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Tracy Martin

HOW TO USE **AUTOMOTIVE DIAGNOSTIC SCANNERS**



By Tracy Martin



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On the front cover: Modern tablets and other mobile devices may be used as state-of-the-art diagnostic scanners.

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About the Author

Tracy Martin writes for *Motorcycle Consumer News*, *RoadBike*, *Friction Zone*, *PowerSports*, and *Dealer News* magazines. Author of three books, Tracy co-authored the *MSF's Guide to Motorcycling Excellence, Second Edition*. Published by Motorbooks, Tracy's latest book, *Motorcycle Electrical Systems: Troubleshooting and Repair*, is available at booksellers everywhere. His first book, *How to Diagnose and Repair Automotive Electrical Systems*, is also available at bookstores. In addition to writing, Tracy teaches the Total Control Advanced Riding Clinic with Lee Parks, author of *Total Control*. Tracy has presented riding skills and motorcycle suspension seminars across the United States and recently in England and the Russian Federation.

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Preface

With the availability of code readers and scan tools targeted at the consumer market through retailers such as Sears, Walmart, auto parts stores, and online, it's more than evident that the aftermarket automotive electronic equipment manufacturers have realized a need for owners and enthusiasts to have access to what once was solely the domain of dealership and professional technicians—an automobile's on-board diagnostic system. What seemed to be missing was a source of information that tied everything together. I wrote this book about scan tools and code readers in the same easy-to-read style as my first five books, both for automotive- and motorcycle-related subjects, to fill this information gap. This book is a second edition of my *How to Use Automotive Diagnostic Scanners*. There are expanded sections in many of the chapters, especially in chapters four and five, where I cover updated and new scan tools and code readers. I also cover smart phone apps (Bluetooth and WiFi) and laptop/PC-based scan tools.

In this book, the first generation of on-board diagnostics (OBD-I) will be discussed in chapter one and chapter two will cover OBD-II, the diagnostic monitoring system in all vehicles sold in the United States since 1996, and the system that code readers and scan tools interface with. Also included is a brief history of automobile air pollution and how this problem has driven the automotive industry to produce these systems in the first place. Chapter three covers electronic fuel injection, oxygen sensors, and catalytic converter operation. Code readers are discussed in chapter four with scan tools following in chapter five. How an engine works, and especially how to separate engine mechanical problems from OBD-II system diagnostics, is discussed in chapter six, and chapter seven provides some practical applications for using a scan tool to diagnose emission-related problems.

If while reading this book you need a refresher on the meaning of "OBD," "DLC," or any other term found in

the text, the Appendix contains a convenient glossary of OBD-II automotive terms.

This book will provide the reader with a sound understanding of how on-board diagnostics relate to engine performance and emission problems. However, because both OBD-I and OBD-II systems, on-board computers—and their numerous sensors and components—are electrical in nature, a basic understanding of automotive electricity will go a long way toward diagnosing and repairing problems with the vehicles that use these systems. My book *How to Diagnose and Repair Automotive Electrical Systems*, also published by Motorbooks, is the perfect companion book to this one. I've also written on the same subject for motorcycles, *Motorcycle Electrical Systems Troubleshooting and Repair*, also published by Motorbooks. You can find more information about these books and some background on myself on my website at: www.tracyAmartin.com. Send me an e-mail if you want to comment on any of the books I have written or just to say hello.

I would like to thank the following individuals for helping me with research and information for this book. Without their assistance, I would be lost more than I usually am. Curt Moore and Craig Healy from the S.C.M. Hotline; their technical editing and suggestions saved me from writing something stupid.

Fisette Justin of the Bosch Automotive Aftermarket Division, who generously provided me with information and photographs on scan tools and code readers; and Elwood's Auto Exchange, where I was able to take many of the photos used in the book. Darwin Holstrom, my editor at Motorbooks International, and my wife, Leslie, whose editing skills have always vastly improved what I write.

So take a break from working under the hood of your car, sit back, relax, and read all about how scan tools, code readers, and your Android or Apple smart phone work with your car or truck's OBD-II on-board computer. Hopefully you'll find what this book contains is entertaining, as well as informative.

Tracy Martin

Dedication

I wrote this book for my son, Tristan, who at the young age of 30 has had to make too many life-and-death decisions in his brave fight against cancer. His courage has been an inspiration to my wife and me as we watch him make it through each day of his treatment. Before his diagnosis, the term “cancer survivor” was only an

ad slogan that I would occasionally read or see on TV, but after witnessing his struggle, it takes on a whole new meaning. I know that he will emerge from this nightmare intact and ready to move on with his life.

With all my love, Dad.





Chapter 1

On-Board Diagnostics, a Brief History

INTRODUCTION

Why We Have Scanners, Code Readers, and On-Board Diagnostics in the First Place

What exactly are automotive scanners, and why do we need them anyway? For years, it seemed, vehicles, vehicle owners, and mechanics got along quite well without them. Where did the need for these tools arise, and do they really do anything, and more importantly, what jobs do they perform, and are they really necessary when repairing an automobile today? If they are now an essential component of vehicle diagnostics (and they are!), how is the automotive do-it-yourself technician, or even automobile owners with only a passing interest in why the “Check Engine” light is on, supposed to understand or even read the computer trouble codes and data streams these diagnostic tools produce? These questions, and others like them, much like most peoples’ impressions of automotive scanners, code readers, and on-board diagnostic computers themselves, frequently leave automotive hobbyists and even some professional repair technicians perplexed and without a clue as to the right answers or what direction to take when it comes to high-tech auto repairs.

It is important when discussing automotive scanners, code readers, and on-board diagnostic systems to provide some background and a little history about the birth and development of these electronic devices. Then we can embark on an exploration of how they operate and what they do in a practical, hands-on manner, and how to use them to make repairs. Let’s start with the basics—a brief description of scanners, code readers, and the vehicle diagnostic computer systems with which they interface.

Both scanners and code readers allow a user to receive and view information from a vehicle’s on-board engine management computer system. The difference between code readers and scanners is one of quantitative capability: code readers are very limited in the automotive diagnostic information they can provide, while scanners can provide the same information as a code reader, but



Not a pretty sight of downtown Los Angeles in 1948 as smog obscures the view down this city street. The term “smog” was borrowed from the British, who originated the use of the word in 1905 as a contraction of the words smoke and fog. The first officially recognized “gas” attack (of smog) happened in Los Angeles in 1943. *Photo courtesy UCLA Library Department of Special Collection, Los Angeles Times Collection*

can also provide additional diagnostic information as well as perform functional testing. By contrast, on-board diagnostic engine management systems perform a number of tasks, including managing fuel-injection and ignition systems, shifting automatic transmissions, managing climate control systems, and controlling vehicle security, navigation, communication, lighting and other computer-related systems. However, by far the most important function on-board computer systems perform in conjunction with the code readers and scanners that work with them (and why these tools are the focus of this book) is to monitor the performance of emission controls, components, and systems, and make the driver aware when vehicle exhaust is polluting the air.

Scanners and code readers are technically only capable of reading the information on-board vehicle engine management computer systems generate.



The on-board computer systems themselves actually monitor all of the engine emissions controls and systems during vehicle operation. Complicating things a bit is the fact that two generations of on-board computer systems exist—known as OBD-I and OBD-II. Originally, on-board computer systems were designed into vehicles by various automobile manufacturers. This first generation of **On-Board Diagnostics** (OBD-I) was developed in the early 1980s and was an attempt by vehicle manufacturers to provide a system that warned a driver/owner whenever there was a malfunction in the emissions control system. Originally quite expensive, OBD-I systems were designed for use by professional technicians, and each operated uniquely. The information and tests that OBD-I systems provided was not standardized among auto manufacturers, and frequently even varied within a single automaker's model years or engine families.

The majority of the first wave of automotive scanners ever produced were manufactured in the United States around 1980. As originally designed, 1980s scan tools for retrieving basic diagnostic information from OBD-I systems used various cables and adapters to plug into myriad types of data connectors found on automobiles that were often specific to vehicle year, make, and model. This complexity made these tools expensive to own—many costing thousands of dollars. In addition, they were designed for use only by professional automotive technicians. As a result, because of the cost and difficulty of use, consumers were largely unaware of their existence. In fact, many car and light truck owners at the time (and subsequently, for years afterward) did not even know their vehicle(s) were equipped with an on-board computer.

Around 1989, the first code readers were sold in automotive parts stores, finally enabling consumers to tap into some of the information their automobiles had been generating and using for almost a decade. However, it wasn't until 1996 that the automotive industry's exclusivity over vehicle on-board diagnostics changed significantly: stricter federal emissions regulations led to standardization of on-board diagnostic systems across manufacturers. Thus, generation two of on-board diagnostics, or OBD-II, was born, and standardized, enabling aftermarket scanners and code readers to read any 1996 or later vehicle's on-board computer information. As more and more consumers purchased these tools, and demand increased, the price naturally

dropped. Today, the average cost range for code readers is between \$100 and \$200, and for scan tools, around \$200 to \$800.

We will cover the details about OBD-II systems in significantly greater depth as we continue with the remainder of this book, as our primary focus is on modern OBD-II computer diagnostic systems in use today. However, before we continue with our in-depth exploration of modern-day OBD-II systems, we will provide in this first chapter a brief overview of the development of scanners, code readers, and OBD-I and OBD-II systems. Later in the chapter, we will provide actual testing instructions for OBD-I diagnostics. OBD-II systems will be covered in the second chapter, electronic fuel injection and catalytic converters in the third chapter, code readers in the third chapter, and finally, scanners in the fourth chapter. The remaining chapters deal with how electronic fuel injection and catalytic converters operate, how to perform basic automotive detective work on mechanical engine conditions, and the proper use of scan tools to diagnose OBD-II-related problems.

However, before we get into too much detail, it is appropriate at this point to provide a brief history lesson as well, as it will prove useful to understanding how automotive on-board computer systems, and the scan tools and code readers they interface with, came into being, and how and why they developed as they did. In order to clearly understand the evolution and development of diagnostic scan tools, it is useful to start in the 1980s and work backwards in time.

All automotive scanners, code readers, and OBD-I and OBD-II systems were gradually developed for broad consumer use as a direct result of auto emissions problems from the past. Scan tools, like so much other 1980s automotive and related technology, including electronic carburetors and fuel-injection systems, only came into being as a result of auto manufacturers being forced by Congress to clean up the exhaust emissions billowing from America's tailpipes.

Manufacturers' initial efforts to control auto pollution followed a "band-aid" approach, which proved to be unpredictable and unreliable, and in many cases, made the cars and trucks equipped with them "undrivable" as well. Manufacturers simply did not have compelling economic impetus or significant legislative arm-twisting to force them to develop the engineering technology to control automotive emissions in an effective or standardized manner. As a result, and by

way of example, many carburetor-equipped cars from the 1970s would simply stall out at idle when engine temperature got too hot, or the engine would surge at part throttle because of lean (lack of fuel) carburetor settings that were required to meet emission standards of the day. After much reluctant trial-and-error engineering, auto manufacturers discovered the only consistent and reliable means to effectively reduce automotive tailpipe emissions was to utilize computer systems and related technology that could address and deal with all the variables of engine performance. Once automotive engineers discovered and confirmed the viability and attractiveness of on-board computer systems as a means of controlling vehicular emissions, a new set of unanticipated problems emerged. They dealt primarily with an inherent lack of communication with, and understanding about, the vehicle's on-board-computer by the owner/driver or automotive technician.

With the introduction of automotive on-board computers, technicians had to have a means of communicating with these devices. Early computer systems used a "Check Engine" light that simply blinked on or off; or in more sophisticated models, the on-board computer used the light to "flash" out diagnostic trouble codes (specific code numbers assigned by manufacturers to specific malfunctions in the emissions control system). With the necessary skills, a trained technician could read the trouble codes based on the sequence displayed by the flashing light on the instrument panel. Initially, the only computer scan tools available to interface with a vehicle's on-board computer system were brand-specific tools that automakers provided exclusively to their own dealership network. This was a great marketing tool—only new car dealerships were able to repair whatever went wrong with emission controls systems on their brand of cars and trucks. Fortunately for the automotive aftermarket, and eventually for the rest of us, Congress declared this monopolistic practice to be illegal.

In the aftermath of the congressional legislation, several electronic tool manufacturers introduced professional-grade scanners in the early 1980s designed for use by independent repair shops. Today, with the ever-growing number of do-it-yourself technicians working under the hoods of their own vehicles, the availability of inexpensive scanners and code readers provides automobile owners with the freedom to choose. They are no longer dependent upon a repair shop or automotive dealership to get their "Check

Engine" light to turn off, or to read and understand the diagnostic trouble codes generated by their vehicle's on-board computer.

However, long before the commonplace availability of scanners, code readers, and on-board diagnostic systems, there was smog. As we shall see, smog has played an integral part in the need for, and mandatory development and widespread use of, these tools.

AIR POLLUTION—A HISTORICAL PERSPECTIVE

As briefly mentioned, the need for on-board diagnostics, scanners, and code readers came into being due to a dramatic increase in the number of vehicles on the road, starting in the late 1940s. This inevitably led to an increasing amount of automotive emissions, which, unfortunately, led in a direct and unstoppable chain of cause-and-effect to the all-too-familiar problem of air pollution (and most educated people would argue, subsequent global warming). As a result, two generations of on-board diagnostics (OBD-I and OBD-II) exist, along with automotive scanners and code readers that communicate with these systems. Consequently, how all of these developments relate to, and evolved from, our interaction with vehicles and the air we breathe is worth a closer look.

In the summer of 1943, while the United States waged war in Europe and Asia, Los Angeles experienced what it officially recognized as its first attack of extreme air pollution, which, borrowing on the term originally coined by the British, was termed smog. According to the *Los Angeles Times*: "A pall of smoke and fumes descended on downtown, cutting visibility to three blocks." Striking in the midst of a heat wave, the "gas attack" was nearly unbearable, gripping workers and residents with an eye-stinging sensation and leaving them suffering with respiratory discomfort, nausea, and vomiting.

The day after the smog attack, the local municipal government blamed the Southern California Gas Company's Aliso Street plant, and the plant's manufacture of butadiene, an ingredient found in synthetic rubber. The plant was temporarily closed for several months, but in the following years the problem persisted, even after the company spent \$1.5 million (a lot of money in those days) to eliminate nearly all of its chemical fumes by completely enclosing the manufacturing process. What local politicians failed to mention, or it appears even thoroughly investigate, was the fact that Los Angeles had had problems with air pollution long before 1943. In fact, as early as 1903, city records reveal that industrial smoke



THOUSANDS DIE FROM EFFECTS OF “KILLER” SMOG IN LONDON

The word *smog* is first recorded in 1905 in a newspaper account of a meeting of a British governmental health agency. At the meeting, Dr. Harold Antoine des Voeux submitted a paper entitled “Fog and Smoke,” in which, in the words of the *Daily Graphic* of July 26, “. . . it required no science to see that there was something produced in great cities which was not found in the country, and that was smoky fog, or what was known as ‘smog.’” The next day the British newspaper, *Globe*, commented: “Dr. des Vœux did a public service in coining a new word for the London fog.” However, this was not to be the only time air pollution would be officially noted and described as a serious health problem in the UK—in fact, far from it. In Glasgow, Scotland, winter inversions of the atmosphere and smoke accumulations from burning coal killed 1,000 people in 1909.

More notably, in December 1952, a toxic mix of dense fog and sooty black coal smoke killed thousands of people in London. When smoke pouring out of London’s chimneys mixed with natural fog, cold-weather conditions caused dense smog to accumulate. The cold temperatures in turn caused Londoners to heap more coal on their fires, making more smoke and smog. The vicious cycle eventually caused catastrophic results. Eyewitnesses likened the killer fog to “somebody had set a load of car tires on fire.” On December 5, visibility was down to 50 feet within minutes. By December 6, 500 people were dead. By December 7, visibility was less than a foot. Ambulances stopped running and gasping Londoners had to struggle as they walked through the smog to city hospitals. By the time the wind blew the toxic cloud away, thousands were dead. In fact, according to a recent study in the journal, *Environmental Health Perspectives*, “as many as 12,000 people may have been killed by the great smog of 1952.”

The lethal smog attack in London in 1952 remains the single deadliest environmental episode in recorded global

history. Prior to this event, people who lived in large cities more-or-less accepted air pollution as part of city living. In the aftermath of this incident, governments worldwide seriously questioned, and attempted to eradicate or at least limit, the poisonous side effects of the industrial age.

Smog is now classified into three types: London smog, photochemical smog, and smog from burning biomass. As described, London smog arises from the mixture of the natural atmosphere with the byproducts of coal used to heat homes and businesses. During cool, damp periods (typically in the winter), coal soot and sulfur oxides can combine with fog droplets to form a dark acidic fog. Fortunately, London smog is largely a phenomenon of the past, as most modern heating sources in Europe and the United States use cleaner-burning fossil fuels, such as oil and natural gas. Also, the use of alternative energy sources, like hydroelectric and nuclear energy, have also contributed to the elimination of London smog.

Unfortunately, the other two forms of smog are still with us—one of which, in fact, is significantly worsening, and contributing to serious global environmental concerns, like global warming. Photochemical smog, the most prevalent and destructive form of smog, is more of a haze than a true fog. It is produced by chemical reactions in the atmosphere triggered by sunlight. A combination of volatile organic compounds (hydrocarbon exhaust pipe emissions) and nitrogen oxides (NOx) produce an oxidant, ozone, along with other irritating chemicals that all combine to produce photochemical smog. The other type of smog is the oldest type of smog known to man. It is produced from the burning of wood. This type of smog combines aspects of both London smog and photochemical smog, since the burning of wood, or biomass, produces large quantities of smoke, as well as other volatile organic compounds (VOC) and NOx.

and fumes were so thick that many residents mistook the conditions for a solar eclipse.

However, it wasn’t until 1952 that a link between smog and vehicle emissions was officially confirmed. That year, commercial farmers located near Southland refineries complained of unusual crop damage. The leaves of orange trees, an important California agricultural crop at the time, were discoloring or bleaching—a phenomenon not seen in other parts of the country. Furthermore, tire manufacturers disclosed that rubber was apparently deteriorating faster in L.A. than in other areas of the country. Spurred on by these unusual

circumstances, Dr. Arie Haagen-Smit, a chemistry professor at California Institute of Technology (Caltech) in Pasadena, investigated the underlying source of these problems. Dr. Haagen-Smit was the first to determine the primary ingredient in smog, now commonly referred to as ozone, was not an ingredient in, or direct end product of, tailpipe or smokestack emissions. It was, in fact, created in the earth’s atmosphere. He discovered that when atmospheric conditions were right, sunlight acted as a catalyst in a photochemical reaction that combined the hydrocarbons from oil refineries with the various nitrogen oxides left by partially unburned fuel



In 1952, the “Smog-a-Tears” protesters wearing WWII gas masks in Pasadena, California, took a stand to register their discontent about the awful state of air quality at the time. I can personally recall in about 1959 and the early 1960s having recesses, and sometimes school, cut short on many hot Southern California days due to smog. I remember clearly that it was often difficult to take a deep breath and my eyes would sting from thick brown smog. Often, the view of the San Gabriel Mountains (just a few miles from my school in Pasadena) was completely obscured by smog, and the sun would cast a reddish-brown glow. *Photo courtesy UCLA Library Department of Special Collection, Los Angeles Times Collection*

contained in automobile exhaust. The process formed ozone (smog). Researchers at Caltech were able to show that rubber exposed to high ozone levels could develop cracks in just seven minutes. This was such a reliable phenomenon that early methods for measuring ozone levels included the highly scientific act of stretching rubber bands around jars and then timing how long the bands took to snap. Obviously, something had to be done.

EARLY AUTOMOTIVE EMISSIONS REGULATIONS

In the 1950s and '60s, the problem of air pollution continued to worsen in Southern California, motivating state and local governments to conduct studies to determine the potential sources of smog. Ultimately, these studies confirmed that the overwhelming bulk of smog was attributable to automobile emissions.

With a vehicle population of eight million at the time, and over 71 billion miles driven annually, California's Motor Vehicle Pollution Control Board (MVPCCB) was created in 1960 to regulate automotive emissions. The first pollution control device was mandated in 1966—a requirement that a positive crankcase ventilation valve (PCV) be equipped on all vehicles sold in the state. Using engine vacuum, a PCV valve sucked up unburned fuel created by combustion gases escaping past piston rings into the crankcase. The unburned fuel was then returned to the engine's intake manifold, where it was burned, instead of being allowed to simply vent into the atmosphere. Obviously, vehicle manufacturers were resistant, to say the least, about having to add what they considered an unnecessary component onto the engine of every vehicle. But economic reality dictated that they had no choice if they wanted to sell automobiles



Still the same after all these years. A positive crankcase ventilation (PVC) valve is a simple device that regulates the flow of hydrocarbons from an engine's crankcase, by forcing them into the intake manifold. Instead of polluting the atmosphere, the unburned fuel is burned in the engine's combustion chamber. *Courtesy Kiplinger's Automotive Center*

to California residents. The effectiveness of this device remains evident today, as it is still in use in many cars and light trucks.

The California Air Resources Board, or CARB, was formed in 1967. Its established purpose was to oversee and regulate air pollution in the entire state. CARB developed testing procedures and regulations that were eventually adopted by the United States Congress in the form of Federal emissions legislation. Congress passed the Clean Air Act in 1970 and simultaneously created the US Environmental Protection Agency (EPA). The Clean Air Act called for a 90 percent reduction in motor vehicle exhaust emissions by 1975.

Naturally, serious resistance came from automobile manufacturers, since the new mandatory technology was anticipated to cost millions of dollars to implement. Dire predictions about doubling, at a minimum, the manufacturing cost, and end consumer price, of new cars and trucks were rampant; but in the end, despite considerable opposition, auto manufacturers were forced to comply and did (even though for some compliance wasn't achieved until 1981).

As a result of this Federal legislation, the reduction of three major exhaust pollutants—carbon monoxide (CO), hydrocarbons (HC), and nitrogen oxides (NOx)—was accomplished by implementing a series of emissions controls, including: exhaust gas recalculation (EGR), charcoal canister vapor recovery systems, and three-way catalytic converters. Prior to this uniform Federal legislation, earlier pollution-control devices and systems installed by respective manufacturers largely followed a “band aid” approach, and these vehicles



This Ford EGR valve adds exhaust gases back into the engine's intake manifold to reduce NOx emissions into the air. Engine vacuum operates the valve, and the plastic sensor on top measures valve position (how far open or closed it is), and relays this information to the on-board computer.



This OBD-II catalytic converter is quite a bit smaller than the ones used on OBD-I vehicles. Unlike OBD-I converters, it's placed right next to the exhaust manifold, which shortens the time needed for the catalytic converter to reach operating temperatures. The smaller size also provides a desirable weight reduction over older designs. *Courtesy of Younger Toyota*

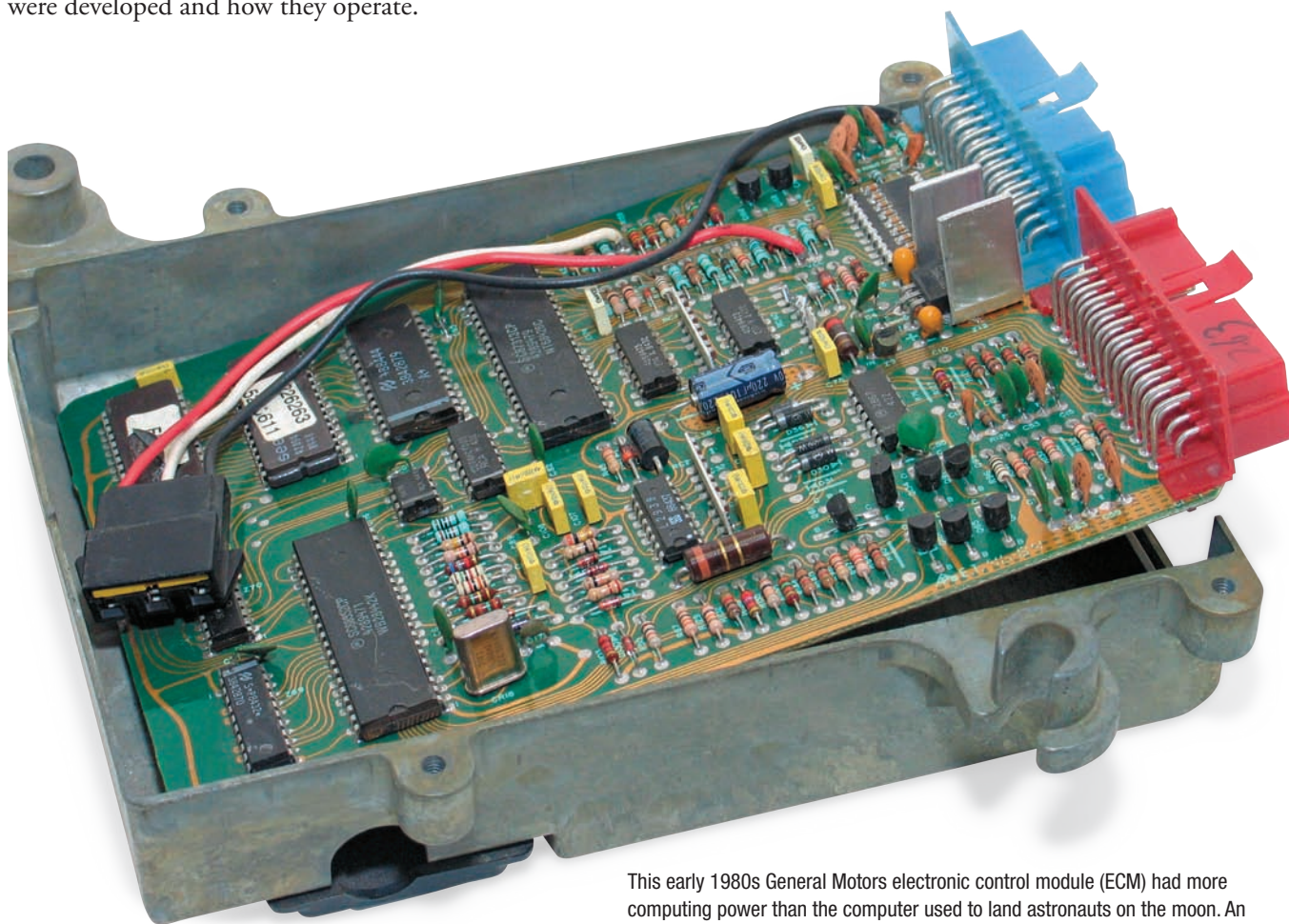
suffered drivability issues as a result. Up until the point of the Federal legislation, the majority of emissions control measures and systems operated independently from each other, and were controlled by mechanical means. It wasn't until 1981, and the introduction of on-board computers, three-way catalytic converters, and oxygen sensors, that engine performance and overall driveability improved.

So what exactly does smog, and the related legislative efforts to minimize it, have to do with the development of automotive scanners and code readers? Everything. The existence and development of two generations of on-board diagnostic systems, OBD-I and OBD-II, and the creation and use of automotive scanners and code readers to interface with automotive computers, are integrally linked with the effort to clean up the air we breathe and have unfortunately polluted. That first “gas attack” in L.A. in the summer of 1943 was the official start of a “war” on smog that has now been going on for well over half a century. What started out simply, with voluntary emissions regulations and bans on the burning of trash in backyards, progressed to federal legislative requirements being imposed upon all automobile manufacturers, requiring all vehicles to have the capability to monitor their own emissions while operational and to warn the driver about any failures of emission controls.

Now let’s take a closer look at how OBD-I systems were developed and how they operate.

ON-BOARD DIAGNOSTICS— GENERATION ONE, OR OBD-I

All internal combustion engines produce exhaust emissions as a result of incomplete combustion of the air/fuel mixture. The cause is the absence of sufficient amounts of available oxygen during the combustion process to completely burn all the fuel present. Because the amount of unburned fuel is so small, fuel economy is not typically an issue. However, when a reduction in emissions was mandated by the federal government, the small amount of unburned fuel became problematic, and of paramount concern. Three organizations, CARB, the EPA, and the Society of Automotive Engineers (SAE), started serious research on this issue in 1980, and by 1988, the first generation of computer on-board diagnostic systems (OBD-I) were required to be installed on every vehicle sold in California. The rest of the nation soon followed in California’s footsteps.



This early 1980s General Motors electronic control module (ECM) had more computing power than the computer used to land astronauts on the moon. An electronically controlled carburetor uses an ECM like this one for fuel delivery control. The computer also controls other emission system components.

To effectively reduce toxic emissions, automakers had to come up with a computerized emission control system that could perform the following functions: 1) respond instantly to supply the exact fuel/air mixture for any given driving condition; 2) calculate the optimal time to fire an engine's spark plugs for maximum engine efficiency; and 3) perform both of these tasks without adversely affecting engine performance or fuel economy.

Until the Federal Clean Air Act deadline of 1975, fuel delivery, at least for the vast majority of vehicles, was primarily accomplished by a carburetor, while ignition timing was determined by mechanical means—i.e., an ignition distributor using springs, weights, and engine vacuum. These old mechanical systems had been in use for more than 80 years, and consequently, were not precise enough or fast enough to meet the new, stricter emissions standards. A plan was needed that called for a carburetor and ignition distributor with brains. The introduction of the automotive on-board computer provided the means to accomplish the task; the OBD-I system was designed to effectively monitor its own performance with regard to tailpipe emissions.

Though not very sophisticated by today's standards, the automotive computers used in the early 1980s were fast enough and accurate enough to effectively control fuel delivery via an electro-mechanical carburetor or electronic fuel-injection system. Computer-controlled systems utilize software programs with specific pre-set reference values for air/fuel ratios and spark advance (ignition timing). By monitoring inputs from various sensors, including engine temperature, engine speed, air temperature, engine load, road speed, transmission gear selection, exhaust gas oxygen, and throttle position, and then comparing the resultant values against an internal reference library, the computer is able to make incremental corrective adjustments hundreds of times each second to maximize the air/fuel ratio to optimal levels. By commanding the output devices under its control, including fuel delivery solenoids (carburetors), fuel injectors, ignition modules, EGR valves, and idle speed controls, the computer is able to keep the engine operating within proper optimal pre-set values, and in the process, keep emissions at acceptable levels.

OBD-I was originally designed to monitor the performance of fuel-delivery systems, at least as related to emissions output, as a means of warning the driver if something went wrong that might cause an increase in pollution. Additionally, OBD-I was theoretically designed with the ability to “self-diagnose” fuel and

ignition systems, and to monitor their ability to keep emissions under control. The OBD-I system's ability to display “trouble codes” that would essentially instruct service technicians which part or parts to replace if something went wrong, was viewed as a side benefit by auto manufacturers.

By the early 1980s, most automotive engineers were of the opinion that auto mechanics of the near future would not need to have a high degree of technical training, or need an in-depth understanding of on-board computer technology, in order to successfully repair automobiles. It was believed that a vehicle's on-board computer and OBD-I system were sufficient to determine a fault in the fuel or ignition systems. According to this line of thought, the systems would set and display the appropriate trouble code, thereby enabling the mechanic to simply read the code by watching a flashing light on the dashboard and replace the specified malfunctioning component.

However, engineers and automakers were in for a big surprise. Parts replacement, as dictated by trouble codes, ultimately didn't actually fix many of the disabled or malfunctioning vehicles. In fact, poor connections in computer wiring harnesses, engine vacuum leaks, plus bad computers that couldn't diagnose themselves, bad sensors that wouldn't set a trouble code, and engines with mechanical problems all played havoc with the auto repair industry for several years. Instead of unskilled mechanics with little training using the OBD-I system to diagnose and repair problems, just the opposite happened: automotive repair technicians had to have a higher level of training than ever before. The simple process of reading and understanding OBD-I data streams was not really simple at all since there was no, or very little, information available to an independent automotive technician as to how to do this. Furthermore, this newfound lack of expertise also arose because automotive systems, which were previously unrelated (like the ignition, fuel, and exhaust systems, or emissions controls), were now all electrically connected via the on-board computer. If something went wrong with one system, a trouble code might be set to indicate a problem existing in another system. Erroneously relying on the information from the vehicle's computer, which they believed they understood, technicians all too often went off on a wild-goose chase, often spending hours looking for a problem that existed in an unrelated area of the engine's various systems and controls. These frustrating exercises in diagnostic futility were costly and time-consuming, and stood out in stark

contrast to the simpler times of automotive repair, before the advent of computer-controlled diagnostics.

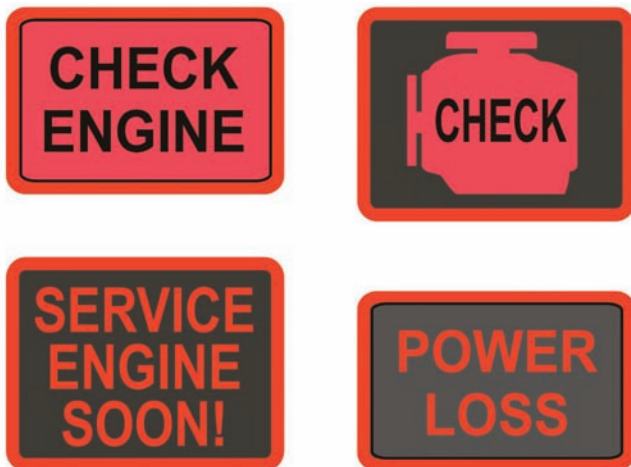
For example, in the “good-old-days,” i.e., before automotive computers, if a car arrived at an auto repair shop with black smoke pouring from its exhaust pipe, the mechanic on duty knew he would soon be repairing or rebuilding a carburetor—he didn’t even have to open the hood to figure this out. However, when a carbureted car equipped with an OBD-I system came in with black smoke coming from the exhaust, diagnosis wasn’t as easy. The problem could be the carburetor (which now had wires connected to it), but it could also be the computer itself or one of its sensors, or it could be a bad electrical connection, a vacuum leak, or even an exhaust leak. Adding to the diagnostic dilemma, there may or may not have been a trouble code set and the “Check Engine” light on the dashboard may or may not have been turned on. The mechanic, who now fully understood why his or her title had recently been elevated to “technician,” had to spend some quality diagnostic time to uncover the root cause of the problem. Not only did technicians have to have a sound understanding of basic engine operation, they now also had to know how the engine management system controlled the fuel and ignition systems, and how these systems interrelated with various sensors and controls.

Unfortunately, due to a prevailing lack of understanding about how the new computer-controlled systems operated, combined with insufficient training of automotive technicians, many perfectly good components were replaced unnecessarily. Without proper training to deal with the new technology, many in the automotive industry, including technicians and independent repair businesses alike, chose to simply quit. Fortunately, those who stayed had to acquire a strong desire to learn how electronic ignition systems, computer-controlled carburetors, and cutting-edge electronic fuel-injection systems worked. But most importantly, they had to learn how to communicate with a vehicle’s on-board computer.

To make things even more interesting, since there was no standardization required between automakers, each had free reign to design and implement its own OBD-I components and strategies. Consequently, some makes and models of vehicles had more diagnostic information available than others. Some required a scan tool to retrieve trouble codes, while others used a flashing light on the dash to convey codes to technicians. Different methods were required to get on-board computers to cough up their respective stored information. In some instances, two wires in certain cars and trucks had to be jumped together at the vehicle’s



Because manufacturers were not required to standardize OBD-I diagnostic systems, the Monitor 4000E from OTC Tools needed lots of cables and adapters in order to connect to vehicles from General Motors, Ford, Chrysler, and Toyota. The small square boxes to the right of the scan tool are software cartridges for different years and makes of vehicles. This scanner dates from early 1990. At the time, it was much too expensive for home technicians. *Courtesy OTC Tools*



OBD-I “Check Engine” lamps were supposed to warn drivers when a vehicle had a malfunction that affected tailpipe emissions. Various means were used to turn them off, including removing the bulb, using an ice pick to break the bulb, and even, on some occasions, fixing the actual problem that caused the light to turn on in the first place.

diagnostic link in order to cause the dash light to flash a sequence of codes. Moreover, diagnostic connectors were often difficult to find, since they could be located under the hood, behind dash panels, or tucked away in the center console. In addition, these diagnostic systems came in many different sizes and shapes, and required a variety of connectors and cables before they could properly work with various scan tools. Further compounding the problem, the trouble codes themselves were also unique to each manufacturer. In some cases, differences in, or even different types of, on-board computer systems existed between makes and model years of vehicles from the same manufacturer. Thus, manufacturers had discretion in design engineering as to how “bad” a component would actually have to be before it would cause the “Check Engine” light to turn on, or when it would miraculously turn off if the problem mysteriously fixed itself. Even the computers themselves had different names, depending upon which make of vehicle they were installed into. Some of the more common names included: Chrysler’s Logic and Power Modules, Single Module Engine Controller (SMEC), and Single Board Engine Controller (SBEC); General Motors’ Computer Command Control (CCC) and Electronic Control Module (ECM); and Ford Motor Company’s Electronic Control Assembly (ECA), Multifunction Control Unit, (MCU), and Electronic Engine Control I, II, III, and IV (EEC-I to IV). There were countless others, including those associated with



Because OBD-I diagnostic systems varied so widely between various car and truck manufacturers, a vehicle-specific service manual, along with a scan tool, were absolutely essential in order to properly and adequately diagnose “Check Engine” lights and associated drivability problems.

European and Asian imports. Consequently, consulting a service manual or otherwise having access to vehicle-specific OBD-I information, and then knowing which procedures to perform, was absolutely essential if there was going to be any chance at all of figuring out what was wrong with a system and making the appropriate repairs.

From an emissions point of view, the first-generation OBD-I systems had some serious drawbacks—many of these systems couldn’t even determine if an engine and its pollution control systems were actually operating as they should. In fact, the vehicle could be spitting out lots of raw, unburned fuel from its tailpipe, and the computer, despite its OBD-I monitoring system, would not turn on any warning lights—instead conveying the message to the driver to just keep driving, everything’s OK.

A frequent example of this type of scenario occurred whenever the vehicle’s ignition system had an intermittent misfire. In such cases, raw unburned fuel would be sent through the catalytic converter, and in the process, cause high exhaust emissions that could ruin the converter. In an effort to compensate and correct the problem, the on-board computer would try to lean-out the fuel system. Unfortunately, in such instances, the computer wasn’t really able to “fix” this type of problem; but as long as all the sensors remained within pre-set electrical values, the dash warning light or “Check Engine” light would remain off, failing to turn on as it was originally intended to do in just such a scenario.

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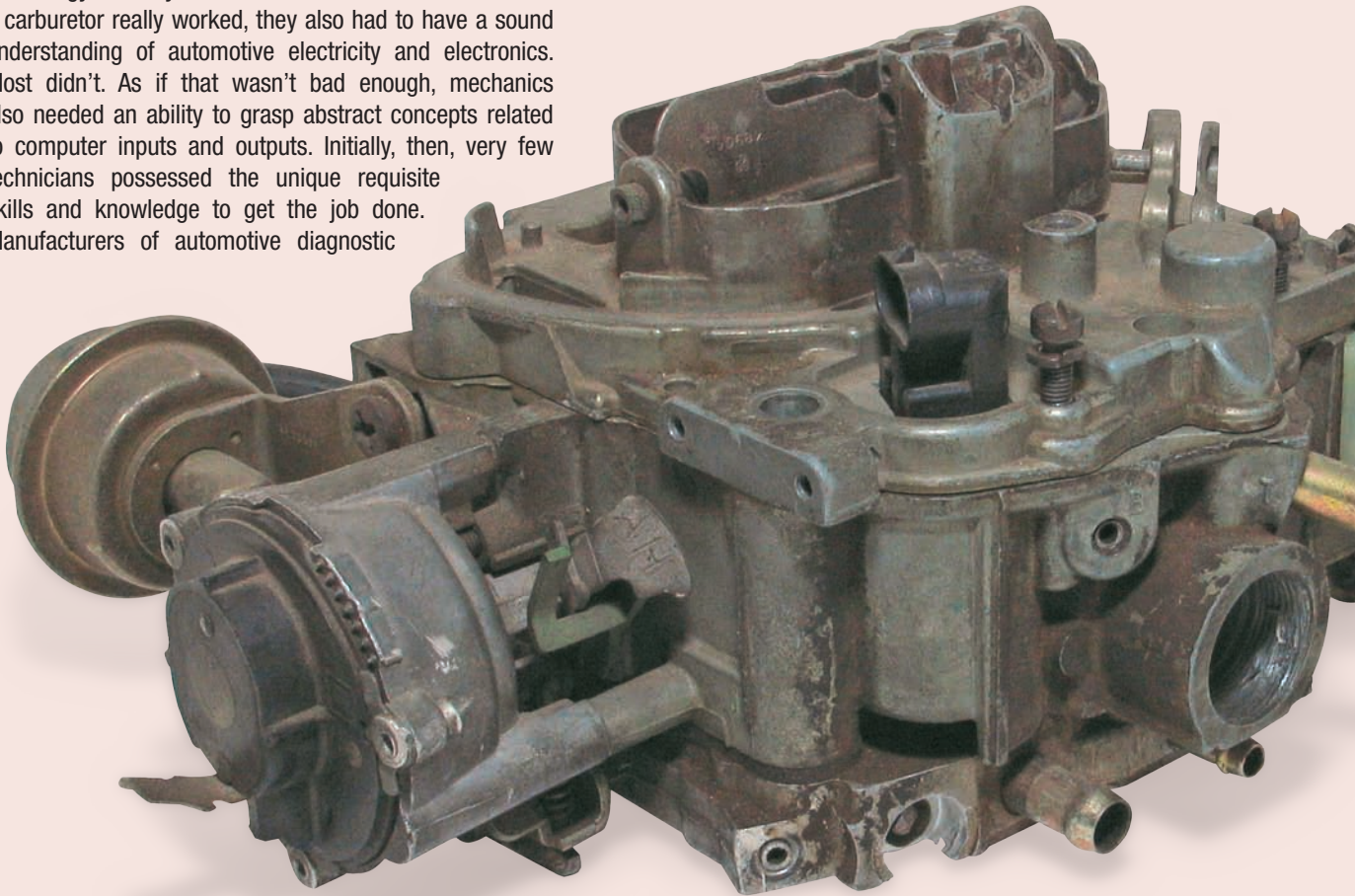
ELECTRONIC CARBURETORS

Most early OBD-I vehicles used an electronically computer-controlled carburetor for fuel delivery. At the time, technicians often speculated that auto manufacturers needed to use up all the carburetor castings and machine tooling before they could make the transition to electronic fuel injection. Meanwhile, automotive engineers argued that their employers needed time to determine how best to mass produce reliable fuel injection systems. The truth probably lies somewhere in between. Consequently, computer-controlled carburetors were around in large production numbers from 1980 until around 1988. Electronic fuel-injection systems were phased in during the mid-1980s. The last carbureted vehicle sold in the United States was made by Isuzu in 1994.

In the early 1980s, many independent repair shops operated in crisis mode whenever vehicles using carburetors with wires coming out of their castings started showing up with drivability problems. Since most automakers were less than forthcoming when it came to sharing diagnostic and repair information, most mechanics at the time were not prepared to deal with the new automotive computer technology. Not only did mechanics have to understand how a carburetor really worked, they also had to have a sound understanding of automotive electricity and electronics. Most didn't. As if that wasn't bad enough, mechanics also needed an ability to grasp abstract concepts related to computer inputs and outputs. Initially, then, very few technicians possessed the unique requisite skills and knowledge to get the job done. Manufacturers of automotive diagnostic

test equipment, like Sun, Allen, and Bear, provided training programs to remedy this problem—no doubt, in the hopes of selling more equipment. Technicians who were unable to adapt and learn the new technology went on to do something else, instead of diagnosing drivability problems on automobiles. This abrupt change in technology caused many independent repair facilities to permanently close their doors.

Fortunately, the reality was that many of these computer-controlled carbureted systems actually worked pretty well. But a sadder reality was that these new systems were not widely understood. Misadjustments and wasted “repairs” were all too common, resulting in these early systems receiving a negative reputation. It was common practice for uneducated mechanics in unfamiliar territory to disconnect the wires coming from a carburetor as the primary method of solving most drivability issues. Naturally, this “solution to the problem” made the engine run even worse than when it was first brought into the repair shop, as these systems were programmed to default

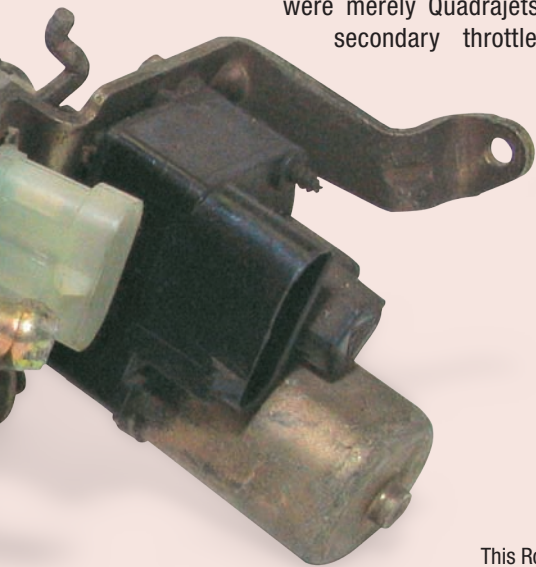


to an overly rich fuel mixture, resulting in the dumping of too much fuel into the engine. As these early carbureted cars and trucks started racking up the miles in the mid-to late 1980s, worn-out carburetors were exchanged for “rebuilt” units. But, as might now be expected, carburetor re-manufacturers were no better at rebuilding computer-controlled carburetors than most mechanics. Consequently, the “rebuilt” carburetors were often worse than the ones they replaced, since the technicians responsible for the rebuilds often mixed up internal parts between carburetor models. In addition, “rebuilt” carburetors were very expensive—often costing hundreds of dollars more than the standard non-electrically-controlled carburetors prevalent a few years before.

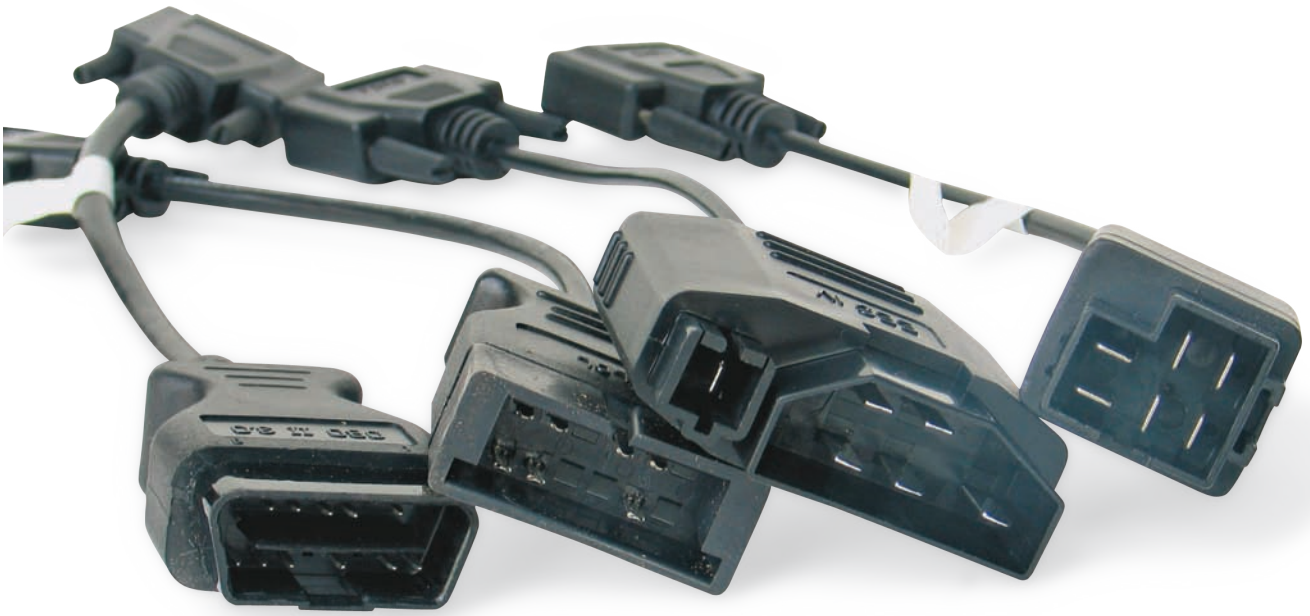
Nonetheless, computer-controlled carburetors did, in fact, do what they were designed to do—they adjusted fuel delivery. They did this by several means, including vacuum solenoids, switches, stepper motors, and electronic solenoids that controlled fuel-metering rods. Among the better-performing units were Rochester’s Dualjet and Quadrajet carburetors, and Motocraft’s 7200 Variable Venturi carburetor. The Quadrajet carburetors had been around for years before they were redesigned to perform as electronically controlled carburetors; in the computer-controlled configuration they were actually quite successful and “tuneable.” Dualjets were merely Quadrajets cut in half, with no secondary throttle plates. The more

notable Variable Venturi (“VV”) carburetor by Motocraft was similar to some modern motorcycle carburetors, in that its venturi, an opening that air passes through on its way to the intake manifold, was adjustable and changed in accordance with engine vacuum or load. The “VV” carburetor had a jet needle and a slide to control air and fuel flow, but only one fuel circuit. By contrast, standard carburetors had a fixed venturi and seven fuel circuits. Consequently, in a standard carburetor, several fuel delivery circuits were needed to match fuel flow with airflow. The “VV” carburetor offered performance that matched electronic fuel injection of the time; it was used on Ford’s Crown Victoria and Mercury Grand Marquis cars (can you say . . . police cruiser?). Unfortunately, the “VV” carburetor was also one of the least understood computer-controlled carburetors of the time, and was subject to misadjustment and gross general mechanical abuse from less-than-knowledgeable mechanics.

Nowadays, electronic fuel-injection systems have completely replaced the automotive carburetor, rendering it nearly obsolete, except in those cases where it lives on in classic restored vehicles. The trend toward fuel injection systems is here to stay, with expansion of its use in motorcycles, watercraft, snowmobiles, and even lawn tractors. Most of the vehicles that once used the early computer-controlled carburetors have gone on to the junkyard, but automotive enthusiasts will always keep some of them “alive” today.



This Rochester Dualjet carburetor used a solenoid to control metering rods to vary the amount of fuel delivered to the engine. The computer-controlled carburetor was an intermediate step between older carbureted technologies and newer electronic fuel-injection systems. The black plastic connector, located on the top of the carburetor, controlled the fuel-mixture solenoid, while the white connector (right) is for the throttle position sensor (TPS). The funny-looking thing at the far right is an idle speed control motor.



Three of these data link connectors fit OBD-I systems. From right to left: Chrysler, Ford, and General Motors. These connectors were used from the early 1980s until the arrival of the next generation of OBD-II computer systems in 1996. The OBD-II connector is at the far left. *Courtesy Actron*

continued from page 15

Another example of the serious shortcomings of the first generation of OBD-I computer systems was with their interaction with catalytic converters. Converters would frequently get plugged up—whether from an overly rich fuel system, coolant leak into the combustion chamber, or just from high mileage—and cause a severe lack of engine power. Consequently, the converters were often illegally removed and never replaced. OBD-I systems were unable to detect that the converter was missing, so no “Check Engine” light would ever come on, and the vehicle could be driven endlessly, with no apparent emissions problems, at least as far as the unaware owner was concerned.

Various versions of OBD-I vehicles were in mass production by US manufacturers as early as 1980, even though OBD-I compliance was technically not required until 1988. Early OBD-I cars and trucks used computer-controlled carburetors at the heart of their fuel systems; these computer-controlled carburetors were later replaced by more sophisticated electronic fuel-injection systems. Even though the earliest produced OBD-I vehicle is nearly 35 years old today, it’s still important to understand the basics of how each manufacturer interpreted the original legislative OBD-I mandates, as well as to know how to read codes and perform diagnostic testing on these vehicles—if only because there are a large number

of 1980s car and truck enthusiasts. As these vehicles age into the next generation of classic cars, knowing how their computer systems work will be useful to maintaining them in restored condition.

However, since the vast majority of vehicles on the road today are equipped with OBD-II computer systems, we will not only provide a brief overview of their development and how they operate, we will devote the remainder of this book to covering them in detail.

ON-BOARD DIAGNOSTICS— GENERATION TWO, OR OBD-II

OBD-I systems were primarily in use since 1980, and were doing an adequate job of meeting federal emission standards of the day. However, like on-board computer technology, emission regulations continued to evolve. They were, and still are, forever increasing the limits of exactly how much “bad” stuff could come out of a vehicle’s exhaust. Naturally, a new standard was on the horizon—the second generation of OBD-II computer diagnostics. Automakers were given several years lead-time to develop this new technology. General Motors was the first to use it on a limited basis starting in 1994. By 1996, all cars and light trucks sold in the United States were required to have OBD-II systems.

There are several primary differences between OBD-I and OBD-II systems. The most notable difference is standardization. All vehicle manufacturers were required to follow the same rules and regulations, which included specifications for the design and installation of a universal data link connector on every vehicle, uniform automotive terminology, and consistent trouble code identifiers and definitions. One significant difference between both systems is the OBD-II system's ability to monitor the effectiveness of catalytic converter operation as the vehicle is being driven. By contrast, OBD-I systems were not even able to determine if the converter had been removed from a vehicle. Another major difference is the level of diagnostics available. Where an OBD-I system may have used only one or two codes for a single sensor, OBD-II systems can have as many as four or more codes for each individual computer sensor. In addition, automakers were given the freedom to use individualized "P1" codes, which were allowed to be specific to each brand of automobile. When manufacturer-specific P1 codes are combined with the numerous standardized OBD-II generic codes, there are literally thousands of diagnostic codes to cover nearly all of the systems equipped on today's vehicles.

RETRIEVING CODES AND TESTING—OBD-I

In view of the large number of older cars and trucks still on the road today, there are still lots of OBD-I systems

in need of a little TLC (tender loving care). While the focus of this book is OBD-II systems and the scanners and code readers that interface with them, the rest of this chapter will cover how to perform diagnostic testing on the first generation of OBD-I systems from General Motors, Ford, and Chrysler, the primary manufacturers of OBD-I vehicles.

Many modern OBD-II scanners and code readers for the do-it-yourself consumer market are not capable of performing on OBD-I vehicles. A few scanners do come with OBD-I data link cables and adapters, and will work on earlier OBD-I vehicles; however, these scan tools are more expensive than those that are only capable of interfacing with OBD-II vehicles.

