25

Computers and Sensors—Operation, Diagnosis, and Service

OBJECTIVES: After studying Chapter 25, you should be able to:

1. Prepare for the interprovincial Red Seal certification examination in Appendix VIII (Engine Performance) on the topics covered in this chapter.
2. Explain the purpose, function and operation of on-board computers.
3. Discuss programming differences between a PROM and an EEPROM.
4. Discuss the operation and testing procedures for throttle position, manifold absolute pressure and coolant temperature sensors.
5. Explain the operation of heated and non-heated exhaust gas oxygen sensors.
6. Explain adaptive strategy.

COMPUTER CONTROL

Modern automotive control systems consist of a network of electronic sensors, actuators, and computer modules designed to regulate the powertrain and vehicle support systems. The **powertrain control module (PCM)** is the heart of this system. It coordinates engine and transmission operation, processes data, maintains communications, and makes the control decisions needed to keep the vehicle operating.

Automotive computers use voltage to send and receive information. Voltage is electrical pressure and does not flow through circuits, but voltage can be used as a signal. A computer converts input information or data into voltage signal combinations that represent number combinations. The number combinations can represent a variety of information—temperature, speed, or even words and letters. A computer processes the input voltage signals it receives by computing what they represent, and then delivering the data in computed or processed form.

NOTE: Standardized Emissions Terminology
In the early 1990s, the Society of Automotive Engineers developed a common list of terms (SAE J1930) for emission related parts, i.e., ignition, fuel delivery and emission control components. These terms, by law, have been used in all Canadian and U.S. automotive service and training publications since January 1, 1995. Many automobile manufacturers began using the new terms in 1993 when California adopted J1930.

As an example, the on-board computer had been known as a Micro-computer, a Processor, an Engine Control Assembly (ECA), or an Engine Control Unit (ECU) depending on the manufacturer. The new term, standard in the industry, is Powertrain Control Module (PCM).

It is important to note that older publications before the mid-1990s may use different terms than current texts.

THE FOUR BASIC COMPUTER FUNCTIONS

The operation of every computer can be divided into four basic functions. See Figure 25–1.

- Input
- Processing
- Storage
- Output

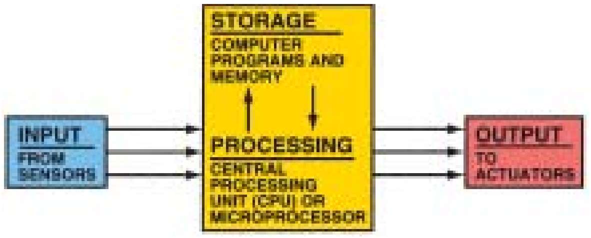


Figure 25–1 All computer systems perform four basic functions: input, processing, storage, and output.

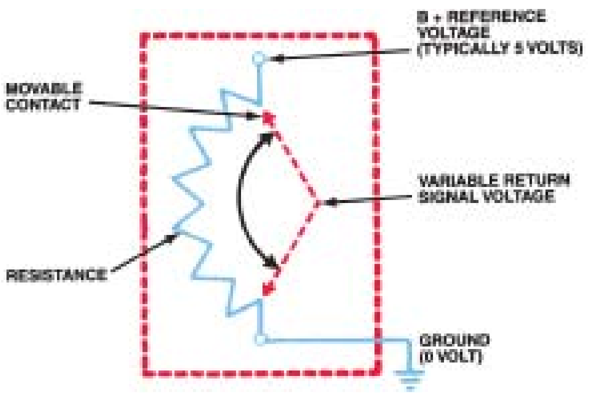


Figure 25–2 A potentiometer uses a movable contact to vary resistance and send an analog signal.

These basic functions are not unique to computers; they can be found in many noncomputer systems. However, we need to know how the computer handles these functions.

Input

First, the computer receives a voltage signal (input) from an input device. The device can be as simple as a button or a switch on an instrument panel, or a sensor on an automotive engine. See Figure 25–2 for a typical type of automotive sensor.

Vehicles use various mechanical, electrical, and magnetic sensors to measure factors such as vehicle speed, engine RPM, air pressure, oxygen content of exhaust gas, airflow, and engine coolant temperature. Each sensor transmits its information in the form of voltage signals. The computer receives these voltage signals, but before it can use them, the signals must undergo a process called **input conditioning.** This process includes amplifying voltage signals that are too small for the computer circuitry to handle. Input conditioners generally are located inside the computer, but a few sensors have their own input-conditioning circuitry.

Processing

Input voltage signals received by a computer are processed through a series of electronic logic circuits maintained in its programmed instructions. These logic circuits change the input voltage signals, or data, into output voltage signals or commands.

Storage

The program instructions for a computer are stored in electronic memory. Some programs may require that certain input data be stored for later reference or future processing. In others, output commands may be delayed or stored before they are transmitted to devices elsewhere in the system.

Output

After the computer has processed the input signals, it sends voltage signals or commands to other devices in the system, such as system actuators. An **actuator** is an electrical or mechanical device that converts electrical energy into a mechanical action, such as adjusting engine idle speed, altering suspension height, or regulating fuel metering.

Computers also can communicate with, and control, each other through their output and input functions. This means that the output signal from one computer system can be the input signal for another computer system.

DIGITAL COMPUTERS

In a **digital** computer, the voltage signal or processing function is a simple high/low, yes/no, on/off signal. The digital signal voltage is limited to two voltage levels: high voltage and low voltage. Since there is no stepped range of voltage or current in between, a digital binary signal is a square wave.

The signal is called digital because the on and off signals are processed by the computer as the digits or numbers 0 and 1. The number system containing only these two digits is called the **binary** system. Any number or letter from any number system or language alphabet can be translated into a combination of binary 0s and 1s for the digital computer.

A digital computer changes the analog input signals (voltage) to digital bits (*bi*nary digi*ts*) of information through an **analog-to-digital (AD) converter** circuit. The binary digital number is used by the computer in its calculations or logic networks. Output signals usually are digital signals that turn system actuators on and off.

The digital computer can process thousands of digital signals per second because its circuits are

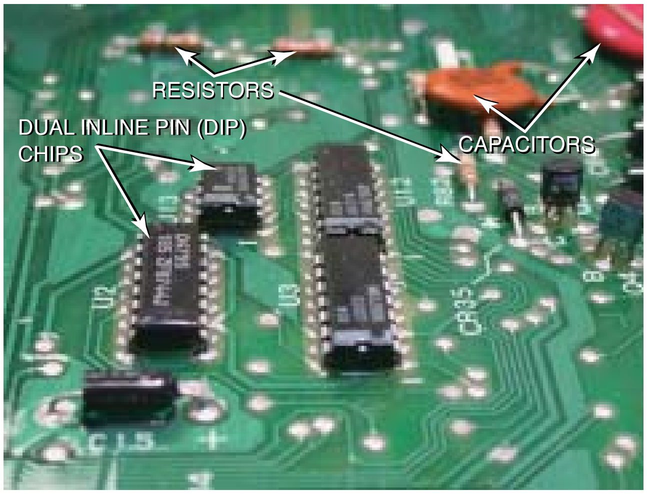


Figure 25–3 Many electronic components are used to construct a typical vehicle computer. Notice all of the chips, resistors, and capacitors that are used in this computer.

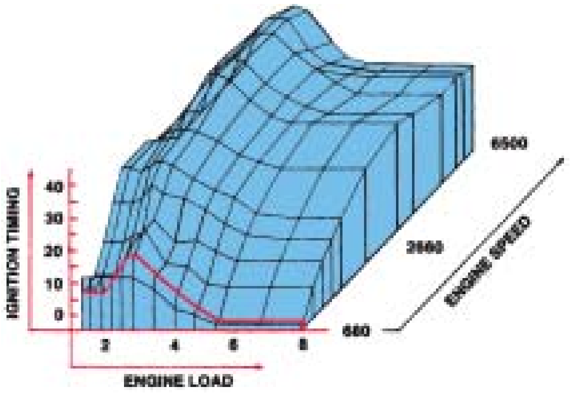


Figure 25–4 Typical ignition timing map developed from testing and used by the vehicle computer to provide the optimum ignition timing for all engine speeds and load combinations.

Figure 25–5 A replaceable PROM used in a General Motors computer. Notice that the sealed access panel has been removed to gain access.

able to switch voltage signals on and off in billionths of a second. See Figure 25–3.

Parts of a Computer

The software consists of the programs and logic functions stored in the computer's circuitry. The hardware is the mechanical and electronic parts of a computer.

Central Processing Unit (CPU) The microprocessor is the **central processing unit (CPU)** of a computer. Since it performs the essential mathematical operations and logic decisions that make up its processing function, the CPU can be considered the heart of a computer. Some computers use more than one microprocessor, called a coprocessor.

Computer Memory Other integrated-circuit (IC) devices store the computer operating program, system sensor input data, and system actuator output data, information necessary for CPU operation.

Computer Programs

By operating a vehicle on a dynamometer and manually adjusting the variable factors such as speed, load, and spark timing, it is possible to determine the optimum output settings for the best driveability, economy, and emission control. This is called **engine mapping.** See Figure 25–4.

Engine mapping creates a three-dimensional performance graph that applies to a given vehicle and powertrain combination. Each combination is permanently mapped digitally onto an IC chip called a **programmable read-only memory (PROM).** This allows an automaker to use one basic computer for all models; a unique PROM individualizes the computer for a particular model. Also, if a driveability problem can be resolved by a change in the program, the manufacturers can release a revised PROM to supersede the earlier part.

Some manufacturers use a single PROM that plugs into the computer. See Figure 25–5. Other computers use a non-replaceable calibration module that contains the system PROM. If the on-board computer needs to be changed, the replaceable type of PROM or calibration module must be removed from the defective unit and installed in the replacement computer.

The original PROM was programmed to reduce emissions, improve fuel economy and provide acceptable power. Replacing the factory PROM with an aftermarket "hot" PROM to increase engine performance often increases engine emissions as well.

In order to reduce tampering and the use of aftermarket PROMs, the Environmental Protection Agency (EPA) mandated that the on-board computer be tamper resistant. As a result, beginning in 1994, PROMs are soldered into place and are not replaceable.

Some PROMs are made in a way that they can be erased by exposure to ultraviolet light and reprogrammed. These are called EEPROMs (electronically erasable), or EPROMs (erasable PROMs).

The new EEPROM chips allow technicians to reprogram them with special electronic service tools. Replacement computers must be programmed (either in the car or on the bench) before the vehicle will run; further updating can be done any time. This type of service is usually done by dealership technicians, although aftermarket reprogramming tools are becoming common.

Clock Rates and Timing

The microprocessor receives sensor input voltage signals, processes them by using information from other memory units, and then sends voltage signals to the appropriate actuators. The microprocessor communicates by transmitting long strings of 0s and 1s in a language called binary code. But the microprocessor must have some way of knowing when one signal ends and another begins. That is the job of a crystal oscillator called a **clock generator.** See Figure 25–6. The computer's crystal oscillator generates a steady stream of one-bit-long voltage pulses. Both the microprocessor and the memories monitor the clock pulses while they are communicating. Because they know how long each voltage pulse should be, they can distinguish between a 01 and a 0011. To complete the process, the input and output circuits also watch the clock pulses.

Computer Speeds

Not all computers operate at the same speed; some are faster than others. The speed at which a computer operates is specified by the cycle time, or clock speed, required to perform certain measurements. Cycle time or clock speed is measured in megahertz (4.7 MHz, 8.0 MHz, 15 MHz, 18 MHz, etc.).

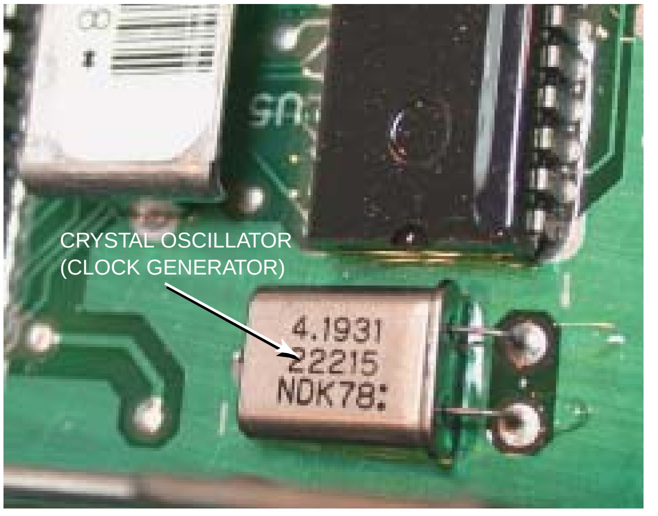


Figure 25–6 The clock generator produces a series of pulses that are used by the microprocessor and other components to stay in step with each other at a steady rate.

Baud Rate

The computer transmits bits of a serial data stream at precise intervals. The computer's speed is called the baud rate, or bits per second. (It is named for J. M. E. Baudot [1845–1903], a French inventor and telegraphy expert.) Just as km/h helps in estimating the length of time required to travel a certain distance, the baud rate is useful in estimating how long a given computer will need to transmit a specified amount of data to another computer. Storage of a single character requires eight bits per byte, plus an additional two bits to indicate stop and start. This means that transmission of one character, or "word," requires 10 bits. Dividing the baud rate by 10 tells us the maximum number of words per second that can be transmitted. For example, if the computer has a baud rate of 600, approximately 60 words can be received or sent per minute.

Automotive computers have evolved from a baud rate of 160 used in the early 1980s to a baud rate as high as 60 500. The speed of data transmission is an important factor both in system operation and in system troubleshooting.

