

## Electrical Engineering Basics & Using a Digital Multi-Meter (DMM)

Electricity is a powerful thing, but not quite as mysterious once you understand the basics. Perhaps one of the most difficult reasons people have in understanding electricity is because it is something that you can't see. The best analogy that I can think of with electricity is water, and although they aren't exactly the same, it makes a good parallelism that helps a great deal in gaining an understanding.

Electricity, like water, flows from a source along its given paths; however, electricity only flows along a closed circuit and must eventually return to its source forming a closed circuit. A source of electricity can either be generated, like from a power plant, or stored, like in a battery.

The basic concepts of electricity are as follows: voltage, current, power, resistance, and the more complex concepts of capacitance and inductance.

### Voltage

Voltage is the measure of electric potential. Voltage is relative and must be measured as the difference between two points, just like elevation. You can say that something is 6 feet off the ground, but the same point can be 100 feet above sea level, because where you start measuring from, or the zero reference level, is different. In the case of an electric circuit, the zero reference point is referred to as **ground**. An analogy with water would be the amount of water flowing in a lake.

- Voltage is measured in volts, abbreviated: 'V'

### Current

Current is the measure of the rate of electric flow, or the movement of electricity through a circuit. If a circuit is incomplete or broken, then no current will flow. An analogy with water would be the rate or speed of the water flowing through a lake. In electric circuits, current is what can be lethal. High voltages are not nearly as dangerous as high currents. An analogy with water would be to consider walking across a slow moving, large body of water as compared to trying to move through narrow white-water rapids.

- Current is measured in Amperes, or amps, abbreviated: 'A'

### Power

Power is the rate at which electric energy is transferred by an electric circuit. It is a measure of electric work. One of the two most important equations in electrical engineering is the relation between voltage, current and power. You cannot have power without voltage and current, and power is equal to voltage multiplied by current.

- Power is measured in Watts, abbreviated: 'W'

In electric equations: power is abbreviated 'P', current is abbreviated 'I', and voltage is abbreviated 'V'.

- Power = Current \* Voltage (P = IV)

### Resistance

Resistance, as its name implies, is the measure of an electric conductor's ability to resist the flow of current in a circuit. The opposite of resistance is admittance, or conductance. Every material has a measure of resistance. A material that has a low resistance is considered a good conductor (like most metals). A material that has a high resistance is considered a good insulator (like rubber). An analogy with water would be the thickness of a hose; a kinked hose has a high resistance to the flow of water, whereas a fire hose has a low resistance and water flows through it with ease.

The second of the most important equations in electrical engineering is referred to as Ohm's law. It relates the electric potential (voltage) in a circuit with the rate of electric flow (current), and is named after German physicist Georg Ohm, who discovered the linear relation between the two.

- Resistance is measured in Ohms, abbreviated: 'Ω'

In electric equations resistance is abbreviated 'R'.

- Ohms Law: Voltage = Current \* Resistance (V = IR)

### Capacitance & Inductance

Capacitance and inductance, in a simplistic definition, is the measure of a material's ability to store voltage and current, respectively. Capacitance and inductance are much more complicated concepts in electrical engineering, and the majority of basic circuits that are encountered are **purely resistive** (have no capacitance or inductance).

- Capacitance is measured in Farads (after Michael Faraday), abbreviated: 'F'
- Inductance is measured in Henrys (after Joseph Henry), abbreviated: 'H'

In electric equations: capacitance is abbreviated 'C', inductance is abbreviated 'L'.

### Electric Circuits

Electric circuits are created to take advantage of the abovementioned properties of electricity. In order to make electric circuits easy to document, just like music and the alphabet, symbols were created to represent the basic building blocks of circuits.

## Batteries

A battery is a source of power that provides a constant source of **voltage**. A battery supplies a circuit power, which means that it provides both voltage and current. However, an important distinction is that a battery provides a constant voltage; the current that a battery supplies is based on the circuit that surrounds it. A standard battery: AA, AAA, C, and D all provide 1.5 volts. A 9 volt battery, as the name implies, supplies 9 volts. A car battery supplies 12 volts.

A battery supplies direct current (DC) as opposed to mains power. Mains power is supplied from a wall outlet and provides alternating current (AC). An AC power source provides power at a specific alternating rate. In the United States, mains power provides 120 volts at a rate of 60 cycles per second, or Hertz (Hz). In Europe, mains power provides 230 volts at a rate of 50 Hz. AC power can be distributed exponentially more efficiently than DC power, which is why mains power is AC. AC circuits are much more complicated and the remainder of this document refers to DC circuits.

