Basic Electricity

PART TWO

We concluded last month's Basic Electricity article talking about circuits and their operation. We'd like to continue as promised with part two of our mini-series.

This month we deal with shorted circuits, current and voltage measurement, and some specific electrical components.

Short Circuits

If we believe everything we hear, all of the defects are shorts. "There must be a short," the technician says. Nothing can happen other than a short?

In this circuit we've been working with, the wire from the battery to the switch may rub against the frame (ground) and the bare wire may touch the frame. If it does, the wire is said to be shorted, the circuit has a short.

If you operate the switch but the switch does not open in its off position, the switch is shorted. If rust forms across the contacts of the bulb's socket, the socket is shorted.

But if any of the connecting wires break so that current cannot flow, there is an open. If the lamp's filament burns out, there is an open. If one of the intercell connectors of the battery breaks, there is an open. If the battery connection is corroded so that current can't get through it, there is an open.

Not all circuit defects are shorts.

Current Measurement

If we had wired up this combination of circuits on a bench we would want to actually make measurements of the current and voltage. To measure the current an ammeter is connected in series with the circuit or its elements because the current of the circuit must pass through the meter. To find the total current drain on the battery the ammeter is connected in the line at point A of Fig. 9. If the meter is of the clamp-on type, it can simply be clamped over the line coming from the battery. If the meter has two leads that must be connected into a break in the line, we'll probably disconnect the line at the battery and connect the red (+) ammeter lead to the post of the battery and the black (−) meter lead to the connector we removed. Of course, we could instead connect the ammeter at point B, right? I hope you agree, because the current coming in is the same as the current going out.

By hooking up the ammeter into either of those points the current of each of the individual series circuits can be determined by turning each switch individually. But if we wanted to measure the current of one of the series circuits regardless of what the other circuits are doing (and sometimes we might want to do that), the meter will be connected into point C, or into the ground line at D.

An important point about connecting an ammeter into a circuit is to get the right polarity, regardless of where it's connected. The red (+) lead of the meter must connect to the line coming from the positive post of the battery, and the black to the line going to the negative, that is, to ground.

Test meters take many different forms. An engine analyzer might have separate meters for amps, volts,

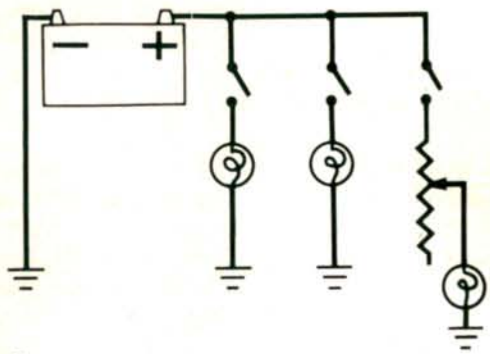


Figure 8

By varying the resistance of the rheostat, the brightness of the lamp can be changed.

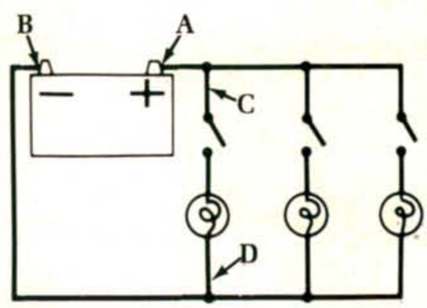


Figure 9

Points of current measurements with the ammeter. If the ammeter is *not* of the clamp-on type, the wires (connections) must be broken into so that the ammeter is "in series" with the circuit(s) being measured.

and ohms. A starting-charging system tester might have a combination current-volt meter. The most common hand-held meter is a combination Volt-Ohm-Ammeter that's called a VOM. The M stands for milliamperes (.001 amp), but there is usually a separate connector that allows the meter to measure up to 10 amps. If the meter has a pointer that moves over a fixed scale, it is called an analog meter, whereas the one with flashing numbers is called a digital meter.

Meters vary in accuracy. And there are times when high accuracy is needed, and times when it's not. If you have an old meter hanging around, don't throw it away. But if you are going to buy your first meter, the extra cost for one of higher accuracy will pay off.

Voltmeters vary not only in accuracy but also in sensitivity. The sensitivity is determined by the amount of power that the meter absorbs from the circuit that's being measured. We don't think of a meter as a power-using device, but there is some energy required to move the pointer on the analog meter or to change the numbers of the digital meter. The power required is expresed as the resistance of the coil of the meter and any associated calibration resistors, or the resistance of the input circuit of a digital meter. For example, an inexpensive analog VM might have an impedance (another word for resistance) of 2000 ohms per volt. Just a few years ago a good meter had an impedance of 20k Ω/volt. Read that as "twenty thousand ohms per volt." Ω is the symbol for ohms.

