BASIC ELECTRONICS FOR AUTOMOTIVE ENTHUSIASTS

INTRODUCTION

Once upon a time, long ago, a person did not need to know a lot about electronics when it came to automotive engines, since about the only things electrical were the ignition and starting/charging systems. Today nothing could be farther from the truth. With the computer-controlled systems in use now, a basic understanding of electronics is invaluable to the do-it-yourselfer. The purpose of this article is not to make an electrical engineer out of the reader (you have to pay big bucks for that), rather to make the average automotive enthusiast knowledgeable when it comes to basic electronics so that he/she may do his/her own electrical troubleshooting and repairs, and maybe even save a buck or two.

One thing to keep in mind while reading is that this is all based on theory, which is rarely (if ever) the same as reality. For example, an automotive battery is usually rated at 12 Volts, right? We all know from experience that if we put a volt meter across a battery's terminals we will not read exactly 12 Volts, whether the battery is fully charged or not. This does not mean that the battery is defective, just that we need to accept the fact that theory and reality are two different animals.

THE LANGUAGE

Let us start with some basic terminology. Obviously, electronics must have something to do with electrons, right? There is no need to go into involved physics or chemistry here, but a fundamental understanding is helpful. All matter is made up of atoms. Atoms have negatively charged electrons orbiting their nucleus (the ones that we care about anyway). Some materials allow electrons to "jump" from atom-to-atom. These materials are called electrical *conductors*. Copper is a very good electrical conductor. Some materials do not allow movement of electrons between atoms. These materials are called electrical *insulators*. Rubber is a very good electrical insulator. *Voltage* refers to electrical "pressure" (or potential), an abundance of electrons just waiting for somewhere to go. Voltage is represented by the letter 'V' (some old-schooler's use the letter 'E') and is measured in (you guessed it) Volts. When these electrons start to move from atom to atom through a conductive material this is called *Current*. Current is represented with the letter 'I' (for 'I'ntensity) and is measured in Amperes, or Amps, or simply the letter 'A'. Any restriction to current flow through a conductor is called *Resistance.* Resistance is represented by the letter 'R' and is measured in Ohms (or the Ω symbol).

THE INEVITABLE "OHM'S LAW"

The study of electronics comes with the necessity for some math, the most basic of which is Ohm's Law. Ohms Law deals mostly with the relationships of these three fundamentals- Voltage, Current, and Resistance. The need to understand Ohm's Law cannot be emphasized strongly enough. According to Ohm's Law the amount of current flow through a conductor is a function of the voltage applied to the conductor divided by the resistance of the conductor. (A note here, voltage DOES NOT flow, current does) Stated mathematically:

$$I = \frac{V}{R}$$

Of course this formula can be re-arranged so that as long as any two values are known the third can be calculated:

$$R = \frac{V}{I}$$

$V = RI$ (read “Voltage equals Resistance times Current”)

So, lets apply this to a very simple circuit by (hypothetically) connecting a light bulb that measures 10Ω (ohms) resistance across the leads of a 12 Volt battery. With a 12 Volt battery and a 10Ω resistance, we divide 12 by 10 to come up with 1.2 Amps flowing through the bulb. In this example the bulb may also be referred to as the *Load* of the circuit.

Why would we connect a light bulb to a battery…to make it give off light, of course! This brings up another parameter that must always be considered; Power dissipation. When electrons move through a conductive material they create friction, this friction generates power that must be dissipated. In the case of the light bulb this power is released as light (and heat). Power is represented by the letter ‘P’ and is expressed in Watts. Power is a function of current multiplied by resistance, or:

$P = IV$

In the previous example we had 1.2 Amps flowing through a light bulb with 12 Volts applied to the bulb. Multiplying 12 Volts by 1.2 Amps the bulb must dissipate 14.4 watts of power (in the form of light and heat).

Many electronic components are rated by the amount of power that they can safely dissipate before burning up. Some are rated by the maximum allowable current flow, some by the maximum voltage that may be applied to the component.
Some examples:

- Resistors are rated by maximum power dissipation.
- Diodes are typically rated by maximum current flow.
- Capacitors are rated by maximum allowable applied voltage.

