Resistors, Volt and Current

Posted on April 4, 2008, by Ibrahim KAMAL, in General electronics, tagged

In this article we will study the most basic component in electronics, the resistor and its interaction with the voltage difference across it and the electric current passing through it. You will learn how to analyse simple resistor networks using nodal analysis rules. This article also shows how special resistors can be used as light and temperature sensors.

Imagine the electricity

As a beginner, it is important to be able to imagine the flow of electricity. Even if you've been told lots and lots of times how electricity is composed of electrons traveling across a conductor, it is still very difficult to clearly imagine the flow of electricity and how it is affected by Volt and Resistors. This is why I am proposing this simple analogy with a hydraulic system (***figure 1***), which anybody can easily imagine and understand, without pulling out complicated fluid dynamics equations.

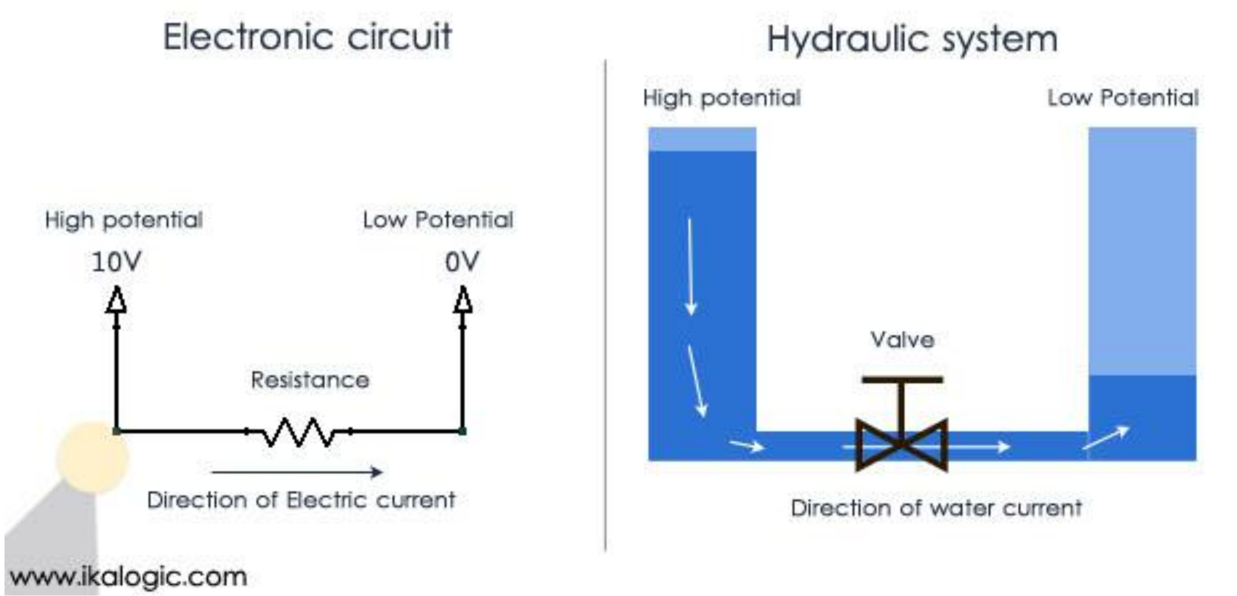


figure 1

Notice how the flow of electricity resembles the flow of water from a point of high potential energy (high voltage) to a point of low potential energy (low voltage). In this simple analogy water is compared to electrical current, the voltage Difference is compared to the head difference between two water reservoirs, and finally the valve resisting the flow of water is compared to the resistor limiting the flow of current.

