INTRODUCTION

Electricity may be difficult for some people to learn for the following reasons:

- It cannot be seen.
- Only the effects of electricity can be seen.
- It must be detected and measured.
- The test results must be interpreted.

Electricity is the movement of electrons from one atom to another. The dense center of each atom is called the nucleus. The nucleus contains protons , which have a positive charge. Electrons, which have a negative charge, surround the nucleus in orbits. Each atom contains an equal number of electrons and protons.

In a normal, or balanced, atom, the number of negative particles equals the number of positive particles. That is, there are as many electrons as there are protons. Figure 1.

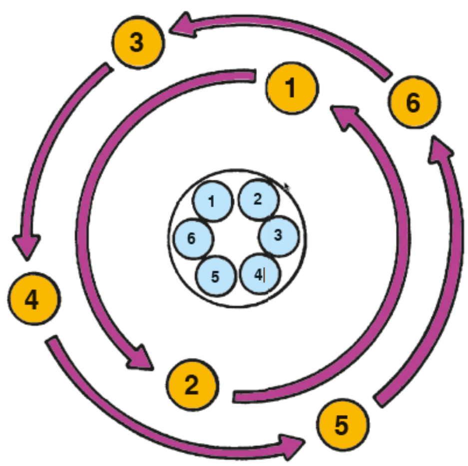

Figure 1. A balanced atom

The outermost electron shell or ring, called the valence ring , is the most important part of understanding electricity.

If the valence ring of an atom has three or fewer electrons in it, the ring has room for more. The electrons there are held very loosely, and it is easy for a drifting electron to join the valence ring and push another electron away. These loosely held electrons are called *free electrons*.

When the valence ring has five or more electrons in it, it is fairly full. The electrons are held tightly, and it is hard for a drifting electron to push its way into the valence ring . These tightly held electrons are called *bound electrons*.

Conductors are materials with fewer than four electrons in their atom's outer orbit. Electric current is the controlled, directed movement of electrons from atom to atom within a conductor. Copper is an excellent conductor because it has only one electron in its outer orbit. This orbit is far enough away from the nucleus of the copper atom that the pull or force holding the outermost electron in orbit is relatively weak. Examples of other conductors are silver and gold. Figure 2.

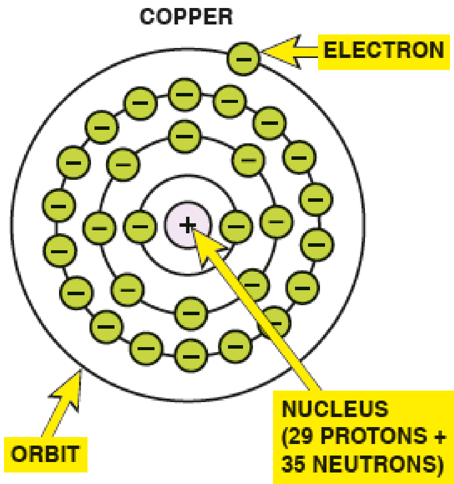

Figure 2. Copper is a conductor.

Some materials hold their electrons very tightly; therefore, electrons do not move through them very well. These materials are called insulators. Insulators are materials with more than four electrons in their atom's outer orbit. Examples of insulators include plastics, porcelain, fiberglass, wood, glass, rubber, and ceramics. Figure 3.

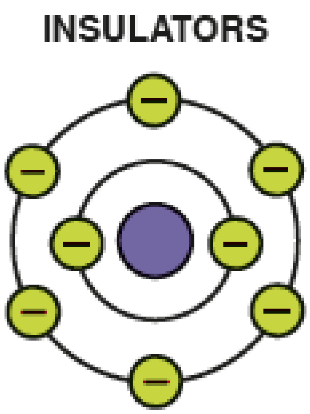

Figure 3. An insulator.

Current Flow. The following events occur if a source of power, such as a battery, is connected to the ends of a conductor—a positive charge (lack of electrons) is placed on one end of the conductor and a negative charge (excess of electrons) is placed on the opposite end of the conductor. For current to flow, there must be an imbalance of excess electrons at one end of the circuit and a deficiency of electrons at the opposite end of the circuit.

The negative charge repels the free electrons from the atoms of the conductor, whereas the positive charge on the opposite end of the conductor attracts electrons. As a result of this attraction of opposite charges and repulsion of like charges, electrons flow through the conductor. Figure 4.

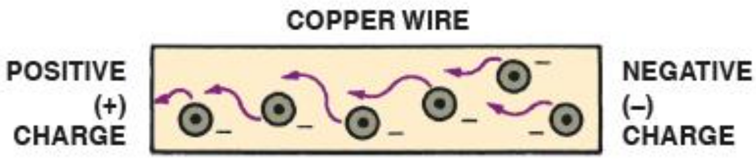

Figure 4. Electricity is the movement of electrons through a conductor.

It was once thought that electricity had only one charge and moved from positive to negative. This theory of the flow of electricity through a conductor is called the *conventional theory* of current flow. Most automotive applications use the conventional theory.

The discovery of the electron and its negative charge led to the *electron theory*, which states that there is electron flow from negative to positive.

Units of Electricity. Electricity is measured using meters or other test equipment. The three fundamentals of electricity-related units include the ampere , volt, and ohm.

Amperes. The ampere is the unit used throughout the world to measure current flow. The ampere is the electrical unit for electron flow, just as "gallons per minute" is the unit that can be used to measure the quantity of water flow. The capital letter **I**, for intensity, is used in mathematical calculations to represent amperes. Amperes are measured by an ammeter. Figure 5.

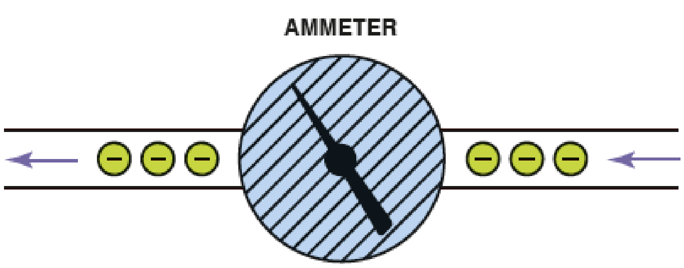

Figure 5. The ammeter displays current flow in amperes.

Volts. The volt is the unit of measurement for electrical pressure. Voltage is also called *electrical potential* because if there is voltage present in a conductor, there is a potential (possibility) for current flow. The symbol used in calculations is **E**, for electromotive force. Volts are measured by a voltmeter. Figure 6.

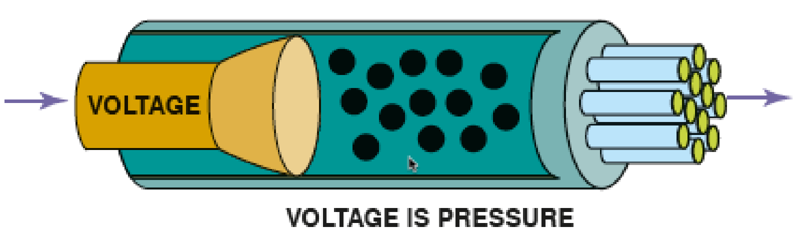

Figure 6. Voltage is the electrical force that causes the electrons to flow through a conductor.