(More on diodes and capacitors later)

Example:
To calculate how much current a ¼ watt resistor can tolerate with 12 volts applied we would re-arrange the power formula to solve for current:

$$I = \frac{P}{V}$$

so that 0.25W/12V 0.021A max. (means “*approximately equal to*”)

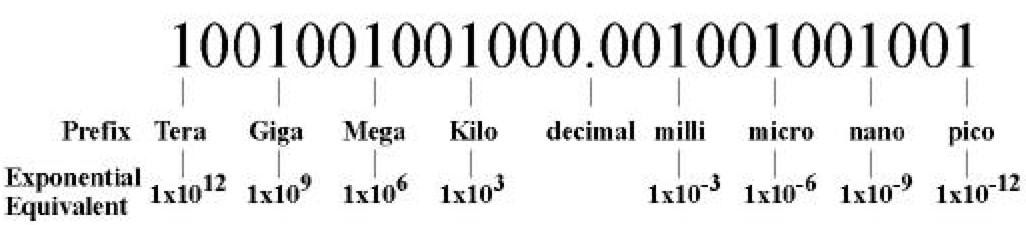
And since $R = \frac{V}{I}$ if we divide 12V/0.021A we know that the smallest value of ¼ watt resistor that can be used is approximately 571Ω. Anything smaller in resistance would allow more current to flow thus exceeding the power rating of the resistor and it would go up in smoke! This can be a rather visually spectacular (and sometimes costly) event.

An important thing to recognize here is that there MUST physically exist a path from one battery terminal (or any other voltage source) to the other in order for current to flow and activate any electronic device (or load) be it a light bulb, a motor, or anything else.

This brings up a much-debated question: "*In what direction does the current flow?*" Some people claim that current flows from positive to negative, some claim that it flows from negative to positive. Well guess what…they're BOTH right! Remember that current flow is when an electron "jumps" from one atom to another. When this electron leaves an atom it leaves a "hole" in that band of the atom that it just left. These "holes" can be thought of as flowing in the opposite direction of the electrons, thus the reason that both statements can be correct. Electron Flow (the direction of the electrons themselves) is from negative to positive, Conventional Flow (the direction of the holes) is from positive to negative. Both methods of current flow are correct and sometimes interchanged in educational courses, making things somewhat confusing. For example, in a battery (automotive or otherwise) the negative terminal has the abundance of electrons while the positive terminal has very few (as long as the battery is charged), thus creating a voltage potential, or electrical pressure between the battery's terminals. It is the alternator's job to replenish the negative terminal with fresh electrons as the battery is "drained" (electrons flowing from the negative terminal, through the various electrical systems, back to the positive battery terminal). For our purposes we will stick with Conventional (hole) flow (from positive to negative), as this seems to be the most commonly used and easiest to understand.

ENGINEERING NOTATION

You see it every day, Mega-this…Giga-that…these are a type of scientific notation used quite frequently in electronics and computers. A good way to understand engineering notation is a graphical representation of the good-ole number line (this is not a binary representation, the "1's" indicate the significant positions of engineering notation):



All of the engineering notation prefixes are represented with the first letter of the prefix with the exception of *micro*, which is represented with the Greek symbol "μ".

***FYI: Exponents are sometimes represented simply with the capital letter "E", especially on calculators and in computer applications. For example,* $5x10^3$ *(5,000) would read as* 5E3.**

Some common examples:

- Resistors are most often expressed in *Kilo*-Ohms (KΩ). 1KΩ is equal to 1000 or $1x10^3$ Ohms.
- Current is often expressed in *milli*-Amps (mA). 5mA is equal to 0.005 or $5x10^{-3}$ Amps.
- Capacitors are mostly rated in *micro*-Farads (μF), *nano*-Farads (nF), or *pico*-Farads (pF). Some common values:
  - 47μF is equal to 0.000047 or $47x10^{-6}$ Farads.
  - 15nF is equal to 0.000000015 or $15x10^{-9}$ Farads.
  - 22pF is equal to 0.000000000015 or $22x10^{-12}$ Farads.

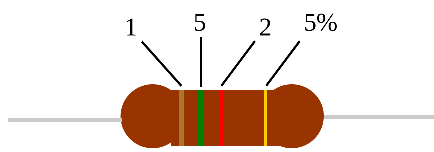
Notice that the exponents in engineering notation are always a multiple of three!

