Think Positive!

The electrical system of a passenger car, truck or van is an enigma to many technicians. Far too many of us have not had meaningful electrical training, training focused on troubleshooting or on repairing electrical problems. Many training programs merely show us electrical components, how they are disassembled, what the parts are called, where mechanical wear and tear is most likely and how the component is reassembled. Often, little training time is devoted to using a multimeter to actually check the component or circuit for proper operation.

This first of two articles focuses on testing, troubleshooting and providing real numbers you can use to find electrical problems. This part covers general information about the electrical system and testing the voltage (positive or power) side of the electrical system. Part Two will cover testing the ground side.

Figure 1 represents a simplified electrical system. At first glance, it might seem a little cluttered. Any schematic can seem a little overwhelming at first, so ignore your urge to turn the page. Take a few moments to find something you are familiar with, and you will get more comfortable. In the center is what we used to call an *alternator*. The preferred name is now *generator*, although nothing's different except the name. To the right is the battery and starter motor. To the left of the generator is the PCM and three separate electrical circuits. All components connect to a voltage source and a ground.

The Battery

The battery provides the electrical power needed to crank the engine. The battery must store electrical energy in chemical form. If a battery sits too long without being charged, it will internally self-discharge and eventually won't crank the engine. Battery voltage indicates battery state of charge, if the battery is at rest. In other words, the battery has not been discharged or charged in several hours, which allows the battery chemistry to settle and reach a rest state. Measuring battery voltage at rest is called *Open Circuit Voltage* or *OCV*.

Figure 2 shows the OCV measurement procedure and includes a reference chart reflecting the percent of battery charge for a given OCV reading. The DMM test leads are connected to the battery terminals.

A battery should maintain 100 percent state of charge, an OCV of 12.66 volts, for several weeks with no load on the battery. A reading above 12.66 but not more than 12.80 volts is due to surface charge, which doesn't affect the battery. Battery OCV should not drop below 12.66 volts because then sulfation will begin to degrade the plate surfaces. Always keep battery OCV up to 12.66 volts by timely charging. If a vehicle is in your shop for a few days, watch the OCV. If OCV drops below 12.66 volts, run the engine for 10 minutes every few days to keep the battery fully charged. If the engine can't run, place a small battery charger on the terminals and trickle charge at 1-2 amps for 4 hours. Keeping the OCV at 12.66 volts optimizes battery life. Avoid prolonged charging of a fully charged battery. This will raise battery temperature unnecessarily and may cause internal battery damage.

The Generator

On many vehicles, the generator begins operating as soon as the engine begins to run, but some vehicles have to hit a target rpm of approximately 1000-1200 rpm before the generator starts to charge. The generator must charge the battery and generate all electrical energy to operate the vehicle. The battery's only function once the engine is running is to help stabilize the charging system in maintaining a proper charging voltage.

The generator output voltage is called the *charging voltage*. Since this is the system's operating voltage when the engine is running, all electrical and electronic circuits depend on the charging voltage for their operating voltage. A low charging voltage means all vehicle circuits struggle to operate properly on the lower voltage, just like a flashlight with weak (low voltage) batteries producing low light level. Most circuits don't function well at lower than normal operating voltage. On the other hand, if the operating voltage is higher than normal, circuits run exceptionally hot or fast, but must handle higher than normal current, which causes premature circuit failures from burned out components.

What then should we consider normal charging voltage? The charging voltage should be in the range of 13.8-15.1 volts. **Figure 2** shows the DMM test leads measuring the charging voltage at the battery terminals just as in OCV measurement, except the engine is running. Use the battery terminals as test points for checking the charging voltage because they are usually easier to reach than the generator terminals.

Less than 13.8 volts for a charging voltage may indicate a weak charging system due to something as simple as a loose alternator (I mean, *generator*) belt or as serious as a defective generator. Sometimes the charging voltage may be slightly lower than 13.8 volts if the weather is extremely hot and the vehicle has a lot of electrical circuits running at the same time, such as the A/C at high blower speed, high beams, wipers, etc.