It is possible to have pressure (volts) without any flow (amperes). For example, a fully charged 12-volt battery placed on a workbench has 12 volts of potential, but because there is no conductor (circuit) connected between the positive and negative terminals of the battery, there is no flow (amperes). Current only flows when there is pressure and a circuit for the electrons to flow in order to “equalize” to a balanced state.

Ohms. Resistance to the flow of current through a conductor is measured in units called ohms. The symbol used in calculations is **R**, for resistance. Ohms are measured by an ohmmeter. Resistance to electron flow depends on the material used as a conductor. Figure 7.

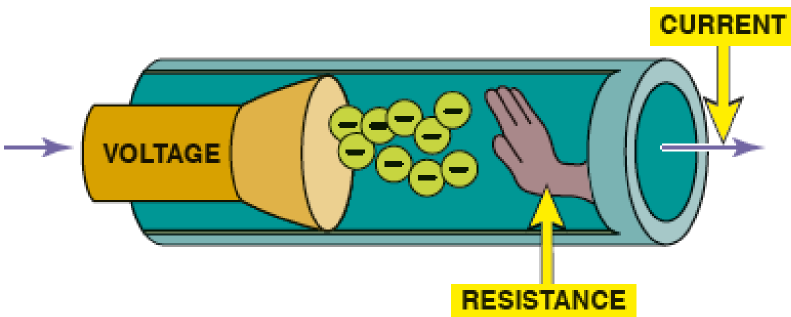

Figure 7. Resistance to the flow of electrons through a conductor is measured in ohms.

Ohm’s law can also be stated as a simple formula used to calculate one value of an electrical circuit if the other two are known. If, for example, the current (I) is unknown but the voltage (E) and resistance (R) are known, then Ohm’s law can be used to find the answer. Figure 8.

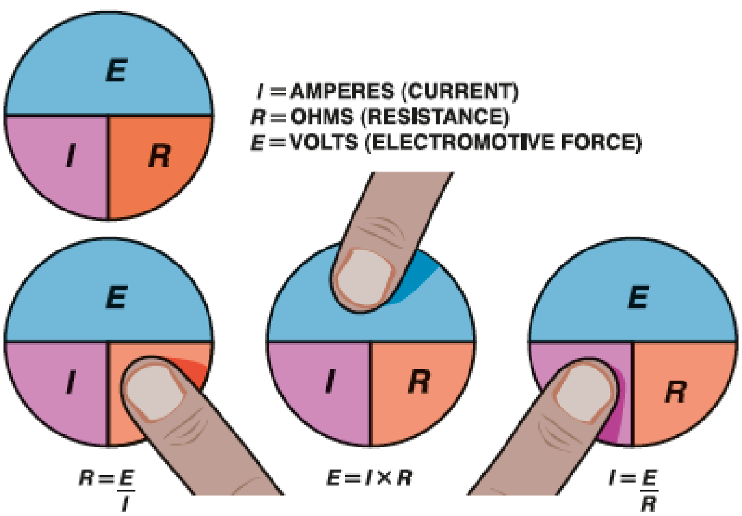

Figure 8. To calculate one unit of electricity when the other two are known, cover the unknown unit to get the formula.

Watts. A watt is the electrical unit for power, the capacity to do work. The symbol for power is P. Electrical power is calculated as amperes times volts, figure 9:

P (power) = I (amperes) × E (volts)

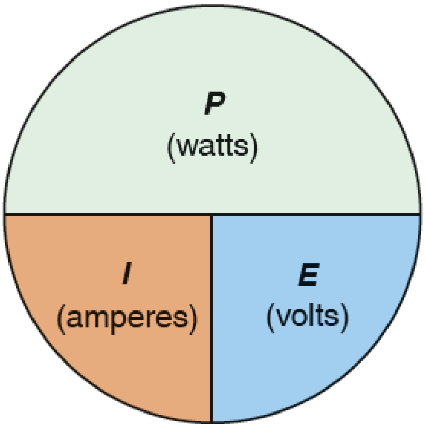

Figure 9. To calculate one unit when the other two are known, cover the unknown unit to see what unit needs to be divided or multiplied to arrive at the solution.

If any two of these factors are known, then the other remaining factor can be calculated. For example, the amperage required to operate a 55-watt low beam headlight bulb can be calculated using Watt's law. The vehicle's 12-volt battery supplies the voltage to operate the lamp. Using the formula I = P/E, the calculation is 55/12 = 4.6 amperes.

ASE TEST TOPICS

1. Verify concern; perform visual inspection; determine needed action.

The diagnostic process is a strategy that eliminates known good components or systems in order to find the root cause of automotive electrical problems.

Before a minute is spent on diagnosis, be certain that a problem exists. If the problem cannot be verified, it cannot be solved or tested to verify that the repair was complete. After the nature and scope of the problem are determined, the complaint should be verified before further diagnostic tests are performed.

Many problems can be found simply by performing a thorough visual inspection. The inspection should include the following:

- Look for corroded connectors, especially battery connections.
- Measure the battery voltage.
- Note any unusual noises, smoke, or smell
- Check everything that does and does not work. This involves turning things on and observing that everything is working properly.
- Look for evidence of previous repairs. Any time work is performed on a vehicle, there is always a risk that something will be disturbed, knocked off, or left disconnected.

2. Research applicable vehicle and service information, such as vehicle service history, service precautions, technical service bulletins, and service campaigns/recalls.

Service information is needed to correctly service or repair vehicles because it contains all the specifications, as well as the specified procedures to follow when servicing or repairing a vehicle. The most comprehensive and accurate service information is the service information from the vehicle manufacturer.

A technical service bulletin (TSB) is issued by the vehicle manufacturer to notify service technicians of a potential problem or other critical information. TSBs are designed for dealership technicians but are republished by aftermarket companies and made available along with other service information to shops and vehicle repair facilities.

A campaign is typically issued when a manufacturer wants to improve a product's performance or increase the customer's satisfaction. If the campaign involves a safety or emissions concern, it is considered a recall. A recall can occur when either the manufacturer or the National Highway Traffic Safety Administration (NHTSA) determines there is a concern.

Whenever service work is performed, a record of what was done is usually kept on file or stored electronically on a network or online server for several years. The service technician should check the vehicle service history if working on a vehicle with an unusual problem.

3. Check voltages and voltage drops in electrical/electronic circuits; interpret readings and determine needed repairs.

Digital multimeter (DMM) and digital volt-ohm-meter (DVOM) are terms commonly used for electronic high-impedance test meters. High impedance means that the electronic internal resistance of the meter is high enough to prevent excessive current draw from any circuit being tested. Most meters today have a minimum of 10 million ohms (10 megohms) of resistance. Figure 10.