Fortunately, there are no worries—OBD-I codes can still be read, and some computer testing performed, using other methods and tools. The tools required for retrieving trouble codes from OBD-I equipped vehicles are simple and inexpensive; they include a 12-volt test light, several jumper wires, and several large paper clips.

If nothing else, by taking a look at this older technology, current technicians will gain a greater appreciation for the usefulness, capability, and efficiency of the modern OBD-II diagnostic systems of today. We'll start out by taking a look at General Motors OBD-I trouble codes, and perform some testing of General Motors' computer diagnostics.



Actron scanners and code readers from left: CP9575 PocketScan Plus, CP9670 AutoScanner, CP9680 AutoScanner Plus, and CP9690 Elite AutoScanner. When OBDII was first introduced in 1996, only professional quality scan tools from OTC, Snap-On Tools, and other aftermarket manufacturers were available to interface with OBDII-compliant vehicles. These tools cost \$3,000+ and were limited in what they could display. Today, the Actron scanners pictured cost \$100-\$400 and offer far more information and ease-of-use than older scanners. *Courtesy Actron*

GENERAL MOTORS—OBD-I SYSTEMS

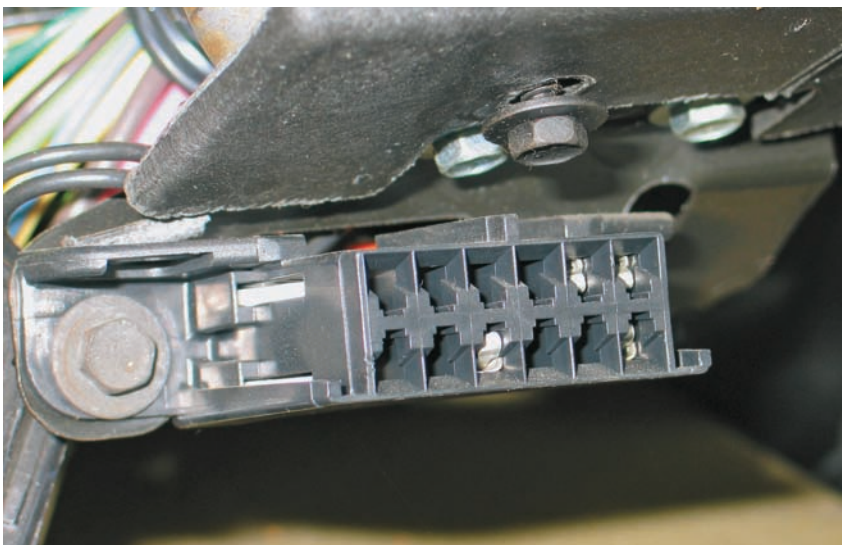
Early on, General Motors designed one of the more sophisticated OBD-I systems. For at least a few years afterwards, the other big automakers had to play catch-up with their own designs and technology. Remember, General Motors referred to its OBD-I on-board computer as an “Electronic Control Module” or ECM; thus, ECM and on-board computer will be used interchangeably in this discussion dealing with first-generation General Motors vehicles.

The General Motors OBD-I system is capable of functioning in four states of operation: 1) “Field Service” state; 2) “Back-up” state; 3) “10K” or “Special” state; and 4) “Road Test” or “Open” state. Each of these diagnostic test states monitors different aspects of the vehicle’s computer system. The most common diagnostic mode used on these types of vehicles is the “Field Service” state because it is the easiest to use. In “Field Service” mode, trouble codes can be retrieved simply by using an appropriate scan tool or by watching the flashing “Check Engine” or “Service Engine Soon” lights. (Please note: Not all General Motors vehicles equipped with OBD-I systems can perform all functions; consequently, the specific vehicle service manual should be consulted when attempting to work on these vehicles. In addition, code definitions may differ from one vehicle to the next, and appropriate diagnostic procedures may vary as well. A service manual or other source of vehicle-specific OBD-I information is absolutely essential in order to successfully perform diagnostic tests, and/or to read trouble codes, on these vehicles.)

Trouble codes are easy to read on General Motors vehicles provided the scan tool used has OBD-I capabilities, and a correct General Motors diagnostic cable adapter is utilized. After identifying the year, make, model, and engine type of the vehicle to be diagnosed, simply follow the instructions on the scanner’s display to either read trouble codes or erase them from the computer’s memory. In addition to reading codes, the OBD-I system on General Motors vehicles will display a live data stream on the scanner that can be used to further diagnose engine performance problems. If you don’t have an OBD-I-capable scan tool, a manual method for retrieving trouble codes (covered in more depth in this section) is easy, once the computer’s code sequence is understood.

Retrieving Trouble Codes—General Motors “Field Service” State

In order to get a General Motors OBD-I computer to perform diagnostic scanning of a vehicle’s emissions system, it must be placed into operational mode before testing can occur. To enable the “Check Engine” light to flash out the trouble codes stored in the vehicle’s OBD-I system, the computer must first be placed into “Field Service” state. The first step in this process is to locate the Assembly Line Communication Link (ALCL) or Assembly Line Data Link (ALDL) connector. Generally, the ALDL or ALCL connector is located under the dash on the driver’s side of the car (but not always!). A component locator listed in a service manual can help you properly identify the test connector location. The most common type of ALDL



General Motors was one of the few manufacturers that located their early OBD-I assembly line data link (ALDL) connector next to the steering wheel. It was not until the emergence of OBD-II systems that other automakers followed suit, eventually moving their data link connectors (DLC) inside the passenger compartment within 16 inches of the steering column. *Courtesy Elwood's Auto Exchange*

or ALCL connector used has 12 pins (which makes it readily identifiable). The second step in the code retrieval process is to connect pins “A” and “B” on the ALDL or ALCL connector together with a paper clip, and turn the ignition key to the “RUN” position—do *not* start the vehicle. The ECM (electronic control module or computer) will then be placed into the “Field Service” state (see Fig. 1-1).

Once the ignition key is in “RUN” position, the “Check Engine” light should start to flash out code numbers, starting with a code #12, which is the default position or baseline. Code #12 is indicated by a single flash (representing the number one or first numeral in the number 12), followed by a pause, and then followed by two more flashes (representing the number two or second numeral in the number 12). The code #12 sequence will repeat three times (all code flashing sequences are repeated three times, in case you miss it!). If no malfunctions in the emissions system are found, no other trouble codes will be displayed, and the default or baseline code #12 will continue to repeat. In essence, a continually repeating code #12 means the computer system has passed all tests and nothing is wrong (that it can detect!).

However, if a malfunction is detected somewhere in the emissions system, a different trouble code will subsequently be displayed by the ECM after code #12 finishes flashing three times. Thus, when there is a malfunction, the flashing sequence changes, and the assigned malfunction-specific trouble code will now be displayed after the baseline code #12 is finished being displayed in a set of three repeating flashes in the pulsing sequence already described.

For example, a malfunctioning TPS sensor has been assigned a trouble code #21 by General Motors. If a malfunction in the TPS sensor was detected by the ECM, the specific malfunction trouble code (or fault code) assigned by General Motors (code #21 in this case), which is stored in the ECM’s memory, would cause the “Check Engine” light to flash in a code-specific sequence. In the example of a TPS sensor malfunction with a #21 trouble code, the following sequence would be displayed on the dash’s “Check Engine” light: A series of three code #12 pulses would flash, followed by a series of three sets of code #21 flashes (code #21 would be displayed as two flashes, a pause, and then a single flash). If the only malfunction in the emissions system

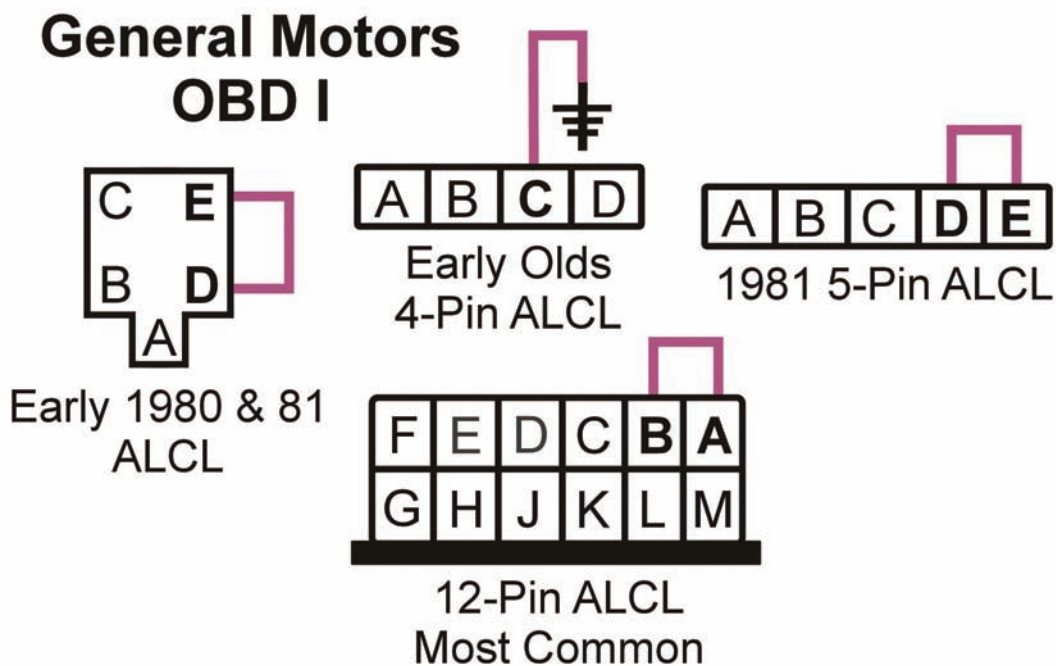


Fig. 1-1—General Motors used different Assembly Line Communication Link connectors (ALCL) in their OBD-I systems. In some service manuals this connector is referred to as the Assembly Line Data Link (ALDL) connector. By far the most common connector in use was the 12-pin ALCL. By placing a jumper wire between terminals “A” and “B” on the ALCL connector, the Electronic Control Module (ECM) was triggered into diagnostic mode. Also shown are two 5-pin (top left and top right) and one 4-pin (top center) data link connectors. Jumper wire connections are shown in purple.

was in the TPS sensor, trouble code #12 would flash, followed by three flashes of code #21 and then another series of three repeating baseline-code #12 flashes. Trouble codes #12 and #21 would each continue to flash out in their respective sequences until the ignition is turned off.

General Motors OBD-I systems are capable of displaying two types of codes: hard and soft. A hard code represents a malfunction actually found by the computer in one of the emission control-related systems as the computer scan is being performed. A soft code represents a malfunction that occurred sometime previously during prior operation of the vehicle. These soft codes are stored in the ECM's memory, but they do not represent current malfunctions that are actually present in a system at the time the codes are retrieved. Soft codes can be likened to intermittent codes, inasmuch as they have occurred at some interval(s) in the past, but are not currently occurring. A soft code is really nothing more than the computer displaying an old code stored in its memory that was once a hard code. Consequently, a technician viewing a soft code has no way of determining if the soft code represents an old malfunction that has already been repaired and a prior technician simply failed to erase the associated code, or a true intermittent malfunctioning component. Technically, the computer can actually only detect current malfunctions or hard codes and then store them in memory. Thus, for a soft code to truly represent a malfunction that occurs only intermittently, the malfunction must once again show up as a hard code.

To determine if a code is hard or soft, write down all the codes that are flashed out in the "Field Service" state (so you can subsequently reference them). Then clear the codes by erasing them from the computer's memory. This can be accomplished by disconnecting the battery (make sure the ignition key is in the "OFF" position when this is done or the computer can be damaged). Once the codes are erased, repeat the code retrieval process again as previously explained. Any flashing codes that are duplicates of the first set of codes will be actual hard codes, and will represent malfunctions that are detected by the computer to be currently occurring in various vehicle components. Any trouble codes that were present in the initial code retrieval test, but do not show back up in the subsequent code retrieval test, represent soft or intermittent codes. Any soft codes mean that code-specific malfunctions were detected on a previous

computer scan of emission control-related systems (and stored in the computer's memory as trouble codes), but are not presently detected to exist by the ECM during the subsequent testing. Thus, the malfunctions originally detected by the ECM are determined to be only intermittent (or potentially resolved) malfunctions that happened only during a previous driving condition.

In addition to enabling a technician or other user to read codes, an OBD-I system's "Field Service" state will also cause the ECM to energize solenoids and relays. This function is useful for determining if these components are working and are under the control of the computer. Some of the actuators that an ECM is capable of energizing in "Field Service" state are the exhaust gas recirculation (EGR) solenoid, the canister purge, and the radiator coolant fan. The idle air control motor will "seat," or move into its closed position, on all 1987 and later model port-fuel-injected (PFI) and throttle body-injected (TBI) engines. On certain pre-1987 General Motors vehicles equipped with TBI engines, the ECM in its "Field Service" state will cause the idle air control, once energized, to move in and out. Again, the significance of such a test is to determine if the ECM can control these components, and that they are, in fact, working.

Whenever an engine is started in the "Field Service" state (leave the paper clip in the ALDL connector), the "Check Engine" light will flash rapidly, at a rate of approximately 2.5 times per second, indicating closed loop operation. Closed loop mode occurs when the ECM and oxygen sensor form an informational loop—the oxygen sensor senses exhaust gas oxygen content and relays this information to the ECM. Based on the relayed information, the ECM corrects the fuel mixture and the process is repeated. By contrast, when the engine goes into open loop operation mode (where the oxygen sensor's input to the ECM is ignored) the "Check Engine" light will flash only once per second. (Additional information on open and closed loop modes of engine operation can be found in chapter 3.)

In addition, when the "Check Engine" light is on and when it is off is a significant test function as well. In closed loop operational mode, when the light is "ON," oxygen sensor voltage will register high—above .45 volts, indicating a rich air/fuel mixture. When the "Check Engine" light is in the "OFF" position, the oxygen sensor voltage will register low—below .45 volts, indicating a lean air/fuel mixture. Knowing whether the oxygen sensor voltage is low or high is useful for determining if the oxygen sensor is switching

at a proper rate, as it should whenever the vehicle is in closed loop mode. The knowledge also helps determine if there are any other malfunctions in the fuel system. (Again, be sure to consult chapter 3 for additional in-depth discussion of open/closed loop operational modes and oxygen sensor operation.)

General Motors—“Back-up” Diagnostic State

The General Motors OBD-I system is set to automatically revert to “Back-up” state if one of its sensors fails during vehicle operation. Also known as the “limp-in” mode, the “Back-up” state allows a computer system that is operating in a less-than-perfect manner to attempt to keep the engine running long enough to get the vehicle to a place where it can be repaired without leaving the driver stranded on the road. While in “Back-up” state, spark advance is fixed, resulting in a lack of engine power; the effectiveness of the fuel delivery system is determined only from input based on rpm and input from the coolant sensor and throttle position sensor. Information from other sensors is ignored. In other words, even without all of the computer sensors operational, and that are normally required for engine management, the ECM will still try to keep the engine running based on minimal information. The ECM can be placed into “Back-up” state by placing a 3900 Ohm resistor between Pins “A” and “B” on the ALDL (or ALCL) connector (the same pins used for retrieving trouble codes). On port-fuel-injected cars that cannot be started, placing the ECM into “Back-up” state may get the engine started. If so, this usually indicates a faulty mass airflow sensor (MAF) or defective ECM.

General Motors “10k” or “Special” State

The “10k” or “Special” state is useful for taking readings of rpm or ignition timing, as this state serves to stabilize the engine. It can make diagnosis easier to understand. It is also useful whenever the need arises to compare one vehicle’s readings against another’s. Once in “10K” or “Special” state, the ECM will bypass its own internal timer and allow the system to go directly into closed loop mode without the customary delay, stabilizing the engine. Ignition timing (spark advance) is also fixed at a predetermined point, further stabilizing the engine. Idle speed is fixed at 1,000 rpm. Thus, a beneficial consequence of fixed spark timing and fixed idle speed is that readings between different vehicles can be compared and interpreted more easily, and are more consistent.

General Motors—“Road Test” or “Open” Diagnostic State

Normal vehicle operation takes place in the “Road Test” or “Open” diagnostic state. In this diagnostic state, there is no need to use a jumper wire on the ALDL. In this state, the ECM performs all normal idle speed and spark advance control functions. If the ignition timing or the idle speed needs to be checked, placing the ECM into “Road Test” state will facilitate testing. Most scan tools are capable of automatically reading all ECM data in this state. However, it should be noted that the ECM computers on some older model General Motors vehicles are not capable of outputting all data information in “Road Test” state, as this function is not programmed into their software. Consequently, the lack of data may indicate that something is wrong with the ECM, when it’s not.

FORD MOTOR COMPANY— OBD-I SYSTEMS (EEC-I THRU IV)

In 1983, Ford Motor Company introduced its fourth-generation Electronic Engine Control (EEC-IV) system. Prior to the release of the EEC-IV, all Ford vehicles were equipped with either EEC-I, II, or III electronic carburetor systems, or MCU (microprocessor control unit) carbureted systems. These early systems were quite limited in their ability to self-diagnose much of anything. We hope that most of the cars and trucks that used them are now permanently retired in junkyards. The EEC-IV system and electronic fuel-injected systems



This ABS diagnostic link connector was used on Ford Motor Company vehicles from the early 1980s until 1995. This Ford connector is identical to the Ford OBD-I engine management connector, except for color. On Ford vehicles, the OBD-I connector is black or gray, and located “somewhere” under the hood, at least according to most component locator manuals. *Courtesy Elwood’s Auto Exchange*

were a much-needed improvement over predecessor models, as they could perform several self-tests as well as generate and store trouble codes. A data stream could also be displayed if a scan tool was used as well.

The OBD-I systems on EEC-IV vehicles are capable of performing four basic self-diagnostic tests: 1) “Key On/Engine Off” self-test (“KOEO”); 2) “Continuous Memory” (“CM”) self-test; 3) “Key On/Engine Running” self-test (“KOER”); and 4) several miscellaneous EEC-IV-related self-tests.

Ford Diagnostic Testing—“Key On/Engine Off” (“KOEO”) Self-Test

We’ll start with the most common series of tests—the “Key On/Engine Off” or “KOEO” self-tests. The “KOEO” tests are designed to monitor and/or test various components and circuits controlled by the Electronic Control Assembly, or ECA. Prior to commencing any “KOEO” self-test, the engine must be at normal operating temperature for all testing, so be sure to take the car for a

short test drive first. To start a self-test, connect a jumper wire between Pin #2 on the Self-Test Connector and the Self-Test Input (STI) connector. A test light should then be connected between Pin #4 on the Self-Test Connector and battery positive (See Fig. 1-2). The code sequence can be read by either watching the test light flash, or by observing the “Service Engine Soon” light located on the dash on later model EEC-IV vehicles (earlier vehicles may or may not have a “Check Engine” light to perform this function).

With the test light and jumper wire in place, turn the ignition to the “RUN” position. The test light will flicker and then flash out the “On-Demand” codes. “On-Demand” codes are not stored in the ECA’s memory, but rather, they represent hard codes (or “Hard Faults”) that are occurring contemporaneous with test procedures. “On-Demand” codes consist of only two digits on vehicles up to 1991, but show three digits on all 1991 to 1995 cars and trucks. “On-Demand” codes will flash out in sequence from lowest to highest. If no codes are

Ford OBD I

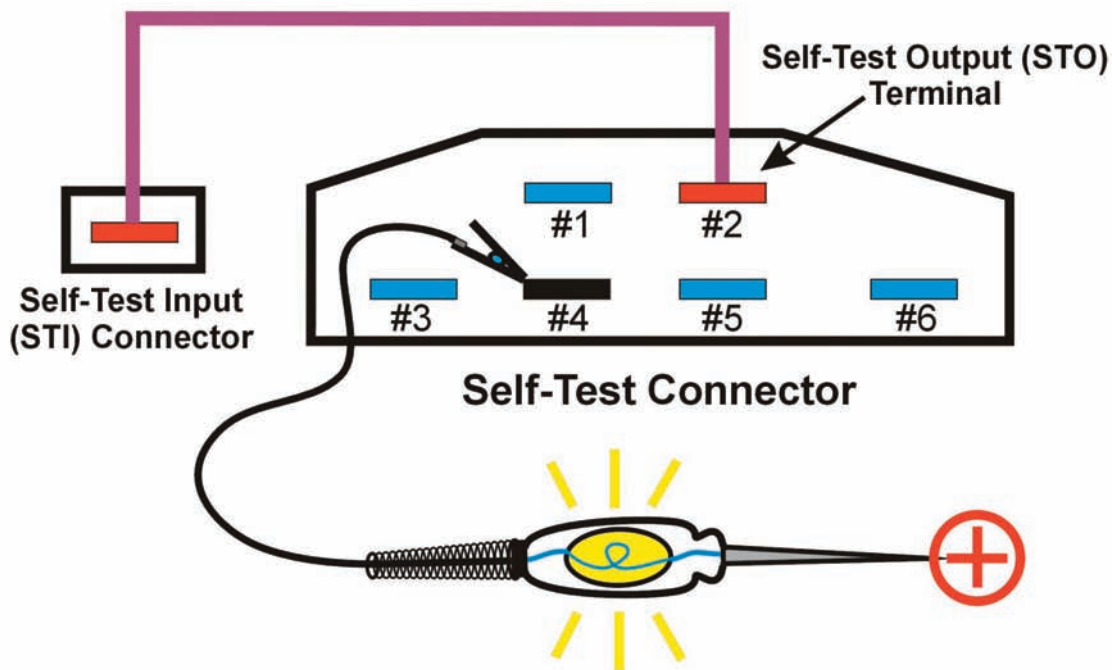


Fig. 1-2—Depending on the vehicle, the Self-Test Connector on Ford vehicles is located in different places under the hood, and can be either black or gray in color. A jumper wire connected between Terminal #2 (self-test output) and the self-test input (STI) connector will place the ECA (Electronic Control Assembly—Ford’s name for its on-board computer) in self-test mode. A test light connected as shown in the illustration will then flash out the trouble codes. On later model vehicles (after 1986) the “Check Engine” light takes the place of a test light for purposes of reading codes.

present, a “Pass” #11, or code #111, will flash. After a six-second pause, the ECA will then output a separator code #10 (a single flash). The separator code simply serves to separate the “On-Demand” codes from other codes to follow. After another six-second pause, the “Continuous Memory” codes (those codes stored in the ECA’s memory) will then flash out. These codes represent soft codes (or “Soft Faults”), or malfunctions that occurred during past vehicle operation but are no longer present during current test procedures. If no “Continuous Memory” codes are present, a “Pass” #11, or code #111, will again flash.

Once any problems have been repaired, all trouble codes should be erased from the ECA’s memory so that some poor technician at a later time doesn’t chase after malfunctions associated with what appear to be soft codes that are really not problems any longer. To erase all trouble codes, start the “KOEO” self-test, and as soon as the codes commence to flash out on the test light, simply unplug the jumper wire between the STI connector and the Self-Test Connector. This will erase all existing codes. Another method that accomplishes code erasing is to simply disconnect the battery for at least 10 seconds. However, it should be noted that disconnecting the battery causes the ECA to lose its adaptive memory, which may cause the engine to run roughly. Consequently, after disconnecting the battery, a “Re-Learn” procedure should be performed. Consult a vehicle-specific service manual for a detailed explanation on how to perform this procedure, as it is not the same for different years or models of Ford vehicles.

Ford Diagnostic Testing—“Output” State Self-Test

Once the “On-Demand” and “Continuous Memory” codes have been displayed, a self-test in the “Output” state can be performed. This self-test checks the ECA’s ability to control various EEC-IV solenoids and is useful to determine if the ECA and its controlled components are working properly, or at all. To energize or turn on the solenoids, open the throttle and then quickly close it. To deactivate or turn off the solenoids, open and close the throttle again. This is a good test for verifying proper electrical and mechanical operation of the EEC-IV system’s solenoids.

Ford Diagnostic Testing—“Key On/Engine Running” (“KOER”) Self-Test

The “Key On/Engine Running” (“KOER”) self-test is similar to the “KOEO” self-test, only this time the engine must be running. To perform a “KOER” self-test, make sure the engine is hot. Connect a test light

and jumper to the Self-Test Connector in the same manner as was performed in the “KOEO” self-test, and then start the engine. The ECA will pulse (flash) an engine ID code—two pulses for a four-cylinder engine, three pulses for a six-cylinder engine, and four pulses for a V-8 engine. Engine ID codes don’t have anything to do with the self-test—they are simply confirming the type of engine in use.

After the engine ID code pulses, a pause that lasts between 6 and 20 seconds will follow. On most vehicles, a “Dynamic Response” code #10 (a single flash) will then appear. You now have about 15 seconds to “goose” (Ford’s actual terminology!), or snap open, the throttle. The ECA will monitor any changes in engine rpm, TPS voltage, and MAP frequency in response to the throttle opening, and will determine if anything is amiss. If any of the responses received are not what the ECA expects, a new trouble code will then be pulsed to indicate a problem with one of its sensors.

Once the “goose” test is complete, the test light may flicker. After that, there will be another six-second pause. The “On-Demand” codes will flash out next. If there are no “On-Demand” codes, a “Pass” #11, or code #111, will flash. After the “On-Demand” codes have finished flashing, a computed timing self-test can be performed next. The ECA will fix the ignition timing for two minutes at 20° (+/-3°) above base ignition timing, allowing ignition timing to then be checked with a timing light for accuracy.

Ford Diagnostic Testing—The “Wiggle Test”

A Ford “Wiggle Test” is a good way to find intermittent electrical problems with a computer system’s wiring harness and connectors on Ford OBD-I vehicles. Perform this test only after any “Continuous Memory” codes have been erased. That way, no invalid or misleading soft codes will display and only current malfunctions can be detected. To put the ECA into “Wiggle Test” mode, connect a test light to the self-test connector in the same manner as was performed in the “KOEO” self-test (vehicles with a “Check Engine” light do not require a test light for monitoring). Turn the ignition to the “ON” position. Connect a jumper wire between Pin #2 on the Self-Test Connector and the STI connector. Next, remove the jumper and then immediately reconnect it in the same place. If the ECA detects any intermittent shorts or “opens” in any of its sensor circuits, the “Check Engine” light, or test light will momentarily flash. With the ECA in “Wiggle Test” mode, the



In Ford's "Wiggle" self-test mode, the ECA (computer) will flash if there are any "opens" or shorts in any computer wiring. A screwdriver handle is used to "beat" on sensors and connectors, and the heat gun will cause connectors to expand. Heating or tapping on sensors and connectors is a good way to stress electrical connections and amplify any connector problems.

wiring harness can be "wiggled" and/or the computer sensors can be tapped with a screwdriver handle or heated with a heat gun. Again, if the ECA detects an electrical short or "open," the "Check Engine" light will flash. Just like the "KOEO" and "KOER" self-tests, the "Wiggle Test" can be performed during a test drive.

Ford Diagnostic Testing—"Power Balance" Test

On any model of Ford vehicle equipped with a sequential fuel-injection system, an OBD-I diagnostic system can perform a cylinder "Power Balance" test. This will test the engine's mechanical condition. After the "On-Demand" codes have finished pulsing, hold the engine idle speed above 1,000 rpm for two seconds in order to initiate a "Power Balance" test. Then let the engine return to idle. The ECA will then perform the first level of its "Power Balance" self-test. During this test, the ECA is looking for

the same drop in rpm each time it shuts off a cylinder's injector. Thus, once a cylinder's fuel injector is turned off, the computer reads the rpm drop; the computer then does the same thing to each fuel injector sequentially. If all of the fuel injectors show the same rpm drop when they are shut off, the test is successfully passed and a code #9 (nine flashes) will be pulsed. If any one of the cylinders fails the test, that cylinder's number will instead be flashed, i.e., if cylinder #3 fails the test, the test light will flash three times, etc., respectively). If any cylinder fails, the "Power Balance" self-test can be repeated at the next level of sensitivity by snapping the throttle open. Each level of sensitivity will lower the amount of acceptable rpm drop that the ECA looks at. Again, any cylinder that fails will be indicated by an appropriate series of pulses in the test light. Snapping the throttle open again at a higher (third) level will render the test even more sensitive to the drop in rpm measured by the vehicle's ECA.

DAIMLERCHRYSLER CORPORATION— OBD-I SYSTEMS

Chrysler introduced its version of electronic fuel-injection systems into its vehicles in late 1983. The names and numbers of computers it has employed over the years have frequently changed. Between the years 1983 and 1987, Chrysler's on-board computers were made up of two separate units: a "Logic Module" and a "Power Module." The "Logic Module" was the smarter of the two, essentially serving as the brains of the system since it contained a tiny microprocessor chip that received data from various sensors. The "Logic Module" was usually located on the right-hand passenger-side compartment, behind the kick panel. In contrast, the "Power Module" was typically located under the hood, near the battery, and was a mere servant, taking its instructions from the "Logic Module." The "Power Module" was responsible for switching actuators on and off, including the fuel injectors, ignition coil, fuel pump, etc. Beginning in 1987, and until 1990,

Chrysler introduced and used a "Single Module Engine Controller" model, or "SMEC." This computer used two separate circuit boards housed inside a single plastic case. However, from 1989 to 1995, with improved technology the two circuit boards were combined into a single unit called a "Single Board Engine Controller" or "SBEC." Even Chrysler's OBD-I dash warning light underwent name changes—initially called a "Power Loss" or "Power Limited" light, its name changed when the "SMEC" system came into being. Thereafter, the light was called a "Check Engine" light—the same name employed by General Motors.

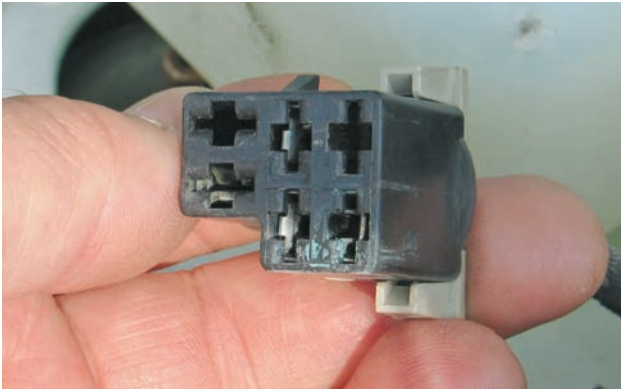
Unfortunately, the number of tests that can be performed, and the corresponding information that can be generated using only a "Power Loss" or "Check Engine" light on Chrysler vehicles, is somewhat limited—basically these systems are only capable of reading trouble codes. The good news is that if the scanner being used to test an older Chrysler OBD-I system has OBD-I capabilities and is used in conjunction with a



This Actron CP9190 scan tool can interface with most domestic OBD-I vehicles. The OBD-I connectors included with the tool are (left to right) for the following: Chrysler/JEEP, General Motors, Ford, and OBD-II. It is also capable of reading OBD-II and CAN data from any vehicle from 1996 or later. *Courtesy Actron*

This Chrysler "Power Module" was used to activate the ignition coil and other solenoids. It received instructions from a companion "Logic Module" (not shown). The large opening at left is the location of the air intake for the engine. When the vehicle was in use, moving air passed over the electronics inside the power module and kept everything cooled off.





Pictured is Chrysler's OBD-I data link connector. Located under the hood in all vehicles, it was often difficult to find. This connector was used from the early 1980s until it was replaced in 1996 by the newer OBD-II DLC connector. *Courtesy Elwood's Auto Exchange*

Chrysler-compatible cable adapter, there are numerous functional tests that can be performed. Codes and sensor data can also be accessed.

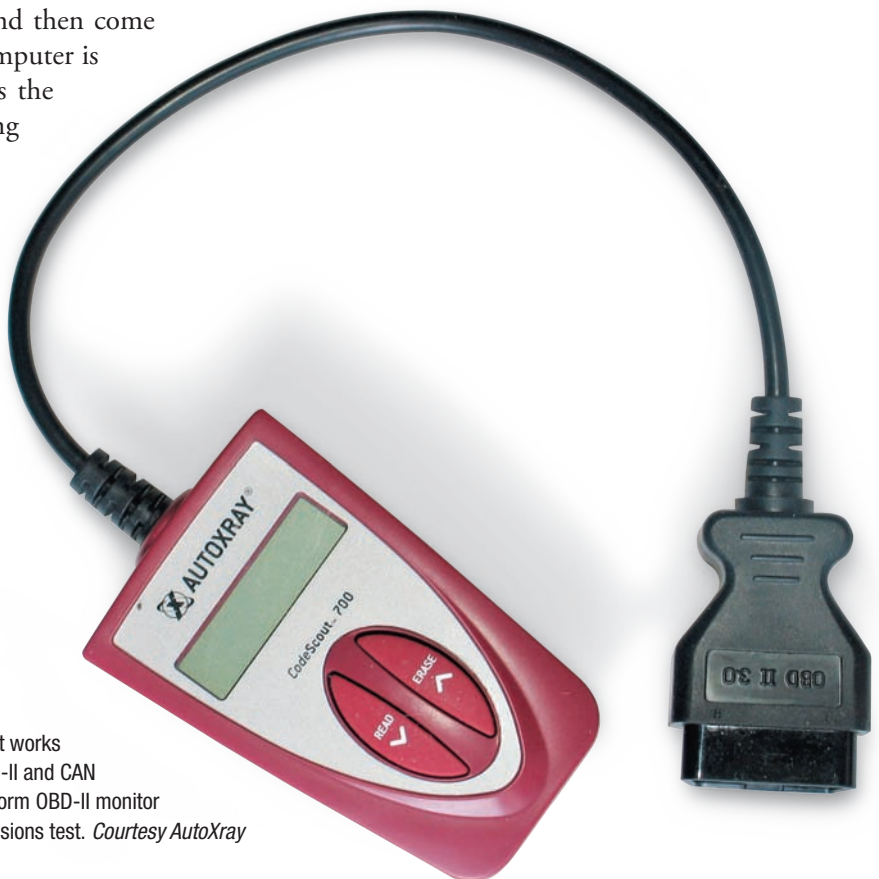
To access codes via use of the "Power Loss" light or "Check Engine" light, turn the ignition key to "ON" and then to "OFF," and then on and off again, and then finally leave it on. This will put the system into diagnostic mode. After accessing diagnostic mode, the "Power Loss" light will momentarily go out, and then come back on for about two seconds. The computer is performing a "bulb check," which tests the computer's ability to control the warning light. There will be a brief pause, and then the light will begin pulsing out the diagnostic trouble codes, which will end with Code #55—indicating the end of the sequence. Later model Chrysler vehicles equipped with an "SMEC" computer will pulse code #88, which will start the trouble code sequence; similar to the earlier bulb test, the code sequence will end with code #55. Any codes displayed between beginning code #88 and ending code #55 are trouble codes. All

Compared to professional scan tools of the past, not to mention most of the scan tools available today, this AutoXray CodeScout 700 is a bargain at around \$90. It works on all vehicles from 1996 and later, and can read OBD-II and CAN diagnostic trouble codes, as well as erase codes, perform OBD-II monitor tests, and indicate if a vehicle will pass or fail an emissions test. *Courtesy AutoXray*

codes can subsequently be erased by disconnecting the battery for at least 10 seconds.

Once the computer has finished outputting all of the trouble codes, a "Switch" test can be performed. Switched outputs include stepping on the brake pedal, turning the air conditioning switch on and off, or moving the transmission gear selector on a pre-1990 automatic transmission-equipped vehicle. Operating any switched output will cause the "Power Loss" light to either turn on or off. On vehicles equipped with a combination "Power Module/Logic Module" type of electronic computer system, rotating the front wheels, while at the same time counting the number of times the "Power Loss" light goes on or off, will test if the vehicle speed sensor is functioning. One wheel revolution should equal the equivalent of eight on/off cycles.

With the use of a scan tool, an Actuator Test Mode (ATM) can also be accessed on OBD-I-equipped Chrysler vehicles. In ATM test mode, various actuators can be operated via inputs from the scan tool. For example, the ignition coil can be made to produce a spark. Alternatively, the fuel injectors can be cycled off and on, or the idle speed controllers can be made to



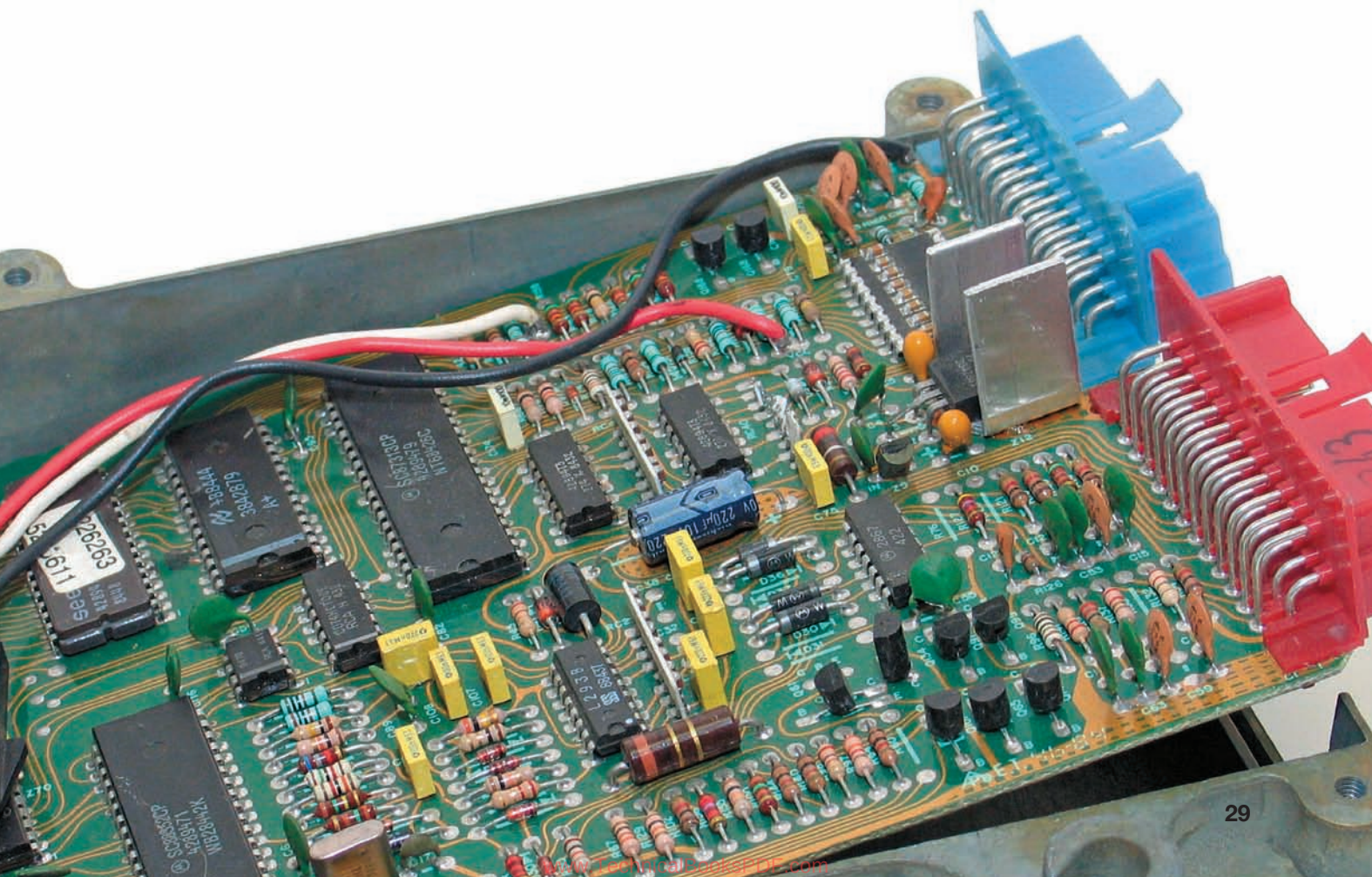
operate, as can a whole host of other solenoids and relays. On later model vehicles, even the gauges on the instrument panel can be operated with a scanner tool, along with many other components.

THE END OF OBD-I DIAGNOSTICS AND THE FUTURE OF OBD-II

By 1988, some version of the first generation of OBD-I computer systems was present in all cars and light trucks sold in the US. However, as seen, there was no standardization between automakers with regard to OBD-I form, function, or technology. In fact, about the only thing the early OBD-I computers had in common with each other was that they all had some type of dash indicator warning light that was supposed to illuminate whenever the electronic-controlled computer system detected a problem. The first generation of OBD-I computers was designed, in part, to let drivers know whenever a malfunction existed that affected the emissions coming from the tailpipe.

However, unlike the first generation of OBD-I computers, the second generation of OBD-II on-board computers now serves primarily as on-board emissions

testers. Technology has improved to the point where the reliability of modern OBD-II computers assures functional monitoring of emissions systems every time the engine is started. These systems are so effective that many states have completely eliminated the old drive-through, “sniff-the-tail-pipe” emission tests of yesteryear on those vehicle models manufactured in 1996 or later. Given modern OBD-II systems’ abilities to detect and store information for subsequent retrieval, myriad problems are simply and easily communicated to each state’s emissions’ testing program facilitators simply by the act of plugging in a universal OBD-II diagnostic link connector and watching the data stream pour forth. These problems range from a loose gas cap to a misfiring spark plug, or disconnected vacuum hose to a bad computer sensor. In addition to easier emissions testing, the second generation of OBD-II on-board computers provides a much-improved diagnostic tool for both professionals and home technicians alike, by enhancing their abilities to diagnose most engine performance-related problems.





Chapter 2

OBD-II On-Board Emissions Monitor

TRANSITIONS: FROM OBD-I TO OBD-II

In 1988, the California Clean Air Act was signed into law by the governor of the state. This new law set forth all the various rules and regulations for statewide management of air quality for the next 20 years. As part of these new regulations, the specifications for standardization of second-generation OBD-II on-board diagnostics were implemented. Liking what it saw in California, the United States Congress subsequently amended its federal Clean Air Act in 1990, and in so doing, included California's provisions mandating standardization of OBD-II on-board diagnostics. The target date for uniform federal OBD-II implementation was 1996; the law specified that by this date all manufacturers had to achieve 100 percent OBD-II compliance for all vehicles sold in the United States. It's important to remember that OBD-II as originally conceived was not an engine management system, but rather, was simply a set of emissions-related rules and regulations that automakers were required to follow in the manufacture of all passenger cars and light trucks bound for the United States.

The standardization of OBD-II technology came on the heels of efforts to control the quantity and quality of automobile emissions via the first generation of OBD-I on-board computers. While the installation of OBD-I computers on some manufacturers' vehicles was certainly a step in the right direction, the consumer and governmental pressure placed on automobile manufacturers to limit auto emissions was not sufficient to force voluntary compliance within set guidelines, or for that matter, at all. Thus, automakers' efforts to curb emissions were not a big success, especially when it came to the practical reality of independent repair shops attempting to repair vehicles with malfunctioning emissions systems.

Because California's OBD-I state regulations were "loose," to say the least, and in view of the fact that all other states did not have any regulations whatsoever that attempted to control or limit automobile emissions,

manufacturers only did the bare minimum (more or less) required by the California Air Resources Board (CARB) and the EPA, and no more. With no uniformity between automakers, each manufacturer devised its own technology and procedures for utilization of OBD-I systems to monitor emissions and to warn drivers of emission-related problems. Independent repair shops were faced with the prospect of having to purchase expensive diagnostic tools (scanners) and related computer software that only worked on a few models of vehicles they might be required to repair. Compounding the harsh economic reality facing independent repair shops trying to stay a step ahead of increasing OBD-I usage, was the fact that different original equipment manufacturers (OEMs) required separate software cartridges as well as numerous specialized cables and adapters that had to be used in order to read a specific vehicle's OBD-I codes and data. The absence of readily available information, in the form of OEM repair manuals, parts' specifications, or manufacturer's recommended tests and procedures, only made matters worse.

Consequently, the \$9 billion US automotive aftermarket industry could see the handwriting on the wall if automakers were allowed to continue this trend to have it their own way. Obviously, there was greater economic incentive for automakers to keep everything on a proprietary basis, rather than to push the trend toward uniform standardization of on-board diagnostic systems to establish minimum emissions' controls standards. In this way, OEM's could control access to repair information and limit on-board vehicle communications (scanner interfaces) for their exclusive use, thereby essentially forcing automobile owners to take their vehicle(s) to a new car dealer for any and all emissions-related repairs. In addition, it was not inconceivable that auto manufacturers would have strong incentive to place individualized computer chip technology into all vehicle electronic components, thereby effectively cutting the aftermarket industry out of the electronic parts replacement marketplace, as well as severely limiting purchasing decisions for consumers.



Imagine purchasing a mass airflow sensor from a local auto parts store and installing it into a vehicle, only to learn after the fact that the vehicle's unique on-board computer searched in vain for an "ID" chip from Ford, GM, Chrysler, Toyota, or Honda, etc., which it could not find. Consequently, the new airflow sensor would not be recognized by the OBD-I system as a suitable original equipment replacement part, and as a result, the OBD-I computer would consequently turn on the "Check Engine" light, or worse, prevent the car from starting altogether. While this may sound like a science fiction nightmare, the reality was that the technology that existed in the mid-1990s was specifically designed so that this repair/replace scenario, and others similar to it, would routinely occur, leaving the consumer confused, frustrated, and trapped, and at the mercy of auto manufacturers' increasingly secretive and ingenious design technology.



Independent auto repair shops would have had an increasingly difficult time repairing customer vehicles if OEMs had not been "persuaded" by the government to share and standardize diagnostic and repair information. However, even today, new car dealerships still have an advantage over independent repair shops, since proprietary factory codes and data are still far more comprehensive than what is available through the aftermarket industry. *Kiplinger's Automotive Center*

Fortunately, not all OEMs were as shortsighted as suggested by the previous example. In the early 1990s, Nissan and a few other manufacturers performed valuable marketing surveys on their existing customers. They learned that if a customer's Nissan vehicle was easily repaired by a dealership, or more importantly, by an independent repair shop, the customer was more inclined to be satisfied with the purchase, and more likely to purchase another Nissan vehicle, and/or recommend such a purchase to friends or family. Not surprisingly, vehicle ease-of-repair was a top factor in consumers' decision-making processes as to whether or not to purchase another vehicle of the same brand. These



OBD-II ON-BOARD EMISSIONS MONITOR

Scan tools like this OTC Monitor 4000E made it possible for independent auto repair facilities to compete with new car dealerships for vehicle owners' repair business. As a beneficial result, vehicle owners gained the option of having choices as to which facility to use to get a vehicle repaired. In addition to reading trouble codes and data streams, professional scan tools such as this also offer tune-up specifications and troubleshooting tips.

marketing surveys also forced auto manufacturers to face the flip side of the coin. If a particular vehicle proved to be difficult or costly to diagnose and/or repair, especially by the aftermarket repair industry, the customer was inclined to blame the manufacturer for the problem, and not the independent repair shop.

As a result of these marketing surveys, Nissan rose to the challenge and ensured Nissan training materials and Nissan-specific technical information was available to independent repair facilities. In the process, Nissan also provided the aftermarket industry with access to materials that were previously solely proprietary.

Another more obvious factor that kept automakers from precluding the aftermarket repair industry from technical information about developing automotive computer technology was that the sheer number of cars and trucks requiring maintenance and/or repair was expanding. The economic good news for everyone involved was, quite simply, that if independent repair shops were driven out of business and forced to close, automotive dealerships would become so overwhelmed with business that a minimum six-month waiting period for consumers to have vehicles repaired would have ensued. Ultimately, this would have led to extremely angry customers, who would naturally focus their anger on automotive dealerships and manufacturers.

Fortunately for everyone, this potential nightmare never materialized. In the final OBD-II mandates enacted by Congress in 1997, auto manufacturers were required

to provide the aftermarket industry with access to essential emissions control-related technical information and materials. A passage in the EPA Federal Register reads: "Manufacturers are required to make available to the aftermarket any and all information needed to make use of the OBD system, and such other information, including instructions for making emission-related repairs, excluding trade secrets." The legislative intent behind the phrase "any and all" in this passage was to include emissions control-related technical information, software reprogramming capability, essential electronic test equipment, and relevant training information. This specific OBD-II mandate from Congress in 1997 is the sole reason vehicle owners can now easily purchase any aftermarket scan tool or code reader, plug it into any vehicle, and read the OBD-II codes and other relevant associated computer information.



New car dealerships still have greater detailed diagnostic information available to them than is available to independent auto repair facilities, since proprietary codes and data streams can still only be read by OEM-approved equipment. Nevertheless, the ability to diagnose difficult emissions and engine performance problems has always come down to the skill and capabilities of the technician who is performing the work, and is not solely a function of the type of equipment used. *Courtesy Younger Toyota*

STANDARDIZATION

In April 2002, the Society of Automotive Engineers (SAE) published a document known as Number J-1930, which specified that manufacturers must use and define standardized automotive terms. Included within the scope of J-1930, as written, is the following clarification: “This document focuses on diagnostic terms applicable to electrical/electronic systems, and therefore also contains related mechanical terms, definitions, abbreviations, and acronyms.” This clause means that standardized trouble codes were mandatory, and that all manufacturers would be required to use the same definitions on every OBD-II vehicle. In addition, automotive terminology, acronyms, and emission testing procedures were also required to be standardized.

For example, a scan tool could be connected to a diagnostic link connector (DLC), and a specific (hypothetical) diagnostic trouble code (DTC) would be displayed as “#P0401.” This specific diagnostic trouble code would be universally defined as an “Exhaust Gas Recirculation Flow Insufficient Detected.” The benefit

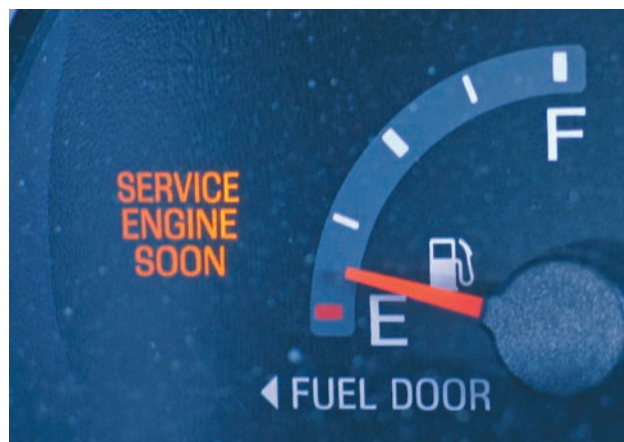
of all this standardization for technicians was uniformity, predictability, and reliability. Thus, every term and acronym utilized in connection with an OBD-II system on any vehicle would mean the exact same thing on a 1996 Pontiac Trans Am as on a 2007 Mercedes Benz CLK550 Cabriolet, or even a 2001 Toyota Corolla.

MALFUNCTION INDICATOR LAMP (MIL)

Every time an OBD-II-equipped vehicle is started, the OBD-II system scrutinizes the engine management system and waits for something bad to happen. If a malfunction occurs, a malfunction indicator lamp (MIL) serves as the sole communication between the OBD-II system and driver. An MIL indicator light comes in several variations on a theme, including: “Check Engine,” “Check,” or “Service Engine Soon.” The MIL light is programmed to turn on whenever various systems experience a malfunction that might increase exhaust emissions by 50 percent or more above levels measured and predetermined by Federal testing procedures when the vehicle was new. However, potential tailpipe emissions are not the only reason an MIL might light up—malfunctions associated with other systems, such as electronically controlled auto-matic transmission systems, climate control systems, body system control, and others, will all cause an MIL to come on. Excluding mandatory emissions-related malfunctions, which an OBD-II system



Today, standardization of automotive on-board computer diagnostic systems makes it possible for anyone with an OBD-II-compliant code reader or scan tool to take a peek inside a vehicle's powertrain control module (PCM). Fortunately, it no longer matters if the vehicle being worked on is a General Motors, Ford, Jeep, Mazda, or even a Mercedes Benz model, as they all have the same standard diagnostic connector link (DCL) into which an OBD-II-compliant scanner can plug. *Courtesy Mercedes Benz of Hagerstown*



A “Service Engine Soon” light is the only way an OBD-II system can communicate with a driver about a malfunction occurring within a vehicle's emission system. Unfortunately, when a malfunction occurs, and the “Service Engine Soon” light lights up, the vehicle owner usually wants the light turned off as soon as possible, and is not particularly interested in repairing the vehicle, especially if the repairs might cost a lot of money. While this scenario was frequently feasible with older OBD-I system vehicles, it is much more difficult for automobile owners today (given the greater level of diagnostic capabilities of the newer OBD-II systems) to make a viable option of ignoring warning lights.

must monitor and convey to a vehicle owner via an MIL light, each manufacturer can independently decide what other malfunctions can illuminate an MIL.

An MIL functions in the following manner: When the ignition is first turned to the “RUN” position, but the engine is not yet started, the MIL will light up. Some automakers have designed the MIL to stay on until the engine is started, while others have programmed it to turn on and then immediately off after only a few seconds. Once the engine is started, and assuming no potential problems with emissions are detected, the MIL will turn off and stay off, until the engine is started again. All MIL lights are designed so that once an engine is running, the MIL normally remains off.

If a malfunction is detected in any of the emission systems, the MIL will flash in different patterns, depending upon the severity of the problem. Minor problems probably will not cause an MIL to come on at all. A single quick flash of an MIL light usually indicates a momentary malfunction that could *potentially* cause high emissions. Drivers usually do not see this type of quick flash, unless they happen to have been looking directly at the MIL at the time. A quick flash of the MIL means a malfunction was detected in a system, but it was not serious. Fortunately, the diagnostic trouble code (DTC) for the specific malfunction will be stored in the OBD-II system’s memory for later retrieval via a scan tool or code reader.

However, if an MIL stays on while a vehicle is operational, it typically indicates an ongoing emissions-related problem that should be repaired as soon as possible. The most serious emissions-related problems cause a MIL to flash rapidly. Such rapid-flash sequences mean the vehicle is spewing out pollutants at a high rate. When this type of scenario occurs, the car may be drivable, but severe damage could be occurring to vehicle components, especially the catalytic converter. This type of situation should not be ignored, as the car or truck will continue to pollute unless repairs are made; in addition, the catalytic converter may have to be replaced (and no consumer wants this, as the converters are quite expensive). Unlike earlier OBD-I systems, which couldn’t even tell if a catalytic converter was present, much less operational, a damaged “cat” (catalytic converter) in a OBD-II-equipped vehicle will cause the OBD-II system to continually set a diagnostic trouble code until the malfunction is repaired. As a result, failure to repair an emissions-related malfunction on an OBD-II vehicle will prevent the vehicle from

passing an emission test—and in most states, no pass means no vehicle registration.

