Basic Electricity Part2

Notation, resistors and Ohm's Law.

Ron C. Johnson

Whether you are starting out in electronics, golf, playing the piano, or basket weaving the same principles apply: Get the basics down cold and you'll be off to a good start. From there you can work your way into the more complex stuff with a minimum of problems. (That's what I did, and today I'm an incredible basket weaver.)

So fasten your seat belts, grip your calculator firmly, and take a deep breath...

We now enter the land of the mobile Ohm.

No doubt you have spent the last month wondering why you would want to know about Ohm's Law anyway. Though the math is simple and you probably had no trouble with it, you may have been building projects for years and never needed to use it. Just the same, Ohm's Law will help in understanding the concepts to come later. Also you may be interested in designing some of your own projects, in which case this will all be useful. Another electrical law we will talk about this month is Kirchoff's Voltage Law. Again, though basic and a bit math oriented, this is useful in understanding how circuits work.

I said last month we would get into some circuits and some of the components used in them. First, though, we should establish a common numbering system and standard coding for resistors, capacitors and other components so that we are talking the same language later on.

Counting Like Scientists And Engineers

In electronics, as we said last month, mathematics plays an important role in determining the quantities of various parameters. We talked about voltage, current, resistance and power to start with. These are all determined with math and can have values which range from extremely small to extremely large. In order to express these numbers without filling pages with zeros we use a system of numbering called *scientific notation*.

In scientific notation we take a number like 2,540,000 volts, which is the same as 2.54 X 1,000,000 volts, and express it as 2.54 X 10^6 volts.

For those of you not familiar with this notation, our goal is to make a shorter expression of the same number. 1,000,000 is the same as 10^6. When we multiply it times the 2.54 we end up with the original number.

Similarly, we can express .00000001579 Amps as 1.579 X 10^{-8} Amps.

The easy rule to remember is that when we convert a number to scientific notation we count the number of decimal places we will move the decimal point and use that number as the exponent of ten. If we move the decimal to the left (in a large number), the exponent is positive. If we move the decimal to the right (in a small number), the exponent is negative.

That is scientific notation.

In *engineering notation* we shorten up the number even further by using prefixes before the units we are expressing. The common prefixes which correspond to exponents of ten are given in Figure 1. Referring back to our examples, for the first one we can take the prefix "mega" from the table (as it corresponds to 10^6) and we get 2.54 mega volts, or 2.54MV.

In the second example we have an exponent of ten to the -8. From the table we can see that there is no prefix for 10^{-8}, so we must move the decimal right one place so that we have 10^{-9}, which has the prefix "nano". This gives us 15.79 nano amps, or 15.79nA.

When converting to engineering notation the rule is that the first part of the number should be between 0 and 999. By choosing to place the decimal point so that the number falls in that range you can always find an exponent of ten for which there is a common prefix.

Probably most of you have encountered these systems of notation before, but maybe you haven't used them for a while. In Figure 2 a table of electrical quantities with their scientific and engineering notations has been set up. If you want practice in converting, just cover the middle and right columns with a piece of paper and do the conversions yourself. Then uncover the answers and see how you did. (Betcha nobody does them!)

Okay, now I have you all convinced that the rest of this is going to be pure math. Right? No. We'll try to keep it to a minimum. What we really need the engineering notation for right now is to understand the resistor color code.

Fig. 1: Prefixes for Engineering Notation

Prefix	Symbol	Multiplier	Exponent
Giga	G	1,000,000,000	10^9
Mega	M	1,000,000	10^6
Kilo	K	1,000	10^3
milli	m	.001	10^{-3}
micro	u	.000001	10^{-6}
nano	n	.000000001	10^{-9}
pico	p	.000000000001	10^{-12}

Fig. 2 Table of Electrical Quantities with Scientific Notation and Engineering Units

Electrical Quantity	Scientific Notation	Engineering Units
254,200,000 volts	$2.542 X 10^8$	254 Megavolts
.00276 Amps	$2.76 X 10^{-3}$	2.76 milliamps
8990 ohms	$8.99 X 10^3$	8.99 kilo ohms
750,000 watts	$7.50 X 10^5$	750 kilowatts
.0000047 Siemens	$4.77 X 10^{-6}$	4.77 microSiemens
.000000000012 Farads	$1.2 X 10^{-11}$	12 picoFarads

Violet And The Bad Boys

Resistors (and, less often, capacitors) use a code consisting of bands (or sometimes dots for capacitors) of color on the component to indicate the value of the component. We learned last month that resistors are the components which have the property of resistance built into them. Resistance is that property which opposes the flow of current in a circuit and is measured in ohms. The colored bands on a resistor give us the value of resistance and the tolerance of the resistor. The tolerance is an indication, in percent, of how precisely the resistor was manufactured. If it has a ten percent tolerance the actual value of the resistor will be within plus or minus ten percent of the value given by the colored bands on it.