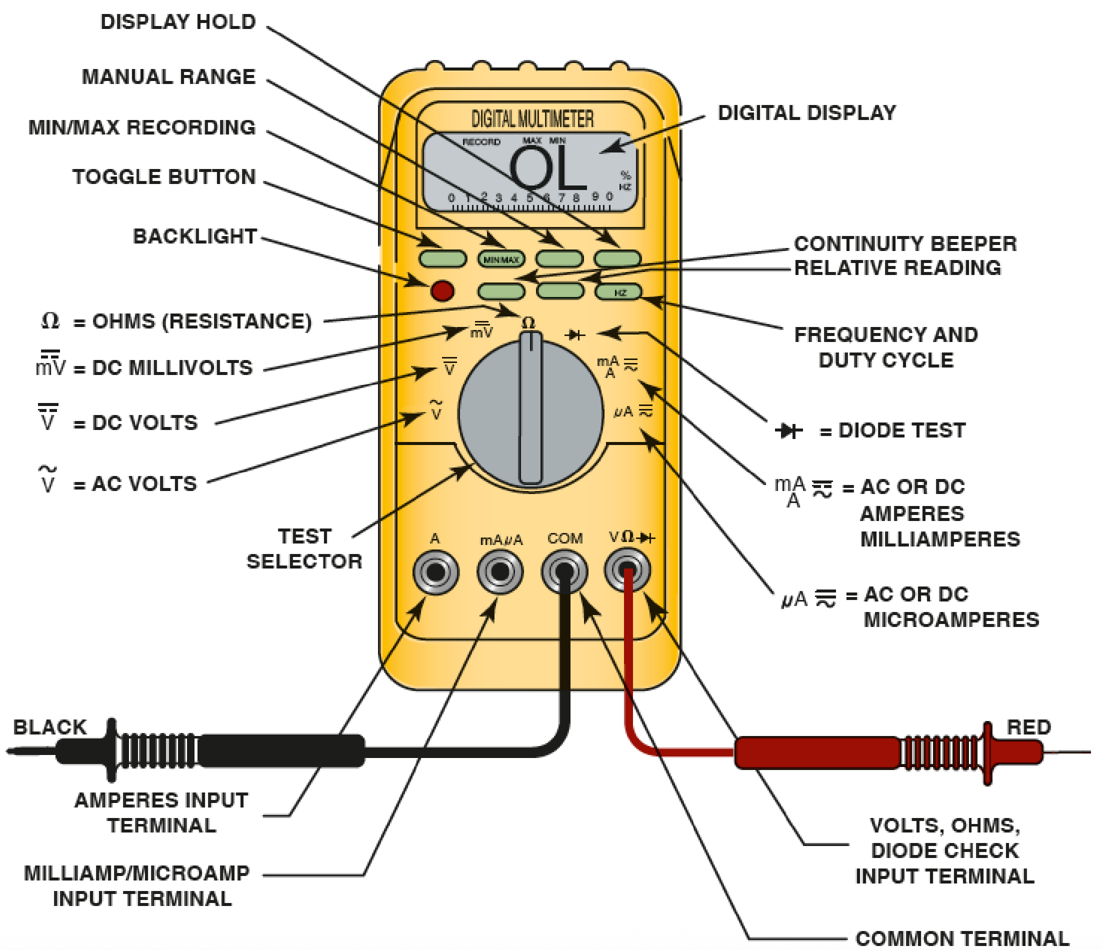

Figure 10. Digital multimeter (DMM).

A voltmeter measures the pressure or potential of electricity in units of volts. A voltmeter is connected to a circuit in parallel. Voltage can be measured by selecting either AC or DC volts.

- DC volts (DCV). This setting is the most common for automotive use. Use this setting to measure battery voltage and voltage to all lighting and accessory circuits.
- AC volts (ACV). This setting is used to check for unwanted AC voltage from alternators. Some sensors are checked using the AC volts setting.

To measure voltage, such as battery voltage:

- Place the black lead on battery negative terminal.
- Switch the meter to DC volts.
- Measure battery voltage at the positive terminal. Figure11.

Figure11. Measuring battery voltage.

Voltage drop is the drop in voltage that occurs when current is flowing through a resistance. That is, a voltage drop is the difference between voltage at the source and voltage at the electrical device to which it is flowing. Excessive voltage drop indicates resistance in the circuit.

To measure voltage drop on the charging system set the meter to read DC volts and connect the positive test lead (red) to the output terminal of the alternator. Attach the negative test lead (black) to the positive post of the battery. If the voltmeter reads higher than 0.4 volt, there is excessive resistance (voltage drop) between the alternator output terminal and the positive terminal of the battery. Figure 12.

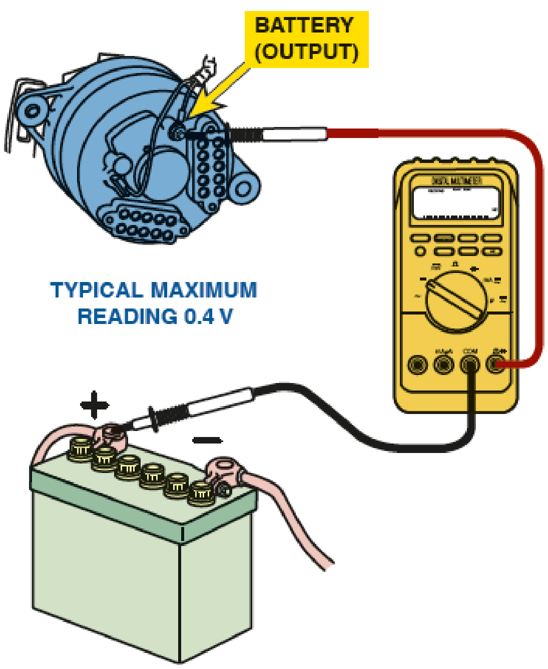

Figure 12. Measuring voltage drop on the alternator positive circuit.

4. Check current flow and wattage in electrical/electronic circuits; interpret readings and determine needed repairs.

An ammeter measures the flow of current through a complete circuit in units of amperes. The ammeter must be installed in the circuit (in series) so that it can measure all the current flow in that circuit. Digital meters require that the meter leads be moved to the ammeter terminals. Figure 13.

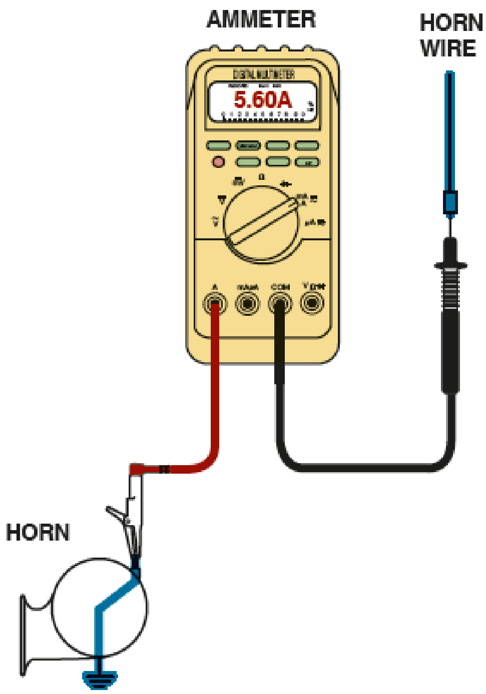

Figure 13. Measuring current in a horn circuit.

5. Check continuity and resistances in electrical/electronic circuits and components; interpret readings and determine needed repairs.