Control Module Locations

The on-board automotive computer has many names. It may be called an electronic control unit, module, controller, or assembly, depending on the manufacturer and the computer application. The Society of Automotive Engineers (SAE) bulletin J1930 standardizes the name as a **powertrain control module (PCM).** The computer hardware is

Figure 25–7 This powertrain control module (PCM) is located under the hood on this pickup truck.

Figure 25–8 This PCM on a Chrysler vehicle can only be seen by hoisting the vehicle because it is located next to the radiator in the airflow to help keep it cool.

all mounted on one or more circuit boards and installed in a metal case to help shield it from electromagnetic interference (EMI). The wiring harnesses that link the computer to sensors and actuators connect to multipin connectors or edge connectors on the circuit boards.

On-board computers range from single-function units that control a single operation to multifunction units that manage all of the separate (but linked) electronic systems in the vehicle. They vary in size from a small module to a notebook-sized box. Most early engine computers were installed in the passenger compartment either under the instrument panel or in a side kick panel where they can be shielded from physical damage caused by temperature extremes, dirt, and vibration, or interference by the high currents and voltages of various underhood systems. See Figures 25–7 and 25–8. Later model PCMs are larger, have increased memory and are usually located in the engine compartment where they are cooled by air from the radiator fan. Shorter wiring harnesses with fewer connections are another advantage.

FUEL CONTROL SYSTEM OPERATING MODES

A computer-controlled fuel metering system can be selective. Depending on the computer program, it may have different operating modes. The on-board computer does not have to respond to data from all of its sensors, nor does it have to respond to the data in the same way each time. Under specified conditions, it may ignore sensor input. Or, it may respond in different ways to the same input signal, based on inputs from other sensors. Most current control systems have two operating modes: open and closed loop. The most common application of these modes is in fuel-metering feedback control where the computer responds to a signal from the oxygen sensor and, if needed, changes the amount of fuel delivered; this is closed loop mode.

During periods of prolonged idle, cold engine operation, wide open throttle or no oxygen sensor signal, the computer only looks at ROM (read-only memory), permanent memory stored in the computer. This is open loop mode.

The latest PCMs have increased memory and operate in closed loop mode under many conditions that were not monitored on older systems.

BASIC COMPUTER OPERATION

Input

Battery power is supplied to the computer when the ignition switch is closed. Because (most) input sensors must operate with a fixed voltage in order to generate a reliable signal, battery voltage is reduced to 5 volts by an internal regulator before being sent to the major input sensors. See Figure 25–9. In our example, these are the throttle position, manifold absolute pressure, and the engine coolant temperature sensors.

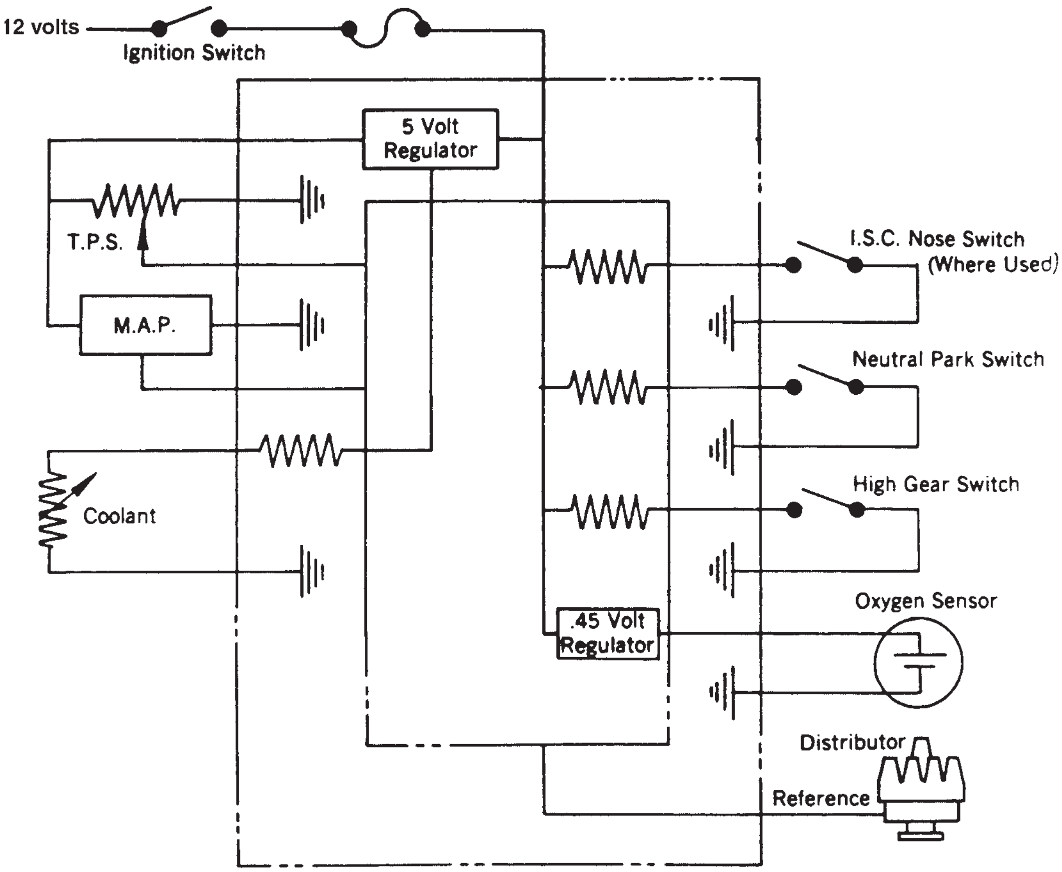


Figure 25–9 Basic computer inputs. (Courtesy General Motors)

THROTTLE POSITION SENSOR

Most computer-equipped engines use a **throttle position (TP)** sensor to signal the position of the throttle. See Figure 25–10 and 25–11. The TP sensor consists of a **potentiometer** variable resistor. A typical sensor uses three wires:

- A 5 volt reference feed wire from the computer
- A ground wire
- A voltage signal wire back to the computer; as the throttle is opened, the voltage to the computer changes

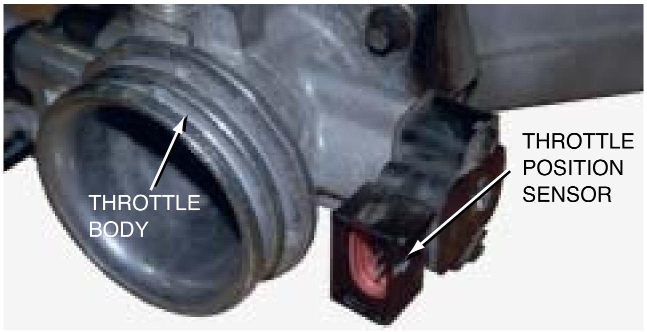


Figure 25–10 A typical throttle position (TP) sensor mounted on the throttle plate of this port-injected engine.

Normal throttle position voltage on most vehicles is about 0.5 volts at idle (closed throttle) and 4.5 volts at wide-open throttle (WOT). The TP sensor voltage at idle is usually about 10% of the TP sensor voltage when the throttle is wide open. The computer senses this change in throttle position and changes the fuel mixture and ignition timing. The actual change in fuel mixture and ignition timing is also partly determined by other sensors, such as the manifold pressure (engine vacuum), engine RPM, the engine coolant temperature, and oxygen sensor(s). Some throttle position sensors are adjustable and should be set according to the engine manufacturer's exact specifications. A defective or misadjusted throttle position sensor can cause hesitation on acceleration and other driveability problems. On some vehicles equipped with an automatic trans-

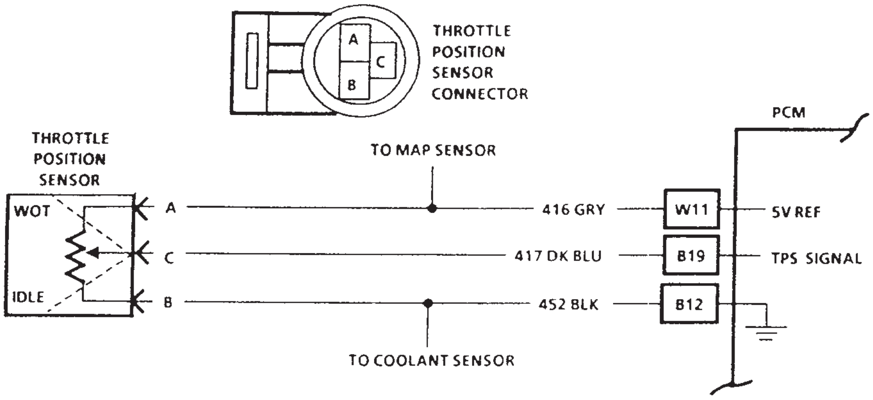


Figure 25–11 Schematic of a typical throttle position (TP) sensor circuit. Movement of the wiper on the potentiometer sends a voltage signal (0.5 to 4.5 volts) to the computer. (Courtesy General Motors)

mission, the throttle position sensor also affects the application of the torque converter clutch (TCC).

The throttle position (TP) sensor used on fuel-injected vehicles acts as an electronic accelerator pump. If the TP sensor is unplugged or defective, the engine may still operate satisfactorily, but hesitate upon acceleration as though the carburetor were in need of a new accelerator pump. Holding the throttle to the floor while cranking usually causes fuel injection to stop or reduce. This is called “clear flood” mode and is used to clear a flooded engine.

Manifold Absolute Pressure Sensor

The **manifold absolute pressure (MAP)** sensor is used by the engine computer to sense engine load. The typical MAP sensor consists of a ceramic or silicon wafer sealed on one side with a perfect vacuum, and exposed to intake manifold vacuum on the other side. See Figure 25–12. As the engine vacuum changes, the pressure difference on the wafer changes the output voltage (or frequency) of the MAP sensor.

Engine Load	Manifold Vacuum	Manifold Pressure	MAP Sensor Voltage Signal
Heavy (WOT)	Low (almost 0 mm Hg)	High (almost atmospheric)	High (4.6–4.8 V)
Light (idle)	High (430–530 mm Hg) (17-21 in. Hg)	Low (lower than atmospheric)	Low (0.8–1.6 V)

Figure 25–12 This MAP sensor is installed on the bulkhead with a vacuum hose attached that runs to the intake manifold. Some MAP sensors are attached directly to the intake manifold.

The PCM uses information from the MAP sensor to control ignition advance, timing, and fuel delivery. A typical MAP sensor uses three wires (see Figure 25–13), similar to a TPS.

- A 5 volt reference feed wire from the computer
- A ground wire
- A voltage (or frequency) wire back to the computer; as manifold vacuum changes, the voltage signal back to the computer also changes

Barometric Pressure Sensor

The **barometric pressure (BP** or **BARO)** sensor is used by the engine computer to sense the barometric pressure. This input not only allows the com-

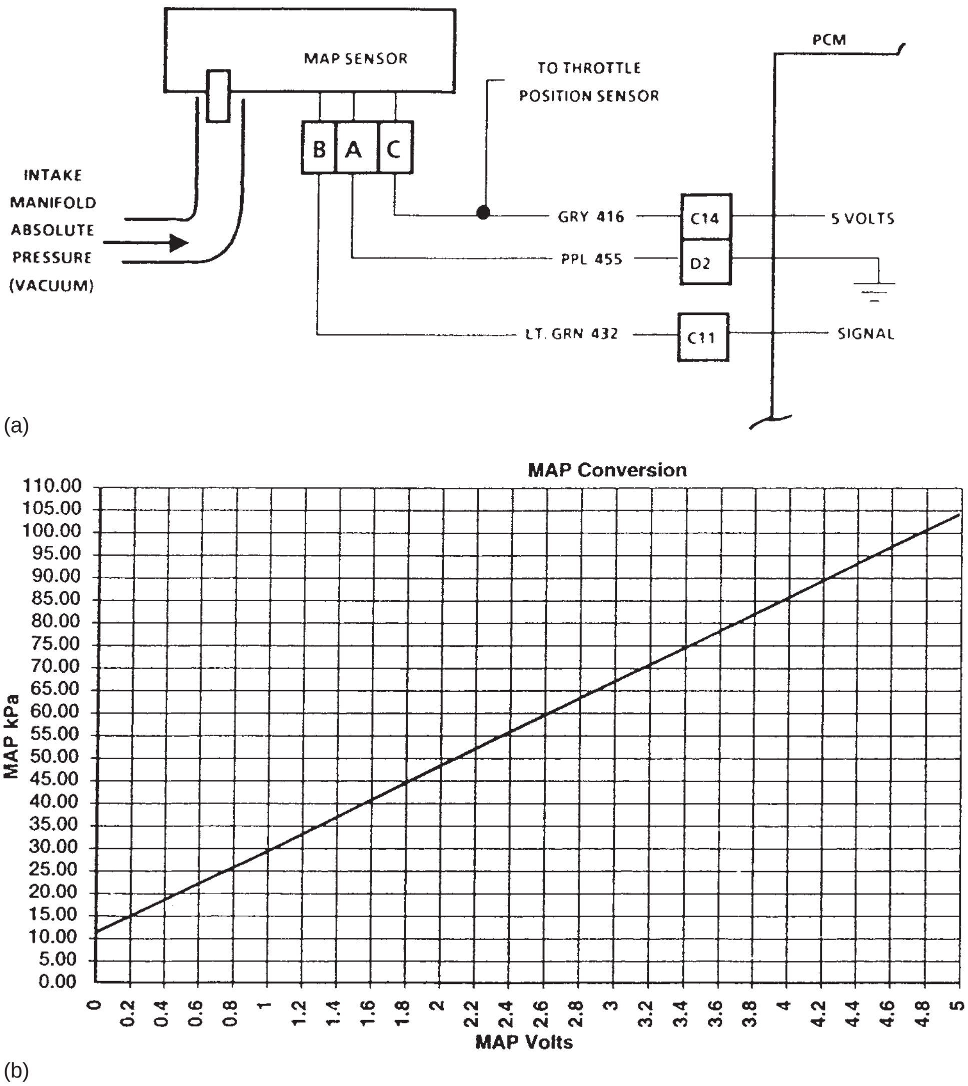


Figure 25–13 (a) Schematic of a typical manifold absolute pressure (MAP) sensor circuit. (b) As manifold pressure (vacuum) changes, the voltage signal to the computer also changes. (Courtesy General Motors)

puter to adjust for changes in atmospheric pressure due to weather, but also is the primary sensor used to determine altitude.