IDENTIFYING RESISTOR VALUES

Resistors that are used on a “Thru-Hole” PC board are identified with color bands. Each color represents a number as follows:

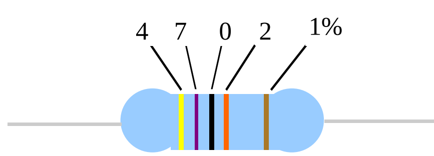
	BLACK	0
	BROWN	1
	RED	2
	ORANGE	3
	YELLOW	4
	GREEN	5
	BLUE	6
	VIOLET	7
	GRAY	8
	WHITE	9

5% tolerance resistors are typically tan (or dark brown) in color and usually have four color bands, only the first three of which identify the value of the resistor (there is usually a noticeable space between the third and fourth bands). The first two are values and the third is the “multiplier” or the number of zeros to add to the first two numbers. For example if the first three bands are BROWN | GREEN | RED you would read a “1”, then a “5”, then “2” zeros, or 1,500 Ohms, or 1.5KΩ. The fourth band is the tolerance band. The tolerance band indicates how much variation is possible from the indicated resistance value. A gold tolerance band represents a possible 5% deviation, silver is 10%, no tolerance band is 20% (10% and 20% resistors are rare).



1,500 (1.5K) Ohm 5% resistor

1% tolerance resistors are typically blue in color and usually have five color bands, only the first four identify the value of the resistor (again, there is usually a noticeable space between the fourth and fifth bands). The first three are values and the fourth is the “multiplier” or the number of zeros to add to the first three numbers. The fifth band is once again the tolerance band. 1% resistors always have a brown tolerance band. For example if the first four bands are YELLOW | VIOLET | BLACK | RED you would read a “4”, then a “7”, then a “0”, then “2” zeros, or 47,000 Ohms, or 47KΩ.



47,000 (47K) Ohm 1% resistor

"Surface Mount" (SM) resistors (no leads) are identified similarly, except instead of color bands they have numbers written right on the resistor (except for the really small ones that aren't big enough to put numbers on). 5% tolerance SM resistors are usually black and typically have three numbers, the first two being values and the third is the "multiplier". 1% tolerance SM resistors are usually blue and typically have four numbers, the first three being values and the fourth is the "multiplier". (Some 1% SM resistors are black, but will normally have four numbers.) For example a 1.5KΩ 5% tolerance resistor would read "152" ("1", "5", and "2" zeros) and a 47.5KΩ 1% tolerance resistor would read "4752" ("4", "7", "5", and "2" zeros). A 10KΩ 5% SM resistor (black) would read "103" where a 10KΩ 1% SM resistor (black or blue) would read "1002".

1,500 (1.5K) Ohm 5%
Surface-Mount resistor

4,750 (4.75K) Ohm 1%
Surface-Mount resistor

IDENTIFYING CAPACITOR VALUES

Capacitors are marked one of two ways.

- Larger capacitors (usually polarized) will have the value written directly on the capacitor, typically larger than 0.1µF (*micro*-Farads)
- Smaller capacitors (usually non-polarized) may be marked identically to SM resistors, but have only three numbers. This method is always marked in pF (*pico*-Farads). For example a capacitor with the number 220 would read "2", "2", and no zeros or 22pF. Larger value capacitors that are physically small may also be marked using this method. For example a 1.0ìF capacitor might be marked 105 which would be read "1", "0", and "5" zeros which comes to 1,000,000pF, or 1.0µF (if the conversion from 1,000,000pF to 1.0µF doesn't "click" refer back to the number line).

POLARIZED VS. NON-POLARIZED CAPACITORS

As mentioned previously, capacitors are typically rated by the capacitance (in Farads) and by the maximum voltage that may be applied to the capacitor. Some capacitors are polarized, meaning that which lead is connected to the voltage source (whether a positive or negative voltage) and which is connected to ground is very important. These are typically 0.1µF or larger. The most common type of polarized capacitor (Electrolytic) is of a cylindrical shape and has the negative lead marked with a series of "-" signs along the length of the capacitor (usually this lead is also shorter than the positive lead). With polarized capacitors the negative lead MUST be connected to a lower voltage than the positive. Since automotive systems mostly deal with positive voltages, the negative lead is usually connected to the system ground and the positive lead to a positive voltage.