An ohmmeter measures the resistance in ohms of a component or circuit section when no current is flowing through the circuit. An ohmmeter contains a battery and is connected in series with the component or wire being measured. Figure 14.

- Zero ohms on the scale means that there is no resistance between the test leads, thus indicating continuity or a continuous path for the current to flow in a closed circuit.
- Infinity (OL) means no connection, as in an open circuit.

Figure 14. Using a digital multimeter set to read ohms (Ω) to test this lightbulb. The meter reads the resistance of the filament.

6. Check electronic circuit waveforms; interpret readings and determine needed repairs.

An oscilloscope (usually called a scope) is a visual voltmeter with a timer that shows when a voltage changes. The voltmeter part means that a scope can capture and display changing voltage levels. The scope can display these changes in voltage levels within a specific time period as waveform.

A two-channel scope can display the waveform from two separate sensors or components at the same time. This feature is very helpful when testing the accelerator position sensor or brake switch inputs to ensure they change at the appropriate voltage levels. Figure 15.

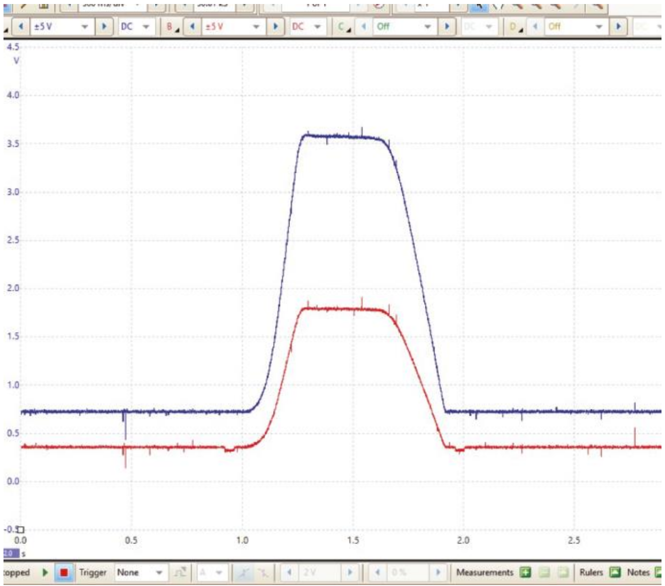

Figure 15. A two-channel scope being used to compare the two inputs from an accelerator position sensor.

One of the easiest things to measure and observe on a scope is battery voltage. A lower voltage can be observed on the scope display as the engine is started, and a higher voltage should be displayed after the engine starts. Figure 16.

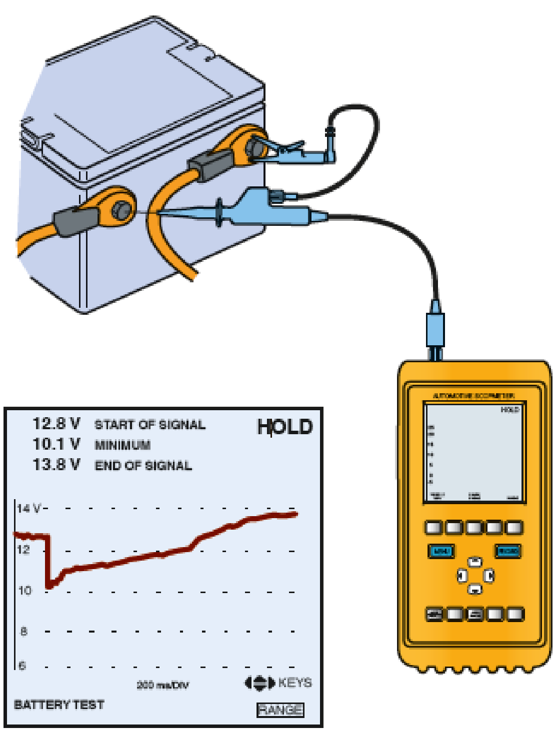

Figure 16. Scope connected to the vehicle battery.

7. Use scan tool data, bidirectional controls, and/or diagnostic trouble codes (DTCs) to diagnose electronic systems; interpret readings and determine necessary action.

The diagnostic process determines what problems or symptoms are associated with the stored DTCs that need to be identified and addressed to find the root cause of the customer concern. The best way to look at scan data is in a definite sequence and with specific, selected bits of data.

For example, with the key on, engine off (KOEO), engine coolant temperature (ECT) should be the same as the intake air temperature (IAT) after the vehicle sits for several hours.

Bi-directional Testing. Most scan tools are capable of performing bi-directional testing including actuator tests and adjustments. Bi-directional control can be used to turn on and off certain components or functions.

Bi-directional actuator tests allow the technician to check the condition of items that are controlled by a module such as turning on headlights or sounding the horn.

8. Find shorts, grounds, opens, and resistance problems in electrical/electronic circuits; determine needed repairs.

Open Circuits. An open circuit is any circuit that is not complete, or that lacks continuity, such as a broken wire. Figure 17.

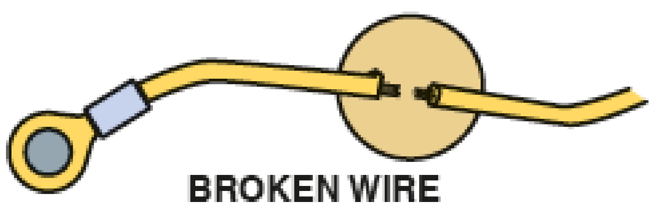

Figure 17. Open circuit.

Short-to-Ground. A short-to-ground is a type of short circuit that occurs when the current bypasses part of the normal circuit and flows directly to ground. Figure 18.

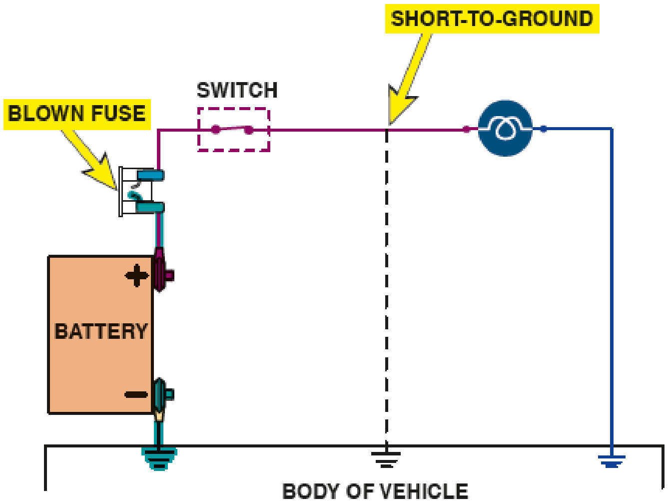

Figure 18. Short-to-ground usually blows a fuse or burns wiring.

High Resistance. High resistance can be caused by any of the following, figure 19:

- Corroded connections or sockets
- Loose terminals in a connector
- Loose ground connections

Figure 19. High resistance connections may be warm or hot to the touch.

