Chapter 7

Computer Control Fundamentals

After studying this chapter, you will be able to:

- Explain how efficiency is obtained by electronic engine controls.
- Describe the operation of the electronic control module.
- List the major circuits of the electronic control module.
- Explain the operation of major input sensors.
- Explain the operation of major output devices.
- Describe the basic control loop of the computer control system.
- Identify the key elements of an OBD II system.

Know These Terms

Accessory equipment sensors
Active testing
Adaptive strategy
Atmospheric sensors
Central processing unit (CPU)
Closed loop
Control loop
Control module
Controller area networks (CAN)
Data bus
Data link connector
Diagnostic trouble code (DTC)
Drive train sensors
Electric motor
Electronic control module (ECM)
Electronic engine control system
Electronic output devices
Engine sensors
Failure record
Fixed memory
Freeze frame record
General-circuit failure
High-input failure
Input processor
Intrusive testing
Keep alive memory (KAM)
Knock sensors
Long-term fuel trim
Low-input failure
Malfunction indicator light (MIL)
Monitors
On-board diagnostics generation one (OBD I)
On-board diagnostics generation two (OBD II)
Open loop
Output devices
Output processor
Oxygen (O_2) sensor
Passive testing
Pulse width
Range/performance failure
Reference voltage
Rheostat
Sensors
Short-term fuel trim
Solenoid
Transducers
Virtual sensors
Volatile memory
X-by-wire

Compared to vehicles of the past, cars and light trucks have greater fuel economy, produce less pollution, and perform better. Many of the improvements introduced to the vehicle over the years to achieve these results involve the electronic devices. This chapter discusses on-board computers and how they monitor and control the various engine, drive train, and vehicle systems. This chapter not only provides a review of computer control systems, but also prepares you for many of the subsequent chapters in this text.

Electronic Engine Control Systems

The most important advance in the areas of driveability, fuel economy, and performance is the development of the on-board computer to control the engine and drive train systems. The on-board computer system is usually called the ***electronic engine control system.*** This system is composed of electrical, electronic, and mechanical devices that monitor and control engine operation. Electronic engine control systems always have a central computer that interacts with the other components. Some systems have one or more related computers that control some of the electrical devices drawing heavy current. Other systems use the second computer to operate the fuel injection system or control automatic transmission operation.

On-board computers control parts of the fuel system, ignition system, emissions system, drive train, and accessories such as the air conditioner. A few vehicles have control systems that also operate parts of the valve train. Although the engine-control computer is often connected to and receives information from other vehicle computers, it is primarily used to control engine and vehicle systems. Vehicle manufacturers often refer to computerized engine controls as emission-control devices. While these controls help to clean up the exhaust gases, they do so by improving overall engine efficiency. The computer and its related parts are constantly tuning all engine systems and components for optimum performance.

The basic computer control system consists of three main areas:

- Input devices.
- Computer.
- Output devices.

The actual engine and drive train components being affected constitute a fourth area of a basic computer control system.

The heart of a computer control system is the computer, or ***control module.*** It receives inputs from components called input devices, or ***sensors.*** It then uses internal logic circuitry to determine the actions to be taken. Next, it sends commands to components called ***output devices.*** The output devices cause changes in engine or drive train operation. The results of these changes are picked up as new readings by the sensors. **Figure 7-1** illustrates this cycle. The computer control system works in a repeating cycle, or loop.

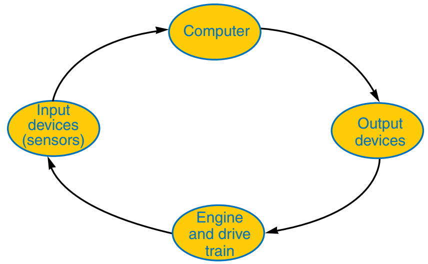


Figure 7-1. *A typical computer control system cycle or "loop." This loop applies to all automotive computer control systems.*

Electronic Control Module

The ***electronic control module (ECM)*** processes and interprets the electrical inputs from the sensors through the use of miniaturized electronic components arranged to use logic. All information processing in a computer is a binary operation. This is a series of on-off signals, no matter how complex the information or signal. The manipulation of these signals is what operates the computer.

All ECMs are divided into several internal circuits that process the sensor inputs and issue commands to the appropriate output devices. A schematic of a simple ECM system is shown in **Figure 7-2.** Although each of the internal ECM circuits operates independently, the circuits exchange information and share sensor inputs.

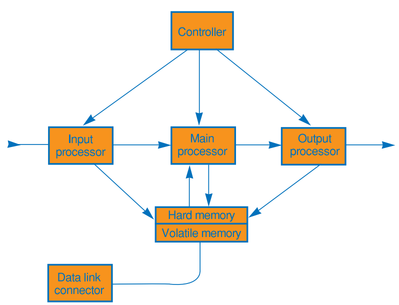


Figure 7-2. *The general relationship of computer control system components. All vehicle computer control systems operate in this manner. The types and number of sensors and output devices varies.*

The engine control computer in various makes and models of vehicles is called by different terms, according to individual manufacturer preferences. Some of these terms include:

- On-board computer.
- Microprocessor.
- Controller.
- Engine control module (ECM).
- Electronic control unit (ECU).
- Electronic engine control (EEC).
- Powertrain control module (PCM).
- Vehicle control module (VCM).

Since there are over two dozen motor vehicle manufacturers, the number of names for the computer can cause confusion. In this book, the engine-control computer is always called the ECM for engine control module. Calling engine control computers ECMs makes it easier to separate them from other vehicle computers and the computers used in diagnostic equipment.

Multiple ECMs

Almost all vehicles have more than one control. There may be separate control modules for the transmission, anti-lock brakes, air conditioner, and body electrical circuits. These control modules communicate with each other and act as a single unit when tasks in different parts of the vehicle must be coordinated.

Note: The computers that control engine operation on most vehicles should not be confused with those operating the anti-lock brake system (ABS), cruise control, air bags, anti-theft system, climate control system, or suspension.

Main Control Modules

In most vehicles, one computer has the job of managing the data flows of the other vehicle control modules. The job may be assigned to the vehicle control module (VCM), body control module (BCM), or instrument cluster module (ICM). The control module also monitors and sometimes controls other vehicle systems besides the engine and transmission. Examples are anti-lock brakes, stability control systems, and audio/video systems.

Having one computer control all information passing between control modules means that some other computers or components can be eliminated. Other advantages include centralized control of many vehicle systems, reducing the possibility of crossed signals and interference.

Thirty-Two-Bit ECM

The latest ECMs are 32 bit. This means that they can process a piece of information consisting of 32 numbers and letters as a single piece of data. Older ECMs could process only 16 numbers and letters as a single data piece. A 32-bit computer works much faster than older models, interfaces better with CAN busses, and can store as many as 4 billion numbers. The 32-bit ECM controls all of the electrical devices on a vehicle, either directly or through other ECMs attached through a CAN system. CAN systems are discussed later. **Figure 7-3** shows a 32-bit ECM installed on the vehicle firewall.

ECM Communications

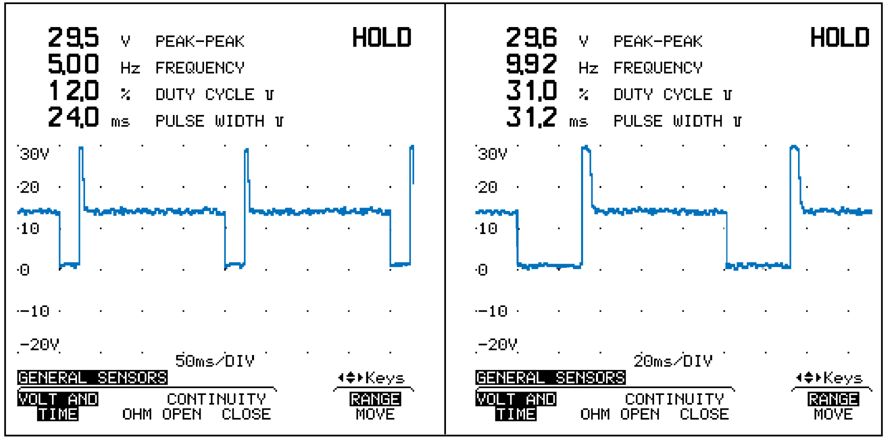
Signals from the input sensors and to the output devices are analog signals, or signals composed of variable, nondiscreet voltage levels. The analog signals to and from the sensors vary from millivolts to battery voltage, depending on the system, and are usually referred to as ***reference voltages.*** Computers are digital devices working with a series of on and off, or discreet, signals. This information is referred to as serial data or the data stream.

The ECM operates output devices by turning them on and off. Output device operation is controlled by varying the length of time the device is operated, either by applying voltage or supplying ground. The length of time over which the signal or ground is provided is called the ***pulse width,*** **Figure 7-4.** The ECM also provides external communications to other on-board computers and diagnostic equipment, which are discussed in the next section.

Multiplexing and Data Busses

As explained earlier, the ECMs in most vehicles communicate with each other. They transfer information via a path called a data bus. The ***data bus*** is simply a roadway for data transfer between the ECMs and other control modules.

Figure 7-3. *The ECM in this vehicle operates all of the vehicle systems, either directly or by controlling messages to other vehicle computers. Fins are cast into the body for heat removal.*



A B

Figure 7-4. *Varying the length of the pulse width allows the ECM to control the operation of many devices. A—Narrow pulse width. B—Wide pulse width. Note the difference in the length between the pulses. (Fluke)*

Many circuits can travel on the same bus sorted by voltage, frequency, and the type of signal they use. This network is referred to as multiplexing. Multiplexing is the use of a single wire or pathway to transmit two or more messages at the same time. The same wire can be used to transmit any number of messages if the complete circuit for each message is separate. Many operations can be carried on at the same time over the same wire, without interfering with each other. The simplest type of multiplexing is a battery ground cable, which carries the electrical impulses of the ignition, headlight, and radio circuits while keeping each separate.

Data busses are made of copper wire. Copper is used for minimal electrical resistance. In the future, fiber optics may be used to create the vehicle data bus. Since fiber optics have the ability to simultaneously transmit multiple signals with almost no resistance, information can be transmitted, received, and processed at a much faster rate than over copper wire.

Data Bus Class

The speed at which a data bus carries information defines its class. At present, there are three classes of busses:

- Class A busses carry information at a maximum speed of 10 kilobits per second.
- Class B busses carry information at speeds of 10 to 125 kilobits per second.
- Class C busses carry information at up to one million kilobits per second.

In the future, Class D busses, capable of carrying over one million kilobits per second, may be developed. The bus itself does not determine speed, since it is simply a wire. Bus speed, and therefore class, is determined by the ECMs that are connected to the bus. A Class C bus may sometimes carry information at Class A or B speeds, depending on the speeds of the attached ECMs. However, a bus cannot carry information at a speed higher than its maximum.

Controller Area Network (CAN)

Vehicle manufacturers are now using a more sophisticated bus called a ***controller area network (CAN).*** The CAN consists of a bus connecting various ECMs. On a CAN system, however, each ECM has a unique address, or code. Therefore, every signal from an ECM has an identification code telling all other ECMs from where the information originates. The circuits inside of each ECM read the code before processing the signal. If the information is not intended for the ECM, it is ignored. This keeps information from entering the wrong ECM. In some cases, the main computer determines where the information should be sent.