These few examples do not by any means cover all of the possibilities when it comes to identifying resistor/capacitor values, just some of the more common ones.

FYI:

Q) IS A MEGABYTE (MB) REALLY A MILLION BYTES?   A) NO.

Digital information is stored as binary bits. One bit can only have two states, 0 or 1. This means that one "address" bit can access only two memory locations (or CELLS): CELL_0 and CELL_1. Two address bits can access 2x2, or four possible memory locations. Three bits can access 2x2x2, or eight possible memory locations. A pattern starts to become visible in that the number of possible locations that can be addressed is equal to 2^n (2 to the power of "n"), where "n" is equal to the number of "address" bits. As we keep adding one bit at a time then:

$2^1 = 2$

$2^2 = 4$

$2^3 = 8$

$2^4 = 16$

$2^5 = 32$

$2^6 = 64$

$2^7 = 128$

$2^8 = 256$

$2^9 = 512$

$2^{10} = 1024$

This is where the notation starts. 1 KB (Kilo-Byte) of digital storage is actually 1024 memory locations or "addresses". Since 1,000,000 is equal to 1,000x1,000 then a MB is equal to 1,024x1,024 bytes, or 2^{20} which comes out to 1,048,576 bytes, not an even million. This means that in order to access 1MB of memory, 20 "address" lines (bits) are required between the microprocessor and the memory device(s).

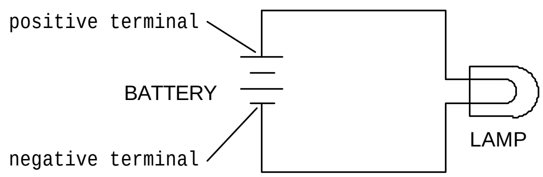
AC/DC

Before becoming the name of the great rock-'n-roll band, AC/DC was the abbreviation for Alternating Current and Direct Current, respectively. Alternating Current meaning that the direction of electron flow is constantly changing. Direct Current meaning that the electrons are always flowing in one direction only.

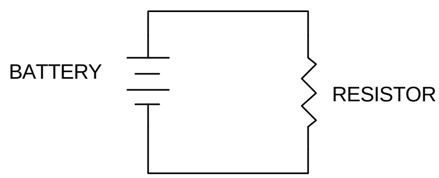
In this section the reader will be introduced to some common schematic symbols as well as some very basic DC and AC circuits.

DIRECT CURRENT (DC)

The most basic DC circuit would consist of a voltage source and a load, such as our battery and lamp circuit. Shown schematically:

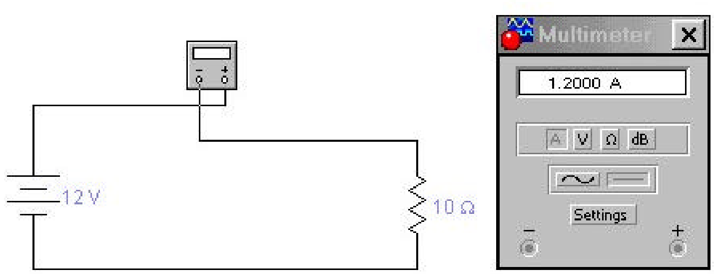


Since a simple DC lamp is nothing more than a resistor that emits light, we can show this same circuit using a resistor instead of a lamp:



So lets give these components some values and analyze this circuit. We'll say the battery is 12V and the resistor is 10Ω.

Since $I = \frac{V}{R}$ we would divide 12 by 100 to come up with 1.2Amps flowing through the resistor, as shown in the following simulation:



Obviously if a Voltmeter is placed across the resistor the reading will be 12V since it's basically connected directly to the battery's terminals. This can also be proved mathematically since $V = RI$ we would multiply 10Ω by 1.2 Amps to come up with 12 Volts.

Notice that in order to measure current the circuit MUST be broken and the meter placed in series in the circuit. In this example it would not matter if we placed the meter between the positive terminal of the battery and the resistor, or between the negative terminal of the battery and the resistor. The only thing to keep in mind is the polarity of the meter leads. Notice in the simulation diagram that the meter's positive lead is connected to the positive terminal of the battery, and the negative lead to the resistor. If the leads of the meter were reversed, the meter would read –1.2 Amps.