A MAP sensor and a BARO sensor are usually the same sensor. The MAP sensor is capable of reading barometric pressure just as the ignition switch is turned to the “on” position before the engine starts. Therefore, altitude and weather changes are available to the computer. During mountainous driving, it may be an advantage to stop and then restart the engine so that the engine computer can take another barometric pressure reading and recalibrate fuel delivery based on the new altitude. The computer on some vehicles will monitor the TP sensor and use the MAP sensor reading at wide-open throttle (WOT) to update the BARO sensor if it has changed during driving.

Engine Coolant Temperature Sensor

When the engine is cold, the fuel mixture must be richer to prevent stalling and engine stumble. When the engine is warm, the fuel mixture can be leaner to provide maximum fuel economy with the lowest possible exhaust emissions. Because the computer controls spark timing and fuel mixture, it will need to know the engine temperature. An engine coolant temperature sensor (ECT) threaded into the engine coolant passage will provide the computer with this information. See Figure 25–14. This will be the most important sensor while the engine is cold. The ignition timing can also be tailored to engine (coolant) temperature. A hot engine cannot have the spark timing as far advanced as a cold engine. Most coolant sensors have very high resistance when the coolant is cold and low resistance when the coolant is hot. This is referred to as having a **negative temperature coefficient (NTC),** which is opposite to the situation with most other electrical components. See Figure 25–15.

A typical CTS uses only two wires (see Figure 25–16):

- The computer sends a 5 volt signal through an internal resistor to the coolant temperature sensor and measures the voltage between the two resistors. The changing resistance in the sensor causes the voltage to be high with a cold engine and low with a warm engine.
- A ground wire.

If the coolant temperature sensor has a poor connection (high resistance at the wiring connector), the computer will supply a richer than normal fuel mixture based on the resistance of the coolant sensor. Therefore, poor fuel economy and a possible-rich trouble code can be caused by a defective sensor or high resistance in the sensor wiring. If the sensor was shorted or defective and has too low a resistance, a leaner-than-normal fuel mixture would be supplied to the engine. A too-lean fuel mixture can cause driveability problems and a possible lean diagnostic trouble code.

Oxygen Sensors

Most automotive computer systems use oxygen sensors (02S) in the exhaust system to measure the oxygen content of the exhaust. See Figure 25–17. If the

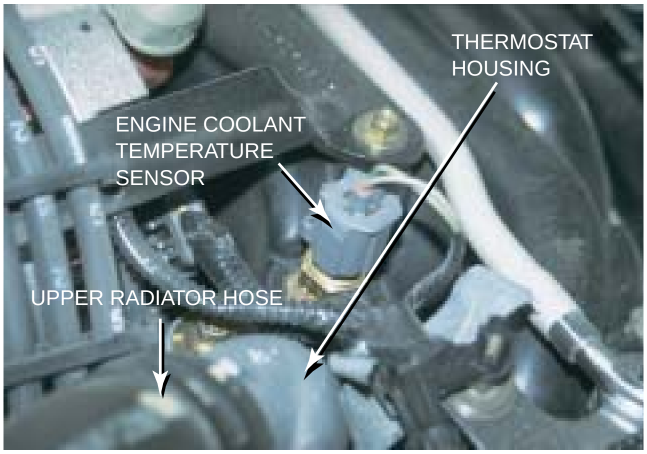


Figure 25–14 A typical engine coolant temperature (ECT) sensor. ECT sensors are located near the thermostat housing on most engines.

Coolant Sensor Temperature to Resistance Values (Approximate)		
°C	°F	Ohms
100	210	185
70	160	450
38	100	1800
20	70	3400
4	40	7500
–7	20	13 500
–18	0	25 000
–40	–40	100 700

Figure 25–15 Engine coolant temperature resistance values. Note the resistance decreases as the temperature rises. These are typical values only; always refer to the vehicle specifications. (Courtesy General Motors)

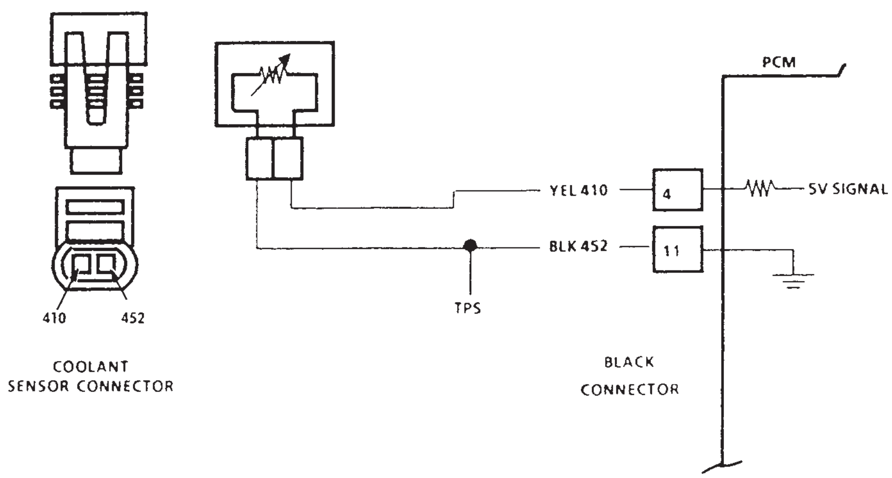


Figure 25–16 Schematic of a typical engine coolant temperature sensor circuit. The computer measures the voltage signal between the PCM resistor and the ECT resistance. (Courtesy General Motors)

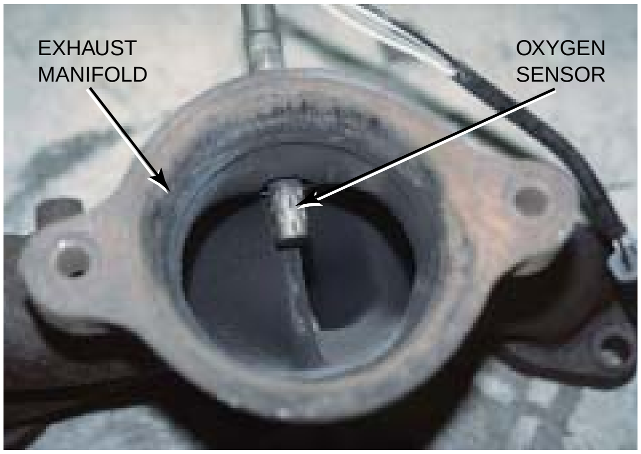


Figure 25–17 Many fuel control oxygen sensors are located in the exhaust manifold near its outlet so that the sensor can detect the presence or absence of oxygen in the exhaust stream for all cylinders that feed into the manifold.

exhaust contains very little oxygen (O_2), the computer assumes that the intake charge is rich (too much fuel) and reduces fuel delivery. On the other hand, when the oxygen level is high, the computer assumes that the intake charge is lean (not enough fuel) and increases fuel delivery. There are several different designs of oxygen sensors, including:

- **One-wire oxygen sensor**. This one wire of the one-wire oxygen sensor is the O2S signal wire. The ground for the O2S is through the shell and threads of the sensor and through the exhaust manifold.
- **Two-wire oxygen sensor.** The two-wire sensor has a signal wire and a ground wire for the O2S.
- **Three-wire oxygen sensor.** The three-wire sensor design uses an electric resistance heater to help get the O2S up to temperature more quickly and to help keep the sensor at operating temperature even at idle speeds. The three wires include the O2S signal, the power, and ground for the heater.
- **Four-wire oxygen sensor**. The four-wire sensor is heated O2S (HO2S) that uses an O2S signal wire and signal ground. The other two wires are the power and ground for the heater.

Zirconia Oxygen Sensors

The most common type of oxygen sensor is made from zirconia (zirconium dioxide). It is usually constructed using powder that is pressed into a thimble shape and coated with porous platinum material that acts as electrodes. See Figure 25–18 and 25–19. The oxygen sensor reacts with the exhaust gases to produce a voltage from 0 volts to 1 volt (0 mV to 1 000 mV) by comparing the oxygen content of the exhaust to the oxygen content of the outside air (21%).

Zirconia oxygen sensors (O2S) are constructed so that oxygen ions flow through the sensor when there is a difference between the oxygen content inside and outside the sensor. An ion is an electrically charged particle. The greater the differences in the oxygen content between the inside and outside of the sensor, the higher the voltage.

- **Rich mixture.** A rich mixture results in little oxygen in the exhaust stream. Compared to the outside air, this represents a large difference and the sensors create a relatively high voltage of about 1.0 volt (1000 mV).
- **Lean mixture.** A lean mixture leaves some oxygen in the exhaust stream that did not combine with the fuel. This leftover oxygen reduces the difference between the oxygen content of the exhaust compared to the oxygen content of the outside air. As a result, the sensor voltage is low or almost zero volts.
- **O2S** voltage above 450 mV is produced by the sensor when the oxygen content in the exhaust is

Figure 25–18 Typical zirconia oxygen sensor.

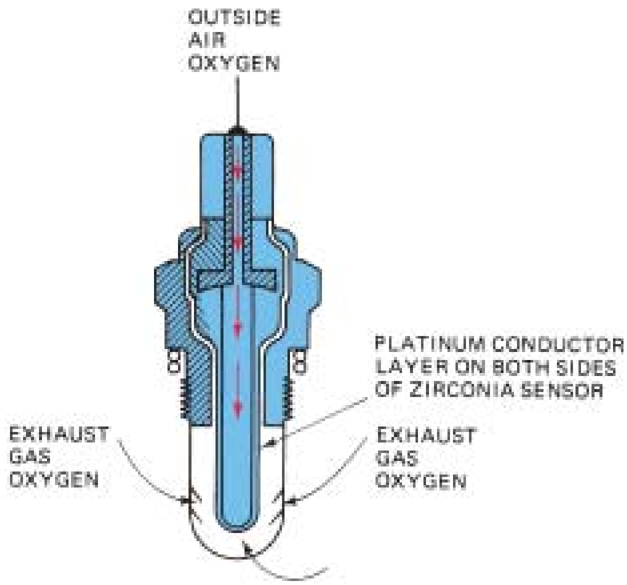


Figure 25–19 A cross-sectional view of a typical zirconia oxygen sensor.

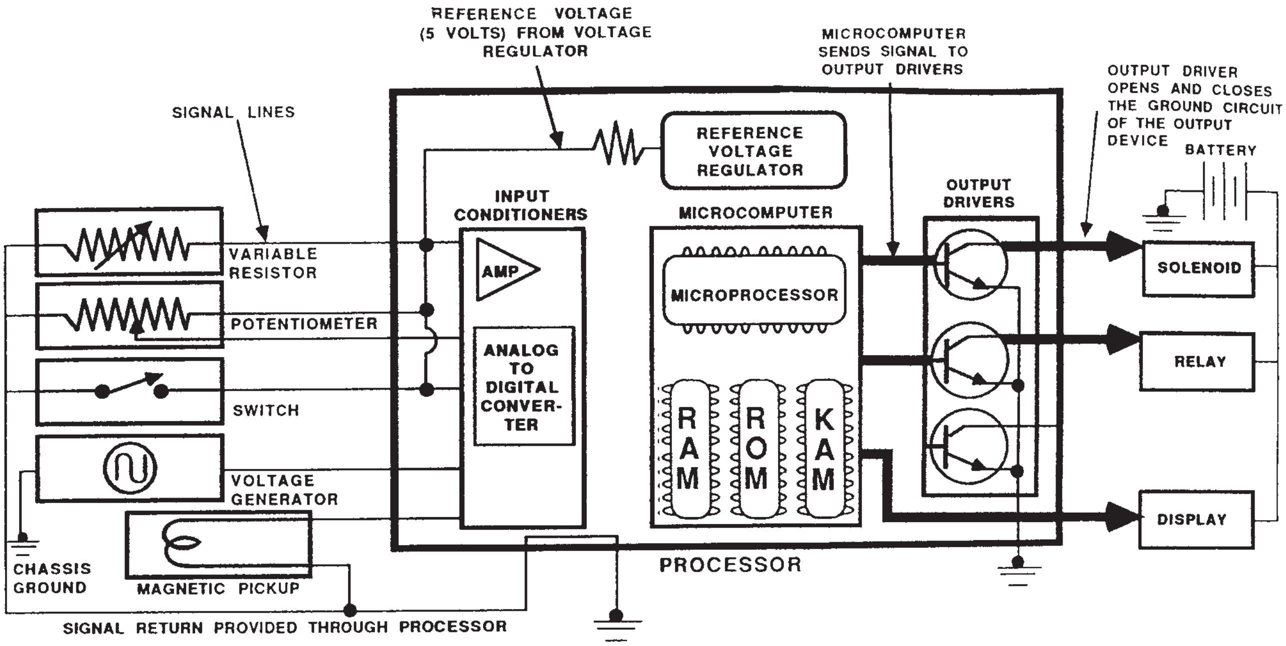


Figure 25–20 Microprocessor schematic showing input, processing, and output. Note that input sensors operate from a 5 volt reference signal and the output devices operate from battery voltage. (Courtesy Ford Motor Co.)

low. This is interpreted by the engine computer (PCM) as being a rich exhaust.

