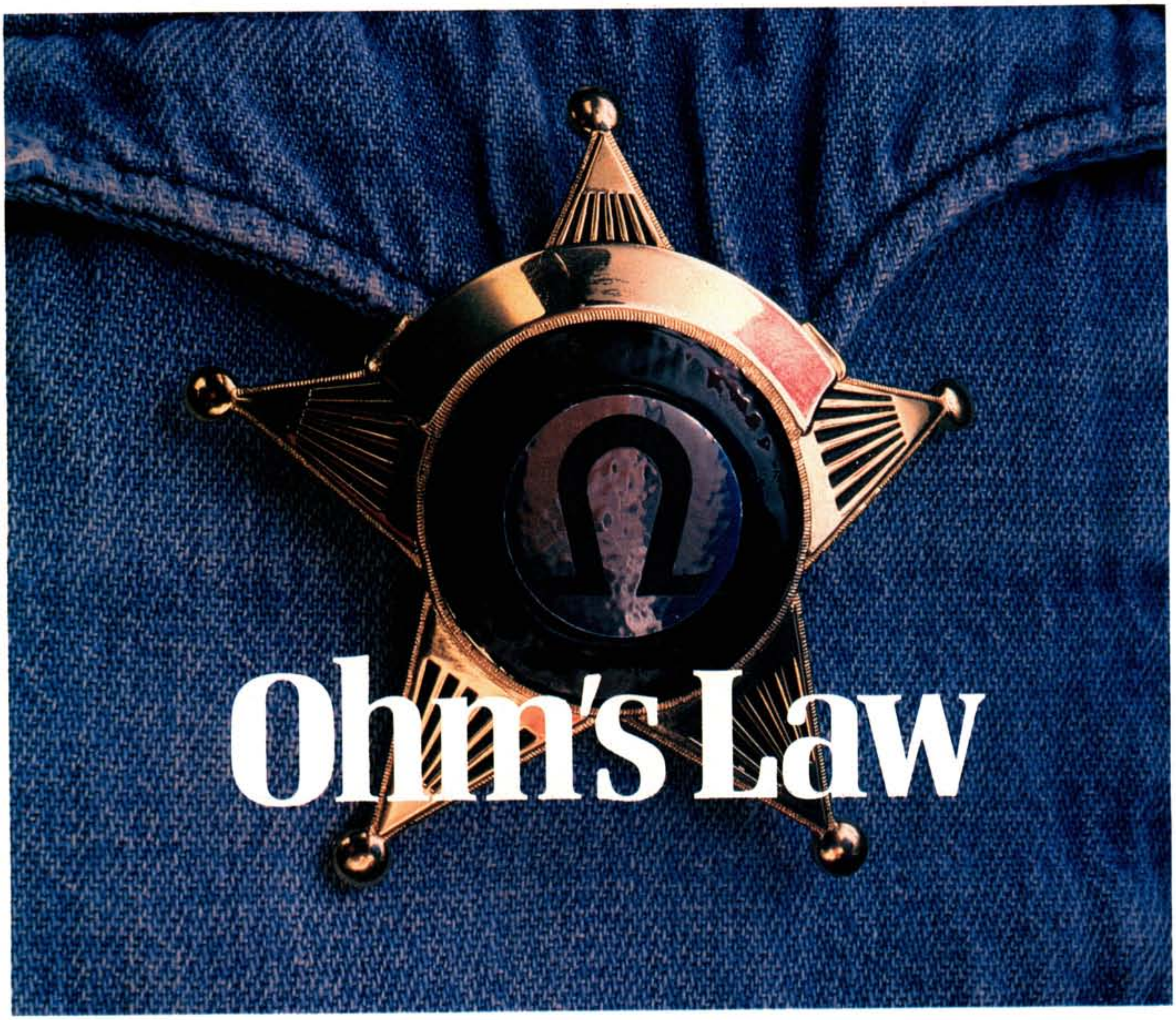


Everybody believes in gravity. If you climb a ladder you hold on tight, because you know if you slip you fall DOWN. Those of us playing with a full deck would hardly expect to fall UP. The law of gravity works. Think about it. Every safety precaution we take on the ladder is based on our faith in that law. The penalties for disobeying the law of gravity will always be predictable, and will be executed with great speed.