SERIES RESISTOR CIRCUIT: THE VOLTAGE DIVIDER
The basic Voltage Divider circuit consists of a voltage source and two resistors in series, as shown below:

Notice now that each component has a unique identifier: V1, R1, and R2. These are called *Reference Designators*.

To easily find out the voltage at the node where R1 and R2 connect we would use the Voltage Divider formula:

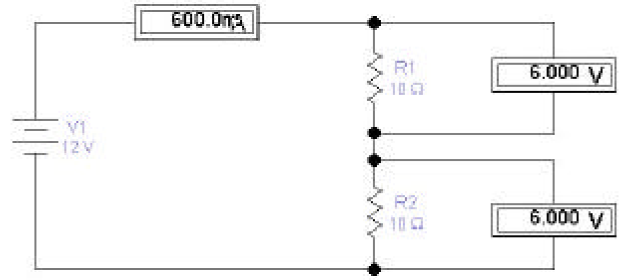
$V = \frac{R2}{R1 + R2}(Vsource)$ where V is the voltage at the R1/R2 junction and $Vsource$ is the voltage applied to the circuit, or the battery voltage in this case. So let's crunch the numbers:

$V = \frac{10}{10 + 10}(12)$ which comes out to 6V. Notice that this is exactly one-half of the battery voltage. As a rule if the two resistors are equal (regardless of the value) then the voltage at the junction where the two resistors connect will be half of the applied voltage.

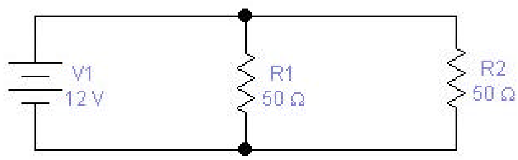
Another way to calculate the voltage at the R1/R2 junction would be to calculate the current flow through the circuit then multiply that current by each resistor value.
In a series resistor circuit the total resistance is found by simply adding all of the resistor values. In this case 10 + 10 = 20Ω total resistance, or Rt (R total)

Since $I = \frac{V}{R}$ then we take the 12V source and divide by Rt of 20Ω to come up with 0.6Amps (or 600mA). Then take the 0.6A and multiply that by 10 and come up with a 6V "drop" across each resistor. See the simulation diagram below.

In a series resistor circuit all of the resistor voltage drops will add up to the applied voltage.



PARALLEL (or shunt) RESISTOR CIRCUIT
When resistors are connected in parallel, as shown below:



then the formula for calculating the total circuit resistance is:

$$Rt = \frac{1}{\frac{1}{R1} + \frac{1}{R2} + \frac{1}{Rn}}$$ where *n* represents the total number of resistors in parallel.

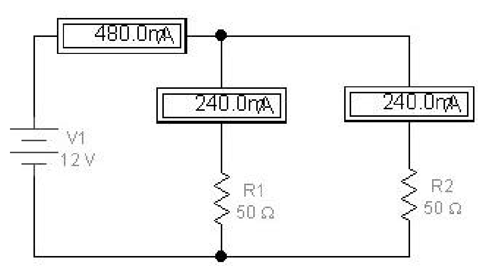
Using this formula the total parallel resistance comes out to be 25Ω. It's no coincidence that this is exactly half of each resistor value. When all of the resistors are equal in a parallel resistor circuit then the total resistance is equal to the resistor value divided by the total number of parallel resistors.

Once again if we place the leads of a voltmeter across either resistor we will read the battery voltage since we're measuring directly at the battery's terminals. What happens when a resistor is connected in parallel with another resistor is that another path for current flow is added.

The total current flow in a parallel resistor circuit is the sum of the current flow through each resistor. Stated mathematically:

$$It = \left(\frac{V1}{R1}\right) + \left(\frac{V1}{R2}\right)$$ (*It* represents *Itotal*, or the total circuit current)

After crunching the numbers we find that there is 0.24A (or 240mA) flowing through each resistor for a total of 0.48A (or 480mA) being drawn from the battery, as shown in the following simulation:



…to be continued with intro. to AC