 *By Greg Vrana, Technical Editor*


**The AutoXray EZ-Link OBD II scanner is compatible with all 1996 and later US, European, and Asian OBD II-compatible vehicles.**

# Analytic technology: DIAGNOSE WHAT AILS YOUR AUTO

**AUTOMOTIVE ONBOARD DIAGNOSTICS HELPS YOUR ENGINE PERFORM AT PEAK EFFICIENCY, REDUCES EMISSIONS, AND EVEN HELPS YOU FIX YOUR CAR. PLUS IT GIVES YOU AN EXCUSE TO BUY A NEW TOY.**



SINCE THE EARLY 1980S, car manufacturers have used a computer-based PCM (power-train-control module) to control the fuel and ignition system in your car. Tightened emissions standards have forced car makers to put sophisticated pollution-control systems under the PCM's supervision as well. As the PCM system grew in complexity, engineers added onboard diagnostics to help technicians troubleshoot malfunctioning engines. Today, onboard computers play such an important role in reducing vehicle emissions that, since the 1994 model year, the US EPA (Environmental Protection Agency) has established requirements for OBD (onboard-diagnostic) systems. The latest system, OBD II, has been standard equipment on US light-duty cars and trucks since the 1996 model year.

If you think of your car's engine as a device that converts gasoline chemical energy into mechanical energy, then you might believe that the engine that powered your car to work today and the engine that went into the first car Henry Ford built in 1903 are almost the same. In the eyes of the EPA, however, the engines differ significantly. For example, the hydrocarbon emissions of a subcompact car built in 1988 are less than one-thirtieth of a 1921 Ford Model T (**Reference 1**). This statistic is even more impressive when you consider that the subcompact has four times the horsepower and nearly twice the gas mileage, and it weighs 300 lbs more than the Model T. As the EPA's emissions regulations become more stringent, car makers continue to turn to more sophisticated software running on more powerful microprocessors to monitor and control your car's performance.

The two biggest sources of pollution from your car are the fuel system and the exhaust. In an ideal world, your car's engine would burn gasoline with oxygen from the air to create heat, carbon dioxide, and water. Unfortunately, the combustion process also releases unburned hydrocarbons, nitrogen-oxide gases, and carbon monoxide. The good news is that today's engines and fuel mixtures are so effective that most hydrocarbon emissions are a product of evaporative losses, which come from the car's fuel tank and when you refuel your car.

EPA OBD II guidelines require car manufacturers to monitor all emissions-related systems in your car. These systems may include the car's air conditioner, catalytic converter, evaporative-emissions-control system, EGR (exhaust-gas-recirculation) system, fuel-delivery system, heated-oxygen sensor, and secondary-air-injection system (**Reference 2**). OBD

II also requires the detection of engine misfires, which can damage the catalytic converter. Every time you take a trip, the OBD system tests your car's emissions systems to make sure the car is not polluting beyond acceptable limits. The EPA FTP (Federal Test Procedure) sets allowable emissions levels for light-duty cars and trucks. If the OBD II system detects an emissions component that has failed or has deteriorated to the point at which the vehicle's emissions may rise to more than 1.5 times the FTP standard, the PCM must illuminate the malfunction-indicator lamp. In some cars, this indicator is called the Check Engine or Service Engine Soon light. When the malfunction-indicator lamp is on, the PCM also stores a DTC (diagnostic trouble code) in memory along with the operating conditions at the time of the failure in a "freeze frame." When a sensor malfunctions and no longer sends valid information, the PCM substitutes default values for the faulty sensor's signal so you can still drive your car and seek repairs.