From this analogy you can deduce some rules that you should keep in mind during all your electronics work:

- *Electric current through a single branch is constant at any point (exactly as you cannot have different flow rates in the same pipe; what's getting out of the pipe must equal what's getting in)*

- *There wont be any flow of current between two points if there is no potential difference between them. In other words, for a flow of current to exist, there must be a voltage difference between two points.*

- *The quantity of water in the reservoir can be compared to the electric charge stored in a battery. When the level of water in the two tanks become the same, there is no more flow of water, and comparatively, a battery is empty and cannot deliver anymore current when the two electrodes have the same voltage.*

- *The electric current in a conductor will increase with the decrease of the resistance, exactly as the rate of flow of water will increase with the decrease of the resistance of the valve.*

I could write a lot more deductions based on this simple analogy, but we can summarize those rules in the most fundamental equations of electronics: Ohm's law, that you shall learn in the rest of this article.

The resistor

figure 2

The resistor can be defined by it's main purpose, *a device to control or limit the flow of current*, hence we can say that the main parameter of a resistor is it's resistance, which is measured in Ohm's (Ω). Never less, another design consideration when working with resistors is its rated power, measured in watts (W), which is the quantity of power the resistor can dissipate without burning out.

It is also important to note that resistors are not only used for current limiting, they can also be used as voltage dividers to generate very precise voltages out of bigger voltages. Some sensors are based on a resistance that varies depending on light, temperature or shear stress, like the LDRs (light dependent resistors), Thermistors (temperature dependent resistors) or strain gauges. For more information and pictures, see Special resistors at the end of the article.

Ohm’s law

$$\boxed{V = I \times R}\ldots(1)$$

$$\boxed{I = \frac{V}{R}}\ldots(2)$$

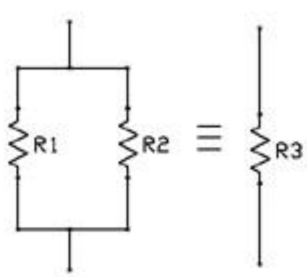
$$\boxed{R = \frac{V}{I}}\ldots(3)$$

figure 3

Legend (***figure 3***): **R**: Resistance (Ohms), **V**: Voltage (Volts) and **I**: Current (Amps).

It’s clear that those three equations at the left are different variations of Ohm’s law, but the three of them must be very clear in your mind in order to proceed to more complicated circuits. You have to be able to understand and imagine the meaning of the equation (**2**) for example, which implies that a rise of voltage with a constant resistance will cause a rise of current. However, it wouldn’t be logically true to say that a current rise will cause a voltage rise if the resistance is constant (even though this is mathematically true) because it’s the voltage, the potential difference, that will create a flow of current, not the opposite (refer to the analogy of the two water tanks). Also, equation (**3**) can be used to deduce the value of the resistance to used to limit the flow of current to a certain value under a constant known voltage difference. Those are just examples showing you the importance of this rule. You will learn how to use them along the rest of the article. Even the most sophisticated electronic simulations software uses this equation, along with some other equations to solve and simulate the most complicated circuits.

Series and parallel resistors



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

figure 4.A

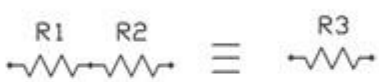
Understanding what is the effect of connecting resistors in series or in parallel is very important and will help you to analyze and simplify an electronic circuit, using those simple mathematical relations for series and parallel resistors:

- In this example circuit (***figure 4.A***), R_1 and R_2 are connected in parallel, a single resistor R_3 can provide the exact same function of the two resistors R_1 and R_2, according to the law ***figure 4.A.***

- Which, in case of only two parallel resistors, can be written as:

$$R_3 = \frac{R_1 \times R_2}{R_1 + R_2}$$

- Not only this relation can be used to simplify complicated circuits, but it can also be used to create resistors of values that you don't have.
- Notice also that the value of R_3 will always be smaller than the two other equivalent resistors. Which is logic, because adding more resistors in parallel provides additional paths to the electrical current, decreasing the overall resistance of the circuit.
- Series resistors can also be grouped together and replaced by one resistor, whose value would equal the summation of the two initial resistors, which is again very logical, due to the fact that this configuration of resistance will provide additional resistance to the flow of current. Therefore the equivalent resistor R_3 can be very simply calculated by the relation (***figure 4.B***):



$$R_3 = R_1 + R_2$$

figure 4.B

- At last, be careful of this very common pitfall among beginners, which is shown in ***figure 4.C***. It must be very clear that for two resistors to be considered as series resistors, they must be share the same current, as you will see in the rest of the tutorial.