There is a law in the world of electricity that works in the same way—Ohm's Law. It's the only law west of the fuse box, and maintains law and order between the three powers of the electrical world—voltage, current, and resistance. The penalties for ignoring Ohm's Law when we troubleshoot electrical systems will also be predictable, although the aggravation of struggling with an unsolved problem may drag on and on.

Let's stop for a moment and thank George Simon Ohm, a German physicist who presented his theory way back in 1827. Mr. Ohm's proposed legislation didn't fare too well with his peers. If Mr. Ohm could only know that the world has since named the unit of electrical resistance after him, he would feel a lot better.

Simply stated, Mr. Ohm's Law suggested that the amount of voltage (in volts), current (in amps), and resistance (in ohms), have a predictable relationship to each other. If you know the values for any two of the three great electrical powers, you can always determine the value of the third. After all, as George tried to tell them way back when—it's the Law.

Ohm's Law for Voltage

One more time. Voltage in volts (E) is equal to current in amps (I), times resistance in ohms (R), or

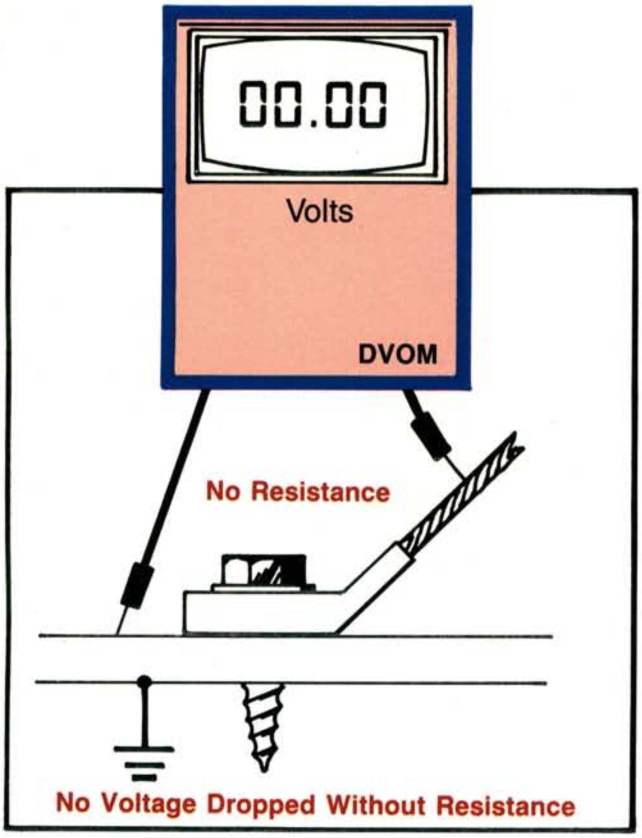
$$E = I \times R$$

Some Ohm's Law formulas will use "V" instead of "E" as the symbol for voltage, but the formula is the same otherwise. (I doubt George cares which letter you use.) When we multiply the amount of resistance (R) in the circuit times the current (I), the product is voltage (V).

Way back in the October 1988 issue of *Import Service*, we explained voltage drops, and used Ohm's Law to do it. The reason we used Ohm's Law, was that it's almost impossible to explain a voltage drop without it.

The very definition of a voltage drop involves Ohm's Law, because a voltage drop can only occur when current passes through a resistance. If there is no resistance, there is no voltage drop, regardless of how much current flows. Even George would have a hard time explaining a voltage drop without his law.

Ohm's Law and some simple math make it all clear. Remember, if there is no resistance, there is NO VOLTAGE DROP.