SCAN TOOL COMMUNICATION

Most OBD-I systems relied on a manual procedure to retrieve trouble codes. The procedure involved counting the number of flashes an MIL or “Check Engine Soon” light emitted. By contrast, OBD-II systems do not flash out diagnostic trouble codes (DTCs) via the “Check Engine” light. Instead, DTCs are only read with a scan tool, code reader, laptop, or desktop computer with appropriate software. OBD-II systems must have



Say “thank you” to the EPA for mandating that automakers provide a standardized method of communication between OBD-II systems and non-factory OBD-II-compliant scan tools and code readers. Without standardization, owners, auto enthusiasts, and independent mechanics would be excluded from performing engine diagnostic work and repairs; even something as simple as turning off a “Check Engine Soon” light would be a “dealer only” proposition. *Courtesy AutoXray*



In view of the fact that independent repair shops could only use aftermarket scan tools as their sole and exclusive means of digital communication between a scanner and OBD-II vehicle, communication methods had to be standardized. Standardization enabled scan tool manufacturers to design scanners compatible with any OBD-II vehicle. Scan tool communication is accomplished by a protocol that is governed by a set of rules and procedures that regulate data transmission between computers, as well as between test equipment (scan tools) and computers. Today, there are five communication protocols in use on OBD-II vehicles: 1) ISO-9141-2; 2) SAE J-1850 PWM; 3) SAE J-1850 VPM; 4) Keyword 2000; and 5) CAN, or controller area network. Fortunately, most scan tools automatically determine which protocol is in use, and are then able to immediately display codes and/or a data stream from a vehicle's powertrain control module (PCM). Here is a brief description of each protocol:

- **SAE J-1850 PWM**—The Society of Automotive Engineers J-1850 Pulse Width Modulation (PWM) protocol is commonly used by Ford Motor Company on all of its domestic vehicles, as well as by Jaguar and Mazda. The speed at which data can be sent is 41.6 kilobits per second—four times faster than the ISO protocol.
- **SAE J-1850 VPM**—The Society of Automotive Engineers J-1850 Variable Pulse Width Modulation (VPM) protocol has been used by some DaimlerChrysler vehicles and most General Motors vehicles since 1998. Data transfer rates are 10.4 kilobits per second (same as ISO).
- **Keyword 2000**—The Keyword 2000 (ISO 14230) protocol is used mostly on vehicles manufactured and sold in Europe in the last year or two. Data transfer rates are 10.7 kilobits per second.
- **CAN**—The Controller Area Network protocol was developed by Bosch and is a recognized international standard (ISO-11898) that is used on all 2004 and subsequent model years of Ford, Mazda, Mercedes, and Toyota vehicles. The CAN protocol became mandatory on all vehicles manufactured in 2008 and later. CAN is the “hot rod” of OBD-II protocols because its data transfer rate is one megabit per second—over 100 times faster than most other protocols.

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CONTROLLER AREA NETWORK—CAN

A controller area network consists of multiple system components that use micro-controllers to communicate with each other. These communication systems are similar to integrated cable networks found in business offices, where desktop computers, file servers, printers, and digital phone systems all connect to, and communicate with, each other. However, controller area networks predate many office systems, as they were found as early as 1992 on some Mercedes Benz models, and in 1993 on BMW's 740i/iL.

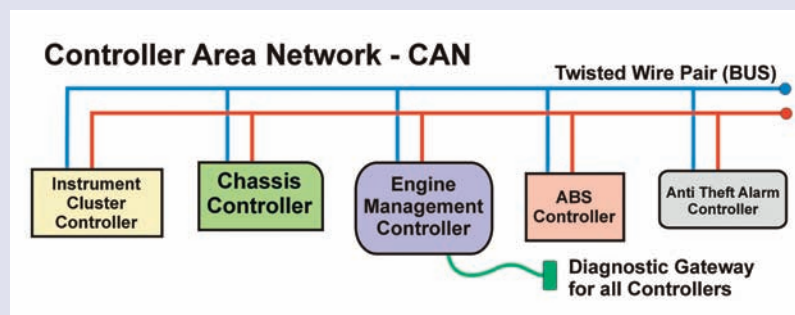
Starting in 2003, CAN was used on some OBD-II vehicles to communicate with scan tools, and in 2004, Ford, Mazda, Mercedes, and Toyota equipped all of their OBD-II vehicles exclusively with CAN for all vehicle-to-scan-tool communications. Developed by Intel, Bosch, and a few others, CAN communication technology has been around for over 20 years. In 2012 Bosch released CAN FD 1.0 or CAN Flexible Data-Rate. This specification uses a different frame format that allows a different data length as well as optionally switching to a faster bit rate. CAN FD is compatible with existing CAN 2.0 (first published in 1991) networks allowing CAN FD devices to coexist on the same network with existing CAN protocols.

The concept of how CAN works is simple: Computers, their sensors, and all power-consuming components on a vehicle are connected to each other via a single wire; this single wire is really two wires twisted together and is called a "twisted pair." The twisted pair of wires used by a CAN system to communicate within the computer system are called a BUS, which is, quite simply, nothing more than a glorified communication network. The BUS allows all electronic information to be available at all times within the network of components, since digital messages are sent out by each computer, or controller, and received by all computers connected to the network.

For example, assume a driver wants to turn on a vehicle's high beams. A conventional automotive electrical system would operate as follows: The driver would pull back on the turn signal lever to switch on the high beams. This action

would electrically trigger a relay that would, in turn, send power to the left and right high beam headlights. Performing this same function on a CAN type of system actually happens quite differently, and with much more sophistication. When the driver switches on the high beams, the chassis control computer receives the switched input and then triggers an internal power transistor (instead of a relay) that sends 12 volts to the high beams. But that's not all. In the event one of the high beam bulbs has burned out, the chassis controller would measure the current flowing to both lights (in this case the current to the high beams would be half of its normal rate), and would then send out a message that one of the high beams was not working via a unique identifier code along the BUS wire. All controllers or computers in the system would get the message and check to see if the message ID code applied to them (and the systems they specifically control). If the ID code did not apply to a particular computer or controller, the message would be ignored. However, when an instrument cluster controller receives the coded message, it recognizes the unique coded message as one that pertains to a system within its control, so it turns on a warning light on the instrument panel, informing the driver that there is a lighting system malfunction. In addition, an engine management controller also recognizes the message ID (i.e. one of the high beams is fried), and it also stores a trouble code in its memory for later retrieval by a technician using a scan tool connected to a diagnostic gateway.

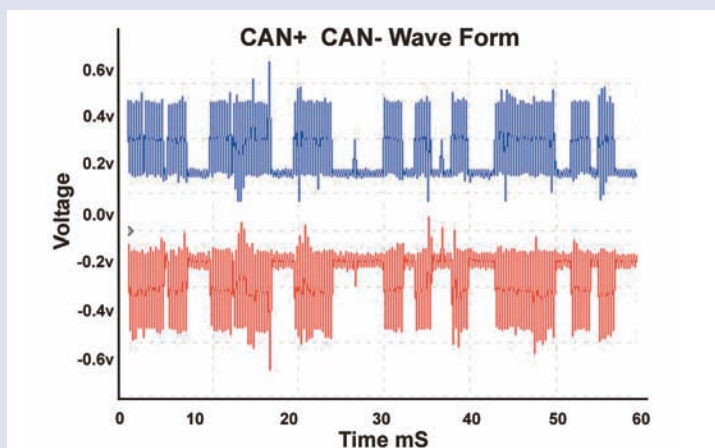
Furthermore, significantly greater levels of diagnostics are available with CAN communication systems. For example, if a high beam circuit had a wire that was shorted to ground, a CAN system would quickly measure the current going to the high beam circuit, determine it is too high, and immediately shut off the power transistor that supplies power to the high beams before any damage could occur. The action would prevent the chassis controller from moving into meltdown mode. In such a case, a different diagnostic message would be sent out across the network since the code stored in the engine management computer



Controller Area Network, or CAN, is changing the way vehicle electronics are utilized. Smaller, lighter wiring harnesses and more reliable electrical connections are used, and because CAN systems encompass a vehicle's entire electrical system, and manage it with a single on-board computer, a higher level of diagnostic capabilities is possible. Both professional and do-it-yourself technicians will all have to learn to adapt to this new technology.



Controlled area network, or CAN, uses two wires to communicate with a scan tool—CAN+ (top waveform) and CAN- (bottom waveform). Both wires use a bi-directional signal, which means messages can be sent in both directions. The CAN signal is like Morse code, in that the data is a series of long and short pulses. The two signals are an exact inversion of each other. This is called a differential BUS. It is resistant to electrical noise from outside the vehicle.



might read “Excessive Current in High Beam Circuit.” As a direct result of this superior level of circuit protection, no fuses would have to be used in the entire automobile. In addition, controllers would serve to switch power on and off to various components via transistors, instead of mechanical relays. Thus, the only relay used on an entire vehicle would be a starter solenoid.

While these systems are capable of performing self-diagnosis on many electrical-related problems, at least to some extent, they must still utilize wiring harnesses (though smaller) and connectors, all of which frequently have the same common electrical problems technicians have come to know and love. Consequently, while the diagnostic capabilities a CAN system assists knowledgeable technicians with solutions to electrical problems, they will not actually replace repair technicians any time in the near future.

Another example of how a CAN-BUS system integrates functions from multiple controllers can be seen in an alarm system. If an alarm is set, and a would-be thief disturbs the car, several messages are sent out by the alarm controller: The first message instructs the chassis controller to turn on the hazard lights and sound the horn. A second message is sent to the engine management controller which prevents operation of the electronic fuel pump. Once these messages are sent, no amount of “hot wiring,” ignition lock drilling, etc., will allow the engine to start or run.

Messages sent by controllers on some CAN systems are eight bytes long and travel at a speed of 500 k/bps (kilobytes per second) through the CAN-BUS system. This works out to roughly 4,500 messages per second. In fact, a CAN system transmits

data at a rate of one megabyte per second, or 30 pages of information each second. If two messages are sent at the same time, they are prioritized; one will be sent immediately and the other will be stored in the memory of the sending controller until BUS traffic allows it to be sent. Using a voltmeter to monitor CAN messages does not work, as it will only show 2.5 volts on the BUS wires when a message is present. Thus, a digital lab scope is the only way to actually see a message being sent.

Another significant advantage of CAN systems over conventional automotive wiring is that fewer wires are used. For instance, the single wire BUS used on a CAN system utilizes shorter wires, which makes for a lighter wiring harness with more reliability. Additional benefits include less interference with low-voltage electronic fuel injection sensor signals, enhanced diagnostic functions for the entire electrical system, and available software updates whenever new electrical components are added. By 2008, all vehicles were required to use some form of CAN in order to ensure standardized communication with scan tools and other diagnostic equipment. Eventually, entire electrical systems on cars and trucks will use CAN—it’s only a matter of time.

This is a PCM from a late model Toyota. It uses CAN protocol to communicate with a code reader or scan tool. CAN systems are able to send and receive information much faster than earlier OBD-II protocol systems. Most new scan tools and code readers available today are able to use CAN protocol.

Courtesy Younger Toyota



continued from page 35

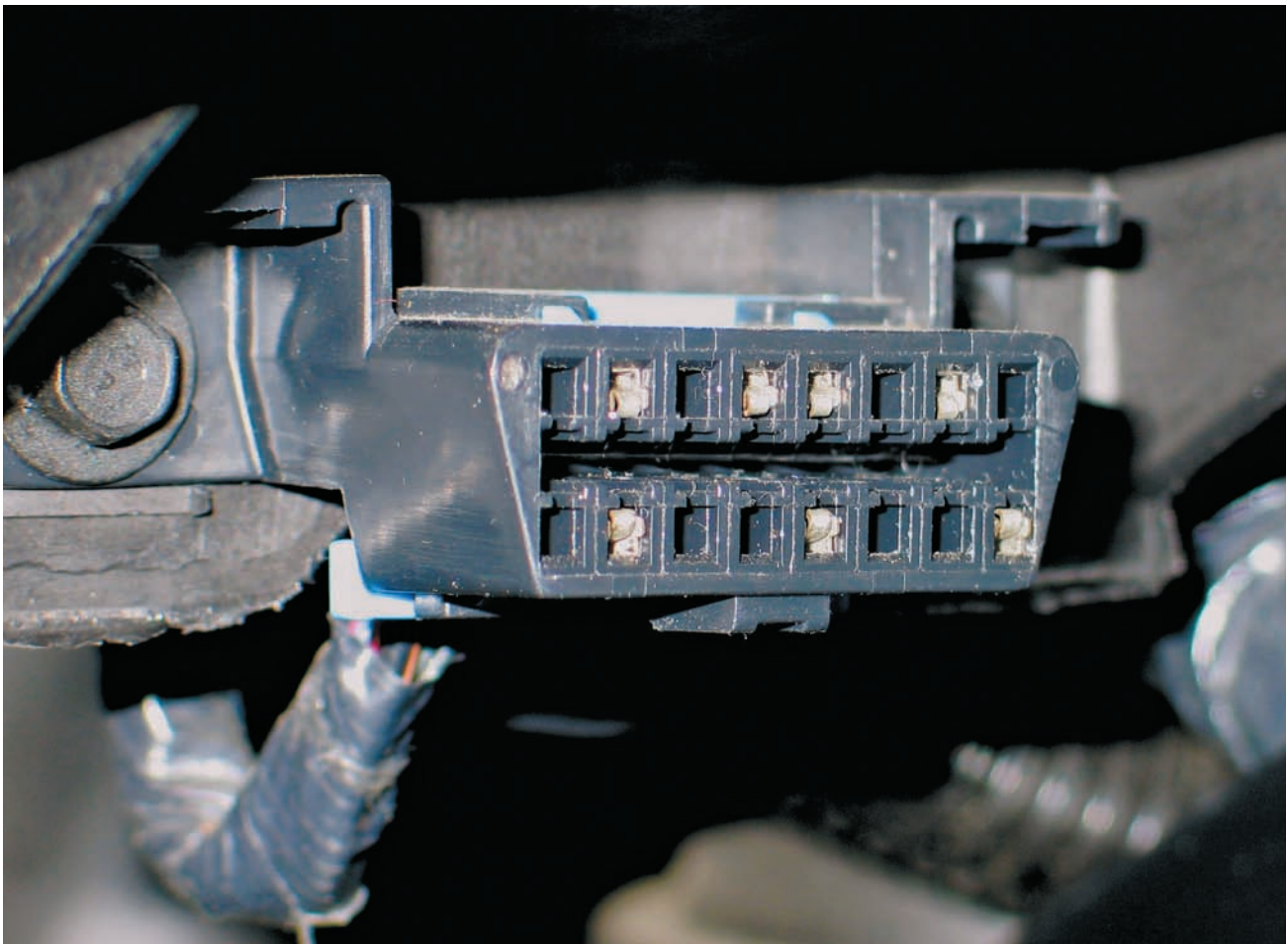
OBD-II DATA LINK CONNECTOR—DLC

The location of the diagnostic link connector (DLC) on earlier OBD-I vehicles was often a mystery. Many manufacturers located the connector in roughly the same place on each model, but not always. Some manufacturers were truly innovative in their placement of the DLC—in fact, some of the more well-hidden are found (hopefully!) on the 1994 Honda Prelude (under the passenger seat), the 1994 VW Passat (under the center console), and the 1993 Range Rover (under the passenger seat, tangled up with all the power seat wiring and the PCM).

With newer OBD-II systems today, playing hide-and-seek with the data link connector is not as much fun, or as difficult, as it used to be. Automakers must follow rules, specifically, standard SAE J-1962, regarding placement of a DLC. Every DLC must be in a centralized location within a vehicle's passenger compartment, and it

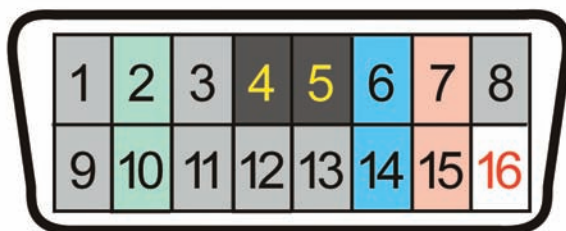
must be within 16 inches (400mm) of the steering wheel. Some manufacturers' interpretation of this standard is more loosely drawn than others, and as a result, some DLCs still remain well-hidden. See the Appendix for a list of non-standard locations for data link connectors on various models of vehicles.

Fortunately, once the DLC is located, they all have a uniform appearance and function, and will connect to any OBD-II-compatible scan tool or code reader. Figure 2-4 illustrates what the 16 pins in a DLC are configured for. Pins 1, 3, 8, 9, 11, 12, and 13 are not assigned to OBD-II functions; rather, these pins are used exclusively by manufacturers for their proprietary information or for enhanced diagnostics. Manufacturers will typically use some combination of these unassigned pins to communicate with dealership service department level scanners and other equipment that uses OEM software.



The standard 16-pin OBD-II diagnostic link connector (DLC) is supposed to be located within 16 inches of the steering wheel. Unfortunately, that's not always the case. Some automakers do a good job of hiding them behind covers, under center consoles, and inside glove boxes. Fortunately, once the DLC is located, any OBD-II-capable scan tool or code reader can plug into it and start reading its data. See the Appendix for a list of hard-to-find DLC locations.

OBD II Diagnostic Link Connector



OEM Discretionary Use (unassigned)

Pin 2 Bus (+) **Pin 10** Bus (-) (SAE J-1850)

Pin 4 Chassis Ground **Pin 5** Signal Ground

Pin 6 CAN High **Pin 14** CAN Low (SAE J-2284)

Pin 7 "K" Line **Pin 15** "L" Line (ISO-9141)

Pin 16 Vehicle Battery Power

The remaining specifically assigned OBD-II pins can be used and accessed by everyone as follows:

- Most European and almost all Asian vehicles use pins 4, 5, 7, 15, and 16 (ISO-9141) for their communication protocols.
- Ford, Mazda, and Jaguar use pins 2, 4, 5, 10, and 16 (SAE J-1850 PWM) for their respective communication protocols.
- DaimlerChrysler and most General Motors vehicles use pins 2, 4, 5, and 16 (SAE J-1850 VPM) for the same function; and
- As of 2003, a limited number of manufacturers, including Ford, GM, Mazda, and Saab, use pins 4, 5, 7, and 15 for their respective communication protocol. The trend toward using specifically assigned pins continued until 2008, when it became mandatory for all manufacturers to use specifically assigned CAN pins.

A data link connector has its own power source and grounds. Pins 4 and 5 are grounds, while pin 16 is battery power. These specific pins provide the scanner with both power and ground so they don't require an external power source. Many scan tools use batteries so they can be used when not connected to a vehicle in order to store previous recorded data.

Fig. 2-4—Almost all scan tools will automatically configure themselves to read whatever protocol a vehicle is using to send data to a scanner. Starting in 2003, some vehicles began using CAN, or controller area network systems, as a method of communication.

If a scan tool or code reader is not capable of reading CAN protocol, but you still want to determine if a vehicle uses CAN, a close look at a diagnostic link connector (DLC) will help. A DLC has 16 cavities that hold metal pins that serve as electrical connectors for a scan tool or code reader. Not all 16 cavities have pins present in them on all vehicles. It can visually be determined which communication protocol a vehicle is using simply by looking at the pins inside the diagnostic link connector. If the pins that correspond with a specific communication protocol are populated (instead of blank—no pin), the vehicle uses that protocol. For example, if pins 5, 6, 14, and 16 (the specific pins assigned to CAN communication protocol systems), are populated, the vehicle uses CAN protocol.

DIAGNOSTIC TROUBLE CODES—DTC

A PCM processes a staggering number of diagnostic trouble codes. There are over 4,000 generic diagnostic trouble codes, or DTCs, just for the powertrain alone. This number doesn't include the thousands of codes for body control functions, lights, power windows, climate control, memory seats, mirrors, sound systems, anti-theft alarms, or codes for the chassis control. Why are there so many? The high level of diagnostic detail requires a voluminous number of powertrain DTCs.

For example, an on-board computer could use or set up to five DTCs for just one sensor, depending upon what's wrong with that circuit. For example, a Manifold Absolute Pressure (MAP) sensor has five diagnostic trouble codes to cover a range of malfunctions, including:

- P0105—Manifold Absolute Pressure Circuit Malfunction
- P0106—Manifold Absolute Pressure Range/Performance Problem
- P0107—Manifold Absolute Pressure Low Input
- P0108—Manifold Absolute Pressure High Input
- P0109—Manifold Absolute Pressure Circuit Intermittent

Not only can an OBD-II computer tell if a MAP sensor is malfunctioning, it can also tell if it's disconnected, electrically open or shorted, is receiving no engine vacuum,



Whenever a scan tool or code reader is first purchased, it's a good idea to practice using it; this is easily done by making a PCM set a diagnostic trouble code (DTC). The first step is to disconnect an easy-to-reach sensor, then take the car for a short test drive. In this example, the air intake temperature sensor was disconnected. By connecting a scanner or code reader to the PCM, a diagnostic trouble code can be read. Voila! A #P0113 DTC is displayed on the scan tool, along with the definition of the code: "Intake Air Temperature, Circuit High Input." After clearing the DTC, and turning off the ignition key, the sensor should be plugged back in. This exercise will verify that both the scan tool and OBD-II system are operating as they should. *Courtesy AutoXray*

or if its output signal logically disagrees with other sensor inputs. In general, OBD-I vehicles previously had only one code for a MAP sensor, and this did not provide enough information to offer much of a diagnosis. In the early days of OBD-I diagnostics, a technician could simply memorize the majority of common trouble codes instead of having to look them all up in a service manual, especially at dealerships where only one brand of vehicle was being repaired. Obviously, that's not the case today. With thousands of codes available, technicians must have access to good sources of technical information and code definitions. In addition to displaying codes, many scan tools, and even some code readers, can display trouble code (DTC) definitions, as well as some repair tips and tune-up specifications.

Definitions for DTCs are available from scan tool manufacturers via the Internet. There is also an abbreviated list of generic OBD-II DTCs in this book's Appendix.

All generic OBD-II diagnostic trouble codes use five alphanumeric characters for identification. On all OBD-II DTCs, the first character on the left (as shown in Figure 2-5) identifies in which operating system within the vehicle the DTC is detecting a malfunction. There are four basic operational systems that have diagnostic trouble codes: "P" represents the powertrain system (engine and transmission); the "B" represents body for air bag, instrument cluster, lighting, power seats, memory mirror, etc.); the "C" stands for chassis

(ABS brakes and traction control); and "U" represents network communication.

The second character from the left always indicates whether the DTC is a generic OBD-II code that everyone can access, or a specialized manufacturer's code that only technicians associated with that specific manufacturer can access. When the SAE came up with the original DTC list, many manufacturers agitated to use their own code numbering systems. Consequently, the SAE indulged the manufacturers to some extent by separating standard OBD-II generic codes (P0 codes) from manufacturer-specific "P1" codes. All auto manufacturers have exclusive scan tools and other diagnostic equipment capable of reading their own proprietary (P1) codes and other proprietary data, which are above and beyond the generic OBD-II codes and data streams that typical aftermarket scanners and code readers can read. The additional proprietary information that manufacturers' scan tools are capable of reading is known as enhanced diagnostics. DTCs with a second character of "0," "2," or "3" are generic OBD-II codes. Any DTC with a "1" for its second character is a manufacturer specific OEM (original equipment manufacture) code; all the rest are generic OBD-II codes that any scan tool can access. "P1" fault codes are primarily proprietary for manufacturer's use only; however, certain sophisticated scan tools can interpret some of them.

The third character position in a DTC indicates which specific system is experiencing a malfunction. The malfunctioning system sets a system-specific trouble code. In any OBD-II DTC, this character really provides the most useful information to a technician since the general location or system within a vehicle that is experiencing a malfunction can be identified without having to look up the DTC. The third character system code numbers are as follows:

1. Faults relating to the air/fuel control systems
2. Faults relating to the fuel system's fuel injectors
3. Faults relating to the ignition system, including misfires
4. Faults relating to Auxiliary emission controls, including EGR, AIR, CAT, and EVAP
5. Faults relating to vehicle speed, idle control, or auxiliary inputs
6. Faults relating to computer systems, PCM, or CAN
7. Faults relating to the transmission or transaxle, and

OBD II Diagnostic Trouble Code

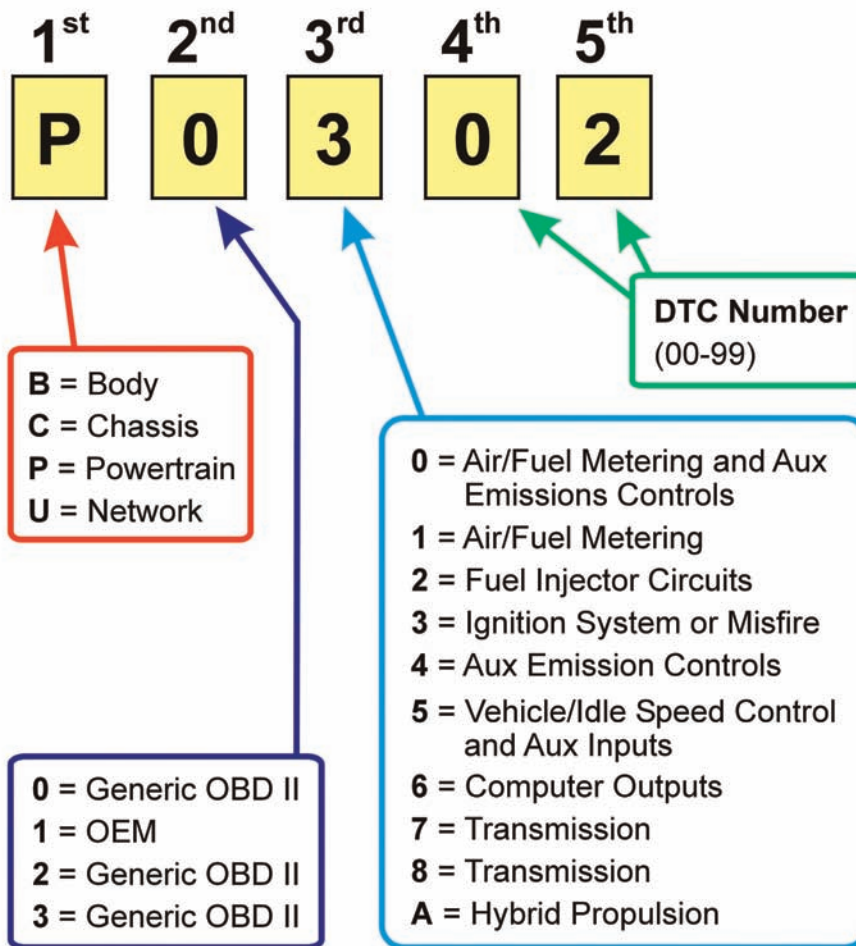


Fig. 2-5—Standardization of diagnostic trouble codes make this #P0302 diagnostic trouble code easy to read. The “P” indicates a powertrain code (indicating a malfunction exists somewhere in the powertrain system); code that everyone can access (as opposed to a manufacturer specific code that only technicians associated with that specific manufacturer could access); the “3” reveals specifically an ignition system misfire; and the last two characters (0 and 2) confirm cylinder number 2 is misfiring.

8. Faults relating to hybrid propulsion powered vehicles.

The fourth and fifth characters in a DTC are similar to older OBD-I codes, in that both digits are read together to ascertain more system-specific information about the actual component that is experiencing a malfunction. These characters display a specific code, which represents a malfunction within a system or a component within a system, which the PCM communicates whenever it detects a malfunction or fault.

FREEZE FRAME DATA

In addition to detecting and displaying diagnostic trouble codes, OBD-II systems also feature another diagnostic tool known as freeze frame data. Every time a DTC is set, the equivalent of a snapshot of overall generic emissions information stemming from engine operating conditions and other data is taken and stored in a PCM’s computer memory. Freeze frame data should not be confused with a similar function known as a failure record. A failure record is another type of snapshot equivalent that is recorded at the time a specific malfunction last occurred, and

then subsequently updated each time the same specific malfunction occurs again. Not all auto manufacturers use failure records in their OBD-II computer software, but they all definitely use freeze frame data.

Whenever a diagnostic trouble code is set on most vehicles (though not all), freeze frame data is registered and recorded for subsequent retrieval by a technician. Freeze frame data typically includes the following information:

- DTC number
- Open or Closed Loop status
- Engine coolant temperature (ECT)
- Vehicle speed (VSS)
- Intake air temperature (IAT)
- Engine rpm
- Misfire data (specific misfiring cylinders may be listed)
- Calculated engine load percentage
- Manifold airflow pressure (MAP)
- Fuel pressure (if controlled by the PCM)
- Up and down stream oxygen sensor (HO₂S) voltage (listed for each bank of cylinders)
- Short and long term fuel trim (STFT—LTFT) Percentage
- Total number of DTCs stored in memory

Some automakers provide more freeze frame data than many scan tools are capable of reading; consequently, not all scan tools can display all freeze frame data information. However, to the extent available, freeze frame data is valuable to a technician attempting to duplicate similar conditions during road testing to determine if an emissions problem really has been fixed. In addition, intermittent failures that are normally hard to reproduce can be reproduced more easily by using freeze frame data. Furthermore, since certain failures in one emissions system can cause or contribute to problems in another system, freeze frame data allows a technician to compare readings between various engine operating systems to determine if any of the information doesn't make sense or is inconsistent.

OBD-II MONITORS

How does an OBD-II system determine when to set a particular diagnostic trouble code? It runs up to 12 different diagnostic tests, called monitors, which check all systems within its control for any malfunctions that potentially could affect emissions. Sometimes these monitors are referred to as inspection and maintenance (I/M) readiness tests or readiness flags. Monitors are



This Actron scan tool is displaying freeze frame data captured when a powertrain control module (PCM) set a #P0113 diagnostic trouble code. Freeze frame data is useful when diagnosing why a code was set in the first place, since specific operating conditions are registered and stored at the exact moment a malfunction occurred. Freeze frame data is erased on most vehicles whenever the DTC is erased or cleared, so it's always a good idea to write down all stored data before erasing any trouble codes. *Courtesy Actron*

divided into two groups: continuous monitors and non-continuous monitors.

Continuous monitors are the more important of the two, as any failure or malfunction in any system associated with these monitors would have more serious consequences for emissions. Continuous monitors help protect a catalytic converter from damage, so it can functionally reduce emissions. Consequently, these monitors are highest priority for OBD-II systems. Excess fuel delivery or ignition misfires are a catalytic converter's worst nightmare, since either condition will cause enough damage to make replacement of a "cat" necessary. Continuous monitors start running as soon as enabling criteria, or specific engine-operating parameters, are met. Enabling criteria are simply minimum engine operating conditions that must be met in order for a continuous monitor to run. For example, an engine must be at a minimum threshold operating temperature before a catalyst monitor can run.

Non-continuous monitors are not as critical as continuous ones, as they don't have the same effect on emissions and don't run as often as continuous monitors. This is because the minimum enabling criteria for continuous monitors is much less extensive (or lower) than for non-continuous monitors. Consequently, the lower minimum threshold for operation causes them to run



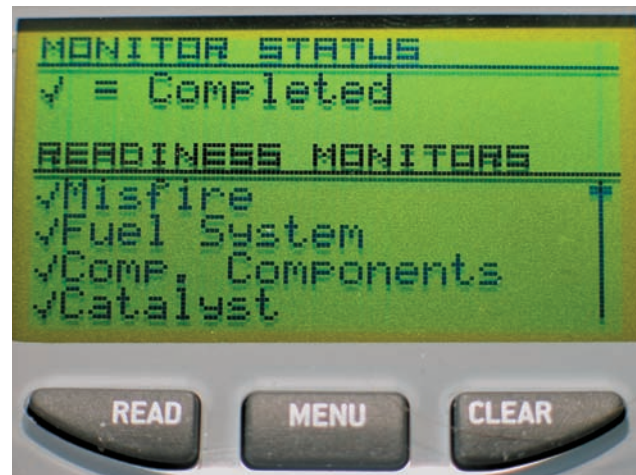
most of the time the vehicle is operational. In contrast, non-continuous monitors may run only occasionally, and not necessarily each time the vehicle is driven, again because they don't have the same significant effect on emissions as continuous monitors.

There are 12 OBD-II system monitors. The first three are continuous monitors. All the rest are non-continuous monitors. The last three non-continuous monitors are newer in existence, and are therefore not usually found on earlier OBD-II vehicles. The 12 OBD-II monitors are as follows:

- Ignition misfire—*Continuous*
- Fuel system—*Continuous*
- Comprehensive component monitor—*Continuous*
- Catalyst efficiency
- Heated catalyst
- EGR system
- Evaporative system
- Heated oxygen sensor
- Secondary air injection
- Air conditioning
- Positive crankcase ventilation
- Thermostat

The powertrain control module (PCM), or computer, has to run all of the monitors while at the same time manage the engine's fuel delivery and ignition systems. This software configuration is continuously running in the background, invisible to a technician, monitoring OBD-II diagnostics and engine systems management. However, this organizational software does not assist with setting DTCs or other OBD-II functions. OBD-II monitors perform software calculations for their own operation thousands of times per second, so something must be in charge of overseeing all these tasks in order to keep things occurring in orderly fashion. Just as a conductor of a symphony orchestra keeps 100 musicians in sync with the score of the music, OBD-II systems must keep monitors coordinated and prevented from interfering with each other and with engine management systems. General Motors and Ford call this software, which is the equivalent of an OBD-II system conductor, a "Diagnostic Executive," while DaimlerChrysler refers to it as a "Task Manager." A "Task Manager" or "Diagnostic Executive" performs all of the following functions:

- Starts and runs the monitors
- Prioritizes the monitors



The status of OBD-II I/M readiness monitors is shown on this AutoXray CodeScout 2500 code reader. System monitors with a checkmark next to them are completed, which simply means a PCM has successfully conducted tests on these components used by that monitor. In the instance shown, the misfire, fuel system, comprehensive component, and catalyst monitors have all finished operational testing. The scroll bar on the right side of the display lets users scroll down to see the rest of the monitors and their status. *Courtesy AutoXray*

- Updates the readiness status for the monitors
- Prevents conflicts between any of the monitors
- Directs the monitors to run in the correct order
- Manages the operation of the monitors and keeps them from interfering with engine management
- Displays test results for all monitors on a scan tool
- Keeps track of the drive cycles that control DTCs, and
- Stores DTCs and freeze frame data and controls the status of the malfunction indicator lamp.

A "Task Manager" places the monitors in one of four modes of operation: *Normal*, *Pending*, *Conflict*, and *Suspend*. Monitors only run when they are in *Normal* mode; any other mode will cause the monitor(s) to postpone testing.

- **Pending mode**—A monitor is placed in pending mode whenever a signal from a sensor is discrepant from what the PCM is programmed to expect. The monitoring test will be postponed pending repair of the malfunction. For example, if an oxygen sensor's voltage levels are too high or too low, the "Task Manager" will not perform a catalyst efficiency monitor test, as this test requires proper functioning of front and rear O₂ sensors.

- **Conflict mode**—A monitor is placed in conflict mode whenever the simultaneous operation of two monitors could possibly conflict with each other. One monitor will be delayed until the other is finished testing. For example, if a PCM commands an EGR valve to open while performing an EGR system monitor, the comprehensive component monitor for the idle air controller (IAC) cannot also run at the same time since EGR operation would affect an IAC actuator's performance.
- **Suspend mode**—A monitor is placed in suspend mode whenever it is delayed to allow proper sequencing of tests in relation to other monitors and enabling criteria. For example, if a PCM needed to run an evaporative system monitor, but the fuel tank was almost empty, an EVAP monitor would be suspended or delayed from performance until the gas tank was restored to between 20 and 80 percent full.

DRIVE CYCLES AND ENABLING CRITERIA

In order for a monitor to start its programmed test, certain minimum enabling criteria must be met. These enabling criteria, or minimum threshold operating conditions, are collectively called a “drive cycle” or “trip,” and amount to nothing more than starting the vehicle when it is cold and driving it until the engine reaches normal operating temperature. Then the car is driven at different speeds, and the ignition is finally turned off. Some monitors require only one complete “drive cycle” before a test can start, while other monitors may require more than one drive cycle or trip. If the minimum requirements of a “drive cycle” are not met, a monitor cannot run its test(s), and therefore, will be unable to make any determination as to whether or not a malfunction exists within components or sub-systems tested by that monitor.

Each monitor has two readiness states: ready or not ready. When a monitor status is ready, the required “drive cycle” has been performed and the monitor has successfully completed running its tests. When monitor status is not ready, the “drive cycle” for that monitor has not been successfully completed. Therefore, the monitor cannot run the tests for its system. EPA guidelines specifically allow up to two monitors to be in a not-ready state during vehicle operation for model years 1996 through 2000, but only one monitor for 2001 and newer model-year vehicles. Some scan tools and code readers refer to “complete” and “incomplete” in place of ready or not ready.

A generic OBD-II “drive cycle” exists, that is supposed to run all monitors. Unfortunately, this generic “drive cycle” doesn't always work as it should, since many auto manufacturers require very specific combinations of engine temperature, speed, and load changes to be present in order to trigger a particular monitor. Quite frankly, nothing beats access to genuine factory service information when trying to convince an OBD-II system to run its monitors.

Following are the steps required to prepare a vehicle for emissions testing. These are the basic requirement for a generic OBD-II “drive cycle” or “trip.” Completing the drive cycle and checking the readiness monitors will verify if the vehicle has been repaired correctly and/or is ready for emissions testing.

Step 1—the fuel tank should be between 30 and 70 percent full. Some systems, especially the EVAP system, need to have a specific level of fuel in order for the tests to be accurate. If the fuel tank is nearly empty, or completely full, many of the basic, and EVAP specific, tests will not run.

Step 2—The vehicle must also have an alternator that is operating correctly and a reasonably strong battery. If the vehicle has to be occasionally jump-started, the memory from the powertrain control module (PCM) will be erased, including the data that tracks the results from various stages of the current drive cycles. In addition, if the battery is weak or undercharged, some of the tests will not run.

Step 3—The vehicle should sit overnight, or for at least eight hours, in an environment that is less than 90° F. The engine temperature needs to match the air temperature in order to establish an accurate baseline for the testing. This can be checked using a scan tool and monitoring the IAT and ECT temperature values. If during testing the outside temperature is over 90° F, the fuel in the tank may be too volatile and the EVAP system may not run all of its tests. In addition, the keys must be removed from the ignition and all of the doors should be closed while the vehicle sits overnight. Many onboard computers “boot up” when the keys are in the ignition, and some vehicle PCMs will run until all the doors are closed after the engine is turned off and the ignition key removed.

Step 4—After cold starting the engine, it should be left to idle for two to three minutes in park or neutral. While at idle, turn on the headlights, heater, and defroster for a three- to five-minute warm-up phase until the engine idle is at its normal rpm. Next, put the vehicle in gear and do some city driving at a speed of about 25 mph. Accelerate up to about 35 to 40 mph a few times before slowing down to complete stops. Accelerate from each stop moderately—no drag race starts.

Step 5—Take a short trip on the freeway or highway. Enter the freeway on-ramp and perform acceleration from $\frac{1}{2}$ to $\frac{3}{4}$ throttle up to highway speeds. Maintain a speed of around 60 mph for a minimum of five miles—having the cruise control on will help to maintain steady speed. Find a section of roadway that will allow the vehicle to coast down from 60 mph until almost stopped. Try not to use the brakes or downshift until the end of the coast-down.

Step 6—Perform additional city driving after step five. Follow the procedure for step four.

Step 7—Use a scan tool to verify that all the readiness monitors are showing a status of “read.” If all monitors are “ready,” and there are no present or pending codes, then the vehicle has been properly repaired and is ready for an emissions testing.

By performing the preceding generic OBD-II “drive cycle” (or a manufacturer’s specific “drive cycle”), all the monitors should run, complete their tests, and be in a ready state. If any malfunctions in any systems are found, the appropriate diagnostic trouble codes will be set and displayed once a scan tool is connected to a PCM. Some monitors may require two consecutive “drive cycles” or “trips” before they can actually be run. For more information on manufacturer-specific “drive cycles,” see chapter 7.

Monitor	A	B	C	D	E	F	
Ignition Misfire (types 1 & 3)	Continuous	1	2	1	3 Trips	80	A Times monitor runs per trip.
Ignition Misfire (types 2-severe)	Continuous	1	1	1	3 Trips	80	B Number of trips required, with a fault present, to set a Pending DTC.
Fuel System	Continuous	1	1 or 2	1	3 Trips	80	C Number of trips required, with a fault present, to command the MIL “On” and store a DTC.
Comprehensive Component	Continuous	1	2	1	3 Trips	40	D Number for trips required, with no faults present, to erase a Pending DTC.
Catalyst Efficiency	Once per Trip	1	2	1	3 Trips	40	E Number of trips required, with no faults present, to turn off the MIL.
Heated Catalyst	Once per Trip	1	2	1	3 Trips	40	F Number of warm-up cycles required to erase the DTC after the MIL is turned off.
Exhaust Gas Recirculation (ERG)	Once per Trip	1	2	1	3 Trips	40	
Evaporative System	Once per Trip	1	2	1	3 Trips	40	
Heated Oxygen Sensor	Once per Trip	1	2	1	3 Trips	40	
Secondary Air Injection	Once per Trip	1	2	1	3 Trips	40	

The chart lists information about each respective monitor in an OBD-II system. Continuous monitors are shown in yellow, while non-continuous monitors are in orange. Column “F” represents the number of warm-up cycles it takes a PCM to erase all diagnostic trouble codes. In general, warm-up cycles are defined as occurring whenever engine temperature is below 122° F on start-up, and coolant and air temperatures are within 11° F of each other during a cold start.

MISFIRE MONITOR

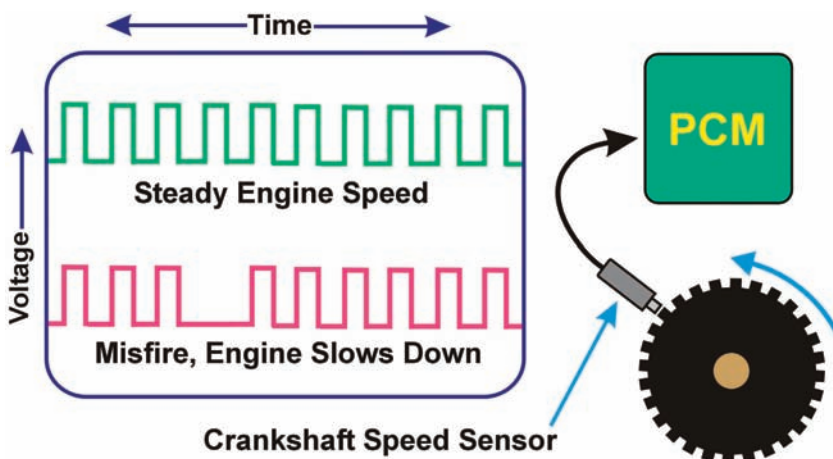
A misfire monitor continuously checks for engine cylinder misfires. Because of the potential severity of damage caused to a catalytic converter by ignition misfires and raw fuel subsequently entering the converter, this monitor is continuous and runs most of the time the vehicle is being driven. Additionally, this monitor does not require as much minimum threshold enabling criteria as other monitors; in other words, as soon as the engine is started on most vehicles, a misfire monitor starts running. While many misfires can be caused by an ignition system, other malfunctions can also cause them as well, including vacuum leaks, improper EGR valve operation, air/fuel ratio problems, incorrect ignition timing caused by a faulty cam belt, fuel injector malfunctions, and a sticking PCV valve. All of these potential malfunctions can set a #P0300 diagnostic trouble code—which represents a “random/multiple cylinder misfire detected.” If the misfire code displayed has a number other than “0” in either of the last two digit positions, such as a #P0305, for instance, then a specific cylinder is misfiring, and is specified by the last number (in this case, cylinder #5).

Misfires are detected whenever a PCM measures engine speed fluctuations via either a cam sensor or crankshaft speed sensor. The rotational speed of each cylinder’s power stroke is measured and then compared with the power stroke that precedes and follows it, i.e. before and after the misfire occurs. If a misfire occurs in a cylinder, that cylinder will not push as hard on the crankshaft and engine speed slows for a fraction of a second. A PCM will measure this pause in engine speed and set a misfire DTC.



The General Motors crank sensor on the left and cam sensor on the right provide crankshaft position and cylinder-firing-sequence information to a vehicle’s PCM. In addition to triggering the ignition system’s firing of spark plugs, a crank sensor can also detect ignition misfires by monitoring the rotational speed of the crankshaft. If engine speed slows for even a fraction of a second, a code for an ignition misfire may be set.

There are three kinds of misfires: They are known as Type 1, 2, and 3. Type 1 and 3 misfires are “two-trip” monitor malfunctions. “Two-trip” monitor malfunctions occur whenever a misfire is detected on a first “trip” or “drive cycle,” and the PCM then records and stores the malfunction as a pending diagnostic trouble code, without turning on the malfunction indicator light (MIL) until the malfunction occurs again during a second “trip” or “drive cycle.” If the misfire fault happens



A powertrain control module (PCM) monitors engine speed via a cam or crankshaft sensor. The waveform in green (top of diagram) indicates a steady engine speed—thus, no misfire. If an ignition-related misfire or other type of misfire occurs, the engine’s rotational speed slows for a fraction of a second because no power stroke from the misfiring cylinder is received (waveform in red at bottom of diagram). Not only can a PCM detect a misfire, it can also determine which specific cylinder is misfiring based on the crankshaft’s position when the misfire occurs. In addition, sometimes a PCM will set a misfire code because of an improperly balanced tire and wheel, since this condition could change the speed of an engine in a manner similar to that of a true misfire.

a second time under similar conditions of engine speed, load, and temperature while driving, the MIL will be turned on and a DTC set. In essence, the PCM wants to see the problem occur more than once before letting a driver know there is a malfunction in a system that has been set and displayed as a DTC.

Type 2 misfires are the most serious as they cause damage to a catalytic converter. When a Type 2 misfire is detected, the MIL will come on immediately; if the problem persists, the MIL will flash continuously once each second. In addition to actual real misfires, false misfires can also turn on a MIL and set a DTC. False misfires can be caused by a worn or loose camshaft-timing belt or by driving a vehicle on a ridged road with a washboard surface. Both of these conditions can affect crankshaft speed, and could cause a PCM to set a false trouble code, or inappropriately turn on the malfunction indicator light.

COMPREHENSIVE COMPONENT MONITOR (CCM)

The comprehensive component monitor, or CCM, checks input and output components for the presence of electrical shorts. It opens and monitors systems within its control for any out-of-range values. In addition, it also checks for functionality and rationality. Just as earlier OBD-I systems checked individual sensors for electrical values that were out-of-range, OBD-II systems

have a similar function via the operation of a continuous monitor known as a CCM. Fortunately, OBD-II systems have additional advantages over OBD-I systems; a CCM also monitors the length of time it takes various sensors to meet minimum enabling criteria after engine start-up, and monitors sensor inputs to ensure they correlate and make sense in their relationship with one another.



This coolant sensor is just one of many computer sensors monitored by a comprehensive component monitor or CCM. Some OBD-II systems are capable of diagnosing a stuck-open thermostat simply by monitoring the rate at which the coolant temperature rises after engine start-up. If coolant temperature does not reach a predetermined point after so many minutes of engine running, a DTC could be set to indicate a problem with the engine's thermostat. *Courtesy Elwood's Auto Exchange*

Comprehensive Component Monitoring

Input Components:

MAF Sensor	Vehicle Speed Sensor
Knock Sensor	Intake Air Temperature
MAP Sensor	Cam Position Sensor
Brake Sw	Coolant Temperature
Gear Selector Sw	Throttle Position Sensor
Cruise Control Sw	Crank Angle Sensor
Fuel Type Sensor	

Output Components:

Idle Speed Control	Warm-up Catalyst Bypass Valve
Heated Fuel Systems	Electronic Transmission Control
Glow Lamp (Diesels)	

Similar in some respects to older OBD-I diagnostics, a comprehensive component monitor (CCM) continuously watches various sensors and controls to make sure they're all doing what they're supposed to do. However, unlike less sophisticated OBD-I systems, the CCM on an OBD-II system also takes input and output logic into account as it evaluates component performance. If sensor readings don't make sense to a CCM, it will record a malfunction; if the malfunction is perceived as serious enough, or persistent, the CCM will turn on the "Service Engine Soon" light.



This Ford throttle position sensor (TPS) provides the on-board computer with driver demand information. Specifically, the information relayed confirms how hard a gas pedal is being pressed. The TPS output signal has to correlate with other sensors, like a mass airflow sensor (MAF) and a manifold absolute pressure (MAP) sensor. For example, if the TPS sensor shows that the throttle is wide open, then the MAP or MAF sensors should indicate that the engine is operating under maximum load and producing maximum torque. If any of these sensors does not logically agree with the output of the others, the comprehensive component monitor may set a DTC to indicate a malfunction.

For example, if an engine coolant temperature sensor (ECT) and an intake air temperature sensor (IAT) both read 55° F when the engine first starts up, a PCM would expect the ECT to increase at a fairly rapid rate as the engine warms up. If, after five minutes, the ECT only reads 70° F, the PCM would set a #P0116 diagnostic trouble code, which represents an “Engine Coolant Temperature Circuit Range/Performance” malfunction. However, if after five minutes of driving the engine temperature rises to significantly hotter than 250° F, an ECT reading would not be logical since the engine cannot possibly warm up that quickly. Another example that illustrates this point happens whenever a throttle position sensor (TPS) reads three-quarters open, but the engine rpm is only at 600 at idle. Thus, the TPS sensor would fail the CCM monitor’s rationality test because the TPS values do not match engine rpm.

FUEL SYSTEM MONITOR

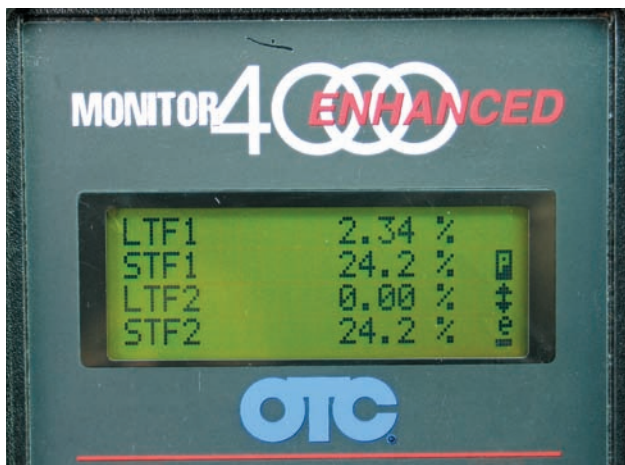
A fuel system monitor uses the adaptive fuel corrections programs stored inside the PCM to monitor the fuel system and engine performance. This continuous monitor requires more minimum enabling criteria be met than a misfire monitor does. The PCM on OBD-II vehicles uses the strategy of adaptive learning to constantly adjust and correct fuel delivery to the engine. Two programs are used to accomplish fuel correction—short-term fuel trim (STFT) and long-term fuel trim (LTFT). Together, these

programs keep the air/fuel ratio close to 14.7:1, the ideal ratio to enable a catalytic converter to operate at optimum efficiency. More information on air/fuel ratios and catalytic converter operation can be found in chapter 3.

Short-term fuel trim (STFT) is constantly changing based on an oxygen sensor’s input to the PCM. If the exhaust gas oxygen content indicates a lean air/fuel ratio condition, the STFT is adjusted to add more fuel to the engine. STFT uses a software program that stores information in different “cells” that correspond with each possible engine speed and engine load combination (see Figure 2-9). (Engine load simply represents how hard the engine has to work, or how much power it must produce to run a vehicle.) As driving conditions change, STFT is adapted to correct fuel delivery. For example, if engine speed is 2,500 rpm, with an engine load of 40 percent, the STFT could be +3 percent, indicating that at that speed and engine load an additional 3 percent more fuel needs to be added to keep a catalytic converter functioning properly. If, under the same conditions, an O₂ sensor indicates the air/fuel mixture is too rich or has too much fuel present, the STFT would reduce its correction factor by minus 2 percent. STFT continues producing continuous adjustments or corrections in the air/fuel ratio as long as the engine is running. STFT is expressed on a scan tool as a percentage of (+/-) 10 percent.

PCM Fuel Correction											
RPM	5500	0	-1	-2	0	-5	-6	0	+2	+5	-7
	5000	+6	+3	-8	-7	-3	+4	+3	-1	0	+1
	4500	-6	-5	+4	+3	-2	0	+1	-4	+2	-2
	4000	-4	-3	+1	+5	+2	-1	-2	-8	-5	+4
	3500	+6	-2	-8	-7	+3	-4	+3	+6	+5	-3
	3000	+2	-6	-3	+2	+3	-6	0	-5	-2	0
	2500	0	-5	+1	+3	0	-2	-1	+2	+5	-3
	2000	-8	-6	-2	+4	+5	-4	+6	-3	-8	-4
	1500	+4	+5	-7	+3	-5	-8	+1	+3	+4	+6
	1000	+3	+1	-1	-2	-4	0	+2	0	-7	-6
		10	20	30	40	50	60	70	80	90	100
Engine Load %											

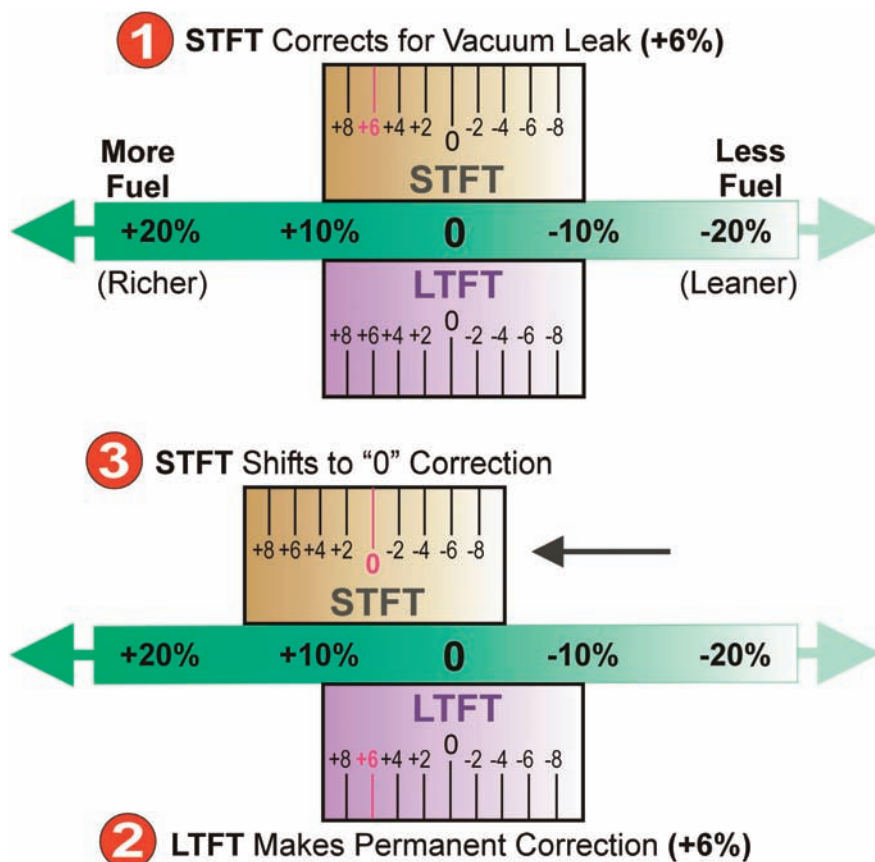
Fig. 2-9—This chart illustrates how a PCM’s adaptive learning strategy continuously adjusts to correct fuel delivery. Every single combination of engine rpm and engine load condition has a number assigned to it (engine load is the amount of power an engine has to make to run a vehicle). As operating conditions change, the fuel correction number also changes based upon an oxygen sensor’s input to the PCM. In the example shown in the graph, the adaptively learned number “+3” means that at 2500 rpm with a 40 percent engine load a fuel correction factor of “+3” is required to maintain the correct air/fuel ratio for the catalytic converter. Adaptive learning allows the PCM to constantly adjust the air/fuel ratio to match the mechanical wear of any engine cylinder, as well as dimensional tolerances found in the manufacturing process.