A battery is a two terminal device and the voltage that a battery supplies is the difference between the two terminals. A battery has a polarity associated with it, which means the order of the two terminals in a circuit matters. The two terminals are denoted positive (+) and negative (-). The circuit symbol for a DC battery is shown in Figure 1.

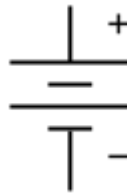


Figure 1: Battery Circuit Symbol

## AC/DC Converters

Most electronic devices need DC power. Since a wall outlet provides AC power, an AC to DC converter must be used. AC/DC converters typically look similar to Figure 2. An AC/DC converter, just like a battery, provides a specific DC voltage. The current that it provides is determined by the circuit that surrounds it. If you read the label on an AC/DC converter, it will list the voltage that it supplies as well as the **maximum current** that it is capable of supplying.



Figure 2: Typical AC/DC Converter

## Resistors

A resistor is simply a device that consumes electricity. Using this definition, almost anything in a circuit can be modeled as a resistor, such as: a light bulb, a heater, an electric motor, etc. The total resistance of a simple circuit determines how much current a battery supplies. Resistors are often used in circuits to control the amount of current provided to other components using Ohm's law. A resistor used in this fashion looks as seen below in Figure 3. A resistor is a two terminal device, but unlike a battery, is not polarized, which means the orientation is unimportant.



Figure 3: Resistor

The color bands on a resistor can be used to determine the resistance value of a resistor using Figure 4 below. In a four band resistor, as in Figure 3, the first two bands refer to the significant digits, the third band refers to the magnitude and the fourth band refers to the tolerance. In the example above, the color bands are: Orange-Orange-Brown-Gold, which is  $33 \times 10$  or  $330 \Omega$  with a tolerance of 5%.

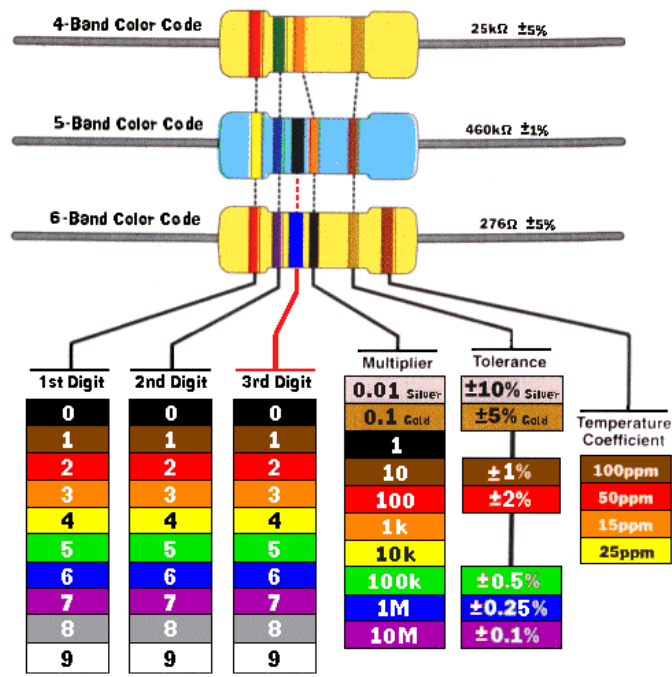


Figure 4: Resistor Color Codes

Resistors dissipate power, but also have a maximum power rating. The resistor shown in Figure 3 is a standard ¼ Watt resistor. The circuit symbol for a resistor is shown below in Figure 5.



Figure 5: Resistor Circuit Symbol

A typical circuit will contain more than one resistor. In this case, the equivalent resistance can be determined. When resistors are in series, as in Figure 6, their resistance can be added together.

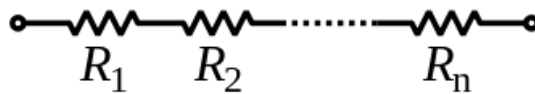


Figure 6: Resistors in Series

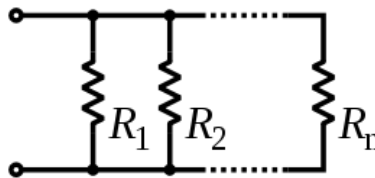


Figure 7: Resistors in Parallel

When resistors are in parallel, as in Figure 7, their resistance can be determined using the following equation:

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \dots + \frac{1}{R_n}$$

In a simple circuit with a battery and resistor, as shown in Figure 8, Ohm’s law is used to determine the current provided by the battery. If the battery is a AA battery providing 1.5 volts and the resistor is a 100 Ω resistor, then using  $V = IR$ , the current is 0.015 A, or 15 mA. Resistors consume the voltage in a circuit that a battery supplies.

