Table of Contents

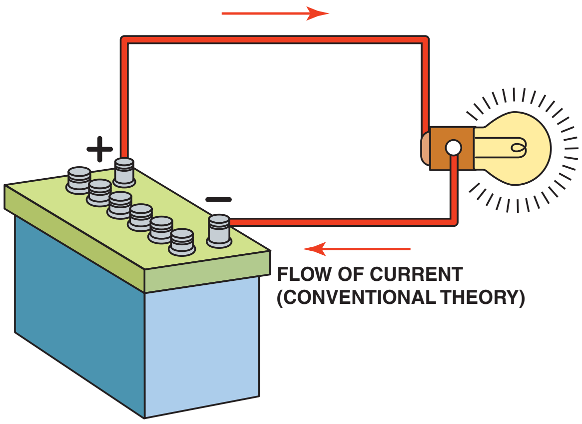


FIGURE 14 Conventional theory states that current flows through a circuit from positive (+) to negative (−). Automotive electricity uses the conventional theory in all electrical diagrams and schematics.

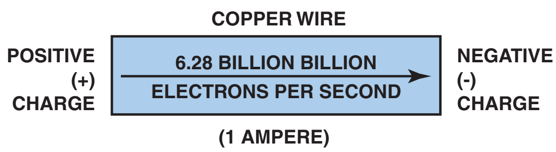


FIGURE 15 One ampere is the movement of 1 coulomb (6.28 billion billion electrons) past a point in 1 second.

CONVENTIONAL THEORY VERSUS ELECTRON THEORY

- **Conventional theory.** 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. ● **SEE FIGURE 14**.
- **Electron 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. Most automotive applications use the conventional theory.

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. When 6.28 billion billion electrons (the name for this large number of electrons is a **coulomb**) move past a certain point in 1 second, this represents 1 ampere of current. ● **SEE FIGURE 15**.

The ampere is the electrical unit for the amount of electron flow, just as "gallons per minute" is the unit that can be used to measure the quantity of water flow. It is named for the French electrician, Andrè Marie Ampére (1775–1836). The conventional abbreviations and measurement for amperes are as follows:

1. The ampere is the unit of measurement for the amount of current flow.
2. *A* and *amps* are acceptable abbreviations for *amperes*.

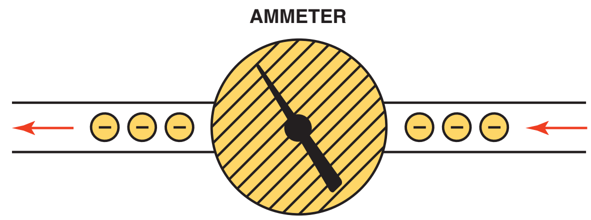


FIGURE 16 An ammeter is installed in the path of the electrons similar to a water meter used to measure the flow of water in gallons per minute. The ammeter displays current flow in amperes.

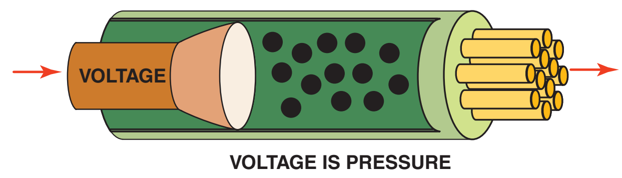


FIGURE 17 Voltage is the electrical pressure that causes the electrons to flow through a conductor.

3. The capital letter *I*, for *intensity*, is used in mathematical calculations to represent amperes.
4. Amperes do the actual work in the circuit. It is the actual movement of the electrons through a light bulb or motor that actually makes the electrical device work. Without amperage through a device it will not work at all.
5. Amperes are measured by an **ammeter** (not ampmeter). ● **SEE FIGURE 16**.

VOLTS The **volt** is the unit of measurement for electrical pressure. It is named for an Italian physicist, Alessandro Volta (1745–1827). The comparable unit using water pressure as an example would be pounds per square inch (psi). It is possible to have very high pressures (volts) and low water flow (amperes). It is also possible to have high water flow (amperes) and low pressures (volts). Voltage is also called **electrical potential**, because if there is voltage present in a conductor, there is a potential (possibility) for current flow. This electrical pressure is a result of the following:

- Excess electrons remain at one end of the wire or circuit.
- There is a lack of electrons at the other end of the wire or circuit.
- The natural effect is to equalize this imbalance, creating a pressure to allow the movement of electrons through a conductor.
- It is possible to have pressure (volts) without any flow (amperes). For example, a fully charged 12 volt battery sitting on a workbench has 12 volts of pressure potential, but because there is not a conductor (circuit) connected between the positive and negative posts of the battery, there is no flow (amperes). Current will only flow when there is pressure and a circuit for the electrons to flow in order to "equalize" to a balanced state.