If there is high resistance anywhere in a circuit, it may cause the following problems:

1. Slow operation of a motor-driven unit, such as the windshield wipers or blower motor
2. Dim lights
3. “Clicking” of relays or solenoids
4. No operation of a circuit or electrical component

Locating a Short Circuit. A short-to-ground always blows a fuse and usually involves a wire on the power side of the circuit coming in contact with metal. Therefore, a thorough visual inspection should be performed around areas involving heat or movement, especially if there is evidence of a previous collision or previous repair that may not have been properly completed. Some ways to locate the short circuit include:

- Circuit Breaker Method. Circuit breakers are available that plug directly into the fuse panel, replacing a blade-type fuse. As long as the shorted component or wire is circuit, the circuit breaker will click on and off. All components and connectors in the defective circuit should be disconnected one at a time until the circuit breaker stops clicking.
- Test Light Method. To use the test light method, simply remove the blown fuse and connect a test light to the terminals of the fuse holder. If there is a short circuit, current flows through the test light and on to ground through the short circuit, and the test light lights. Unplug the connectors or components protected by the fuse until the test light goes out.
- Additional methods of finding a short circuit are:
  - Use a circuit breaker and gauss gauge to find the location of the short circuit.
  - An electronic tone generator tester can be used to locate a short-to-ground or an open circuit. The tone generator tester generates a tone that can be heard through a receiver (probe). The tone is heard as long as there is a continuous electrical path along the circuit. The signal stops if there is a short-to-ground or an open in the circuit.

9. Measure and diagnose the cause(s) of abnormal key-off battery drain (parasitic draw); determine needed repairs.

The battery electrical drain test determines if any component or circuit in a vehicle is causing a drain on the battery when everything is off. This test is also called the ignition off draw (IOD) or parasitic load test.

- The fastest and easiest method to measure battery electrical drain is to connect an inductive DC ammeter that can measure low current (10 milliamperes). Figure 20.

Figure 20. A mini clamp-on digital multimeter can be used to measure the amount of battery electrical drain that is present. In this case, a reading of 20 milliamperes (displayed on the meter as 00.02 ampere) is within the normal range of 20 to 30 milliamperes.

- A battery electrical drain test can also be done using a DMM set to read DC amperes. The vehicle negative battery cable is disconnected and the meter inserted in series between the battery post and the negative cable.

CAUTION: If using this method DO NOT turn on any circuits in the vehicle (open doors or turn on the ignition). Any high current load will blow the fuse in the meter.

Using either method, wait 20 minutes for all computers and circuits to shut down and then read the meter. Normal = 20 to 30 milliamperes (0.02 to 0.03 ampere) or less. If any one of the many control modules (PCM, BCM, EBCM, etc.) is staying on and not going to sleep disconnect one module at a time and check to see if the battery drain has been reduced or eliminated.

10. Inspect, test, and replace fusible links, circuit breakers, fuses, diodes, and current limiting devices.

Circuit protection devices are used in every circuit to protect the wiring from overheating and damage caused by excessive current flow as a result of a short circuit or other malfunction. These can be fusible links, fuses, circuit breakers, or PTC devices.

A fusible link is a type of fuse that consists of a short length (6 to 9 inches long) of standard copper-strand wire covered with a special nonflammable insulation. This wire is usually four wire numbers smaller than the wire of the circuits it protects. For example, a 12-gauge circuit is protected by a 16-gauge fusible link. Figure 21.

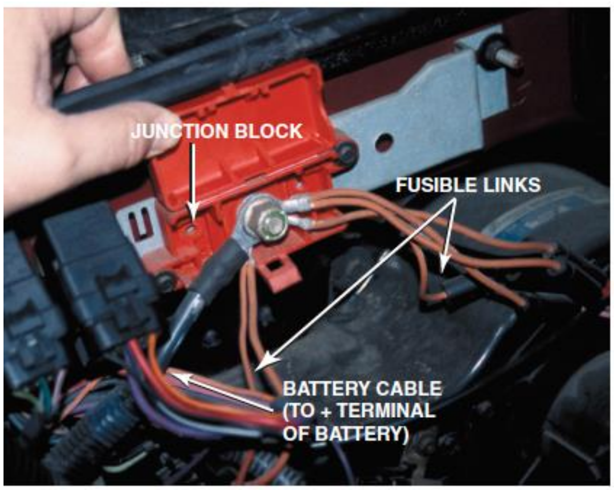

Figure 21. Fusible links and junction box.

A fuse is constructed of a fine tin conductor inside a glass, plastic, or ceramic housing. Each fuse has an opening in the top of its plastic portion to allow access to its metal contacts for testing purposes. Figure 22.

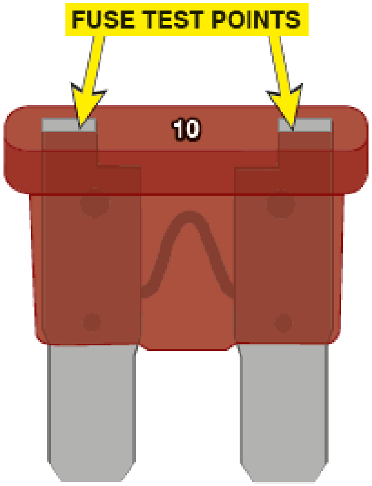

Figure 22. A test light will light at both test points if the fuse is good.

Circuit breakers are used to prevent harmful overload (excessive current flow) in a circuit by opening the circuit and stopping the current flow to prevent overheating, and possible fire, caused by hot wires or electrical components. Some circuits that use circuit breakers are power seats, power door locks, and power windows. Figure 23.

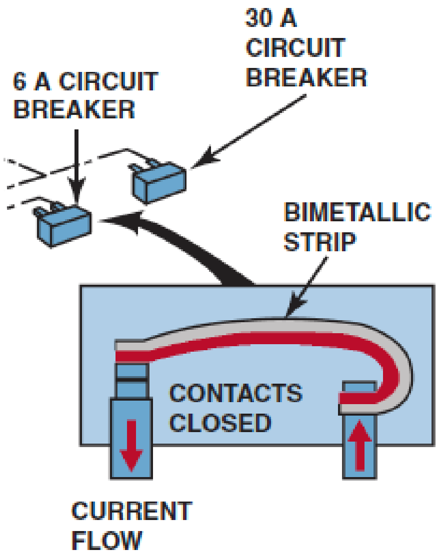

Figure 23. Excessive current causes the bimetallic strip to bend, opening the circuit.

Positive temperature coefficient (PTC) circuit protectors are solid state (without moving parts). Unlike circuit breakers or fuses, PTC circuit protection devices do not open the circuit, but rather provide a very high resistance between the protector and the component. Figure 24.