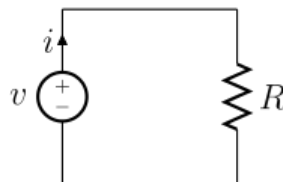


Figure 8: Simple Circuit

## Diodes

A diode is an electric component that is used to help regulate the direction of current flow. An analogy with water would be a check valve, which allows water to flow in only one direction. A diode is a polarized two terminal device. One terminal is referred to as the anode, while the other is referred to as the cathode. Current can only flow from the anode to the cathode. Current flows from the positive terminal of a battery towards the negative terminal. In the simple circuit shown in Figure 8, the arrow indicates the direction of current flow. The circuit symbol for a diode is shown in Figure 9, with labels indicating the anode and cathode (not shown in the symbol). The triangle in the symbol can be used to help remember the direction of current flow. A typical diode will consume about 0.7 volts when current flows through it, but does not control the current in a circuit.



Figure 9: Diode Circuit Symbol with Labels

## Light Emitting Diode (LED)

An LED is a special type of diode that emits light when current flows through it. An LED behaves exactly as a diode in a circuit and will also regulate the direction of current flow. However, an LED will consume slightly more voltage. A typical LED will consume around 1.7 volts, although different colors consume different voltages. The circuit symbol for an LED is shown in Figure 10. The current flowing through an LED will dictate the brightness, the more current, the brighter the LED. However, since LEDs do not regulate current, a resistor must be used in series with an LED to control the current flow. A typical LED requires 20 mA for normal brightness.



Figure 10: LED Circuit Symbol with Labels

## Ground

As mentioned in the voltage section, voltage is the measure of a difference between two points. A circuit thus needs a zero voltage reference point, referred to as ground. The circuit symbol for ground is shown in Figure 11.



Figure 11: Ground Circuit Symbol

## Voltage and Current Behavior in a Circuit

A circuit consists of branches and nodes. The boundary of a node is defined when a wire meets another component. The boundary of a branch is defined when a wire splits into multiple wires. The **voltage** at each node in a circuit will be the same, while the **current** in each branch will be the same.

The simple circuit in Figure 8 consists of only one branch as there is only path to take from the positive to the negative terminal of the battery; however, there are two nodes, one connecting the positive terminal of the battery to the resistor, and the other connecting the resistor to the negative terminal of the battery.

The circuit shown in Figure 12 still contains only 2 nodes: one node connecting the positive terminal of the battery with both resistors, and a second connecting the resistors to the negative terminal of the battery. However, the circuit contains three branches: one that runs from the wire split through the battery to the other wire split, one that runs from the wire split through R1 to the other wire split, and one that runs from the wire split through R2 to the other wire split. Figure 13 shows the three branches. Figure 14 shows the two nodes.

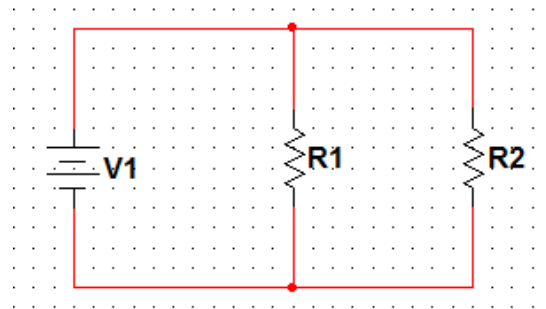


Figure 12: Example Circuit

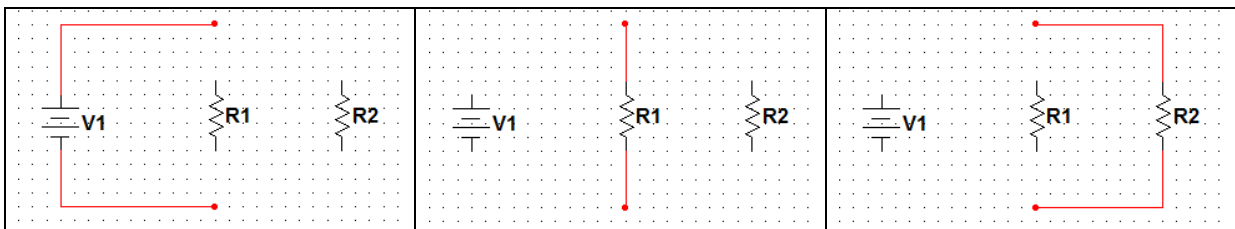


Figure 13: Example Circuit Branches

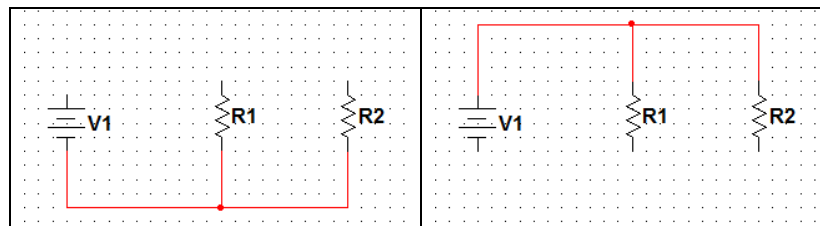


Figure 14: Example Circuit Nodes



To take a voltage measurement, the probes must be connected to the two nodes of interest.