Figure 3 shows a resistor, its bands, and the corresponding values of the color code.

The mnemonic used to remember the color code, (or at least the one that is printable) is:

Bad Boys Race Our Young Girls But Violet Generally Wins.

(Good Stuff!)

Figure 3 shows how the first letter of each word of the mnemonic represents a color and its value. Note that the first two bands give the first two digits, the third gives a multiplier (which corresponds to an exponent of ten), and the last band is the tolerance. If there is no fourth band the tolerance is assumed to be 20%.

Sometimes there are five bands on resistors. These are usually precision resistors and the extra band (the third one) is an extra digit to more precisely indicate the value of the resistor.

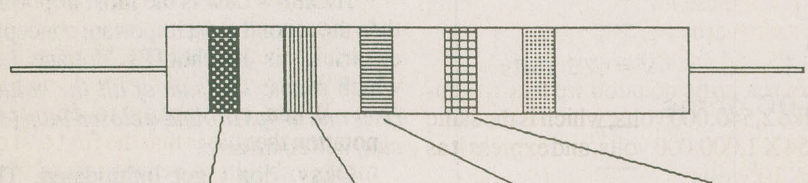
For all you keeners who want to practise determining values from the color code, Figure 4 gives several examples with their resistances. To practise, just cover the right hand column while you figure out the answers and then check to see how you did.

Onward And Upward

Let's get on with the good stuff then.

One of the last things we did last month was set up a simple circuit with a battery, wire, and a lamp. We calculated how much current was flowing, whether it was within the specs of the lamp, and how much power was being dissipated. That circuit was called a *series* circuit because everything was connected end to end. All the current in the circuit flowed through all the components. (Note that whenever we talk about current we say that it flows "through" a component or conductor.)

If all the current flows through all of the components, what would happen if the wire became disconnected from the battery or if the filament of the lamp burnt out? Obviously there would no longer be a path for current to flow and all of the current would stop. (Remember we must have a complete circuit or circle for current to flow in.) This is called an *open cir-*



Colour	Band #1 Digit 1	Band #2 Digit 2	Band #3 Multiplier	Band #4 Tolerance
Black	0	0	10^0	-
Brown	1	1	10^1	1
Red	2	2	10^2	2
Orange	3	3	10^3	3
Yellow	4	4	10^4	4
Green	5	5	10^5	-
Blue	6	6	10^6	-
Violet	7	7	10^7	-
Grey	8	8	10^8	-
White	9	9	10^9	-
Gold	-	-	10^{-1}	5
Silver	-	-	10^{-2}	10

Fig. 3. The resistor color code.

Colour code	Equivalent Resistance
Red, Red, Orange, Gold	22 Kohm, 5 %
Green, Blue, Gold, Gold	5.6 ohms, 5 %
Grey, Red, Red, Silver	8.2 Kohm, 10 %
Brown, Black, Brown	100 ohms, 20%
Orange, Orange, Blue, Gold	33 Megohm, 5 %
Yellow, Violet, Yellow, Silver	470 Kohms, 10%

Fig.4. Examples of the color code.