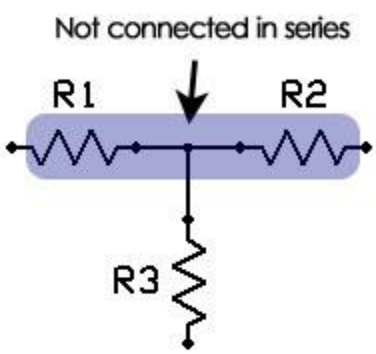


figure 4.C

Resistor used for current limiting

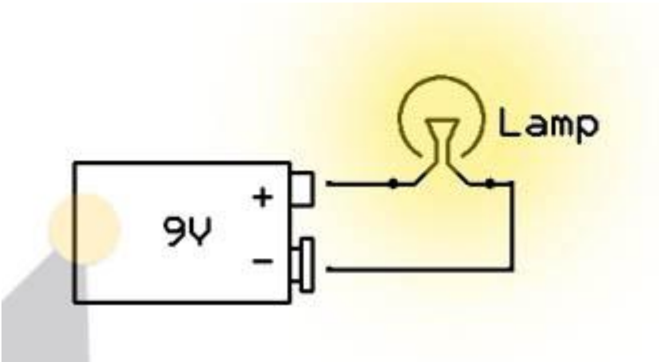


figure 5.A

The most basic role of resistors is current limiting, which consist of precisely controlling the quantity of electrical current that is going to flow through a device or a conductor. To understand how current limiting resistors work, let's first study this simple schematic (***figure 5.A***), where a lamp is directly connected to a 9V battery. A lamp, like any other device that consumes electricity to accomplish a certain task (like providing light in this example) has an internal resistance, that determines how much current it will consume.

So, from now on, any resistive device can be replaced in by a resistance especially in electronics schematics (you can also notice in ***figure 5.B*** *-which is equivalent to the 9V battery and the lamp-* the symbol of a resistor in the schematics, and how it is connected to the the Positive and Negative power sources).

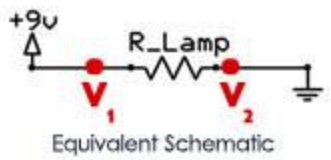


figure 5.B

Now if the lamp is to be considered a resistor, we can then use Ohm's law to calculate the current passing through it. Ohm's law states that the current passing through a resistor is equal the the voltage difference across it divided by the resistance of that resistor.

This is mathematically written as: $I = \frac{V}{R}$, or more accurately as: $I = \frac{V_1 - V_2}{R}$

Where (***$V_1 - V_2$***) is the voltage difference across the resistor and (**R**) is the value of the resistor.

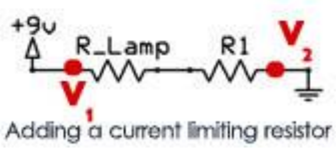


figure 5.C

Now notice the ***figure 5.C***, where a current limiting resistor have been added. This resistance will limit the current going to the lamp, simply as it's name implies. You can control, to a very precise extent, the amount of current flowing through the lamp simply by choosing the right value for the resistor R_1. A large resistor will highly reduce the current while a small resistor will allow more current (exactly as in our hydraulic analogy, where the valve is compared to a resistor).

Mathematically speaking, this can be written as: $$I = \frac{V_1 - V_2}{R_{lamp} + R_1}$$

It is then clear that the value of the current will decrease if the value of the resistor R_1 increases. However it is important to note that this comes with a cost, which is the heat dissipated into the current limiting resistor, and you must chose a resistor of a suitable power rating, as you will see in the rest of the tutorial.