In addition to the identification code, information from the sending ECM also includes a priority code. If two ECMs send a signal to a third ECM, the signal with the highest-priority code is processed first. Sometimes an ECM may interrupt a low-priority message to receive a higher-priority message. The ECM resumes processing the lower priority message once the higher-priority message has been processed. Determining priority may be the job of the main computer. This type of ECM programming is sometimes called dataflow or multithread programming.

Troubleshooting and service procedures are the same for vehicles using CAN systems and older buses. Older scan tools, however, will not work on CAN systems without the use of a special adapter. Newer scan tools are designed to work with CAN systems. One unusual problem that sometimes occurs with CAN systems is a failed ECM creating enough electrical interference to confuse the other ECMs, causing false codes and erratic operation. Sometimes the only way to diagnose this problem is to disconnect ECMs one at a time to isolate the problem to a particular one. This may also be necessary when internal communications seems to have failed.

ECM External Communications

There are three types of external serial communication used in automotive computer systems. Most vehicles use a system called universal asynchronous receive and transmit (UART). This signal is used for communication between the ECM, off-board diagnostic equipment, and other control modules. UART is a data line that varies voltage between 0–5 volts at a fixed-pulse-width rate. Vehicles may use UART, but may also depend on the use of Class 2 and CAN serial communication. Class 2 data is transferred by toggling the line voltage from 0–7 volts, with 0 being the rest voltage, and by varying the pulse width. The variable pulse width and higher voltage allows Class 2 data communication to better utilize the data lines.

ECM Internal Components

There are several main circuits in the ECM. These circuits are:

- Input processor.
- Memory.
- Central processing unit (CPU).
- Output processor.

These circuits are not individually serviced. They are all replaced when the ECM is replaced. However, it is important to have some idea of how each circuit works. The following sections explain these circuits in detail.

Input Processor

The ***input processor*** takes the analog voltage from the input sensors and converts it into digital pulses that can be used by the computer circuits. Most sensors can send information at a faster rate than the ECM can process. The input processor reduces the amount of incoming information to a manageable level by averaging a series of analog voltage pulses into a single digital pulse.

The input processor also serves as a protective device. Early ECMs were easily damaged if a sensor or wire became shorted or grounded. Newer input processors limit the amount of current entering the ECM, preventing shorts and voltage surges from damaging the ECM.

Memory

The memory contains the preset values for a properly running engine. There are two kinds of memory in the computer: fixed and volatile. The fixed memory circuits in most ECMs cannot be changed. However, the fixed memory in some ECMs is replaceable, while others can be modified with the ECM in the vehicle. The volatile memory is able to receive and store information from the sensors and output devices.

Fixed Memory. ***Fixed memory*** is used to retain the operating instructions for the ECM and the vehicle's base engine or system information. There are four types of fixed memory.

Read-only memory (ROM) contains the basic instructions that tell the ECM how to operate. If power to the ECM is disconnected, the information is not lost. ROM is installed at the factory and, if defective, requires ECM replacement.

Programmable, read-only memory (PROM) contains the operating parameters for the engine, drive train, or system. This information is used by the ECM as a reference for proper input sensor, output device, engine, drive train, and vehicle operation. If power to the ECM is removed, the information in the PROM is not lost. In some cases, the PROM can be removed if it is defective or an updated PROM is needed to correct a driveability problem. However, in ECMs, the PROM is permanently affixed to the circuit board. Most computer-controlled vehicles use PROMs in their ECMs.

Some ECMs use erasable, programmable, read-only memory (EPROM). These are affixed to the ECM circuit board and can be reprogrammed by exposing the ECM to an ultraviolet light to clear the EPROM and then programming it with the new information. Unfortunately, this can only be done by the ECM manufacturer, which makes it necessary to replace any ECM that has a defective EPROM or if updated programming is needed to correct a problem.

Many of the newest ECMs use electronically erasable, programmable, read-only memory (EEPROM) or flash-erasable, programmable, read-only memory (FEPROM). These types of memory, while affixed to the ECM, can be easily programmed or updated using computerized equipment. All or part of a vehicle's operating information is downloaded or "burned into" the EEPROM or FEPROM. Some EEPROM- and FEPROM-equipped ECMs can be programmed away from the vehicle.

Volatile Memory. The information in ***volatile memory*** changes with vehicle operation and indicates ongoing changes in the control system or other engine systems. Volatile memory is used to store diagnostic codes and temporary information on vehicle operating conditions from the input sensors. The incoming information can be used by other computer circuits as part of the ECM's learning function. If power to the ECM is disconnected, all information stored in volatile memory is lost.

All ECMs have random-access memory (RAM). While the vehicle is operating, information from the sensors, such as minimum intake airflow rate and diagnostic trouble codes, is stored in RAM and constantly updated. Some ECMs can compensate for wear and changes in sensor output and output device response.

Keep Alive Memory. The ECM stores basic operating parameters in what is known as ***keep alive memory (KAM).*** KAM is sometimes referred to as keep alive RAM or nonvolatile RAM. The ECM can access this information and use it to adjust the output devices to compensate for the sensor's reduced output. This is usually referred to as an ECM's ***adaptive strategy.*** The basic operating parameters in KAM allow the ECM to maintain vehicle operation even though sensors are providing abnormal readings. The vehicle can be driven to a service facility in this limp-in mode.

Note: Some newer ECMs can retain volatile memory for several days without battery power.

Central Processing Unit (CPU)

The ***central processing unit (CPU)*** actually controls ECM operation. It directs the operation of the other circuits, telling them which tasks to perform. It can be thought of as the ECM's manager, directing the flow of information through the various circuits. The CPU also determines the overall status of the engine/vehicle and compensates for short- and long-term changes in engine operation.

The CPU takes the information from the input processor and compares it with information in memory. If the input signals match the data in memory, the CPU takes no action. If the inputs do not match the preset data, the CPU instructs the output processor to change the operation of the output devices until the input signal matches the data in memory. Some inputs are simply for reference, such as intake air temperature and atmospheric pressure. The CPU compensates for these input readings by modifying the operation of other systems. Some outputs, such as air-fuel ratio, are directly and aggressively adjusted by the CPU.

Output Processor

The ***output processor,*** or output driver, takes the digital ECM commands and converts them into analog electrical signals for the output devices. Since most output devices are operated by simply turning them on and off, the output signal (pulse width) is varied in length. The output processor often acts like a relay, using the small voltage inputs from the main processor to control the flow of high current into solenoids or motors. On a few vehicles, the output processor is a separate unit, sometimes called the output or power computer.

The ECM makes use of quad drivers. These are output chips containing power transistors and other components that can absorb high current in the event that an output device or connection is shorted to ground. This prevents damage to the ECM internal components. The output processor also protects the ECM from voltage spikes or shorted output devices.

Other ECM Components

All ECM's have a chip that acts as an internal clock. This internal clock times engine operation and is used by the ECM to coordinate its internal operations. Some ECM clocks track the actual time of day as long as they are connected to battery power. Most ECMs have a backup processor that has preset engine operating information. Should the ECM malfunction, this chip, often called a mem-cal, allows the vehicle to operate in limp-in mode. While the vehicle will not run efficiently, it can be driven to a shop for service.

Specific Functions of Computer Control Systems

While monitoring input sensors and adjusting output devices, the ECM performs many functions within its circuits that are important to vehicle operation and safety. The following sections describe some of these specific ECM functions.

Short- and Long-Term Fuel Trim

The ECM interprets sensor readings and adjusts the fuel system to compensate. The ECM makes adjustments to the injector pulse width, which is how long the injectors stay open. This is done by constantly checking the input sensor data in short term memory and making adjustments based on this information. The process is called ***short-term fuel trim.*** Some manufacturers refer to this as an integrator. Short-term fuel trim adjustments are made in response to temporary changes in engine operation, such as increased load when driving up a hill.

The ECM can also make longer, semipermanent adjustments to the air-fuel ratio in response to engine operation. This process is called ***long-term fuel trim,*** sometimes referred to as block learn. Long-term fuel trim adjustments are made when the ECM determines that the vehicle is operating under set conditions for an extended period of time, such as hot or cold weather, high altitudes, or with an on-going driveability problem.

Scan tools can monitor short- and long-term fuel trim. The scan tool interprets both fuel trim readings as a count number or percentage. The ECM in some systems can monitor the fuel trim to detect problems.

Idle Speed Control

The ECM controls the amount of air flowing into the engine at idle by controlling a throttle positioner or air bypass valve. The rate of airflow will not be less than a set minimum, which is called minimum idle speed control or minimum idle air rate. On most engines, minimum idle is automatically set by the ECM when the vehicle reaches certain speed and operating conditions. A few vehicles require the idle speed control to be set by the technician, usually with a scan tool.

Engine and Vehicle Protection

Most ECMs are designed to protect the engine and vehicle from damage due to excessive engine or vehicle speed. Manufacturers add programming to the ECM that will limit the fuel pump output, fuel injector operation, or ignition module operation if engine speed becomes excessive, usually between 6000–7800 rpm. In some cases, the ECM will not allow the vehicle to exceed a predetermined road speed. The ECM will also shut down the engine during extreme deceleration conditions, such as during a collision.

Clear Flood Mode

Some ECMs will shut down the fuel injectors if the throttle position sensor indicates the throttle valve is being held past a certain angle during start-up. This is called clear flood mode. It prevents engine damage if the driver depresses the accelerator while cranking the engine.

Clear flood mode also allows technicians to clear the cylinders should they become flooded with fuel. Some technicians will use the clear flood mode while testing the ignition or starting system when engine operation is not desired. Clear flood mode is discussed in more detail in Chapter 17.

Caution: Not all ECMs have clear flood capability. Check the vehicle's service manual before attempting to use this feature.

Voltage Monitoring

The ECM monitors battery voltage in order to compensate for electrical loads placed on the charging system. If the ECM detects a drop in battery voltage, engine idle speed is slightly increased to compensate. This increases alternator output in response to electrical loads. If the battery voltage drops below 10–10.5 volts or goes above 14.5–15 volts for an extended period, the ECM stores a trouble code.

Some ECMs also have control over the voltage regulator. These ECMs can increase alternator output to increase battery voltage. If excessive charging is detected, they can shut down the alternator for a time.

Overheating Protection

The ECM monitors engine coolant temperature in order to adjust inputs to the output devices to compensate for changes in engine temperature. Another feature programmed into most ECMs is overheating protection. On most engines, the ECM will shut off the air conditioning compressor, turn any electric cooling fans on, and increase the engine idle speed to force more coolant through the engine. Increasing idle speed also increases the rotational speed of a belt-driven fan.

A few ECMs provide overheating protection by selectively disabling cylinders in the engine to redistribute heat. If the ECM detects an overheating condition, it will shut off the fuel injectors and spark to selected cylinders in an alternating pattern. This decreases the build-up of engine heat.

Sleep Mode

To reduce parasitic battery drain, some ECMs may go into sleep mode. Most engine and powertrain control modules power down shortly after the ignition switch is turned to the off position. Some body control modules, such as those for ABS, stability control, or power windows, remain powered up for a brief period of time. Others, such as security and keyless entry systems, do not have a sleep mode and remain energized at all times.

Input Sensors

Input sensors are installed on the engine and vehicle and measure the actual conditions in the engine, vehicle, and surrounding atmosphere. The input sensors are the ECM's "nerves." Input sensors monitor a wide variety of engine and drive train functions. They monitor conditions in the engine and drive train, outside atmospheric conditions, and direct or indirect driver inputs.