- **O2S** voltage below 450 mV is produced by the sensor when the oxygen content is high. This is interpreted by the engine computer (PCM) as being a lean exhaust.

Titania Oxygen Sensor

The titania (titanium dioxide) oxygen sensor does not produce a voltage but rather modifies one as it samples the presence of oxygen in the exhaust. All titania oxygen sensors use a four-terminal variable resistance unit with a heating element. A titania sensor samples exhaust air only and uses a reference voltage from the PCM. Titania oxide oxygen sensors use a 14-mm thread and are not interchangeable with zirconia oxygen sensors. One volt is applied to the sensor and the changing resistance of the titania oxygen sensor changes the voltage of the sensor circuit. As with a zirconia oxygen sensor, the voltage signal is about 450 mV when the exhaust is rich, and low (below 450 mV) when the exhaust is lean.

PROCESSING AND MEMORY

The microprocessor is the decision making part of the computer. It takes data from the various input sensors and compares it with information stored in memory. See Figure 25–20.

Computers have two types of memory: permanent and temporary. Permanent memory is called **read-only memory (ROM)** because the computer can only read the contents; it cannot change the data stored in it. This data is retained even when power to the computer is shut off. Part of the ROM is built into the computer, and the rest is located in an IC chip called a **programmable read-only memory (PROM)** or calibration assembly.

Temporary memory is called **random-access memory (RAM)** because the microprocessor can write or store new data into it as directed by the computer program, as well as read the data already in it. Automotive computers use two types of RAM memory: **volatile** and **nonvolatile.** Volatile RAM memory is lost whenever the ignition is turned off. However, a type of volatile RAM called **keep-alive memory (KAM)** can be wired directly to battery power. This prevents its data from being erased when the ignition is turned off. Both RAM and KAM have the disadvantage of losing their memory when disconnected from their power source. One example of RAM and KAM is the loss of station settings in a programmable radio when the battery is disconnected. Since all the settings are stored in RAM, they have to be reset when the battery is reconnected. System diagnostic trouble codes (DTC) are commonly stored in RAM and can be erased by disconnecting the battery.

Adaptive strategies that compensate for wear and aging are another function of KAM. The original computer program in ROM is written for the average engine operating under average conditions, but this is often not the case.

Fuel delivery calculations are based on information from the engine sensors; throttle position, air and coolant temperatures, engine speed and load are a few of these inputs. Based on these data, the computer refers to a look-up table stored in ROM and injects a given amount of fuel into the engine. The resulting air–fuel mixture is monitored by an exhaust-mounted oxygen sensor, which sends data back to the computer.

When the oxygen sensor detects a lean or rich condition, the computer increases or decreases fuel volume as a correction. When a major shift is determined over a period of time, the computer changes the original program to reflect different fuel requirements. This is called adaptive strategy and is stored in KAM. Many vehicles run well, even with low fuel pressure or restricted fuel injectors.

If the battery is disconnected, all adaptive information stored in KAM is lost; the computer now defaults to the original program and begins the relearning process.

Nonvolatile RAM memory can retain its information even when the battery is disconnected. One use for this type of RAM is the storage of odometer information in an electronic speedometer. The memory chip retains the distance accumulated by the vehicle. When speedometer replacement is necessary, the odometer chip is removed and installed in the new speedometer unit.

The computer processes the input voltage signals through a series of logic circuits maintained in its programmed instructions. The logic circuits change the input data into output voltage signals or commands that control output transistors.

OUTPUT

Actuators are electrical or mechanical devices that convert electrical energy into mechanical action. The computer sends a voltage signal to the base circuit of an output driver transistor which activates the device, usually a relay or solenoid. See Figure 25–21.

When the ignition switch is closed, battery voltage is supplied to the actuators; no current flows until ground is supplied by turning the transistor on. This is known as ground side control and is the most common circuit. Technicians often check output circuits by grounding the wire between the actuator and the microprocessor. Any actuator that runs at 100% duty cycle can be tested by grounding. Actuators such as fuel injector solenoids never run at 100% duty cycle and can be damaged by grounding. Follow the service instructions exactly when working with computer circuits.

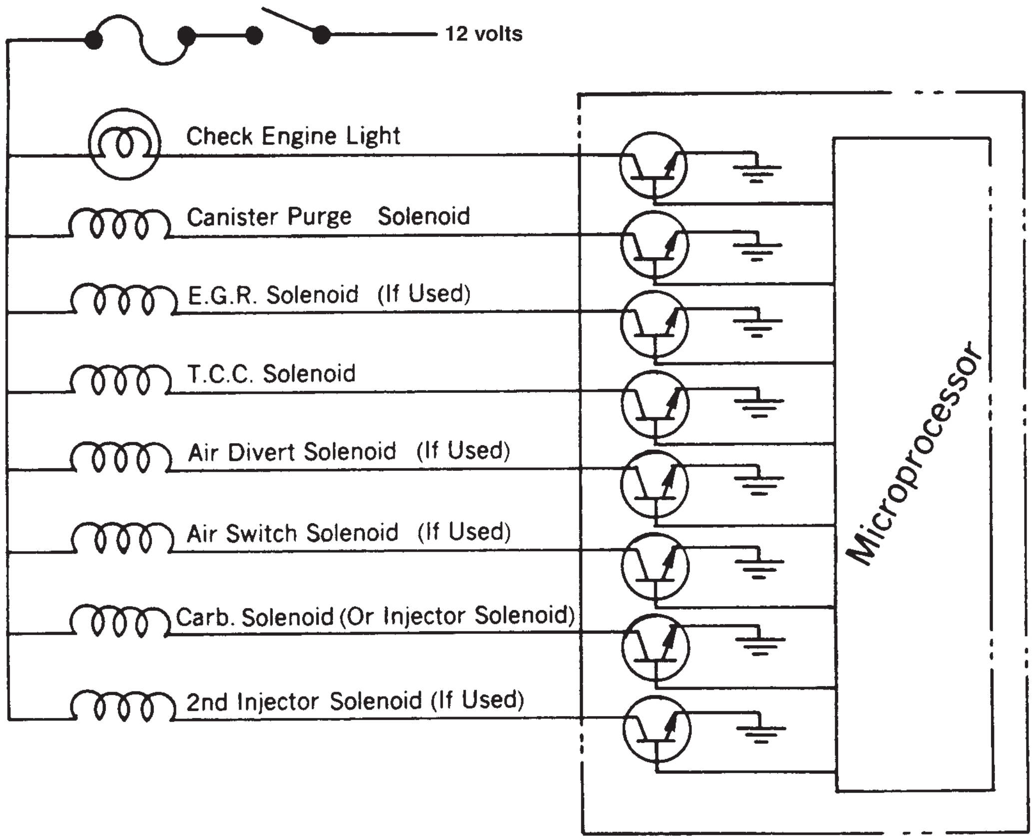


Figure 25–21 Basic computer outputs. (Courtesy General Motors)

Our basic computer shows only a single driver transistor for each device; most computers bank the transistors into a group of four called quad-drivers, but the function is the same.

Output devices are usually tested for resistance with an ohmmeter, or checked for current flow; a shorted solenoid coil, as an example, will allow excessive current to flow which could damage the driver transistor in the computer.

SENSOR TESTING

The correct operation of computerized engines depends on accurate and dependable sensors. Proper testing of sensors is an important part of computer problem diagnosis and troubleshooting.

Testing the Engine Coolant Temperature by Visual Inspection

The correct functioning of the engine coolant temperature (ECT) sensor depends on the following items that should be checked or inspected:

- **Properly filled cooling system.** Check that the radiator reservoir bottle is full and that the radiator itself is filled to the top.

> **CAUTION:** Be sure that the radiator is cool before removing the radiator cap to avoid being scalded by hot coolant.

  The ECT sensor must be submerged in coolant to be able to indicate the proper coolant temperature.
- **Proper pressure maintained by the radiator cap.** If the radiator cap is defective and cannot allow the cooling system to become pressurized, air pockets could develop. These air pockets could cause the engine to operate at a hotter than normal temperature and prevent proper temperature measurement, especially if the air pockets occur around the sensor.
- **Proper antifreeze–water mixture.** Most vehicle manufacturers recommend a 50/50 mixture of antifreeze and water as the best compromise between freezing protection and heat transfer ability.
- **Proper operation of the cooling fan.** If the cooling fan does not operate correctly, the engine may overheat.

Testing the ECT Using a Multimeter

Both the resistance (in ohms) and the voltage drop across the sensor can be measured and compared

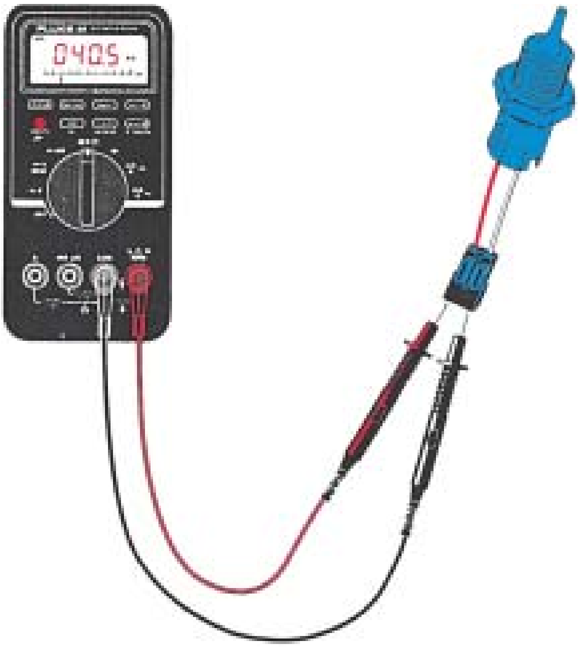


Figure 25–22 Measuring the resistance of the ECT sensor. The resistance measurement can then be compared with specifications. (Courtesy of Fluke Corporation)

with specifications. See Figure 25–22. See the following chart showing examples of typical engine coolant temperature sensor specifications. Some vehicles use a second resistor in the ECT circuit to provide a more accurate measure of the engine temperature. See Figure 25–23.

General Motors ECT Sensor without Pull-Up Resistor

°C	°F	Ohms	Voltage Drop Across Sensor
−40	− 40	100 000+	4.95
−8	18	14 628	4.68
0	32	9420	4.52
10	50	5670	4.25
20	68	3520	3.89
30	86	2238	3.46
40	104	1459	2.97
50	122	973	2.47
60	140	667	2.00
70	158	467	1.59
80	176	332	1.25
90	194	241	0.97
100	212	177	0.75

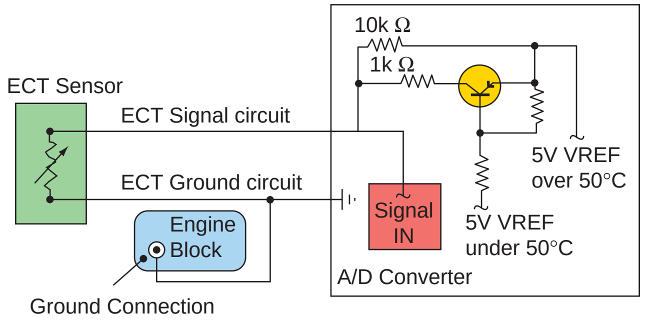


Figure 25–23 When the voltage drop reaches approximately 1.20 volts, the PCM turns on a transistor. The transistor connects a 1 kΩ resistor in parallel with the 10 kΩ resistor. Total circuit resistance now drops to around 909 ohms. This function allows the PCM to have full binary control at cold temperatures up to approximately 50°C (122°F), and a second full binary control at temperatures greater than 50°C (122°F).

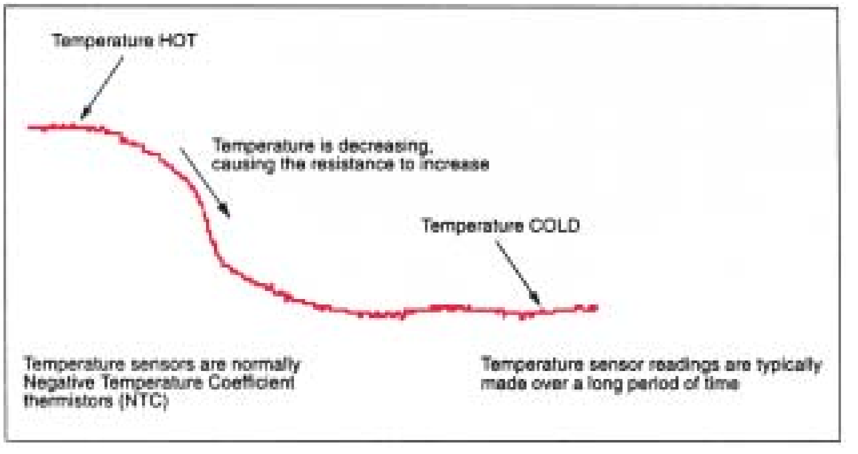


Figure 25–24 A typical ECT sensor being tested using a digital storage oscilloscope. The illustration shows the voltage of the sensor after the engine was stopped. As the resistance of the sensor increased, the voltage decreased. (Courtesy of Fluke Corporation)

If resistance values match the approximate coolant temperature and there is still a coolant sensor trouble code, the problem is generally in the wiring between the sensor and the computer. Always consult the manufacturer's recommended procedures for checking this wiring. If the resistance values do not match, the sensor may need to be replaced.