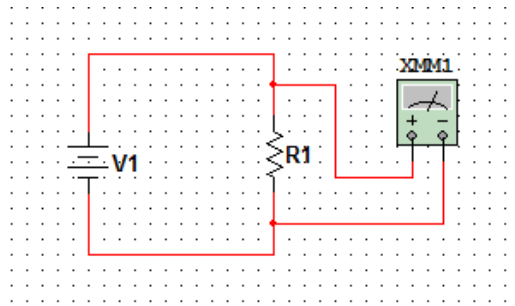


Figure 16: Voltage Measurement

### AC Voltage Measurements

In order to select and measure AC voltages, use the 12 o'clock to the 2 o'clock positions of the dial. In this mode, the red probe should be in the right connector (V $\Omega$ mA). This mode works exactly as the DC voltage mode. This will give you the root-mean-squared (RMS) value of the AC voltage.

### DC Current Measurements

In order to select and measure DC currents, use the 2 o'clock to the 5 o'clock positions of the dial. In this mode, the red probe should be in the right connector (V $\Omega$ mA) for all but the '10A' mode. Just as with the voltages, the DMM is capable of measuring a wide range of currents. Typically currents in DC circuits will be small, and as such the DMM can measure from micro-amps (0.000001 amps) to 10 amps. The appropriate scale should be selected on the dial for measurements.

To take a current measurement, the branch of interest must be broken with the probes inserted in series with the break to complete the circuit.

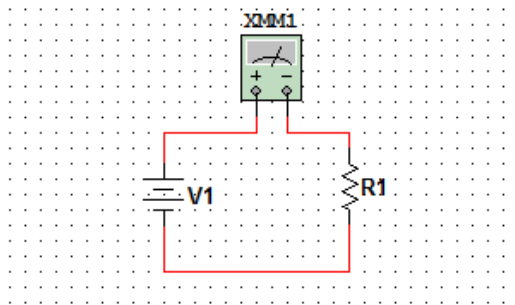


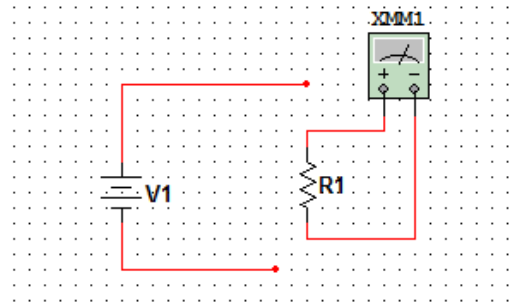
Figure 17: Current Measurement

### Resistance Measurements

In order to select and measure resistances, use the 6 o'clock to the 9 o'clock positions of the dial. In this mode, the red probe should be in the right connector (V $\Omega$ mA). Just as

with voltages and currents, the DMM is capable of measuring a wide range of resistances, from ohms to mega-ohms (1,000,000 ohms). The appropriate scale should be selected on the dial for measurements.

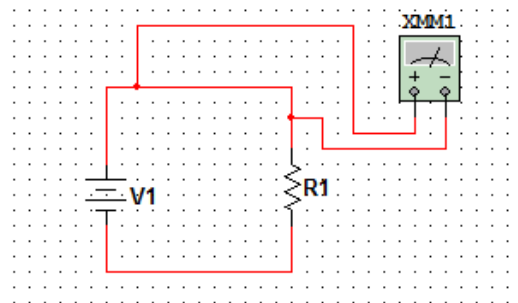
To take a resistance measurement, the probes must be connected to the two terminals of the resistor. In order to take accurate resistance measurements, the resistor must not be in the circuit when taking a measurement.



**Figure 18: Resistance Measurement**

### **Continuity Measurements**

The continuity mode is at the 5 o'clock position of the dial. In this mode, the red probe should be in the right connector (VΩmA). The continuity mode is very useful for troubleshooting circuits. This mode is used to test if there is a direct connection (minimal resistance) between the two probes.



**Figure 19: Continuity Measurement**