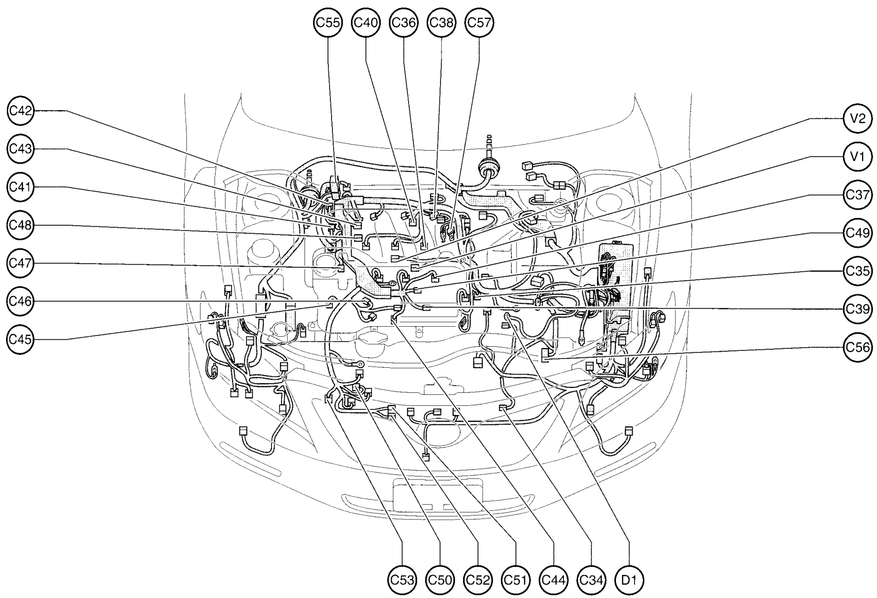
Types of Sensors

There are many types of input sensors. Sensors are grouped according to the vehicle systems they affect. Typical sensors measure:

- Engine temperature and speed.
- Vehicle speed.
- Crankshaft position.
- Camshaft position.
- Manifold vacuum.
- Intake airflow.
- Intake air temperature.
- Barometric pressure.
- Exhaust gas oxygen.
- Engine knocking.

Figure 7-5 shows the location of some common engine sensors. A brief description of input sensor operation is provided in this section. More detail about certain specialized sensors is given in later chapters.

In many sensors, a reference voltage from the ECM is passed through a resistor unit. This voltage is modified as the resistance of the sensor varies with conditions. Some of these sensors contain a contact unit that slides along a resistor, **Figure 7-6.** These units are sometimes called ***rheostats.*** As the contact moves along the resistor, the resistance



C34	VSV (ACM)
C35	Air Fuel Ratio Sensor (Bank 2 Sensor 1)
C36	Fuel Injector (No.5)
C37	Fuel Injector (No.6)
C38	Ignition Coil (No.5)
C39	Ignition Coil (No.6)
C40	VVT Sensor (Bank 1 Exhaust Side)
C41	VVT Sensor (Bank 1 Intake Side)
C42	Camshaft Timing Oil Control Valve (RH Exhaust Side)
C43	Camshaft Timing Oil Control Valve (RH Intake Side)
C44	VVT Sensor (Bank 2 Exhaust Side)
C45	VVT Sensor (Bank 2 Intake Side)
C46	Camshaft Timing Oil Control Valve (LH Exhaust Side)
C47	Camshaft Timing Oil Control Valve (LH Intake Side)
C48	VSV (ACIS)
C49	Noise Filter (Ignition LH)
C50	Crankshaft Position Sensor
C51	Heated Oxygen Sensor (Bank 2 Sensor 2)
C52	Heated Oxygen Sensor (Bank 1 Sensor 2)
C53	A/C Compressor
C55	Engine Control Module
C56	Transmission Control ECU
C57	Junction Connector
D1	Starter
V1	Knock Control Sensor (Bank 2)
V2	Knock Control Sensor (Bank 1)

Figure 7-5. *Driveability service information contains diagrams showing the location of input sensors, output devices, the ECM, and other components of the computer control system. (University of Toyota/Toyota Motor Sales USA)*

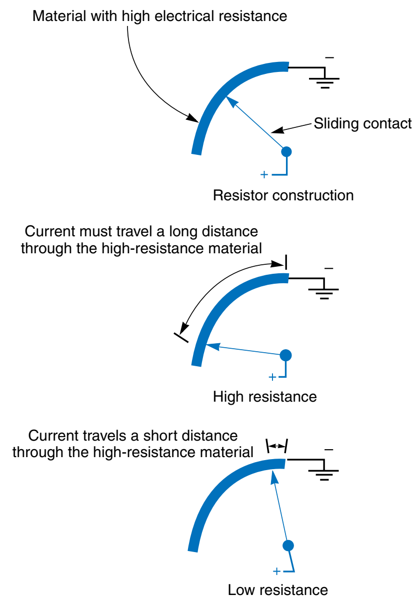


Figure 7-6. *A variable resistor is used to measure the position of a part, such as the throttle plate. It consists of a resistor and a sliding contact. The position of the contact on the resistor determines how much current can flow through the switch. The ECM reads the change in current flow as a signal indicating the change in position.*

increases or decreases. This results in a change in the voltage drop across the sensor. The ECM reads the variation in voltage as an input signal. For example, the resistance in some airflow sensors varies according to the position of the resistor unit. The resistance of a manifold vacuum or EGR position sensor varies according to movement within the resistor unit.

In other sensors, changes in temperature affect the resistance within the sensor. Therefore, temperature changes alter the voltage drop across the sensor. The ECM reads this change in voltage as a change in temperature. Intake air temperature and engine coolant temperature sensors are typical of temperature-sensitive, resistance-type sensors. A typical coolant temperature sensor is shown in **Figure 7-7.** Some vehicles are equipped with an exhaust temperature sensor. This sensor is used to tell the ECM when exhaust temperatures are high enough for the oxygen sensor readings to be reliable, **Figure 7-8.**

Some sensors are called ***transducers.*** They consist of an iron plunger inside of a small wire coil. Current flows through the coil when the engine is operating, creating a magnetic field. When the plunger is moved by outside force, such as a vacuum diaphragm or driver-operated linkage, it changes the strength of the magnetic field in the coil. Changes in the magnetic field cause a change in the amount of current flowing through the coil. The ECM can read this as a change in position of the monitored device. **Figure 7-9** shows a typical transducer.

Atmospheric Sensors

Atmospheric sensors measure conditions outside of the vehicle. Atmospheric sensors include those that measure air temperature and barometric pressure. Air-

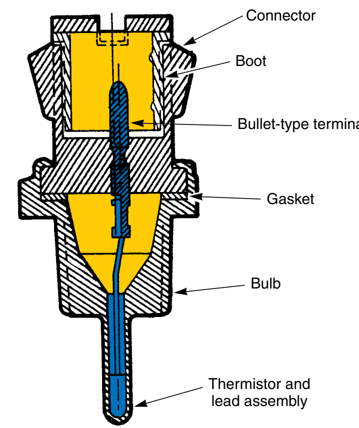


Figure 7-7. *Cutaway of a engine coolant temperature sensor. As temperature increases, the resistance of the material in the sensor decreases. (Ford)*

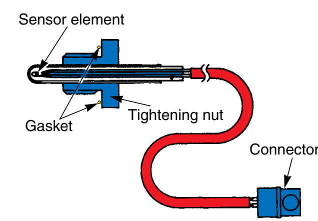


Figure 7-8. *Some vehicles use an exhaust temperature sensor to monitor when exhaust temperatures are right for accurate oxygen sensor readings. Most manufacturers do not use this sensor. (Subaru)*

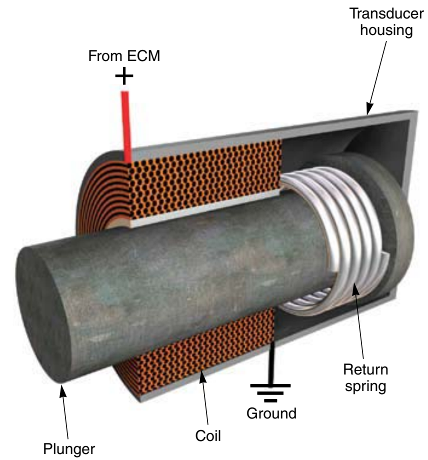


Figure 7-9. *A transducer is simply a wire coil with a metal plunger. Movement of the metal plunger causes fluctuations in the coil's magnetic field. This results in a voltage change that can be read by the ECM.*

temperature sensors work like coolant temperature sensors, which are discussed later. In some cases, the coolant and air-temperature sensors are identical.

Intake-Air Temperature Sensors

When the air entering the engine is warm, less fuel is needed to operate the engine. The intake-air temperature sensor (IAT) monitors the temperature of the incoming air, **Figure 7-10.** An IAT's resistance changes in response to air temperature. On some vehicles, the sensor is part of the mass airflow sensor. Intake-air temperature sensors are also known as manifold air temperature (MAT) sensors.

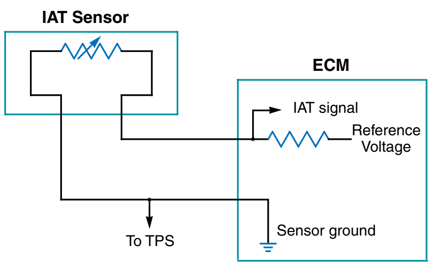


Figure 7-10. *The intake air temperature (IAT) sensor allows the ECM to compensate for air temperature when determining the correct air-fuel ratio.*

Barometric Pressure Sensors

Some materials change resistance as the pressure placed on the material changes. As a result, the strength of a voltage signal passing through the material varies as the pressures placed on the material changes. Some of these materials are piezoelectric crystals.

Air pressure is different at sea level than it is in the mountains. A vehicle adjusted to operate normally at sea level will perform differently at higher elevations without readjustments. Barometric pressure sensors measure atmospheric pressure. The sensors send a voltage signal to the ECM. In turn, the ECM compares the input to that from the manifold vacuum sensor and adjusts the air-fuel ratio, spark timing, and other outputs to maintain good performance.

Engine Sensors

Engine sensors measure conditions in or on the engine. Some of the engine conditions measured include temperature, speed, manifold vacuum, and airflow.

Manifold Absolute Pressure Sensors

Almost all engines have a manifold absolute pressure (MAP) sensor. Manifold absolute pressure refers to the difference between the pressure in the intake manifold and the outside air when the engine is running.

MAP sensors use a pressure-sensitive material and operate in the same way as a barometric pressure sensor. The ECM uses the MAP sensor input in combination with other sensor inputs to determine the engine load. The ECM then determines the best ignition timing and air-fuel ratio for the situation. The manifold vacuum and barometric pressure sensors are usually installed in the same housing. The schematic for a MAP sensor is shown in **Figure 7-11.**

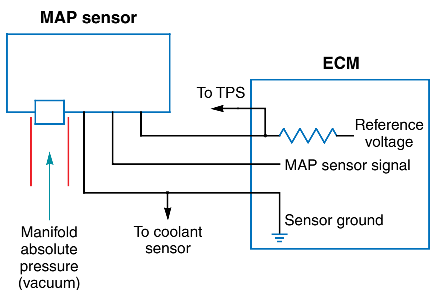


Figure 7-11. *Manifold absolute pressure (MAP) sensors are used to determine the difference in air pressure between the manifold and outside air.*

Mass Airflow Sensors

Many engines have a mass airflow sensor (MAF), which precisely monitors the amount of air entering the engine. The ECM uses the mass airflow sensor input to determine how much fuel to inject to match the amount of air entering the engine. Three types of airflow sensors are used: heated element, air valve, and Karman vortex.