Voltage does *not* flow through conductors, but voltage does cause current (in amperes) to flow through conductors. ● **SEE FIGURE 17**.

The conventional abbreviations and measurement for voltage are as follows:

1. The volt is the unit of measurement for the amount of electrical pressure.
2. **Electromotive force**, abbreviated **EMF**, is another way of indicating voltage.

FIGURE 18 This digital multimeter set to read DC volts is being used to test the voltage of a vehicle battery. Most multimeters can also measure resistance (ohms) and current flow (amperes).

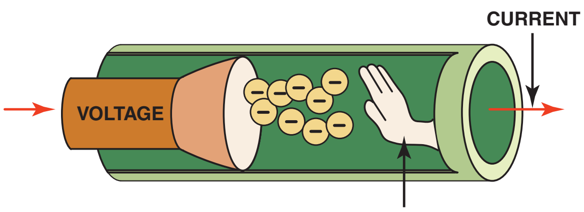


FIGURE 19 Resistance to the flow of electrons through a conductor is measured in ohms.

3. *V* is the generally accepted abbreviation for *volts*.
4. The symbol used in calculations is *E*, for *electromotive force*.
5. Volts are measured by a **voltmeter**. ● **SEE FIGURE 18**.

OHMS **Resistance** to the flow of current through a conductor is measured in units called **ohms**, named after the German physicist, George Simon Ohm (1787–1854). The resistance to the flow of free electrons through a conductor results from the countless collisions the electrons cause within the atoms of the conductor. ● **SEE FIGURE 19**.

The conventional abbreviations and measurement for resistance are as follows:

1. The ohm is the unit of measurement for electrical resistance.
2. The symbol for ohms is Ω (Greek capital letter omega), the last letter of the Greek alphabet.
3. The symbol used in calculations is *R*, for *resistance*.
4. Ohms are measured by an **ohmmeter**.
5. Resistance to electron flow depends on the material used as a conductor.

WATTS A **watt** is the electrical unit for *power,* the capacity to do work. It is named after a Scottish inventor, James Watt (1736–1819). The symbol for power is *P*. Electrical power is calculated as amperes times volts:

$$P \text{ (power)} = I \text{ (amperes)} \times E \text{ (volts)}$$

The formula can also be used to calculate the amperage if the wattage and the voltage are known. For example, a 100 watt light bulb powered by 120 volts AC in the shop requires how many amperes?

A (amperes) = *P* (watts) divided by *E* (volts)

A = 0.83 amperes

● **SEE FIGURE 20**.

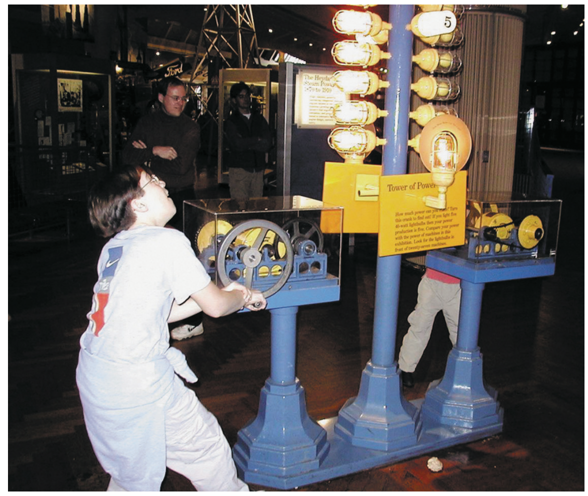


FIGURE 20 A display at the Henry Ford Museum in Dearborn, Michigan, which includes a hand-cranked generator and a series of light bulbs. This figure shows a young man attempting to light as many bulbs as possible. The crank gets harder to turn as more bulbs light because it requires more power to produce the necessary watts of electricity.