The charging voltage should range on the lower side (close to 13.8-14.0 volts) in warm weather and on the higher side (close to 14.6-14.8 volts) in cold weather to match the charging requirements of a battery. A battery charges easier in warm weather so the charging voltage can be lower.

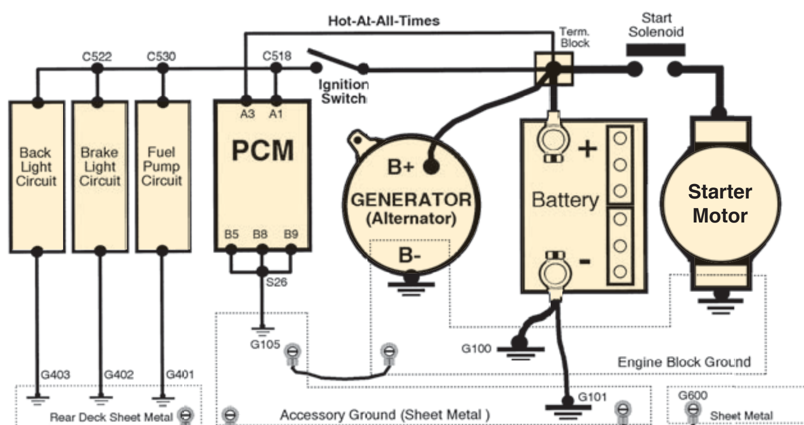
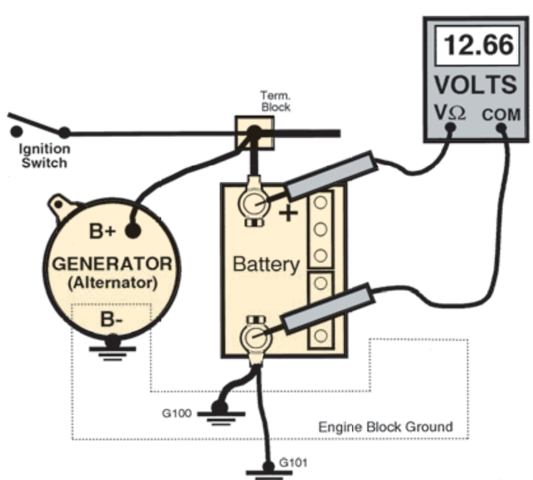


Figure 1: *Basic Electrical System*



Battery Open Circuit Voltage vs. State of Charge

Voltage	% Charge
12.66	100%
12.58	90%
12.51	80%
12.45	73%
12.43	70%
12.35	60%
12.28	50%
12.20	40%
12.12	30%
12.04	20%
11.97	10%
11.89	0%