The heated element MAF consists of a wire or film made of temperature-sensitive, resistance material. This element extends into the intake air passage and contacts the stream of incoming air. A heated element sensor is shown in **Figure 7-12.** The ECM directs a reference voltage through the element. As current flows through the element, it heats up and its resistance increases. Since the reference voltage from the ECM is constant, increasing resistance decreases the amount of current flow and, therefore, the voltage returning to the ECM. Airflow through the air passage removes heat from the element, reducing its resistance and increasing the voltage signal. Therefore, the voltage signal goes up when airflow is increased and goes down when airflow is reduced. The ECM reads the voltage variations and calculates the amount of air flowing into the engine.

The air valve MAF consists of a moveable flap, attached to a rheostat, that extends into the airstream in the intake air passage. The flap is spring loaded so that airflow is opposed by spring pressure. As airflow into the engine increases and decreases, the flap moves. The rheostat receives a reference voltage from the ECM. Variations in airflow cause the flap to move, which in turn moves the rheostat contact arm. This increases or decreases the voltage signal to the ECM, which reads it as changes in airflow.

Figure 7-12. *Mass airflow sensors (MAF) are installed in the air intake duct between the air filter and throttle valve. (Cardone)*

The Karman vortex MAF consists of a metal-foil mirror, LED, and light receptor (photo transistor). The light produced by the LED is reflected from the metal-foil mirror into the photo transistor. The metal-foil mirror is placed in the intake air passages, where the incoming air causes it to vibrate. Increases and decreases in airflow change the rate of vibration and, therefore, the amount of light that reaches the photo transistor. The photo transistor changes this light into a voltage signal that can be read by the ECM as airflow rate.

Mass airflow sensors are not used on some multiport injection systems, nor on throttle body injection systems. The vehicle computer systems monitoring other sensor inputs and calculating the amount of air entering the engine. These are known as speed-density systems. In a typical speed-density system, the ECM computes airflow from inputs provided by the MAP, engine speed, throttle position, vehicle speed, and intake air temperature sensors. This process is discussed in greater detail in Chapter 9.

Engine-Coolant Temperature Sensors

To properly adjust the fuel mixture and ignition timing and to operate the emission controls, the ECM must know engine temperature. In addition, the ECM relies on engine temperature to decide whether to place the system in closed or open loop and to turn the radiator fans and air conditioning compressor on or off. Since the temperature of the engine coolant is a good indicator of overall engine temperature, every vehicle has at least one engine-coolant temperature (ECT) sensor. A few systems have a second sensor to more closely monitor engine warm up.

The engine-coolant temperature sensor consists of a heat-sensitive, resistance material. Unlike most resistors, the material's resistance decreases with increases in temperature. The ECM sends a reference voltage to the sensor, which passes through the resistance material before returning to the ECM. When the coolant and sensor are cold, the material has a very high resistance. Electricity flowing through the sensor meets this resistance and the voltage signal returning to the ECM is low. As the coolant warms the material, the resistance decreases. This increases the voltage signal returning to the ECM. The ECM reads these variations in voltage as engine temperature. A typical engine-coolant temperature sensor is shown in **Figure 7-13.**

Engine Speed and Position Sensors

Some sensors develop a voltage signal by creating or varying a magnetic field. If a magnetic field is used to create the voltage signal, no outside voltage source is needed. In other sensors, a voltage signal created in the ECM is modified by the operation of the sensor.

Magnetic-field sensors use a magnetic field generated by moving parts. In a typical system, a toothed wheel passes near a small pickup coil, creating a magnetic field. This magnetic field produces a small voltage signal to the ECM, **Figure 7-14.** Some sensors create a signal by interrupting an existing magnetic field. As shown in **Figure 7-15,** either

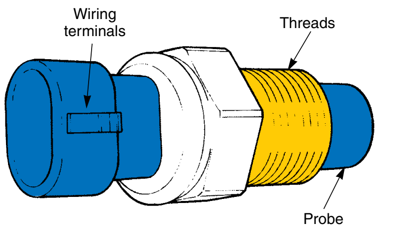


Figure 7-13. *Parts of an engine coolant temperature sensor. These sensors are normally installed in the intake manifold or in the thermostat housing. (Chrysler)*

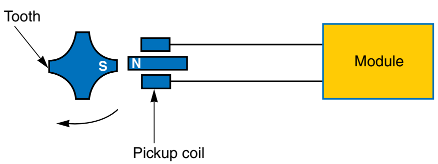


Figure 7-14. *Rotating teeth create a magnetic field in the pickup coil. The pickup coil is composed of a small wire that responds to changes in this magnetic field. A small voltage is produced that can be read by the ECM.*

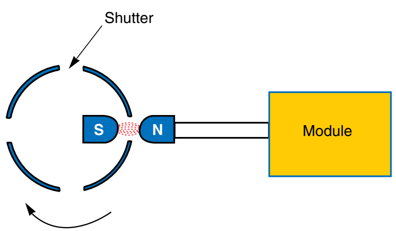


Figure 7-15. *The Hall-effect switch shown here is a wire coil with current flowing through it. Current produces a magnetic field around the coil. When the rotating shutter breaks the magnetic field, the voltage of the current flowing through the coil is changed. This is sent as a signal to the ECM.*

a shutter or rotating magnets are used to affect the magnetic field. Interrupting the magnetic field creates a voltage fluctuation in the circuit, which is read by the ECM.

In some systems, the input signal is generated as a byproduct of the operation of the ignition system. In these cases, the signal generated by a Hall-effect switch is used to trigger the coil discharge and also as an input to the ECM. These sensors are discussed in more detail in Chapter 8.

Crankshaft-position and camshaft-position sensors are installed near the crankshaft or camshaft, **Figure 7-16.** A disk with a series of magnetized teeth is installed on the crankshaft or camshaft. As the shaft rotates, the disk passes near the sensor, creating a magnetic field. This magnetic field creates a voltage signal to the ECM. The ECM can process this signal to determine engine speed. The ECM can also determine the crankshaft and camshaft position and, therefore, the position of each piston by reading the pattern of voltage signals.

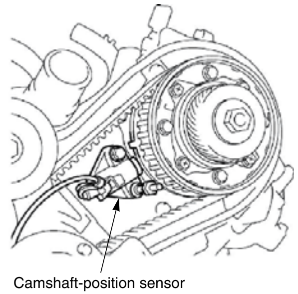


Figure 7-16. *The camshaft-position sensor used with a cam-in-block engine is often mounted directly behind the coolant pump. The camshaft-position sensor for an overhead camshaft may be installed on the front of the cylinder head, as shown here. (University of Toyota/Toyota Motor Sales USA)*

Many speed sensors are referred to as 3X, 7X, 18X, 24X, or other numbers followed by an X. These numbers indicate how many signals the sensor sends during one crankshaft revolution. For example, the camshaft-position sensor in a 6-cylinder engine may be an X3 sensor. One rotation of the camshaft produces six signals from the pickup. Since the camshaft turns at one-half of the engine speed, the camshaft makes one half turn for every complete crankshaft revolution. The pickup, therefore, produces three signals during one crankshaft revolution. These sensors are always referenced to crankshaft revolutions even if they are operated by the camshaft.

Light Sensors

Some sensors use light emitting and collecting devices to measure speed or position rotating parts. A typical light sensor contains three major components. Light is produced by a device called an emitter. This light is directed at a light-absorbing device called a detector. A rotating device called an interrupter periodically blocks the light beam between the emitter and detector.

Emitters can be LEDs or infrared emitting diodes (IREDs). The detector is a light-sensitive semiconductor, often called a photodiode or phototransistor. Current flows in the detector whenever the engine is running. Light striking the detector affects the amount of current flowing through the semiconductor. The ECM monitors the current flow and reads variations as an input signal. The interrupter is attached to a rotating part of the vehicle, such as the speedometer cable or camshaft. Depending on the design, the interrupter blocks the light beam in one of two ways, as shown in **Figure 7-17.**

In **Figure 7-17A,** the interrupter is equipped with small mirrors spaced at intervals on the disc. When light from the emitter strikes a mirror, it is reflected into the detector. As the disc turns, the mirror moves out of position and light is no longer reflected into the detector. This causes a change in current flow in the semiconductor. Further disc movement causes the next mirror to line up with the emitter and collector, again changing current flow.

In **Figure 7-17B,** the interrupter disc is constructed with shutter blades at intervals on its outer edge. When one of the shutter blades passes between the emitter and detector, the light beam is broken. This causes a change in current flow in the semiconductor. When the shutter blade passes, the light beam is restored and current flow changes again.

Ion Sensors

Ion sensors can be used as speed sensors, triggering devices, and misfire monitors. The main component of the ion sensor is a capacitor that sends a low voltage signal across the spark plug electrodes. This current passes across the spark plug gap without producing a spark. The plug electrodes are used as probes to determine how much carbon is present in the cylinder. Carbon is a good conductor. If the gases in a cylinder have a high carbon content, more current will flow across the plug electrodes than if the carbon content is low. The signal produced by this current flow is analyzed by the ECM to determine:

- ❑ Whether complete combustion has occurred. Unburned hydrocarbons have less resistance than exhaust gases.
- ❑ Whether spark plug knock has occurred. An explosion in the cylinder creates more unburned hydrocarbons than normal combustion.
- ❑ The position of the camshaft. In this case, a Hall-effect camshaft sensor is not used.
- ❑ If cylinder misfiring has occurred.

The main job of the ion sensor is to monitor cylinder combustion to determine whether the combustion process has occurred properly. The ion sensor is also part of a more accurate method of determining camshaft position and checking for misfires.

Throttle Position Sensors

The throttle position sensor (TPS) measures the amount of throttle opening using a variable resistor or transducer. These sensors are mounted on the outside of the throttle body.

The throttle position sensor is sent a voltage signal by the ECM. The voltage is modified by the variable resistor in the TPS. The altered voltage signal from the TPS is interpreted by the ECM as throttle position. This process is shown in **Figure 7-18.**

Some throttle position sensors are simple on-off units. These sensors usually tell the ECM that the throttle is in the idle position. Note that the idle switch is part of the throttle position sensor in **Figure 7-18.** Some throttle position sensors are adjustable.

Knock Sensors

Knock sensors contain a small crystal that reacts to pressure changes. See **Figure 7-19.** Many knock sensors modify an incoming voltage. However, some actually produce a small electric current. The crystal is sensitive to certain types of vibrations, such as those produced by engine knock. When engine knocking is creating a vibration, the crystal modifies or creates an electric current that is picked up by the ECM. The ECM interprets this signal as the engine knocking.