SOURCES OF ELECTRICITY

FRICTION When certain different materials are rubbed together, the friction causes electrons to be transformed from one to the other. Both materials become electrically charged. These charges are not in motion, but stay on the surface where they were deposited. Because the charges are stationary, or static, this type of voltage is called **static electricity**. Walking across a carpeted floor creates a buildup of a static charge in your body which is an insulator and then the charge is discharged when you touch a metal conductor. Vehicle tires rolling on pavement often create static electricity that interferes with radio reception.

HEAT When pieces of two different metals are joined together at both ends and one junction is heated, current passes through the metals. The current is very small, only millionths of an ampere, but this is enough to use in a temperature-measuring device called a **thermocouple**. ● **SEE FIGURE 21**.

Some engine temperature sensors operate in this manner. This form of voltage is called **thermoelectricity**.

Thermoelectricity was discovered and has been known for over a century. In 1823, a German physicist, Thomas Johann Seebeck, discovered that a voltage was developed in a loop containing two dissimilar metals, provided the two junctions were maintained at different temperatures. A decade later, a French scientist, Jean Charles Athanase Peltier, found that electrons moving through a solid can carry heat from one side of the material to the other side. This effect is called the **Peltier effect**. A Peltier effect device is often used in

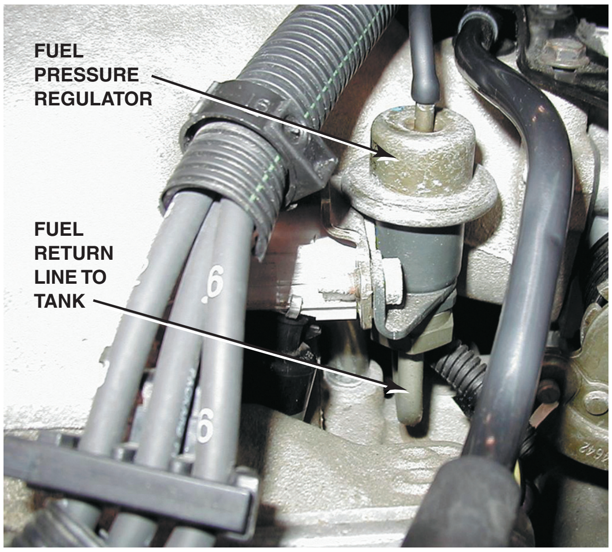


FIGURE 5 Fuel should be heard returning to the fuel tank at the fuel return line if the fuel-pump and fuel-pressure regulator are functioning correctly.

TECH TIP

Quick and Easy Leaking Injector Test

Leaking injectors may be found by disabling the ignition, unhooking all injectors, and checking exhaust for hydrocarbons (HC) using a gas analyzer while cranking the engine (maximum HC = 300 PPM). This test does not identity which injector is leaking but it does confirm that one or more injector is leaking.

- Check all fuel-injection electrical connections for corrosion or damage.
- Check for gasoline at the vacuum port of the fuel-pressure regulator if the vehicle is so equipped. Gasoline in the vacuum hose at the fuel-pressure regulator indicates that the regulator is defective and requires replacement.

SCAN TOOL VACUUM LEAK DIAGNOSIS

If a vacuum (air) leak occurs on an engine equipped with a speed-density-type of fuel injection, the extra air would cause the following to occur:

- The idle speed increases due to the extra air just as if the throttle pedal was depressed.
- The MAP sensor reacts to the increased air from the vacuum leak as an additional load on the engine.
- The computer increases the injector pulse width slightly longer due to the signal from the MAP sensor.
- The air–fuel mixture remains unchanged.
- The idle air control (IAC) counts will decrease, thereby attempting to reduce the engine speed to the target idle speed stored in the computer memory. ● **SEE FIGURE 6.**

FIGURE 6 Using a scan tool to check for IAC counts or percentage as part of a diagnostic routine.

TECH TIP

No Spark, No Squirt

Most electronic fuel-injection computer systems use the ignition primary (pickup coil or crank sensor) pulse as the trigger for when to inject (squirt) fuel from the injectors (nozzles). If this signal were not present, no fuel would be injected. Because this pulse is also necessary to trigger the module to create a spark from the coil, it can be said that "no spark" could also mean "no squirt." Therefore, if the cause of a no-start condition is observed to be a lack of fuel injection, do not start testing or replacing fuel-system components until the ignition system is checked for proper operation.