This scanner is displaying both long-term and short-term fuel trim for a V-8 engine. The OBD-II system uses two oxygen sensors (one for each side or bank of a V-8) to monitor exhaust gas oxygen content. Based on the information received from the oxygen sensors, fuel trim calculations are processed. Fuel trim is expressed in percentages, with "0%" indicating no fuel correction is required for a specific engine rpm and calculated load value. LTF1 stands for long-term fuel trim on bank 1 (one side of the V-8), and STF1 stands for short-term fuel trim on bank 1 (the same side). LTF2 and STF2 represent the long-term and short-term fuel trim percentages for the other bank of cylinders.

Courtesy OTC Tools

The LTFT only adjusts or changes its own fuel correction values when the STFT adjusts air/fuel ratio levels past certain predetermined correction values. In such cases, the LTFT makes a more permanent correction to fuel delivery. In response, the STFT then accepts the new LTFT correction value as its "0" correction point. By way of example, if an engine has a small vacuum leak, the air/fuel mixture will be lean because too much air, and insufficient fuel, is present in the intake manifold. The STFT would temporarily adjust fuel delivery by adding more fuel to the engine in order to correct the problem. In this example (illustrated in the graph below), the STFT would add +6 percent more fuel (Number 1 in graph). If the vacuum leak occurs over a long period of time, the LTFT would make a more permanent adjustment in fuel correction of +6 percent (Number 2 in graph). Accepting this permanent adjustment, the STFT would then adjust its values again and use the LTFT +6 percent fuel correction number as its "0" point for all future fuel corrections (Number 3 in graph), or at least until LTFT adjusted value again. If the vacuum leak is large enough, LTFT would be required to adjust



Whenever an engine is running, the short-term fuel trim (STFT) program is also operating, as is the long-term fuel trim (LTFT) program. STFT makes fuel corrections quickly while LTFT makes fuel delivery corrections more slowly and determines its corrections based on the quicker STFT changes in fuel correction.

its fuel delivery correction too far to make proper fuel delivery to the engine possible, so the PCM would then set a #P0173 (Fuel Trim Malfunction) diagnostic trouble code and possibly turn on the malfunction indicator lamp (MIL).

OXYGEN SENSORS AND HEATED OXYGEN SENSOR MONITORS

Oxygen sensors provide major inputs to a PCM for adjusting air/fuel ratio for optimum catalytic converter efficiency. In addition to the fuel system, the EGR, catalyst, and EVAP systems also rely on oxygen sensor input for their performance. OBD-II-equipped vehicles may use as many as four O₂ sensors. Because O₂ sensors' performance affects so many other systems, it is important that these sensors start operating within a few minutes of start-up since all oxygen sensors must be hot in order to operate (600° F). All OBD-II system O₂ sensors use an electric heating element, in addition to hot exhaust gas, to accomplish rapid heating of the sensors.

An oxygen sensor monitor and heated oxygen sensor monitor are both "two-trip" monitors, meaning a PCM will watch for the occurrence the same malfunction on two separate "drive cycles" before determining if a malfunction exists on an oxygen sensor. If a malfunction in an O₂ sensor is found during a first "trip" or "drive cycle," the PCM will temporarily save the malfunction in its memory as a pending code. The malfunction indicator lamp (MIL) does not come on at this time. If the same malfunction is again sensed during a second "trip" or "drive cycle," the PCM will turn the MIL on and also permanently store a DTC code in its long-term memory. O₂ monitors check multiple operating systems for any of the following: heater functionality, signal voltage that is too high or too low, the rapidity with which signal voltage changes, an "open" or shorted O₂ circuit, and the length of time it takes for signal voltage to cross a 0.450 millivolt threshold (often referred to as cross counts).

CATALYST EFFICIENCY MONITOR AND HEATED CATALYST MONITOR

No matter how efficiently an engine operates, a small amount of fuel always remains after the combustion process. A catalytic converter's job is to burn up this extra remaining raw fuel at the same time it is also eliminating or reducing other harmful emissions. It performs this process, in part, by storing oxygen and then adding it to the unburned fuel from the engine.

The converter then chemically combines the stored oxygen and fuel so it is burned inside the converter.

A catalyst efficiency monitor (CEM) uses two oxygen sensors to determine if a catalyst is operating properly. One O₂ sensor, known as an "upstream" O₂ sensor (because of its "upstream" location between the engine and catalytic converter), determines the level of oxygen content in exhaust gases and then sends a signal communicating this level to the PCM for fuel delivery adjustments. A second O₂ sensor, commonly known as a "downstream" O₂ sensor (because of its "downstream" location between the catalytic converter and the exhaust's tail pipe), monitors a catalytic converter's ability to store oxygen. If a converter becomes damaged, and its ability to store oxygen compromised, a "downstream" O₂ sensor's signal will then match that of the "upstream" oxygen sensor's signal, which causes the converter to fail the monitor's test.

By contrast, a heated catalyst monitor tests a catalytic converter's ability to warm up quickly after the engine is started. The time it takes a converter to heat up is another indication of how well it is operating. Both a catalyst efficiency monitor and a heated catalyst monitor are "two-trip" monitors. As with oxygen sensors, if a malfunction is found during a first "trip" or "drive cycle," the PCM temporarily saves the record of the malfunction in its memory as a pending code. The MIL does not come on at this time. If the same malfunction is again sensed during a second "trip" or "drive cycle," the PCM turns the MIL on and also permanently stores a DTC code in its long-term memory.

EGR SYSTEM MONITOR

An exhaust gas recirculation system (EGR) redirects and adds a precise minimal amount of exhaust gases to the intake manifold while the engine is running at part throttle in order to reduce peak combustion temperatures to below 2,500° F so as to control and prevent the release of harmful oxides of nitrogen or NO_x gases into the atmosphere. An EGR system monitor checks the functionality of the EGR valve. There is no "EGR sensor"; consequently, a PCM uses several methods instead to monitor EGR flow, including: 1) a differential pressure feedback sensor (DPFE) that determines EGR flow by measuring pressure at two points between the exhaust and intake manifold; 2) an EGR temperature sensor, which measures temperature rise in the EGR passageway from the hot exhaust; and finally, 3) an EGR valve position sensor, which



All computer-controlled EGR valves regulate the flow of a small amount of exhaust gases into the intake manifold to reduce combustion temperatures and control the release of harmful oxides of nitrogen into the atmosphere. On General Motors vehicles, the EGR valve is bolted to the intake manifold. The tube at the bottom of the valve (with the aluminum colored, tin-foil-like wrapping) is connected directly to the exhaust manifold. The EGR valve is electrically operated by a vehicle's powertrain control module, or PCM, and opens only at part-throttle after the engine reaches normal operating temperature. *Courtesy Elwood's Auto Exchange*

measures the amount or distance the valve opens. On certain vehicles, the PCM also monitors "upstream" oxygen sensor output voltage whenever the EGR valve is commanded to operate, as a means of determining if the EGR system is working properly.

Like the other sensors previously discussed, an EGR system monitor is also a "two-trip" monitor. Again, if a malfunction is found during a first "trip," the PCM will temporarily save the malfunction in its memory as a pending code. The MIL does not come on at this time. However, if the same malfunction is sensed during a second trip, the PCM will now turn on the MIL as well as permanently save a DTC code in its long-term computer memory.

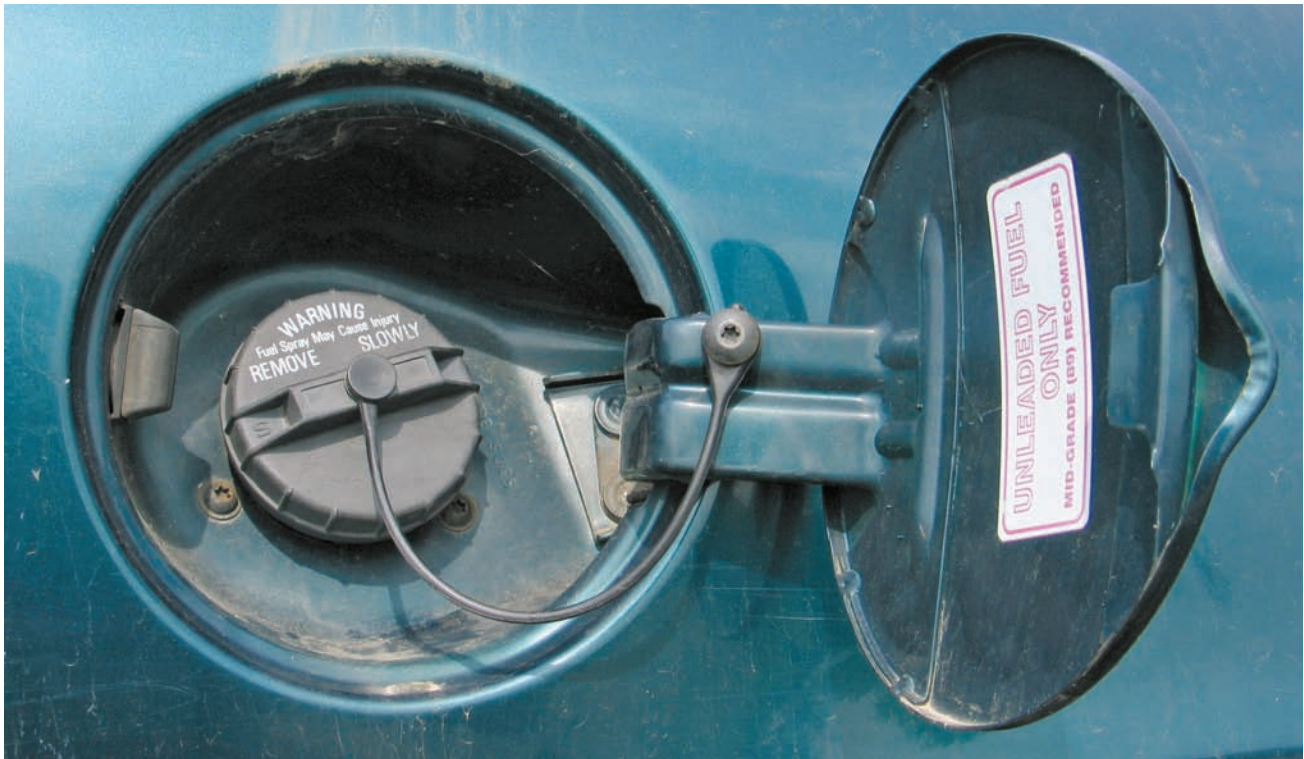
EVAPORATIVE SYSTEM MONITOR

Every OBD-II vehicle is equipped with an evaporative system monitor, or EVAP monitor, as it is more commonly known. This system monitor helps prevent fuel-system vapors from escaping into the atmosphere. An EVAP system routes gasoline fumes from the fuel tank into a charcoal canister storage container via hoses and tubes; the fumes are then stored in the canister and eventually re-routed back to the engine, where they are subsequently burned off in the combustion process. Switching valves and solenoids are used to accomplish the routing of these vapors within an EVAP system. In addition, an EVAP system monitor also tests all of the switches, valves, and hoses, as well as the gas cap, to ensure the EVAP system is leak-free. An EVAP system monitor also checks an EVAP system's ability to route fuel vapors on command. Any leakage in excess of a pre-set, predetermined amount will cause the system to fail an EVAP monitor's tests.

Like most of the sensors and systems previously discussed, an evaporative system monitor is also a "two-trip" monitor. Consequently, as with the others, once a malfunction is found during a first "trip," the PCM temporarily saves the malfunction in its memory as a



Pictured is a charcoal canister with various fuel venting hoses. This emission control device has been in use for a long time and serves as the main storage container for fuel vapors from the fuel tank. Once the engine is started and operational, the PCM will purge vapors from the canister at certain specified parameters and send them to the engine for subsequent burn-off. OBD-II systems are programmed to monitor both the fuel tank and vapor recovery system, including all of its various vapor hoses, for leaks every single time the engine is started. *Courtesy Elwood's Auto Exchange*



Every time an engine is started on an OBD-II vehicle, an evaporative system monitor, or EVAP, checks the fuel tank venting system and gas cap for any leaks. If a gas cap is left open, off, or loose, after adding gas to a fuel tank, the malfunction indicator lamp (MIL) will come on, and a diagnostic trouble code (DTC) will also be set. *Courtesy Elwood's Auto Exchange*

pending code and does not turn on the MIL at this time. However, when the same malfunction is sensed again on a second “trip,” the PCM does turn the MIL on and also permanently sets a DTC code in its long-term memory bank. Furthermore, if a gas cap is left off, loose, or open, after filling the gas tank, the PCM will set a #P0455 diagnostic trouble code defined as “Evaporative Emission Control System Leak Detected” (a gross leak). This DTC is accompanied by illumination of the malfunction indicator lamp on the dash, to alert the driver to the need for repairs.

SECONDARY AIR INJECTION MONITOR

The use of air injection as a method for emissions control has also been around for a long time, and as a result of its efficiency, it is still in use today on some vehicles equipped with OBD-II systems. The process of air injection occurs when fresh air is injected by an air

pump into the intake manifold or exhaust, to assist with catalytic converter warm-up when the engine is started cold. The additional air injected into the exhaust serves to add oxygen to exhaust gases, or in certain vehicles, directly into the catalytic converter for the same purpose.

A secondary air injection monitor uses an “upstream” oxygen sensor to determine if the air injection system is fully functioning. Like the majority of other monitors previously discussed, a secondary air injection monitor is also a “two-trip” monitor, which will require two complete “trips” or “drive cycles” before the PCM will turn on a MIL or permanently store a DTC for a recurring malfunction that appeared in a system during both “trips” or “drive cycles.” More information regarding the operation of electronic fuel injection systems, catalytic converters, exhaust gas’ regulating systems, and other emission control components and systems, is discussed in greater depth in chapter 3.



Chapter 3

Catalytic Converters, Oxygen Sensors, and Electronic Fuel Delivery

This chapter will focus on how catalytic converters, oxygen sensors, and electronic fuel injection all function together in an OBD-II environment. By taking a detailed look at the chemistry of what goes into an internal combustion engine, and what comes out as byproducts of the combustions process, we will see how a catalytic converter operates. In addition, the chapter will explore how the PCM, oxygen sensors, and the fuel injection system control the amount of fuel and oxygen in the exhaust gases, and their subsequent effect on the catalytic converter's ability to function.

OBD-II AND CATALYTIC CONVERTERS

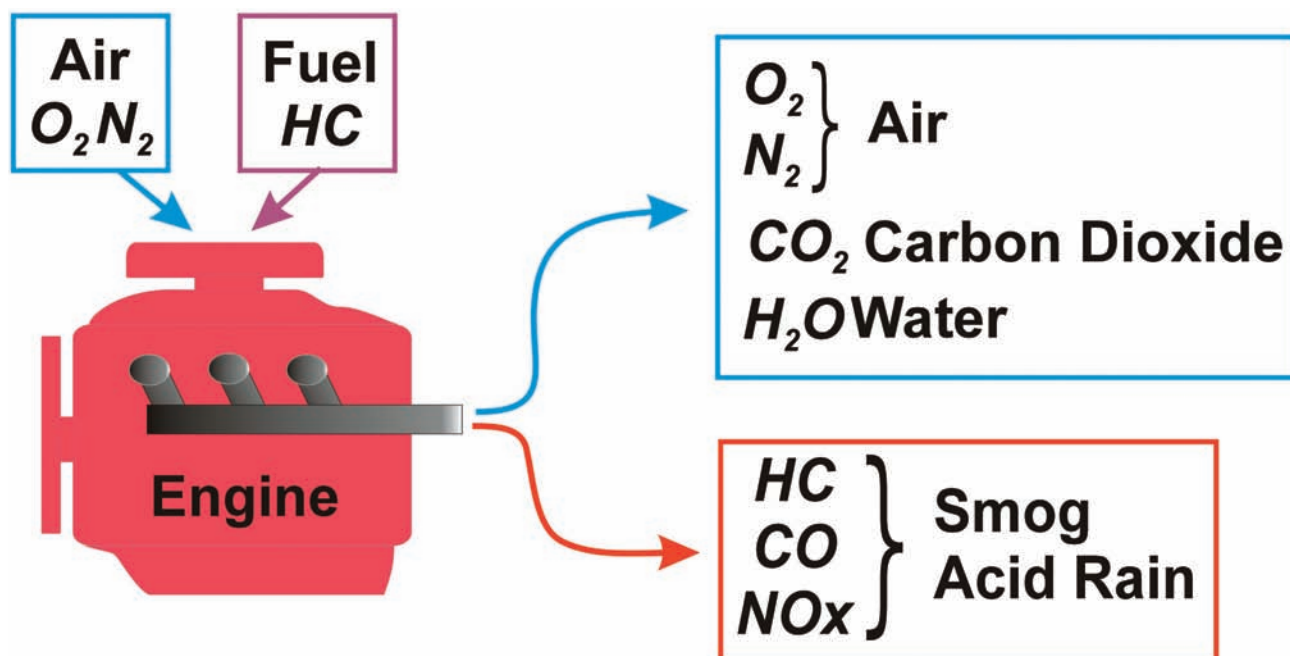
A catalytic converter is the major player in the effort to reduce the bad stuff emanating from a vehicle's tailpipe. Understanding exactly what a "cat" does, and how it reduces exhaust emissions, will help when interpreting OBD-II catalytic converter-related DTCs and their causes. We'll start by exploring which chemicals are used by an internal combustion engine, how they are processed, what comes out of the engine's exhaust, and what happens inside a catalytic converter. Understanding the interrelationship of OBD-II systems and catalytic converter functions will help with the task of interpreting 5-gas emission readings and emission failure test reports.

But first, we need a crash course in the chemistry of air and fuel and the dynamics of how they are processed within an internal combustion engine and catalytic converter. The atmosphere breathed by an internal combustion engine is composed of 78 percent nitrogen and 21 percent oxygen. Nitrogen (N_2) is an inert gas, which means it simply takes up space and does not burn in the combustion process. Internal combustion engines create power from their ability to extract oxygen (O_2) from the atmosphere and combine it with hydrocarbons

from gasoline, and then burn the combined air/fuel mixture. The combustion process creates heat, which causes nitrogen gases inside the combustion chamber to expand and push the piston down the cylinder, which then rotates the engine's crankshaft. Engines with high compression ratios, long-duration camshafts, superchargers, turbochargers, and large displacement engines all create more power because they convert greater amounts of fuel and oxygen into heat.

Gasoline is made mostly from hydrocarbons (HC), which, when combined with oxygen (O_2), and ignited, produce heat. If piston engines were 100 percent efficient, all of the HC and O_2 would be burned in the combustion process, and only water (hydrogen bonded with oxygen—or H_2O), nitrogen (N_2) and carbon dioxide (CO_2) would be left. Unfortunately, the combustion process is not 100 percent efficient, and harmful unwanted gases always remain. These chemical "leftovers" are emitted from a vehicle as exhaust emissions in the form of three hazardous gases: carbon monoxide, hydrocarbons, and oxides of nitrogen (NOx). The first of these three harmful gases is carbon monoxide (CO), which is colorless, odorless, and poisonous. Carbon monoxide is what kills people when they leave a car running inside a closed garage. The next unwanted byproduct of combustion is unburned fuel or HC (hydrocarbons), also called VOC for volatile organic compounds. The last unwanted gas is oxides of nitrogen, or NOx, as it is commonly called. When combined with HC, NOx produces smog, which makes people's eyes sting on a hot summer day and makes it hard for all living things to breathe. No matter how hi-tech the design, all piston engines produce these pollutants.

Catalytic converters, or "cats," have been on cars since the early 1980s. Modern converters are



This diagram shows that when air (oxygen and nitrogen) is mixed with hydrocarbons in the form of gasoline, and then burned inside an engine, the resulting exhaust gases should consist of oxygen, nitrogen, carbon dioxide, and water (blue arrow). Unfortunately, even after more than 100 years of perfecting piston engine design, this process is still not as efficient as it could be. Consequently, pollution, in the form of unburned fuel, or hydrocarbons (HC), carbon monoxide (CO), and nitrous oxide (NO_x), is still emitted from exhaust gases (red arrow). Only the addition of a catalytic converter can eliminate the unwanted byproducts of combustion. Unfortunately, even with the addition of a catalytic converter, ozone-depleting CO₂ gases (a major cause of global warming) are still an unavoidable byproduct of the combustion process.

constructed using an extruded honeycomb structure or core. The core, or substrate, is sprayed or dipped and then coated with precious metals, including platinum, palladium, and rhodium. Platinum and palladium accelerate the oxidation of HC and CO so they won't exit the tailpipe and pollute the atmosphere. The use of rhodium helps reduce NO_x emissions.

In order for a catalytic converter to start the process of converting harmful exhaust emissions into more desirable exhaust compounds, the "cat" must be hot, around 500° F, which is known as the "light-off" temperature; normal operating temperatures for catalytic converters range between 750° and 1,500° F or higher. A "cat" should normally last the life span of an engine. However, if the fuel system consistently runs an air/fuel mixture that is too rich, or an ignition system continually misfires, the temperatures within the "cat" can increase to more than 2,500° F, which will shorten its lifespan or destroy it. Other factors affecting converter longevity are the use of leaded fuel, excessive engine oil burning, or the presence of antifreeze in the exhaust from a blown head gasket or cracked cylinder head.

CONVERTING BAD INTO GOOD

Early catalytic converters in use in the mid-1970s were two-way, meaning they were only capable of reducing two harmful gases from exhaust emissions—hydrocarbons (HC) and carbon monoxide (CO); unfortunately, harmful NO_x gases were not eliminated by these early-model "cats." However, since the 1980s, three-way catalytic converters have been the norm, and they do effectively reduce all three of the harmful gases contained in exhaust emissions—namely, HC, CO, and NO_x.

A three-way catalytic converter removes or eliminates all three harmful gases from exhaust emissions during a two-stage process that consists of two separate catalyst stages—reduction and oxidization. This two-stage design is also known as a dual bed converter. The reduction catalyst processing stage is the first stage that all exhaust gases must pass through, and its function is to ideally eliminate, or at least reduce, NO_x emissions. An NO_x molecule is composed of one atom of nitrogen and several oxygen atoms. By using the elements platinum and rhodium, the reduction catalysts rips the nitrogen atom out of the molecule, thus freeing the oxygen. The free nitrogen atoms bond with each other to create N₂.

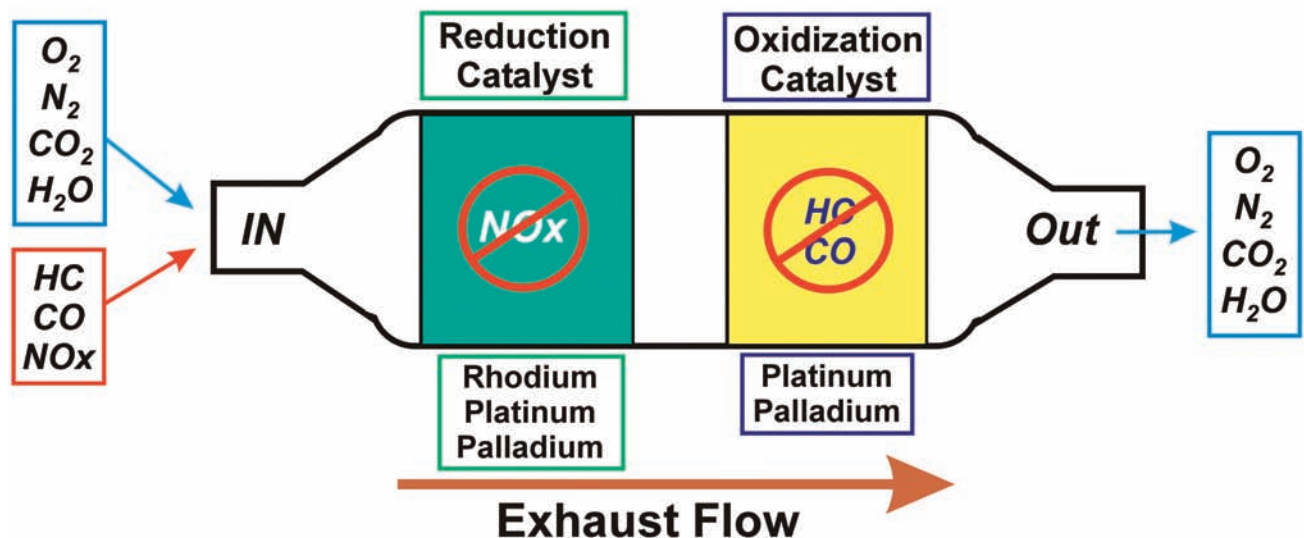
(essentially nitrogen), which makes up 78 percent of the earth's atmosphere. The free O_2 is then passed into the second stage, or oxidation stage, of the catalytic converter, where it will be put to good use.

The second processing stage, or oxidation catalyst stage, reduces HC and CO from exhaust emissions by adding the oxygen freed from the NOx molecule during the reduction processing stage of the "cat," with excess oxygen from exhaust gas. Based on input from an oxygen sensor, the PCM attempts to maintain an ideal average air/fuel ratio of 14.7:1. Thus, the fuel-injection system constantly varies the air/fuel mixture ratio between just slightly rich, and slightly lean, of the ideal average 14.7:1. This variation in air/fuel mixture allows enough oxygen to exist in exhaust gases for the oxidation catalyst stage of the catalytic converter to convert HC and CO into harmless water and less harmful carbon dioxide (two compounds naturally found in the earth's atmosphere). Certain catalytic converter designs require more oxygen than is normally produced by a standard "cat" design, so these special "cats" use an external air source and a pump in order to pump air into the center

of the "cat," so there is sufficient oxygen present in the oxidation catalyst stage to remove harmful emissions. The gases coming out of a catalytic converter are so clean that when sniffed by a 5-gas analyzer, typical readings register "0" detected presence of HC, CO, and NOx. In fact, a "cat" is so effective in cleaning exhaust gases, that the rate of suicide from breathing engine exhaust has dropped significantly since the introduction of catalytic converters on vehicles.

It is interesting to note that all through the 1980s, and midway through the 1990s, automotive textbooks and service manuals claimed that a catalytic converter's ability to eliminate HC, CO, and NOx, was sufficient to completely rid the earth of pollutants from automobiles. While this might be true to a limited extent, it wasn't until the late 1990s, and especially now in the new millennium, that humans have realized that simple reduction of harmful chemicals from automobile emissions is not sufficient to solve the problem of global warming. Today, most scientists worldwide agree that man-made CO_2 emissions are the primary cause of rising temperatures on earth. Ironically, the higher the CO_2

3-Way Catalytic Converter



Catalytic converters used on both OBD-I systems and OBD-II systems are referred to as three-way converters because they reduce or eliminate three bad gases coming from the engine—HC, CO, and NOx. There are two stages during which a catalytic converter reduces and eliminates harmful gases from exhaust emissions. The first processing stage of a three-way catalytic converter is known as the reduction catalyst stage; this stage eliminates NOx. During the second processing stage of the converter, all, or nearly all, HC and CO gases are consumed in the oxidation catalyst. Some converter designs involve the use of a tube that supplies additional air (oxygen) to the center of the "cat" to aid the oxidation process. Fortunately, all of the gases that exit the catalytic converter are safe to breathe and do not make smog. When the converter is operating efficiently, the only gases exiting the tailpipe are oxygen, nitrogen, carbon dioxide, and water vapor.

levels an internal combustion engine produces, the more efficient it is at burning fuel. Unfortunately, the larger the engine, the greater amount of CO_2 it actually produces. The use of smaller, more fuel-efficient engines on vehicles, as well as hybrid engines that use a combination of battery power and power extracted from hydrocarbons (gasoline), looks to be more promising for effective pollution control, at least for the immediate future.

AIR/FUEL RATIOS AND 5-GAS EXHAUST ANALYZERS

Exhaust gas analyzers (EGA) have been around for years. These diagnostic tools can measure two, three, four, or five exhaust gases, depending on the sophistication level of the model utilized. While the cost of these tools (typically upwards of \$3,000) is customarily beyond the

budgets of most shade-tree mechanics, knowing how they are used by professional technicians is helpful to understand and interpret readings from exhaust gases contained in emissions-failure reports or work orders from repair shops or new car dealers.

The 5-Gas Air/Fuel Ratio graph shown in Figure 3-3 provides the easiest explanation and illustration of the relationships between exhaust gases as well as their relationship with, and how air/fuel mixtures affect them. An ideal average air/fuel ratio of 14.7:1 produces the most efficient and complete burning of the air/fuel mixture during combustion. This is the ideal ratio that an EFI system averages at idle or cruise in “closed loop” operational mode. The chart in Figure 3-3 illustrates why the ideal air/fuel ratio of 14.7:1 produces the lowest level emissions of HC, CO, and NOx gases. As an air/fuel

5 Gas—Air/Fuel Ratio Graph

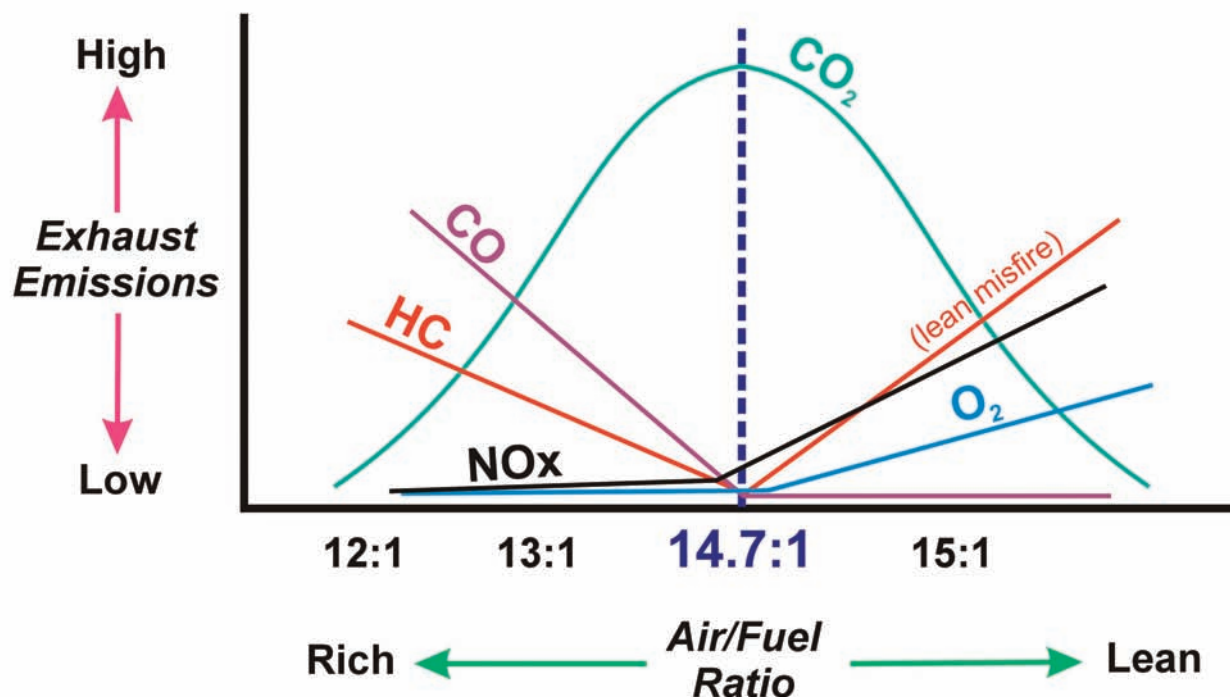


Fig. 3-3—This graph provides a quick reference for interpreting exhaust gas readings produced by a 5-gas analyzer. A 14.7:1 air/fuel mixture ratio is ideal for combustion since harmful, unwanted gases like HC, CO, and NOx, are at their lowest levels achievable with current mainstream technology. As the air/fuel ratio inclines toward the rich side of ideal, both HC and CO start to rise. When the air/fuel ratio indicates a rich fuel mixture, combustion temperatures are relatively low, and NOx production will be zero. When the fuel mixture tends toward the lean side of ideal, CO is zero because enough oxygen is present for complete combustion. However, if the mixture is more lean than desirable, too much oxygen will be present in the fuel mixture, and not enough fuel, so what is known as a lean misfire will occur. A lean misfire inhibits combustion, and causes extremely high levels of hydrocarbons, or HC (raw unburned fuel), to exit the cylinder.

mixture gravitates toward the rich side of the ideal 14.7:1 ratio, both hydrocarbons (HC) and carbon monoxide (CO) emissions start to rise. Since CO is a byproduct of incomplete combustion, it is only produced when insufficient oxygen is present in the air/fuel mixture. By contrast, the presence of CO in exhaust emissions indicates a rich air/fuel mixture—consequently, if exhaust gas readings detect CO in exhaust gas, the air/fuel mixture must necessarily be rich (more fuel, less air). Lack of oxygen in a rich mixture will also cause HC to rise, since not all of the fuel can be burned.

So far we've only looked at three bad gases: HC, CO, and NOx. Now let's take a look at carbon dioxide (CO₂) emissions. CO₂ is often overlooked as an exhaust gas, but it does have value for air/fuel mixture fine-tuning. CO₂ readings peak in output at the same average, ideal 14.7:1 air/fuel ratio. The higher the CO₂ percentage present, the more efficiently the engine is combusting air and fuel. Since CO₂ readings flatten out at peak, it can often be difficult to tell on which side of the ideal 14.7:1 air/fuel ratio (either rich or lean) the air/fuel mixture is. Levels of carbon monoxide (CO), are required to determine when CO₂ is at its highest point (which is the same point the engine is at its most efficient). CO₂ is at its maximum when CO readings first drop to 0 percent. By looking at CO percentages in conjunction with CO₂ percentages, peak CO₂ can be determined. CO₂ levels can tell you how efficient an engine is and how close to ideal its fuel mixture is.

In lean air/fuel mixtures, or those that tend to the lean side of the ideal 14.7:1 ratio, CO is close to or at 0 percent, because sufficient oxygen is present in the exhaust gases to support complete combustion. Thus, O₂ is also a lean air/fuel mixture indicator, since if an O₂ reading detects the presence of O₂ in exhaust gases, the air/fuel mixture must necessarily be lean. However, this is not always the case. A false lean air/fuel mixture reading can be caused by the presence of a malfunctioning air-injection system or by leaks in an exhaust system. As the air/fuel mixture continues to lean out further (less fuel, more air), the molecules of hydrocarbons (HC) become spaced farther apart in relation to the molecules of air, rendering combustion via ignition from a spark plug that much more difficult. As HC molecules become even more widely spaced, because less fuel is present, a lean misfire will occur once the spark plug fails to ignite the air/fuel mixture. When this occurs, raw, unburned fuel passes directly into exhaust gases, causing HC readings to skyrocket.

In addition, NOx emissions also increase whenever air/fuel mixtures are on the lean side of ideal and there is excess oxygen present during combustion. A lean mixture burns hotter than a rich air/fuel mixture. As a result, increased temperatures produce NOx as a byproduct of the combustion process. The engine's exhaust gas recirculation (EGR) system subsequently



The 5-gas exhaust analyzer shown here measures the amount of hydrocarbons (HC), carbon dioxide (CO₂), oxygen (O₂), carbon monoxide (CO), and oxides of nitrogen (NOx), present during the combustion process. In view of the fact an OBD-II system can itself indirectly determine if an engine is producing excessive levels of HC, CO, or NOx simply by monitoring a catalytic converter's performance, 5-gas analyzers are no longer used as frequently as they once were. An exception is the occasional use (more common in certain states) for verification of emission repairs, or to perform basic engine diagnostic work.

Courtesy Kiplinger's Automotive Center

reduces the presence of NO_x by adding inert exhaust gas (in the form of nitrogen) back into the intake manifold. The inert nitrogen gas serves to reduce combustion temperatures from lean air/fuel mixtures, thereby reducing NO_x gas levels emitted during combustion.

The 5-gas readings illustrated in Figure 3-3 represent readings obtained from exhaust gases coming directly from the engine. Exhaust gas readings sampled at locations after a catalytic converter, or at the tailpipe itself, will be “masked” by the operation of the catalytic converter. This is because the converter’s job is to eliminate HC, CO, and NO_x gases from exhaust emissions, so that only small amounts of O₂ and CO₂ will be present in the exhaust.

Besides utilizing a 5-gas analyzer exhaust reading to determine if an engine is running with a rich or a lean air/fuel mixture, an exhaust gas analyzer can also uncover other mechanical engine-related problems. By holding an analyzer’s sampling probe just above the level of coolant present in a radiator (naturally, with the radiator cap removed), any reading that detects the presence of hydrocarbons (HC) could indicate a possible blown head gasket or cracked cylinder head. Technicians must be careful performing this test, since if they suck any coolant up into the probe, the 5-gas analyzer test machine will be completely ruined. A different mechanical condition test can be performed by inserting a 5-gas analyzer’s sampling probe into a crankcase breather hose; high HC readings from this test can indicate worn piston rings or other cylinder sealing problems.

A 5-gas analyzer tool can also be used to perform a cylinder power balance test. By shorting individual spark plugs to ground, and then taking a gas reading, the efficiency with which each cylinder combusts the air/fuel mixture can be revealed. Each time a cylinder is “shut off” (no spark), HC readings will increase and CO₂ will drop. Comparison of each non-operating cylinder will reveal how hard each one is working. If one cylinder is performing less optimally than others (its CO₂ reading does not drop as much as other, stronger cylinders), this test will confirm that cylinder was not pulling its weight (so to speak), and a possible mechanical problem may exist. Fuel injectors can also be tested for optimal fuel atomization and spray pattern. HC readings should increase the same amount for each cylinder as each cylinder’s corresponding spark plug is shorted to ground and the cylinder has stopped running. Consistent HC readings confirm all fuel injectors are spraying the same amount of fuel into the engine.

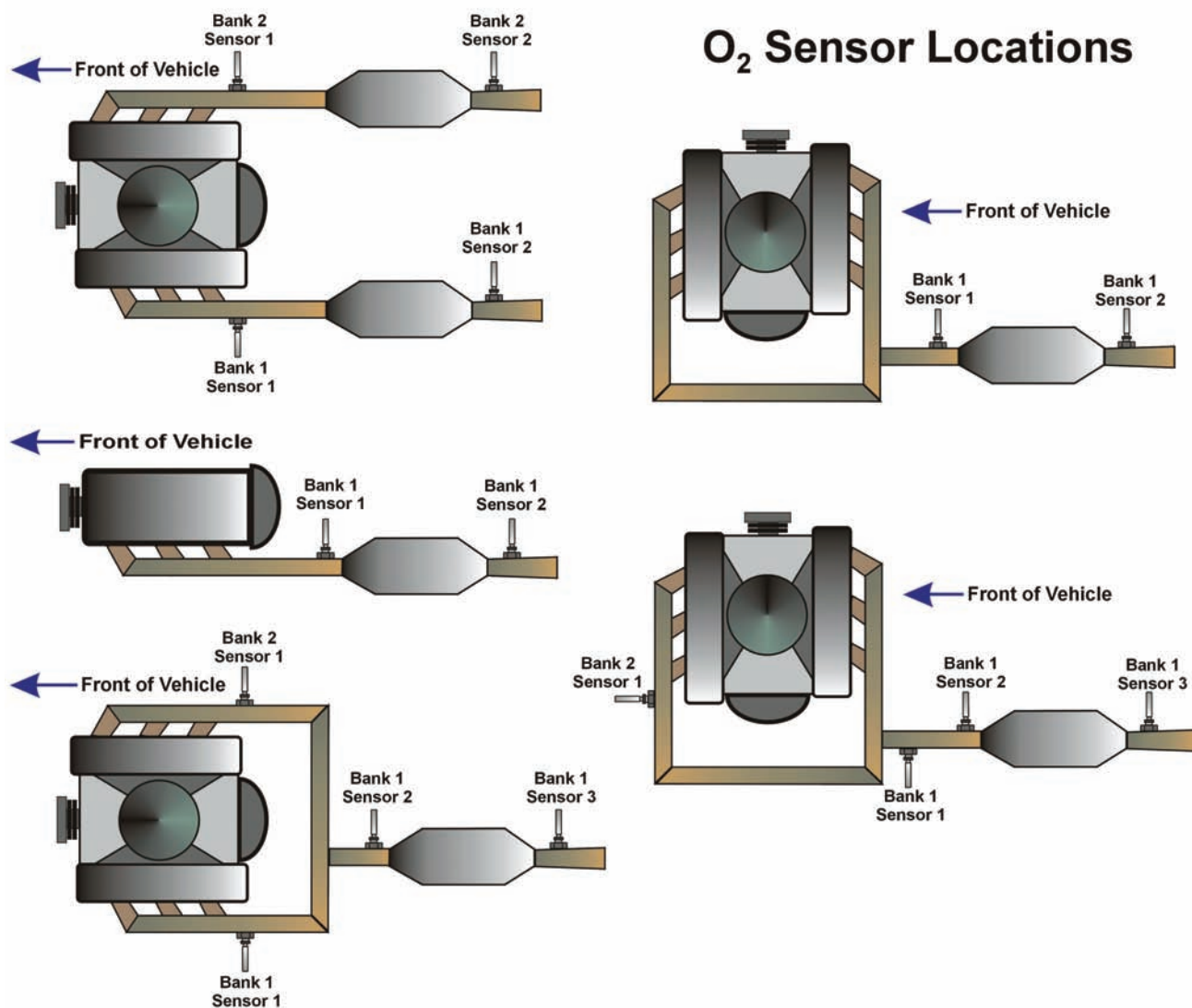
Readers should now have a better idea about how electronic fuel injection, oxygen sensors, and catalytic converters operate. With a little history under the belt and some solid working knowledge of the operations and relationships of various vehicle systems, it’s time to move onto the subject of scan tools and code readers. Since scanner data streams and related diagnostic trouble codes are so closely interwoven with engine management systems, having a basic idea of how the fuel/air chemistry operates in an internal combustion engine will help with understanding the information scanner tools provide, as well with diagnosing and interpreting OBD-II system diagnostic trouble codes and their root causes.

ALL ABOUT OXYGEN SENSORS

So far, we have explored the chemistry of air and fuel as they are consumed by the engine, and the operation of a catalytic converter. It’s important to keep in mind the reason we have EFI and OBD-II engine management systems at all is to provide proper air/fuel ratios to keep



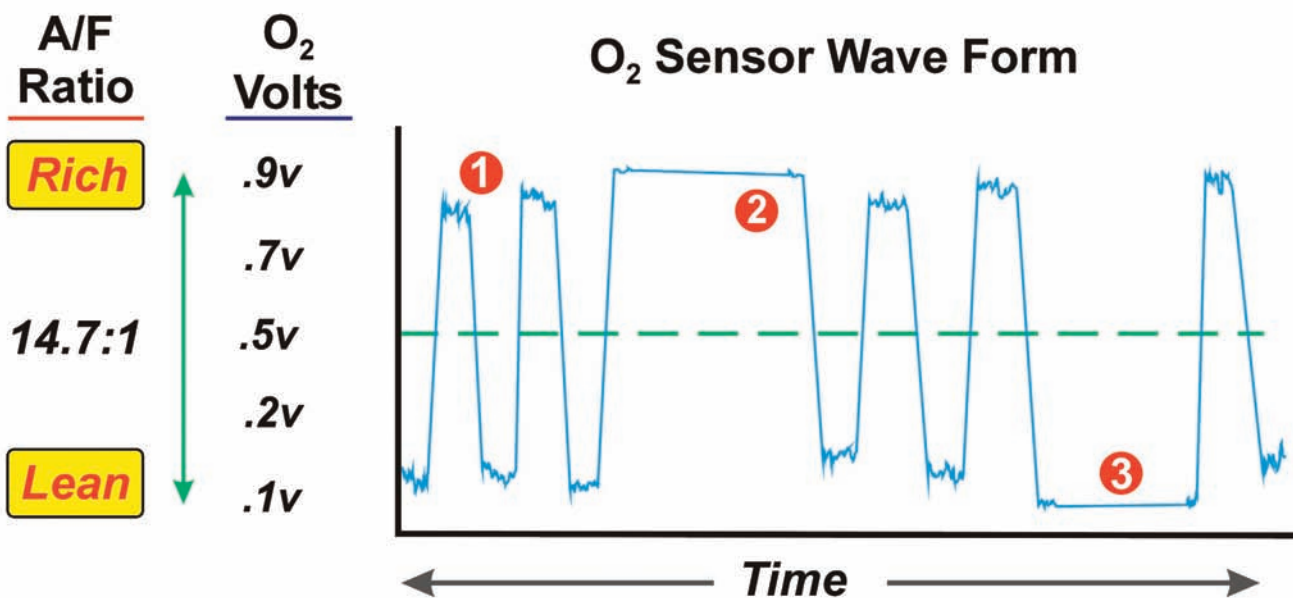
These are four oxygen, or O₂, sensors with different numbers of wires coming from them. All modern OBD-II systems use oxygen sensors fitted with internal heaters. The internal heating element keeps the sensor at ideal operating temperature, even if exhaust gas temperature drops low due to prolonged engine idling. In addition, the heating element immediately gets the sensor hot enough to operate whenever an engine is started cold, so the system can operate in “closed loop” mode more quickly. The number of wires an oxygen sensor has can identify if the sensor uses an internal heating element. Oxygen sensors with one or two wires don’t have internal heaters and are typically found only on older OBD-I systems. Oxygen sensors with three or four wires have internal heating elements and are found on certain vehicles equipped with OBD-I systems and all modern OBD-II systems.



Since auto manufacturers can locate oxygen sensors wherever they want to, it can often be confusing to identify which O₂ sensor one is dealing with when viewing oxygen sensor data on a scan tool. It is not uncommon to replace a wrong O₂ sensor simply because of difficulty identifying sensor locations. This diagram shows different engine configurations and exhaust-system layouts, as well as their related “upstream” and “downstream” oxygen sensors in relation to a catalytic converter. By way of illustration, the engine depicted top left uses four oxygen sensors: Bank 1/Sensor 1, and Bank 1/Sensor 2 are used on the right side of the engine; Bank 2/Sensor 1 and Bank 2/Sensor 2 are located on the other side, and comprise the other bank of cylinders on this “V” engine type. Other converter/oxygen sensor layouts are shown as well.

catalytic converters operating at peak efficiency at all times. A properly functioning oxygen sensor is the key to the correct amount of air and fuel burning inside a combustion chamber before exiting the engine as exhaust gas, and eventually passing through a catalytic converter. Earlier OBD-I systems used only one or two O₂ sensors, located between the engine and a catalytic converter. Oxygen sensor(s) on these early emission systems provided information the computer used to constantly correct

the air/fuel ratio to match a converter’s requirements for reducing exhaust emissions. More modern OBD-II systems use one or more O₂ sensors, also located between the “cat” and the engine, plus an additional O₂ sensor, or sensors, located between a catalytic converter and the tailpipe. In OBD-II systems, the first oxygen sensor (or set of sensors) located between the engine and catalytic converter is/are known as the “upstream” sensor(s), while the O₂ sensor(s) located between the converter and the



This graph shows an oxygen sensor's waveform as displayed on a lab oscilloscope. In the illustration, the engine is at 2,000 rpm with a steady throttle. On the graph, position number 1 indicates the O₂ sensor is operating in "closed loop" mode because voltage keeps fluctuating up and down (reflecting continuous fuel correction adjustments made by a PCM), around an average of about 0.5 volts. When the throttle is snapped open (position number 2 on the graph), O₂ sensor voltage rises to 0.9 volts, indicating a rich fuel mixture. Between position numbers 2 and 3 on the graph, the fuel system returns to "closed loop" operational mode. Position number 3 on the graph indicates a lean air/fuel mixture when the throttle is suddenly closed. This lab scope waveform confirms the O₂ sensor is working correctly. Certain scan tools can display oxygen sensor output voltages in graphic formats that look similar to the one displayed here.

tail pipe is/are known as the "downstream" sensor(s). The "upstream" sensor(s) next to the engine have nothing to do with the "downstream" oxygen sensors.

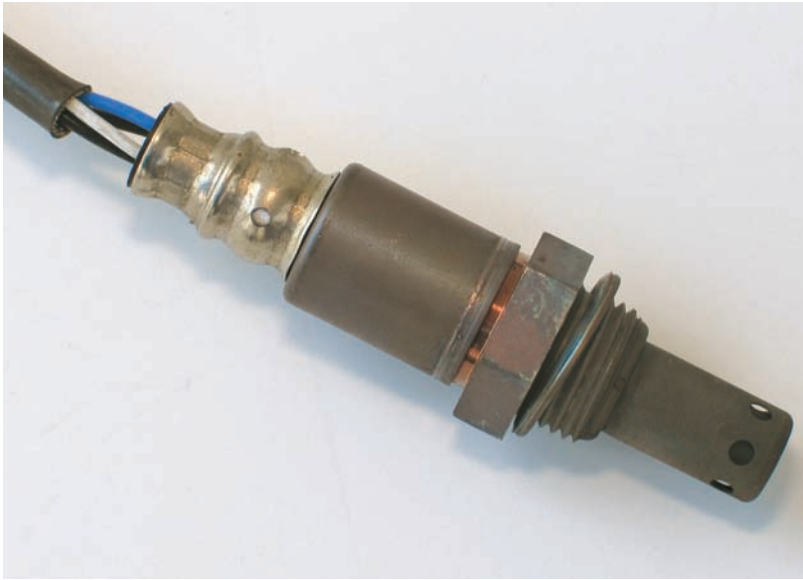
All OBD-II systems have a minimum of two, and as many as four, oxygen sensors. Essentially there will always be an O₂ sensor located between the engine and the catalytic converter, and another O₂ sensor located between the converter and the exhaust tailpipe. This is true even when two catalytic converters are used (see Figure 3-4). We'll start with a discussion of the two types of commonly used O₂ sensors equipped in vehicles today—zirconia and titania. Later, we will have in-depth coverage of "upstream" and "downstream" oxygen sensors.

The first type of oxygen sensor is a zirconia dioxide sensor. It acts as a galvanic battery by comparing oxygen content inside the exhaust to the oxygen content in the surrounding atmosphere, in order to generate a small, variable DC voltage. That voltage is then interpreted by a PCM as a signal that represents an air/fuel ratio that may be ideal, too lean (too much oxygen/too little fuel), or too rich (too much fuel/too little oxygen). Here's how it works: When oxygen content in the exhaust gas is low (a rich air/fuel mixture), the difference between the level of

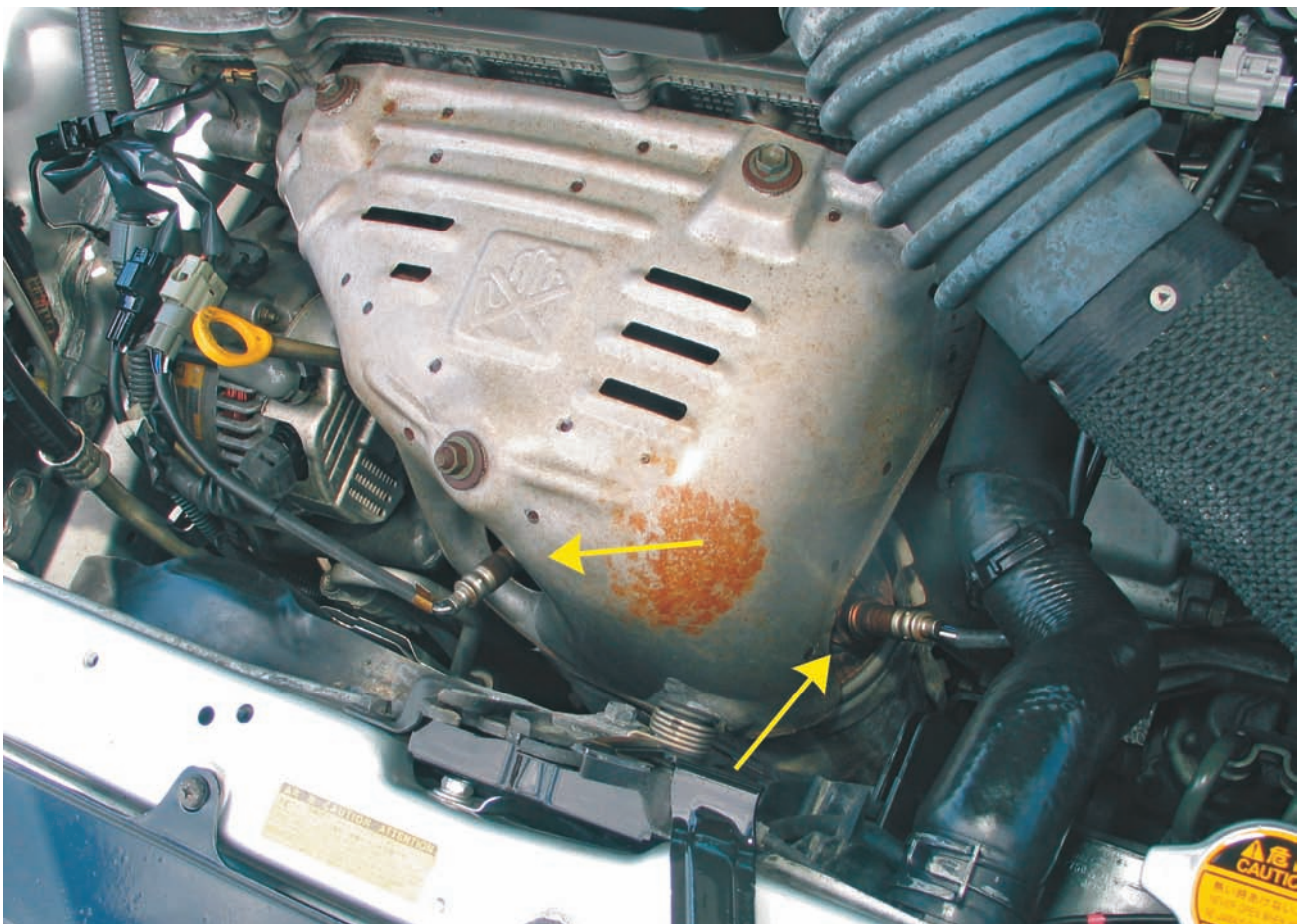
exhaust gas oxygen and the level of oxygen in the atmosphere is high, causing the sensor to produce a relatively high voltage—between 0.5 volts to 0.9 volts. Conversely, when the O₂ sensor detects a high exhaust gas oxygen content (a lean air/fuel mixture), and compares it with the oxygen in the outside atmosphere, the difference is smaller, so consequently, lower voltages are generated—between 0.1 volts to 0.4 volts. The output voltage is then interpreted by a PCM as either ideal, too much fuel (rich), or too little fuel (lean).