Figure 2: *Measuring OCV*

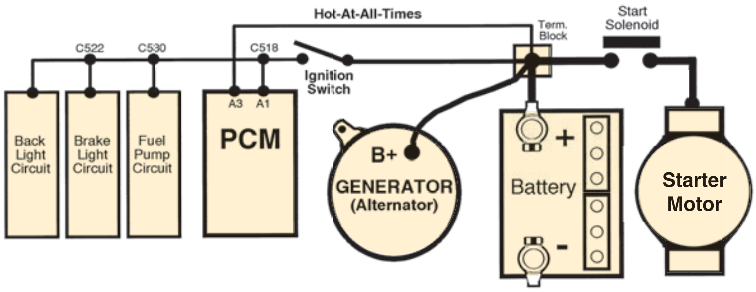


Figure 3: *The Voltage Side of the Electrical System*

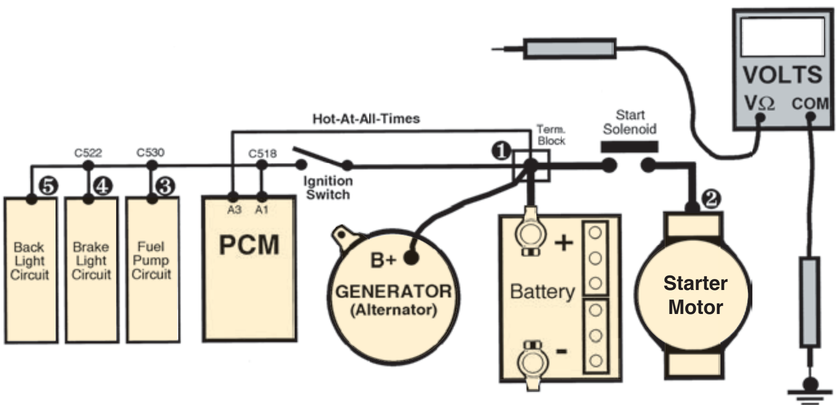


Figure 4: *Checking B+ on the Voltage Side of the Electrical System*

A battery charges with more resistance when cold, so the charging voltage should be higher. It is part of the job of the voltage regulator to sense ambient temperature and adjust the charging voltage accordingly. It is necessary to check the charging voltage of several vehicles to determine how low or how high a charging voltage actually is for a given temperature. Practice, practice, practice!

Now that we have this basic information in place, we can explore the voltage side of the circuit using **Figure 3**.

Fuses have been deleted from the voltage side of our electrical schematic diagram to keep things simple. Fuses may be at several different points in the circuit. A fuse protects a circuit from excessive current because a fuse blows when current through it exceeds its amp rating. For example, a 10 amp fuse can safely carry up to 10 amps with no trouble, but it will probably blow at about 14-15 amps.

If the current through a circuit begins to rise dangerously above the fuse rating, that could be due to one or two factors. First, the operating voltage could be higher than normal, pushing more than 10 amps through the resistance of the load on the circuit the fuse is protecting. Second, circuit resistance may be too low, and current has been allowed to rise too high. Low circuit resistance could occur if the voltage side of the circuit is shorted to ground or if the load resistance gets too low.

The positive side of the battery and the generator output terminal are connected together. This voltage point is known as B+, meaning the positive operating voltage source. Some generators also have B+ embossed on the generator housing, so the term is not new. The value of B+ is battery voltage when the engine is not running and charging voltage (from 13.8 to 15.1 volts) when the engine is running. Remember the actual charging voltage depends in part on the ambient temperature, so B+ should be on the high side in cold weather and on the low side in hot weather.

The common B+ point on the vehicle is the junction of generator B+ and battery B+. In our schematic we use a terminal block. Testing B+ at this point has advantages but also limitations. First of all, OCV (battery B+) should always be checked at the battery terminals just in case a battery cable has a voltage drop between a battery terminal and the terminal block. Second, to accurately test charging voltage, *always* measure at the battery terminals to see how much charging voltage is getting to the battery. However, if you simply want to check B+ with the engine running to see what voltage is present for a given ambient temperature, it is safe to measure B+ at the terminal block.

Testing the Voltage Side of the Electrical System

Once B+ is known, it can be traced to all points on the vehicle to see whether there is an excessive voltage drop at any point in the vehicle's wiring. Connectors become corroded and block some of the B+ as current flows through a circuit. The same thing can happen when wires corrode. Each voltage drop reduces the B+ available in that circuit. We call this an unnecessary or unwanted voltage drop.

It is important to remember when you check B+ throughout the electrical system each circuit must be ON at the time the voltage tests are made at that circuit. If a circuit is OFF when the B+ to a circuit is checked, there is no current through the circuit, so the B+ terminal will read full B+, even if there is a problem in a connector, in the wiring or even in the load.

For purposes of illustrating this test procedure using **Figure 4**, let's set up the following conditions: B+ with the engine OFF is 12.75 V because the battery has a little surface charge. B+ with the engine running is 14.5 volts. The DMM is set to read 20 V DC and is grounded to the battery's negative terminal. The DMM in **Figure 4** shows the black (COM) test lead touching ground, but the true ground for the DMM should *always* be the battery's negative post.