Resistors used as Voltage divider

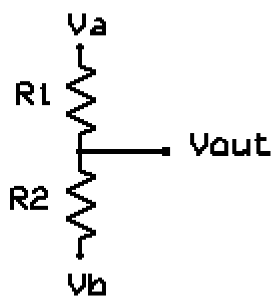


figure 6.A

As the name implies, resistors can also be used as voltage divider, in other words they can be used to generate any voltage from an initial bigger voltage by dividing it. The mathematical relation for this resistor configuration shown in ***figure 6.A*** (that you could easily prove using the Nodal analysis method) is:

$$V_{out} = \frac{R_2 V_a + R_1 V_b}{R_1 + R_2}$$

equation 6.A

In case both resistors have the same value ($R_1 = R_2 = R$), the equation can be written as:

$$V_{out} = \frac{R(V_a + V_b)}{2R} = \frac{(V_a + V_b)}{2}$$

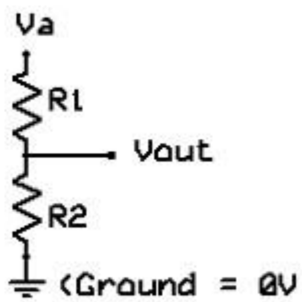


figure 6.B

Another common special case of this resistor configuration, is when the lower resistor is connected to ground (0V) as shown in ***figure 6.B***. Replacing ***Vb*** by 0 in the ***equation 6.A***, we get:

$$V_{out} = \frac{R_2 V_a}{R_2 + R} = V_a \times \left(\frac{R_2}{R_1 + R_2} \right)$$

equation 6.B

Which is the most common voltage divider equation. You could imagine a lot more of special cases for this resistor configuration, and you shall discover them as you are working your way into the field of electronics.

Nodal analysis

Now that you're beginning to deal with electronic schematics, it is important to be able to analyze them and calculate any required voltage, current or resistance. There are many ways to study an electronic circuit, one of the most common methods is the ***Nodal analysis***, where you simply apply a set of rules on a circuit of any size and calculate step by step all the required variables.

Definition of a node

A node is any point in the circuit (***figure 7.A***). Points that are connected to each others by wires, without any other component between them are considered as a single node. Therefore, the infinite number of point in a wire are considered as only one node.

All points that are grouped as a single node have the same voltage.

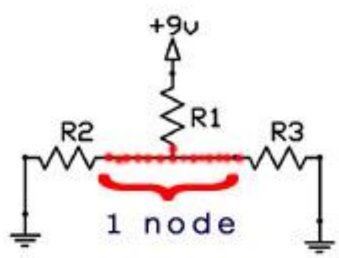


figure 7.A

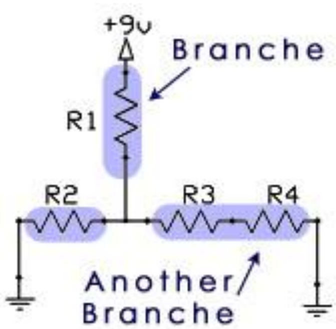


figure 7.B

Definition of a branch

A branch is a set of 1 or more components connected in series, and all the components that are connected in series in the same chain are considered as 1 branch (***figure 7.B***).

The current flowing along a branch is the same at all points.

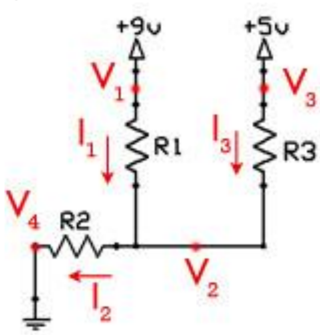


figure 7.C

Application

All nodes voltages are relative to a fixed reference node, usually the ground connection whose symbol is (⏚) and whose voltage is always equal 0 Volts. Current always flows from a node to another node of lower voltage.

The voltage of a node can be determined from the voltage of a nearby node, using the relation:

$V_1 – V_2 = I_1 \times R_1$, and rearranging we get: $V_2 = V_1 – (I_1 \times R_1)$, where V_2 is the voltage of the node to be determined, V_1 is the voltage of the reference node which is known, I_1 is the current flowing from node 1 to node 2 and R_1 is the equivalent resistance between the two nodes.