The other type of oxygen sensor is a titania O₂ sensor; it operates somewhat differently from a zirconia type sensor, but the end results are the same. Instead of producing a small voltage, a titania O₂ sensor uses a reference voltage from a PCM and then adjusts its internal resistance based on the oxygen content found in the exhaust gas. A titania sensor's resulting voltages are similar to those of a zirconia sensor. A rich fuel mixture produces higher voltages (above 0.45 volts), while a lean fuel mixture produces lower voltages of less than 0.45.

Both oxygen sensor types must be hot (600°F) before they can function. Oxygen sensors have to rely on hot exhaust gases to maintain optimal operating



Many manufacturers use the same type of O₂ sensor to sense oxygen content in exhaust gases, whether the location of the sensor(s) is “before” the catalytic converter (between the engine and the “cat”) or “after” the catalytic converter (between the “cat” and the exhaust tailpipe); these sensors are also commonly referred to as “upstream” and “downstream” O₂ sensors, respectively. Early OBD-II-compliant vehicles often used oxygen sensors that were interchangeable between “upstream” and “downstream” locations. Newer OBD-II-compliant vehicles are equipped with wiring harnesses of different lengths to accomplish the same function, some of which have different connectors, making it impossible to plug a rear “downstream” O₂ sensor into a front “upstream” O₂ sensor harness. The late-model Toyota O₂ sensor in the photo may look exactly the same for front “upstream” and rear “downstream” applications; however, the connectors are different, thereby making interchangeability difficult. *Courtesy Younger Toyota*



This 2.4-liter, four-cylinder engine for a Toyota RAV4 uses two “upstream” oxygen sensors (yellow arrows). One sensor monitors exhaust gas from cylinders 1 and 2, while the other monitors similar exhaust gases from cylinders 3 and 4. Even though these O₂ sensors are located inside the exhaust manifold, they still use their own internal electric heaters to quickly drive up their temperatures to minimum operating levels when the engine is cold. *Courtesy Younger Toyota*

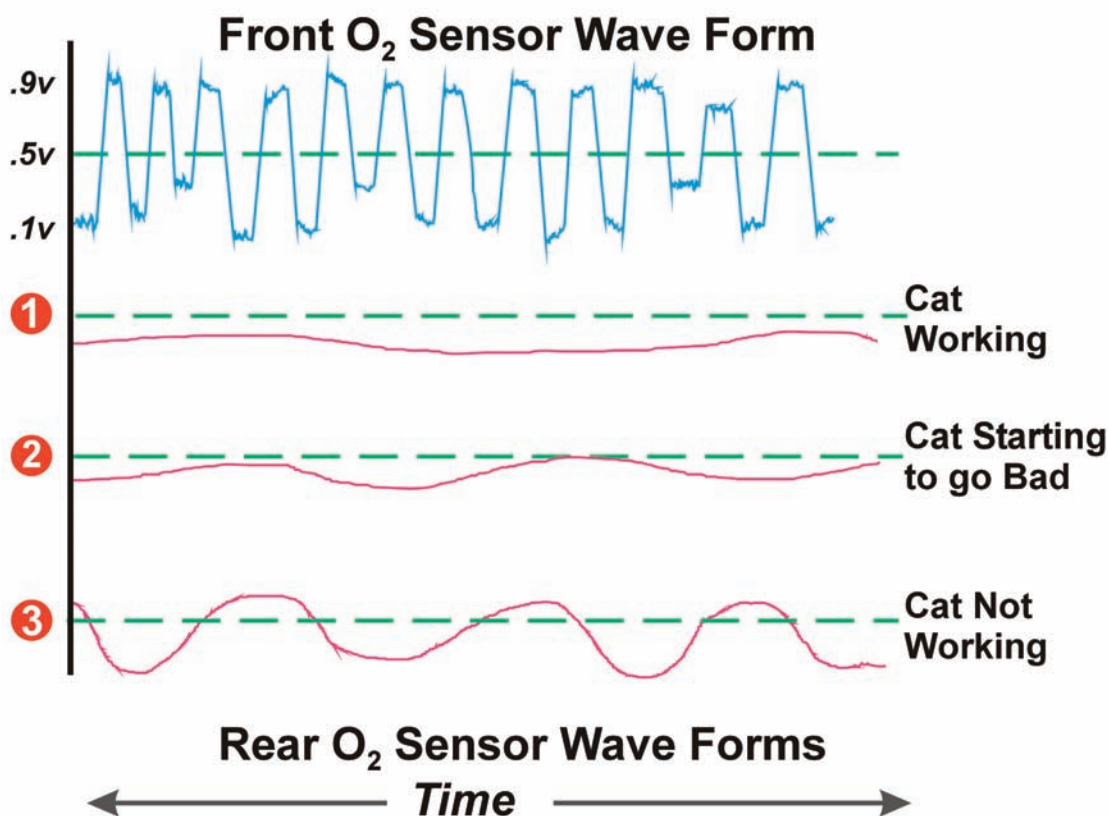
temperature levels. Consequently, all modern OBD-II sensors use an internal electric heating element to prevent them from cooling down at idle (when engine exhaust gas temperature is low), and to facilitate a faster sensor warm-up time during cold starting.

“UPSTREAM” O₂ SENSOR

An “upstream” O₂ sensor operates in the same manner and performs the same function in both earlier OBD-I systems and in more modern OBD-II systems. The “upstream” O₂ sensor is responsible for “closed loop” operation, in conjunction with a PCM and the fuel-injection system. Operation of an “upstream” O₂ sensor

can be observed via a scan tool that displays engine data streams or via use of a digital voltmeter connected directly to an oxygen sensor’s output signal wire. By monitoring O₂ sensor voltage, it’s fairly easy for a PCM or scanner tool to determine if a sensor is indeed working, and if so, how well it’s working.

To test an O₂ sensor, the engine should be warmed up to normal operating temperature by driving the vehicle, rather than merely letting it idle for a few minutes. Set up a scan tool to enable it to read an “upstream” O₂ sensor (some vehicles have more than one), or use a digital voltmeter connected to an oxygen sensor. Start the engine and maintain speed at 2,000



The lab oscilloscope waveforms in the graph represent O₂ sensor voltage output over time (voltage is shown on the vertical scale, while time is shown on the horizontal scale). Viewing oxygen sensor output voltages in a graphic format allows technicians to observe the quality of a sensor’s output signals. The waveform in blue (top) shows the operation of a front “upstream” (before the converter) O₂ sensor, as it alternates between a lean and rich mixture during “closed loop” operation. As depicted in the graph, waveform No. 1 represents the waveform for the rear “downstream” (after the converter) O₂ sensor during the same time period as front “upstream” O₂ sensor operation. The rear “downstream” sensor’s voltage signal confirms that the catalytic converter is operating normally. No. 1 voltage waveform only changes slightly, and much slower than the upstream oxygen sensor; this illustrates the converter’s ability to store and release oxygen. The graph’s waveform No. 2 represents a catalytic converter starting to lose its ability to store oxygen, as the rear “downstream” O₂ sensor is starting to look similar to the voltage output of the front “upstream” O₂ sensor. The waveform in No. 2 is alternating between high and low voltages readings, and it is changing more rapidly than the waveform No. 1. In the graph, waveform No. 3, shows the catalytic converter is completely worn out and can no longer store and release enough oxygen to reduce exhaust emissions—in effect the cat is “chemically” not there and therefore the downstream O₂ sensor looks more similar to the upstream O₂; both voltage signal waveforms look more alike. When the upstream and downstream O₂ sensor waveforms look too much alike (electrically speaking) the PCM will set a DTC that indicates the catalytic converter is not functioning.

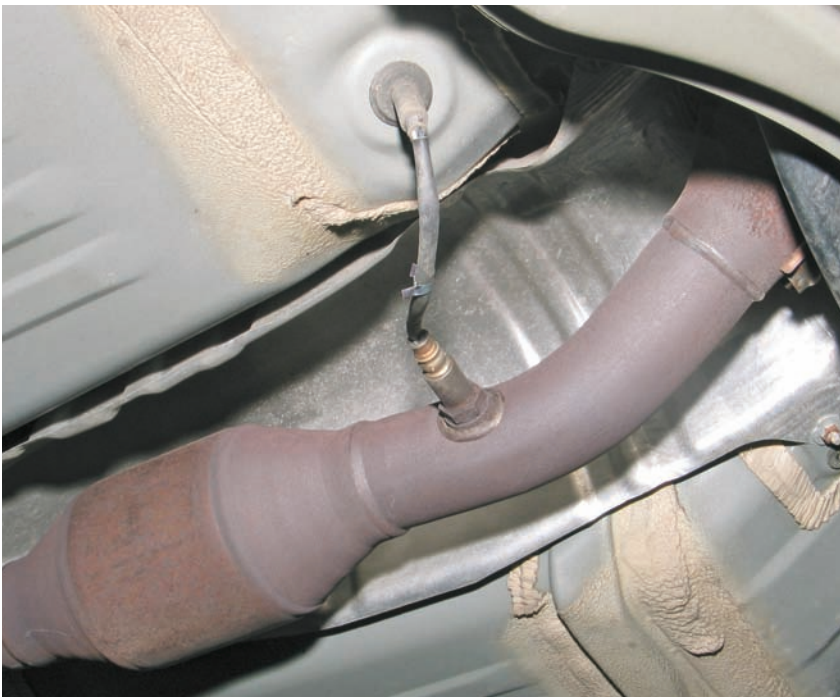
rpm for 60 seconds. If O_2 voltage starts fluctuating back and forth, somewhere between 0.2 and 0.8 volts, the EFI system is operating in “closed loop” mode. (However, bear in mind that for purposes of this test, it doesn’t really matter if the system is in “closed loop” or “open loop” operational mode). Next, while watching the scan tool or voltmeter, snap the throttle open. O_2 voltage should increase to 0.9 volts, indicating a rich fuel mixture. Normally, there is a slight delay from the time the throttle is opened until the time a scan tool is able to display an increase in voltage. This delay should be taken into account when using a scan tool for oxygen sensor testing. When using a digital voltmeter, changes in O_2 sensor voltage should be instantaneous.

Then, hold engine speed steady again at 2,000 rpm, and quickly close the throttle. This time, O_2 voltage should drop to 0.1 volt or less, since the PCM has cut off fuel to the engine in order to create a leaner mixture. How fast an O_2 sensor responds to fluctuations in exhaust gas oxygen, as well as the range of voltage displayed (0.1v to 0.9v), indicates whether the sensor is good or bad. A good sensor should be able to make voltage transitions instantly (a digital voltmeter connected directly to an O_2 sensor’s signal wire is usually much quicker at displaying results than a scan tool). A lazy or worn-out O_2 sensor will only make slow voltage transitions; it also won’t be able to reach 0.9 volts, no matter how rich the fuel mixture.

“DOWNSTREAM” O_2 SENSOR

The main function of a “downstream” O_2 sensor is to monitor a catalytic converter’s performance, to ensure its proper function. In view of its function, a “downstream” O_2 sensor is also sometimes called a “cat monitor oxygen sensor.” To determine a catalytic converter’s efficiency, a PCM compares voltage signals from the “upstream” and “downstream” O_2 sensors. In “closed loop” operational mode, the fuel system alternates the air/fuel ratio between a slightly rich mixture and a slightly lean mixture. This air/fuel ratio supplies the catalytic converter with oxygen, so that when the air/fuel mixture is leaned out (more air added), the “cat” will store oxygen to reduce emissions. When the fuel mixture is adjusted to a richer mix, the “cat” releases oxygen into the exhaust gas, and then uses it to convert hydrocarbons (raw fuel) and carbon monoxide (a harmful byproduct of combustion) into water vapor and carbon dioxide. This eliminates, or at least reduces, noxious exhaust emissions into the atmosphere.

A catalytic converter’s ability to store and release oxygen is an indication of how healthy it is. When a “cat” stores oxygen as a result of a lean air/fuel mixture, oxygen is low (as sensed by a “downstream” O_2 sensor). This results in a fairly constant output voltage signal. By contrast, when the air/fuel mixture is rich, the stored oxygen inside the “cat” is released, and again, the oxygen exiting the “cat” will only change an incremental



This rear or “downstream” oxygen sensor is about a foot away from the “cat” (not shown), and located to its right, up next to the engine. On this Toyota, the rear “downstream” O_2 sensor is nearly identical to the front “upstream” oxygen sensor; in fact, on this vehicle, the wiring harness length and connector are the only differences between the front “upstream” and rear “downstream” O_2 sensors. *Courtesy Younger Toyota*

amount, causing the “downstream” O_2 sensor to register only minimal voltage changes.

Even when brand new, a catalytic converter’s ability to store oxygen is limited. When the maximum available storage limit of a converter is reached, a “downstream” O_2 sensor will indicate either a high oxygen content (indicated by low voltage on a scan tool), or low oxygen content (high voltage displayed on a scan tool). During normal operation, the downstream O_2 sensor’s high and low voltages are relatively small when compared to the front, or “upstream,” O_2 sensor. Automotive engineers call this storage process “Cat Punch-Thru,” and depending upon whether voltage is high or low, the process is specifically called either “Lean Punch-Thru” or “Rich Punch-Thru,” respectively.

As a vehicle is driven mile after mile, its catalytic converter’s performance will ultimately degrade, thus correspondingly causing the converter’s ability to store oxygen to be reduced. In order for an OBD-II system to test a catalytic converter, both “upstream” and “downstream” O_2 sensors are used. A worn-out “cat” in poor operating condition will cause a “downstream” O_2 sensor’s voltage levels to more closely match those voltage readings from an “upstream” oxygen sensor. When both of the signals from the “upstream” and “downstream” sensors reach a pivotal point of equality that is predetermined, a PCM will set a DTC indicating the catalytic converter’s monitor has failed, and the converter is no longer operating as it should.

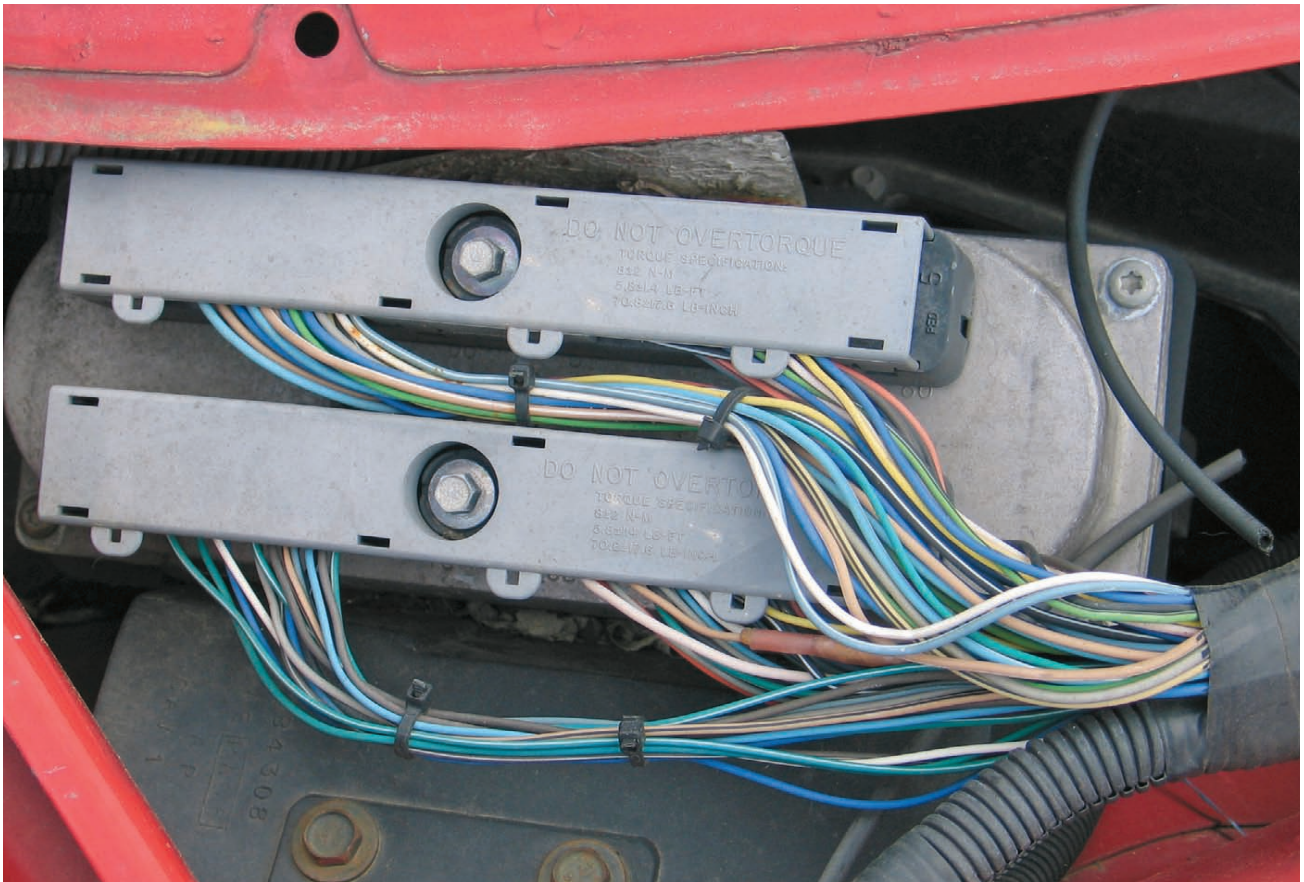
SHORT HISTORY OF FUEL-INJECTION SYSTEMS

With a final gasp of breath, the use of carburetors on vehicles sold in the US died in about 1994, with the last of these relics produced by Isuzu. How these mechanical fuel delivery devices came to be replaced by modern electronics will provide some insight and perspective into modern fuel-injection systems in use today. In fact, the combination of electronic fuel-injection systems with OBD-II diagnostic systems that are equipped with oxygen sensor operation is the only method of fuel delivery that effectively works with catalytic converters. Now that we have covered how catalytic converters and oxygen sensors operate it’s time to tie everything together with a discussion of how electronic fuel-injection operates. We’ll start out with a brief look back at the origins of automotive fuel-injection and follow up with an interview with a very special guest.

Driven by ever-tightening federal emissions standards, the widespread use of electronics for controlling fuel delivery on cars and trucks began in earnest in the early 1980s. The trend toward using solid-state electronics in the automotive field started in 1975, beginning with the replacement of mechanical ignition systems by electronic ignition modules, and later by electronic fuel injection systems. However, mechanical fuel-injection is not a new innovation in vehicle applications. It was used in diesel engines as early as the mid-1920s, while the first practical use of fuel-injected, gasoline-powered engines dates to World War II, when it was first used on military



Older OBD-I systems were not designed to monitor the performance of a catalytic converter. In fact, a converter could be damaged or even completely missing, and an OBD-I diagnostic system would not even turn on a “Check Engine” MIL light to warn a driver that the vehicle was puking out pollutants. Only with the introduction of modern OBD-II diagnostic systems can a converter’s performance be monitored as part of on-board diagnostics. In addition, the PCM on an OBD-II system will flash a “Service Engine Soon” MIL light if the converter is being damaged by an ignition misfire. *Courtesy Kiplinger’s Automotive Center*



In addition to running the electronic engine management system and OBD-II emissions diagnostics, a powertrain control module, or PCM (shown), also shifts the automatic transmission and manages body control functions, such as power door locks, vehicle alarm, power windows, and climate control.
Courtesy Elwood's Auto Exchange

aircraft. For example, the fuel-injected Wright R-3350 Cyclone, an 18-cylinder radial engine, was used in the B-29 Superfortress bomber.

One of the first commercial gasoline-powered injection systems for automobiles was developed by Bosch and used on the 1955 Mercedes-Benz 300SL. In 1957, Chevrolet introduced a mechanical fuel-injection option, made by General Motors' Rochester division, for its great small-block engine, the 283 V-8. The Chevrolet fuel-injection system used a crude method to measure airflow into the engine via a spoon-shaped plunger, which moved in proportional response to the amount of air entering the engine. The plunger was connected to a fuel metering system that mechanically injected fuel into the cylinders. Subsequently, during the 1960s, the popular Hilborn mechanical fuel-injection system was widely used in all types of auto racing, but these systems were designed to yield maximum horsepower, and consequently, had relatively bad manners during

the ubiquitous part-throttle driving conditions typically found on America's expanding road networks and developing freeways. Consequently, Hilborn mechanical fuel-injection systems were not typically in use on street-driven cars, except for perhaps the occasional hot rod.

One of the earliest electronic fuel-injection systems for mainstream automotive commercial use was developed by Bendix; called the "Electrojector," the system was used on the DeSoto Adventurer and other Chrysler Corporation cars as early as 1958. This system was most likely the first electronic throttle body injection (TBI) system ever used in a production automobile. These early fuel-injection systems, whether mechanical or electronic, never gained popularity because they were difficult to manufacture, hard to maintain, and did not provide any real benefits to consumers. Consequently, American auto manufacturers went with what they knew for providing fuel delivery in vehicles, and what they knew best was the good old carburetor.

At the time, carburetors were more reliable and less costly to manufacture than any type of fuel injection; however, this was not the case in Europe, where Bosch continued to develop and refine its fuel-injection technology. One of the first fuel-injection systems developed by Bosch for production vehicles was introduced on 1967 Volkswagens using VW's Type 3 engines. Called "D-Jetronic," (the "D" stood for the word "Druck," which is a German word for pressure), this system was a speed-density type of fuel-injection system. Speed-density simply meant the engine's speed, along with the density of the air inside the intake manifold, were both used to determine the amount of fuel to be injected into the engine. An electro-mechanical pressure sensor (an early form of a modern-day MAP sensor (manifold absolute pressure sensor) was used to calculate engine load, or how much fuel an engine would require for any given operating condition. The D-Jetronic system found its way into use on Volkswagen, Mercedes-Benz, Porsche, Saab, and Volvo vehicles. General Motors used a copy of the D-Jetronic system on its Cadillac models starting in 1977.

However, in 1974 the D-Jetronic system was already being replaced on European cars by the improved L-Jetronic and K-Jetronic fuel injection systems. The L-Jetronic system ("L" stands for "Luft," which means air in German) used a mass airflow sensor (MAF) equipped with a mechanical flapper door that moved whenever an engine's throttle was opened. The door was connected to a variable resistor that sent a voltage signal to an on-board computer. This system used electronic injectors. Often called "port fuel injection," this system used one injector for each cylinder. This type of electronic fuel-injection (EFI) system was also popular on Japanese cars during the 1980s, and remained popular on European vehicles as well.

Today, all vehicles made for the American marketplace are equipped with EFI systems. In addition to cars and light trucks, there are many non-automotive applications for EFI systems as well, including motorcycles, scooters, all-terrain vehicles (ATVs), and even lawn tractors. Consequently, today's professional automotive technicians, as well as home do-it-yourself mechanics, who are lacking a basic understanding of how EFI systems work, are severely limited in their ability to perform basic diagnostics, even with the help of a scan tool connected to an OBD-II system.

Starting with simple, basic concepts and comparisons between older carbureted fuel systems and newer EFI systems should offer some insight as to how more modern systems operate. So what do carburetors and fuel injection have in common, and more importantly, what do they have to do with each other? Older carburetor systems and modern EFI systems share similar basic functions and fuel delivery duties. Consequently, a good understanding of how a simpler carburetor's fuel circuits operate will help make sense of how a more sophisticated EFI system operates. Once a technician grasps the basics of EFI operation, most types of electronic fuel injection are relatively easy to understand.

CARBURETORS

The fuel-delivery functions a carburetor performs are not substantially different from similar functions of newer EFI systems. Therefore, understanding how fuel delivery circuits inside a carburetor operate will make electronic fuel-injection concepts and operational functions easier to understand. All gasoline-powered engines need only three basic ingredients to run: 1) the correct amount of fuel for any given rpm and throttle opening; 2) a spark from the ignition coil at the right time; and 3) sufficient cylinder compression to ignite the air/fuel mixture. A carburetor is basically a hunk of aluminum with a bunch of holes drilled into it. A carburetor's job is to match the supply of fuel to the amount of air entering the engine. The volume of air is controlled by the driver's right foot whenever the driver operates the gas pedal. As air pressure within the carburetor changes, fuel and airflow through the various holes in the carburetor into the engine.

All of the functions a carburetor performs are duplicated in a modern electronic fuel-injection system. Carburetors use several hydraulic fuel circuits that deliver fuel to the engine's intake manifold. Fuel moves through a carburetor's fuel circuits as a result of differences in air pressure at various points in its passageways and openings. A carburetor's fuel-delivery system is made up of at least six basic separate fuel circuits, each with a specific job to perform. Following are the basic fuel circuits found in most carburetors.

1. **Float circuit**—The float circuit regulates fuel into a carburetor and stores it in a float bowl, where it is available for use by five other fuel delivery circuits. When the level of fuel drops in the float bowl, a



Carburetors have been around for over 100 years. This one from the 1970s performed all the same basic functions as a modern fuel-injection system. Although carburetors were simple to repair, fairly reliable, and inexpensive to produce, they unfortunately weren't precise enough to provide reliable fuel delivery with the requisite degree of accuracy required by today's emission standards. *Courtesy Elwood's Auto Exchange*

needle valve supplies more fuel to keep the bowl full—similar to a valve in a toilet bowl that keeps water in the bowl when the device is flushed.

2. **Choke circuit**—During cold start-up the choke circuit adds extra fuel and air to the engine to keep it from stalling, until it reaches normal operating temperature. Early carburetors used a manual choke circuit operated by a cable and choke knob on a dashboard, while later models used an automatic choke controlled by a bi-metallic spring.
3. **Idle circuit**—The idle mixture circuit provides fuel for the engine at idle speeds; this circuit is controlled by an idle mixture screw that regulates
- the amount of fuel entering the engine when the carburetor's throttle plate(s) are closed.
4. **Fuel transfer circuit**—The transfer circuit is made up of a series of small holes located in the carburetor's main passageway that progressively add fuel as the carburetor's throttle plate(s) are first opened. This circuit provides smoothly transitioning fuel delivery from idle to part-throttle operation.
5. **Main circuit**—During steady throttle operation, fuel is delivered from the float bowl through the main circuit and into the engine. The amount of fuel is controlled by the main jet, which is

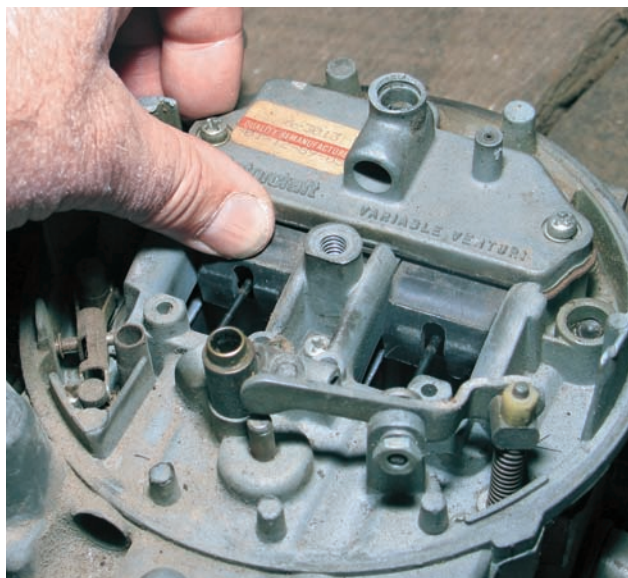
basically a small hole located in the bottom of the float bowl that restricts the flow of fuel. The size of the main jet is carefully matched to airflow through the carburetor—too large a hole and fuel economy suffers—too small a hole and engine performance feels sluggish or flat at part-throttle.

6. **Accelerator pump circuit**—Whenever the throttle is opened suddenly, the accelerator pump circuit squirts fuel directly into the intake manifold. Since air is about 400 times lighter than gasoline, air would normally reach the intake valve and combustion chamber well ahead of the fuel delivered by the carburetor. Thus, this “squirt” of fuel from the accelerator pump circuit allows the main fuel circuit to play “catch-up” with the column of moving air entering the engine. The accelerator pump circuit prevents a flat spot and possible backfire during abrupt engine acceleration.

Although carburetors have been performing fuel delivery functions in vehicles for well over a hundred years, and have worked pretty well and pretty much the same, there are some functions carburetors simply can't handle. Unfortunately, a carburetor's ability to deal with



This single-barreled, cast iron carburetor would best be used today as a paperweight, or possibly as a replacement part in a classic car or truck awaiting restoration. Vintage auto parts suppliers still sell rebuild kits for this old hardware. *Courtesy Elwood's Auto Exchange*



Similar in design to a motorcycle carburetor, this Ford Variable Venturi carburetor rivaled some electronic fuel injection systems in both engine performance and fuel economy. “VV” carbs were used throughout most of the 1980s. Many police cruisers used them because of the exceptional power and throttle response they provided. *Courtesy Elwood's Auto Exchange*

constantly changing operating conditions is limited with regard to its reactions to changes in altitude, its efforts to compensate for engine temperature, its lack of precise control of fuel for emissions purposes, and its overall use of too much fuel during steady-state engine operation and acceleration. In a word, carburetors are just too “dumb” to continue being able to provide accurate air/fuel mixtures in modern vehicles. What is needed is a fuel delivery system with brains.

ELECTRONIC FUEL INJECTION

The design and concept behind all EFI systems is essentially the same: A computer, with various engine sensors providing electronic information, is used to control the exact period of time fuel will be injected into an engine. In addition to performing all of the functions of a carburetor, EFI systems also control engine idle speed and ignition timing system functions. They primarily regulate fuel delivery via electromagnetic valves (fuel injectors) that electronically turn on for precise lengths of time as measured in increments of $\frac{1}{1000}$ of a second or milliseconds. Once the fuel injectors are turned on,



This Ford Motor Company throttle body and four injectors comprise a modern EFI system for a four-cylinder engine. Because each cylinder has a source of fuel located close to its intake valve, there is virtually no lag between throttle opening and fuel delivery. Better overall engine performance and fuel economy give EFI systems many advantages over carbureted systems.

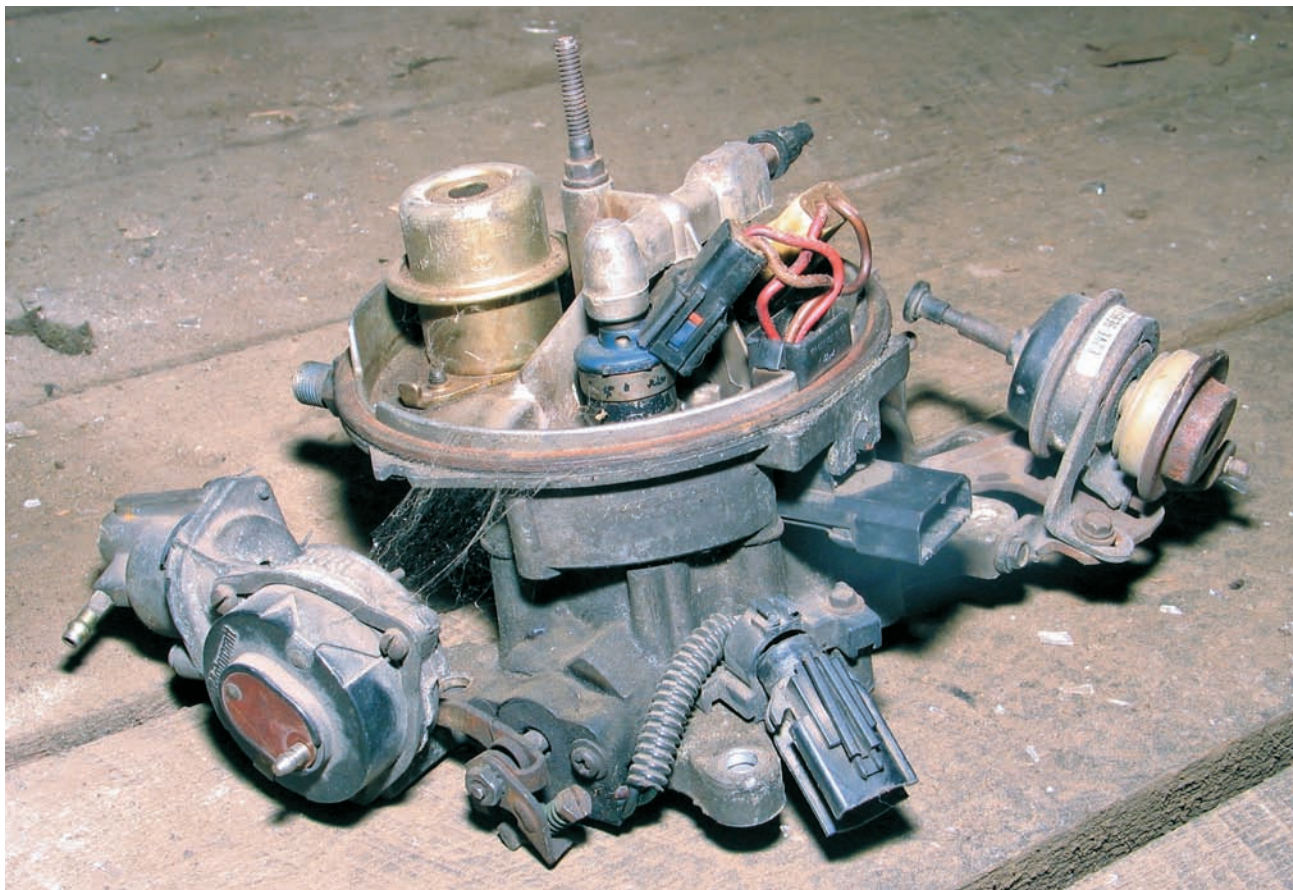
they spray fuel into the engine. The amount of “ON” time is called injector pulse width, and the longer this is, the greater the amount of fuel injected. The on-board computer, or PCM in an OBD-II system, is continuously receiving data from its various sensors and calculating how much injector “On” time should be used for fuel delivery.

While all EFI systems use fuel injectors that operate in a similar manner, several different EFI designs and computer strategies existed prior to the inception of OBD-II systems in 1996. One of these designs was throttle body injection, or TBI, which used only one or two injectors located where a carburetor would normally be installed. In this type of system, after fuel is injected into the throttle body, it must travel through the intake manifold before reaching each cylinder. Since the air/fuel mixture has to travel different distances to reach the engine’s cylinders, this system had inherent fuel distribution problems, as it caused differing amounts of fuel to reach the cylinders. Thus, consistency in fuel delivery was lacking. Consequently, TBI injection is no longer used in view of its inherent inability to regulate

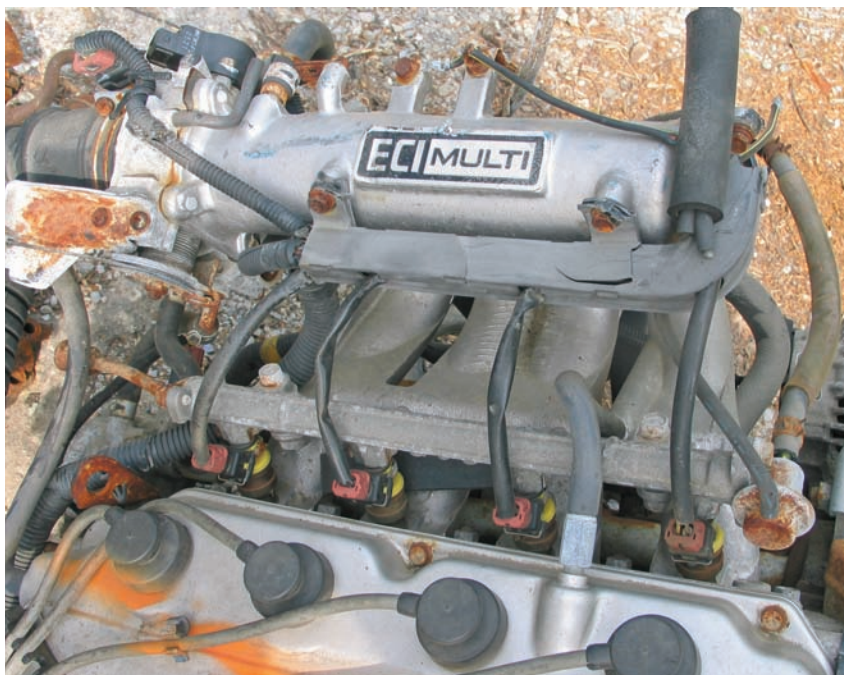
equal amounts of fuel to each cylinder, and in the process, effectively control emissions.

Unlike TBI injection, port fuel injection (PFI) uses an individual injector for each cylinder. A PFI system is more efficient than a TBI system because fuel is sprayed directly at the back of the engine’s intake valves; consequently, it has less distance to travel before getting to the combustion chamber, rendering fuel delivery more precise. However, PFI systems were eventually phased out of production and replaced by more sophisticated sequential port fuel injection (SPFI) systems. The injectors on SPFI systems are pulsed in accordance with an engine’s sequential firing order—similar to how ignition systems are timed and spark plugs are fired. Thus, SPFI systems provide even more accurate fuel delivery, which in turn, helps reduce exhaust emissions and increases fuel mileage and performance.

Finally, one other type of fuel injection system exists: Bosch’s “K” or “KE-Jetronic.” This system uses an airflow sensor in which a metal plate moves in relation to engine airflow. As the throttle is opened, the sensor measures the increased amount of air entering the engine. A fuel distributor then delivers fuel to each injector mechanically. These systems are found only on European cars like Mercedes, BMW, Volkswagen, Saab, and Volvo. The last “KE-Jetronic” system manufactured for the US market was used by the 1993 VW Passat.



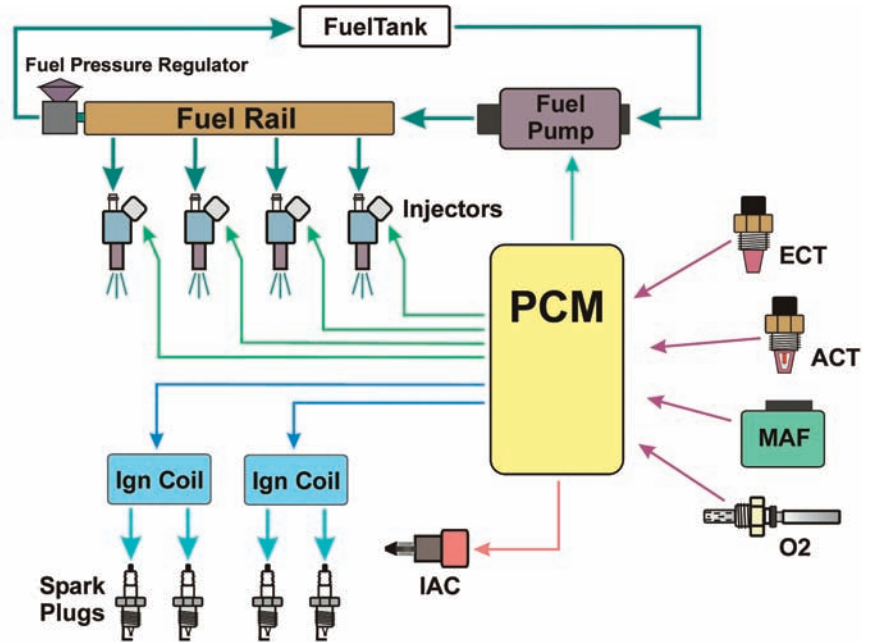
This throttle body electronic fuel injection unit is from a Ford EEC-III vehicle from the mid-1980s. Two Bosch high-pressure injectors are used (at the top with wires coming out of them). The fuel pressure regulator can be seen on the top at left. These types of systems provided better drivability than a simple carburetor, got fairly good fuel economy, and were able to meet the emissions requirements of their day. *Courtesy Elwood's Auto Exchange*



More sophisticated PFI (port fuel injection) systems provided more accurate fuel delivery than throttle body injection systems since these systems provided individual cylinders with their own source of fuel, i.e., a fuel injector. On this Mitsubishi PFI system, the individual injectors are sandwiched between the cylinder head and fuel rail. In addition to separate electronic fuel injectors, each cylinder also has an individual intake runner. The lengths of the intake runners allow more air to enter the engine at higher rpm, thus boosting the amount of torque the engine produces. *Courtesy Elwood's Auto Exchange*



Electronic fuel injectors like this General Motors example are nothing more than simple electro-mechanical valves that operate via electronic pulses from a vehicle's PCM. Power is continuously supplied to the injector, while the PCM pulses the ground return wire to turn the injector on and off. Fuel injectors are fairly simple to test, as they only require a digital Ohmmeter to test injector resistance, and a test light, or noid light, to test for injector pulse from the PCM. Unfortunately, getting to an injector may be tough, depending on how buried they are under engine covers and intake manifolds. *Courtesy Elwood's Auto Exchange*



A basic engine-management control (ECM) system. The powertrain control module (PCM) controls both the fuel delivery and ignition systems. An electronic fuel pump pressurizes fuel in the fuel rail, which acts like a storage tank for the injectors. In the system shown, excess fuel is returned to the fuel tank via the fuel pressure regulator. When the PCM pulses the injectors, fuel is sprayed into the engine. Based on computer sensor inputs (shown at far right), the PCM also fires both ignition coils as the engine rotates.



This K-Jetronic fuel-injection system is mostly mechanical in operation. Bosch developed this form of fuel injection as a result of their experience with diesel engine injection systems. These systems were reliable and fairly easy to repair, but expensive to do so. They could not control fuel delivery precisely enough to be used on any OBD-II systems, and were phased out of production in 1993. Prior to 1993, they were used on Volkswagen, Saab, Mercedes, Volvo, and BMW vehicles. *Courtesy Elwood's Auto Exchange*

INTERVIEW WITH A PCM

While a carburetor may undoubtedly be a dumb hunk of aluminum, there are those who would argue a PCM (powertrain control module) is nothing more than a dumb wafer of silicone with wires attached. To settle the matter, we searched for and found a PCM willing to be interviewed, and ready to answer questions about how electronic fuel injection systems work. This OBD-II-compliant PCM has more smarts than most, so we're lucky to have this opportunity. In this Motorbooks Workshop series exclusive, the first ever "face-to-processor" interview, we got the chance to ask all the questions about EFI systems that everyone's been dying to get the answers to.

MotorBooks—Thanks, PCM, for agreeing to talk with us. We don't often get a chance to interview automotive on-board computers. Can you introduce yourself and give us a general description of what you do?

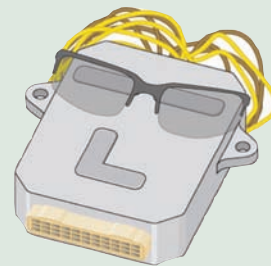
PCM—Thanks for having me! It's so great to hear that people are interested in what I do. Some less-enlightened people have unkindly referred to me as an overgrown calculator. While there is some truth to that description, it's not exactly true, since I do have more computing power than a calculator, though less than a typical laptop. I have really fast access to my memory and can perform close to a million calculations per second. Plus, I have a network of friends that supply me with information when needed. You see, I have connections—a bunch of sensors that feed me information on various engine-operating conditions. These sensors serve me at a moment's notice, acting like my own eyes and ears. It's discerning friends like these that allow me to keep things under control. I can also calculate fuel delivery and ignition settings that correctly respond to whatever the "nut" behind the steering wheel might have in mind while driving the vehicle I'm installed in.

MB—Hmm. That is impressive. Sounds like you don't often get enough credit. Why don't you take us through the steps you would typically go through while managing the engine and its various systems? For instance, what do you do when the ignition key is first turned to the "On" position?

PCM—I take voltage readings from the engine coolant temperature sensor as well as the outside air temperature sensor. To illustrate, assuming the outside air and engine temperatures read 50° F, I'll increase the injector "On" time, or pulse width, to add extra fuel to start the engine. But I also command the idle air controller, or IAC, to provide some extra air to the engine to increase its idle speed when it starts. Otherwise the stupid thing would stall. I'll also check in with my barometric pressure sensor, or BARO, to determine what altitude I'm operating at, so I can fine-tune and match fuel delivery to atmospheric pressure or altitude. Oh, I almost forgot, I also have to turn

Mr. PCM here has the computing power to manage his vehicle's fuel and ignition system. But is he smart enough to deal with the intricacies of an OBD-II diagnostic system and all it entails? Find out in this section when you read the first interview with a PCM ever recorded.

Courtesy Alan Lapp, Level Five Graphics



on the fuel pump for a couple of seconds to prime the fuel system. I can't leave it running for safety reasons, unless of course, the engine is already started and stays running.

MB—Wow. That's a lot. I had no idea you were so busy when the engine starts up. I guess I just took engine starting for granted. Once the engine is running, is there anything else you do to control basic engine operation?

PCM—Yes. In fact, it often feels like my job is never done. Basically, to manage engine operation I must control four things: 1) injector "On" time; 2) ignition timing; 3) engine idle speed; and 4) fuel pump operation. However, please understand that these four functions are the bare minimum I must perform in order to keep the engine running smoothly. To be truly efficient, I must also perform numerous additional functions, like controlling the cooling fan to keep the engine from overheating and shifting the automatic transmission. At the same time, I am often called upon by the driver to control the heating and air conditioning or the lighting system. Furthermore, to show the driver I really care about safety, I also use a "drive-by-wire" system as a precaution; this system controls the throttle so the tires won't lose traction when the road is wet or slippery. In this way, I can prevent certain irresponsible drivers from doing burnouts and donuts. Finally, I also control lots of other, littler, more incidental stuff that I need not bother you with now. And not to brag, but I should point out that not all PCMs have as many sensor inputs as I do, nor do they control as many vehicle systems as I do. I guess I'm just a little bit smarter than most PCMs.

MB—Truly, I had no idea your job was so demanding and stressful. I admire you for keeping things together so well. Recently, I've been hearing about this thing called an OBD-II system, or on-board diagnostics II. What can you tell me about it? Are you required by the EPA to use OBD-II?

PCM—Yeah, I've not only heard about OBD-II, I have to deal with one in my vehicle—kind of like a bad case of the flu that never goes away. I am required by the EPA to work with one, but I keep the OBD-II thing locked deep in the recesses of my software and occasionally feed it



While they might look different, all of these fuel injectors operate in the same manner. Each uses a coil of wire that acts like an electromagnet to open a valve whenever the PCM sends out an injector pulse triggering fuel delivery to the engine. Injectors are either all the way open and on, or completely closed and off. A PCM takes readings from all of its sensors and calculates the injector “on” time, or pulse width. How long the injectors are “on” and open determines how much fuel will be injected into the engine.

electrons. First, I want to officially go on the record and state that OBD-II has absolutely nothing to do with engine management—that’s exclusively my job. The OBD-II system is separate and more like “Big Brother.” It’s always watching me, waiting for something bad to happen. As a computer, I consider myself perfect in every way, always functioning at optimal performance, but on rare occasion, like anyone else, if one of my sensors or actuators or part of the ignition system screws up, I have hell to pay. When this happens, the OBD-II system writes it down as a fault code, or DTC, electronically speaking. If things get bad enough, my OBD-II software will turn on a “Check Engine Soon” MIL light to alert the driver that I am functioning under duress, with a specific malfunction occurring somewhere in one of my systems. To sum up, I have a close professional working relationship with my OBD-II system counterpart, but we’re not particularly close otherwise.

MB—Gee, I had no idea. Sounds tough, but it sounds like you’ve found a way to work it all out smoothly. Let’s get back to the reason for this interview—namely, how electronic fuel-injection systems operate. What happens when the ignition key is turned from the “ON” position to the “Start” position and the engine cranks over?

PCM—As soon as the engine starts rotating, I receive pulsing signals from both the crank and camshaft position sensors. These signals let me know the engine is trying to start; so the first thing I do is turn the fuel pump back

on. Since I know the engine is cold, I’ll send signals to all the injectors to spray fuel each time the engine makes a complete revolution. This adds extra fuel required for cold starting conditions. Once the engine is warmed up, I’ll use a camshaft position signal to determine which cylinder is about to open its intake valve. Then I’ll pulse, or energize, individual injectors in the same firing order as the spark plugs in order to create an atomized cloud of fuel that will wait right at the intake valve, so that as soon as the valve opens, the cloud will get sucked into the cylinder. This strategy is called “sequential port fuel injection” because the injector firings are timed with each cylinder’s intake valve opening. Older EFI systems, that aren’t as sophisticated as I am, can only pulse all of the injectors simultaneously every other crankshaft revolution. That’s why those older systems had a hard time controlling emissions and didn’t generate as much engine power as my system. And that’s why they’re not around anymore, but I still am.

MB—Well, I can see why you would be. That’s a lot of work to perform, and it sounds fairly sophisticated. But once the engine is started, is your job done? Can you kick back and relax? Or does something else happen?

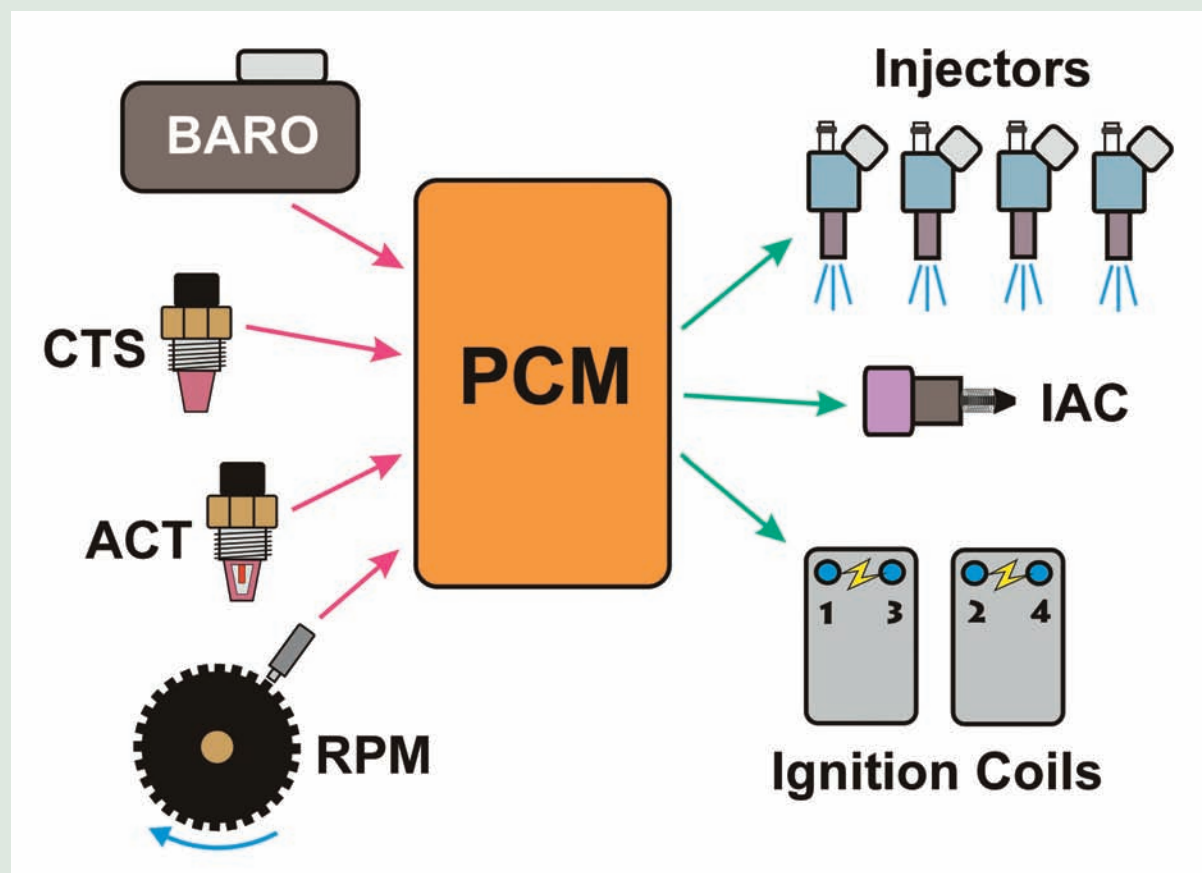
PCM—Well, that depends. If the driver lets the engine idle for awhile, the engine temperature will increase. Then I have to shorten the injector pulse width so that less fuel is delivered to the engine. I’ll also gradually lower

(continued)

the idle speed. On the other hand, if the driver shifts the transmission into drive and steps on the gas, then I have to jump into high gear to really make things happen quickly, since I am required to add fuel as the engine requires it. I rely on four different informational signal inputs to determine appropriate base injection “on” time, or pulse width, including engine rpm from the crank sensor, camshaft position, throttle position from the TPS sensor (sometimes referred to as driver demand), and engine load from the mass airflow (MAF) sensor. These input signals allow me to adjust and control injector pulse width and ignition timing to match exactly the needs of the engine at any moment.