If E = I x R,

Then 1 amp x 0.00 ohms (no resistance) = 0 volts

Any number multiplied times zero equals zero.

Any amount of current multiplied times zero resistance will always be equal to zero volts or no voltage drop. Fair enough?

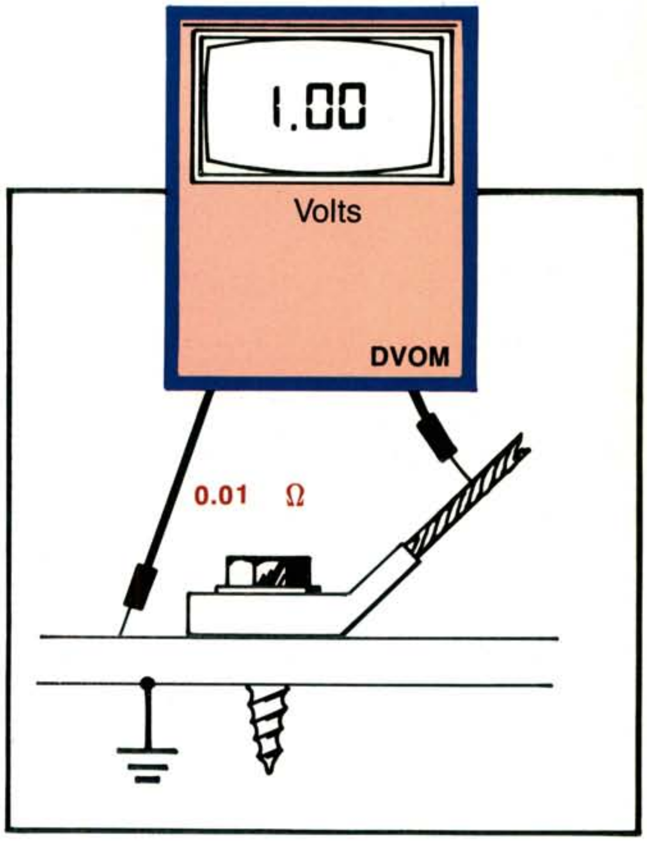
Even if we have 100 amps of current, then:
100 amps x 0.00 ohms will still equal 0 volts.

Add Resistance to the Equation

Let's throw some resistance into the equation. Not much. Just enough resistance to read with our DVOM. Even a digital ohmmeter will only read down to tenths of an ohm, or 00.0. So let's throw in a resistance value so small that even our DVOM can't see it. We'll add 0.01 or one one-hundredth of an ohm to the circuit.

Not enough resistance to cause problems, you say? Take it away, George.

E = I x R
E = 100 amps x 0.01 ohm
E = 1 volt (a whopping big 1 volt)



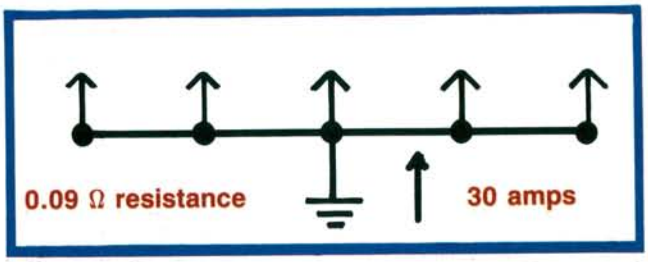
All it took was 0.01 ohm of resistance in a ground cable to cause a 1 volt drop (in this case a voltage loss) in a circuit with 100 amps flowing through it. You already know that a 1 volt drop in a circuit can cause big problems, and the resistance that caused this sizable voltage drop was too small to detect with your DVOM.

In cases like this, our ohmmeter is useless, and a voltage drop test is the only way to detect these small but harmful levels of resistance in a circuit.