Normal operating temperature varies with vehicle make and model. Some vehicles are equipped with a thermostat with an opening temperature of 82°C (176°F), whereas other vehicles use a thermostat that is 90°C (195°F) or higher. Before replacing the ECT sensor, be sure that the engine is operating at the temperature specified by the manufacturer. Most manufacturers recommend checking the ECT sensor after the cooling fan has cycled twice, indicating a fully warmed engine. See Figure 25–24.

NOTE: Many manufacturers install a pull-up resistor inside the computer to change the voltage drop across the ECT sensor. This is done to expand the scale of the ECT sensor and to make the sensor more sensitive. Therefore, if measuring *voltage* at the ECT sensor, check with the service manual for the proper voltage at each temperature.

Testing the ECT Sensor Using a Scan Tool

Comparing the temperature of the engine coolant as displayed on a scan tool with the actual temperature of the engine is an excellent method to test an engine coolant temperature sensor.

1. Record the scan tool temperature of the coolant (ECT).
2. Measure the actual temperature of the coolant using an infrared pyrometer or contact-type temperature probe.

HINT: Often the coolant temperature gauge in the dash of the vehicle can be used to compare with the scan tool temperature. Although not necessarily accurate, it may help to diagnose a faulty sensor, especially if the temperature shown on the scan tool varies greatly from the temperature indicated on the dash.

The maximum difference between the two readings should be 5°C (10°F). If the actual temperature varies by more than 5°C (10°F) from the temperature indicated on the scan tool, check the

ECT sensor wiring and connector for damage or corrosion. If the connector and wiring are okay, replace the ECT sensor. If the connector and wiring are okay, check the sensor with a DVOM for resistance and compare to the actual engine temperature chart. If that checks out okay, check the computer.

NOTE: Many manufacturers use two coolant sensors, one for the dash gauge and another one for the computer.

INTAKE AIR TEMPERATURE SENSOR

The intake air temperature (IAT) sensor is a negative temperature coefficient (NTC) thermistor that decreases in resistance as the temperature of the sensor increases. The IAT sensor can be located in one of the following locations:

- In the air cleaner housing
- In the air duct between the air filler and the throttle body as shown in Figure 25–25
- Built into the mass air flow (MAF) or air flow sensor

Figure 25–25 The IAT sensor on this General Motors 3800 V-6 engine is in the air passage duct between the air cleaner housing and the throttle plate.

- Threaded into the intake manifold where it senses the temperature of the air entering the cylinders

NOTE: An IAT installed in the intake manifold is the most likely to suffer damage due to an engine backfire, which can often destroy the sensor.

The purpose and function of the intake air temperature sensor is to provide the engine computer (PCM) the temperature of the air entering the engine.

- **Cold air**—is more dense and contains more oxygen and therefore requires a richer mixture to achieve the proper air–fuel mixture. Air at 0°C (32°F) is 14% denser than air at 40°C (104°F).
- **Hot air**—is less dense and contains less oxygen and therefore requires a leaner mixture to achieve the proper air–fuel mixture.

The IAT sensor is a low-authority sensor and is used by the computer to modify the amount of fuel and ignition timing as determined by the engine coolant temperature sensor.

Engine temperature is most accurately determined by looking at the engine coolant temperature (ECT) sensor. In certain conditions, the IAT has an effect on performance and driveability. One such condition is a warm engine being stopped in very cold weather. In this case, when the engine is restarted, the ECT may be near normal operating temperature such as 93°C (200°F) yet the air temperature could be −30°C (−20°F). In this case, the engine requires a richer mixture due to the cold air than the ECT would seem to indicate.

Testing the Intake Air Temperature Sensor

If the intake air temperature sensor circuit is damaged or faulty, a diagnostic trouble code (DTC) is set and the malfunction indicator lamp (MIL) may or may not be on depending on the condition and the type and model of the vehicle. To diagnose the IAT sensor follow these steps:

Step 1 After the vehicle has been allowed to cool for several hours, use a scan tool and observe the IAT and compare it to the engine coolant temperature (ECT). The two temperatures should be within 3°C (5°F) of each other.

Step 2 Perform a thorough visual inspection of the sensor and the wiring. If the IAT is threaded into the intake manifold, remove the sensor and check for damage.

Step 3 Check the voltage and compare to the following chart.

Manifold/Intake Air Temperature Sensor Temperature vs. Resistance and Voltage Drop (Approximate)			
°C	°F	Ohms	Voltage Drop Across Sensor (V)
–40	–40	100 000	4.95
–8	+18	15 000	4.68
0	32	9400	4.52
10	50	5700	4.25
20	68	3500	3.89
30	86	2200	3.46
40	104	1500	2.97
50	122	1000	2.47
60	140	700	2.00
70	158	500	1.59
80	176	300	1.25
90	194	250	0.97
100	212	200	0.75

TECH TIP ✔

Poor Fuel Economy? Black Exhaust Smoke? Look at the IAT.

If the intake air temperature sensor is defective, it may be signaling the computer that the intake air temperature is extremely cold when in fact it is warm. In such a case the computer will supply a mixture that is much richer than normal.

If a sensor is physically damaged or electrically open, the computer will often set a diagnostic trouble code (DTC). This DTC is based on the fact that the sensor temperature did not change for a certain amount of time, usually about 8 minutes. If, however, the wiring or the sensor itself has excessive resistance, a DTC will not be set and the result will be lower than normal fuel economy, and in serious cases, black exhaust smoke from the tailpipe during acceleration.

Testing the Manifold Absolute Pressure Sensor

Most pressure sensors operate on 5 volts from the computer and return a signal (voltage or frequency) based on the pressure (vacuum) applied to the sensor. If a MAP sensor is being tested, make certain that the vacuum hose and hose fittings are sound and making a good, tight connection to a manifold vacuum source on the engine.

TECH TIP ✔

Check the Hose

A defective vacuum hose to a MAP sensor can cause a variety of driveability problems including poor fuel economy, hesitation, stalling, and rough idle. A small air leak (vacuum leak) around the hose can cause these symptoms and often set a trouble code in the vehicle computer. When working on a vehicle that uses a MAP sensor, make certain that the vacuum hose travels consistently *downward* on its route from the sensor to the source of manifold vacuum. Inspect the hose, especially if another technician has previously replaced the factory-original hose. It should not be so long that it sags down at any point. Condensed fuel and/or moisture can become trapped in this low spot in the hose and cause all types of driveability problems and MAP sensor codes.

Four different types of test instruments can be used to test a pressure sensor:

1. A digital voltmeter with three test leads connected in series between the sensor and the wiring harness connector (see Figure 25–26)
2. A scope connected to the sensor output, power, and ground
3. A scan tool or a specific tool recommended by the vehicle manufacturer
4. A breakout box connected in series between the computer and the wiring harness connection(s). A typical breakout box includes test points at which pressure sensor values can be measured with a digital voltmeter (or frequency counter, if a frequency-type MAP sensor is being tested)

NOTE: Always check service literature for the exact testing procedures and specifications for the vehicle being tested.

Use jumper wires, T-pins, or a breakout box to gain electrical access to the wiring to the pressure sensor. Most pressure sensors use three wires:

1. A 5 volt wire from the computer
2. A variable-signal wire back to the computer
3. A ground or reference low wire

The procedure for testing the sensor is as follows:

1. Turn the ignition on (engine off)
2. Measure the voltage (or frequency) of the sensor output
3. Using a hand-operated vacuum pump (or other variable vacuum source), apply vacuum to the sensor

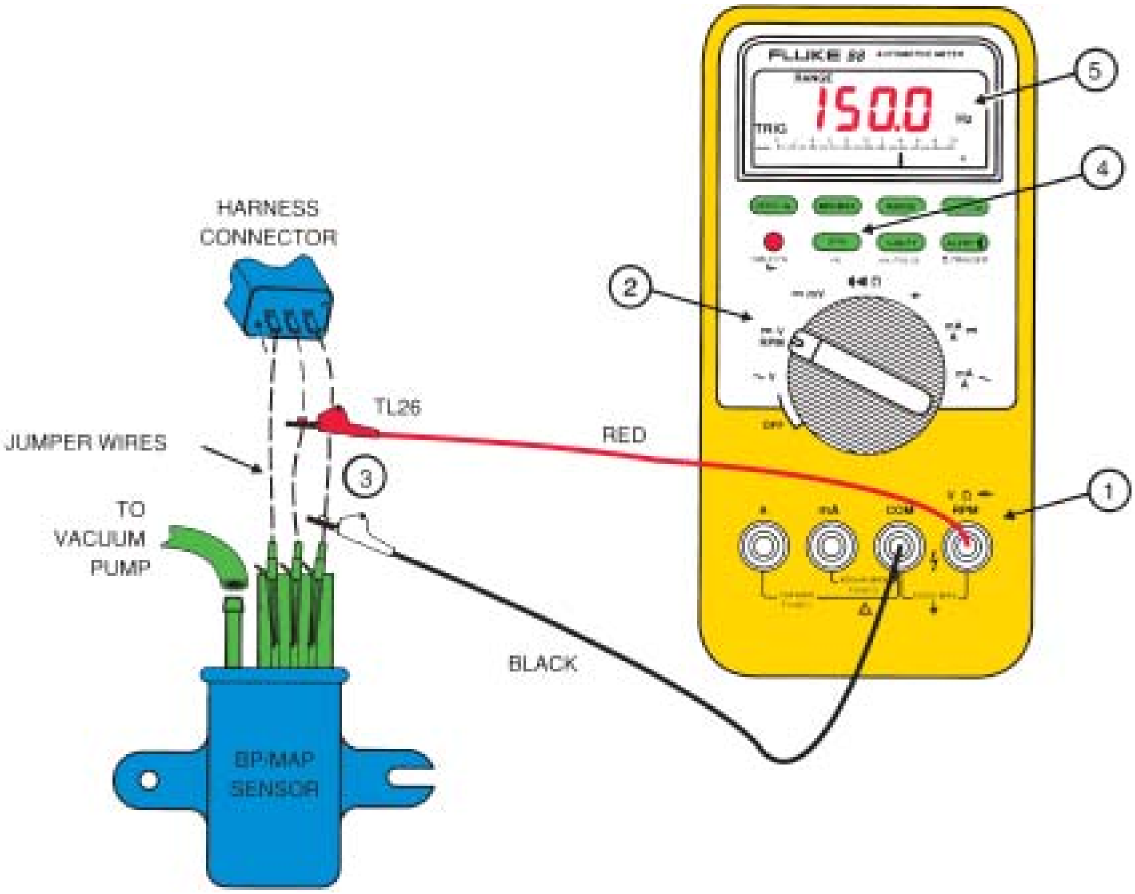


Figure 25–26 A digital multimeter set to test a MAP sensor. (1) Connect the red meter lead to the V meter terminal and the black meter lead to the COM meter terminal. (2) Select DC volts. (3) Connect the test leads to the sensor signal wire and the ground wire. (4) Select hertz (Hz) if testing a MAP sensor whose output is a varying frequency—otherwise keep it on DC volts. (5) Read the change of frequency as the vacuum is applied to the sensor. Compare the vacuum reading and the frequency (or voltage) reading to the specifications.

A good pressure sensor should change voltage (or frequency) in relation to the applied vacuum. If the signal does not change or the values are out of range according to the manufacturers' specifications, the sensor must be replaced.

Testing the Throttle Position Sensor

A TP sensor can be tested using one or more of the following tools:

- A digital voltmeter with three test leads connected in series between the sensor and the wiring harness connector or backprobing using T-pins.
- A scan tool or a specific tool recommended by the vehicle manufacturer.
- A breakout box that is connected in series between the computer and the wiring harness connector(s). A typical breakout box includes test points at which TP voltages can be measured with a digital voltmeter.
- An oscilloscope.

Use jumper wires, T-pins, or a breakout box to gain electrical access to the wiring to the TP sensor. See Figure 25–27.

NOTE: The procedure that follows is the usual method used by many manufacturers. Always refer to service literature for the exact recommended procedure and specifications for the vehicle being tested.

The procedure for testing the sensor using a digital multimeter is as follows:

1. Turn the ignition switch on (engine off).
2. Measure the voltage between the signal wire and ground (reference low) wire. The voltage should be about 0.5 volt.

Figure 25–27 A meter lead connected to a T-pin that was gently pushed along the signal wire of the TP sensor until the point of the pin touched the metal terminal inside the plastic connector.

NOTE: Consult the service literature for exact wire colours or locations.

3. With the engine still not running (but with the ignition still on), slowly increase the throttle opening. The voltage signal from the TP sensor should also increase. Look for any "dead spots" or open circuit readings as the throttle is increased to the wide-open position. See Figure 25–28 for an example of how a good TP sensor would look when tested with a digital storage oscilloscope (DSO).

HINT: If TP sensor specifications are not available, remember that the TP sensor voltage at idle should be about 10% of the voltage at the **wide-open throttle (WOT)** position. Therefore, if the WOT voltage is 4.5 volts, then TP sensor voltage at idle should be about 0.45 volts.

4. With the voltmeter (or scan tool) still connected, slowly return the throttle down to the idle position. The voltage from the TP sensor should also decrease evenly on the return to idle.

The TP sensor voltage at idle should be within the acceptable range as specified by the manufacturer. Some TP sensors can be adjusted by loosening their retaining screws and moving the sensor in relation to the throttle opening. This movement changes the output voltage of the sensor.

All TP sensors should also provide a smooth transition voltage reading from idle to WOT and back to idle. Replace the TP sensor if erratic voltage readings are obtained or if the correct setting at idle cannot be obtained.