Similarly, and still using the same Ohm's law, the current in a branches can be determined if the voltages at the two nodes at both ends of the branches are known, using the relation: $I_1 = \frac{V_1 - V_2}{R_1}$ Current entering the node equals current leaving the node, thus in the given example (***figure 7.C***), this can be written as:

$$I_1 + I_2 = I_3$$

It is important to be able able to feel the meaning of those simple mathematical relations; For example in the ***figure 7.C*** above, the current is flowing from V_1 to V_2, and thus V_2 must be smaller than V_1 and that's exactly what the relation: $V_2 = V_1 – (I_1 \times R_1)$ is proving.

The idea is to dig your way around the circuit to be analyzed with those given rules. Using the appropriate rule at the appropriate time, is the key to a fast and easy circuit analysis and understanding, and this skill is gained by practice and experience. Finally, remember that computers can do it, and so do you.

Calculating required rated power of a resistor

When buying resistor to build a certain circuit, you may be asked: "what is the power rating of the resistors you want to buy?" or you may simply be given 1/4 Watt resistor as they are the most standard class of resistors.

As long as you're working with resistor of higher value than 220Ω, and your power supply delivers 9V or less, it is safe to work with 1/8 watt or 1/4 watt rated resistors. But if the voltage across a resistor increases over 10V or the resistor's value is less than 220Ω, you should calculate the power carried away by the resistor, otherwise, it may burn up in fumes and can even cause serious burns and injuries.
To calculate the required power rating of the resistor, you must first know the voltage difference across the resistor (V) and the current flowing through it (I), then the power (P) is: $P = I \times V$, where I is the electrical current in Amperes (A), V is the voltage in Volts (V) and P is the power dissipation in Watt (W).

Here you can see some resistors having different power ratings (***figure 9***). You notice that the main difference between different power ratings is the size of the resistor.

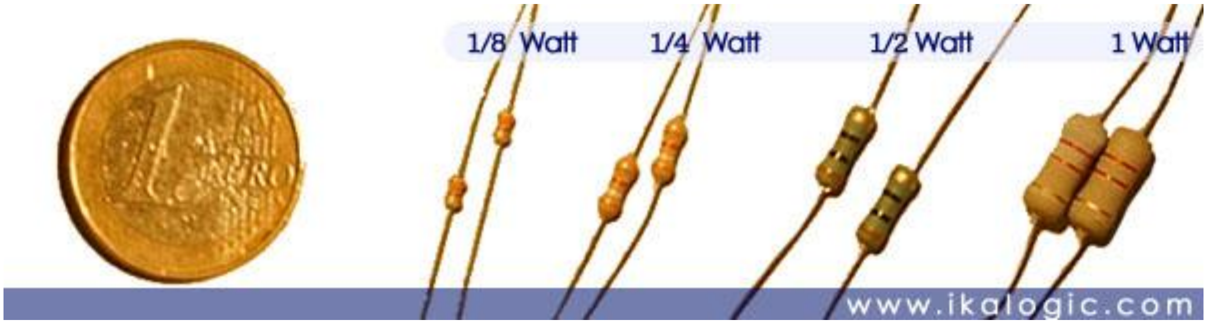


figure 9

Special resistors

Resistors can get more sophisticated than this, from simple variable resistors (also called potentiometers), to highly accurate temperature, light, and pressure sensors. Some of them are going to be discussed in this section.

- Variable resistor (Potentiometer)

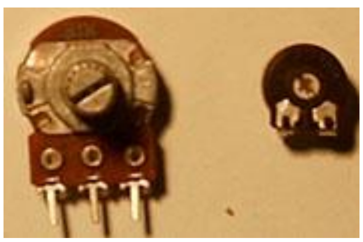


figure 10.A

Figure 10.A shows how potentiometers look like in reality, they vary in size and shape, but they all work the same way.