Therefore, one of the best indicators of a vacuum leak on a speed-density fuel-injection system is to look at the IAC counts or percentage. Normal **IAC counts** or percentage is usually 15 to 25. A reading of less than 5 indicates a vacuum leak.

If a vacuum leak occurs on an engine equipped with a mass airflow-type fuel-injection system, the extra air causes the following to occur:

- The engine will operate leaner-than-normal because the extra air has not been measured by the MAF sensor.
- The idle speed will likely be lower due to the leaner-than-normal air–fuel mixture.
- The idle air control (IAC) counts or percentage will often increase in an attempt to return the engine speed to the target speed stored in the computer.

PORT FUEL-INJECTION SYSTEM DIAGNOSIS

To determine if a port fuel-injection system—including the fuel pump, injectors, and fuel-pressure regulator–is operating correctly, take the following steps.

1. Attach a fuel-pressure gauge to the Schrader valve on the fuel rail. ● **SEE FIGURE 7.**

FIGURE 7 Checking the fuel pressure using a fuel-pressure gauge connected to the Schrader valve.

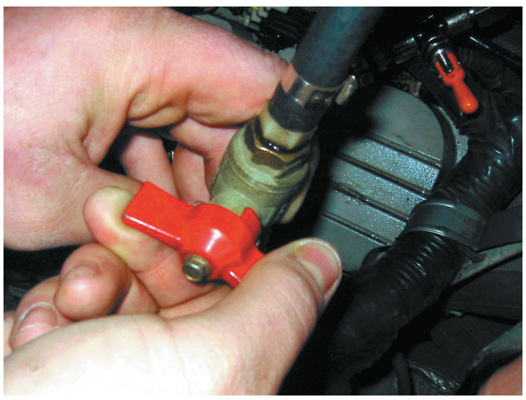
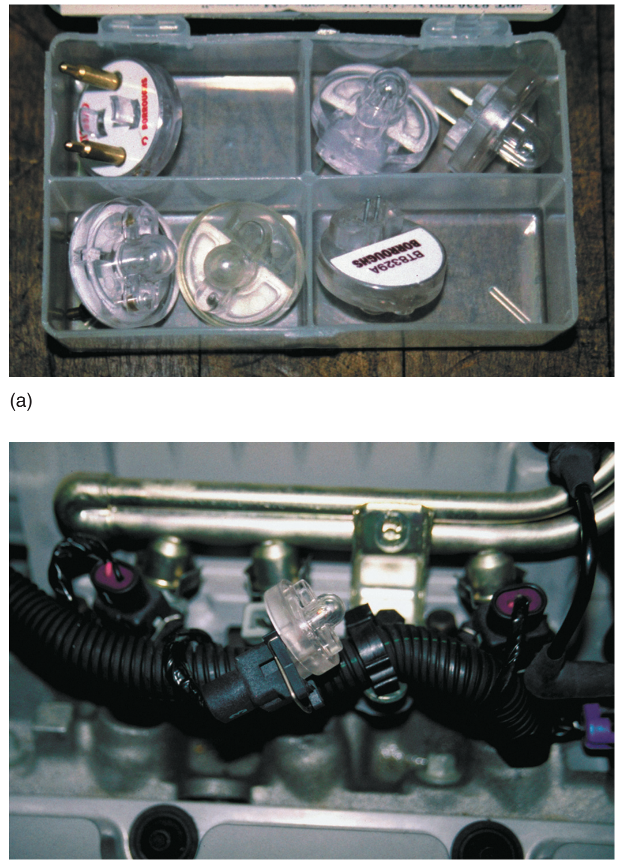


FIGURE 8 Shutoff valves must be used on vehicles equipped with plastic fuel lines to isolate the cause of a pressure drop in the fuel system.

2. Turn the ignition key on or start the engine to build up the fuel-pump pressure (often about 35 to 45 PSI. Always check service information for the specified fuel pressure).
3. Wait 20 minutes and observe the fuel pressure retained in the fuel rail and note the PSI reading. The fuel pressure should not drop more than 20 PSI (140 kPa) in 20 minutes. If the drop is less than 20 PSI in 20 minutes, everything is okay; if the drop is *greater,* then there is a possible problem with:
   - The check valve in the fuel pump
   - Leaking injectors, lines, or fittings
   - A defective (leaking) fuel-pressure regulator

   To determine which unit is defective, perform the following:

- Reenergize the electric fuel pump.
- Clamp the fuel *supply* line, and wait 10 minutes (see Caution box). If the pressure drop does not occur, replace the fuel pump. If the pressure drop still occurs, continue with the next step.
- Repeat the pressure buildup of the electric pump and clamp the fuel return line. If the pressure drop time is now okay, replace the fuel-pressure regulator.
- If the pressure drop still occurs, one or more of the injectors is leaking. Remove the injectors with the fuel rail and hold over paper. Replace those injectors that drip one or more drops after 10 minutes with pressurized fuel.