Your car comes equipped with onboard-refueling-vapor-recovery and evaporative-emissions-control systems to minimize hydrocarbon emissions from your fuel tank. The onboard-refueling-vapor-recovery system prevents hydrocarbon vapors from escaping into the atmosphere when you refuel your car by trapping the vapors in an evaporative emissions canister. The canister is filled with activated carbon, which stores hydrocarbon vapors for the evaporative-emissions-control system until the PCM purges the vapors to the engine for burning. The PCM must perform several tests on the evaporative-emissions-control system. One test must check for leaks as small as 0.020 in. in diameter in the fuel system. The PCM begins this "small-leak" test by closing the valve to the vapor canister and drawing a small vacuum in the fuel tank. If the PCM fails to detect a vacuum, a large system leak is likely. One possible cause of a large leak may simply be a missing gas cap. Once the PCM verifies that the proper vacuum level exists, it waits a certain amount of time and measures the vacuum again. If the PCM records an insufficient vacuum, it stores a DTC and lights the malfunction-indicator lamp. Measuring differences in vacuum levels to detect small leaks requires the PCM to measure precisely how

### AT A GLANCE

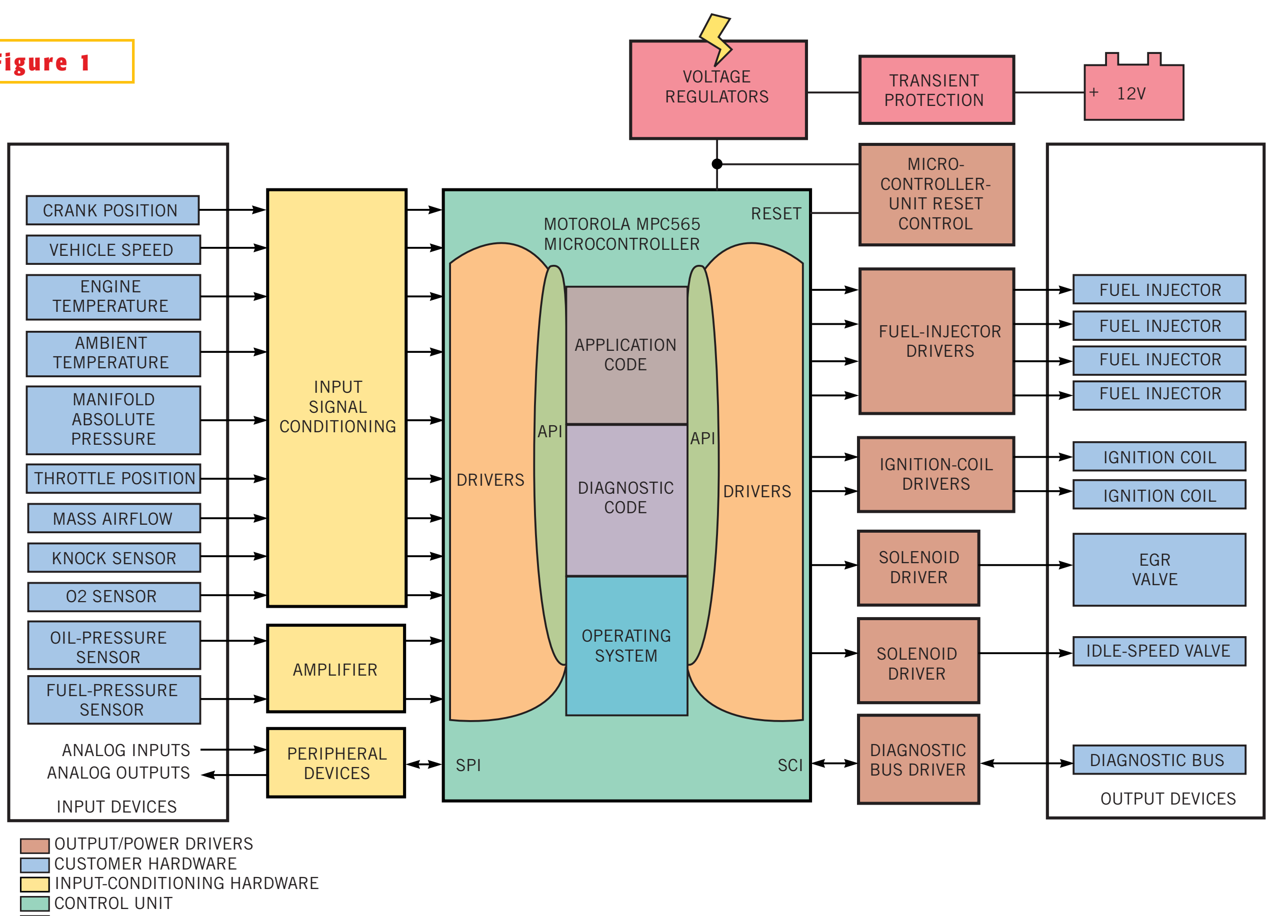
▷ Since the early 1980s, car manufacturers have used microprocessor-based power-train-control modules to control fuel and emissions systems in your car.