Since the computer came to the automobile, we hear talk of a "10 megohm" voltmeter. That means that the internal resistance is 10 million ohms, and further means that the meter draws an extremely small amount of power from the circuit that the meter is trying to measure. So what?

Most circuits in the car carry comparatively high power, from about half an amp to about two hundred amps. The power taken from those circuits by a 20k ohm meter is too small to have any practical effect on the circuit and the meter's reading will be correct. But the solid-state circuitry of computers uses very low power, like a few milliamps (thousandths of an amp or .001 amp). Using a 20k ohm meter on such a circuit robs enough power to give an incorrect reading, and may in some cases damage a computer or one of its sensors. So, if the car manual or other instruction says to use only a 10 megohm voltmeter, the least expensive way to go is to use a 10 megohm voltmeter.

Ammeters for measuring large currents, above 10 amps, usually come with a shunt that must be connected into the measuring point. The shunt is a calibrated resistor of very low ohmic value. It produces a certain voltage drop, in millivolts (.001 V), according to the amount of current passing through it. The actual meter is a sensitive voltmeter which can read the very small drop, but it is calibrated in amperes.

The shunt is actually a bar of metal, usually brass. And you might say, "This is a calibrated resistor?" You'll remember back a ways we said that every wire has some resistance. Even a bar of brass has some resistance, very small, but for the shunt it's carefully calibrated.

Voltage Measurement

The most-used instrument in electrical system diagnosis is the voltmeter, which tells us that electrical pressure is available at a certain point.

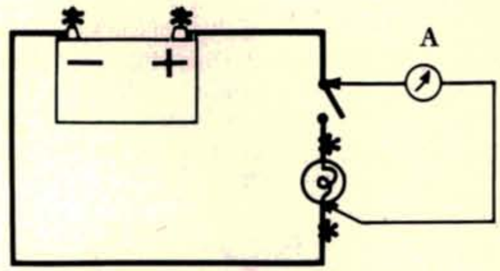


Figure 10

The voltmeter connected as shown in the text. Asterisks show other points the meter might be connected to in looking for system faults.

While the ammeter is connected in series with the other elements of the circuit, the voltmeter is connected in parallel, that is across the component to be measured. This measures the electrical pressure across the device. Let's connect the voltmeter across the switch as shown in point A of Fig. 10. With the switch open, the meter will read 12 volts *if* the lamp is not burned out. When the switch is closed the voltmeter will drop to zero. If the switch contacts are dirty, they can cause a resistance which will cause a voltage drop and therefore a reading on the voltmeter.

We will, however, connect the voltmeter in series in certain situations. Before replacing an electrical component that isn't working, we want to be sure that there is voltage at the input of that device. So we'll disconnect the plug or the wire terminal from the device and measure voltage at the plug insert or terminal. The red (+) meter lead will connect to the plug or terminal, and the black lead (–) to ground. A meter reading of 12 volts shows that there is pressure ready to push current through the device if the circuit within the device is complete. But because the device didn't work before the plug was disconnected the internal circuit is not complete. We say it has an open, sometimes said to be open-circuited. Nevertheless you see that the voltmeter was connected in series.

You might be asking at this point, "What if there had not been a reading on the meter?" That would indicate an open somewhere upstream in the circuit, either a broken wire or a switch that was not making contact.

More Circuit Elements

Switches

Fig. 11A is the symbol for a single pole switch, or more simply an ON-OFF switch. A double pole switch as in Fig. 11B will actuate two circuits with one throw of the switch. The contacts might be worked by a battery handle such as the common "toggle" switch. The headlight switch is a push-pull type where the contact surfaces on the sliding portion connect together two or more fixed contacts. The ignition switch on most cars is also a push-pull switch, worked by a rod from an arm so that rotary motion of the key is changed to a linear push-pull motion. To switch accessories the designer might use the toggle, push-pull, or rotary switch according to how he wants it to fit into the general layout of the panel and the mechanisms the switch needs to work with.

Figure 11A

A single pole switch. The common on-off switch.

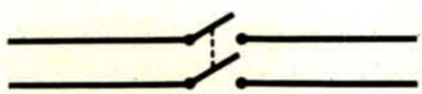


Figure 11B

A double pole, single throw switch switches off and on two individual circuits with a flip of one switch.

The one critical aspect of the switch is its contact rating. The size of the contacts, and to some extent the material of the contacts, affect the amount of current (the amperage) that can be switched by those contacts without causing severe arcing and burning of the contacts. Of course, such arcing and burning will limit the life of the switch, sometimes to only one operation.