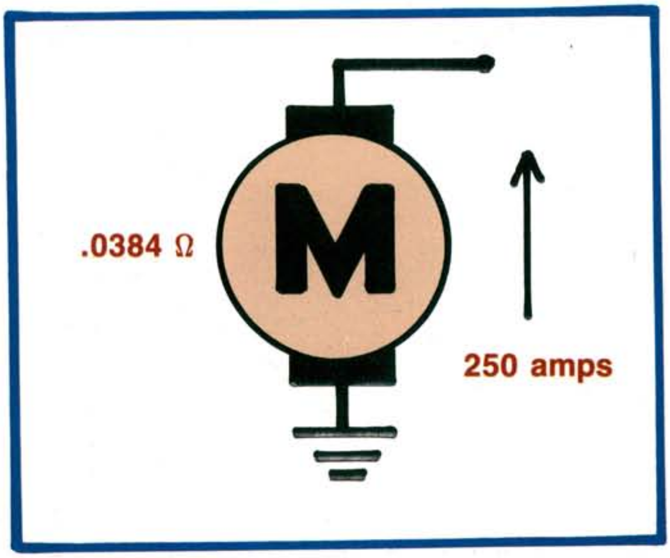
Practice With Ohm's Law for Voltage

These examples will point out how a little bit of resistance can cause a big voltage drop.

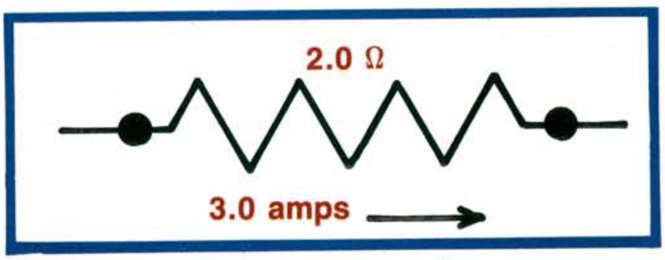
$$E = I \times R$$



1) If a common ground connection has 0.09 ohm of resistance, and 30 amps is passing through it, what is the voltage drop measured by the DVOM?
Answer: *2.7 volts (2.7 = 30 amps x 0.09 ohm)*



2) A starter motor draws 250 amps of current when cranking and has a resistance of 0.0384 ohm. How much voltage does the starter motor drop?
Answer: *9.6 volts (9.6 = 250 amps x 0.0384 ohm)*



3) A ballast resistor is supposed to pass 3.0 amps of current in normal operation and it has 2.0 ohms of resistance. How much of a voltage drop should you measure across the resistor?
Answer: *6.0 volts (6.0 = 3.0 amps x 2.0 ohms)*

Ohms Law for Current

Let's move a few things around in our formula and use it to figure current instead of volts. Current (in amps) is equal to the voltage in volts (E), divided by the resistance in ohms (R).

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

If we measure the voltage drop in a circuit, and know the resistance (either from manufacturers' specifications or by measurement with an ohmmeter) then we can determine the current in the circuit (in amps) with Ohm's Law for current.

All too often, I've heard it said that you don't need Ohm's Law to fix electrical problems. Let's see.

Recently, I was asked to look at a cruise control problem on a car. It seems that when the engage button was depressed, the cruise control's 5 amp fuse would blow. The circuit is shown in **Figure 1**. A very simple circuit.

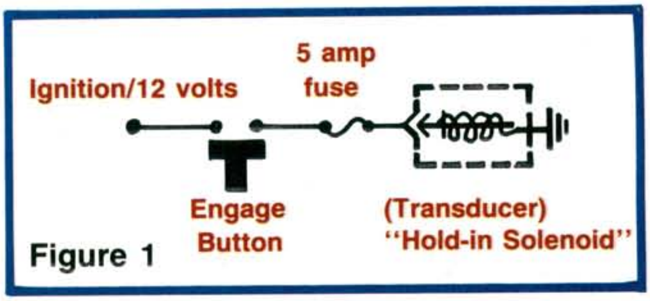


Figure 1

As you can see, the "engage" button is in series with a 5 amp fuse and the Hold-in Solenoid. The fuse blows each time the engage button is depressed. The resistance of the Hold-in solenoid measured 1.5 ohms with a DVOM. How much current is flowing through the circuit if the operating voltage is 12 volts?