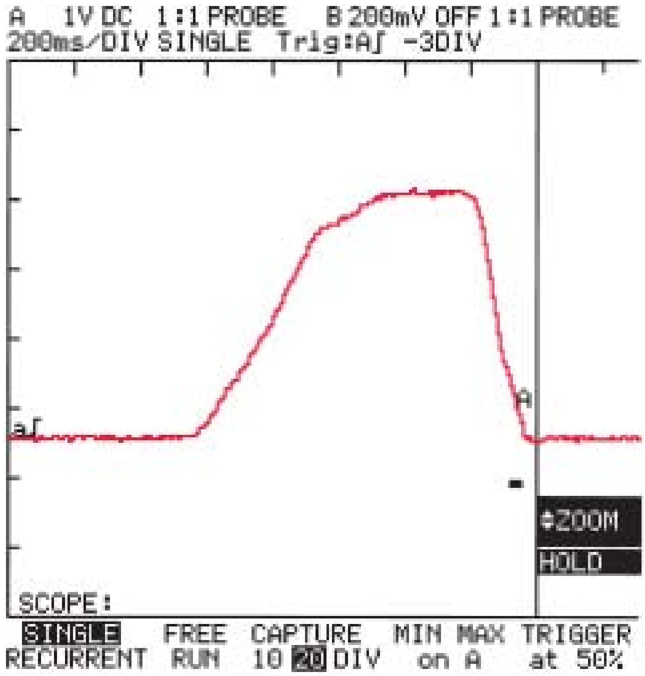


Figure 25–28 A typical waveform of a TP sensor signal as recorded on a DSO when the accelerator pedal was depressed with the ignition switch on (engine off). Clean transitions and the lack of any glitches in this waveform indicate a good sensor. (Courtesy of Fluke Corporation)

TECH TIP ✔

Check Power and Ground Before Condemning a Bad Sensor

Most engine sensors use a 5 volt reference and a ground. If the 5 volt to the sensor is too high (shorted to voltage) or too low (high resistance), then the sensor output will be **skewed** or out of range. Before replacing the sensor that did not read correctly, unplug the sensor and measure both the 5 volt reference and ground. To measure the ground, simply turn the ignition on (engine off) and touch one test lead of a DMM set to read DC volts to the sensor ground and the other to the negative terminal of the battery. Any reading higher than 0.6 volt (600 mV) represents a poor ground. See Figures 25–29 and 25–30.

Testing the Oxygen Sensor

Zirconia oxygen sensors produce a voltage (like a small battery) when in the *absence* of oxygen, when the sensor is hot (over 315°C or 600°F). The output

Figure 25–29 Checking the 5 volt reference from the computer being applied to the TP sensor with the ignition switch on (engine off).

Figure 25–30 Checking the voltage drop between the TP sensor ground and a good engine ground with the ignition on (engine off). A reading of greater than 0.6 V (600 mV) represents a bad computer ground.

voltage of a typical oxygen sensor varies depending on the oxygen content of the exhaust gases passing the sensor.

Typical oxygen sensor values are as follows:

- **Rich exhaust.** Oxygen sensor voltage above 800 mV
- **Lean exhaust.** Oxygen sensor voltage below 200 mV

Testing an Oxygen Sensor Using a Digital Voltmeter

The oxygen sensor can be checked for proper operation using a digital high-impedance voltmeter.

1. With the engine off, connect the red lead of the meter to the oxygen sensor signal wire. See Figure 25–31.
2. Start the engine and allow it to reach closed-loop operation. To achieve closed-loop operation, the engine computer must have achieved three criteria including:
   a. The engine coolant temperature must be above a certain temperature, usually above 40°C (104°F).
   b. The oxygen sensor(s) must be producing a usable, variable voltage signal.
   c. A certain amount of time must elapse after engine start for closed loop to be achieved. This time could vary from a few seconds to several minutes depending on the vehicle and the temperature.
3. In closed-loop operation, the oxygen sensor voltage should be constantly changing as the fuel mixture is being controlled.

The results should be interpreted as follows:

- If the oxygen sensor fails to respond, and its voltage remains at about 450 millivolts, the sensor may be defective and require replacement. Before replacing the oxygen sensor, check the manufacturers' recommended procedures.
- If the oxygen sensor reads high all the time (above 550 millivolts), the fuel system could be supplying too rich a fuel mixture or the oxygen sensor may be contaminated.
- If the oxygen sensor voltage remains low (below 350 millivolts), the fuel system could be supplying too lean a fuel mixture. Check for a vacuum leak or partially clogged fuel injector(s). Before replacing the oxygen sensor, check the manufacturer's recommended procedures.

Testing the Oxygen Sensor Using the Min-Max Method

A digital meter set on DC volts can be used to record the minimum and maximum voltage with

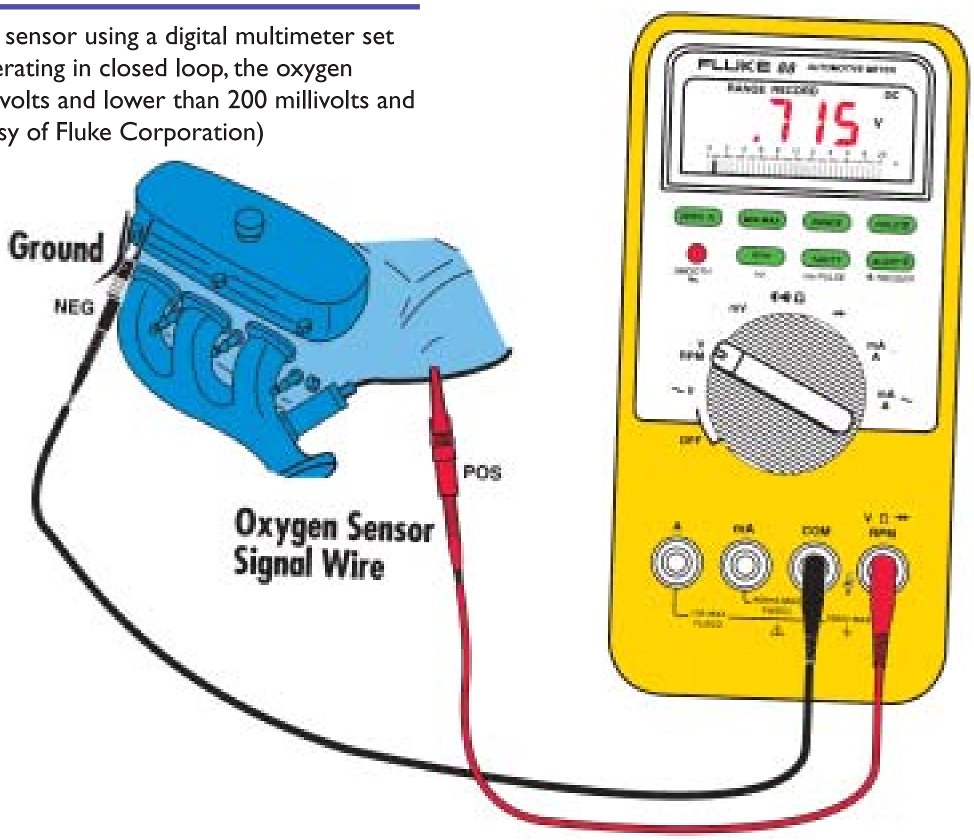


Figure 25–31 Testing an oxygen sensor using a digital multimeter set on DC volts. With the engine operating in closed loop, the oxygen voltage should read over 800 millivolts and lower than 200 millivolts and be constantly fluctuating. (Courtesy of Fluke Corporation)

the engine running. A good oxygen sensor should be able to produce a value of less than 300 millivolts and a maximum voltage above 800 millivolts. Replace any oxygen sensor that fails to go above 700 millivolts or lower than 300 millivolts.

Post–Catalytic Converter Oxygen Sensor Testing

The oxygen sensor located behind the catalytic converter is used on OBD II (On-Board Diagnostics—Generation II) vehicles to monitor converter efficiency.

Min/Max Oxygen Sensor Test Chart

Minimum Voltage	Maximum Voltage	Average Voltage	Test Results
Below 200 mV	Above 800 mV	400 to 500 mV	Oxygen sensor is okay.
Above 200 mV	Any reading	400 to 500 mV	Oxygen sensor is defective.
Any reading	Below 800 mV	400 to 500 mV	Oxygen sensor is defective.
Below 200 mV	Above 800 mV	Below 400 mV	System is operating lean.*
Below 200 mV	Below 800 mV	Below 400 mV	System is operating lean. (Add propane to the intake air to see if the oxygen sensor reacts. If not, the sensor is defective.)
Below 200 mV	Above 800 mV	Above 500 mV	System is operating rich.
Above 200 mV	Above 800 mV	Above 500 mV	System is operating rich. (Remove a vacuum hose to see if the oxygen sensor reacts. If not, the sensor is defective.)

*Check for an exhaust leak upstream from the O2S or ignition misfire that can cause a false lean indication before further diagnosis.

Frequently Asked Question ???

What Is the Difference Between a "False Lean" and a "Real Lean" Oxygen Sensor Reading?

A **false lean** signal is a result of oxygen flowing past the oxygen sensor that did not result from combustion inside the engine. Two examples of a false lean oxygen sensor indication include:

1. A cracked exhaust manifold or an exhaust leak upstream from the oxygen sensor (between the exhaust valve and the oxygen sensor) can cause a false lean. As an exhaust pulse occurs, an area of lower pressure develops behind the pulse of exhaust. This lower pressure area *draws* outside air into the exhaust stream and flows past the oxygen sensor. The oxygen sensor voltage drops as a result of this extra oxygen brought into the exhaust at the leak. The drop in oxygen sensor voltage is interpreted by the engine computer as a message that the mixture supplied to the engine is too lean, and it increases the amount of fuel supplied. As a result, the mixture now being supplied to the cylinder is too rich because the oxygen sensor was fooled and provided a false lean signal to the computer.
2. An ignition misfire as a result of a defective spark plug wire or fouled spark plug can cause a false lean. When a spark plug does not fire, the unburned gas and air inside the cylinder are pushed into the exhaust manifold by the piston(s) on the exhaust stroke. The unburned gas and air contain oxygen that is detected by the oxygen sensor as too lean a mixture.

NOTE: Remember, the oxygen sensor is a sensor to detect *oxygen,* not unburned fuel (hydrocarbons or HC)!

As a result of this oxygen being detected, the voltage produced by the oxygen sensor is lower. This lower-voltage signal is interpreted by the computer as a sign that the mixture being supplied is too lean. The computer then increases the amount of fuel delivered. This extra fuel can often cause more spark plug fouling and even more unburned oxygen passing the oxygen sensor.

Because a lean condition can be false, the wise service technician checks the exhaust system and the ignition system before trying to correct a lean indication.

DIAGNOSTIC STORY

The O_2 Sensor Is Lying to You

A technician was trying to solve a driveability problem with a V-6 passenger car. The car idled roughly, hesitated, and accelerated poorly. A thorough visual inspection did not indicate any possible problems, and there were no diagnostic trouble codes stored.

A check was made on the oxygen sensor activity using a DMM. The voltage stayed above 600 millivolts most of the time. If a large vacuum hose was removed, the oxygen sensor voltage would temporarily drop to below 450 millivolts and then return to a reading of over 600 millivolts. Remember:

- High O2S readings = rich exhaust (low O_2 content in the exhaust)
- Low O2S readings = lean exhaust (high O_2 content in the exhaust)

As part of a thorough visual inspection, the technician removed and inspected the spark plugs. All the spark plugs were white, indicating a lean mixture, not the rich mixture the oxygen sensor was indicating. The high O2S reading signalled the computer to reduce the amount of fuel resulting in an excessively lean operation.

After replacing the oxygen sensor, the engine ran great. But what killed the oxygen sensor? The technician finally learned from the owner that the head gasket had been replaced over a year ago. The silicone-silicate additives in the antifreeze coolant had coated the oxygen sensor. Because the oxygen sensor was coated, the oxygen content of the exhaust could not be detected—the result, a false rich signal from the oxygen sensor.

DIAGNOSTIC STORY

The Pickup Truck Story

The owner of a pickup truck complained that the engine ran terribly. It would hesitate and surge, yet there were no diagnostic trouble codes (DTCs). After hours of troubleshooting, the technician discovered while talking to the owner that the problem started after the transmission had been repaired. Before the transmission was repaired, the problem started, yet the transmission shop said that the problem was an engine problem and not related to the transmission.

A thorough visual inspection revealed that the front and rear oxygen sensor connectors had been switched. The computer was trying to compensate for an air–fuel mixture condition that did not exist. Reversing the OSS connectors restored proper operation of the truck.

A changing air–fuel mixture is required for the most efficient operation of the converter. If the converter is working correctly, the oxygen content after the converter should be fairly constant. See Figures 25–32 and 25–33.

SPEED DENSITY

Fuel-injection computer systems require a method for measuring the amount of air the engine is taking in, to be able to match the correct fuel delivery. There are two basic methods used:

1. Speed density method
2. Airflow method

The speed density method does not require an air quantity sensor, but rather calculates the amount of fuel required by the engine. The computer uses information from sensors such as the MAP and TP to calculate the needed amount of fuel.

- *MAP sensor.* The value of the intake (inlet) manifold pressure (vacuum) is a direct indication of engine load.
- *TP sensor.* The position of the throttle plate and its rate of change are used as part of the equation to calculate the proper amount of fuel to inject.
- *Temperature sensors.* Both engine coolant temperature (ECT) and intake air temperature (IAT) are used to calculate the density of the air and the need of the engine for fuel. A cold engine (low coolant temperature) requires a richer air–fuel mixture than a warm engine.