(a)

(b)

FIGURE 9 (a) Noid lights are usually purchased as an assortment so that one is available for any type or size of injector wiring connector. (b) The connector is unplugged from the injector and a noid light is plugged into the harness side of the connector. The noid light should flash when the engine is being cranked if the power circuit and the pulsing to ground by the computer are functioning normally.

CAUTION: Do not clamp plastic fuel lines. Connect shutoff valves to the fuel system to shut off supply and return lines. ● **SEE FIGURE 8.**

TESTING FOR AN INJECTOR PULSE

One of the first checks that should be performed when diagnosing a no-start condition is whether the fuel injectors are being pulsed by the computer. Checking for proper pulsing of the injector is also important in diagnosing a weak or dead cylinder.

A **noid light** is designed to electrically replace the injector in the circuit and to flash if the injector circuit is working correctly. ● **SEE FIGURE 9.** To use a noid light, disconnect the electrical connector at the fuel injector and plug the noid light into the injector harness connections. Crank or start the engine. The noid light should flash regularly.

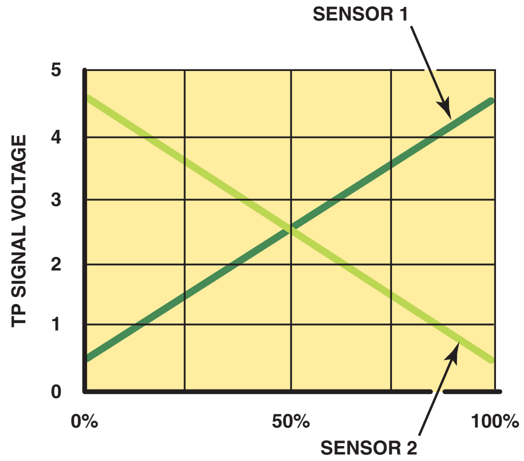


FIGURE 7 The two TP sensors used on the throttle body of an electronic throttle body assembly produce opposite voltage signals as the throttle is opened. The total voltage of both combined at any throttle plate position is 5 volts.

FREQUENTLY ASKED QUESTION

How Do You Calibrate a New APP Sensor?

Whenever an accelerator pedal position (APP) sensor is replaced, it should be calibrated before it will work correctly. Always check service information for the exact procedure to follow after APP sensor replacement. Here is a typical example of the procedure:

STEP 1 Make sure accelerator pedal is fully released.

STEP 2 Turn the ignition switch on (engine off) and wait at least 2 seconds.

STEP 3 Turn the ignition switch off and wait at least 10 seconds.

STEP 4 Turn the ignition switch on (engine on) and wait at least 2 seconds.

STEP 5 Turn the ignition switch off and wait at least 10 seconds.

(a)

(b)

FIGURE 8 (a) A "reduced power" warning light indicates a fault with the electronic throttle control system on some General Motors vehicles. (b) A symbol showing an engine with an arrow pointing down is used on some General Motors vehicles to indicate a fault with the electronic throttle control system.

DIAGNOSIS OF ELECTRONIC THROTTLE CONTROL SYSTEMS

FAULT MODE Electronic throttle control (ETC) systems can have faults like any other automatic system. Due to the redundant sensors in accelerator pedal position (APP) sensors and throttle position (TP) sensor, many faults result in a *"limp home"* situation instead of a total failure. The limp home mode is also called the *"fail-safe mode"* and indicates the following actions performed by the powertrain control module (PCM).