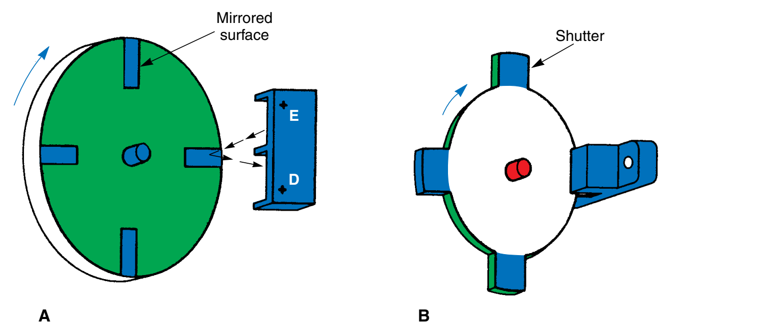


Figure 7-17. *Typical light sensor systems. The signal resulting from either system can be used as speed or position inputs to the ECM. A—Reflector module. Light from the emitter hits the mirror on the rotating disk and bounces back to the collector. B—Interrupter module. The shutter assembly blocks the light path.*

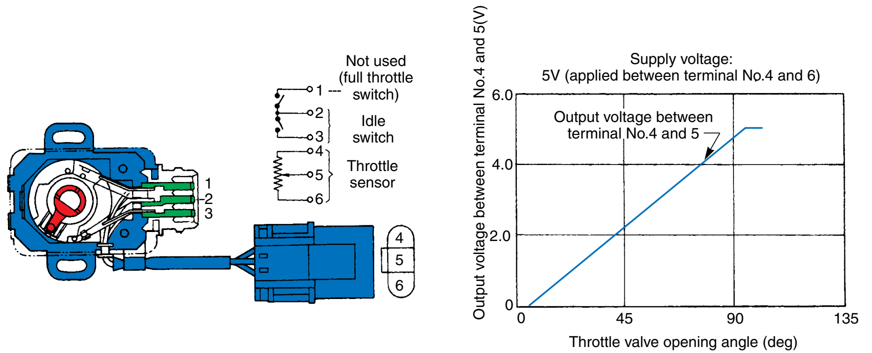


Figure 7-18. *Throttle position sensors are used to monitor the throttle position as it changes with driver input. (Subaru)*

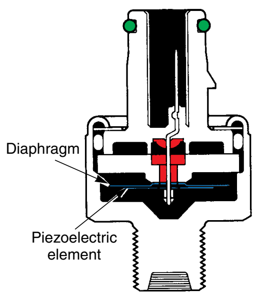


Figure 7-19. *This cutaway of a knock sensor shows the piezoelectric element. This element vibrates and creates a small current or modifies reference voltage.*

Oxygen Sensors

Using a chemical reaction to produce an electric current is a common process. This is the source of electricity in all batteries. The reaction between various chemicals produces extra electrons, which creates an electrical potential, or voltage, at the battery terminals. This same principle is used in the ***oxygen (O_2) sensor*** to measure the oxygen content in the exhaust gas, **Figure 7-20.** Many automotive computer control systems rely heavily on the oxygen sensor for much of the engine's operating information.

Oxygen Sensor Construction

The sensor is made of a material, usually zirconia, that reacts with oxygen to produce extra electrons. The zirconia element is connected to internal electrodes, usually made of platinum. The entire assembly is housed inside of a steel shell. The difference in the amount of oxygen in the exhaust gases and the outside air produces a weak electrical current, which is sent to the ECM. Variations in the oxygen content of the exhaust gases change the strength of the electrical signal. The ECM reads changes in the signal voltage as changes in the air-fuel ratio.

All OBD II–equipped vehicles use heated oxygen sensors (HO_2S). These sensors have an internal element that preheats the sensor during vehicle warm-up. This allows the computer control system to enter closed-loop operation much more quickly.

Some oxygen sensors have titania cores. These sensors modify voltage instead of producing it. This gives a titania-core O_2 sensor the ability to immediately send relevant information to the ECM, rather than having to wait for engine or sensor warm up.

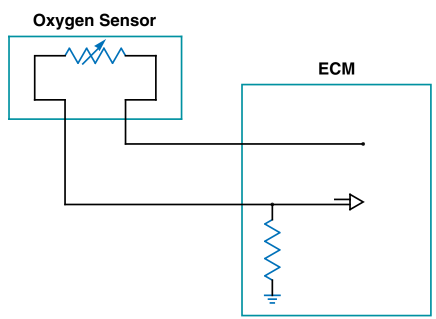


Figure 7-20. *The oxygen sensor is closely monitored by the ECM to determine engine operating condition. If this sensor is defective, it can affect the operation of the entire vehicle.*

Oxygen Sensor Location

All vehicles built after 1995 are equipped with at least two oxygen sensors. One is mounted before the catalytic converter and monitors O_2 levels in the exhaust gas as it enters the converter. The other sensor, which is referred to as a catalyst monitor, is mounted behind the catalytic converter. This sensor monitors O_2 levels of the exhaust gas as it leaves the converter. The second O_2 sensor also acts as a backup should the first one fail.

The oxygen sensor location is designated by engine bank (or side) and sensor position in relation to the engine, **Figure 7-21.** For example, the sensor might be designated as bank 2, sensor 1. This indicates it is located on the engine side opposite of the number one cylinder and is the sensor on that side nearest to the engine. The farthest sensor is always the catalyst monitor. This is usually bank 2, sensor 2 or 3, depending on the number of oxygen sensors.

A variation of the O_2 sensor is the ***NO_X sensor.*** The NO_X sensor is made of zirconia like the O_2 sensor, but is configured in a slightly different way. The platnum electrodes are molded into the element surface instead of being inside of the ceramic element. The resulting electrical signal can be measured by the ECM as NO_X concentration. In **Figure 7-21,** NO_X sensors are shown installed behind the NO_X storage-type catalytic converters.

Drive Train Sensors

Drive train sensors monitor conditions in the transmission/transaxle and other drive train components. Most drive train sensors are driver operated. A driver-operated sensor is any sensor that detects the operation of a device, system, or component commanded by the driver. These sensors are usually installed on the throttle linkage, brake pedal, shift lever, and other drive train and chassis systems.

Vehicle Speed Sensors

Most vehicle speed sensors (VSS) are mounted in the transmission/transaxle case at a point where the sensor can monitor the speed of the output shaft, **Figure 7-22.** Most vehicle speed sensors are permanent magnet generators. Other speed sensors include photoelectric sensors mounted in the speedometer housing. Unlike most sensors, speed sensors produce alternating current.

Some vehicle speed sensors are mounted on the drive wheels to allow the ECM to control wheel traction or adjust engine settings for lowest emissions. The same wheel sensors are often used as inputs to the anti-lock brake module. The operation of most vehicle speed sensors is based on the same principles as engine speed sensors.

Reed Switches

Reed switches are often used to measure speed by determining rotation. A typical reed switch is shown in **Figure 7-23.** The reed switch consists of two thin metal blades, or reeds, that contact each other inside of a closed chamber. The metal reeds can flex without breaking. A small amount of current flowing in the reeds creates a magnetic field, which attracts the reeds to each other. Any outside magnetic field, however, will cause the reeds to repel each other and move apart.

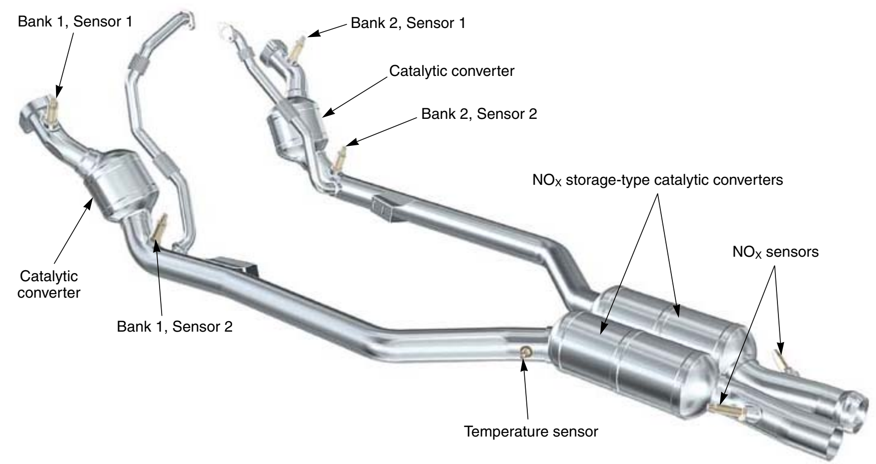


Figure 7-21. *Oxygen sensor location in the exhaust system. Bank 1 is the side of the engine that has the number one cylinder. Sensor 1 is the sensor closest to the number one cylinder. (Daimler)*

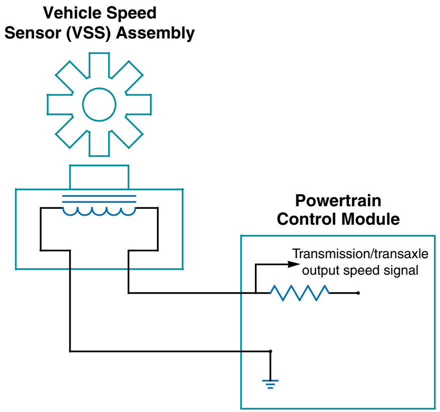


Figure 7-22. *The vehicle speed sensor (VSS) allows the ECM to monitor vehicle speed. Speed sensors are also located on each wheel or in the rear differential of many vehicles.*

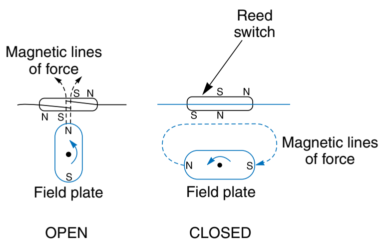


Figure 7-23. *Reed switches are magnetically operated. They are used to measure the rotating speed of a part. (Nissan)*

Reed switches are placed near a magnet attached to the moving part to be monitored. The magnet moving across the reed switch causes the two reeds to move apart and then spring back together. This starts and stops the current flowing through the switch. The variation in current can be read by the ECM. Reed switches are usually installed on the speedometer cable where it enters the speedometer head. These switches are used for cruise control as well as to provide inputs to the ECM.

Brake and Transmission Switches

Brake light and neutral safety switches are on-off switches, which are the simplest type of inputs to the ECM. The switch can be either on to allow current flow or off to prevent current flow. These switches tell the ECM whether the brake is being applied or a particular transmission/transaxle gear is selected.

Most automatic transmission/transaxle sensors are pressure switches, such as the one shown in **Figure 7-24.** Most manual transmission sensors are mechanical switches operated by the shift linkage, **Figure 7-25.** Additional switches are sometimes installed on the transfer case of four-wheel drive units.

Accessory Equipment Sensors

Accessory equipment sensors are used to monitor such conditions as pressure in the power steering system and whether the air conditioner or cruise control is on or off. This allows the ECM to adjust idle speed, spark timing, and other functions to compensate for the additional load placed on the engine.

Voltage Regulator

The alternator voltage regulator acts as a sensor. It sends an output voltage signal at a very low amperage directly to the ECM. In some cases, the ECM reads the voltage directly from the alternator output terminal to the battery. The ECM can then adjust idle speed to compensate for low- or high-voltage conditions.

Power Steering Pressure Switch

Some computer control systems have a pressure switch installed on the high-pressure hose in the power steering system, **Figure 7-26.** The switch is used to determine whether the wheels are being turned to lock. This allows the ECM to compensate by raising engine idle and deactivating the air conditioning compressor. This switch operates in the same manner as the pressure switches installed in the automatic transmission.