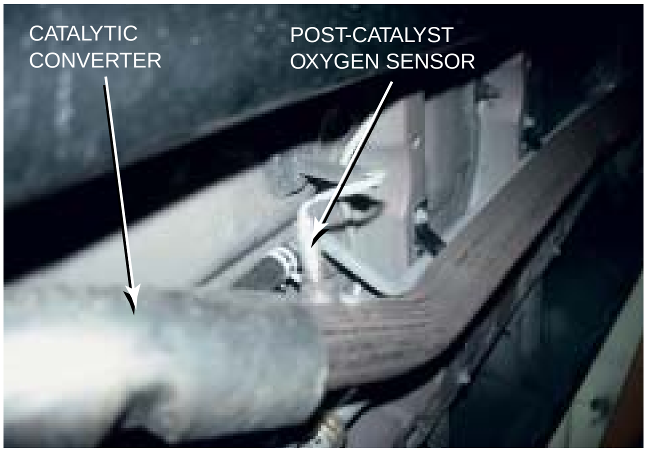


Figure 25–32 Most 1996 and newer vehicles use an oxygen sensor behind the catalytic converter. The purpose of the oxygen sensor is to sense the percentage of oxygen in the exhaust to check the efficiency of the catalytic converter.

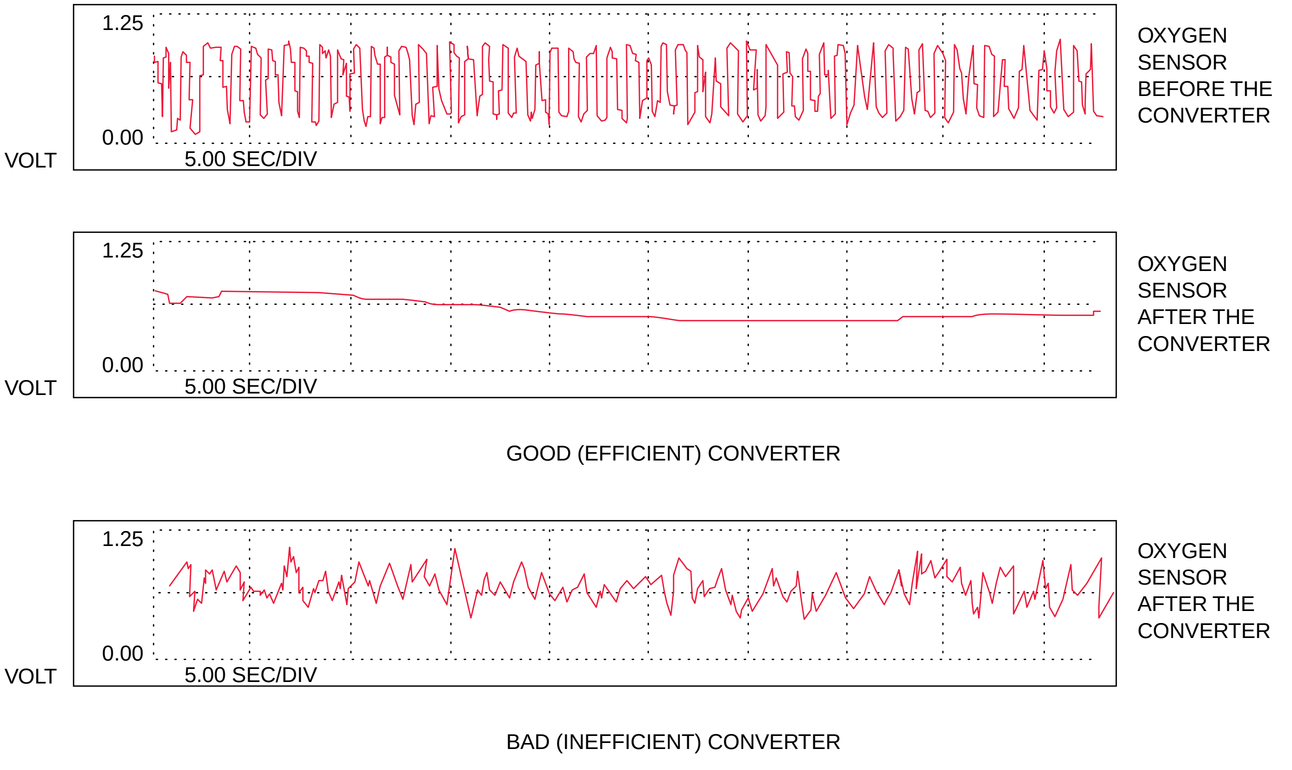


Figure 25–33 The post–catalytic converter oxygen sensor should display very little activity if the catalytic converter is efficient.

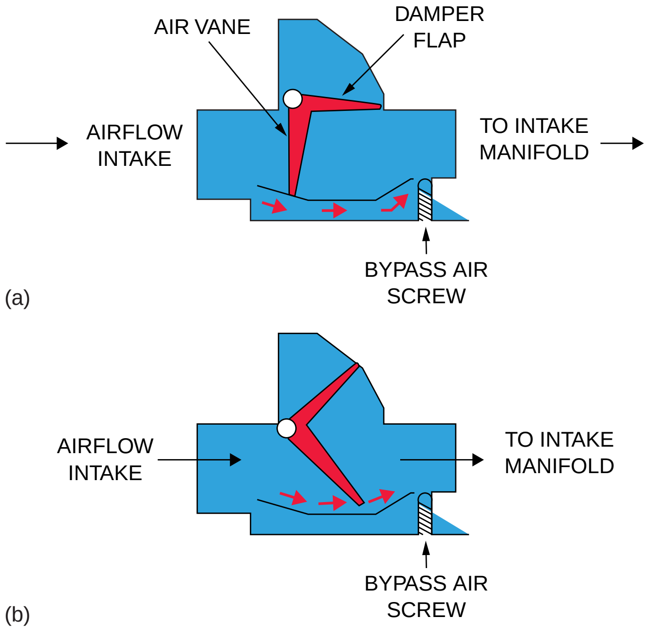


Figure 25–34 A typical air vane sensor. (a) At idle the air flows through a bypass passage. The bypass air screw is adjusted at the factory and should not require adjustment. (b) As the throttle is opened, the airflow moves the vane. The vane is attached to a potentiometer similar to a throttle position (TP) sensor.

Figure 25–35 A typical air vane sensor with the cover removed. The movable arm contacts a carbon resistance path as the vane opens. Many air vane sensors also have contacts that close to supply voltage to the electric fuel pump as the air vane starts to open when the engine is being cranked and air is being drawn into the engine.

AIRFLOW METHOD

The airflow method measures the amount of air as part of the computer input information necessary for accurate fuel delivery control. There are three basic types of airflow sensors used on port-injected engines: the air vane sensor, the hot film sensor, and the hot wire sensor.

AIR VANE SENSOR

This air vane sensor uses a movable vane that translates the amount of movement of the vane into the amount of air being drawn into the engine. An air vane sensor can be tested using a digital meter or an oscilloscope. See Figures 25–34 and 25–35.

HOT FILM SENSOR

The hot film sensor uses a temperature-sensing resistor (thermistor) to measure the temperature of the incoming air. Through the electronics within the sensor, a conductive film is kept at a temperature 75°C (165°F) above the temperature of the incoming air. See Figure 25–36.

Because the amount and density of the air both tend to contribute to the cooling effect as the air passes through the sensor, this type of sensor can actually produce an output based on the *mass* of the airflow. The output of this type of sensor is usually a frequency based on the amount of air entering the sensor. The more air that enters the sensor, the more the hot film is cooled. The electronics inside the sensor, therefore, increase the current flow through the hot film to maintain the 75°C (165°F) temperature differential between the air temperature and the temperature of the hot film. This change in current flow is converted to a frequency output that the computer can use as a measurement of airflow. Most of these types of sensors are referred to as **mass airflow (MAF) sensors** because unlike the air vane sensor, the MAF sensor takes into account relative humidity, altitude, and temperature of the air. The denser the air, the greater the cooling effect on the hot film sensor and the greater the amount of fuel required for proper combustion.

HOT WIRE SENSOR

The hot wire sensor is similar to the hot film type, but uses a hot wire to sense the mass airflow instead of the hot film. Like the hot film sensor, the hot wire sensor uses a temperature-sensing resistor (thermistor) to measure the temperature of the air entering the sensor. See Figure 25–37. The electronic circuitry within the sensor keeps the temperature of the wire at 75°C (165°F) above the temperature of the incoming air.

Figure 25–36 A GM hot film mass air flow (MAF) sensor that has been taken apart. The electronic circuit measures the cooling effect of the air entering the engine and generates a frequency output signal that is proportional to the amount of air passing through the sensor.

Figure 25–37 A typical hot wire MAF sensor located between the air filter and the throttle plate.

Testing Mass Airflow Sensors

Start the testing of a MAF sensor by performing a thorough visual inspection. Look at all the hoses that direct and send air, especially between the MAF sensor and the throttle body. Also check the electrical connector for:

- Corrosion
- Terminals that are bent or pushed out of the plastic connector
- Frayed wiring

DIAGNOSTIC STORY

The Dirty MAF Sensor Story

The owner of a Buick Park Avenue complained that the engine would hesitate during acceleration, showed lack of power, and seemed to surge or miss at times. A visual inspection found everything to be like new, including a new air filter. There were no stored diagnostic trouble codes (DTCs). A look at the scan data showed airflow to be within the recommended 3 to 7 grams per second. A check of the frequency output showed the problem.

Idle frequency = 2.177 kHz (2177 Hz)

Normal frequency at idle speed should be 2.37 to 2.52 kHz. Cleaning the hot wire of the MAF sensor restored proper operation. The sensor wire was covered with what looked like fine fibres, possibly from the replacement air filter.

NOTE: Older AC MAF sensors operated at a lower frequency of 32 to 150 Hz, with 32 Hz being the average reading at idle and 150 Hz for wide-open throttle.

False Air

Airflow sensors and mass airflow (MAF) sensors are designed to measure *all* the air entering the engine. If an air inlet hose was loose or had a hole, extra air

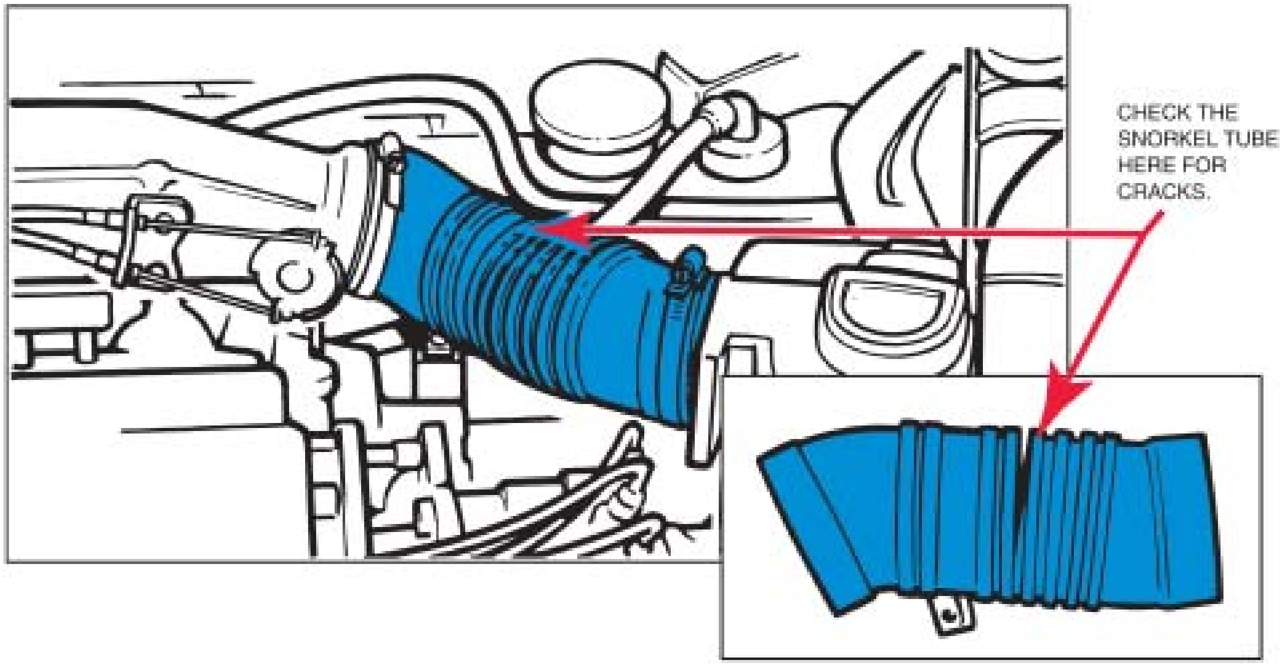


Figure 25–38 Carefully check the hose between the MAF sensor and the throttle plate for cracks or splits that could create extra (false) air in the engine that is not measured by the MAF sensor.

Frequently Asked Question ???

What Is Meant by a "High-Authority Sensor"?

A high-authority sensor is a sensor that has a major influence over the amount of fuel being delivered to the engine. For example, at engine start-up, the engine coolant temperature (ECT) sensor is a high-authority sensor and the oxygen sensor (O2S) is a low-authority sensor. However, as the engine reaches operating temperature, the oxygen sensor becomes a high-authority sensor and can greatly affect the amount of fuel being supplied to the engine. See the chart.

High-Authority Sensors	Low-Authority Sensors
ECT (especially when the engine starts and is warming up)	IAT (intake air temperature) sensors modify and back up the ECT
O2S (after the engine reaches closed-loop operation)	TFT (transmission fluid temperature)
MAP	PRNDL (shift position sensor)
MAF	KS (knock sensor)
TP	

could enter the engine without being measured. This extra air is often called **false air.** See Figure 25–38. Because this extra air is unmeasured, the computer does not provide enough fuel delivery and the engine operates too lean, especially at idle. A small hole in the air inlet hose would represent a fairly large percentage of false air at idle, but would represent a very small percentage of extra air at highway speeds.