$$I = \frac{12 \text{ volts}}{1.5 \text{ ohms}} \quad I = 8.0 \text{ amps}$$

That's certainly enough current to blow that 5 amp fuse, and it tells us that the solenoid resistance is too low. Even if we don't know what the resistance of the Hold-in coil is supposed to be, we can be certain that it is too LOW. We know the operating voltage of the circuit. We also know the rating of the circuit in amps. Ohm's Law tells us the rest.

I checked the resistance of the new Hold-in coil with my DVOM and measured 6.5 ohms of resistance across the coil. Now how much current will flow when the new coil is installed in the circuit?

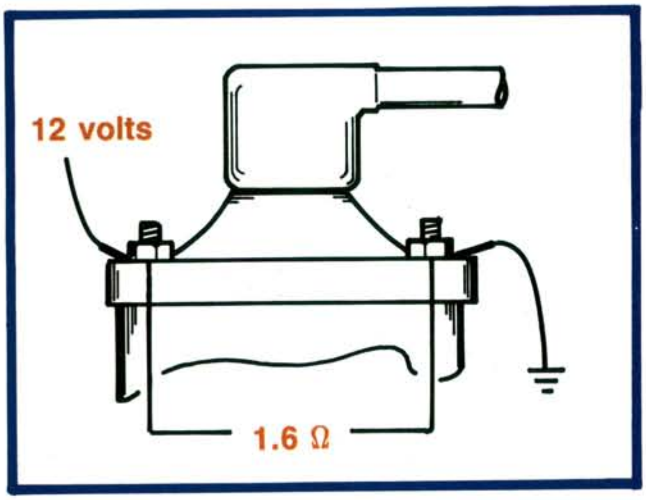
$$I = \frac{12 \text{ volts}}{6.5 \text{ ohms}} \quad I = 1.85 \text{ amps}$$

A current of 1.85 amps is safe for a 5 amp fuse. Guess what? The fuse did not blow with the new Hold-in coil installed. It's nice to know that the part you ordered is the one that will fix the car, especially when it's one of those non-returnable electrical parts.

Thanks again, George.

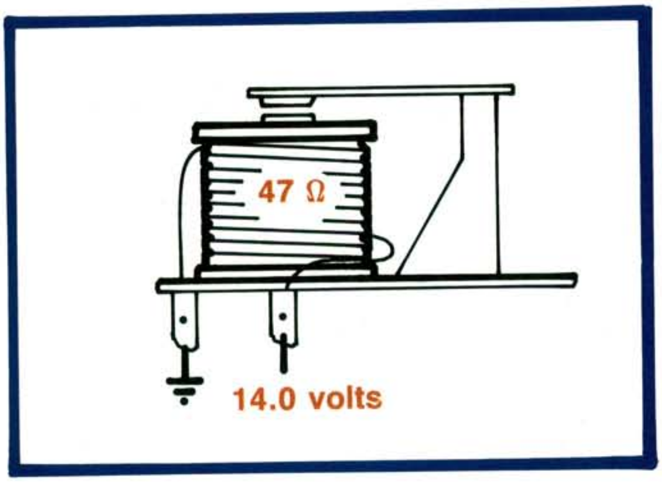
Practice with Ohm's Law for Current

Here are more examples of ways to use Ohm's Law for current, to properly diagnose circuit problems:



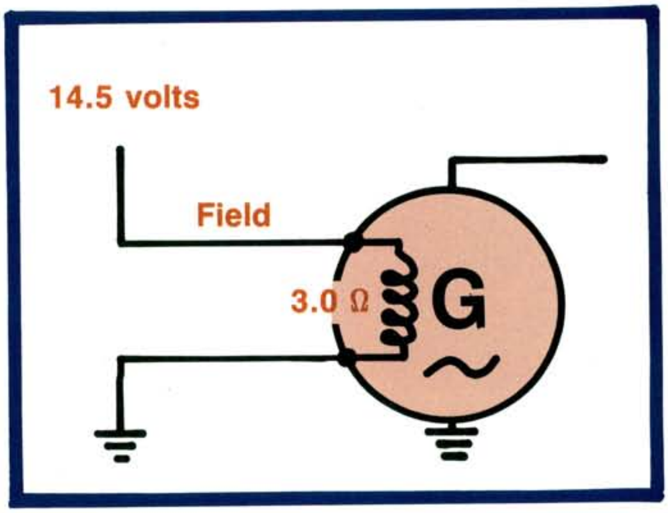
1) An ignition coil primary winding measures 1.6 ohms. How much current flows when the voltage applied is 12 volts?

Answer: *7.5 amps* $= \frac{12 \text{ volts}}{1.6 \text{ ohms}}$



2) A relay winding measures 47 ohms. How much current flows through the relay winding if 14 volts is applied?

Answer: *.30 amp* $= \frac{14 \text{ volts}}{47 \text{ ohms}}$



3) An alternator's field winding measures 3.0 ohms with a DVOM. How much excitation current flows through the rotor when the alternator charging voltage is 14.5 volts?

Answer: *4.83 amps* $= \frac{14.5 \text{ volts}}{3.0 \text{ ohms}}$

Ohm's Law for Resistance

If we put resistance on one side of the equation we get the following:

$$\mathbf{R} = \frac{\mathbf{E}}{\mathbf{I}}$$

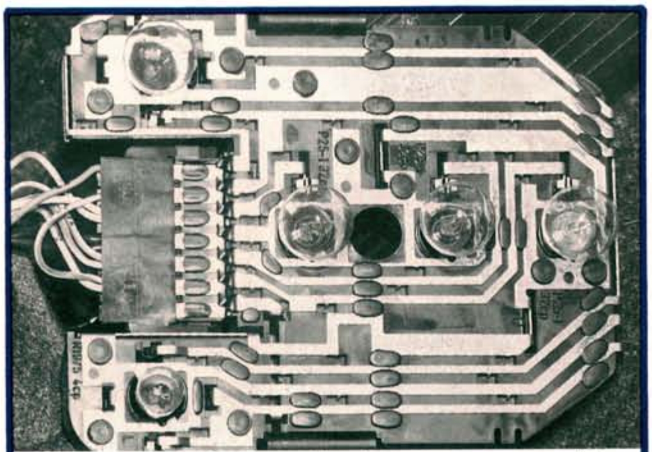
Now we can find resistance if we know voltage and current. Since each can be determined with our DVOM, finding resistance becomes easy. We simply divide voltage by current to find the resistance in ohms.

You may be wondering why we don't just check the resistance with an ohmmeter. Good question.

Some electrical components have one resistance when they are hot, or ON. They have another resistance when they are cold, or OFF. Lamps are a good example. Turn signal lamps, brake lamps, and indicator lamps all have different resistance values in a circuit.

When the lamps are off, their cold (lower) resistance is what the circuit "sees." When the lamps are on, their hot (higher) resistance is what the circuit "sees."

You can't determine the hot resistance without Ohm's Law. The hot resistance value becomes important when a dash warning light won't go off after a lamp has been replaced. Here's a real example from a previous **Electrical Service** article in *Import Service.* Now you'll understand why this problem happens as it does.



On 1986-88 Saab 9000s, there's a pictogram or safety monitor on the dash below the tachometer. The pictogram warns the driver of rear-light failures. But what if you replace a burned out rear bulb and the pictogram remains on? There's a good chance that the new bulb's resistance is substantially different from that of the other bulbs. Mismatched or corroded bulbs create an imbalance in resistance from the left side to the right side. The imbalance in resistance turns on the pictogram.