B+ Cranking Test

If the engine is OFF and the red (VΩ) test lead touches the terminal block, the reading should be 12.75 V (battery OCV). When the engine begins cranking, battery voltage drops as the load of the starter motor pulls down the battery voltage. A normal engine cranking load with a good battery may drop to a low of 10.0-10.5 volts. Let's say the voltage at (1) drops to 10.5 volts during cranking. Move the red test lead to the B+ feed to the starter motor, and crank the engine again. The voltage at (2) should be no less than 0.5-volt of what was found at (1). This allows a normal voltage drop of 0.5-volt through the battery/starter cable assembly, which ensures no excessive voltage drop on the voltage side of the starter motor circuit. If battery voltage drops too low during this test, that indicates a weak battery unable to maintain sufficient cranking voltage.

Battery Minimum Cranking Voltage vs. Battery Temperature

Voltage	Degrees F.
9.90	100
9.80	90
9.70	80
9.60	70
9.50	60
9.40	50
9.30	40
9.10	30
8.90	20
8.70	10
8.50	0

Figure 5: *Battery Cranking Voltage Chart*

Figure 5 is a chart of the lowest acceptable cranking voltage for a given battery temperature. If the battery voltage drops below the chart voltage for a given battery temperature, the battery is defective and should be replaced even though it can crank the engine. This can happen on mild or warm days where cranking load is lighter.

Once the engine is running, move the red test lead back to (1) to read the charging voltage. The DMM should read 14.5 volts with the engine running at 1500 rpm. If the B+ terminal on the generator is easily accessible, touch the B+ terminal with the red test lead. The reading should be not more than 0.2-volt higher (14.70 V). This indicates an acceptable voltage drop in the generator cable connecting the generator B+ terminal to the terminal block.

With 14.5 volts established as the charging voltage at (1), move the red test lead to Pin A1 of the PCM. This reading can indicate a significant problem in an ignition switch, often undetected for the first several hours troubleshooting a driveability problem. Normally the B+ at PCM Pin A1 should be about 14.3 volts, indicating the ignition switch and associated wiring are not dropping more than an acceptable 0.2 volt.

If the ignition switch contacts or connector C518 have developed corrosion, the B+ at PCM Pin A1 would be considerably lower. Suppose the B+ at PCM Pin A1 measured 9.4 volts because of a 5.1-volt drop across an ignition switch whose contacts have gone bad. The PCM would certainly have problems controlling the engine, creating severe driveability problems. How many sensors and actuators could be replaced before an improvement was noted? Well, in principle, all. Then the PCM would be replaced, again with no improvement in driveability. Ever been there before? A simple problem of a defective ignition switch is easily overlooked without proper troubleshooting techniques.

Next move the red test lead to PCM Pin A3. This is an important PCM B+ input used by the PCM to keep RAM memory alive and to power internal PCM circuits. Low voltage here can affect PCM performance and vehicle driveability, and the problem cannot be detected without a voltage measurement.

Another useful voltage test is to measure the B+ to the fuel pump circuit at (3), just below connector C530 in the diagram. Since the fuel pump is at the rear of the vehicle, a long voltage feed wire connects the fuel pump to the electrical system. The length of the wire alone produces some voltage drop when the fuel pump is running. The slightest amount of additional resistance from a bad ignition switch, corroded connector C530 or damaged voltage feed wire between the ignition switch and the fuel pump, can reduce the operating voltage to the pump enough to reduce fuel pressure. How many times have you seen a technician replace the fuel line filters, pressure regulator and the fuel pump itself, but still not get enough fuel pressure in the fuel rail, all because of an undiagnosed voltage drop in the voltage feed line to the pump?

The remaining two circuits at the left of Figure 4 are the brake lights and the backup lights. Test points (4) and (5) should indicate close to B+ when each circuit is ON. If B+ is 14.5 at the terminal block the B+ level at test points (4) and (5) should be about 14.1-14.2 volts, which allows for a few tenths of a volt drop from the ignition switch and wiring to the back of the vehicle. If both circuits get lower than normal B+ due to a defective connection at C522 causing a voltage drop, both lamps would be dim. If only one circuit is dim, then C522 is good, and the problem may be on the ground side of the dim circuit. That is why we will cover the ground side of the circuit in Part Two.

See you next time. ■

—By Vince Fischelli