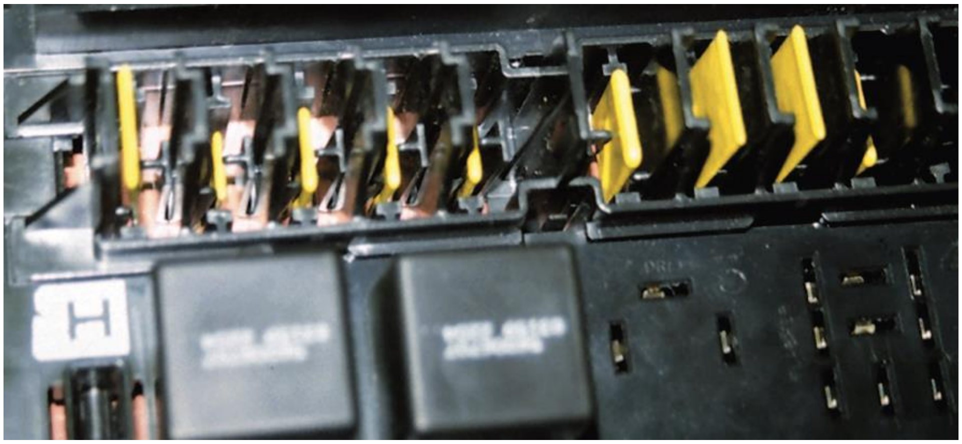

Figure 24. PTC circuit protectors (yellow wafers).

11. Read and interpret electrical schematic diagrams and symbols.

Service information includes wiring schematics of every electrical circuit in a vehicle. A wiring schematic, sometimes called a diagram , shows electrical components and wiring using symbols and lines to represent components and wires.

Wire size is shown on all schematics. Figure 25 illustrates a rear side marker bulb circuit diagram where “0.8” indicates the metric wire gauge size in square millimeters (mm2) and “PPL” indicates a solid purple wire.

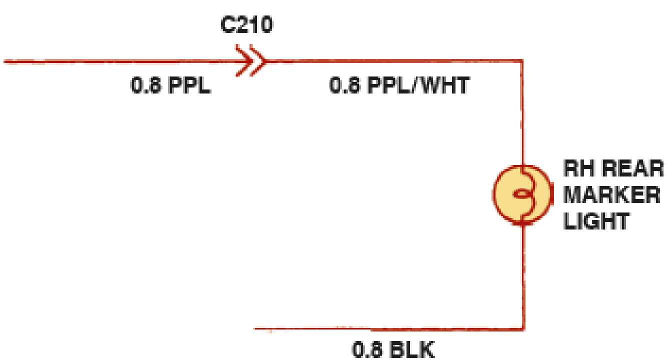

Figure 25. Typical section of a wiring diagram. Notice that the wire color changes at connection S210.

Electrical and electronic symbols are used in automotive wiring and circuit diagrams. Both the conventional and the global symbols are shown side by side to make reading schematics easier. The global symbols are used by many vehicle manufacturers. Figure 26.

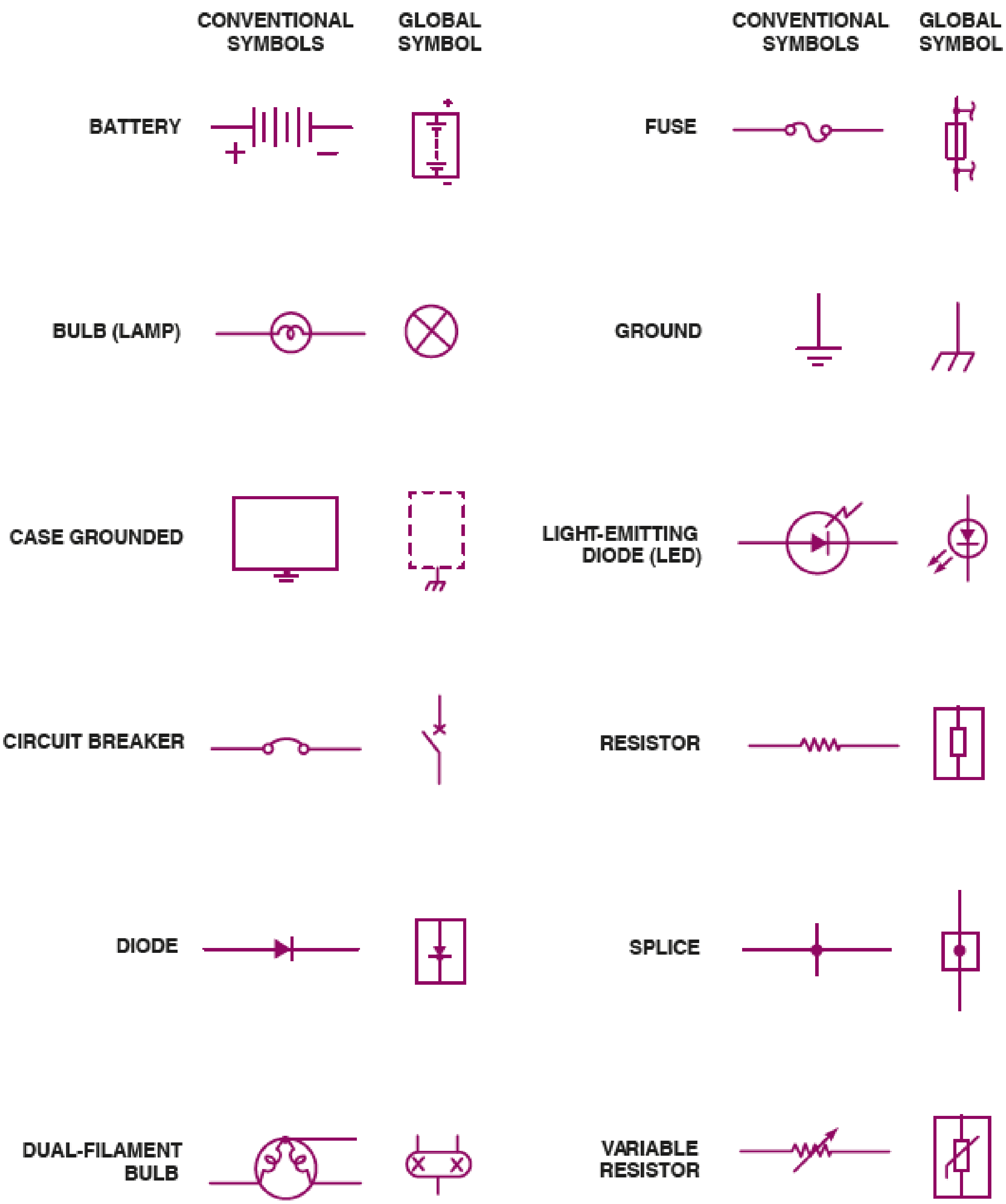

Figure 26. Typical schematic symbols.

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12. Diagnose failures in the data bus communications network; identify network type; determine needed repairs.

Since the 1990s, vehicles have used modules to control the operation of most electrical components. A typical vehicle has 10 or more modules, and they communicate with each other over data lines or hard wiring, depending on the application. Figure 27.