▷ The EPA dictates minimum requirements for onboard-diagnostic systems. All 1996 model year and later US light-duty cars and trucks come with OBD II systems.

▷ An OBD II-equipped car limits air emissions by warning you when your car's emissions systems fail.

▷ In the future, an OBD III system may transmit your car's emissions status to a state regulatory agency without your knowledge.

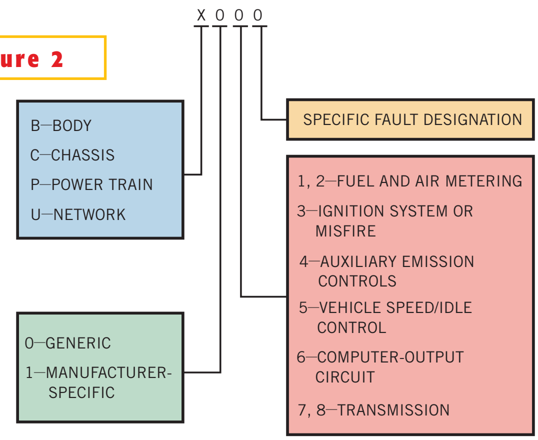
Figure 1




**The Motorola MPC565 microcontroller is designed for automotive-engine-control applications.**

much air is in the fuel tank. Today, car makers use very accurate fuel gauges to determine the amount of fuel and, therefore, air in the fuel system.

Figure 2




**The OBD II DTC comprises four fields designating the type of code and which system or component has malfunctioned.**

The manifold-absolute-pressure sensor in your car measures pressure changes in the intake manifold, which are due to changes in engine load and speed. The heavier the load, the higher the pressure. The PCM also uses the pressure sensor to measure barometric pressure and changes in EGR flow. The PCM places 5V across the sensor and measures the voltage drop across it. Changes in pressure cause the manifold-absolute-pressure sensor's resistance to change, and the PCM detects changes in pressure as a varying voltage. As with most other sensor diagnostics, the PCM checks the pressure sensor for out-of-range readings. The PCM also compares the pressure sensor's output with expected values that the PCM calculates from the throttle position and engine-load factors. Large discrepancies between calculated values and the pressure sensor's values indicate the sensor has deteriorated and needs repair.

The adjustment that the PCM makes to create an optimum air-to-fuel ratio of 14.7-to-1 is "fuel trim." Inputs to the fuel-delivery system include readings from the oxygen sensors in the exhaust system. If the PCM detects a lean combustion, it computes an appropriate positive fuel-trim value to cause the fuel mixture to become rich. A rich combustion results in a negative fuel-trim-adjustment value. Fuel-trim values of −10 to +10% indicate a properly functioning fuel system. The PCM keeps a history of average long- and short-term fuel-trim adjustments. The PCM uses these average fuel-trim adjustments along with the engine load and revolutions per minute to calculate whether the fuel-delivery system has deteriorated beyond FTP standards. If the PCM detects a malfunction, it stores the appropriate DTC and illuminates the malfunction-indicator light.

Recirculating exhaust gases back into the engine's cylinders is one of the most effective emissions-reducing strategies your car uses. By introducing relatively inert exhaust gases into the fuel/air mix, the EGR system reduces the temperature of combustion in the cylinder. The reduced temperature in turn reduces the production of nitrogen-oxide gas. The PCM diagnoses the EGR system by detecting out-of-range values from the system's components. The PCM also collects manifold-absolute-pressure data when the EGR valve changes position to determine how well the EGR system is performing.