We don't often need to worry about the rating of a replacement switch because we'll get the switch to fit a particular hole of a particular car and it will likely be a dealer-only item. The manufacturer of that switch will see that the contact rating is correct for the application.

But when adding accessories we might need to be careful about picking a switch if one is not furnished as part of a kit, or not recommended by the instructions with the accessory.

Let's take a simple example. We'll add a couple of utility lights to a pickup truck. Both lamps will be controlled by the same switch. The light assemblies we've chosen have #4419 sealed beam bulbs. Information on the box says that each bulb draws 2.7 amps of current. Rounding that off to 3 amps and doubling gives 6 amps. Adding a safety factor to give a little longer life, we'll use a 10-amp switch.

Arcing across the contacts is affected by the amount of current being switched and also by the type of circuit being switched. If the switch is going to control a motor, such as a rotating beacon, or a coil, a little extra must be added to the contact rating. The manufacturer's recommendation may at first seem too high. It's not. And of course, too large never hurts the circuit, as long as there's enough mounting room.

If a switch has been overloaded, that is, the contact rating has been exceeded, due to a short in the wiring or in the controlled device, the switch may burn to the point of not making contact. A more sneaky problem is the switch whose contacts get dirty or slightly burned because of arcing over a long time. Whatever part of the contact is still making a connection might allow some current through but not enough to work the device controlled by the switch.

Capacitors

Also called a condenser, a capacitor has two unique properties.

- It can temporarily store a charge of (direct) current.
- It allows AC to pass through it while blocking the passage of DC.

The capacitor is made up of two plates separated by a special insulator called a dielectric. In the most familiar automotive type, the plates consist of two long strips of foil separated by the dielectric. This combination is tightly rolled and placed in that small round can. One of the foils is connected to the case, which often has a bracket that attaches the assembly to ground. The other foil connects to a pigtail coming out one end of the assembly. If a DC voltage is placed across the case and the pigtail lead, the condenser becomes "charged," that is, it will store a charge of current in the plates. This charge can be measured with a meter, but we'll see only a momentary upswing of the needle because the capacitor "discharges" very quickly.

The amount of current that the capacitor will store depends upon the size of the foils and is called the "capacity." Capacity is measured in microfarads, sometimes called "mikes" for short. It will also have a voltage rating, but the units cataloged for auto work will assume a 12-16 volt rating and that rating may not be listed.

Its ability to conduct AC is put to use in the auto to bypass (short out) electrical noise. This noise is often a very high frequency AC called RF, which stands for Radio Frequency. Of course that kind of noise is often heard on one of the radio bands, AM, FM or CB, and is said to be RFI, radio frequency interference. RF is generated when coils are switched. Typical coils that are switched are ignition coils and alternator field coils. Alternator field coils are switched by the voltage regulator.

By putting a capacitor across those devices, the RF is shorted to ground to prevent its transmission along wires that act as antennae.

Electricity and Magnetism

Some other circuit elements require an understanding of a facet of electricity that seems mysterious but the results of which we see every day. Bear with us while we explain it. It's not difficult.

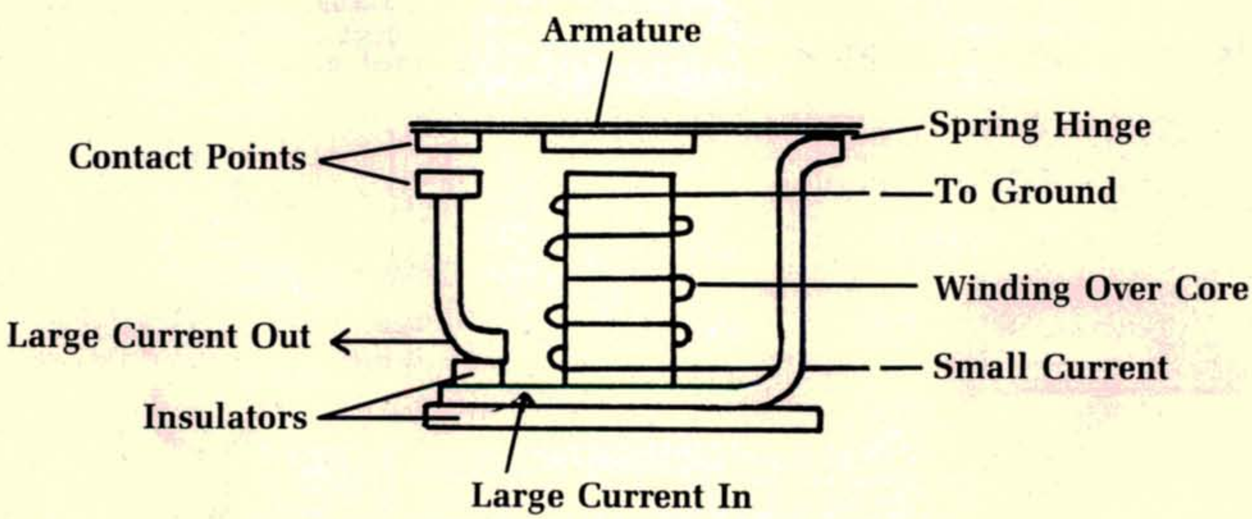
- Whenever there is a movement of electricity, magnetism is produced.
- Whenever there is a movement of magnetism near an electrical conductor, electricity is produced in that conductor.