Lamp Cold Resistance

Check a 1445 lamp's cold resistance with a DVOM as shown in **Figure 2.** Don't use an analog meter, it won't give you a true resistance reading. The 1445's cold resistance, checked with a DVOM, is about 10 ohms.

If a replacement lamp has the wrong cold resistance, it can cause improper circuit operation. Improper resistance may be the result of a manufacturing defect or the use of the wrong lamp. Even if the brake lamps light as they should with the new lamp or lamps, the warning light on the dash will stay lit if the cold resistance of the replacement bulbs is wrong. Learn the cold resistance values of all lamps you use, and be sure the correct cold resistance lamps are used in each application.

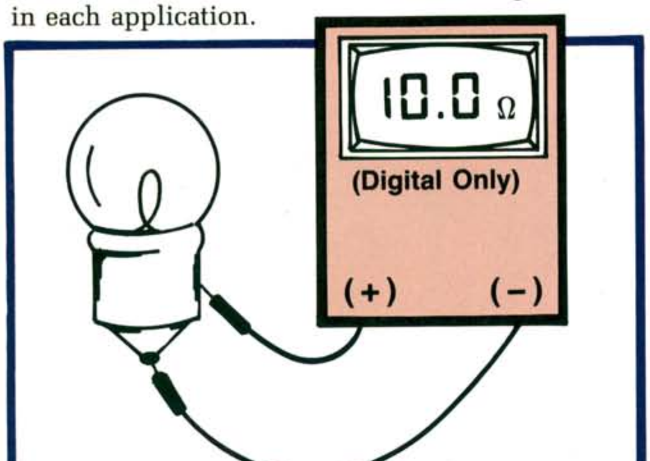


Figure 2 Checking a Lamp's Cold Resistance

Lamp Hot Resistance

A lamp's hot resistance can be determined only by using Ohm's Law. It is much higher than cold resistance. The lamp manufacturer specifies both the operating voltage for the lamp, and the current passed by the lamp at that voltage.

A simple calculation with Ohm's Law gives us the hot resistance in ohms for the 1445 lamp rated at 14.4 volts and 0.135 amp.

$$R = \frac{14.4 \text{ volts}}{0.135 \text{ amp}} \qquad R = 107 \text{ ohms hot resistance}$$

If the dash warning light turns on when the replacement lamp is ON, it may be due to the wrong hot resistance in the circuit caused by a replacement bulb out of specs, or by a replacement bulb whose resistance is different from the resistance of the other bulbs in the circuit. In the past, a common cure for this problem was to replace all the bulbs in the affected circuit. But if we determine the hot resistance of the good lamps in the circuit, and replace the burned lamp with a bulb having the same hot resistance as the rest of the lamps, we don't need to replace all the lamps to turn off the dash warning light.

Practice with Ohm's Law for Resistance

Let's use Ohm's Law to find the "hot" resistance of some automotive lamps.

1) A #53 lamp is rated at 14.4 volts and 0.12 amp. What is its hot resistance?

Answer: *120 ohms* $= \frac{14.4 \text{ volts}}{0.12 \text{ amp}}$

2) A #67 lamp is rated at 13.5 volts and 0.59 amp. What is its hot resistance?

Answer: *22.9 ohms* $= \frac{13.5 \text{ volts}}{0.59 \text{ amp}}$

3) A #756 lamp is rated at 14.0 volts and 0.08 amp. What is its hot resistance?

Answer: *175 ohms* $= \frac{14.0 \text{ volts}}{0.08 \text{ amp}}$

By now, you should begin to see that Ohm's Law is far more than just some stuffy theory. It is a way to understand circuits, and to repair them properly. Each of the variations of Ohm's Law is a law you can depend on.

Thanks, George.

—By Vince Fischelli