### READY, AIM, MISFIRE

The catalytic converter is one of the most expensive emissions-reducing components on your car, and misfires are its worst enemy. A misfire is a result of incomplete combustion, and one cause may be a defective spark plug. Misfires send unburned hydrocarbon gases into the exhaust and into the atmosphere. But the unburned fuel also travels through the catalytic converter and may permanently damage it. For this reason, automotive engineers spend a lot of time designing ways to detect misfires. The most common approach takes advantage of the fact that each cylinder contributes to the rotational velocity of the crankshaft. If a cylinder misfires, the crankshaft velocity decreases momentarily until the next cylinder in the firing order takes over. The PCM uses a sensor on the crankshaft to compute the rotational speed and another sensor on the camshaft to determine which cylinder misfired.

Most misfire-detection systems are low-data-rate systems. Low-data-rate systems meet FTP monitoring requirements on most of today's engines and "full-range" misfire monitoring requirements on four-cylinder engines. Currently, regulations require misfire detection at 0 to 55 mph. Full-range misfire detection extends to full throttle. OBD II regulations from the 2002 model year will require full-range misfire monitoring on most six- and eight-cylinder engines. To meet the new requirements, engineers use high-data-rate misfire monitoring systems with 18 position references per engine revolution as opposed to just one in low-data-rate systems. The greater resolution allows the PCM to use more sophisticated algorithms for detecting misfires. One algorithm

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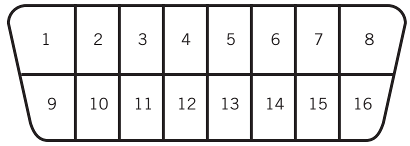
"learns" the normal pattern of cylinder accelerations. From this normal pattern, the PCM can detect deviations or misfires from the positional data. Another algorithm detects a continuously misfiring cylinder by filtering out "noise" in data in the form of crankshaft torsional vibration.

The PCM counts the number of misfires over continuous 200- and 1000-revolution periods. The PCM then computes the total misfire rate and the misfire rate of each cylinder at the end of the evaluation period. The algorithm compares the misfire data against thresholds in an engine load/speed table. The threshold values protect the catalytic converter from excessive temperatures. The PCM flashes the malfunction-indicator lamp once per second while a catalytic-converter-damaging condition exists. If one cylinder consistently misfires, the PCM may shut off that cylinder's fuel injector to prevent damage to the converter (**Reference 3**). Another algorithm uses the 1000-revolution misfire count to determine whether the engine's emissions exceed FTP standards.

The PCM also must guard against detecting "false" misfires. Driving on rough roads can apply torque to the drive wheels and drive train, which can decrease engine speed. These momentary fluctuations in crankshaft velocity may fool the PCM into thinking that a misfire occurred. The misfire software applies additional analyses to crankshaft positional data to detect rough terrain and may turn off misfire detection until your car is on a smoother surface. On cars with automatic transmissions, the PCM may disengage the torque-converter clutch to isolate the engine from the drive wheels. Some cars use the wheel-speed sensors in the antilock-braking system to detect rough driving conditions, so that they know whether to disable misfire detection.




**JAE 1962 PIN ASSIGNMENTS**

| Pin | Description |
|---|---|
| 1 | Discretionary[1] |
| 2 | Bus+line (SAE J1850) |
| 3 | Discretionary[1] |
| 4 | Chassis ground |
| 5 | Signal ground |
| 6 | CAN high (SAE J2284)[2] |
| 7 | K line (ISO 9141-2 and ISO/DIS 14230-4) |
| 8 | Discretionary[1] |
| 9 | Discretionary[1] |
| 10 | Bus – line (SAE J1850) |
| 11 | Discretionary[1] |
| 12 | Discretionary[1] |
| 13 | Discretionary[1] |
| 14 | Can low (SAE J2284)[2] |
| 15 | L line (ISO 9141-2 and ISO/DIS 14230-4) |
| 16 | Unswitched vehicle battery positive |

Notes:
1. Assignments of pins 1, 3, 8 to 9, and 11 to 13 are left to the vehicle manufacturer's discretion.
2. If pins 6 and 14 are not used for SAE J2284, their assignment is discretionary.