MB—Wow. Don’t you get stimuli overload? With all the information coming in from your sensors, how do you actually decide what action to take in response to either driver demand or engine power requirements?

PCM—Sometimes it’s difficult, but I can handle it since I have help. I use three-dimensional mapping programs, sort of the equivalent of visual aids that are burned into my read-only memory or ROM. As engine rpm increases, I simply fire the injectors sequentially so that their firing matches engine speed. At any given rpm, I can monitor the MAF sensor to determine the quantity of air entering the engine. Airflow is directly proportional to engine load (how hard the engine has to work to get the vehicle moving down the road). My fuel and ignition maps contain what are known as “look-up tables,” where predetermined fuel delivery values are stored. From the information gleaned from the “look-up tables,” I can calculate how long to keep the injectors turned on, and when to fire the spark plugs. I have to look up these values each time I pulse an injector or fire a spark plug, so I have to think and react pretty quickly. As you can imagine, things happen pretty fast on a high-revving engine.



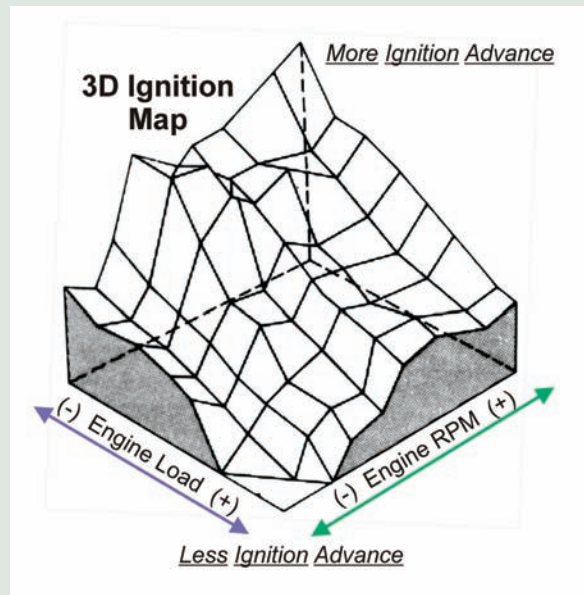
Whenever an engine’s starter motor is cranked over, the PCM receives an rpm signal from the crank sensor, a barometric pressure signal from the BARO sensor, and temperature readings from the coolant temperature and air temperature sensors. Based on this compiled information, the PCM pulses the injectors and fires the ignition coils, which in turn fire the spark plugs. When starting conditions are cold, the PCM will increase engine idle speed using an idle air controller (IAC) in order to prevent the engine from stalling.

MB—Life in the fast lane, huh? But I'm still a little puzzled about something you said earlier, when you talked about driver demand and input from the TPS sensor. Can you explain the relationship between these things?

PCM—Sure. The TPS or throttle position sensor is really the only input signal a driver has direct control over. Its varying voltage signal tells me what the driver is trying to accomplish in the horsepower and torque department. No matter how slow or fast the accelerator pedal is pressed to the floor, I can react faster than the driver to provide proper ignition timing and fuel delivery. In fact, the TPS signal is much like an accelerator pump on a carburetor system, as it gives the engine an extra shot of fuel to match increased airflow when the throttle is opened. Let me provide you with a different perspective on this issue: Whenever the throttle is opened abruptly, a column of air moves through the intake manifold at high speeds. To prevent the occurrence of a "flat spot" during acceleration, gasoline must join with moving air before the intake valve opens. To ensure this occurs timely and properly, I can modify the length of time the injectors stay on, at a computer processing rate of over 100 times per second, so that when the throttle is whacked hard I have the exact amount of fuel waiting to mix with the blast of incoming air. Keep in mind that electricity still travels faster than any action either the driver or engine can perform, so keeping up with changing engine speeds and engine loads is just not a problem for me.

MB—Well, that's understandable. Now that I know what a TPS does, I'm curious about something that used to happen quite often with older carbureted systems. When driving in the mountains, engines would run poorly and carburetors would have to be adjusted for higher altitude conditions. Do you experience a similar phenomenon, and if so, how to you deal with this problem?

PCM—I am happy to say that scenario is a non-issue for me. I simply have to read the input from my barometric pressure sensor, or BARO sensor, and then just adjust the fuel delivery to match the altitude the car is being operated at. The higher the altitude the car is driven, the less air or oxygen is available for combustion. Consequently, I simply shorten the pulse time, or pulse width, of the fuel injectors and add less fuel to the engine. The incremental adjustment I make is called fuel trim, and it provides the engine with exactly the right amount of fuel, regardless of the altitude the vehicle is operated at. Plus, I also use other sensors to trim or fine-tune fuel delivery. As an example, when the air charge temperature (ACT) sensor notifies me the vehicle is operating on a hot day, I adjust optimal fuel delivery parameters and remove a small amount of fuel. On a cold day, I simply do the



This is a three-dimensional (3-D) ignition advance map, which depicts the relationship between engine load, ignition advance, and engine rpm. While an ignition map is shown, fuel maps are similar in that they are nothing more than a simple set of instructions the PCM follows in order to calculate fuel delivery or ignition timing commands. In this example, less ignition spark advance is used at low engine rpm and high engine loads to prevent engine knock or detonation. As engine load decreases and engine rpm increases, more spark advance is used to increase fuel economy. Because hundreds of engine load and rpm combinations are possible, it takes many hours of engine testing on a dynamometer to produce both 3-D ignition maps and fuel maps.

reverse—I add a little more. I am also able to calculate relative humidity using information from the MAF sensor, and can adjust fuel delivery to accommodate associated changes in air density as well.

MB—While all this electronic fuel control wizardry is occurring, how do you determine proper ignition timing, or when to fire the spark plugs?

PCM—Again, I rely on information from my assistants, or sensors. Depending on specific informational inputs I receive from a TPS sensor, engine speed or rpm, and MAF sensor, I either advance or retard ignition spark timing depending on engine demand. For example, if the driver is operating the engine at part throttle combined with moderate engine rpm, I will adjust the ignition timing by advancing it, or starting it earlier for better fuel economy. However, if the reverse occurs and the throttle is opened suddenly, and engine rpm are low, then I must adjust the ignition timing accordingly, by retarding it, or starting it later to prevent engine knock.

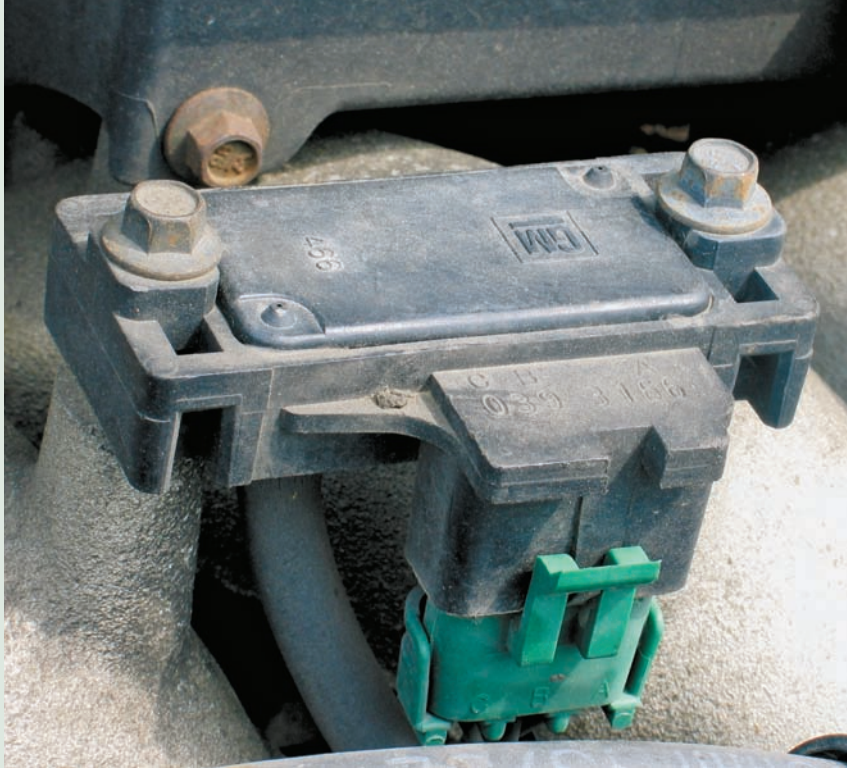
(continued)

This three-wire General Motors mass airflow (MAF) sensor produces a high frequency signal that is sent to a PCM, which then uses the informational signal to calculate total airflow into the engine. Airflow calculations combined with intake air temperature factor in the volume of air entering the engine, with altitude and humidity determinations as well. Less sophisticated manifold absolute pressure (MAP) sensors were eventually replaced by MAF sensors on many vehicles, since they provide faster, more accurate engine load information to a PCM.

Courtesy Elwood's Auto Exchange



This Bosch mass airflow (MAF) sensor uses a hot wire system to measure airflow into the engine. The hot wire, which is located inside the small ring or tube, is visible, and is heated by the sensor's electronics. When the throttle opens, incoming air blows past the heated wire, cooling it down. A MAF sensor's internal microprocessor increases electrical current to the hot wire to maintain the wire's temperature at a predetermined point. By sensing the amount of current required to keep the hot wire at the proper temperature, and comparing it with a measurement of the outside ambient air temperature taken by an additional temperature sensor, the MAF can then calculate engine airflow and even determine relative outside humidity. MAF sensors are used more often today than MAP sensors since they are far more accurate for determining engine airflow.



This General Motors manifold absolute pressure (MAP) sensor serves as the equivalent of an electronic vacuum gauge that measures engine vacuum. Readings from this sensor are used by a PCM to calculate fuel-injector pulse width based on engine load, or how hard the engine is working. All MAP sensors provide the same information, but they send out different electrical signals depending on the specific manufacturer. General Motors and Chrysler MAP sensors produce a varying voltage signal, while Ford MAP sensors produce a digital on-off signal. Furthermore, each MAP sensor may be connected differently to an intake manifold, since some auto manufacturers use a vacuum hose, while others directly mount the MAP sensor onto the intake manifold. *Courtesy Elwood's Auto Exchange*

Later, as rpm increases, I will again advance ignition timing to ensure optimum horsepower production.

MB—You mentioned engine knock. I'm not all that familiar with that. Isn't that a funny noise a vehicle makes? Is there such a thing as a knock sensor? If there is, and I am betting there probably is, how does it work?

PCM—You would win that bet. There is a knock sensor, and its sole purpose is to detect whenever the engine knocks, pings, or detonates. All of these conditions are bad and can cause severe engine damage. Once I receive a signal from the knock sensor, I slightly retard ignition timing until the knocking stops. In fact, I am smart enough to tell which cylinder is knocking, so I will only retard the spark timing for that specific cylinder. Once the ping or knock disappears, I'll immediately advance ignition timing again for better fuel economy and engine power.

MB—You haven't talked about oxygen sensors or catalytic converters yet. What's going on with these emissions devices, and what's your role in their operation?

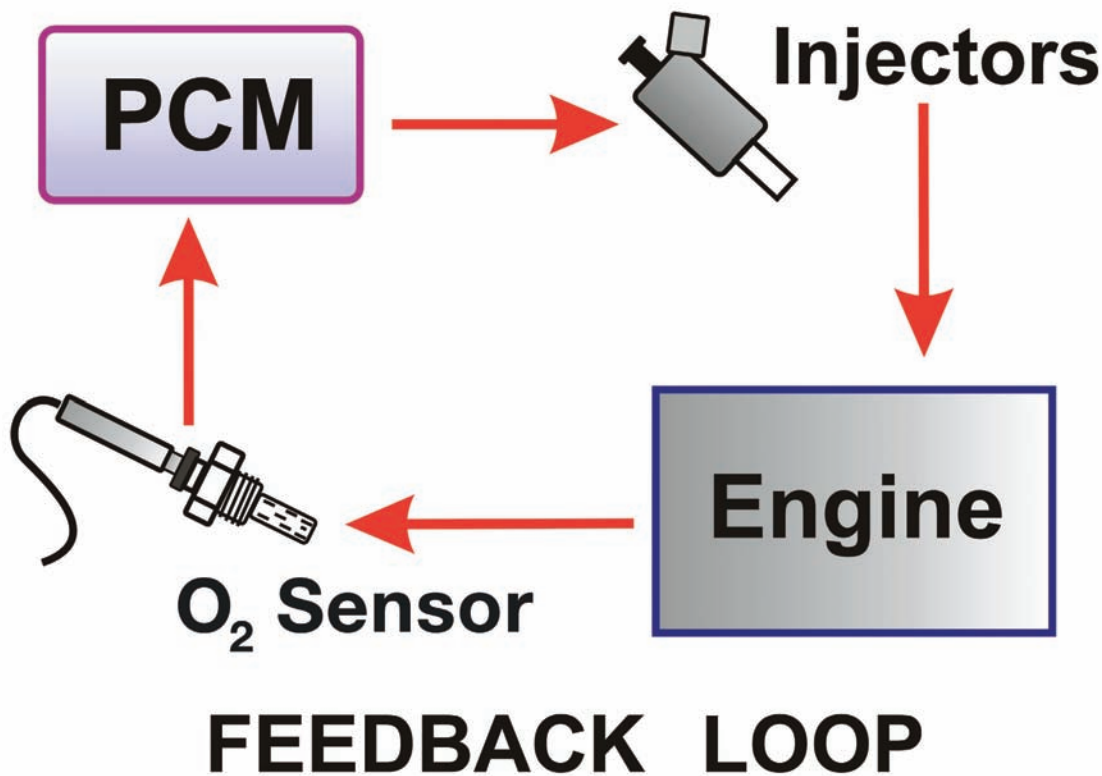
PCM—Well, a catalytic converter, or "cat" as many people commonly call it, controls engine exhaust emissions that occur during two engine-operating conditions—idle and part-throttle. For the "cat" to work properly, the fuel-injection system must be able to average its air/fuel ratio

to just slightly above and slightly below 14.7:1, the ideal proportional relationship. That means 14.7 parts of air to 1 part of fuel. To accomplish this, I use my "upstream" oxygen sensor, which is located between the engine and the "cat." This sensor measures oxygen content in exhaust gas to create a small signal voltage that it sends to me. I then determine what fuel corrections to make to keep the air/fuel ratio averaging 14.7:1. This scenario goes something like this; I inject fuel into the engine, *sense* exhaust gas oxygen and *compare* it to what is needed for an ideal mixture and *correct* subsequent fuel delivery. This strategy is called closed loop operation because it is an informational loop—sense, compare, and correct—get it? I should add that closed loop only takes place when the engine is hot and either at idle or part throttle.

MB—OK, if that's how "closed loop" operation works, is "open loop" operation just the opposite?

PCM—Let's see, how can I explain this? OK, remember how I only use "closed loop operation" during idle or part-throttle driving conditions? Well, I use "open loop" operation for all other driving conditions. For example, cold or hot starting, accelerating, decelerating, etc. All of these modes of engine operation do not require an ideal 14.7:1 air/fuel ratio that I spoke of earlier. So the sense, compare, and correct

(continued)



The diagram depicts what is known as a feedback loop. In a feedback loop, fuel is injected into an engine's cylinders, where it is then burned. An oxygen sensor then senses (determines) the oxygen content in the exhaust gas, and passes this information on to a PCM. The PCM then consults its own internal computer data regarding ideal air-fuel combination ratios for optimal fuel delivery under varying conditions. The PCM also compares the existing fuel conditions or content (as conveyed by the sensors) against the ideal, and then finally adjusts or corrects the fuel mixture by varying injector pulse width. This ensures that fuel delivery under prevailing conditions more closely matches the ideal ratio. Thus, this informational loop consists of sense (an oxygen sensor measuring oxygen content in the exhaust), compare (the PCM consults internal data regarding ideal oxygen content and fuel ratios to maximize fuel delivery) and correct as the PCM varies the amount of fuel the injectors deliver to the engine. This continuous feedback loop is necessary to maintain precise air/fuel ratios required by a catalytic converter. Since this continuous informational/processing loop is endless, it's often referred to as a "closed loop" mode of operation.

form of informational loop is not used or even necessary, so the system is now operating in "open loop" mode.

MB—Well, that's certainly a lot to think about. You sure do know your stuff. It's great that you took time out of your busy schedule to speak with us. Thanks for answering our questions. It was great talking with you.

PCM—My pleasure. Thank you for having me. Interacting with humans can be mildly interesting and sometimes amusing. By the way, if you decide you want more information about OBD-II diagnostic systems, remember to check

back in chapter 2 of this book, as it should answer any further questions you might have about these systems. Also, more information regarding catalytic converters and oxygen sensors can be found earlier in this chapter.

MB—Great! Thanks again. I guess that wraps it up for now. I'd like to thank my audience too, for being part of an exclusive interview with a powertrain control module about how it manages a vehicle's fuel and ignition systems. This is Motorbooks International signing off. Have a great day.

Chapter 4

Professional Scanners and Code Readers

Automotive scan tools have been around since the early days of OBD-I diagnostic systems. In the 1980s, these electronic scan tools were limited in what functions they could perform, as their capabilities often depended largely on which manufacturer's vehicle they were plugged into. New car dealerships had factory scanners that could access a greater degree of information (some of it proprietary or confidential) than aftermarket scan tools could, but manufacturers' scan tools were simply not available to independent repair shops. Back then, all aftermarket scanners were expensive, and as such, were typically beyond the economic reach of the average backyard auto mechanic. Both original equipment manufacturers' (OEM) scan tools and aftermarket scan tools improved substantially over the next dozen years or so in the diagnostic functions they could perform, along with the OBD-I systems that were used in conjunction in cars and light trucks.

By the mid-1980s, early do-it-yourself code readers started showing up in Sears, Pep Boys, and other auto parts chain stores. These early code readers were capable of reading diagnostic trouble codes from PCMs installed in vehicles manufactured by General Motors, Ford Motor Company, Toyota, and Honda. The earliest code readers used LED lights to flash out trouble codes. They were similar to a "Check Engine" (MIL) light equipped on some vehicles because they were not capable of providing any other information. These simple code readers provided home technicians with an easy way to read trouble codes without needing to use a test light or jumper wires, and most importantly, without needing to follow complicated procedures for trouble code retrieval.

Today, modern code readers and scan tools designed for use with OBD-II systems, and specifically for the do-it-yourself market, have a wide variety of capabilities. Most models of scanners and code readers are priced from below \$100 to over \$700, and are therefore more affordable for the average automotive consumer. Once any of these newer scanning tools are connected to an OBD-II system, even a basic code reader (most come



This OTC Monitor 2000 was one of the first aftermarket scan tools available for independent repair technicians. It initially only worked with older, first generation OBD General Motors vehicles, but as other manufacturers improved and updated their OBD-I systems, the Monitor 2000 could be used to read codes and data on vehicles from Ford Motor Company and DaimlerChrysler as well. *Courtesy OTC Tools*

with a CD packed full of code definitions) is capable of providing more useful diagnostic information than the majority of professional scan tools of the past. In fact, some of the scan tools available for the home market today rival the capabilities of professional tools of yesteryear, but for a fraction of the price. In this chapter, we'll take a closer look at the development of professional scan tools and code readers, and will focus how to use, and the many uses of, code readers. Chapter 5 will cover the use of scan tools more in-depth, as well as PC/laptop interface scanners, and personal digital assistant (PDA) scan tools.



This late 1980s model OTC Monitor 4000E scan tool was one of the cutting-edge professional scanners available at the time for the aftermarket industry. Data cartridges pertaining to specific brands of vehicles could be inserted at the base of the unit to provide greater manufacturer-specific information. In addition, an OTC Pathfinder software cartridge could also be used to display generic tune-up specifications and other useful diagnostic tips and information. This OTC Monitor 4000E scanner was one of the first aftermarket scan tools with OBD-II capabilities. *Courtesy OTC Tools*

PROFESSIONAL SCAN TOOLS

Professional scan tools are of two basic types: OEM dealership specific and generic aftermarket. Factory or manufacturer-specific scan tools are only available to new car dealerships for exclusive use on specific makes of vehicles they sell and service. Dealership scanners have all the latest, greatest information available directly from OEMs about the vehicles they manufacture, including technical service bulletins, (TSBs), factory recalls, and other proprietary information. Some of these scanners provide a direct link to the factory, where scanned information about new vehicles is stored in a central database. Factory scan tools also allow professional technicians to perform many more diagnostic tests on specific system components. Most factory scan tools are wireless and can therefore scan cars or trucks in a service area, on the showroom floor, or out on a lot, simply by entering a specific vehicle's VIN. Often, the resultant fix for drivability issues or emissions-related problems on new cars or trucks can come down to a simple need for revisions to a vehicle's OBD-II operating system. OEM scanners can also be used to reprogram a vehicle's PCM with the latest factory software updates.

This Toyota handheld scanner is now retired and lives in a storage cabinet in the service area at a dealership. However, this diagnostic tool is not yet obsolete, as it is still used as a back-up whenever the newer scan tool has a problem. This device is still capable of providing a professional technician working on Toyota vehicles with more vehicle-specific information than most generic aftermarket professional scan tools. *Courtesy Younger Toyota*





This is the latest Toyota/Lexus/Scion scanner tool, which is basically a combat-ready laptop computer built to military specifications that has been “ruggedized” (military jargon) for military and other field use on vehicles. This diagnostic computer system is wireless, but can be directly connected to any vehicle for purposes of performing test drives. The software accompanying the diagnostic program is Microsoft Windows-based, and easy to use, with data stored and displayed in numerous ways. Software updates are easily accomplished, simply by turning a vehicle’s ignition key to the “RUN” position and clicking on the scanner’s mouse pad to “Update.” Because the data transmission is wireless, the vehicle being scanned can be located anywhere within a dealership, whether in the service bays, vehicle storage lot, or showroom. *Courtesy Younger Toyota*



The Genisys EVO scan tool offers a wealth of diagnostic information to professional technicians, and to General Motors, Ford Motor Company, DaimlerChrysler, Toyota, Honda, BMW, Volkswagen, and other automakers. In addition to OBD-II coverage, it also tests many OBD-I systems on a variety of automotive brands. The tool features Asian and European coverage added for component wiring, circuit descriptions, and component and control module locations. Plus, engine and transmission diagnostics systems are covered as well. This Genisys EVO professional scanner is available with Info Tech 2006 software that provides diagnostic trouble code information, data/sensor information, PCM connector information, drivability symptoms, TSB references, a component locator, and vehicle specifications. Even older, pre-OBD-II vehicle information is updated on a yearly basis. Software updates are provided via the Internet, so this scanner’s reference information is easily maintained. *Courtesy OTC/SPX Corporation*



The Genisys EVO is easy to use and makes quick work of mundane tasks like reading or erasing trouble codes. It also serves as a reference tool that provides professional technicians with a wealth of information including wiring diagrams, component locations, and tune-up/maintenance specifications. *Courtesy SPX/OTC Corporation*

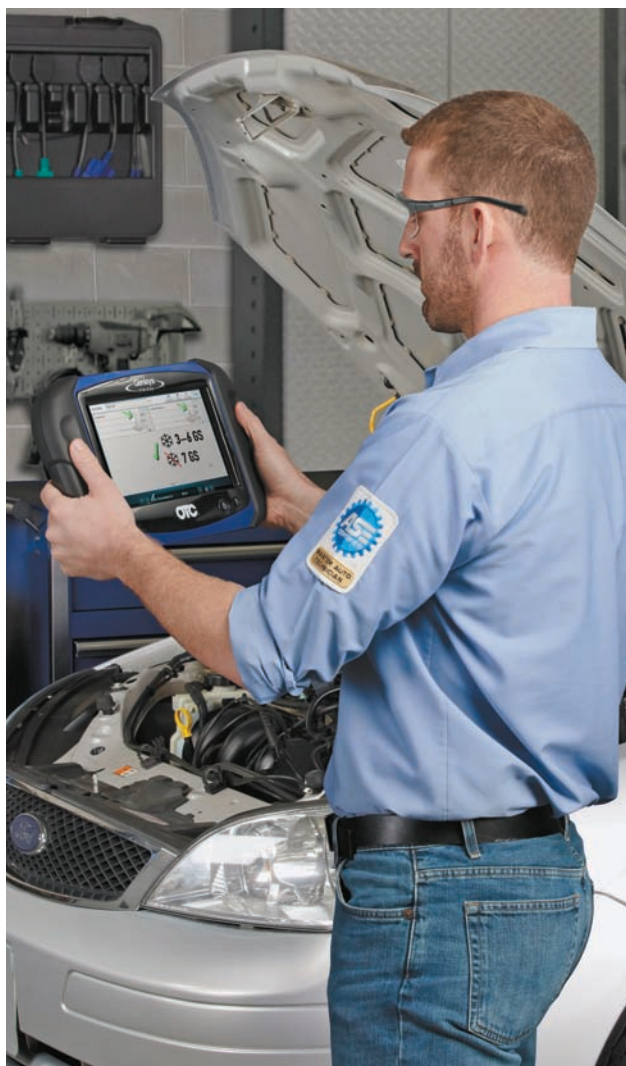


The Genisys EVO covers both OBD-II and OBD-I vehicles. The Genisys EVO kit comes with the necessary cables for OBD-I cars and light trucks. *Courtesy OTC/SPX Corporation*

Since aftermarket professional-grade scan tools offer more functions and more current, comprehensive information than do-it-yourself scanners, they consequently cost more to own and update. These scan tools typically cost from just over \$1,000 to more than \$6,000, depending on options and accessories. The old adage that “you get what you pay for” definitely applies to these tools, as they are truly designed with a professional technician in mind. Since another old adage, that “time is money,” is also true, in the hands of an educated professional automotive technician these scan tools are capable of quickly diagnosing complex drivability problems. They operate at faster processor rates, have more memory than less expensive scan tools, use enhanced diagnostic features, and offer an abundance of vehicle-specific information that is typically provided directly from automakers. In addition, many of these tools can also function as lab scopes (oscilloscopes), displaying waveforms from computer sensors and actuators.



The Genisys Touch is a 10-inch, ruggedized tablet with Bluetooth capabilities. The smaller unit next to the Touch is a vehicle communications interface (VCI) that allows the Touch to connect to a vehicle remotely. Genisys Touch software automatically detects and alerts the technician of on-tool or Web-based repair information. *Courtesy SPX/OTC Corporation*



Not only does the Genisys Touch serve as a scan tool but it also provides on-the-spot technical training. The Touch sends an instant alert if a training video is available for the specific year/make/model that has been selected. The tool teaches technicians diagnostic and test procedures that are commonly used at the OEM level. *Courtesy SPX/OTC Corporation*

Many professional scanners perform automated tests that provide an instant snapshot of vehicle health. Specific information related to DTCs, along with factory technical service bulletins (TSBs) and specifications for repairs and replacement parts, make these tools more useful and desirable than an OBD-I or II generic aftermarket scanner that simply reads and erases diagnostic trouble codes. Other information that professional scanners typically have access to includes detailed DTC information, a database of common “drivability” problems (as well as their potential or recommended “fixes”), a component

locator, data/sensor information, and PCM connector information. In addition to providing full coverage of engine management diagnostic issues, other systems are also covered, including ABS braking, electronic steering and traction control, heating and air conditioning (HVAC), computer-controlled charging, electronic suspension, supplemental restraint systems (air bags), and CAN-controlled electrical systems. Even OBD-II cables can be configured for specific vehicles by using “smart” inserts that allow enhanced manufacturer-specific component testing.

Since professional scan tools often use software that is specific to a vehicle’s year, make, model, and engine, bi-directional testing of various systems and individual components can be performed. This means that the scanner can not only receive information but can send out commands to the OBD-II system as well. With bi-directional testing, a user can program a scan tool to command various components to operate. This allows a quick way to verify that the PCM is in control and can command a solenoid to operate, ignition coil to fire a spark plug, or fuel injector to pulse fuel into the engine. Professional scanners can be connected to a PC or laptop to store scanned information, or to upload or download information via the Internet. Software updates from scanner manufacturers are often available on a quarterly basis; thus, professional scan tools are typically kept more current than less expensive scan tools. However, due to the high cost of professional scanners, most home technicians would have a tough time justifying their expense. But not to worry—a professional grade scanner is not necessarily the only effective tool for performing diagnostic work on OBD-II system vehicles. Fortunately, do-it-yourself electronic diagnostic tools can also provide a great deal of OBD-II-related information. Consequently, let’s take a more detailed look at the most basic OBD-II system interface—code readers.

CODE READERS

Code readers are the most basic of OBD-II electronic interfaces. Their primary function is to simply read and erase diagnostic trouble codes (DTCs). The majority of all code readers (and all of the ones covered in this chapter) provide information about which OBD-II inspection and maintenance (I/M) monitors have been run, or are listed as “completed.” I/M monitors are tests that the OBD-II systems runs to verify that all its systems and components are operating as they should. (See chapter 2 for more information on I/M monitor status.)



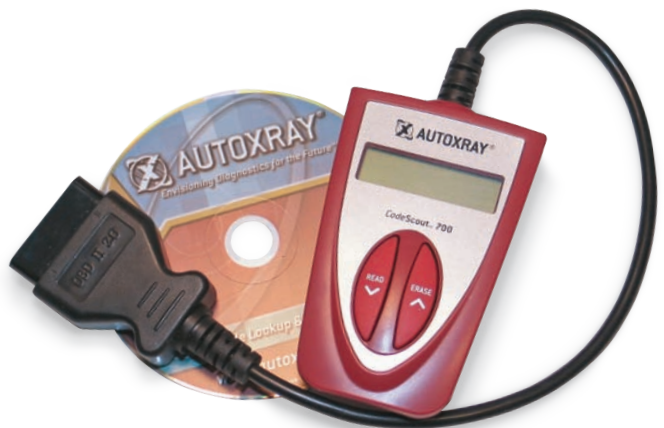
The five code readers shown here range in price from less than \$100 to just under \$250. They provide the basics for working with OBD-II engine management systems found on 1996 and newer cars and light trucks. Most basic code readers have standard features that include diagnostic trouble code reading, clearing trouble codes, and a self-inspection/maintenance (I/M) readiness monitor status. *Courtesy Actron, AutoXray, and OTC Tools*

Code readers are also capable of indicating whether a malfunction indicator lamp (MIL) is on or off. Certain advanced model code readers come equipped with their own built-in reference library of internal diagnostic trouble code definitions, and can display OBD-II freeze frame data as well. Software can also be easily updated on some models when they are connected to a PC with Internet access.

Despite their no-frills image, all code readers are ideally suited for determining if a vehicle is ready and able to pass in-state emissions testing. They are also useful for verifying the need for recommended automotive repairs whenever a car or truck is taken to a dealer for servicing; any DTCs set by a PCM can be read by a code reader and written down prior to dropping the vehicle off. That list can be compared with whatever information the service writer says is wrong with the vehicle.

However, code readers are limited in their ability to perform engine management diagnostics, since they are primarily designed as a general informational tool, and as such, they will not display OBD-II data streams. Typical code readers are generally priced from around

\$80 to just under \$250, depending upon features. We'll take a closer look at five code readers and their diagnostic capabilities, starting with the least expensive, which also happens to be the easiest to use.



The CodeScout code reader from AutoXray is capable of reading all OBD-II communication protocols, including CAN. Simple two-button navigation makes this scan tool quite user-friendly, and simple to operate for performing basic functions like reading and erasing diagnostic trouble codes, or turning off a "Check Engine" MIL light. *Courtesy AutoXray*

CODESCOUT AND POCKETSCAN CODE READERS

The CodeScout model code reader from AutoXray, and the OBD-II PocketScan code reader from Actron, are both similar in features and simplified method of operation. Once either of these code readers is connected to an OBD-II compliant vehicle, either tool is automatically capable of determining which type of OBD-II system communication protocol is being used by a PCM; both can also read newer CAN (Controller Area Network) data protocol. Furthermore, both tools can read and erase generic DTCs, display MIL status, and display I/M monitor status. In addition, these code readers don't require internal batteries for power, but rather, use a vehicle's data link connector (DLC) as a 12-volt power source. Both types of code readers come complete with accompanying software, including a CD with DTC look-up software that includes manufacturer-specific "P1" codes, as well as an electronic user manual with generic OBD-II code definitions in English, Spanish, or French. Additional hard copies of user manuals in English and Spanish are also included as well. The CodeScout sells for around \$80, while the PocketScan runs about \$100. Both tools are available in major retail outlets and chain stores like Sears, Walmart, and most auto parts stores.

Following are specific steps for operating both the CodeScout and PocketScan code readers. By breaking these procedures down into sequential steps, a technician can gain a detailed look at what code readers can and can't do. The first step in using either of these code reader scan tools is to turn them on by plugging the OBD-II cable on the code reader into a vehicle's data link connector, or DLC. Once this is accomplished, a CodeScout's display will flash between "Code" and "Scout," while a PocketScan code reader will flash out "Pocket" and "Scan." If the "Read" key is pressed next, but the vehicle's ignition key has not yet

been turned to the "ON" position, a "No Link" message will be displayed on the scan tool. This indicates the code reader is not yet communicating with the OBD-II system's PCM. However, if the ignition is in the "ON" position, but the scan tool still displays a "No Link" message, turn the ignition key to the "OFF" position for about 10 seconds, and then turn it back on again. Doing this should fix any interface communication problems between the vehicle's PCM and the code reader. Remember, the ignition key must be in the "ON" position to read PCM diagnostic trouble codes and also to check I/M readiness status.

Now that the scan tool is ready to perform, what follows next is a detailed description of how to read and erase diagnostic trouble codes when using either a CodeScout or PocketScan code reader. In addition, two other functions of these scan tools—namely, checking MIL status and monitoring I/M monitors' operation—will also be covered in more depth.

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Diagnostic Trouble Codes and descriptions are just some of the tasks that the Actron CP9560 can handle. PocketScan Plus also provides freeze frame data, permanent DTCs, VIN info, and performs the important task of Inspection Maintenance (I/M) readiness testing by displaying the I/M readiness monitor status. *Courtesy Actron*



READING CODES AND INSPECTION AND MAINTENANCE

Monitors

0 Codes ↓

To read any OBD-II generation vehicle's diagnostic trouble codes set by the PCM, simply press and hold the "Read" key on either code reader for about three seconds. An asterisk * symbol will move across the display panel while the scan tool is in the process of reading DTCs. If no trouble codes are stored in a PCM's memory, an "0 Codes" message will be displayed on the code reader's display panel.

2 Codes ↓

The number of diagnostic trouble codes stored in a PCM's memory will be displayed on the code reader's display screen, alongside an arrow that points downward, which is located to the right of the display. Pressing the "Read" key again will cause the scan tool to scroll the display downward to the first trouble code, and will then display the specific trouble code number on the display screen. Pressing and then quickly releasing the "Erase" key will cause the display panel to scroll through the entire list of trouble codes set by a vehicle's PCM.

P0304 ↑↓

In the example shown, a specific #P0304 ("Cylinder 4 Misfire Detected") diagnostic trouble code is displayed on the code reader's display panel; as shown, the code reader reads the DTCs stored in a PCM's memory and then displays them in this format on the code reader's display panel. Remember, there are no DTC definitions stored internally within these code readers, so the user manual will have to be consulted in order to determine what type of specific malfunction the code represents. Alternatively, this information is also available on DTC "Look-up" software contained on a CD that accompanies each code reader.

P0514 Pd ↑↓

After the code reader displays the first DTC, another press on the "Read" key will allow a technician to see the next specific trouble code set by a PCM, as displayed on the code reader's display panel. In the example shown, it is a #P0514 ("Battery Temperature Sensor CKT Range/Perf") trouble code. The small letters "Pd" located on the right side of the display indicate that this trouble code is pending, which means the specified DTC malfunction occurred once during a single "trip" or "drive cycle." However, in order for the same specific malfunction to cause a PCM to set a hard diagnostic trouble code and to simultaneously turn on a MIL light, the same must occur a second time during a subsequent or second completed "drive cycle." Consequently, the small letters Pd indicate the code reader is displaying a soft diagnostic trouble code (one that is merely pending). This is because the specific DTC may, or may not, eventually be set as a hard code by a vehicle's PCM (and subsequently stored in the PCM's memory, causing the PCM to turn on a MIL light).

MIL ON ↑↓

After all DTCs have been read, pressing the "Read" key again will display MIL status, i.e. whether the MIL light is on or off. To obtain a correct reading for MIL status, a vehicle's engine must have been started first. While it may seem obvious that a malfunction indicator lamp on the instrument cluster is either on or off, a code reader can help determine if a MIL light is really supposed to be on or not. In the graphic display shown, the code reader is displaying what a PCM is commanding a MIL to do. For example, if a code reader shows a MIL is on, but the light is not actually lit up on the dash panel, a malfunction somewhere in the MIL light circuit has occurred. The malfunction could be as simple as a burned out bulb, but it could also be a more complicated MIL circuit-wiring problem. The same conclusion would be drawn if the reverse were true as well—namely, if a code reader showed a MIL light as being off, when in fact, the "CHECK ENGINE SOON" light on the dash was actually lit up. Again, such a scenario would indicate some type of wiring problem in the MIL circuit or, possibly, that a malfunction in the PCM system is causing the MIL status on the instrument panel to disagree with the MIL status on the code reader.

Monitrs ↑↓

By pressing the same "Read" key again the screen will display an abbreviated "Monitors" or "I/M (inspection and maintenance) Monitors" message. OBD-II monitors are actually just simple testing exercises run by a PCM to determine if all sensors and controls within a particular engine management system are operating properly. Either of the code readers we have been discussing will display the status of all monitors available on the specific vehicle that they are connected to.

2 Inc ↑↓

The first I/M monitors displayed on a code reader's display screen are all of those monitors or tests that have not yet been run by the OBD-II system's PCM. Later we'll take a look at monitors that have been run and are listed as "ready." All monitor tests that have not yet been run by the PCM are listed as incomplete, which is typically abbreviated as "Inc" on the code reader's display screen, along with the total number of all such monitors not yet run. In the example shown, two monitors are listed as incomplete or not yet run by a PCM.

Misfire↑

02 Snsr↑

3 Ready↑

Pressing the “Read” key again will cause the code reader to scroll down the monitor list, and eventually display which specific monitors or tests have not yet been run by the PCM. In this example, the “Misfire” and “O2 Sensor” monitors have not yet been performed or completed. Such a scenario would most likely occur because enabling criteria (minimum threshold conditions that must be met before a monitor can be run or completed) for each specific monitor had not yet been met. Typically, operation of the vehicle for additional “drive cycles” would eventually allow all monitor tests to run or be completed.

Once all of the uncompleted or “Incomplete” monitors have been displayed, the “Ready” monitors will be displayed next. Both code readers will display the number of monitors or tests the PCM has already successfully run and completed. In the example shown, the “3 Ready” display message indicates three successful monitors have been run by the PCM and are complete.

Comp ↑

Catalyst↑

EGR ↑

After the actual number of completed (and therefore “Ready”) monitors has been displayed on a code reader’s display screen, and the “Read” key is pressed, the code reader will display the names of the monitors (tests) that have been successfully performed and completed by the PCM, and are therefore “Ready” or in a state of readiness. In the example shown, a Comprehensive Component monitor, Catalyst Efficiency monitor, and EGR (exhaust gas recirculation) monitor have all been successfully completed. The code reader is basically confirming that these systems are in a functioning, ready state, and that no malfunctions or DTCs exist in any of them. Continuing to press the “Read” key in succession will cause a code reader to scroll down through the list of successfully completed monitors. Once the last successful or complete monitor is reached, the arrow at the right of the display will now point up (meaning the bottom or end has been reached). When this occurs, the “Erase” key can be used to scroll back up through all of the monitor displays as well as all the other displays. However, it is important to remember that the “Erase” key should be pressed and then quickly released in order to scroll through the display function; otherwise, the code reader will try to erase any stored codes instead of scrolling.

Knowing which monitors have successfully been run by an OBD-II system’s PCM and are now complete is quite helpful information, since some states’ emissions testing programs require certain, and sometimes all, monitor tests to be run and completed before the vehicle can be passed. S.A.E. (Society of Automotive Engineers) guidelines suggest that all 1996 to 2000 model-year vehicles should fail emissions testing if three or more monitors have not been run and completed by a PCM prior to the state emissions test being performed. Similar guidelines for 2001 and newer vehicle models mandate failure of state emissions testing whenever two or more monitors do not indicate a “Ready” or complete status. See chapter 2 for more information on OBD-II monitor readiness status.

Erasing Diagnostic Trouble Codes

ERASE?

DONE

In order to erase DTCs using these code readers and a vehicle’s PCM, make sure the vehicle’s ignition key in the “ON” position, then press and hold the “Erase” key on the code reader for more than three seconds. The display screen will display the word “ERASE?” To accept, simply press and hold the “Erase” key for more than three seconds again. The display panel will now show a dash moving across the screen. When the screen displays the message “DONE,” all DTCs have been erased from a PCM’s memory. On many vehicles, all the I/M monitors will be erased as well.

continued from page 85

WHERE DO I FIND CODE DEFINITIONS?

Both the PocketScan and CodeScout models of code readers are not capable of displaying DTC definitions because they don't have an internal reference library of diagnostic trouble codes; consequently, another means must be used to look up and determine what specific DTC numbers displayed on a code reader screen actually mean. Fortunately, each code reader comes complete with a CD that contains diagnostic software with trouble code reference. Both generic OBD-II codes (P0XXX series), as well as some manufacturer-specific codes (P1XXX series), are listed and defined for domestic, Asian, and European vehicles. However, a PC or laptop is required to use this software.

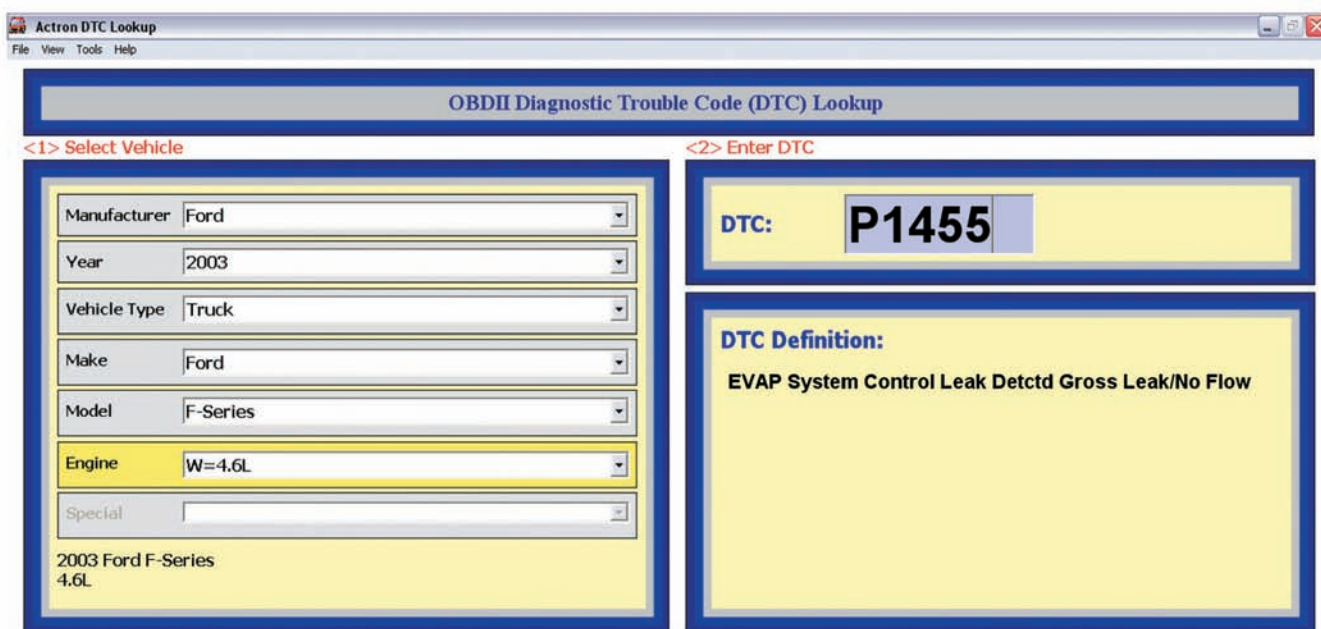
SPX/OTC AUTOCODE

The technologically advanced SPX/OTC 3494 AutoCode is trilingual, displaying read-outs in English, Spanish, and French. It's also the next step up in design, features, and price from code readers previously covered in this chapter. Priced at around \$200, the AutoCode code reader provides significantly more information than basic code readers. Additionally, the viewing screen is larger and capable of displaying up to seven full lines of text. An internal reference library of diagnostic trouble code definitions provides S.A.E.-standardized definitions for

generic (and some manufacturer-specific) trouble codes as the scan tool simultaneously reads them. Alternatively, this code reader's trouble code look-up function also allows a user to enter a specific DTC number and immediately view its definition. In addition to displaying trouble code definitions, this code reader has self-diagnostic capabilities, including functional testing for the display screen, memory, and keypad. The AutoCode code reader also comes equipped with accompanying extensive CD software and a blow-molded storage case. The 80-page User Guide for this code reader is contained on the CD; in addition to describing the functions of this scan tool, the User Guide has an extensive OBD-II glossary and parameter identification data (PID) information. (PID are PCM sensor data and are covered in chapter 2.) This model of code reader also uses internal batteries so it can be powered and used whether connected to a vehicle or not, thus allowing users to view the internal code library and review stored data from and about previously scanned cars or trucks.

AUTOCODE SETUP/TESTS

Let's take a quick, but closer, look at how an AutoCode code reader operates, so that we can gain a better understanding of what this code reader is capable of doing. Starting at the code reader's main menu, several



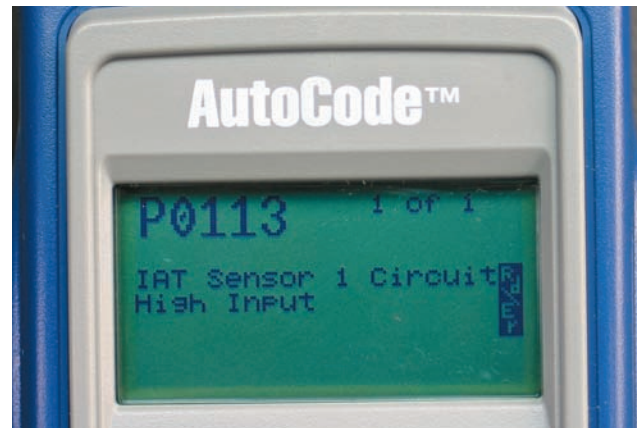
In this graphic, a manufacturer-specific #P1455 DTC for a 2003 Ford truck is shown in the "trouble code look-up" software. Because these code readers do not have their own internal reference library from which to look up specific diagnostic trouble code definitions (whether the DTCs are manufacturer-specific or generic), this software is included with both the CodeScout and PocketScan code readers. *Courtesy Actron*

The technologically sophisticated OTC 3494 AutoCode code reader comes equipped with an internal OBD-II diagnostic trouble code reference library that contains definitions for all generic OBD-II DTCs on domestic, Asian, and European vehicles. Additional features include a display screen contrast adjustment, internal self-tests, keypad tests, and memory tests. The AutoCode 3494 comes with a blow-molded carrying case and CD software containing a user guide and OBD-II diagnostic information. *Courtesy OTC Tools*



sub-menus can be accessed and displayed; these sub-menus are listed under the “Tool Setup/Test” function key, and include all tests, adjustments, optional features, and functions that the code reader performs on itself, like “Adjust Contrast,” “Language Setup,” “Display Test,” “Keypad Test,” “Memory Test,” “Tool Information,” and “Program Mode.”

These self-tests functions are largely self-explanatory. The code reader’s display screen contrast level, for example, may be adjusted by simply pushing the “Up” or “Down” arrow keys. In such a case, screen contrast is listed as a percentage on the left of the screen. Pressing “Enter” when screen contrast is at the desired level will cause the code reader to retain a user’s selected preferential contrast setting. In addition, this code reader’s display screen self-test uses black dots to indicate if the display screen is working properly. If any dots are missing from the display panel, then a problem with the tool’s display screen is indicated. The scan tool’s self-keypad test allows a user to test the functionality of the scan tool’s keypad by pressing each key and watching the display indicate which key was pressed. In addition, this code reader’s memory self-test capability checks whether the internal read-only memory (ROM) of the AutoCode scan tool is fully operational. This test is useful if a user is having difficulty getting the scan tool to display diagnostic trouble code information or freeze frame data. Once the test is complete, and if ROM



The AutoCode’s seven-line display panel capabilities provide significantly greater amounts of information to a user at a glance than single line code readers do. Displayed on the display panel in the photo of an AutoCode code reader is a specific DTC for an intake air temperature sensor, with its identifying number (P0113). The shaded “Rd/Er” symbol located at the far right of the screen indicates that “Read” and “Erase” hot keys are available on the keypad for these functions. Hot keys allow a user to perform a function (such as reading or erasing codes, as in this instance) by pressing a single key instead of scrolling through the various display menus and sub-menus in order to select the specified function. *Courtesy OTC Tools*

memory checks out well, the display screen will show “TEST PASS.” Furthermore, the code reader’s software ID self-test will confirm and display the version of software installed in the tool

READING AND ERASING CODES

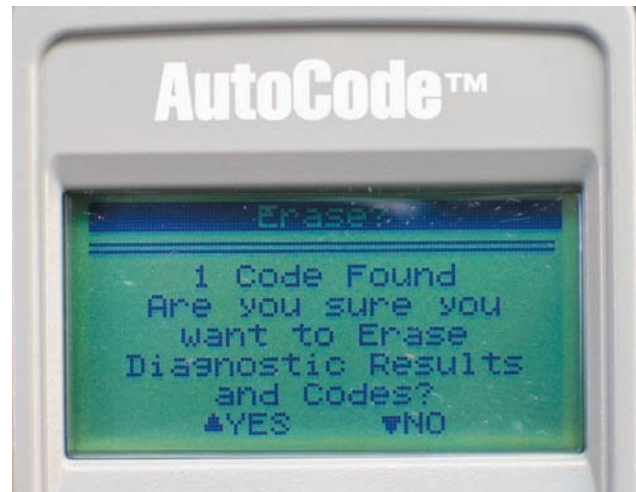
The AutoCode scan tool has two hot keys that correspond with two specific code reader functions: “Read” and “Erase.” With this code reader connected to a vehicle’s diagnostic link connector and the vehicle’s ignition key in the “ON” position, select the “Read Codes” option from the diagnostic display menu, and then press the “Read” key. If no diagnostic trouble codes are present or stored in a vehicle’s PCM, then a “Pass, No Codes Found” message will be displayed on the screen. If any DTCs are found in the vehicle’s PCM, all such trouble codes will be specifically identified as such and displayed sequentially, one at a time. Each DTC’s specific code number will be displayed in the top line of the display panel, while each corresponding specific trouble code definition will be displayed in an abbreviated format on the bottom line.

If the code reader determines that more than one diagnostic trouble code is stored or present in a vehicle’s PCM, the code reader will display a message that lets a user know the specific situation. For example, DTC “1 of 3” (the first of three DTCs found in a PCM), or the first of however many codes are stored or present in the PCM, will be displayed in sequence. In addition, pending codes, sometimes known as *continuous monitor* or *maturing codes*, are specifically identified, and indicated as such by a display panel message that states “Pending” next to the DTC displayed.

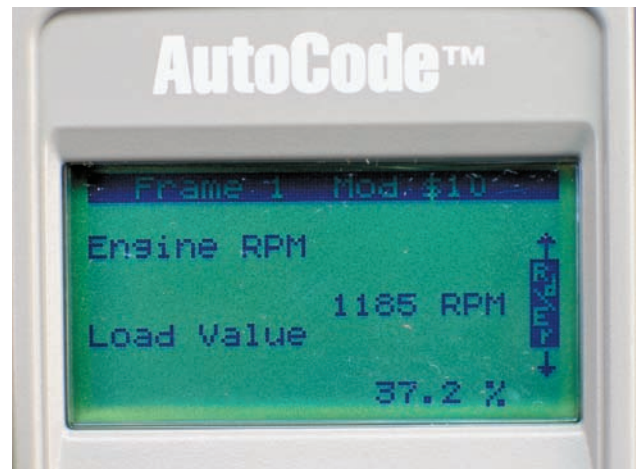
To erase codes from a vehicle’s PCM using this code reader, select the “Erase Codes” function from the code reader’s main menu. With the vehicle’s ignition in the “ON” position, simply press the reader’s “Erase” key and then select “YES” to erase all stored diagnostic trouble codes and freeze frame data from a PCM’s memory. When the code reader has finished erasing all stored DTCs and freeze frame information, “ERASE DONE” will be displayed on the code reader’s screen after the “Enter” key on the reader’s keypad has been pressed.

FREEZE FRAME DATA AND OTHER FUNCTIONS

The majority of code readers can only read and erase a PCM’s DTCs. However, the AutoCode reader is able to capture OBD-II freeze frame data that the PCM simultaneously records whenever a DTC is set. When the “Freeze Frame” function key is selected from the code reader’s main menu, the specific DTC number is displayed on the first line of the code reader’s display screen. The second line of text is “freeze frame” data (see chapter 2 for more information on “freeze frame” data). Freeze frame data is useful for determining the



By pressing the “ERASE” key on an AutoCode code reader, the code reader’s display panel will show the number of DTCs stored in a vehicle’s PCM. Users are then asked if they really want to erase all trouble codes, which must be confirmed by selecting the “YES” button (or “NO” key if this action is not desired) on the keypad. In addition to erasing all trouble codes from a PCM’s memory, all freeze frame data (if any) will also be cleared as well once the “ERASE” function is selected and confirmed.
Courtesy OTC Tools



As seen here, when the specific #P0113 (“intake air temperature sensor malfunction”) DTC was set by a PCM on this vehicle, the PCM simultaneously recorded and stored freeze frame data. Freeze frame data can be displayed on an AutoCode screen for each corresponding DTC displayed. By using the down arrow key on the code reader, all of the freeze frame data will scroll up on its display screen. More information on freeze frame data can be found in chapter 2. *Courtesy OTC Tools*

malfunction that caused a specific trouble code to be by a PCM set in the first place. Freeze frame data is a snapshot of all the vehicle’s sensor data at the time the DTC was set. Depending upon a vehicle’s manufacturer, freeze frame data will typically be erased, along with any

DTC information, when trouble codes are cleared from a PCM on most vehicles. Accordingly, it's usually a good idea to write down all DTCs and freeze frame data displayed by a code reader before erasing any DTCs or related freeze frame information from a vehicle's PCM.

