To begin your study of Ohm's Law you'll need to measure the voltage across a resistor. Using a high impedance digital meter will prevent you from loading down the circuit.

UNDERSTANDING OHM'S LAW

At one time, some scientists considered Ohm's Law not to be worth the paper it was written on. But those scientists never put it to the test. When was the last time you did?

BY STAN CZARNIK

IT IS DIFFICULT, IF NOT IMPOSSIBLE, TO THINK ABOUT electrical resistance without also thinking about some form of mathematical representation. A digital readout, a moving needle, or even a color-coded resistor, it all comes down to numbers. That was not always the case.

Some of the first experiments in conductivity were those of the solitary English scientist, Henry Cavendish (1731–1810). Without access to batteries, Cavendish used primitive capacitors, called Leyden jars, as a source of current. Cavendish studied the effect known in modern electronics as voltage drop by directing static discharges through glass tubes of different sizes containing solutions of salt in water. But Cavendish had no measuring instruments. So he completed the test circuits with his own body and figured the various degrees of conductivity by the kind of shock he received: The first voltmeter was the human nervous system!

There were other studies of electrical conductivity. The French physicist Andre Marie Ampere (1775–1836) noted that conductors possess certain "imperfections." He called those imperfections resistance. But the precise relation of resistance to other electrical forces remained unclear.

A Web of Naked Fancies

What was needed was a way of representing those forces in an exact, unambiguous, quantitative fashion. That is the great historical contribution of Georg Simon Ohm (1787–1854).

Ohm's first formal investigations dealt with the length of a current-carrying wire and the attenuation of electromagnetic intensity due to its length. He also studied wire's made of different materials: gold, brass, platinum, lead, and so on. Ohm found that all conductors are not created equal, and that conductivity varied according to both a wires length and cross-sectional area. Those conclusions were made public in 1825.

Ohm's experiments did not impress his contemporaries very much, but Ohm continued his work anyway. He went on to confront the elementary forces and principles that make an electrical circuit what it is. He sought to define the interaction of three key variables. Those are: the electrical potential of a voltaic cell (later known as a thermocouple), the electromagnetic intensity, and the length of a connecting wire, or voltage, current, and resistance.

Those studies were followed by a comprehensive volume entitled *The Galvanic Circuit Mathematically Worked Out* published in 1827. Ohm's book was not greeted with a lot of enthusiasm. In fact, some of the comments were just plain hostile. One critic called it a "web of naked fancies." In other words: Crazy! The web of naked fancies contained Ohm's Law.

Many people have trouble with math, even fairly simple math. I am one of those people. But, Ohm's Law is fundamental to all electrical science, and understanding it can provide the confidence necessary to master more complicated formulas. And there are plenty of those both in and out of electronics.

Current

The fundamental form of Ohm's Law tells us that the level of current in a simple linear series circuit varies directly with the voltage and inversely with the resistance. In other words, current (in amps) equals potential difference (in volts) divided by resistance (in ohms). Algebraically, with I representing current, E standing for voltage, and R for resistance:

$$I = E/R$$

So let's see how that works out. Say you select a resistor and determine its value to be 218 ohms with a multimeter. If you connect the resistor to a couple of 1.5-volt batteries in series, and measure the voltage across the resistor, it should be about 3.00 volts. The current in the circuit can now be predicted by dividing 3.00 by 218. According to my pocket calculator, that equals .013, or 13 milliamps. Check that figure by opening the circuit and measuring the actual current. You will find that predicated value and the actual value are very close.

Repeat the exercise with a few other resistors until you are comfortable with the results. Remember, the numbers you obtain are important, but not nearly as important as your understanding of the relationships involved.

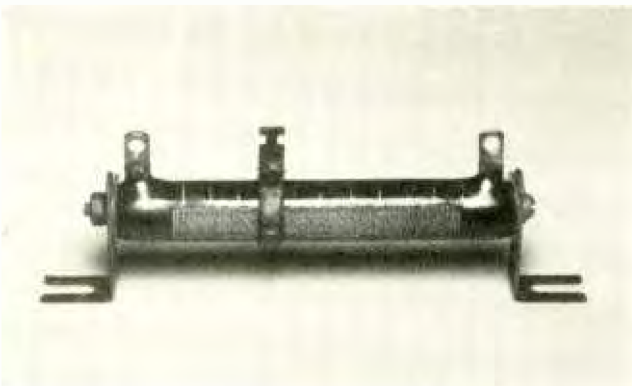
Resistance

The second form of Ohm's Law tells us that resistance equals voltage divided by current. Expressed mathematically, that is:

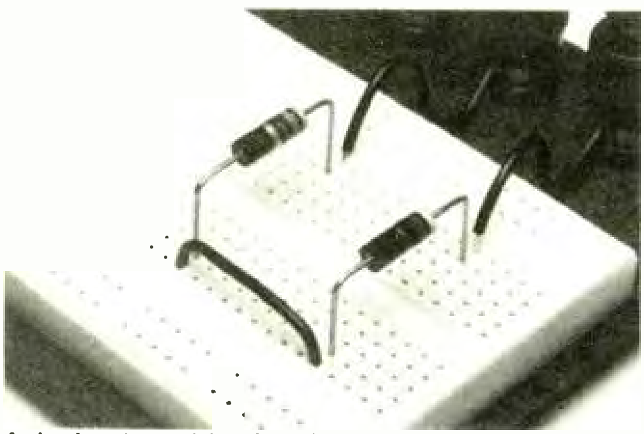
$$R = E/I$$

Choose another resistor, connect it to your battery pack, and determine the current moving through the circuit. For the

Measuring current requires that you open the circuit and place the meter into it as a part of the circuit.



If you dig down to the bottom of your junk box, you may find one of these old-fashioned wire-wound variable resistors. They are interesting devices to experiment with. This one provides from 0 to 10 ohms of resistance.



A simple voltage divider is perhaps one of the most useful circuits you can create. By using a potentiometer in place of one of the resistors, you can perform the experiment with many different values of resistance but fewer parts.

MATERIALS LIST FOR THE OHM'S LAW LAB

1.5-volt "D" or "C" cells (2)
Battery holder
Hook-up wire
Multimeter
Resistors, Assorted
Solderless breadboard
Test cables and clips

sake of our example, we'll say the current is 8.5 milliamps, or .0085 amp. Now measure the voltage. Determine the value of R by dividing E by I, or in our case we divide 3.00 by .0085. That comes out to about 353 ohms. The calculated value of resistance in the circuit is likely to be a bit higher than the value of the resistor, but the two numbers will be quite close. Once again, repeat the exercise a few times with a few different resistors. Potentiometers, rheostats, and other sources of resistance may, of course, be used as well.

With the exception of superconductors, all conductors have resistance. Resistance is a distinctive feature of a given conductor. Given a constant temperature, the voltage and current can vary, but the resistance will remain the same. According to some interpretations, that is the real essence of Ohm's Law.

To demonstrate that, remove one battery from your battery pack. That will give you about 1.50 volts. Now repeat the experiment described previously. With the same resistor, the current flowing through the circuit will be about one-half of what it was originally. One-half the original voltage divided by one-half the original current, will give you a value of R that is very close to one you obtained the first time you performed the experiment.

Voltage and Voltage Dividers

The third and final form of Ohm's Law states that voltage equals the current multiplied by the resistance. Or, expressed as an equation:

$$E = I \times R$$

Start by determining the value of a resistor. Suppose the value is 449 ohms. Now connect that same resistor to the power pack and measure the current moving through the circuit. Suppose the value is about 6.7 milliamps, or .0067 amp. The value of R, 449, multiplied by the value of I, .0067, equals just over 3.00, the value of E. The calculated value of E will be close to actual voltage across the resistor.

This ought to be getting pretty easy, so let's complicate things a bit. Choose a second resistor. Now patch together a series circuit consisting of the two resistors and the battery pack. You have built a simple voltage divider that resembles the one shown in the photographs.

Suppose the value of the second resistor, R2, is 95 ohms. We already know the value of R1. The question becomes: What are the new voltages across R1 and R2?

First, we need to measure the new current. Since there is no "load" on the output, you can open the circuit anywhere and hook up your multimeter. My instrument tells me there are 5.5 milliamps, or .0055 amp, moving through the circuit. To calculate the voltage across R1, just multiply the value of R1 (449 ohms in our case) by the value of I (.0055 amps in our example). Calculate the voltage across R2 in the same way. Your predictions will be very close to the actual voltages across R1 and R2.

Turn off your pocket calculator, disconnect the batteries, put away the voltmeter, and congratulate yourself because you've taken the first steps toward understanding electronics: You know the three fundamental forms of Ohm's Law.

For a brief biography of Georg Simon Ohm, see S.P. Bordeau, *Volts to Hertz; The Rise of Electricity* (1982, Burgess Publishing Company, Minneapolis MN). For more on basic circuit laws, we recommend P. Horowitz and W. Hill, *The Art of Electronics* (1980, Cambridge University Press, Cambridge, MA). ■