Figure 7-24. *Pressure switches such as this one are installed on the case or valve body of automatic transmissions/transaxles to sense internal fluid pressure. When hydraulic pressure applies a band or clutch, the fluid pressure also activates the pressure switch. This signals the ECM that a shift has taken place.*

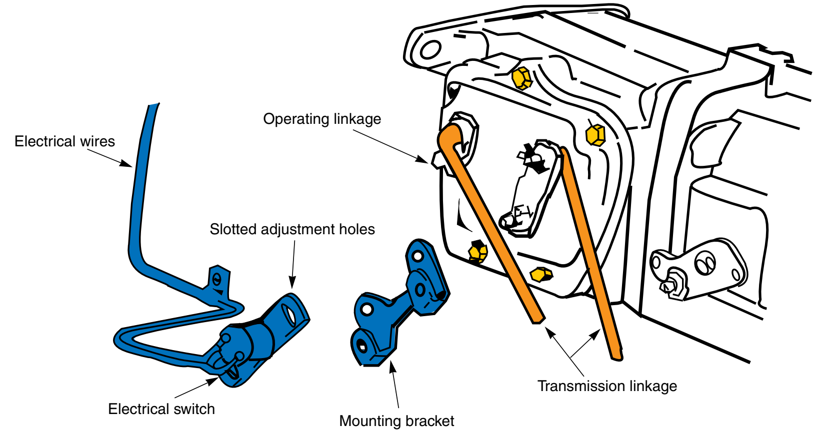


Figure 7-25. *The shift sensor on a manual transmission/transaxle allows the ECM to monitor which gear the transmission is in. The ECM uses this information to adjust engine output.*

Air Conditioning Compressor Relays and Cruise Control

The ECM receives an on-off signal from the air conditioner or cruise control from the air conditioner compressor clutch relay or cruise control module. Some driver-operated, on-off switches deliver a signal to the ECM to indicate that a device or system is functioning. An example is the air conditioner compressor relay, which energizes the compressor clutch coil. The relay and clutch are, in some cases, wired as an input connection to the ECM. When the relay energizes the compressor clutch, a low-voltage signal informs the ECM that the air conditioning compressor is on.

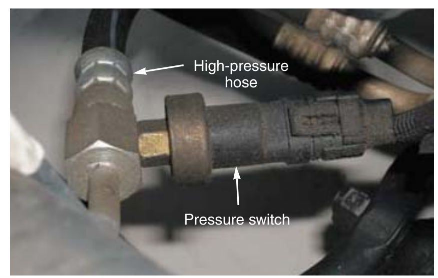


Figure 7-26. *The power steering pressure switch tells the ECM when the steering wheel is locked. The ECM can then increase engine speed to compensate for the extra load.*

Air Conditioning High- and Low-Pressure Sensors

The primary function of a high-pressure switch in an air conditioning system is to monitor system pressure and shut off the compressor if pressure becomes too high, **Figure 7-27.** The high-pressure switch allows the ECM to monitor and compensate for high pressure. Many systems also have a low-pressure sensor. This sensor notifies the

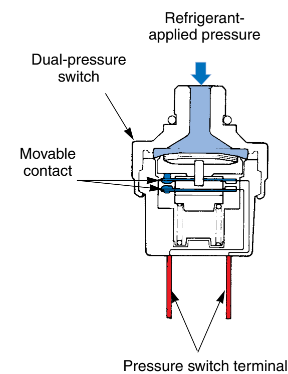


Figure 7-27. *Air conditioning pressure switches are monitored by the ECM for system operation, overpressure, and low refrigerant level.*

ECM that the air conditioning system is low on refrigerant. The ECM then deactivates the compressor clutch to prevent it from engaging.

Virtual Sensors

A ***virtual sensor*** is not a physical sensor at all, but ECM programming that calculates a vehicle operating value. This value is calculated based on input from physical sensors that monitor different engine and vehicle conditions. An example of this is the ECM program used on some early computer control systems to determine mass airflow. The program reads throttle opening, manifold vacuum, engine speed, and intake air temperature to calculate mass airflow. This eliminated the need for an actual MAF sensor. Now, virtual sensors are often used to measure conditions that would be impossible or expensive to measure with actual physical sensors. Examples include the amount of alcohol in gasoline, transmission slippage, exhaust system temperatures, and airflow through the radiator.

Output Devices

Output devices are electromechanical or electronic parts that carry out the commands of the ECM. Output devices can be solenoids, electric motors, or electronic devices. These are explained in the following sections. Output devices are discussed in more detail in later chapters.

Solenoids

The most common output devices are electric solenoids. A ***solenoid*** consists of an iron plunger surrounded by a coil of wire. When the coil is energized by passing current through it, a magnetic field is created and moves the plunger. When the coil is de-energized, a spring returns the plunger to its original position. In many cases, the solenoid plunger is attached to a flow control valve. The valve may control the flow of fuel, air, exhaust gases, or transmission fluid.

Some solenoids are pulsed on and off many times per second. Examples are fuel injectors and idle air control solenoids. Other solenoids operate less frequently, remaining on or off for seconds or minutes. Examples are the air pump switching solenoids, evaporative emissions canister solenoid, digital EGR solenoid, and torque converter control solenoid.

Idle Air Control (IAC) Solenoids

The idle air control (IAC) solenoid, or valve, allows air to bypass the throttle valve into the intake, **Figure 7-28.** The IAC valve is open as long as the throttle plate is closed. When the throttle plate opens, the ECM instructs the IAC valve to close the bypass port, since air through this port is not needed while driving. All of this happens very quickly. Due to the small size of the passages in the bypass, this valve is at times subject to sticking or clogging.

Relays

Electrical relays are also solenoids. Relays are used when an electrical component consumes more power than the ECM can safely deliver, **Figure 7-29.** In these cases, a small amount of current from the ECM energizes the relay (solenoid), closing a set of contact points. A large amount of current then flows through the points to the electrical component. Electrical components controlled by the ECM through a relay include the air conditioner clutch and radiator fan motor.

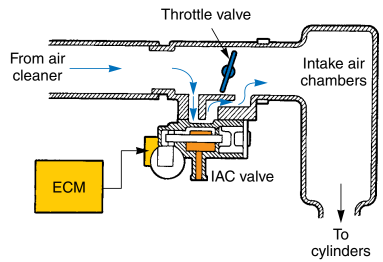


Figure 7-28. *The idle air control (IAC) solenoid allows air to bypass the throttle valve when the throttle valve is closed. When the throttle valve is opened, the valve shuts off.*

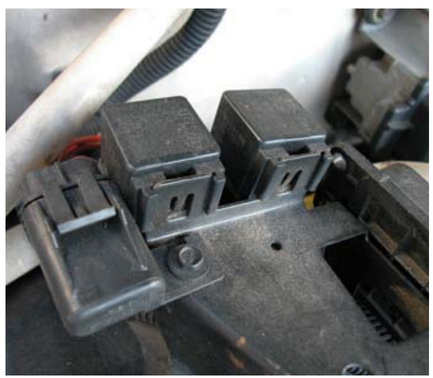


Figure 7-29. *The vehicle uses many relays to control high-amperage power. This relay controls the air conditioning compressor clutch.*

Electric Motors

Electric motors are sometimes used as output devices. These motors are usually dc motors, similar to the starter motor. Some motors are reversible and can be driven forward and backward, according to the current delivered to them. The motor for an electric cooling fan is an example of an ECM-controlled motor, **Figure 7-30.** Some vehicles use an electric motor to operate the throttle plate. There is no mechanical linkage between the accelerator pedal and the throttle plate. This type of system is known as an electronic throttle control.

Small electric motors are often attached to the throttle linkage to precisely control idle speed. They open and close the throttle through a system of gears, that allow the motor to extend or retract a plunger. These motors are often called stepper motors or servo motors. They are designed to operate through an exact amount of travel, or "step."

Electronic Output Devices

Electronic output devices can be ignition modules or other solid-state components. These devices are similar to relays, since low current from the ECM controls high current flowing in the electronic component. Many of these electronic components are input sensors as well as output devices. An example is the ignition module used on many vehicles. The module controls the timing and strength of the output from the ignition coil based on commands from the ECM. It also sends engine speed and crankshaft position signals to the ECM. See **Figure 7-31.**

X-by-Wire

X-by-wire is the term used for an electronic system that performs a job formerly done by a mechanical or hydraulic system. For example, drive-by-wire is an electronic system that moves the throttle plate, where older systems used cables and linkages. Shift-by-wire is the replacement of hydraulic transmission valves with computer-controlled solenoids. Each new generation of vehicle uses more and more X-by-wire systems.

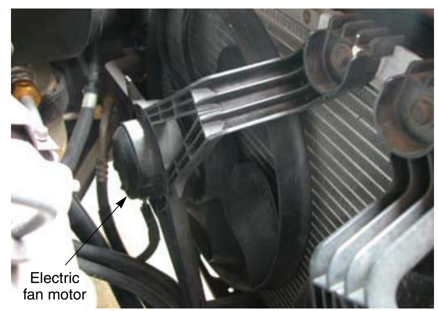


Figure 7-30. *Electric cooling fans can be controlled by the ECM. The ECM can turn the fan on and off and determine whether it runs at high or low speed.*

Electronic Throttle Control

A common and increasingly used type of X-by-wire system is electronic throttle control. This system replaces the cable or rod-and-lever linkage of earlier systems with a system of electronic devices driven by the ECM. Refer to the schematic in **Figure 7-32.** The throttle control is usually an enclosed motor that operates the throttle plate through gears, **Figure 7-33.** The electronic throttle control has a fail-safe spring that returns the throttle to idle if contact between the throttle and ECM is lost. This prevents a dangerous situation from developing should any part of the control system fail.

Control Loop Operation

A ***control loop*** can be thought of as a constantly recurring cycle of causes and effects. The purpose of a control loop is to maintain a certain condition, even when other conditions are constantly changing. Many control loops are relatively simple. An example of a simple control loop is the regulator valve that controls engine oil pressure. When oil pump output exceeds the spring setting of the pressure regulator, the spring is compressed and the valve opens. Oil escapes past the valve into the oil pan, lowering oil pressure. When pressure is lowered, the spring closes the valve. Refer to **Figure 7-34** for the oil pressure control loop. This action keeps oil pressure at the same level no matter how fast the oil pump is turning.

In the computer control system, the control loop is much more complex, but the basic principle is the same. The control loop tries to keep the air-fuel ratio as close to 14.7:1 as possible under all engine operating conditions. It does this by receiving inputs from the sensors, processing them, and issuing commands to the output devices. The control loop is from input sensors, to ECM, to output devices, to engine/system, and back to input sensors. Examples of simple loops include:

- Oxygen sensor>ECM>fuel injectors>engine>oxygen sensor
- Knock sensor>ECM>ignition module>spark plugs>engine>knock sensor
- Engine coolant temperature sensor>ECM>radiator fan>engine>engine coolant temperature sensor

The ECM combines all of these simple loops into one complex loop that considers the input from all sensors, makes decisions, and sends commands to all output devices, **Figure 7-35.** When a vehicle is first started, it operates using preset parameters in the ECM while the ECM is monitoring sensor input. This is called ***open loop.*** Once the vehicle reaches its normal operating temperature, the