- Engine speed is limited to the default speed (about 1200 to 1600 RPM).
- There is slow or no response when the accelerator pedal is depressed.
- The cruise control system is disabled.
- A diagnostic trouble code (DTC) is set.
- An ETC warning lamp on the dash will light. The warning lamp may be labeled differently, depending on the vehicle manufacturer. For example:
  - General Motors vehicle–Reduced power lamp (● **SEE FIGURE 8**)
  - Ford–Wrench symbol (amber or green) (● **SEE FIGURE 9**)
  - Chrysler–Red lightning bolt symbol (● **SEE FIGURE 10**)
- The engine will run and can be driven slowly. This limp-in mode operation allows the vehicle to be driven off of the road and to a safe location.

The ETC may enter the limp-in mode if any of the following has occurred:

- Low battery voltage has been detected
- PCM failure
- One TP and the MAP sensor have failed
- Both TP sensors have failed
- The ETC actuator motor has failed
- The ETC throttle spring has failed

FIGURE 9 A wrench symbol warning lamp on a Ford vehicle. The symbol can also be green.

FIGURE 10 A symbol used on a Chrysler vehicle indicating a fault with the electronic throttle control.

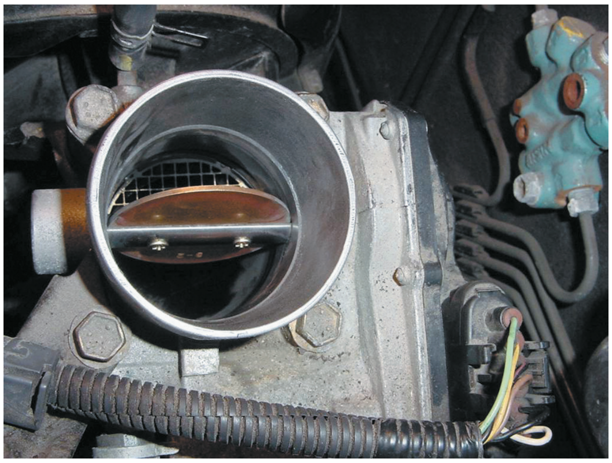


FIGURE 11 The throttle plate stayed where it was moved, which indicates that there is a problem with the electronic throttle body control assembly.

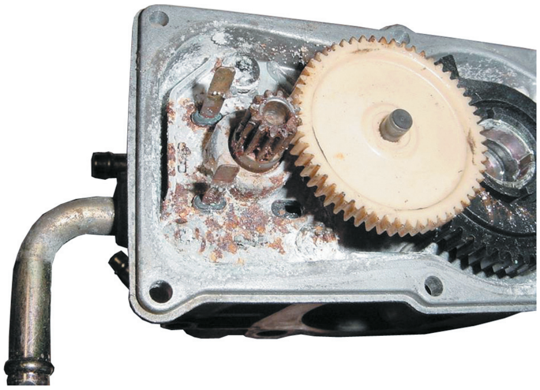


FIGURE 12 A corroded electronic throttle control assembly shown with the cover removed.

REAL WORLD FIX

The High Idle Toyota

The owner of a Toyota Camry complained that the engine would idle at over 1200 RPM compared with a normal 600 to 700 RPM. The vehicle would also not accelerate. Using a scan tool, a check for diagnostic trouble codes showed one code: P2101–"TAC motor circuit low."

Checking service information led to the inspection of the electronic throttle control throttle body assembly. With the ignition key out of the ignition and the inlet air duct off the throttle body, the technician used a screwdriver to push gently to see if the throttle plate worked.

Normal operation–The throttle plate should move and then spring back quickly to the default position.

Abnormal operation–If the throttle plate stays where it is moved or does not return to the default position, there is a fault with the throttle body assembly.

● **SEE FIGURE 11.**

Solution: The technician replaced the throttle body assembly with an updated version and proper engine operation was restored. The technician disassembled the old throttle body and found it was corroded inside due to moisture entering the unit through the vent hose. ● **SEE FIGURE 12.**

VACUUM LEAKS The electronic throttle control (ETC) system is able to compensate for many vacuum leaks. A vacuum leak at the intake manifold for example will allow air into the engine that is not measured by the mass airflow sensor. The ETC system will simply move the throttle as needed to achieve the proper idle speed to compensate for the leak.

DIAGNOSTIC PROCEDURE If a fault occurs in the ETC system, check service information for the specified procedure to follow for the vehicle being checked. Most vehicle service information includes the following steps:

STEP 1 Verify the customer concern.

STEP 2 Use a factory scan tool or an aftermarket scan tool with original equipment capability and check for diagnostic trouble codes (DTCs).