**Figure 3** The J1962 diagnostic connector allows you to download DTCs into an OBD scanner.

## SNIFFING FOR OXYGEN

Oxygen sensors in your car's exhaust system provide valuable information to the OBD II system. A heated-oxygen sensor is the most common oxygen sensor in use today. Heated sensors provide data sooner to the emissions-feedback system and, therefore, help reduce pollution. Most cars have a heated-oxygen sensor ahead of (precatalyst) and behind (postcatalyst) the catalytic converter. By measuring the amount of oxygen in the precatalyst and postcatalyst exhaust streams, the PCM can evaluate the converter's efficiency.

Catalytic converters use precious metals, such as platinum, palladium, and rhodium, to take up excess oxygen in lean exhaust and release oxygen in rich exhaust. This ability allows the converter to transform the by-products of incomplete combustion—hydrocarbon and carbon-monoxide gases—into water vapor and carbon dioxide. By taking up oxygen, the converter reduces nitrogen-oxide gases into nitrogen and oxygen.

Catalytic converters generally do not wear out. Instead, poor engine performance, excessive fuel or oil consumption, and impurities in the fuel impair the converter's efficiency until it no longer does its job. To determine your converter's efficiency, the PCM compares the postcatalyst oxygen readings with the precatalyst sensor's readings. If the catalytic converter is damaged, the postcatalyst oxygen sensor's readings track closely with the precatalyst's oxygen readings. Similar readings mean that the oxygen content of the exhaust entering and exiting the converter is about the same. A good catalytic converter takes up and releases the oxygen in the exhaust so that the post-converter oxygen sensor should detect relatively little change in the oxygen content of the exhaust.

To test the heated-oxygen sensors, the OBD II system monitors the response rate of the precatalyst sensor as the PCM varies the fuel trim from rich to lean and lean to rich. The precatalyst sensor should follow the rich/lean profile of the exhaust. The PCM may detect a false catalytic-converter malfunction if a leak allows oxygen into the exhaust system. An after-market converter can also cause the PCM to think a malfunction exists if the replacement converter performs differently from the original.

The secondary air-injection system uses an electric blower to force fresh air into the exhaust system. The extra oxygen in the exhaust promotes the oxidation of the unburned hydrocarbons and carbon monoxide. The PCM diagnoses the secondary-air-injection system by checking for airflow in the exhaust and for an appropriate lean reading from the precatalyst oxygen sensor.

A typical engine-control system uses a special-purpose microcontroller, such as the Motorola MPC565 (**Figure 1**). The MPC565 is a 32-bit RISC processor with a floating-point unit, three time-processor units, one J1850, and three controller-area-network interfaces. The microcontroller also has a 36-kbyte SRAM, a 10-kbyte dual-port time-processor unit RAM, a 4-kbyte decompression RAM, and as much as 1 Mbyte of on-chip flash memory. The MPC565 can run at 56 MHz, which may seem unimpressive until you consider that the part operates over –40 to +125°C. As OBD requirements grow, PCMs will need more memory and processing power. Today, a typical engine controller devotes 40% of its memory to running OBD II diagnostics.

## OFF-BOARD DIAGNOSTICS

Monitoring and diagnosing the emissions-control systems in your car is only part of the PCM's job. The other part is helping the service technician troubleshoot your car when you bring it in after the malfunction-indicator lamp turns on. Every time the PCM detects a malfunction in the OBD II system, it stores a DTC and a freeze frame of the engine's operating conditions at the time of the fault. The technician can download the trouble code and freeze frame with a special diagnostic tool, often called an OBD scan tool or scanner. The OBD II program standardized the interface to and the format of the DTCs. The OBD II standard makes life easier for independent service technicians and after-market scan-tool vendors.