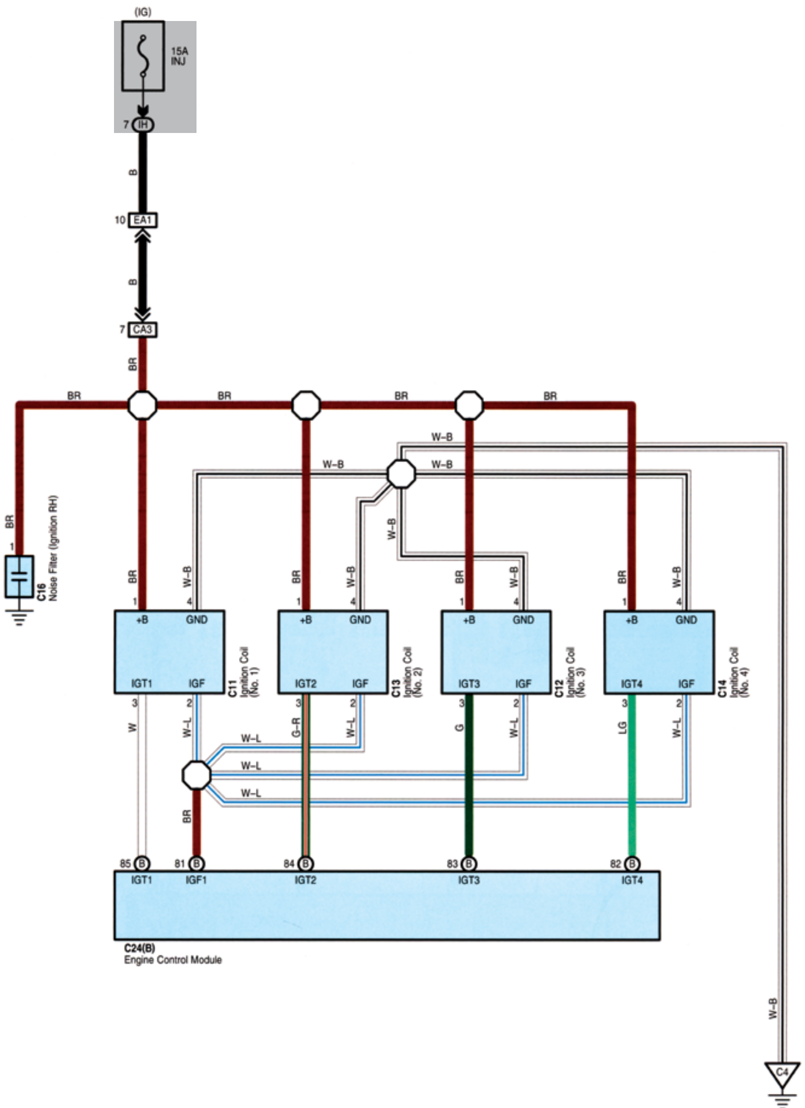


Figure 7-31. *The ignition module is one of the few automotive devices that functions both as an input sensor and an output device. More information on the ignition module is located in Chapter 8. (University of Toyota/Toyota Motor Sales USA)*

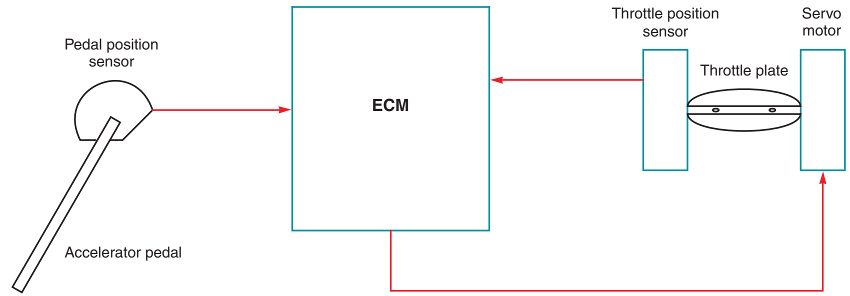


Figure 7-32. *Schematic of the electronic throttle control system. The pedal and throttle position sensors provide input to the throttle servo motor. The motor opens and closes the throttle plate as necessary.*

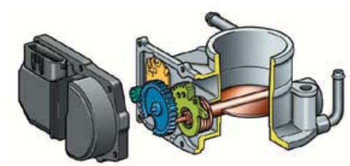


Figure 7-33. *An electronic throttle has a small electric motor that moves the throttle plate through a set of reduction gears. (University of Toyota/Toyota Motor Sales USA)*

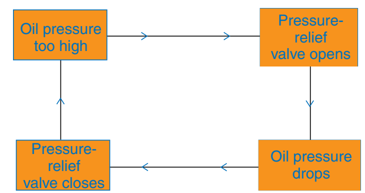


Figure 7-34. *The system that regulates oil pressure operates in a loop similar to the computer control system. Note that each function is a step in the loop leading back to the beginning.*

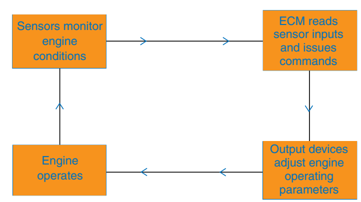


Figure 7-35. *Computer control loop. This is the order of operation during closed loop. Compare this to the one shown in Figure 7-1.*

system enters closed loop, provided there are no problems with any sensor, output device, the engine, or the ECM. During ***closed loop,*** the ECM monitors all sensors for changes and adjust systems to maintain operation within set parameters. Of particular importance is the oxygen sensor. The ECM adjusts air-fuel ratio based on oxygen sensor input.

Data Link Connector

To access the ECM memory, the scan tool's ***data link connector*** is plugged into the ECM diagnostic connector, **Figure 7-36.** Most scan tools display the trouble codes as numbers and save them for easy recall. This makes it easier to perform testing based on one or more trouble codes. Scan tools are able to perform other diagnostic tasks by sending a series of commands to the ECM and output devices and monitoring the resulting system operation. Many scan tools can read voltage levels to and from input sensors to determine whether the sensor is operating properly. Some scan tools have a freeze frame mode, which can take a "snapshot" of sensor and output device readings when a malfunction occurs.

Note: Older systems have provisions for retrieving trouble codes without a scan tool, either by flashing a light in the vehicle dashboard or on the ECM or by producing pulses that can be read on a multimeter.

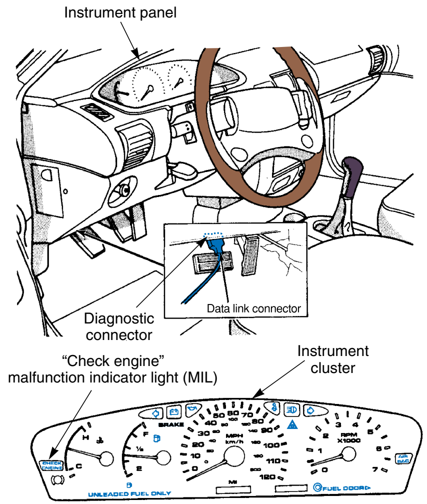


Figure 7-36. *OBD II data link connectors are located within easy access of the driver's seat. (Chrysler)*

On-Board Diagnostics Generation One (OBD I)

Some form of on-board diagnostics has always been used in computer-controlled vehicles. These early self-diagnostic systems are sometimes referred to as ***on-board diagnostics generation one (OBD I).*** The self-diagnostic system not only checks the ECM for proper operation, but monitors the sensors and output devices to ensure that there are no problems. If a sensor or device becomes defective, is disconnected, or provides readings that are out-of-range due to a non-computer-related problem, the ECM stores a ***diagnostic trouble code (DTC).*** On most OBD I systems, this code is a two or three digit number that corresponds to a certain malfunction condition. The ECM illuminates the dash-mounted malfunction indicator light (MIL) when a code is present.

On-Board Diagnostics Generation Two (OBD II)

All 1996 and newer vehicles sold in the United States are equipped with OBD II. ***On-board diagnostics generation two (OBD II)*** not only detects sensor malfunctions and driveability problems when they occur, but also detects potential problems before they affect emissions or even become noticeable to the driver.

Some manufacturers may use other names for their version of the OBD II system. Basic operating principles are the same for all systems, no matter what they are called. OBD II is the term used by the Society of Automotive Engineers (SAE) for enhanced diagnostics systems. This textbook refers to all such systems as OBD II.

Vehicles equipped with OBD II are similar in many ways to other vehicles with older diagnostic systems. However, several additional parameters must be met:

- Redundant sensors for each monitored system. For example, many OBD II vehicles use both a MAF sensor and a MAP sensor.
- Most OBD II vehicles have multiple, heated oxygen sensors before the converter.
- All OBD II vehicles have a heated oxygen sensor after the converter (catalyst monitor).
- Most EGR valves are electronically operated and equipped with a pintle position sensor.
- Sequential multiport fuel injection is used on almost all engines.
- Evaporative emissions systems are equipped with diagnostic switches for purge monitoring. More advanced systems include test fittings, vent solenoids, and a fuel tank–pressure sensor.
- All OBD II equipped vehicles must monitor the air conditioning system for low refrigerant levels, which indicates a leak.

Some service literature for OBD II vehicles has an emblem to indicate the vehicle is equipped with OBD II. The emblem can be found on schematic pages and other charts.

OBD II ECM

The ECM in an OBD II system uses Class 2 data communication. In this communication, data are transmitted at a variable rate of 10.4 to 41.6 kilobits per second (kbps). The ECM in an OBD II system also runs monitors. ***Monitors*** are self checks of various internal and external systems and components. The ECM runs monitors under various engine and atmospheric conditions. In some climates or under some operating conditions, the ECM may not run a particular monitor. If the monitoring process detects a problem, the ECM sets a trouble code.

OBD II PROMs

The OBD II protocol mandates that all PROMs be permanently affixed to the ECM. One of the reasons for this is to prevent installation of aftermarket "hot PROMs." These are designed to enhance a computer-controlled vehicle's performance, which often increases exhaust emissions. Most newer ECMs use EEPROMs or FEPROMs that are write-protected and can only be reprogrammed using special equipment.

OBD II ECM Diagnostic Testing

The ECM in an OBD II system performs diagnostic tests on various systems during operation. The ECM monitors all system components during normal operation. This is called ***passive testing.*** In addition, the ECM in an OBD II system can perform ***active testing.*** In an active test, the ECM orders a particular system or component to perform a specific function while the ECM monitors performance. An active test is usually performed in the event a component or system fails a passive test, such as returning an out-of-range reading. The third test is called an intrusive test. ***Intrusive testing*** is a type of active test that can affect vehicle performance or emissions. Many active and intrusive tests can be performed by the technician using a scan tool.

Trouble Codes

OBD II systems use a five-digit, alphanumeric trouble code, **Figure 7-37.** There are two general categories of trouble codes. The first category consists of codes assigned by the Society of Automotive Engineers. A comprehensive list of these codes is located in Appendix B of this text. The second category consists of manufacturer-specific codes. These codes are exclusive to a manufacturer's particular vehicle control system. Look in the appropriate service manual for these codes. Within these two general categories, there are four levels of diagnostic trouble codes:

- Type A codes are emissions related and will illuminate the malfunction indicator light. In the case of misfire or fuel trim DTCs, the ECM will flash the malfunction indicator light whenever driving conditions cause this code to be set in memory.
- Type B codes are also emissions related. However, the ECM will illuminate the malfunction indicator light only when this type of code appears on two consecutive warm-ups.
- Type C codes are not emissions related. They will not illuminate the malfunction indicator light; however, they will store a DTC and illuminate a service lamp or, on a vehicle equipped with a driver's information center, the service message.
- Type D codes are also not emissions related. They will store a DTC, but will not illuminate any malfunction indicator lights.

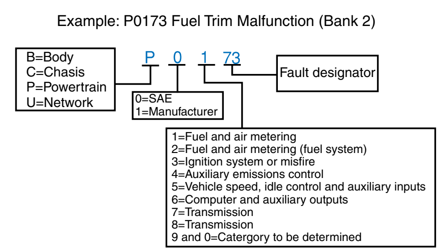


Figure 7-37. *OBD II codes are a series of five digit letters and numbers. The letter and first number is called the alphanumeric discriminator. The second number indicates the nature of the code. The last two numbers compose the fault designator and indicates which sensor or circuit is at fault and the type of problem.*

Malfunction Indicator Light

If a DTC is present, the vehicle's ***malfunction indicator light (MIL)*** will illuminate to notify the driver that there is a problem. This light is usually amber colored and may also be called the service engine soon, check engine, power loss, sensor, or PGM-FI light.