To diagnose for false air, hook up a scan tool and look at long-term fuel trim numbers at idle and at 3000 rpm.

Tap Test

With the engine running at idle speed, *gently* tap the MAF sensor with the fingers of an open hand. If the engine stumbles or stalls, the MAF sensor is defective. This test is commonly called the **tap test.**

Digital Meter Test of a MAF Sensor

A digital multimeter can be used to measure the frequency (Hz) output of the sensor and compare the reading with specifications.

The frequency output and engine speed in RPM can also be plotted on a graph to check to see if the frequency and RPM are proportional, resulting in a straight line on the graph.

SENSOR TESTING USING DIAGNOSTIC TROUBLE CODES

Many vehicles display diagnostic trouble codes (DTCs), yet do not display scan data. To check if the problem is the sensor itself or the electrical sensor circuit that is at fault, follow these steps.

1. Clear the DTC.
2. Create the opposite sensor condition. For example, if the DTC indicates an open engine coolant temperature (ECT) circuit, unplug the sensor and, using a jumper wire, short the two terminals of the harness (not the sensor) together.

NOTE: If the ECT sensor wires are shorted together, the scan tool will display about 150°C (300°F) and about −40°C (−40°F) if the sensor wires are open (disconnected).

When checking three-wire sensors, such as the throttle position (TP) sensor, MAP, or MAF, use a jumper wire to jump the 5 volt reference back into the signal return after disconnecting the connector from the sensor.

Shorting the 5 volt reference to the signal should cause the vehicle computer to set a shorted sensor DTC. If a shorted sensor DTC is stored, simply clear the DTC and unplug the sensor. If the wiring is okay, the opposite (open) sensor DTC should be set.

TECH TIP ✔

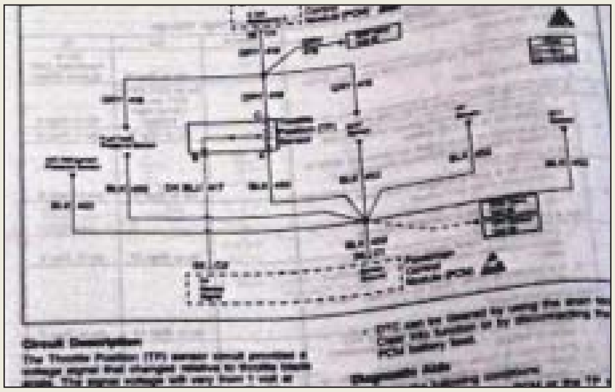
The Unplug It Test

If a sensor is defective yet still produces a signal to the computer, the computer will often accept the reading and make the required changes in fuel delivery and spark advance. If, however, the sensor is not reading correctly, the computer will process this wrong information and perform an action assuming that the information being supplied is accurate. For example, if a mass airflow (MAF) sensor is telling the computer that 12 grams of air per second is going into the engine, the computer will then pulse the injector for 6.4 ms or whatever figure it is programmed to provide. However, if the air going into the engine is actually 14 grams per second, the amount of fuel supplied by the injectors will not be enough to provide proper engine operation. If the MAF sensor is unplugged, the computer knows that the sensor is not capable of supplying airflow information, so it defaults to a fixed amount of fuel based on the values of other sensors such as the TP and MAP sensors.

If the engine operates better with a sensor unplugged, then suspect that the sensor is defective. A sensor that is not supplying the correct information is said to be *skewed.* The computer will not see a diagnostic trouble code for this condition because the computer can often not detect that the sensor is supplying wrong information.

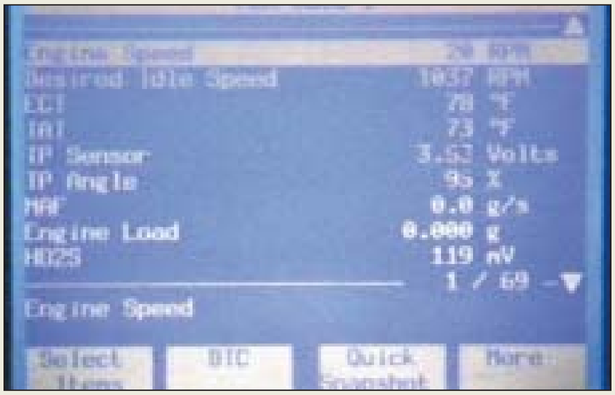
PHOTO SEQUENCE 19 Throttle Position Sensor Diagnosis

P19–1 Besides a scan tool, other equipment that can be used to check a throttle position (TP) sensor includes a scope or graphing multimeter, a digital multimeter equipped with MIN/MAX function, and T-pins to safely backprobe the sensor wires.



P19–2 Consult the factory service manual for the specifications and wire colors used for the TP sensor as well as the recommended testing procedure.

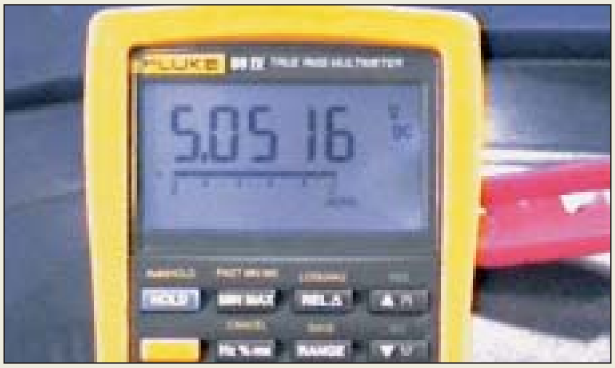
P19–3 A scan tool display showing no diagnostic trouble codes (DTCs). A fault could still exist even though a diagnostic trouble code is not set—it depends on what type of fault and when it occurs.



P19–4 A scan tool can be used to observe the output voltage and the calculated percentage (%) of throttle opening.

P19–5 Most throttle position sensors use a 5 volt reference voltage from the computer. To test that this signal is available at the sensor, carefully backprobe the 5 volt reference (grey on this General Motors vehicle) wire at the connector on the TP sensor. Simply push the T-pin alongside the wire until it touches the metal terminal inside the connector.

P19–6 Connect the red lead from the digital multimeter to the T-pin and attach the black meter lead to a good, clean engine ground.



P19–7 Select DC volts and turn the ignition key on (engine off). The meter reads slightly over 5 volts, confirming the computer is supplying the reference voltage to the TP sensor.

P19–8 Another important step when testing a TP sensor is to verify that the ground circuit is okay. To check the ground of the TP sensor, carefully backprobe the ground wire at the TP sensor connector (black on this General Motors vehicle) and connect the red meter lead to the T-pin.

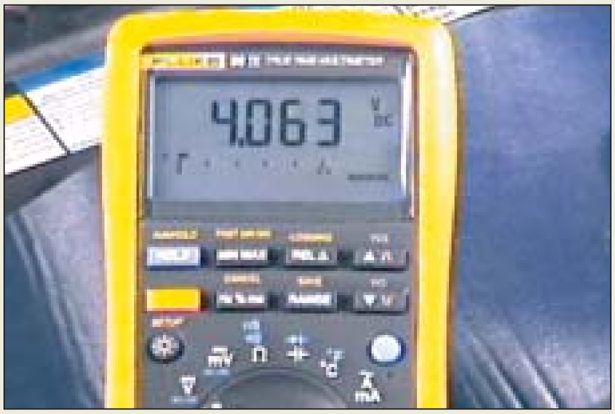
P19–9 Attach the black meter lead to a good, clean engine ground.

P19–10 With the ignition on (engine off) and the digital meter still set to read DC volts, read the voltage drop of the TP sensor ground. The voltage drop is the difference in voltage between the leads of the meter. General Motors specifies that this voltage drop should not exceed 35 mV (0.035 V). This TP sensor ground shows 31.1 mV (0.0311 V).

P19–11 To measure the signal voltage, backprobe the signal wire (dark blue on this General Motors vehicle).

P19–12 Select DC volts and manually range the meter. This Fluke meter changes from the 4 volt scale to the 40 volt scale as the sensor voltage goes slightly higher than 4 volt. For an instant, "OL" appears on the display as it switches ranges. This OL could also indicate a fault.

P19–13 Slowly move the throttle from idle speed to wide open and back to idle speed position. For best results, this test should be performed by depressing the accelerator pedal. This puts the same forces on the sensor as occurs during normal driving.

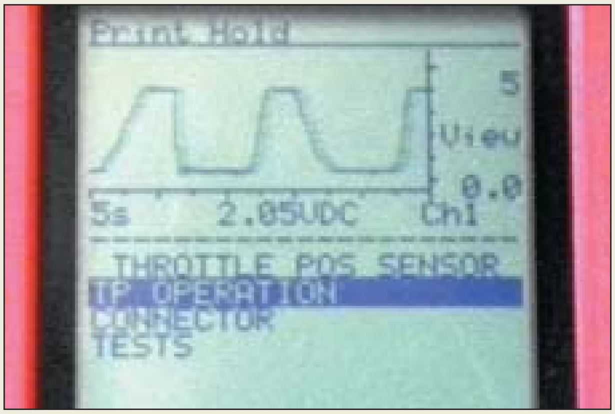


P19–14 The high reading for this sensor was 4.063 volts.

P19–15 Pushing the MIN/MAX button shows the minimum voltage the meter recorded during the test (0.399 volts).

P19–16 A Snap-On Vantage graphing multimeter or digital storage oscilloscope can also be used to test a TP sensor. To test the sensor using the Snap-On Vantage, select TP sensor from the menu.

P19–17 The Vantage has a built-in database that can be accessed to show connector position and wire colour information.



P19–18 After attaching the meter leads to the signal wire and ground (ignition key on, engine off), the graphing multimeter shows the waveform of the voltage signal as the throttle is depressed, released, and depressed again. These are normal for a TP sensor. A fault would show as a vertical line or dip in the waveform.

SUMMARY

1. The vehicle computer is called the powertrain control module (PCM) because it controls the engine and the transmission on most vehicles.
2. The four basic computer functions include: input, processing, storage, and output.
3. Permanent memory is called ROM, PROM, EPROM, or EEPROM.
4. Temporary memory is called RAM or KAM.
5. The central processing unit (CPU) is the “brains” of the computer and does all the calculations.
6. As the temperature of the engine coolant increases, the resistance of the ECT sensor decreases.
7. A throttle position sensor can best be checked with a voltmeter set on MIN/MAX or with a scope.
8. An oxygen sensor should switch rapidly from high to low on a fuel-injected engine operating in closed loop.

REVIEW QUESTIONS

1. List the four functions of a computer.
2. What is meant by the term Baud rate?
3. Explain how to test an engine coolant temperature sensor.
4. Describe the best method to test a MAP sensor.
5. Describe how a zirconia oxygen sensor works and how best to determine if it is operating correctly.

RED SEAL CERTIFICATION-TYPE QUESTIONS

1. Which of the following is an input sensor to the vehicle computer?
   - **a.** Fuel injector
   - **b.** Idle-speed control motor
   - **c.** Combustion chamber temperature sensor
   - **d.** Engine coolant sensor
2. Which part of the computer does the actual calculations?
   - **a.** PROM
   - **b.** RAM
   - **c.** CPU
   - **d.** KAM
3. Typical TP sensor voltage at idle is about ________.
   - **a.** 2.50 to 2.80 volts
   - **b.** 0.5 volts or 10% of WOT TP sensor voltage
   - **c.** 1.5 to 2.8 volts
   - **d.** 13.5 to 15.0 volts
4. The voltage output of a zirconia oxygen sensor when the exhaust stream is lean (excess oxygen) is ________.
   - **a.** Relatively high (close to 1 volt)
   - **b.** About in the middle of the voltage range
   - **c.** Relatively low (close to 0 volt)
   - **d.** Dependent on atmospheric pressure
5. The sensor that most determines fuel delivery when a fuel-injected engine is first started is the ________.
   - **a.** Oxygen sensor (O2S)
   - **b.** Engine coolant temperature (ECT) sensor
   - **c.** Engine MAP sensor
   - **d.** BARO sensor
6. The standardized name for the sensor that measures the temperature of the air being drawn into the engine is called a(n) ________.
   - **a.** Intake air temperature sensor (IAT)
   - **b.** Air temperature sensor (ATS)
   - **c.** Air charge temperature (ACT)
   - **d.** Manifold air temperature (MAT) sensor
7. Which sensor is generally considered to be the electronic accelerator pump of a fuel-injected engine?
   - **a.** Oxygen sensor
   - **b.** Coolant temperature sensor
   - **c.** Throttle position sensor
   - **d.** Engine manifold absolute pressure sensor
8. The sensor that must be warmed up and functioning before the engine management computer will go to the closed loop is the ________.
   - **a.** Oxygen sensor (O2S)
   - **b.** Engine coolant temperature (ECT) sensor
   - **c.** Engine MAP sensor
   - **d.** BARO sensor
9. Which of the following describes an acceptable oxygen sensor voltage range?
   - **a.** 0.5 to 0.7 volt
   - **b.** 200 mV to 800 mV
   - **c.** 300 mV to 500 mV
   - **d.** 400 mV to 800 mV
10. A pull-up resistor inside the computer (ECT circuit) is used to
    - **a.** Expand the scale of the ECT sensor
    - **b.** Dampen voltage fluctuation
    - **c.** Prevent amperage from back-feeding into other circuits
    - **d.** Compare resistance with the intake air temperature (IAT) sensor