So, when current is flowing through a wire, that wire has a coating of magnetism around it. That coating is called a "magnetic field." The strength of that magnetic field (the thickness of the coating) depends on the amount of current flowing through the wire. The wire that simply connects a switch to a lamp has a magnetic field around it but is so small that we can ignore it. But let's take a few hundred feet of wire, say 20-gauge wire, with enamel insulation instead of the heavy plastic or rubber insulation we normally see on wire. Wind a bunch of turns of the wire around a pencil so that we have a coil of about 3/4 inch long. If we connect the ends of the coil to a battery we find that we have a fairly strong electromagnet that can pick up and hold a small steel washer. What happens is that the very small magnetic coating around each of the individual turns combines to produce one big field around the coil. But even this field is kind of loose and sprawling. So let's remove the pencil from the core of the coil and insert a piece of soft iron. A cap screw of the right size will do okay. This will concentrate the magnetic field more tightly. Now when we energize the coil by connecting it to a battery, we'll find that the electromagnet will do its work more efficiently and be able to pick up a bigger steel washer than it did with the pencil core.

This electromagnetism is the basis of not only motors but also of a couple of other gadgets we find around the car called relays and solenoids. No, we haven't forgotten about the other half of electromagnetism, the moving magnet. We're just postponing its discussion for a while.

Relays

A relay is a remote-controlled switch that works on the principle described above. An electromagnet, similar to the one we made, is used to pull down a steel plate which is hinged and also spring-loaded to normally keep the plate away from the core of the coil. On one end of the plate, the one away from the hinge, is a contact point. Underneath the point but not touching it is mounted another contact. When the coil is energized, the steel plate, now called the armature, is pulled down toward the coil core and the two points are in firm contact.



A typical relay allows a small current to control the flow of a larger current.

The idea here is that the coil can be designed to need a very small current in order to pull in the armature. But the contacts operated by the armature can be large and capable of switching a high current. So a small switch in the driver's compartment can switch a very large current in the engine compartment.

The two most common units are the horn relay and the starter solenoid (relay).

In the horn system, the horns themselves draw a comparatively large current. Instead of running two heavy wires up the steering column and having a big switch on the steering wheel, there can be a flimsy switch on the wheel that can be operated by a touch at the top, bottom, side, etc.

There is another benefit in this system. A heavy wire from the battery must run to one of the relay contacts, so let's connect one end of the relay coil to that same heavy wire. For the coil to become energized, its second end only needs to be grounded. So only one small wire goes up the steering column and the steering wheel switch connects that wire to ground to operate the horns.

Relays can have various contact arrangements. The one used in the horn circuit is a normally open (NO) contact set, because the contacts are open until the coil is energized. Some circuits use normally closed (NC) contacts or *both* NO and NC. Other relays might have two or more isolated sets of contacts so that more than one circuit can be switched from one source.

The starter solenoid is a form of relay. The switch that sends current to the starter motor must be very large to handle the heavy current the starter needs. Certainly a small-sized, easily operated key switch can't do the job. So let's use a relay. Except in this case we'll call it solenoid because its action is just a little bit different. Instead of the core of the coil being solid (remember the cap screw we used?), the solenoid is hollow. A plunger, spring loaded at one end of the hollow core, will be pulled in to center itself in the core when the coil is energized. The total movement of the plunger can be quite large compared to the small movement of the armature type relay. Of course we have to pay for this greater movement. The coil must be bigger and the current must be greater, but that greater current is still within the capability of the key switch.

Many starters have the solenoid mounted on or in the starter assembly and the solenoid will do two jobs. First, the long movement of the plunger will move the drive assembly into engagement with the flywheel of the engine. Second, the final bit of the plunger's movement will push a larger copper disc into firm contact with two heavy copper studs, forming the large switch that carries starter current.

In the case of the solenoid being mounted away from the starter, that totally smaller unit just moves a copper disc against the contact studs. This small solenoid is more often called the "starter relay," not to be confused with the "starting relay," an armature type used on some foreign cars. ■