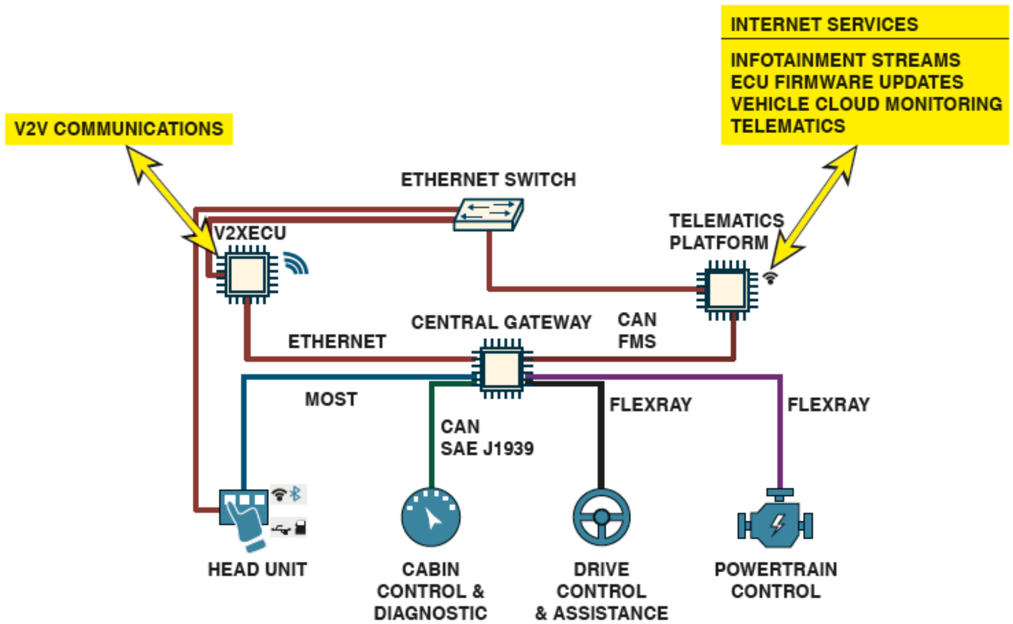

Figure 27. A network example.

The Society of Automotive Engineers (SAE) standards include the following three categories of in-vehicle network communications:

- Class A. Low-speed networks, meaning less than 10,000 bits per second (bps, or 10 kbs), are generally used for trip computers, entertainment, and other convenience features.
- Class B. Medium-speed networks, meaning 10,000 to 125,000 bps (10 to 125 kbs), are generally used for information transfer among modules, such as instrument clusters, temperature sensor data, and other general uses.
- Class C. High-speed networks, meaning 125,000 to 1,000,000 bps, are generally used for real-time powertrain and vehicle dynamic control. High-speed BUS communication systems now use a controller area network (CAN). Figure 28.

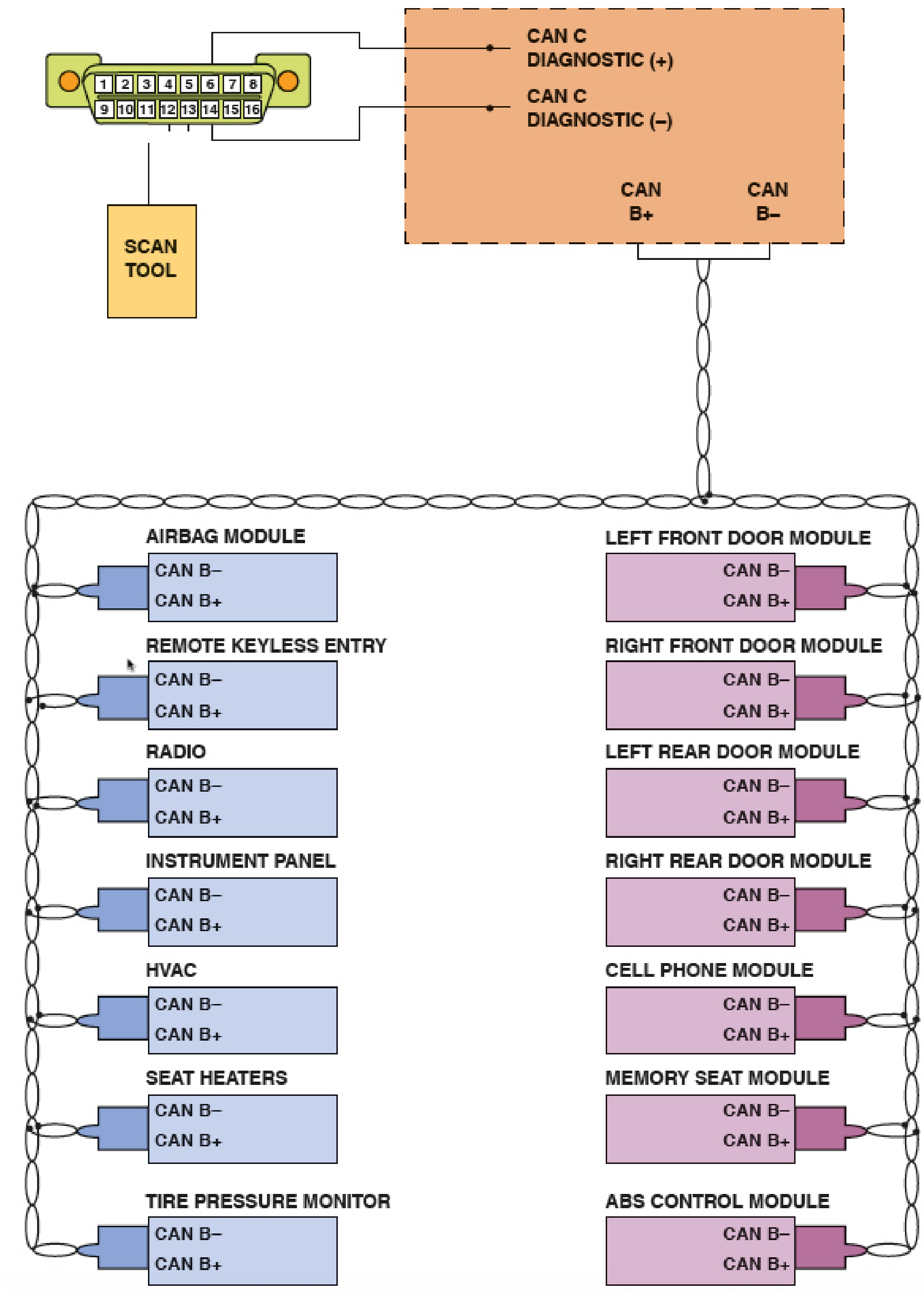

Figure 28. Controller area network (CAN) communication system.

When a network communications fault is suspected, perform the following steps:

STEP 1 Check everything that does and does not work. Often accessories that do not seem to be connected can help identify which module or BUS circuit is at fault.

STEP 2 Perform module status test. Use a factory-level scan tool or an aftermarket scan tool equipped with enhanced software that allows OE-like functions. Check if the components or systems can be operated through the scan tool.

STEP 3 Check the resistance of the terminating resistors. Most high-speed BUS systems use resistors at each end, called terminating resistors. Figure 29.