The OBD II DTC format comprises a leading alphabetic character followed by four digits (**Figure 2**). The letter tells you whether the trouble code refers to the vehicle's body, chassis, power train, or network. The first digit tells you whether the trouble code is a generic SAE (Society of Automotive Engineers) code or a manufacturer-specific code. The second digit refers to a particular vehicle system, and the last two digits represent the component or subsystem at fault. Each DTC has a text message associated with it. For example, the message for P0099 is "Intake Air Temperature Sensor 2 Circuit Intermittent/Erratic."

There are five types of DTCs, depending on the severity of the malfunction. Type A codes are always emissions-related and are the most serious. A Type A code requires only one occurrence of a malfunction for the PCM to light the malfunction-indicator lamp and store the code and freeze frame. A Type B code is also emissions-related, but the malfunction must occur on two consecutive trips for the PCM to light the malfunction lamp and store the code and freeze frame. If the same malfunction does not occur on the second trip, the PCM clears the "armed" diagnostic code.

The freeze-frame data stores the vehicle's operating conditions when the PCM detects the malfunction. The operating data includes mass airflow, engine load and revolutions per minute, and engine-coolant temperature and indicates whether the fuel system is in open- or closed-loop mode. OBD II requires that the PCM save only one freeze frame of data for a malfunction. The PCM saves the freeze frame of the first trouble code detected. If a second malfunction occurs, the PCM ignores it unless the second trouble code has priority over the stored code. Misfire and fuel-trim codes have the highest priority.

Car manufacturers store more information about malfunctions than OBD II requires. The extra information helps technicians more easily diagnose and repair your vehicle. GM, for example, stores a "fail record" any time a diagnostic test fails, including non-emissions-related tests. The GM PCM stores the records in FIFO order, so the most recent malfunctions are saved. Depending on the vehicle, the PCM can store as many as five fail records.

To access this diagnostic information, you have to connect a scan tool to the OBD connector on the lower left side of the driver's side instrument panel on 1996 and later model year US cars. SAE document J1962 describes the 16-pin connector's pinout and physical characteristics (**Reference 4** and **Figure 3**). The problem is that car makers may use any of four serial-data protocols to communicate diagnostic information through the connector.

Diagnostic scan tools come in a variety of configurations. AutoXray makes a handheld model for independent service technicians and consumers. This device understands the generic SAE DTCs, and you can upgrade it to interpret manufacturer-specific DTCs. The scanner also allows you to reset these codes and turn off the malfunction-indicator lamp after you correct the problem. If you're really ambitious, you can use Drew Technologies' CarDAQ 2534 general-purpose bus-interface device (**Figure 4**). The CarDAQ understands several automotive communications protocols and allows you to write your own Windows application using its Win32 API.

You might assume that, with OBD II technology, an OBD III is in the works. As much as OBD II does to help reduce emissions, it can't repair the malfunctions that cause polluting emissions. Regulators want the next best thing by requiring automakers to connect a transmitter to the OBD system. If the regulators can't force you to repair your car when the malfunction-indictor lamp turns on, they want to at least require your car to squeal on you when you're driving around with emissions problems. The OBD III radio transponder would automatically report your problems to a regulatory agency. The system might use satellite or cellular technology to send the report as soon as the malfunction-indicator lamp turns on.

GM Hughes Electronics has built a prototype system that the California Air Resources Board has evaluated (**Reference 5**). The system uses a roadside transmitter to interrogate passing vehicles. Regulators claim that such a system would improve air quality and save money by requiring inspections only for malfunctioning vehicles. On the other hand, some Fourth Amendment privacy issues may have to be cleared up first.

OBD II standards go a long way toward keeping our air cleaner and helping us take better care of our cars. That maze of cables, hoses, and black boxes really does something more than make it nearly impossible to change your own spark plugs. So, the next time you open the hood of your car, take a few moments to admire all the engineering that allows your engine to outperform by many times Ford's Model T while emitting only a tiny fraction of the emissions.□

**Figure 4**

**Drew Technologies' CarDAQ 2534 is a general-purpose bus-interface device for automotive-communications systems.**

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## Author's biography

*Technical Editor Greg Vrana changes the oil himself on his 1996 Ford Explorer Sport. You can reach him at 1-512-338-0129, fax 1-512-338-1239, or e-mailgvrana@earthlink.net.*