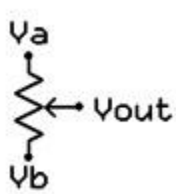


Fig. 10.B

Figure 10.B shows the schematic symbol of a variable resistor. It is often referred to as a potentiometer, because it can be used as a potential (voltage) divider. The pins at the right and left extremities of the potentiometer are equivalent to the fixed point (like Va and Vb in the ***figure 10.B***), while the middle pin is the moving part of the potentiometer, and is used to change the ratio of the resistance at its left to the resistance at its right. Hence the voltage divider equation applies to the potentiometer, which can deliver any voltage from Va to Vb.

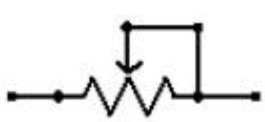


figure 10.C

Also a variable resistor can be used in a current limiting configuration by connecting the output the point ***Vout*** to ***Vb*** like in the ***figure 10.C***. Imagine how the current will flow through the resistance from the left extremity to the right until it reaches the arrow (the moving part that varies resistance) then practically all current will flow through the jumper wire (theoretically some very little current will pass through the rest of the resistor)

This way you can also use a potentiometer to adjust the current flowing into any electronic component, or lamp for example. Actually this is how most of the old light dimmers work.

- LDR (Light Dependent Resistors) and thermistors

figure 11.A

There many electronic sensors that rely on a resistor whose resistance varies with respect to another parameter like light, temperature, or pressure. We are going to briefly study LDRs (Light Dependent Resistors) and Thermistors (Temperature dependent resistors), and you will notice that all resistors based sensors work exactly the same way, as the easiest way to use one of those sensors is to put them in a voltage divider configuration, obtaining a voltage that changes with the measured values, instead of a resistance change. Sensors whose output is Voltage variations are much easier to interface to computers or microcontrollers, as you shall see during the next tutorials.

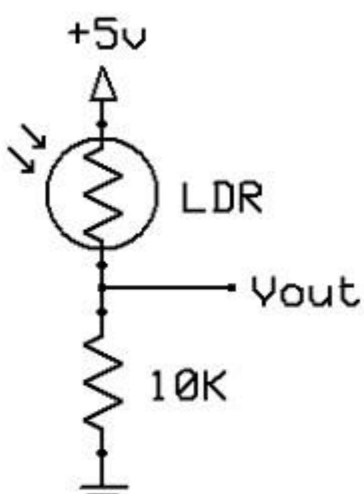


figure 11.B

As you can see in ***figure 11.A***, LDRs vary in size, but they are all resistors whose resistance will decrease when exposed to light, and increase when shed in the dark. They are also referred to as photoresistors, photoconductors or

Cds because they are made of Cadmium sulphide. Unfortunately, LDRs response can be slow, and they also often tend to lack accuracy, but still they are very easy to use (see example here).

For applications that requires more accuracy, and faster response, photodiodes or phototransistors are preferred over LDRs. Usually, an LDR's resistance can vary from 50 in the sun light, to over 10M in absolute darkness. As we said before, The variation of resistance has be converted into a voltage variation, by introducing the LDR into a voltage divider configuration, as shown in ***figure 11.B***.

Recalling ***equation 6.B***, you will see that the output voltage (V_{out}) of this circuit follows the following equation:

$$V_{out} = 5 \times \left(\frac{10 \times 10^3}{LDR + \left(10 \times 10^3\right)} \right)$$

Supposing that the LDR's resistance varies from 10MΩ to 50Ω, calculations would yield that V_{out} varies respectively from 0.005V to 4.975V. This voltage variation can be then fed to an integrated circuit named an Operational Amplifier to create a reliable light sensor.
Similarly, a Thermistor can be used in the exact same way to create a sensor whose voltage varies with temperature variation. However, thermistors comes in much more varieties and types than LDRs, for instance, a thermistor can either be a negative temperature coefficient type (NTC) whose resistance will decrease with temperature rise, or positive temperature coefficient type (PTC), whose resistance will increase with temperature rise. Nowadays, electronics manufacturers provide thermistors of very high quality in terms of accuracy and response time, inneed, it's very common to see thermistors in very precise devices like digital thermostats.

Schematic Symbols

Figure 12 shows the most common symbols for the various types of resistors, which are used when drawing electronic schematics.