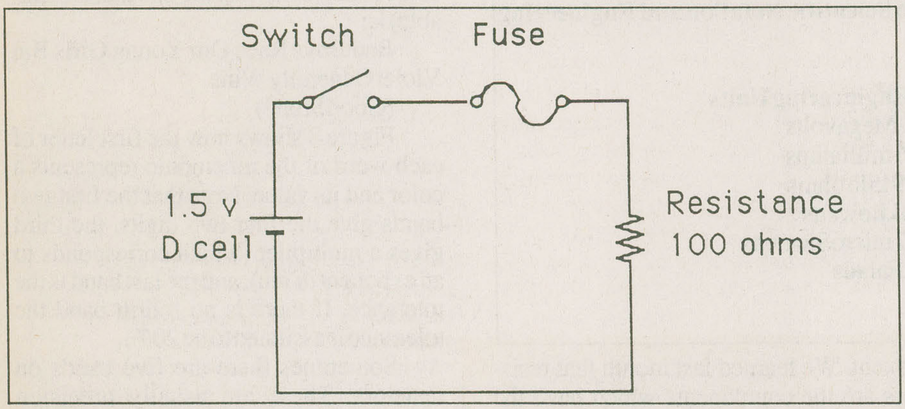


Fig.5. A series circuit.

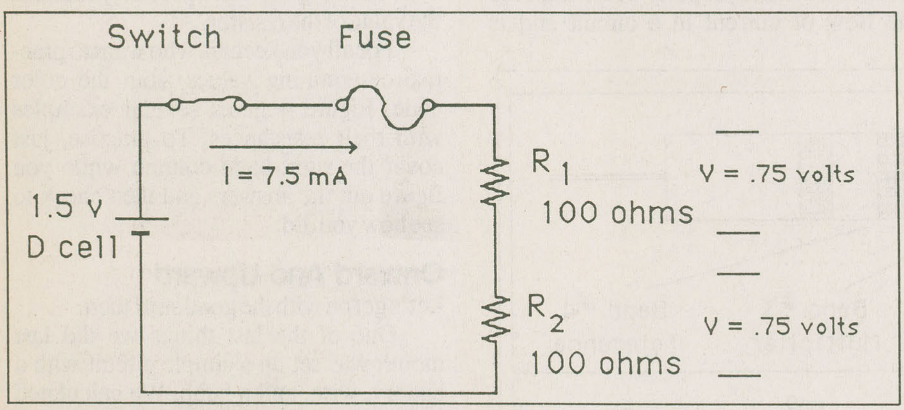


Fig.6. A series circuit with two resistances.

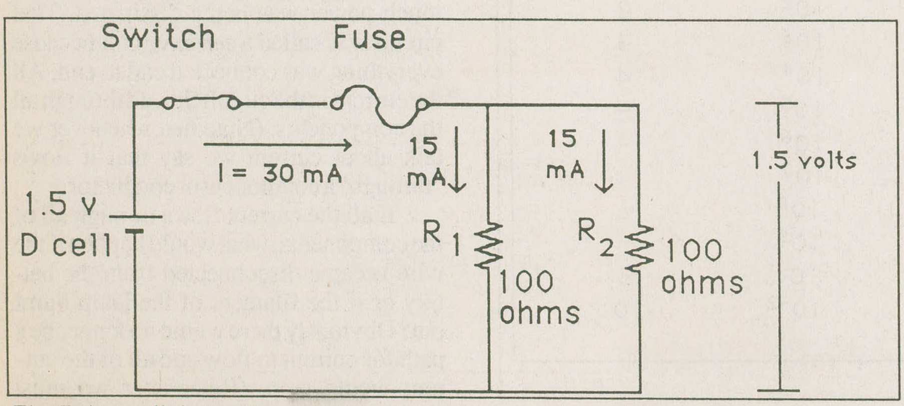


Fig.7. A parallel circuit.

cuit.

In Figure 5 we have the same circuit, but now we have added a switch and a fuse. Both of these are used to create open circuits. The switch is there so you can turn the lamp on and off by interrupting the flow of current to it. The fuse is a safety device. It is constructed in such a way that if the current exceeds its rated value the internal link will melt and create an open circuit so that current can no longer flow. When the circuit is originally designed we determine what is the maximum current we would ever want to flow and choose a fuse with a current rating slightly higher than that. If the current ever reaches that level the internal link melts and current stops.

Kirchoff's Law: Adding Up To Nothing

Let's talk about voltage now. In the last issue we said that when voltage is supplied by a battery or other power source (called a *voltage rise*) we labelled it "E" and if we were talking about a voltage dropped across a resistor or other device we labelled it "V". We also said that, according to Ohm's Law: V = I X R, or we could say the voltage dropped across a resistor is equal to the resistance times the current through it.