The AutoCode also permits a user to view MIL lamp status as well as status of inspection and maintenance monitors whenever the function key for any of these tasks is selected from the reader's main menu. Checking MIL status enables a user to determine if a MIL light is working properly. Remember, MIL status, as displayed on then AutoCode reader, should match MIL status on the vehicle in question (as determined by what the MIL light is doing on the instrument panel or how it appears—on or off). In addition to MIL status, I/M monitors can be viewed on this code reader by selecting that function from the main menu. Depending upon vehicle manufacturer, the status of as many as 10 monitors is available for viewing. The status of any I/M monitors will be indicated as “ready” once a monitor has been run and completed by the OBD-II system. If the vehicle was not driven enough to complete a specific requisite “drive cycle” necessary to run a particular monitor, “INC” (for incomplete status) will be displayed. If the vehicle does not support the performance of a specific monitor or test, “N/A” will display. For example, if a “Secondary Air” monitor is listed as “N/A,” the specific vehicle being scanned does not use that particular emission system.

A “State OBD Check” function is just one more of the many enhanced features found on the AutoCode code reader that can be selected from this tool's main menu. The data displayed during a “State OBD Check” provides basic status information concerning a vehicle's OBD-II system, including MIL status (on or off), number of diagnostic trouble codes found, and number of test monitors available, as well as their current status (ready, incomplete, or not applicable). This test function was primarily designed for quick and easy verification of the status of all OBD-II system functions and components (typically used during state emissions testing—hence its name). Bear in mind, this test should be performed while the engine is running so MIL status can be correctly displayed. Also, remember that the number of codes displayed on a code reader's panel are only OBD-II generic codes and are not pending codes that could show up later after completion of several additional “drive cycles.”

Another great feature found on the AutoCode scan tool is its internal diagnostic trouble code look-up library. When selected from the code reader's main menu, the “Code Lookup” function allows users to enter both generic and manufacturer-specific DTC numbers in order to obtain S.A.E.-standardized definitions of any DTCs entered. Because the AutoCode reader also has internal batteries, users can view the trouble code library even when the tool is not connected to a vehicle. This feature is particularly useful when DTCs have been erased during a previous code scan, but a user nevertheless wants to see definitions for codes without having to pull up stored codes, or having a particular trouble code present. This feature also saves users time that would have otherwise been spent looking up codes in the User Guide or on the Internet.

ACTRON AUTOSCANNER

Another code reader scan tool that is available from the aftermarket is the AutoScanner CP9575 by Actron. The AutoScanner code reader is available for around \$180. It has all the features of a PocketScan code reader, plus access to freeze frame data, an internal diagnostic trouble code look-up reference library, and an internal



The Actron CP9575 allows the user to view vehicle sensors and switch relay inputs in real time while the engine is running. LIVE data information helps pinpoint problem components for a faster diagnosis. In addition, the AutoScanner can display generic and manufacturer-specific DTCs and definitions, and has six modes of OBD II data, permanent DTCs, trilingual, freeze frame, State OBD check (emissions), and drive cycle mode.

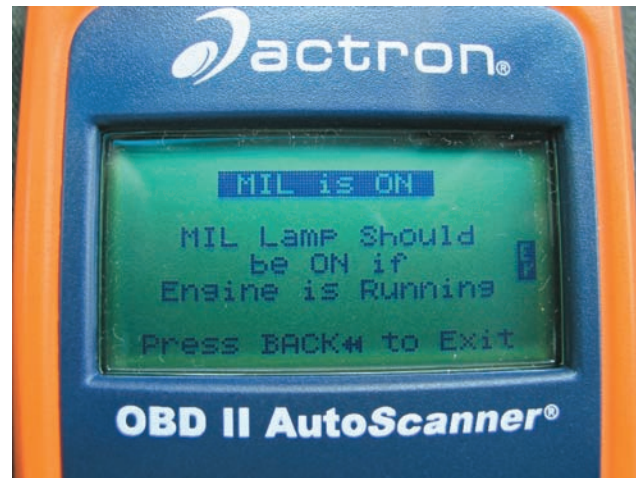
battery for off-vehicle use. In addition, this code reader has a “Review” feature that allows previously scanned vehicle data to be displayed on the code reader even when the device is not connected to a vehicle.

Additionally, the AutoScanner code reader features an optional Internet update cable equipped with a serial port to a USB adapter output cable, enabling the AutoScanner’s software to be easily updated via the Internet. The liquid crystal display (LCD) is 128 x 64 pixels, and is capable of displaying up to seven lines of text on a contrast-adjustable display screen. Whenever this tool is operating on its own battery power, it will automatically shut down to preserve the battery. A low battery indicator (Lb) message will display whenever the battery needs to be replaced. Whenever this code reader is plugged into a vehicle, the automatic shut-down feature is disabled so as not to lose any recorded data or DTCs. Another feature is the code reader’s OBD-II interface cable, which is 63 inches in length, making it easy to use while working under the hood of a car or truck.

Additionally, an AutoScanner’s large display screen enables more information to be viewed at a single glance, while simple, large-text instructions are more readily understandable to users. For example, the display for MIL status provides a message that states “MIL is ON” on the first line and “MIL Lamp should be ON if the Engine is Running” on the next few lines, and “Press BACK << to Exit” on the last line.

Another example of how the AutoScanner’s greater available screen data makes this code reader user-friendly is its display of freeze frame data. The text “FREEZE FRAME” is first displayed at the top of the screen and the correlating specific DTC that caused a PCM to record and store additional freeze frame data is also displayed. For example, a display might read, “#P0443 Catalyst Temp, Bank 1/Sensor 1” DTC. Even the engine temperature at the time the trouble code was set by a PCM is recorded (152° F) and displayed on the last line. Obviously, all of this information can be quite useful for diagnosing what conditions were present when a DTC (and associated freeze frame data) was set.

The AutoScanner code reader has several other unique features that set it apart from more basic code readers. A “Review” function is available, and it comes in pretty handy when information about the most recent vehicle scanned needs to be accessed and read, but the vehicle in question is no longer available for examination. By selecting this “Review” function



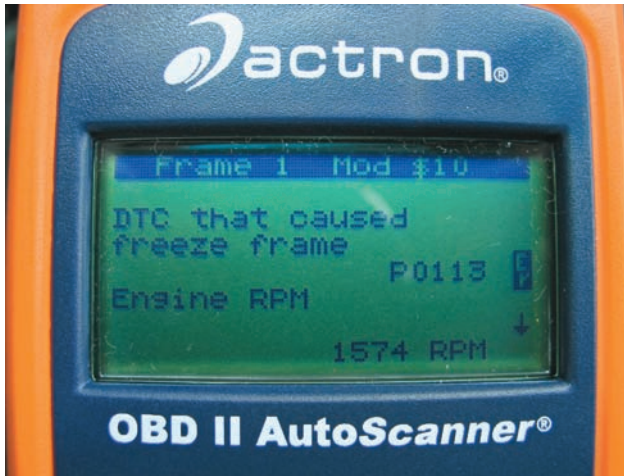
The sample screen in the photo shows malfunction indicator light (MIL) or “Check Engine” light status. A MIL light should be off whenever a vehicle’s engine is running and when no trouble codes have been set or are stored in the PCM. However, if a MIL light’s status is indicated by a code reader as ON, but the MIL light itself is not actually lit up on the instrument panel, it probably indicates a faulty MIL circuit or burned-out MIL lamp bulb.

Courtesy Actron



This is a screen display of a “Review” function from the main menu of an Actron AutoScanner tool; this function displays all of the different types of data in the PCM that are available for review. This screen shows that codes, I/M monitors, and freeze frame data can all be viewed by a user. The shaded “Er” symbol shown at the far right side of the screen indicates that an “ERASE” hot key is available for this function. *Courtesy Actron*

from the diagnostic menu, users can review a vehicle’s trouble codes, I/M monitors, and freeze frame data. In addition, the DTC look-up function provides all S.A.E.-standardized DTC definitions for both generic OBD-II codes and manufacturer-specific “P1” codes. Another unique feature of this code reader is that it can



Pictured on the display screen of an Actron AutoScanner code reader is freeze frame data, which was captured when an associated #P0113 DTC was set by the PCM. The arrow at the far right indicates that additional freeze frame data can be accessed by using the arrow key to scroll down the display. *Courtesy Actron*

be programmed to display its text in three languages—English, French, and Spanish. By selecting the function called “System Setup” from the diagnostic main menu, followed by the “Language Setup” function, one of the three languages can be selected.

AUTOXRAY CODESCOUT AX2500

The CodeScout AX2500 scan tool from AutoXray offers several features not found in other code readers. Priced at around \$200, this scan tool is not only capable of reading OBD-II trouble codes on vehicles in model years from 1996

to present, even including those with CAN protocols, it can also connect to and read data information from older OBD-I vehicles from Ford Motor Company, General Motors, and DaimlerChrysler. Specific vehicle coverage includes General Motors from 1982 to present, and Ford Motor Company and DaimlerChrysler from 1983 to present. This tool can easily be updated via the Internet using AutoXray’s EZ-Update software. Data information from previously scanned vehicles can also be uploaded to a PC or laptop for permanent storage and subsequent viewing. This sophisticated tool can also be programmed by users to produce displays in either English or Spanish.

In addition to reading and erasing DTCs, the AX2500 also displays MIL and inspection monitor (I/M) status. Internal batteries are used, so data can be captured, stored, and viewed, even when the tool is not connected to a vehicle. In fact, after a vehicle is scanned, the data information collected can optionally be saved for later reference. A tag name of up to 10 characters is entered for later recall of vehicle data. For example, “Leslie’s Truck,” or “2003 Ford” represent vehicles that might be stored in the code reader’s memory for later recall. To view previously recorded data when the tool is



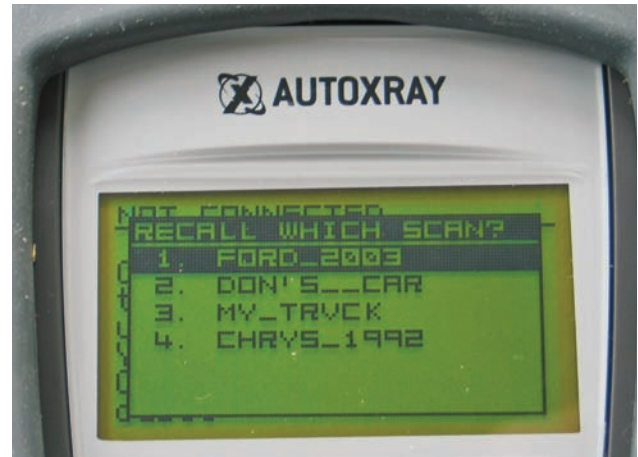
The AutoXray CodeScout AX2500 scan tool is the next progression in code readers. It can read both older OBD-I equipped vehicles as well as modern OBD-II vehicles. Data can be captured, recorded, and uploaded to a PC or laptop for storage and later viewing. Plus, the AX2500 can display both English and Spanish languages. *Courtesy AutoXray*

not connected to a vehicle, simply choose the “SELECT VEHICLE TYPE” function from the menu and then the “PREVIOUSLY SAVED” function. Choose the tag name of the vehicle you want to view information for and then press “Enter.”

The AutoXray AX2500 code reader has a high-resolution display screen, which makes it easy to read and also capable of displaying up to eight lines of scrollable text. As an example, when selecting an OBD-I or OBD-II vehicle, a picture of an on-board computer's connector cable is displayed—a very cool feature. In addition to all the functions of the previous code readers, one of the more advanced main menu selections for the 2500 is an “Information Summary” function. When this function is selected, three pieces of information from an OBD-I or OBD-II system's PCM are displayed: 1) “Check Engine” light status (MIL on or off); 2) the total number of stored diagnostic trouble codes; and 3) the total number of readiness I/M monitors that are present and successfully completed (“ready” status). In addition, this advanced code reader has an internal generic OBD-II code reference library that can easily be selected as a function from the code reader's main menu and then used to look up standardized DTC definitions.

The CodeScout AX2500 is one of few code readers that has advanced capability to read both OBD-I system

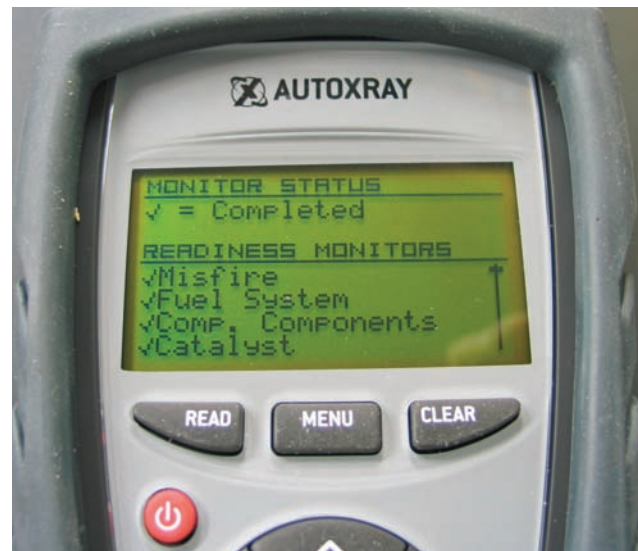
diagnostic trouble codes as well as OBD-II system trouble codes. In fact, OBD-I system codes for General Motors and DaimlerChrysler vehicles can be read and cleared using only this scan tool. Furthermore, the internal diagnostic trouble code library will display message text



Data stored from previous vehicle scans can be stored indefinitely in the AutoXray code reader and subsequently retrieved for later review or use. Here, the code reader's display panel identifies four vehicles that have been given specific tag names by a user (listed on the display screen), and for which previous scanning data and information have been stored. That information is available for subsequent retrieval and review. Vehicle tag names can be up to 10 characters in length. *Courtesy AutoXray*



One handy feature that definitely sets the AX2500 model apart is that in addition to many advanced capabilities, it is also capable of displaying images of OBD-I connectors for General Motors, Ford Motor Company, and DaimlerChrysler vehicles, making it much easier for a technician to recognize which connector specifically goes with which vehicle. The connector displayed on the AutoXray display screen seen here is for a Ford EEC-IV type of older OBD-I system. *Courtesy AutoXray*



With the capability of displaying up to eight lines of text data on a viewing screen, the AutoXray code reader can make it easy for a technician to determine OBD-II monitor status of a vehicle. The scroll bar at the right of the screen indicates that more information (in this case, monitors) is available by scrolling down the display. *Courtesy AutoXray*

for OBD-I trouble codes right as they are being scanned from a vehicle's PCM.

On certain older model OBD-I General Motors and DaimlerChrysler vehicles, the diagnostic trouble codes cannot be erased by this code reader tool. On these vehicles, the battery must be disconnected for the codes to be erased. When the "Clear" (trouble codes) menu item is selected, the tool will display code erasing instructions for these particular vehicles. On Ford OBD-I vehicles three specific types of self-test can be performed: 1) Key on/engine off (KOEO); 2) Key on/engine running (KOER); and 3) memory codes. (See chapter 1

for additional details about Ford Motor Company OBD-I systems.) The AX2500 code reader also comes complete with one OBD-II interface cable for OBD-II vehicles, and three OBD-I interface cables for Ford, General Motors, and Chrysler vehicles. Other features: a soft carrying case, CD software that contains all S.A.E. standardized generic diagnostic trouble code definitions, and an electronic user manual.

Scan tools are the next step up from code readers. They offer more diagnostic features and ease of use. Chapter 5 will discuss the functions and capabilities of several scanners, and how they work with OBD-II systems.



In addition to reading and clearing DTCs, an Actron AutoScanner CP9575 code reader can store data generated from a vehicle that was previously scanned. This information can be viewed even when the code reader is not connected to a vehicle. The tool has the ability to display generic and manufacturer-specific codes and definitions, six modes of OBD II data, and trilingual text (English, Spanish, and French). Other features: freeze frame, State OBD check for emissions, drive cycle mode, and more. *Courtesy Actron*

Chapter 5

Scan Tools



This herd of scan tools represents the next step up from mere code readers for performing OBD-II diagnostic work. From the left they are an Actron AutoScanner Plus, an AutoXray EZ-Scan 4000, an OTC ScanPro, an Actron Elite AutoScanner Pro, and an EZ-Scan 6000 by AutoXray. These scanners provide levels of information found just a few years ago only on professional-grade scan tools. *Courtesy Actron, AutoXray, and OTC Tools*

SCAN TOOLS

Scan tools, more commonly known as scanners, are the next evolutionary step up from simple code readers. Many of these do-it-yourself scan tools now have many, if not more, of the features that only professional-grade scanners from just a few years ago possessed. While all code readers are capable of reading and erasing diagnostic trouble codes, and providing information about a vehicle's ability to pass a state's mandatory emissions test, they don't offer much in the way of the in-depth information necessary for performing more extensive diagnostics and repairs on OBD-II vehicles. The ability to view, record, and play back live PCM data (also known as parameter identification data or PID) is the single biggest feature that really sets scan tools apart from code readers. The scan tools covered in this chapter typically range in price from around \$180 to \$700 dollars. The following is a list of typical features that the majority of these tools offer. However, not all scanners are equipped with all the features listed.

- Backlit display
- Read and erase DTCs
- MIL status, I/M monitor status, freeze frame data, state OBD-II check
- PC or laptop interface (printing capabilities)
- Updatable software via Internet (serial or USB port)
- On-screen code definitions (generic OBD-II and manufacturer-specific codes)
- Store and review data "off-vehicle" (internal battery)
- Trouble code lookup library, OBD-II generic and enhanced codes
- Record and play back vehicle data
- Display data graphically
- Capture live data frames
- Export captured data to spreadsheet format
- Display vehicle VIN
- View live engine data
- Perform various monitor tests
- View OBD-II drive cycle mode

- CAN protocol compatible
- OBD-I compatible, including manufacture-specific code definitions

So with all of these great features, how are technicians and do-it-yourself auto mechanics supposed to know which of these scan tools is right for their needs? Well, the answer depends on what the person is trying to accomplish in conjunction with that person's level of diagnostic skills (or amount of time he/she is willing to spend learning all about OBD-II systems and electronic engine management). When the only thing a person needs or wants to accomplish is the simple task of reading or erasing diagnostic trouble codes from a vehicle's PCM, then a code reader is the tool of choice since they are simple to use and inexpensive.

However, if the intention is to get more seriously involved with OBD-II systems, or if there is a need or desire to diagnose engine systems and sensors down to their basic component levels, then a scan tool is

essential. However, it's important to remember that not all scan tools are created equal. The old adage that "you get what you pay for" definitely applies to scanners. But beware, many scan tools may have far more features and information available than will ever be necessary to meet particular needs, so choose scanners and features wisely so as to avoid wasting money.

Let's start out by taking a closer look at five specific scanners or scan tools, as well as two laptop/PC OBD-II interface tools. You've heard the saying "There's an app for that." There are many phone OBD-II-related apps, from both Google and Apple, and we'll take a look at some of them.

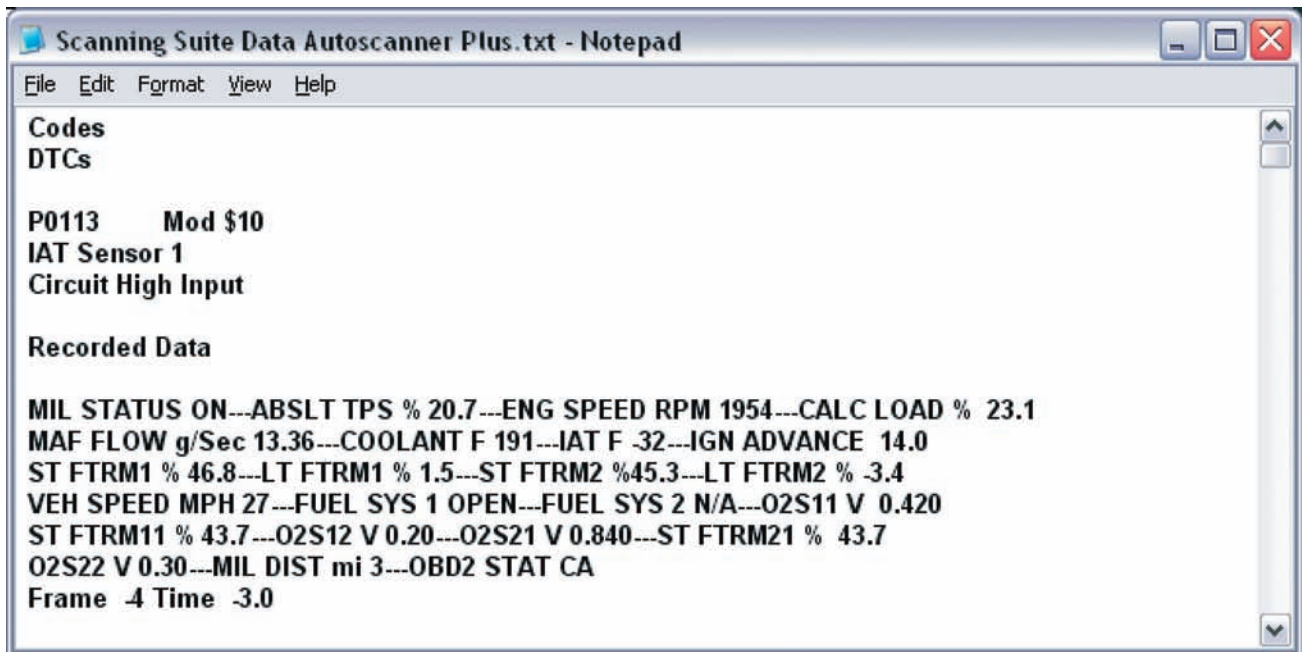
AutoScanner Plus

The AutoScanner Plus CP9580A by Actron is an entry-level scan tool priced at around \$200. In addition to reading and erasing DTCs, this scan tool comes equipped with the following features: a 128 x 64 pixel backlit display screen, a USB cable interface, online updatable software, internal diagnostic trouble code reference library (includes generic OBD-II system DTCs and manufacturer-specific "P1" codes), off-vehicle data review capabilities, record and playback data functions, print data abilities (using PC interface), O₂ monitor testing, OBD-II "drive cycle" modes, and OBD-II system checks for mandatory state emissions testing.

The AutoScanner Plus utilizes manufacturer-specific vehicle information that can be displayed for both current and pending "P1" malfunction codes or DTCs. Whenever pending or current DTCs exist in a PCM, or whenever a technician is using the trouble code lookup function to obtain a manufacturer-specific "P1" code definition, this scan tool will prompt users to enter the manufacturer, year, make, model, and engine of the vehicle being tested. Once this information is entered, users will also be asked if the particular vehicle's setup information (just entered) should be stored internally in the scan tool's memory for future review or use. This is an especially handy feature when a technician uses the scanner on different vehicles and doesn't want to have to configure it each time it is connected.



The AutoScanner Plus CP9580A by Actron not only displays generic OBD-II diagnostic trouble codes, but also displays manufacturer-specific "P1" DTCs. Internet software updating and printing captured data capabilities are possible via a USB cable and a PC or laptop. The tool has been updated with over 4.3 million CodeConnect® Top Reported Fixes that advise users of OBD-II-related issues with specific vehicles. *Courtesy Actron*



This is an example of captured data from an AutoScanner Plus scan tool. This captured data information can be stored and edited on a PC and subsequently printed via a Windows Notepad file. Doing this is a great way of keeping track of specific vehicle drivability problems, symptoms, and repair solutions. The Actron Scanning Suite software used for this function is contained on a CD that is included with the scanner. *Courtesy Actron*

The AutoScanner Plus also comes complete with a CD containing Actron's exclusive Scanning Suite software. The Scanning Suite package includes the following functions: print data, DTC lookup, scan tool update, user manual, and tool setup functions. This scan tool can be connected to any PC or laptop via a USB cable, and can be updated via the Internet. The USB connection also provides the print function for any data stored internally in the tool's memory. All of the following data can be printed to an editable text file: I/M readiness monitors, diagnostic trouble codes (manufacturer-specific and generic OBD-II system codes, pending codes, state OBD check information, freeze frame data, O₂ monitor test results, playback recordings, specific vehicle information, and available OBD-II modules.

Viewing live data from a vehicle is a good way to verify if computer sensors are functioning properly. The scan tool can tap into OBD-II monitors and display resulting OBD-II parameter identification data (PID) on its screen. Data can be viewed in two different ways: 1) the entire data list can be viewed; or 2) a custom list can be developed based on particular PIDs selected by a user. In addition, the operation of switches, solenoids, and relays, as well as computer sensor data, can all be viewed on the scan tool.

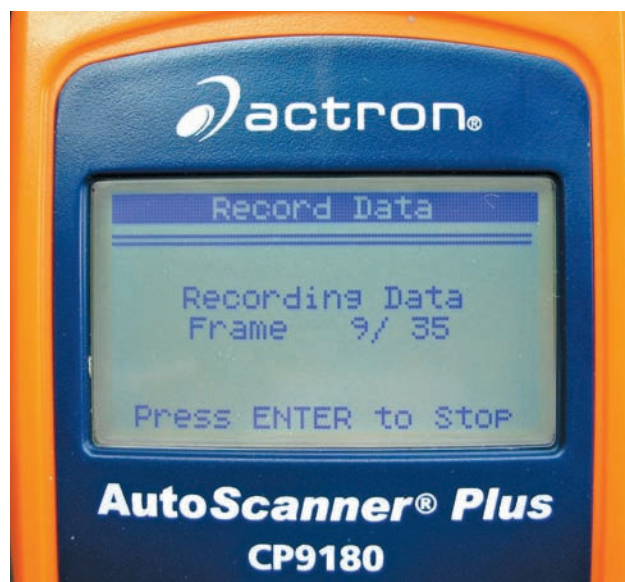


Custom data can be selected from all of the numerous PIDs (parameter identification data, i.e., sensor values) available for any vehicle being scanned. One advantage to choosing the particular data to be displayed, rather than viewing all data possible is that a faster update rate is achievable between the scanner and a vehicle's OBD-II system. (The more lines of data displayed, the slower the update time.) Slower update rates make it difficult to hone in on a specific sensor's value in real time. For example, if a MAF sensor's data is being monitored, and the throttle on a scanned vehicle is quickly opened, the scan tool will update the changing MAF data to match the changes that occurred when the throttle opened. This makes comparisons between the action of the throttle opening and the MAF values easier to relate to drivability issues.

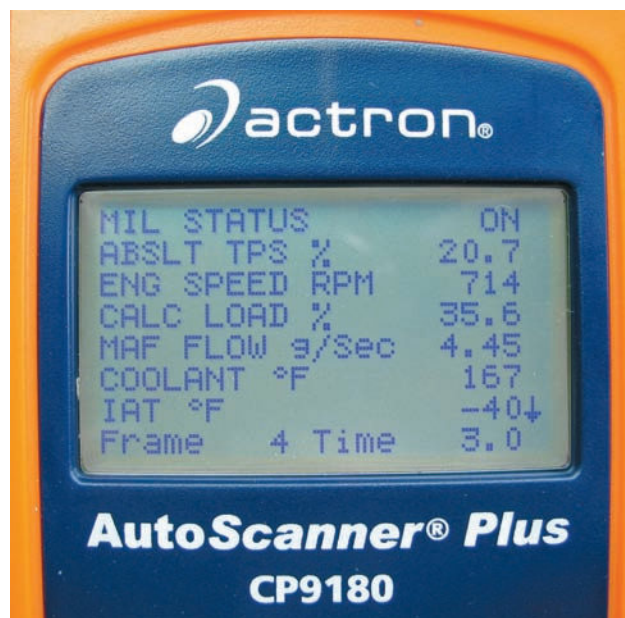
Once a user selects the “View Data” function from the “OBD-II Function List” menu, the scan tool will first validate the parameter identification data (PID) list. Bear in mind, multiple sets of PIDs may be received by the tool if the vehicle being scanned is equipped with more than one computer module. For example, if an OBD-II system produces PIDs from a PCM as well as from a TCM (transmission control module), the scan tool will identify them by their individual identification names (ID) assigned to them by the vehicle’s manufacturer.

This scan tool enables a user to create a custom list of PIDs for those instances when the user only wants to view PIDs pertaining to specific drivability problems. Any number of individualized PIDs can be selected from the total list available, and displayed for viewing, recording, or playback.

The AutoScanner Plus also offers the ability to record and playback data. This is an invaluable tool for discovering hard to diagnose intermittent drivability problems. The entire list of PIDs can be recorded, as can a custom-created list. The recording can be triggered either automatically by a DTC set by a PCM, or manually by a user according to preference. It should be noted that when a PCM causes a diagnostic trouble code to trigger a recording on certain vehicles, the recorded data may, in fact, not show anything useful because of the length of time the PCM might have taken to set particular codes. Once a recording is triggered or started, various frames of data are recorded before and after the trigger point, thus allowing a user to view computer data that occurred immediately prior to and after a particular drivability problem, or whenever a trouble code is set. Frames of data are sequentially numbered and have a corresponding time stamp for identification purposes, so that retrieving them later is simplified. For example, assuming a manual trigger was used to detect a drivability problem, the recording’s frames would be numbered as -3, -2, -1, Trigger, +1, +2, +3, etc. For data review purposes, the trigger point indicates the point at which a drivability problem occurred. The negative-numbered events correlate to points in time recorded by a PCM immediately prior to the triggering event (drivability problem), while the positive numbers correlate to points in time immediately after the triggering event. This scan tool is capable of storing only one recording at a time, which can be played back when the tool is not connected to the vehicle, and/or sent to a PC or laptop for printing. The different brands of PCMs on different manufacturer’s vehicles communicate with scan tools at



Data recordings can be triggered (started) by a manual trigger, or whenever a DTC is set by a PCM. Once a manual trigger is activated by the user, all data before and after the trigger point is recorded in the scanner’s memory. Up to 35 frames of PID data can be recorded and stored in the scanner. The ability to play back recorded data is particularly valuable whenever a user is trying to discover the cause of intermittent drivability problems during a test drive. *Courtesy Actron*



Recorded data can be displayed whether or not the scanner is connected to a vehicle’s DLC connector. The bottom of the display screen seen here shows data from a particular point in time when an engine performance problem occurred (“Frame 4, Time 3.0”). The arrow at right indicates that more data can be displayed by scrolling down. Being able to review data from an exact moment in time when an engine performance problem occurred makes diagnosing its cause that much easier. *Courtesy Actron*

varying speeds and support a different numbers of PIDs; consequently, these variables cause recording length to vary widely among manufacturers and vehicles.

The “State OBD Check” function provides a quick way to display the status of a vehicle’s OBD-II system. This test should be performed with the engine running to correctly display MIL lamp status. The “State OBD Check” function shows MIL status, number of codes found, number of monitors that have successfully been performed (listed as “OK”), monitor tests that remain incomplete (INC), and total number of monitor tests that are simply not available (N/A) on a vehicle being tested. For more information on OBD-II monitors see chapter 2.

An AutoScanner Plus can perform O₂ monitor tests simply by retrieving completed O₂ sensor monitor tests from OBD-II vehicles that are not equipped with controller area network (CAN) protocol. Such O₂ sensor tests are not continuously monitored by OBD-II systems that are not equipped with CAN protocol. However, on OBD-II systems that do use CAN protocol, test results from both continuous and non-continuous monitors can be viewed. Sensors are identified in each test by a signature prefix. For example, the upstream O₂ sensor located closest to the engine on bank 1 (right side of a V-8 engine) would be abbreviated as O2S11—where the O2S represents oxygen sensor and the first numeral 1 represents bank 1 or the right side of engine. The last numeral 1 represents an upstream position. The downstream O₂ sensor for that same right bank, or the right side of the engine, would be abbreviated O2S12. The upstream O₂ sensor on the left side/bank of the engine would be O2S21, while the downstream O₂ sensor on the left side/bank of the engine would be O2S22. (See chapter 3, Figure 3-6, for a graphic diagram of O₂ sensor locations.)

The following O₂ sensor tests are available on most OBD-II vehicles (with or without CAN protocol):

- “Rich-to-Lean” sensor threshold voltage
- “Lean-to-Rich” sensor threshold voltage
- Low sensor voltage switching time
- High sensor voltage switching time
- “Rich-to-Lean” sensor switching time
- “Lean-to-Rich” sensor switching time
- Minimum sensor voltage
- Maximum sensor voltage
- Time between sensor transitions (similar to cross-counts)

EZ-Scan 4000

The EZ-Scan 4000 scan tool from AutoXray features an eight-line, 128 x 64 pixel viewing screen with a backlit display that features a 32-step contrast adjustment. This scanner’s additional features include an auto power off, real-time operating system, battery data backup, and hard carrying case. The 4000 automatically reads all OBD-II protocols, including CAN, and can also capture and play back live data from any vehicle’s OBD-II system. When using the capture mode, a user can select the incremental amount of time each frame of data will record. The default is 1000ms (100



The EZ-Scan 4000 scan tool by AutoXray comes with a blow-molded storage case. The scanner can capture and play back live data streams. Additionally, the 4000 utilizes internal batteries so data can be viewed even when the scan tool is disconnected from the vehicle that was scanned. Furthermore, this scan tool can upload data to a PC or laptop via an included USB cable, which also makes software updates available via the Internet. *Courtesy AutoXray*

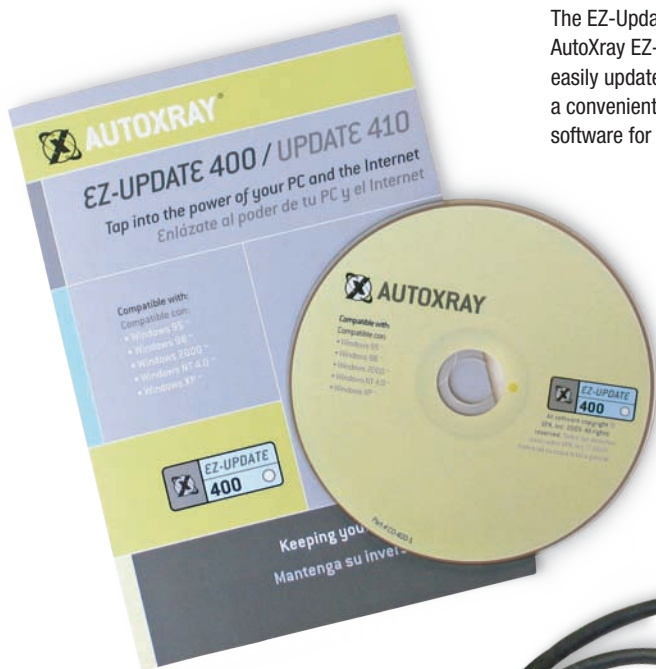


milliseconds, or one second). A capture time length of between 500 milliseconds ($\frac{1}{2}$ second) and 5,000ms (or five seconds) can be set for each frame. Additionally, the 4000's internal batteries allow OBD-II test results to be stored for later off-vehicle viewing. This sophisticated scan tool is typically priced at around \$370 dollars.

The EZ-Scan 4000's scanning functions and basic tool operation are simple. Whenever the "SCAN" function key is pressed, the OBD-II system protocol in use is displayed; the scanner will also display MIL lamp status as being either "ON" or "OFF." The display also confirms for a user whether any diagnostic trouble codes or freeze frame data are present on the vehicle, and will then display "Scan Successful" once these tasks are complete. Using this tool, it is possible to view scanned data both when the vehicle is running and when the scanner is disconnected. Specific data can also be customized to permit a user to view only those PIDs that pertain to specific drivability issues; conversely, if a user wishes to view all PIDs available for any specific

vehicle, this data can be viewed as well. The number and types of data items are vehicle dependent. If any DTC are present when the scan is performed, on-screen definitions are displayed for both OBD-II generic and enhanced manufacture codes.

The EZ-Scan 4000 comes complete with a USB cable adapter for use with AutoXray's EZ-Update 400-USB computer software, the latter of which is available for an additional \$40 dollars or so. This software enables the scan tool to be easily and quickly updated and upgraded via the Internet. Another handy accessory that is available for an additional cost is the EZ-Charge Ax200 Battery Tester. A user simply plugs the tester into the scanner and then selects it as a function from the scanner's main menu. The tester uses battery conductance technology to test battery condition, voltage, and available cranking power. Priced at around \$150 dollars, this battery tester is a useful accompaniment to this scan tool, as it can also check charging system and starting system functions.



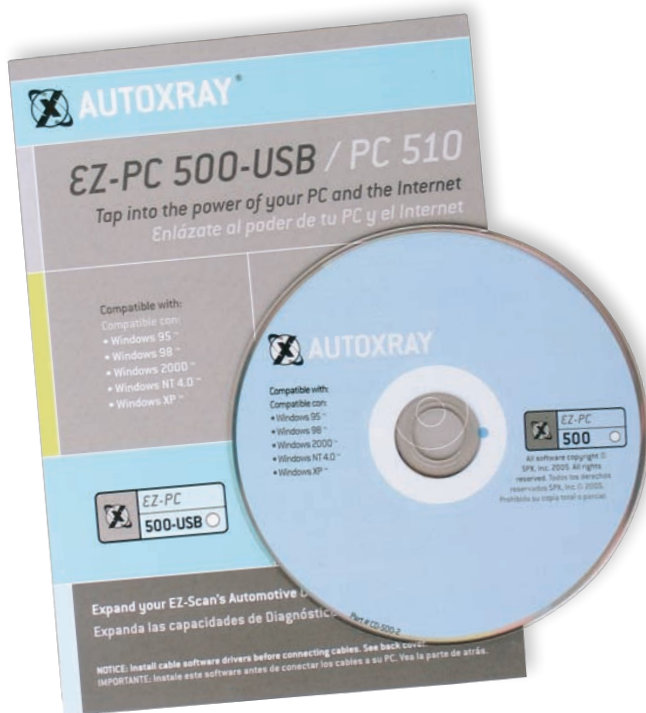
The EZ-Update 400 scanner tool package allows any AutoXray EZ-Scan series scan tool to be quickly and easily updated via the Internet. This software provides a convenient method for keeping current on the latest software for these scanners. *Courtesy AutoXray*

One handy accessory that interfaces with all AutoXray EZ-Scan series scan tools is the EZ-Charge Ax200 Battery Tester. Using conductance technology, the battery tester component is capable of displaying battery test results on a scan tool screen, including specific test results relating to a battery's condition and its cranking power. *Courtesy AutoXray*



EZ-Scan 6000

The EZ-Scan 6000 is a sophisticated scan tool from AutoXray. In scope of available OBD-II functions, it is similar to the 4000 model, except that it has enhanced features and performance capabilities that justify its approximate \$700 price tag. The EZ-Scan 6000 performs all of the same functions as the 4000 model, but can also access OEM enhanced DTCs and information. Furthermore, the AX6000 can connect to General Motors, Ford Motor Company, and DaimlerChrysler vehicles from the OBD-I generation of vehicles from 1983 on. With regard to 1989 to 1995 DaimlerChrysler cars, as well as all 1991 Dodge trucks, vans, and Jeeps, this scanner can reset the emissions maintenance reminder (EMR) lamp. This advanced scanner comes fitted with a blow-molded case, and includes a computer hardware package that features OBD-I and OBD-II compatible cables, plus a USB cable for connecting the scan tool directly to a PC or laptop. A 95-page user's manual covers OBD-II tests and manufacturer-specific OBD-I tests.



AutoXray also produces computer software known as EZ-PC 500-USB, which can be used in conjunction with any AutoXray EZ-Scan scanner. This software package allows any captured vehicle data to be uploaded to a PC or laptop. Data can also be stored and saved as a text file for later reference. *Courtesy AutoXray*



The more sophisticated AutoXray EZ-Scan 6000 scan tool can connect to earlier OBD-I vehicles as well as more modern OBD-II vehicles. Computer cables for General Motors, Ford Motor Company, and DaimlerChrysler vehicles, as well as an OBD-II cable, are included with this scanner. The 6000 can be updated via the Internet with a USB cable connected to either a personal or laptop computer. *Courtesy AutoXray*

The 6000 is easily upgraded via the Internet using AutoXray's EZ-Update Software. In addition, the EZ-Charge Ax200 Battery Tester (previously mentioned in connection with the EZ-Scan 4000 model) will also work with this scanner.

In addition to producing high-grade scanners, AutoXray produces computer software that is compatible with all AutoXray EZ-Scan scan tools. AutoXray's EZ-PC 500-USB software is available for the EZ-Scan 4000, 5000, and 6000 models of scanners. EZ-PC software allows users to upload scanned information directly from the scan tool onto a PC or laptop for later viewing or reference. Once the scan tool is connected to a PC via a USB cable (included with scanners), a "Vehicle Scan Report" can be sent from the tool to the computer.



This invaluable report includes user comments, existing diagnostic trouble codes, pending trouble codes, freeze frame data, readiness status and readiness test results, and OBD-II system operational data.

Another feature of the EZ-PC 500 USB software is the ability to display recorded data in two separate formats—in either what is known as a “Capture Data List” or a “Capture Data Graph.” The top row of a “Capture Data List” contains columns that indicate the specific time intervals during which specific data was captured and recorded. These columns are labeled “-C, -B, -A, Trigger, +A, +B, +C,” etc. These letters represent the specific time intervals before (negative letters) and after (positive letters) the trigger point, i.e., the point at which the recording was triggered manually by a user, or automatically by a PCM setting DTCs. Whenever capture mode is utilized by a user, the user can select the specific period of time each frame of data will record. The default rate is set at 1000ms (milliseconds, or one second). However, capture-time lengths of between 500 milliseconds

(½ second) and as much as 5,000ms (five seconds) can be set. By specifically setting capture rates or lengths of time for the data frame (during which data can be recorded), a user can utilize this scanner to zero in on specific drivability problems or to capture broader ranges of data for more generalized diagnoses of drivability problems.

The useful “Capture Data Graph” data found in the EZ-PC computer software program from AutoXray can be used to overlay data parameters and then view them on the same graph. For example, the data from an upstream oxygen sensor (O2S11) could be compared to the data from a downstream oxygen sensor (O2S12) to determine how each is functioning, separately as well as together, during a driving test. In addition, throttle position sensor data can be graphed along with vehicle rpm and calculated load data, in order to locate a faulty throttle position sensor. Using EZ-PC software is a good, simplified method for verifying when repairs are successful, since data from before and after a specific repair can be compared.

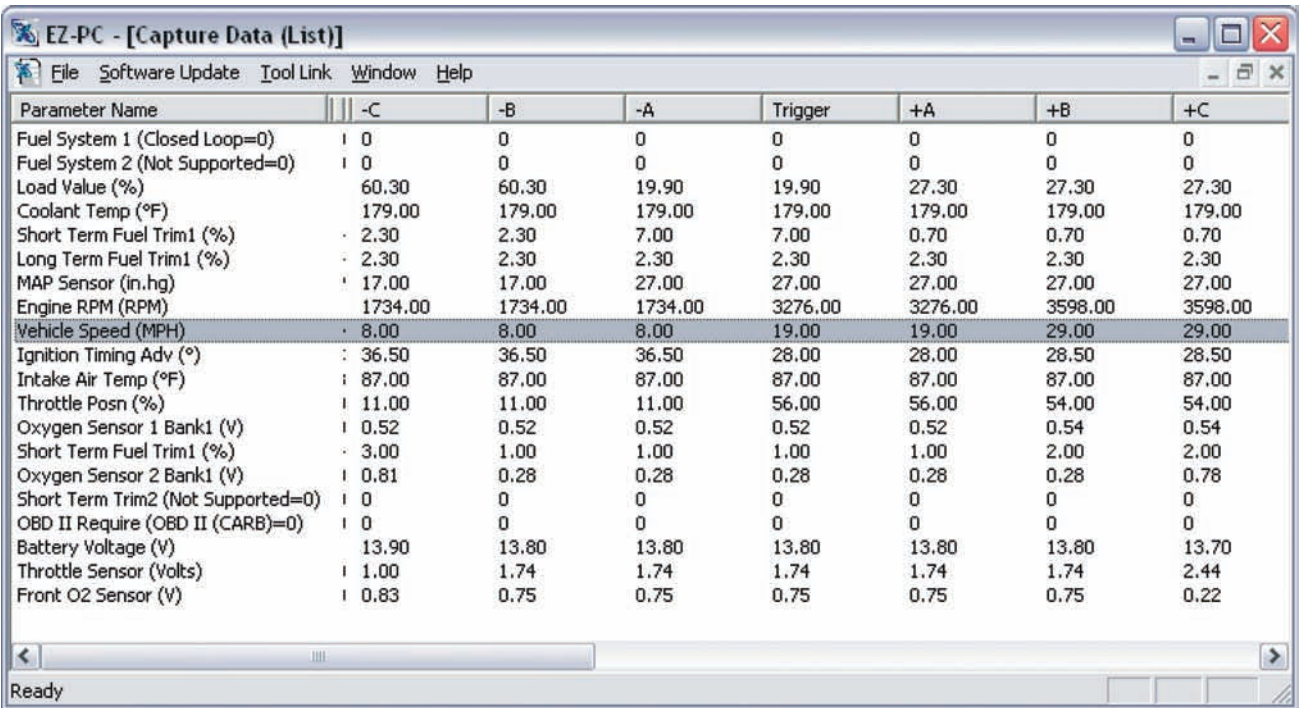
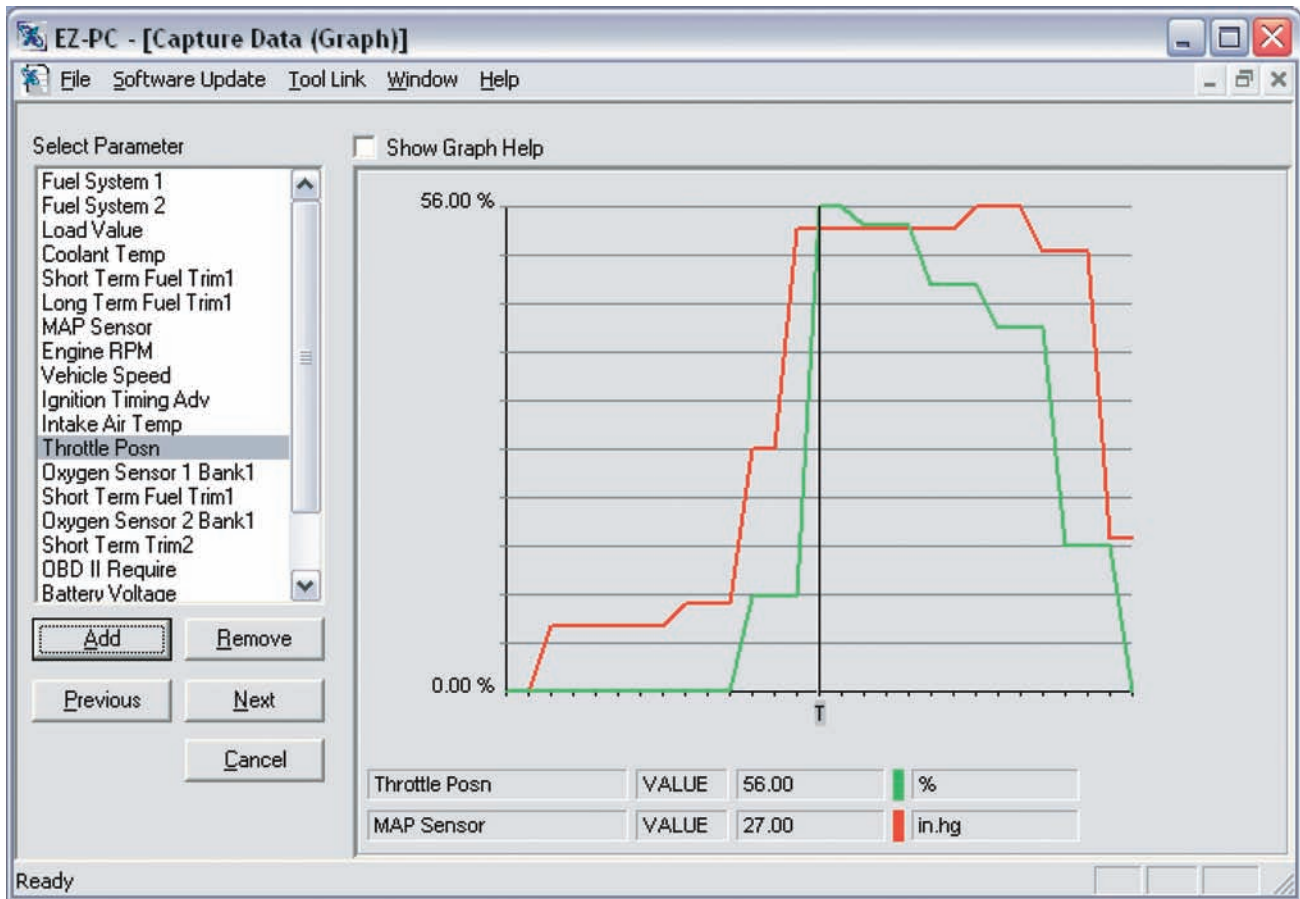


Fig. 5-12—A “Capture Data List” graph produced by AutoXray’s EZ-PC computer software program. Note that each column header represents specific frames of captured data, with the “trigger” point in the middle of the chart. Thus, the data stream from immediately before and after the trigger point can be viewed and analyzed. Each of the various PIDs are listed in the far left column. The vehicle speed has been highlighted in gray for easier viewing. *Courtesy AutoXray*



Captured data from the EZ-PC computer software program shows throttle position (green graph trace) as it relates to MAP sensor values (red graph trace). As many as eight PIDs can be displayed on a graph page at one time. The small lines at the bottom of the graph represent data frames, while the "T" in the middle represents the trigger point for this particular sample recording. *Courtesy AutoXray*

Elite AutoScanner Pro CP9190

The Elite AutoScanner Pro CP9190 is at the high end of the do-it-yourself aftermarket since it offers more features and functions than many professional scanners did only a few years ago. This near professional-grade tool features a large 2½ x 1½ high-resolution display screen that's easy to read. When connected to a vehicle, the screen is backlit for easy nighttime viewing or use inside a dark garage. In addition, this tool can be programmed for English, Spanish, or French languages. Other user-programmable features include a specification for the length of time before the tool automatically shuts off, a keypad on/off beeper alert, and custom user key programming. With a total price around \$550, these features make this tool a competitive choice for diagnosing electronic vehicle malfunctions.

A USB cable allows the CP9190 to be connected to a PC or laptop where recorded vehicle data can be

printed or stored as a text file for later reference. All data or PIDs can be recorded, or the user can select specific PIDs that pertain to diagnostic codes present in the vehicle that the tool is connected to. The Elite AutoScanner Pro and all Actron scanners use TrueLink technology that allows them to link to and communicate with all OBD-II-compliant (1996 and newer) vehicles, including those using the CAN protocol.

The tool's software can be updated online. Updates include OBD-II interface, internal code library, and enhanced OBD-II manufacture-specific codes. The device also has the ability to perform specific manufacturer's tests when the scanner is used to command various components and functions normally controlled by the vehicle's PCM. This feature is useful to verify that computer-controlled actuators can receive signals from the PCM and perform as they should. In addition to reading and erasing trouble codes, the scanner can determine I/M readiness testing

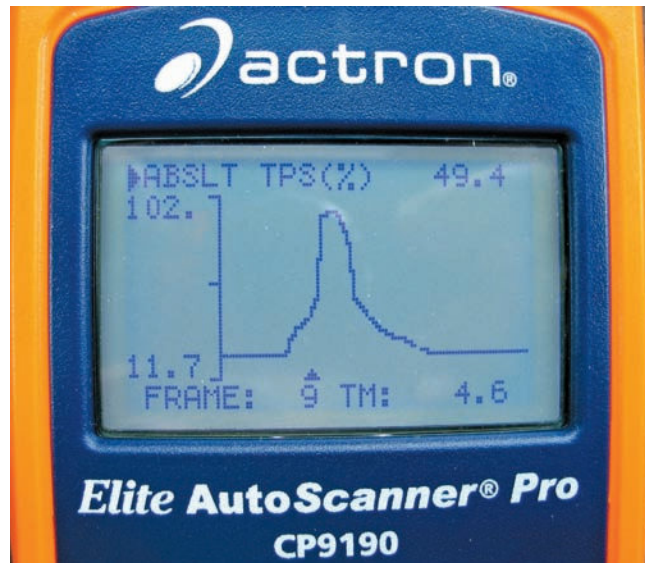


The Actron Elite AutoScanner Pro CP9190 scan tool offers many professional-grade features not typically found in other do-it-yourself types of scanners. For instance, this scan tool's ability to simultaneously and graphically represent live real time data as well as recorded data is a real bonus when diagnosing intermittent drivability problems. This sophisticated tool works with both generations of OBD-I and OBD-II-compliant vehicles, and can perform many manufacturer-specific tests on components and actuators. *Courtesy Actron*

for the vehicle's on-board monitors, display the status of the OBD-II emissions test monitors, and view and save freeze frame data. It can display the "real time" operations of the drive cycle monitors (similar to I/M readiness status), perform O₂ and diagnostic monitors tests, and display OBD-II modules present to specific vehicles.

Two additional functions set the CP9190 apart from other scanners: its ability to graphically display computer sensor data, and its capability to show extensive OBD-I diagnostics.

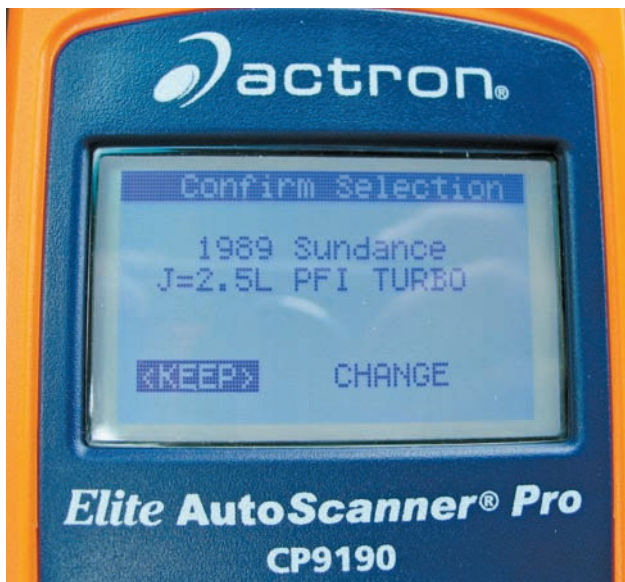
For 1996 and newer OBD-II vehicles, the scanner can display PIDs in graphic form. During playback or when reviewing data, if the symbol "gFi" is displayed, a



This electronic graph on an Elite AutoScanner Pro of a throttle position sensor's (TPS) absolute value signal was recorded during a test drive. All graphs displayed on this tool have a unique scaling feature that automatically sets Y-axis and X-axis values so the data is displayed properly. The bottom of the screen shows frame number and time during this particular recording. *Courtesy Actron*

press of the "Enter" key will display a graph that represent the "numbers" from that PID. This is an extremely useful feature when trying to find intermittent faults with computer sensors. Because the graphs represents numeric values over time, they are an ideal way to visualize abnormal signals produced by a faulty computer sensor. For example, if a throttle position sensor (TPS) is starting to wear out due to high mileage, the voltage signal numbers may look correct when viewed on a scan tool or digital multimeter. Using a graphical display could show very quick, unwanted drops in TPS output voltage that can't be read when just viewing voltage numbers.