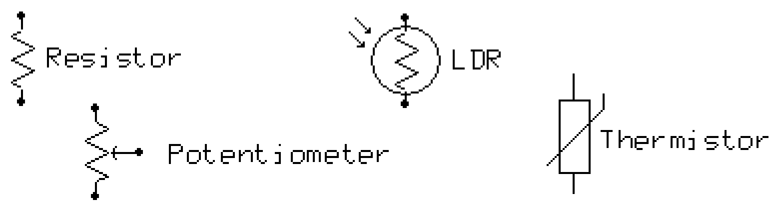


figure 12

Resistors color code

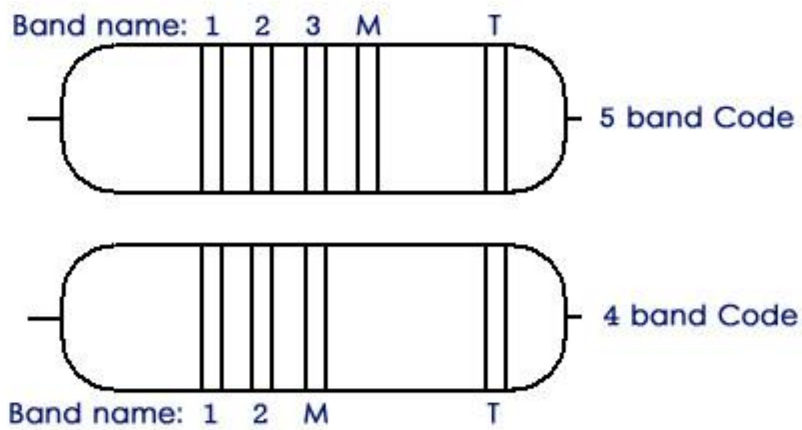


figure 13.A

There are two common ways to know a the value of a resistor, by measuring it using an Ohmmeter, or by reading the color code printed on it, which is much faster, when you get used to it. As you can see in ***figure 13.A***, some resistors have 4 color bands on it, and some have 5. Both of them use the same encoding method. The bands named 1, 2 or 3 in ***figure 13.A*** can be translated into a 2 or 3 digit number using the table below. the band named M is the multiplier, meaning the number obtained from the previous digits have to be multiplied by 10 to the power M (or simply, add M number of zeros after the 2 or 3 digits number). The Value of M is also obtained from the table below. The last band at the right (T) is the tolerance band, which is usually gold meaning 5% tolerance or silver meaning 10%.

Black	*Brown*	*Red*	*Orange*	*Yellow*	*Green*	*Blue*	*Violet*	*Gray*	*White*
0	1	2	3	4	5	6	7	8	9

Table used for translating color bands to numbers

To read a resistor using the color encoding follow the same steps of this example. Let's say you have a resistor like the one shown in ***figure 13.B***, the first step is to locate the tolerance band, it is usually apart from the other bands, and it is typically gold or silver colored. Once the tolerance band is located, note the colors of the bands starting from the other side. The first 2 bands will be translated from the table to become a '1′ and a '0′, this will be considered as 10, then the Multiplied band, being red, will mean that you multiply by 10 the the power 2, or simply, multiply by 100. the the first 2 digits (10) multiplied by (100) will yield a result of 1000. Then, this is a 1000Ω resistor, or 1KΩ.

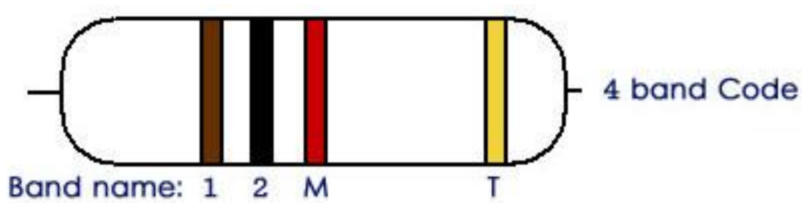


figure 13.B

Source: http://www.ikalogic.com/resistors-volt-and-current/