If Ohm's Law is the most important, then the second most important concept in electricity is Kirchhoff's Voltage Law which states: *The sum of all the voltage rises and drops around a closed loop (circuit) will equal zero.*

Okay, don't get intimidated. This isn't Electricity 101. If you never remember the name Kirchhoff again it's really not that important. The important thing is the concept.

If we look at our circuit in Figure 5 (with the switch closed), we see that the battery supplies 1.5 volts. That is a voltage rise. We calculated last time that the current in the circuit was .015 amperes. (15mA according to engineering notation.) If we use Ohm's Law to multiply the current through the resistor times the resistance, we find that there is 1.5 volts dropped across the resistor. If we note the polarities of the battery and the voltage dropped across the resistor we will see that they are opposite, or oppose each other. If we add them algebraically the sum is zero.

Kirchhoff would be proud of us.

This may not seem very profound in a simple circuit, but it comes in very handy a little later on, so let's look at another simple circuit.

The circuit in Figure 6 is still a series circuit. How do we know? Because there is only one path for current and so it flows through all of the circuit components. In this case, however, we have two resistances connected end to end. (Do you remember the old series Christmas tree lights? Because all of the current flowed through all of the lamps, if one burnt out, creating an open circuit, they *all* went out.)

Let's consider what the relationships between voltage, current and resistance are in this circuit. Has the source voltage changed? No, the battery is still a 1.5 volt cell. Has the circuit resistance changed? Yes, because now instead of one 100ohm resistor we have two. When two resistors are connected in series we can add their values to get the total resistance so: R_T = 100ohms + 100ohms = 200ohms.

If the resistance in the circuit has been doubled, what will happen to the current? Right, it will be one-half what it was before, because: I = V/R = 1.5V/200ohms = 7.5mA.

Now if we work backwards and multiply the current (7.5mA) times each of the resistors (100ohms), we find that each of them has .75 volts dropped across them. If we add those voltages up they will equal 1.5V which is the battery voltage. Again, Kirchhoff would smile approvingly.

We can call this circuit a *voltage divider* because the source voltage is divided between the two resistors. If the resistors were not the same values what would happen? A ratio of voltages would be dropped across them which would be proportional to the values of the resistors, and the total of the two voltage drops would always equal the source voltage.

Splitting The Current

Before we wrap up this month's segment we have to take a look at parallel circuits. Just as the name implies, the resistors in a parallel circuit are arranged in a parallel configuration (see Figure 7). Although you may not always see them drawn this way, if they are in parallel they can be redrawn such that they are parallel to each other because they will be connected together at both ends.

In the circuit in Figure 7 we can see that current will be sourced from the battery and will flow through R_1 (which originally was the resistance of our lamp filament). Because R_1 is connected directly across the battery, which is still 1.5 volts, and R_1 is still 100ohms, there should be: I = V/R = 1.5V/100ohms = 15mAmps.

Okay, I hear all those "but"s. You're saying "Why doesn't the current split and some of it flow through the other resistance?" Well, you are right. The current does split, but since R_2 is connected directly across R_1, and therefore the same 1.5 volts is also across R_2, there will also be 15mA flowing through R_2. If that is the case, then the battery must be sourcing both of those currents for a total of 30mA.

If the battery is supplying 30mA (15mA to each resistor), then what will Ohm's Law tell us about the overall resistance of the circuit?

R_{Total} = V/T = 1.5V/30mA = 50 ohms

The total circuit resistance is 50 ohms, one half that of each resistor. So we now know that connecting resistors in parallel *reduces* the total resistance. (Remember that in series circuits the resistors added together give the sum of the resistors.) The simple way of determining the equivalent resistors in parallel is to use *conductance*.

Arghh! Not more terms!

Sorry, but this one is easy. Conductance (symbolized by G, with units, Siemens) is the reciprocal of resistance: G = 1/R and conductances in parallel can be added together like resistances in series. After the total conductance is determined, we can convert back to resistance by: R = 1/G, so for Figure 7: G_T = 1/100ohms + 1/100ohms = 10mS + 10mS = 20mS. Converting back: R_T = 1/G = 1/20mS = 50ohms.

And that's what we determined it was before.

Enough. We can only take so many thrills at one time.

Next month we will look at series and parallel circuits together, short circuits, meters and how they are used, and tons of other good stuff. ■