_{IN}.

Lets assume for example that R1 and R2 both equal 1,000Ω, the input voltage is equal to 10 Volts.

Using the formula, V_{OUT} is equal to V_{IN} multiplied by the value of (R2 divided by (R1+R2))

A Worked Example:

Lets put some numbers into the formula $V_{OUT} = V_{IN}$ x (R2/(R1+R2))

We know V_{IN} = 10 Volts
R1 = 1,000Ω
R2 = 1,000Ω
So using the numbers instead of variables, the formula can be written as:
V_{OUT} = 10 x (1,000/(1,000+1,000) and 1,000 + 1000 = 2000, so...
V_{OUT} = 10 x (1,000/2000) and 1,000 divided by 2000 = 0.5, so....
V_{OUT} = 10 x 0.5 and 10 x 0.5 = 5
Therefore V_{OUT} = 5V– exactly half V_{IN}