This light may show MIL or the silhouette of an engine when illuminated. The light will illuminate when a component becomes defective, as on OBD I systems, but also when the proper air fuel ratio is not being maintained or when another output is not within specifications. The light can illuminate in one of two ways: on steady or flashing.

MIL On Steady

If the OBD II system detects a problem that does not have the potential to damage the catalytic converter, the MIL will steadily illuminate. This indicates that the system should be checked as soon as possible. While the vehicle is driveable, prolonged operation with the MIL on could cause damage to the converter or other vehicle emission controls, as well as reduce fuel economy and driveability. The MIL will not immediately turn off if the problem corrects itself. OBD II systems require at least three trip sequences (start, warm-up, and stop) before the MIL will turn off after a problem corrects itself.

MIL Flashing

A flashing MIL means that an ongoing engine misfire or other serious problem has occurred. Under severe misfire conditions, the computer may shut off the fuel injector and spark to a misfiring cylinder to protect the catalytic converter. The driver may notice a loss of power. In many cases, the light will stop flashing when the vehicle is restarted or the condition is no longer present. Even if the light does stop flashing, it will often remain illuminated. In any case, the vehicle should be brought to a service facility for diagnosis and repair as soon as possible. Some manufacturers recommend that a vehicle with a flashing MIL not be driven, but be towed to the nearest service facility.

In some cases, the MIL will flash because of an extremely low fuel level allowing air to enter the injection system, a missing fuel filler cap, or excess fuel entering the evaporative control system during refueling. In these cases, the problem is temporary and the OBD II system will cease flashing the MIL after a period of engine operation. However, if there is any doubt as to the cause of the flashing MIL, the vehicle should be checked.

Data Link Connector Location and Design

The OBD II protocol requires manufacturers to place the data link connector in a location where it is out of visual sight, but is easily accessible from the driver's seat. The protocol also requires the use of a standardized, 16-pin data link connector, **Figure 7-38.** The standardized data link connector and codes allows the use of a generic scan tool to read and clear the trouble codes on all vehicles.

Note: Some OBD I equipped vehicles use the 16-pin data link connector. However, these vehicles are not ODB II compliant.

Failure Types

Unlike OBD I systems, OBD II systems can determine the type of problem in a circuit. These failure codes fall into one of four categories:

- General-circuit failure.
- Low-input failure.
- High-input failure.
- Range/performance failure.

A ***general-circuit failure*** is caused by disconnected or damaged wires and connectors, grounds and shorts, or a component that is constantly operating out of range. This type of circuit failure is often the easiest to locate, since in almost all cases it sets a code.

A ***low-input failure*** is set when the ECM receives a weak or abnormally low voltage, current, or operational signal. This failure is caused by high resistance, poor electrical connection, or a contaminated or defective sensor.

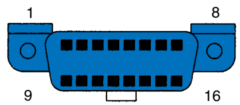
A ***high-input failure*** is caused by a sensor failure or mechanical fault. This type of signal supplies the ECM with excess voltage or current. A false signal may also be transmitted to the ECM.

A ***range/performance failure*** occurs when a sensor is reading slightly lower or higher than normal. This can be due to a contaminated sensor, sensor wear, or poor electrical connections.

Freeze Frame and Failure Record

When a type A or B trouble code is set in the ECM memory, certain vehicle operations at the time the code is set are stored in memory. This information is commonly referred to as the ***freeze frame record.*** Most ECMs store the failure information for only one code that sets a DTC and illuminates the MIL. For example, if a second type B DTC occurs, this information is not updated. However, if a type A fuel trim or misfire DTC occurs, it overwrites the freeze frame information stored for the type B DTC.

Some ECMs have a ***failure record*** that can be accessed in the case of multiple DTCs. It is updated whenever a code is set. ECMs can store several failure records. A failure record



Terminal	General Description
1	Manufacturer's Discretion
2	J1850 Bus + Line*
3	Manufacturer's Discretion
4	Chassis Ground
5	Signal Ground
6	Manufacturer's Discretion
7	ISO 9141 K Line*
8	Manufacturer's Discretion
9	Manufacturer's Discretion
10	J1850 Bus-Line*
11	Manufacturer's Discretion
12	Manufacturer's Discretion
13	Manufacturer's Discretion
14	Manufacturer's Discretion
15	ISO 9141 K Line*
16	Battery Positive Voltage

*Pins 2, 7, 10, and 15 are used for external communications. On some vehicles, these pins may have alternate assignments.

Figure 7-38. *Sixteen-pin data link connector. This connector is used on all OBD II vehicles. Manufacturers usually install sensor leads for other ECMs to the terminals assigned "manufacturer's discretion." Terminals 2, 4, 5, 7, 10, 15, and 16 are assigned by SAE and cannot be changed. (Chrysler)*

is stored anytime a type B, C, or D code is set. Type A codes are not stored in the failure record as the information for these codes is stored in the freeze frame record.

Summary

The most important advance in the areas of driveability, fuel economy, and performance is the development of the on-board computer to control the fuel and ignition systems. These systems are composed of electrical, electronic, and mechanical devices that control engine operation. On-board computers also control parts of the emission control system, drive train, and accessory equipment such as the air conditioner. Most vehicles have several computers, connected by a bus or a controller area network.

The basic components of the computer control system are the computer (ECM), inputs, and outputs. The computer receives electrical inputs, decide on the actions to be taken, and provides instructions to output devices.

There are two kinds of memory in the computer: fixed and volatile. The fixed memory circuits are installed at the factory and cannot be changed. The volatile memory is

able to receive and store information from the sensors. The volatile memory also stores information about malfunctions in the form of diagnostic trouble codes (DTCs).

Inputs to the ECM can be generated from switches, resistance units, magnetic fields, chemical-reaction sensors, pressure-sensitive materials, light-emitting and light-collecting devices, and transducers. Input sensors and switches monitor conditions in the engine and drive train, outside atmospheric conditions, and direct or indirect driver inputs.

Engine sensors are installed on the engine and measure the actual conditions in the engine, such as temperature, engine speed, crankshaft position, manifold vacuum, intake airflow, exhaust gas oxygen, and engine knock. Other engine sensors may be used to measure the temperature of the incoming air, camshaft position, or exhaust gas temperature.

Drive train sensors monitor conditions in the transmission/transaxle and other drive train components. Accessory equipment sensors are used to monitor such conditions as alternator output voltage, whether the air conditioner or cruise control is on or off, and whether the wheels are being turned. Atmospheric sensors measure conditions outside of the vehicle, such as air temperature, barometric pressure, and sometimes humidity. Driver-operated sensors are installed on the throttle linkage, brake pedal, and shift lever. Virtual sensors determine vehicle conditions by monitoring inputs from two or more sensors dedicated to other purposes.

The ECM receives inputs from the input devices, processes these inputs, and sends commands to the output devices. Output devices are those electromechanical or electronic parts that carry out the commands of the ECM. They cause changes in engine operation. Output devices can be solenoids, electric motors, or electronic devices. Functions that were formerly performed by mechanical or hydraulic systems are called X-by-wire systems.

The first computer control systems were known as on-board diagnostics generation one (OBD I). The current generation, OBD II, is a more sophisticated system that can more closely monitor engine conditions and tell when a part or system is deteriorating before it actually fails. The shape and location of the OBD II diagnostic connector is standardized, as are the diagnostic trouble codes set by the system.

Review Questions—Chapter 7

Please do not write in this text. Write your answers on a separate sheet of paper.

1. Electronic engine control systems are composed of ______, ______, and ________ devices that control engine operation.
2. All information processing in an ECM is a(n) _____ operation.
3. List the four main circuits in an ECM.
4. In many sensors:
   (A) a reference voltage from the ECM is passed through a resistor unit in the sensor.
   (B) a voltage is modified as the resistance of the sensor varies with conditions.
   (C) varying voltage from the sensor is passed to the ECM as an input signal.
   (D) All of the above.
5. A 7X speed sensor sends seven signals to the ECM when the crankshaft rotates _____ time(s).
6. A knock sensor produces an electric current in response to a change in:
   (A) temperature.
   (B) speed.
   (C) pressure.
   (D) Both A & C.
7. An oxygen sensor uses a(n) ______ reaction to produce a voltage.
8. Describe a *virtual sensor.*
9. The most common output devices are electric solenoids. Solenoids:
   (A) consist of an iron plunger surrounded by a coil of wire.
   (B) are energized by passing voltage through them, creating a magnetic field that moves a plunger.
   (C) may control the flow of fuel, air, exhaust gases, or transmission fluid.
   (D) Both A & C.
10. ______ is the term used for an electronic system that performs a job formerly done by a mechanical or hydraulic system.
11. A(n) _____ can be thought of as a constantly recurring cycle of causes and effects, the purpose of which is to maintain a certain condition, even when other conditions are constantly changing.

12. When a vehicle is first started, it is in _____ and operates using preset parameters in the ECM. During _____, the ECM monitors all sensors for changes and adjust systems to maintain operation within set parameters.
    (A) closed circuit; open circuit
    (B) closed loop; open loop
    (C) open loop; closed loop
    (D) open circuit; closed circuit
13. OBD II is an acronym for _____.
14. OBD II can:
    (A) correct sensor malfunctions and driveability problems when they occur.
    (B) detect potential problems before they affect emissions.
    (C) Both A & B.
    (D) None of the above.
15. OBD II systems can determine the type of problem in a circuit. List the four types of problems.

ASE Certification-Type Questions

1. Technician A says that volatile ECM memory is called EEPROM. Technician B says that volatile ECM memory is called FEPROM. Who is correct?
    (A) A only.
    (B) B only.
    (C) Both A & B.
    (D) Neither A nor B.
2. All of the following terms are associated with KAM, *except:*
    (A) keep alive.
    (B) programmable read only.
    (C) nonvolatile RAM.
    (D) adaptive strategy.
3. Technician A says using a scan tool is the easiest means of retrieving trouble codes. Technician B says the OBD II system can only be accessed by using a scan tool. Who is correct?
    (A) A only.
    (B) B only.
    (C) Both A & B.
    (D) Neither A nor B.
4. In many sensors, a reference voltage is passed through a ______ to produce a final voltage reading.
    (A) diode
    (B) resistance unit
    (C) capacitance unit
    (D) PROM
5. All of the following are types of airflow sensors, *except:*
    (A) capacitor discharge.
    (B) heated wire.
    (C) air valve.
    (D) Karman vortex.
6. The ECM reads engine ______ to decide whether to place the system in closed or open loop.
    (A) speed
    (B) oil pressure
    (C) temperature
    (D) airflow
7. All of the following statements about computer control systems are true, *except:*
    (A) A Class A bus can carry data only at Class A speeds.
    (B) One computer directly performs all vehicle electronic tasks.
    (C) A Class C bus is faster than a Class B bus, which is faster than a Class A bus.
    (D) A CAN assigns a priority to each bit of information passing over it.
8. Technician A says that a flashing MIL may be caused by a low fuel level. Technician B says that a flashing MIL may be caused by a defect in the starting system. Who is correct?
    (A) A only.
    (B) B only.
    (C) Both A & B.
    (D) Neither A nor B.
9. An example of an electronic output device is the ______.
    (A) ECM
    (B) ignition module
    (C) coolant temperature sensor
    (D) transmission pressure switch
10. Technician A says that many ECM-related electronic components are input sensors. Technician B says that many ECM-related electronic components are output devices. Who is correct?
    (A) A only.
    (B) B only.
    (C) Both A & B.
    (D) Neither A nor B.