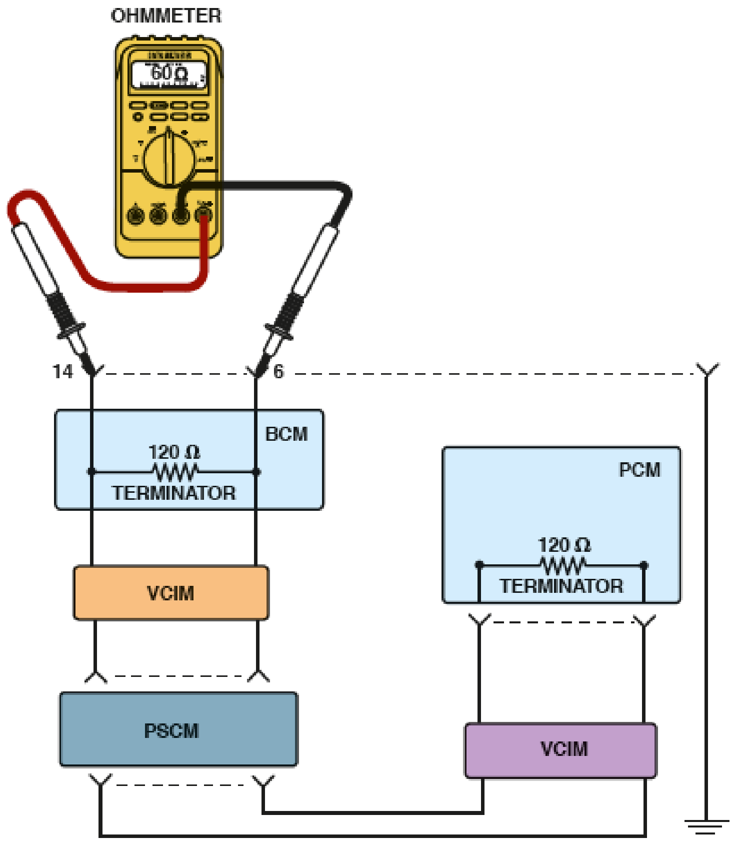

Figure 29. The two 120 Ω terminating resistors in parallel should read 60 Ω.

STEP 4 Check data BUS for voltages. Use a digital multi-meter set to DC volts to monitor communications and check the BUS for proper operation.

STEP 5 Use a digital storage oscilloscope to monitor the waveforms of the BUS circuit. Using a scope on the data line terminals can show if communication is being transmitted. CAN uses a differential type of module communication where the voltage on one wire is the equal, but opposite, voltage on the other wire. When no communication is occurring, both wires have 2.5 volts applied. When communication is occurring, CAN H goes up 1 to 3.5 volts and CAN L goes down 1 to 1.5 volts. Figure 30.

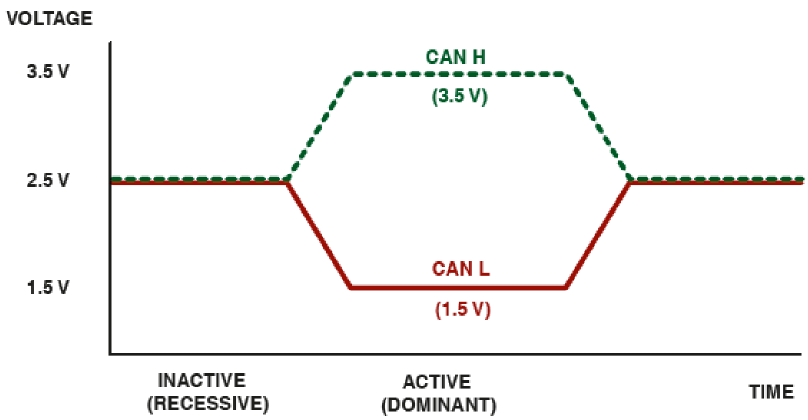

Figure 30. CAN voltage signals.

Typical faults and their causes include the following:

- Normal operation. Normal operation shows variable voltage signals on the data lines.
- High voltage. If there is a constant high-voltage signal without any change, this indicates that the data line is shorted-to-voltage.
- Zero or low voltage. If the data line voltage is zero or almost zero and not showing any higher voltage signals, the data line is short-to-ground.

13. Remove and replace control modules; program, reprogram, code, initialize, and/or configure as needed.

Programming or reprogramming consists of downloading new calibrations from the manufacturer into the PCM's electronically erasable programmable read only memory (EEPROM). Any time a PCM or module is replaced it must be programmed or setup to match the vehicle's systems. Figure 31.

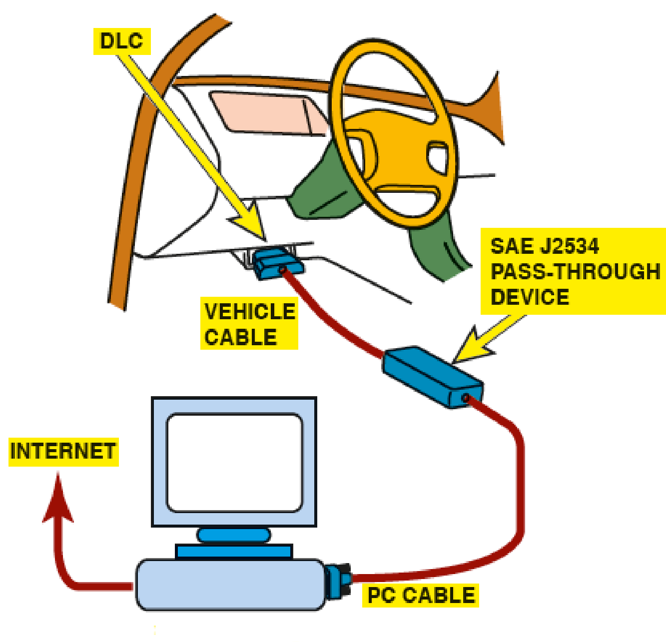

Figure 31. Programming loads from the manufacturers service information into the vehicle PCM.

Battery Maintainer. In order to provide a stable vehicle voltage throughout the reprogramming process, it is recommended that a battery maintainer be connected to the vehicle during the repair. A battery maintainer is designed to hold the vehicle at a specific voltage throughout the duration of the repair. Figure 32.

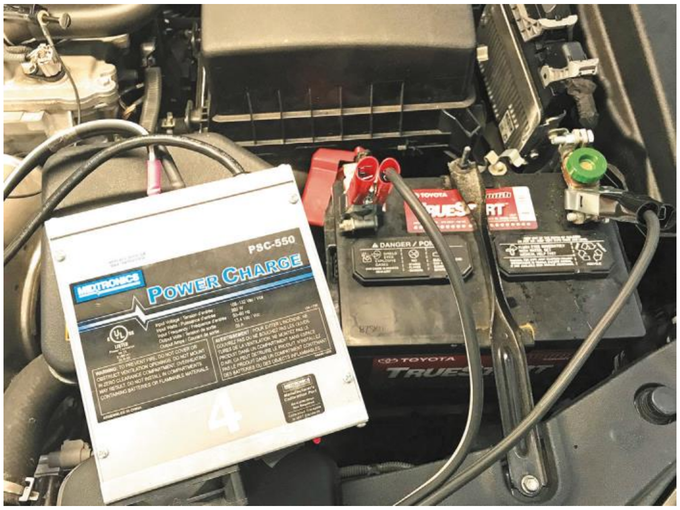

Figure 32. Example of battery maintainer that meets the voltage and current requirements for reprogramming.