The other feature that sets this scanner apart from others is its OBD-I diagnostic capabilities. The Elite AutoScanner Pro covers OBD-I vehicles, including General Motors from 1982 to 1994, and Ford and Chrysler from 1983 to 1995. Cable adapters for each manufacturer's OBD-I diagnostic connector are included with the scanner. Once the scanner is connected to the OBD-I vehicle, the tool can be programmed by the user for the specific OBD-I system in use on the vehicle. The display will instruct the user as to which cable adapter and other connections are required to run tests. During the read codes function, the internal code library will display code definitions for OBD-I systems.



In addition to interfacing with modern OBD-II compliant vehicles, this scan tool specifically supports OBD-I-generation vehicles. Shown on the sample display screen is configuration information from a 1989 Plymouth 2.5L turbocharged engine as it is being programmed into the scanner. This scanner is capable of storing a prior vehicle's configuration, and will ask users to select if they want to keep or change vehicles—a time-saving feature when working on different vehicles or the same vehicle over an extended period of time. *Courtesy Actron*



Some OBD-I generation vehicles have specific cable connections. Fortunately, the Elite AutoScanner Pro seen here is capable of providing a user with instructions required to connect an OBD-I-equipped vehicle directly to the scan tool. The full instructions are displayed as text on the screen. This screen shows that an external 12-volt power supply is required in order to properly connect a Ford Motor Company EEC-IV vehicle to the scanner. *Courtesy Actron*

OTC ScanPro 3409

The OTC (Owatonna Tool Company) 3409 ScanPro is a professional shop-quality, multi-function tool that can retrieve all generic DTCs for foreign and domestic OBD-II-compliant vehicles. It also displays selected enhanced manufacturer-specific diagnostic trouble codes for General Motors, Ford Motor Company, DaimlerChrysler, Toyota, and Honda vehicles. In addition, certain manufacturer-specific trouble codes can be displayed for several Asian and European vehicles. This scanner is priced at around \$570 dollars, but is well worth the price since it can monitor the performance of drivetrain-related components, and is compatible with all OBD-II-system protocols, including CAN.

The 3409 also has a large screen that enables it to display diagnostic trouble codes and their respective EPA-approved code definitions at the same time. Once the scanner is plugged into a vehicle, the 128 x 128 LCD display screen is immediately brightly backlit, making viewing it in a dark shop or under the hood at night possible. In addition, the display screen has a user-adjustable contrast function for viewing in bright sunlight.



The large screen format of the OTC ScanPro 3409 is capable of displaying large amounts of information from OBD-II-system vehicles, including live data streams and graphs. In addition, a “flight record and playback” feature allows data to be captured during vehicle testing. All data can be uploaded to a PC or laptop for storage or subsequent viewing. *Courtesy OTC/SPX Corporation*



Furthermore, all compatible software is menu-driven and user-friendly. Plus, this scan tool can perform many functions, including I/M readiness status and testing, reading and erasing DTCs, freeze frame data capture and display, diagnostic monitor tests, O₂ monitor tests, OBD-II “drive cycle” modes, identification of modules present, and review of all data. In addition to these extensive features, the ScanPro scanner has a “flight record and playback” feature that allows simultaneous recording of live data streams from a vehicle’s PCM. The data, or PIDs, can also be displayed in a graph format. Since the display screen is so large, additional data can be displayed below all graphs, enabling users to view additional information in conjunction with the graph. Whenever recorded data is played back in graph mode, a cursor appears below the graph; this cursor can be moved along the graph’s time axis, while the corresponding numbers represented in the graph are displayed below. The use of graph format data enables users to much more easily and effectively diagnose front and rear O₂ sensor operation, as well as the operation of other sensors.

The ScanPro 3409 scan tool comes complete with its own soft carrying case and detachable OBD-II cable for connecting to vehicles. The heavy-duty OBD-II cable is 7.5 feet long, making it easy to operate the scanner while working under the hood of a car or truck. In addition, a serial cable (purchased separately) can be used to connect the scanner to a PC or laptop, where software updates are available via the Internet. The serial cable can connect the scan tool to a printer, allowing the tool to be programmed for a variety of printer configurations. Moreover, a 120-page user manual is contained within the CD in a PDF read file format that can also be printed out. Internal batteries allow data to be viewed from off-vehicle locations.

LAPTOP INTERFACE SCAN TOOLS

A more sophisticated alternative to a handheld scanner or code reader is a computer interface scan tool. When installed on a personal computer or laptop, these software packages provide users with the same or greater levels of functionality as many scan tools. The hardware component of these packages is a cable and hardware connector that plugs into an OBD-II data link connection (DLC). Depending on the specific scan tool’s manufacturer, these cables can be either a USB cable type or a serial port type. Many companies offering this choice of hardware also allow the use of free “shareware” computer software



Most people don't realize that if they own a laptop they already have one-third of a scan tool. Simply by adding appropriate diagnostic computer software and a hardware OBD-II interface, a laptop can become a powerful, portable scanner with a large, high-resolution display screen. With the respective software loaded onto a laptop, a user-friendly scan tool is created. *Courtesy AutoEnginuity and Scantool.net*

programs to interface with PCs or laptops. Numerous free OBD-II interface programs are available on the Internet.

Compatible OBD-II interface software can be configured to display both generic and manufacturer-specific enhanced data parameters. In addition to lists of diagnostic trouble codes, this software can also display customized gauges (analog and digital), graphs, tables, charts, and alerts. Combined, this information creates a virtual electronic dashboard for the vehicle it's connected to and scanning. In fact, the volume of data material that can be displayed is limited only by users' imaginations and the screen size and resolution of their computers. This software package can be run on either a PC or a laptop, making it easy when work has to be performed in a garage. In fact, when users only want to read and erase codes, but not necessarily record data during a test drive, a PC located on a workbench next to the vehicle being scanned and worked on is a handy tool to have. Moreover, data must be recorded during driving conditions, a laptop offers portability, since it can be taken along for a test drive. For safety reasons, though, performing the latter scanning option obviously requires two people—one to drive and one to

view the PC's display screen—and no, they *both* can't look at the laptop's screen while rolling down the road.

AutoEnginuity Windows-Based Scan Tool

The AutoEnginuity Windows-Based Scan Tool is a professional-grade tool (\$249.95 retail) with enhanced coverage options for 48 auto manufacturers. With its enhanced expansions, users can access ABS, air bag, enhanced powertrain, instrument cluster, transmission and dozens of other body and chassis controllers. Coverage consists of live data, bi-directional controls, adaptive resets and relearns, reading and clearing freeze frame data, systems tests, and trouble code clearing and retrieval, including stored and pending P, U, B, and C trouble codes (including 50,000+ manufacturer specific codes).

Other powerful features include: printing DTC and IM/Mode 6 data in a customizable report format, translated and scaled Mode 6 data (data is viewed in a usable form instead of raw data), data logging in two different formats (XML for browsers and CSV for spread sheets), configurable sensor data where each individual sensor's sampling rate, and ranges. The tool alerts audio



The AutoEnginuity OBD-II interface and software scan tool is more than a code reader. Without live data and bi-directional controls there may not be enough information to properly diagnose and repair a vehicle. Having the ability to see live data, actuate components, and run systems tests makes diagnosis more accurate. *Courtesy AutoEnginuity*

trigger points, and units and scaling value can be set for specific requirements. Once the sensors are completely configured, the setup can be saved. When connecting to the vehicle in the future, the saved configuration can be launched when the tool is connected and the user-interface restored to the point where it was left the last time the vehicle was scanned.

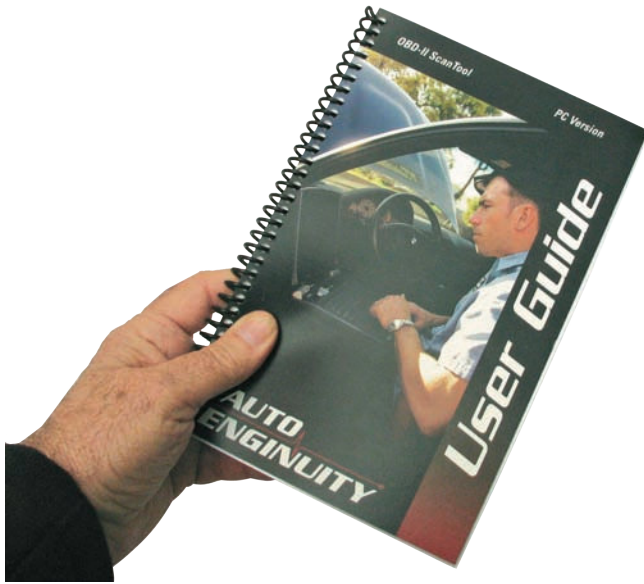
Using the power of Windows-based personal computers, AutoEnginuity leverages technology to access systems and on-vehicle sensors intuitively and more quickly than when using a traditional handheld scan. For example, if a user wanted to add all the sensors for a particular system when viewing a live data screen, a simple click on the column header for sensors completes the task. The user interface for AutoEnginuity is easy to learn and use.

Another example of ease-of-use is the software's graphing ability. Advanced graphing features, including multiple plots on the same graph, tagging plot locations, and printing graphs, can be displayed with a few mouse clicks. For steps that users need to repeat, the software streamlines the operation by providing automation for those steps. For example, automated VIN decoding, reading and clearing DTCs from the entire vehicle in a single step, and printing live data or DTC/emission reports can be accomplished in a single step.

The company provides a "Coverage On Demand" feature that allows users to access vehicle coverage in

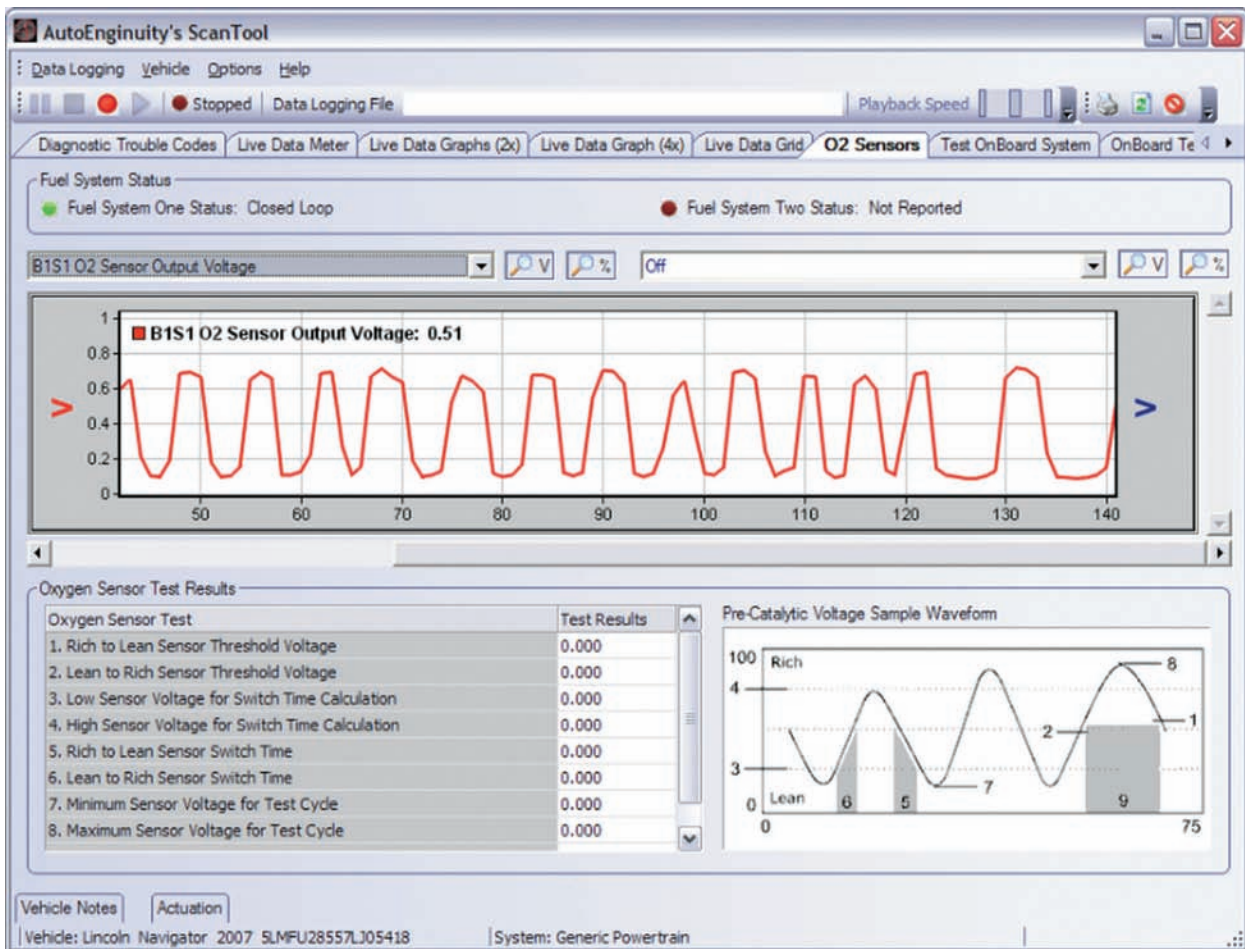


The AutoEnginuity scan tool comes with a DVD, instruction book, USB cable, OBD-II interface, and interface to DLC cable. *Courtesy AutoEnginuity*

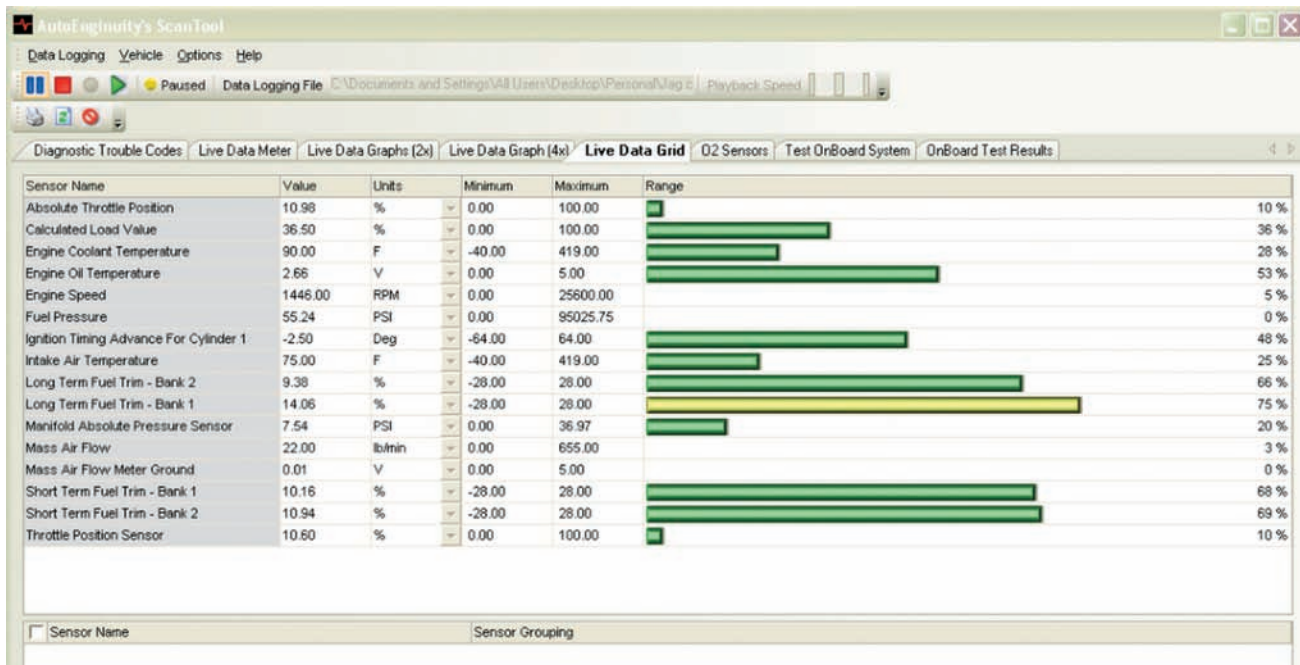


bundles or à la carte. For example, if users normally work only on Asian vehicles, but are faced with a European make, a call to AutoEnginuity will have the software uploaded to their computers within an hour. The scan tool software can be updated frequently through the Internet; base scan tool software updates are available at no cost.

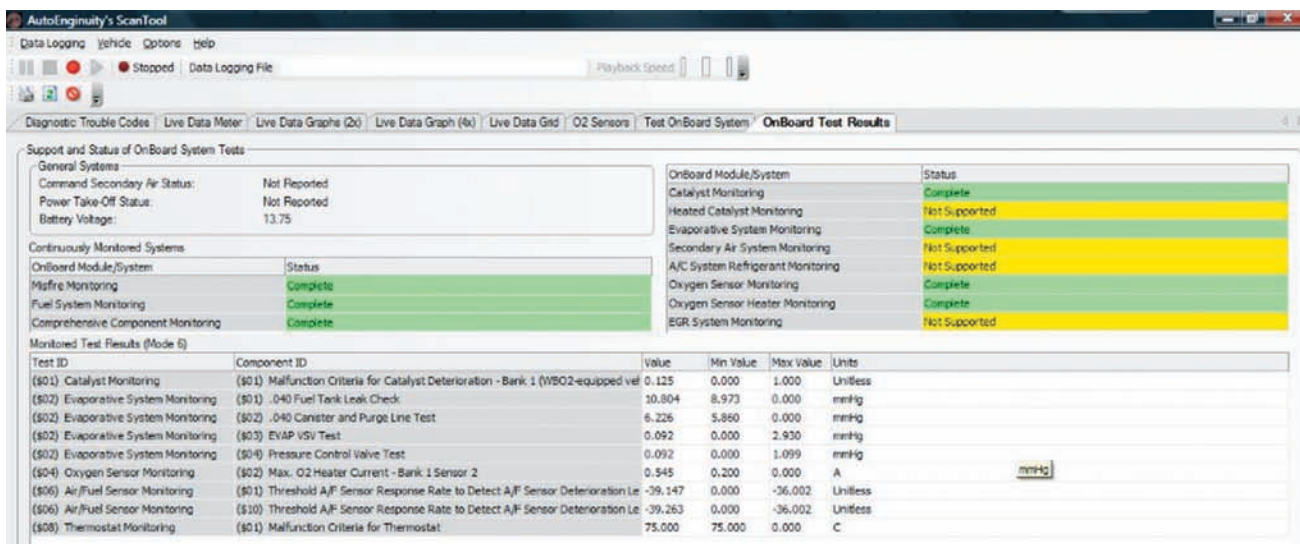
The AutoEnginuity User Guide is an outstanding reference that comes with the scan tool. The guide is a spiral-bound, 5½ x 8½ inch, 118-page book that provides a great resource for using the scan tool as well as understanding how OBD-II systems operate. Sections include: installation of the software, connecting to the vehicle, how to use the live data meter, graph and grid, O₂ sensors, automated OBD-II testing, data logging, customized displays, and more. This well-written, informative book really adds value the scan tool software package. It can be downloaded in a PDF format from the company's website at no cost. *Courtesy AutoEnginuity*



This AutoEnginuity O₂ sensor screen features a live waveform of O₂ sensor 1, bank 1, and pre-catalytic voltage sample waveform for comparison. It also displays O₂ sensor test results that can be saved or printed for later reference. *Courtesy AutoEnginuity*



The live data grid displays sensor name, value, type of units, maximum/minimum values, and range in percent. The range column displays the values in a colored, horizontal bar graph that makes any anomalies stand out (long-term fuel trim in this example). Just like the other AutoEnginuity graphs, this one can be saved and/or printed. *Courtesy AutoEnginuity*



AutoEnginuity's Onboard Testing Results screen provides a comprehensive look at how a vehicle's emissions system is operating. Details include: support and status of on-board system tests, on-board module/system list, monitored test results (mode 6 in this example) that show the test and component IDs, actual min/max values, and unit type. *Courtesy AutoEnginuity*



SCAN TOOLS

This AutoEnginuity live data graph show four traces: calculated engine load, coolant temperature, short-term fuel trim (STFT), and long-term fuel trim (LTFT). Observing STFT and LTFT can help pinpoint a fuel problem, especially when no DTCs are present. For example, running rich creates high negative fuel trim corrections; this can be caused by MAF sensor issues, leaking injections, and other issues. Lean running conditions create high positive fuel corrections and can be caused by a bad MAF or O₂ sensor, vacuum leaks, and unmetered air intake. *Courtesy AutoEnginuity*

OBdwiz and TouchScan

OBdwiz and TouchScan diagnostics software provides the user with the means to read and erase stored, pending, and permanent trouble codes, both generic and manufacturer-specific. There are over 7,000 codes in the included database. OBdwiz and TouchScan are identical and OBdwiz is included with all OBDLink adapters. TouchScan is available as a stand-alone product from www.obsoftware.net for \$24.95. A free trial version of TouchScan can be downloaded from the ScanTool.net website. Both software packages also

OBdwiz Windows software is included with all OBDLink adapters. It is compatible with Windows, Vista, and Windows 7 and 8.

Courtesy Scantool.net



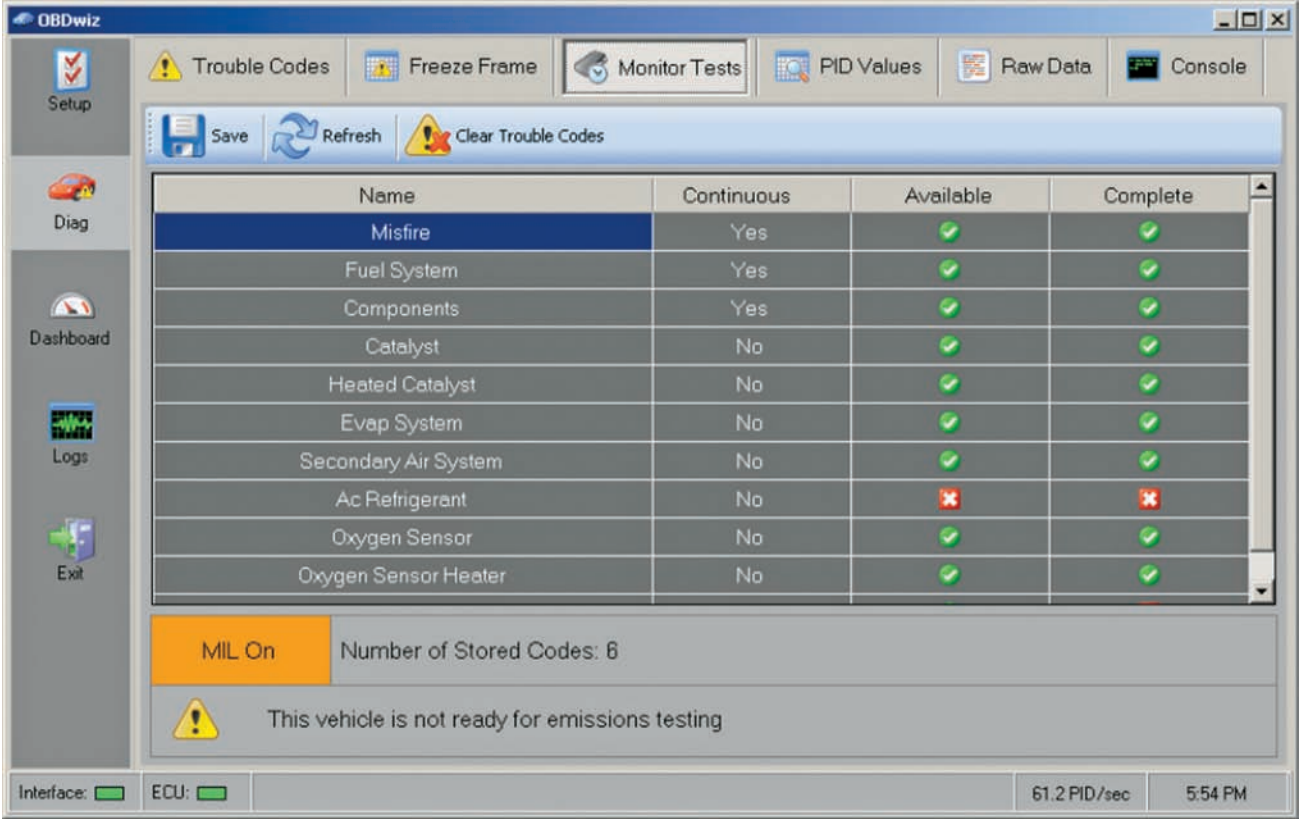


feature built-in, and online, information about probable causes and possible solutions related to DTCs. The packages can access freeze frame data, and display, graph and log 90-plus real-time parameters. In addition, the software can create custom digital dashboards, measure and display fuel economy, and much more. OBDwiz and

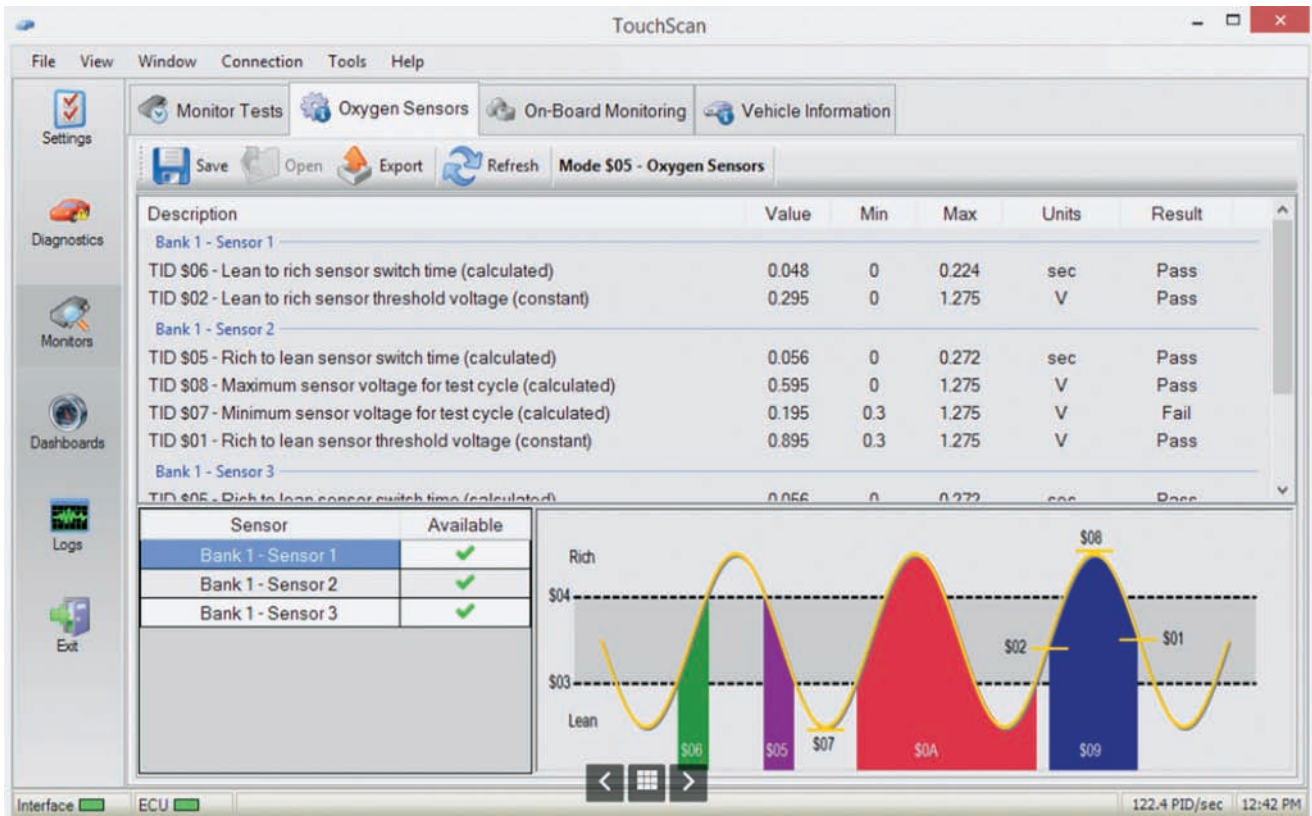
TouchScan are compatible with laptop touchscreen technology. They both come with a 90-day money-back guarantee, three-year “repair or replace” warranty, and free unlimited, online updates. A licensed copy of OBDwiz is included with all the OBDLink adapters (covered later in this chapter).



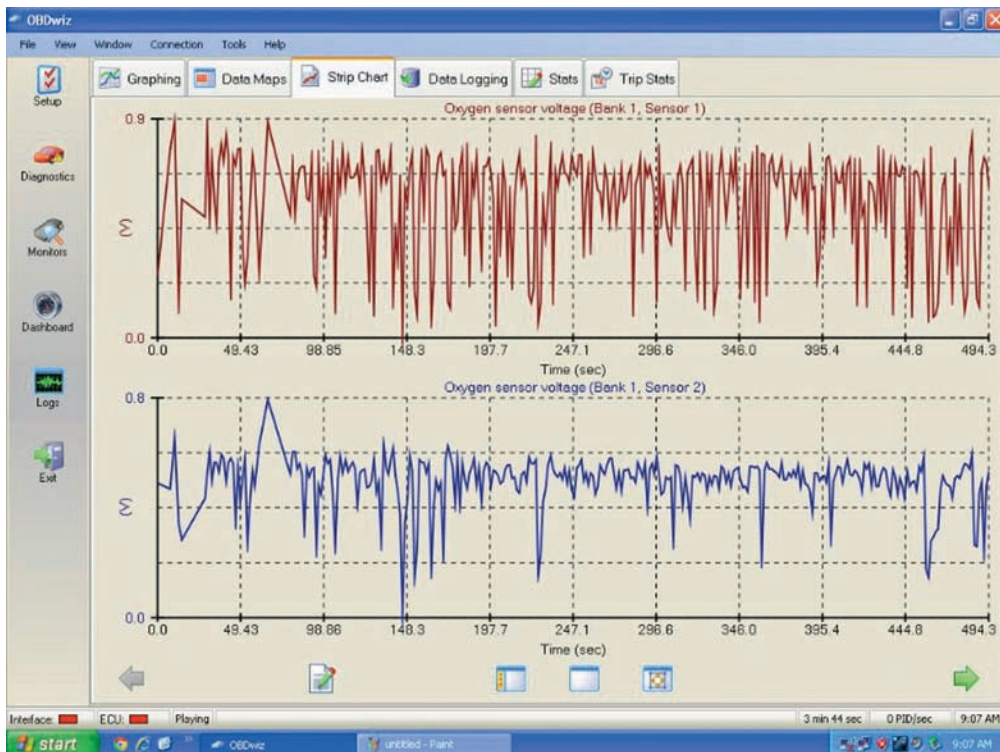
One of the many possible gauge setups from OBDwiz and TouchScan. The six gauges display fuel economy data with engine rpm, vehicle speed, engine load, and temperature. *Courtesy ScanTool.net*



The Readiness Monitor screen indicates that this vehicle is not ready for emissions testing, as it has six stored DTCs. Freeze frame data, PID values, and raw data are available with a simple mouse click.



The screen shows information about oxygen sensors, including min and max voltage values. The information is also represented in a graphic format on the lower right of the screen. *Courtesy ScanTool.net*



TouchScan and OBDwiz supports over 90 sensors (PIDs). They also have support for Oxygen Sensors (Mode \$05), On-board Monitoring (Mode \$06), and Vehicle Information (Mode \$09). This recorded strip chart shows the up and down stream of oxygen sensor values while the engine is running. These types of graphic representations of OBD-II data often make it easier to diagnose difficult sensor issues. *Courtesy ScanTool.net*



OBDLink SX USB is the perfect entry level scan tool designed for the do-it-yourself technician. This \$29.95 USB OBD adapter can turn a tablet, laptop, or PC into a sophisticated diagnostic scan tool, trip computer, and real-time performance monitor. Despite its modest price tag, it is packed with advanced features normally found in more expensive scan tools. The SX USB also includes the latest OBDWiz diagnostic software. *Courtesy ScanTool.net*



OBD-II ADAPTERS AND SMART PHONE APPS

The global smartphone audience surpassed the 1 billion mark in 2012. At the end of 2013, the projected use of smartphones was two smartphones for every nine people on earth, or 1.4 billion. By 2014 over 1.75 billion smartphones will be in use worldwide. It's probably a pretty good bet that if you live in the US and own a 1996, or later, car or light truck you also own a smartphone. What do smartphones have to do with OBD-II? Apps. There are many OBD-II-related mobile applications. Searching Google Play and Apple's iTunes, you'll find over 500 smartphone applications that essentially turn a smartphone into a scan tool. We will take a look at several of the most popular OBD-II apps.

However, having an OBD-II app on a phone doesn't do any good unless there is a way to connect the phone to an automobile's OBD-II system. Typing in "OBD-II smartphone adapter" into Google's search engine produces hundreds of adapters. The adapters connect via a USB cable, Wi-Fi, or Bluetooth, with the Bluetooth interface being the most popular. Following are some of the better OBD-II adapters.

OBDLINK ADAPTERS

OBD Solutions is a leading provider of on-board diagnostics solutions. Their hardware and software offerings cover the full spectrum of on-board diagnostic

Pick a phone. Both iPhone and Android let you choose from hundreds of smart phone, OBD-II-related apps that turn the phone into a scan tool, portable dynamometer, trouble code reference, or automotive repair manual. Both iTunes and Google Play websites have a mind-boggling number of apps for your car or truck that range in cost from free to \$10. An adapter will be required to connect your phone to the OBD-II DLC.

(OBD) applications, including smartphone-to-OBD-II Bluetooth and Wi-Fi interfaces. Founded in 2002, and located in Phoenix, Arizona, they specialize in the design, engineering, and manufacturing of OBD cables, interface software, and development tools. They can be found on the web at: www.obdsol.com. OBDLink, a subsidiary of OBD Solutions, manufactures three interfaces: the LX Bluetooth, MX Bluetooth, and MX Wi-Fi. All can be purchased at www.ScanTool.net.

OBDLink MX Bluetooth Adapter

The OBDLink MX Bluetooth is an easy-to-use, inexpensive, hacker-proof, fast Bluetooth OBD adapter that can turn a smartphone, tablet, laptop, or netbook into a sophisticated diagnostic scan tool, trip computer, and real-time performance monitor. At only 1.97 x 1.77 x 0.91 inches (51 x 45 x 23 mm) the MX is small enough to leave plugged into a vehicle's DLC while driving. Leaving it plugged in when the vehicle is not in use is not



The OBDLink MX Bluetooth works on any 1996 and later model of automobile or light truck. It is compatible with Android, Windows, and other platforms except for Apple iOS. It will work with dozens of third-party apps for smartphones. *Courtesy ScanTool.net*

a problem as the MX won't drain the vehicle's battery; its automatic sleep and wake-up functions operate without the use of switches or buttons. Pairing the MX with a smartphone, tablet, or Bluetooth-equipped laptop is easy and only takes a few minutes.

The MX Bluetooth supports all legislated OBD-II protocols, and works with all 1996 and newer cars and light trucks sold in the United States. It supports EOBD, JOBD, and all other international variants of OBD-II. In addition, it can communicate with MS-CAN, a CAN-BUS protocol used in Ford vehicles to interconnect body and information control units. The MX also speaks with MS-CAN, a single-wire CAN developed by General Motors and used as the communication bus for body, HVAC, and other on-board applications. The MX processing speed is very fast and the device renders smooth graphics, and changes and gauge readings, on a smartphone or tablet display.

OBDLink MX is backwards compatible with the ELM327 command set and works with dozens of third-party apps (including Torque and DashCommand), on virtually every platform (except iOS—iPhones and iPads), and across every device category including: smartphones, tablets, laptop and desktop PCs with Bluetooth capabilities. The OBDLink MX Bluetooth sells for \$99.95 on www.ScanTool.net. Free firmware and



The OBDLink MX is a small unit and can easily stay plugged into a vehicle's DLC while being operated. The power-saving sleep mode feature allows the MX to stay connected even if the ignition is turned off as it won't drain the battery. *Courtesy ScanTool.net*

software updates are available via the OBDLink website so the MX can be kept current. All OBDLink products are covered by a 3-year warranty and a 90-day money-back guarantee.



A licensed copy of the OBDwiz software is included with purchase of any of the OBDLink adapters. It is compatible with many PC-based scan tools and will run on a Windows 2000 or newer computer.
Courtesy ScanTool.net

OBDLink LX Bluetooth Adapter

The OBDLink LX Bluetooth is ideal if it's not going to be connected to either Ford or General Motors proprietary CAN networks. Priced at \$69.95, the OBDLink LX Bluetooth adapter is \$30 less than the OBDLink MX and has all the same features except the Ford and GM CAN-BUS interfaces. Based on the OBDLink MX, the LX Bluetooth offers the same unparalleled performance, delivering up to four times as many samples per second as other adapters when viewing PIDS. The ultra-fast response time creates almost-real-time accurate, detailed graphs and smooth, realistic virtual gauges on a smartphone or tablet. Just like the MX model, the LX comes with OBDwiz PC-based software. The LX works with the OBDLink phone app that can be downloaded free from the Google Play store. Free firmware updates are available and a three-year warrantee is included as well. The LX works with every platform (except iOS—iPhone and iPads), across every device category including: smartphones, tablets, laptop and desktop PCs with Bluetooth capabilities.

OBDLink's MX for Wi-Fi is the only OBDLink adapter that is compatible with both Apple's iOS and Android operating systems, and that transforms connected devices into sophisticated diagnostics tools as



The OBDLink LX Bluetooth adapter has the same features as the MX model except it can't read proprietary Ford and GM CAN-BUS systems.
Courtesy ScanTool.net



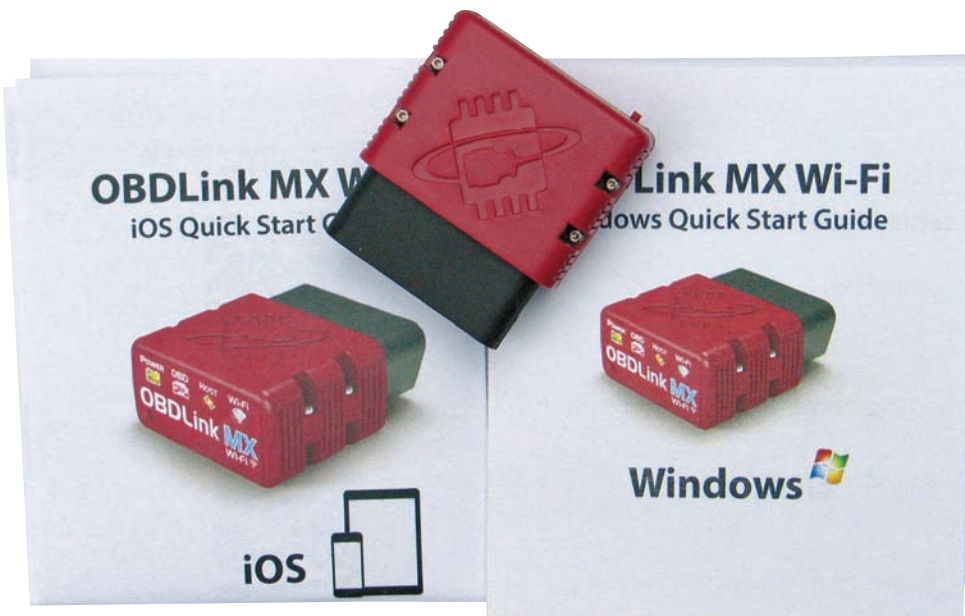
The OBDLink LX has four LED indicator lights: “Power” (shows it’s plugged into the DLC), “Host” (blinks when Bluetooth is communicating), “OBD” (blinks when the OBD system is communicating), and Bluetooth (indicates the status of the Bluetooth connection). *Courtesy ScanTool.net*

well as performance monitors. This adapter will connect to iPhones and iPads via a Wi-Fi (802.11b/g standard) connection. Because Wi-Fi provides a faster connection than Bluetooth, phone and tablet apps are accelerated by up to 250 percent and PC-based applications by up to 300 percent. This really makes OBD-II graphics on these devices look sharp and smooth when displaying live data from an engine management system. Wi-Fi also provides a more secure environment than Bluetooth, so the secrets of a particular OBD-II system will be protected from



The OBDLink MX for Wi-Fi uses BatterySaver Technology, allowing it to be plugged into a vehicle and left in without the danger of draining the battery. The sleep function is fully automatic; no switches or button presses required. *Courtesy ScanTool.net*

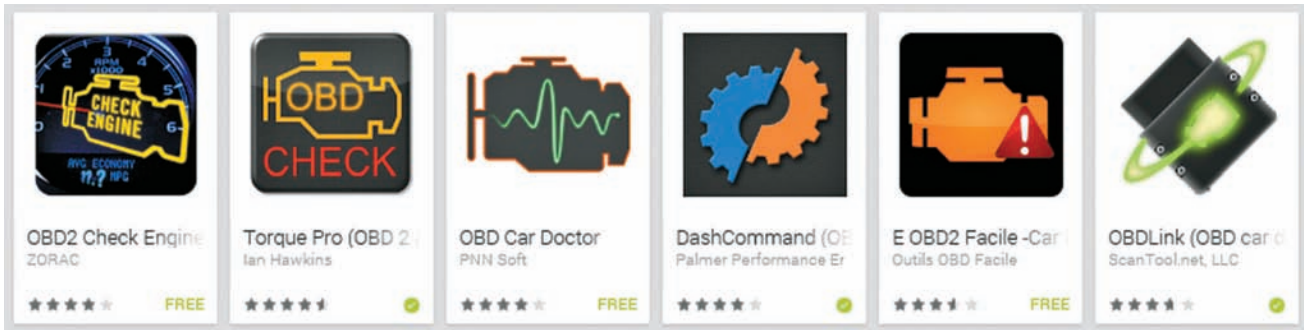
hackers. The MX Wi-Fi supports the SW and MS CAN protocols as well as the five standard OBD-II protocols. Free downloads of the latest firmware and software keep the adapter up to date. The OBDLink MX for Wi-Fi sells for \$119.95 and is available at www.ScanTool.net.



The MX Wi-Fi comes with quick start guides for both iOS and Android operating systems, and a license key for OBDwiz PC software. *Courtesy ScanTool.net*



SMARTPHONE APPS

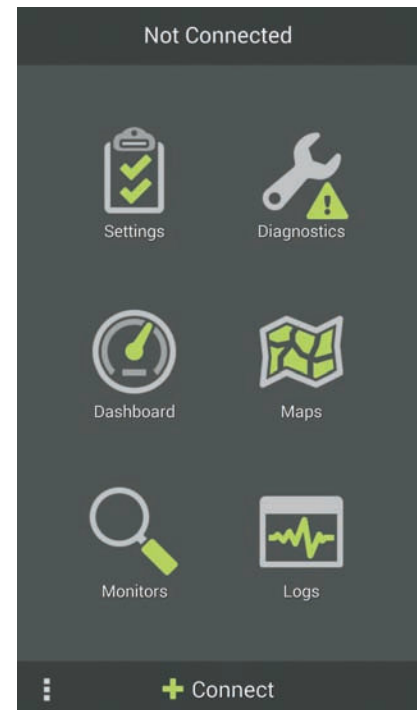


Between Android (Google Play) and iPhone iOS (Apple Store) there are close to 500 apps that utilize sensor output from the OBD-II data link to supply information to these applications. They provide a wealth of information, education, and entertainment, all at a low cost to the user.

Covering both the Android and iPhone market are hundreds of OBD-II related smartphone applications to choose from. Ranging in price from “free” to \$5 or more, they are an inexpensive way to have a fully functional scan tool that as a bonus makes phone calls. Many of these applications do more than simply read and erase trouble codes. They can display real-time data from the car’s engine management system, provide instant fuel economy numbers, create custom dashboards with all types of gauges that can display any output from the OBD-II system, and more. With all the OBD-II data available it’s no wonder that some of these applications also offer some fun behind-the-wheel features. Most smartphones are equipped with the accelerometers and GPS locating capabilities; using these functions can provide a sophisticated view of a car’s performance. The vehicle’s weight, horsepower, torque, and acceleration can all be calculated and displayed in the form of gauges or graphs. Want to find out if that expensive exhaust system or performance air cleaner really added 50 horsepower to the engine’s output? Just run before and after acceleration tests using a smartphone app that tracks vehicle acceleration. Coupled with GPS location, drivers’ ability to pilot their vehicle performance on track or street can be measured, evaluated, and bragged about endlessly. Here is a quick look at several smartphone apps that use OBD-II data.

OBDLink

The OBDLink app works with Android, Apple iOS, and Windows smartphone platforms. It is specifically designed to work only with OBDLink adapters. The app turns a phone or tablet into a full-fledged diagnostic scan tool that can read diagnostic trouble codes, clear the “Check Engine” light, check emissions readiness, estimate fuel economy, and more. In addition, it can create customizable dashboards, display emissions readiness standards specific for each state in the US, use multiple trip meters, and log engine management data in a CSV format (used in Microsoft Excel). It offers GPS tracking that plots vehicle parameters on a map in real-time, and e-mails diagnostic reports. Even though the app is free, there are no ads. Unlimited software updates are available at no cost.



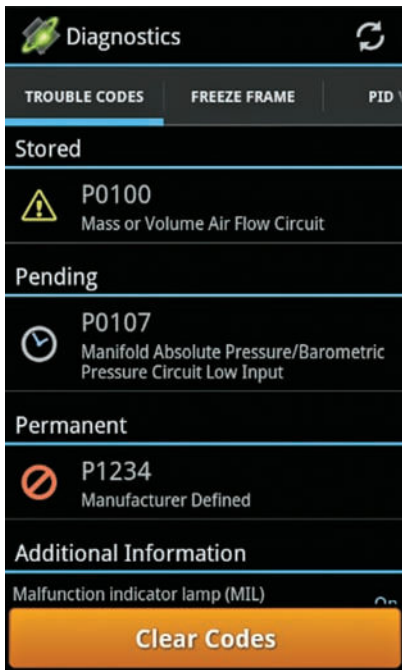
The OBDLink splash screen provides the gateway to numerous OBD-II functions and data. The app is easy to use and offers an easy way to monitor a car’s emissions performance and other engine management information.

Courtesy ScanTool.net

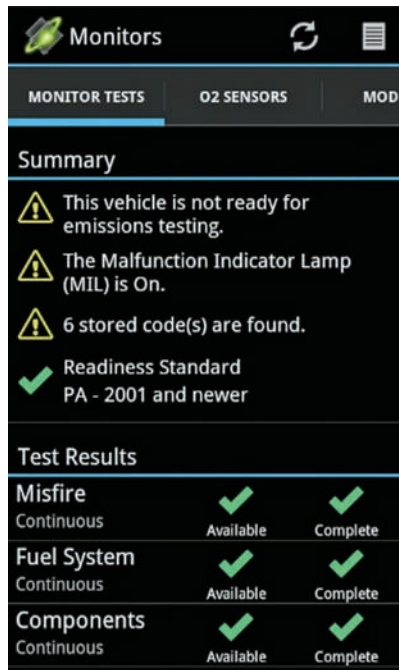


One of the many customizable gauge dashboards available in the OBDLink app. A phone can be mounted on a car's dashboard or windshield, providing a wealth of non-factory gauge information to the driver. *Courtesy ScanTool.net*

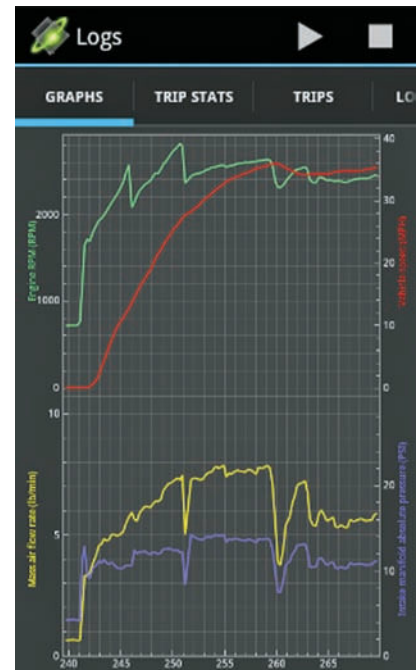
SCAN TOOLS



The trouble codes screen shows stored freeze frame data, pending DTCs, permanent DTCs, the manufacturer's trouble code definitions, and more. *Courtesy ScanTool.net*



The OBDLink monitors screen displays emission testing status, readiness standard (for Pennsylvania, in this example), and the status of all monitors and if they are available and/or complete for emissions testing. *Courtesy ScanTool.net*



This is an example of one of the many graphs that are possible to create in OBDLink. Top left shows engine rpm (note the shift points at the rpm drops); top right is vehicle speed; bottom left is mass airflow; and opposite is manifold absolute pressure from the vehicle's MAP sensor. *Courtesy ScanTool.net*



TORQUE (OBD 2 AND CAR)

One of the most popular apps that uses OBD-II inputs is Torque (OBD 2 and Car), by Ian Hawkins. This Android-only app comes in both free (Torque Lite) and paid versions (Torque Pro), for \$4.95. Torque functions as a scan tool and provides the ability to read and erase fault codes, display freeze frame data, view live sensor data, and check OBD readiness monitors for emission testing. Torque doesn't require anything more than the hardware already present on your Android



Just one of the numerous dashboard gauge setups that Torque offers. From the top left are: engine rpm, speed in mph, coolant temperature, engine load in a graph format, throttle position in percentage, and engine load in a bar graph format.



More than just a scan tool, Torque is packed with automotive performance measurement information. Want to know if the high-flow, super performance air cleaner you installed on your car really does anything in the horsepower department? Now you can find out with before-and-after 0 to 60 mph runs that are displayed on a smartphone.

phone to perform these function. When coupled with the smartphone's sensor data—like GPS antenna, internal compass, barometer and accelerometer—Torque can calculate acceleration rate, fuel economy, 0 to 60 times, quarter-mile time and speed, horsepower, and engine torque. Torque also has a turbo boost feature for vehicles that support MAP and MAF sensors. Some of these features are found in the Pro version only.

Both the Pro and Lite versions of Torque can specify any grouping of data parameters, along with GPS coordinates to be recorded via the apps' logging function. Users can e-mail their saved logs in KML format for importing into Google Earth, or in a CSV format that can be imported into almost any spreadsheet editor for conversion to whatever sort of chart or graph is desired. After inputting vehicle-specific values for engine displacement, vehicle weight, and fuel type into a vehicle profile, Torque Pro uses this information to calculate estimates for fuel economy, engine torque, and horsepower. Users can store multiple profiles for many different vehicles, and store separate logs and dashboard layouts for each profile. The View Map function displays a Google Map with a color-coded log of a user's last few trips; the log indicate relative speeds along a route. Users can also choose to display G-forces or altitude logs on this map. This function is useful for autocross events or amateur road racing as it indicates speed at various points along a route (racetrack). The app provides lots of entertainment value from software that costs less than \$5. A word of caution: Trying to set up all the screens, gauges, graphs, and other information while driving on the road is not a good idea, as this activity is very distracting. Setup should be done parked in a driveway or as a passenger during a drive.



This Torque screen shows test results for various OBD-II sensors. The app compares known good values with what the sensors are reporting and gives each an "OK" or "Not OK" status. This is quick way to ascertain if a sensor is misbehaving and needs a closer look.

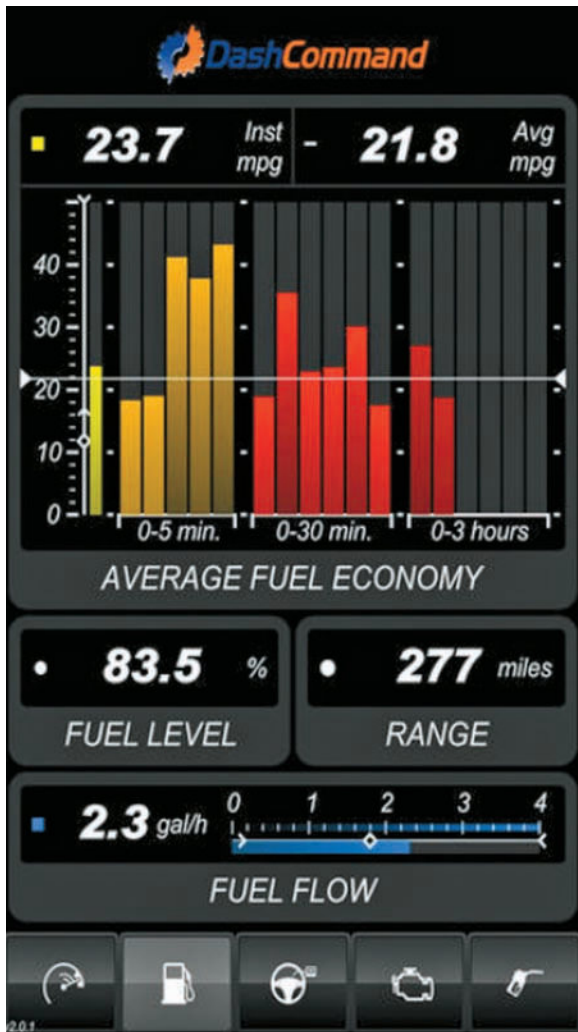
DASHCOMMAND (OBD ELM SCANNER)

DashCommand (\$9.99) by Palmer Performance Engineering works on Android, iOS/iPhone/iPad, and Windows devices, and turns a smartphone or tablet into an advanced display for engine data. In addition to reading and clearing diagnostic trouble codes, and displaying IM readiness status, DashCommand uses a phone's built-in GPS and accelerometer sensors to display vehicle performance including: horsepower, engine torque in real time, and G-forces that indicate cornering forces on a race track. Displays include a skidpad showing lateral and accel/braking Gs with min/max indicators. The



DashCommand's capabilities allow users to create and display stunning virtual dashboards with many styles of gauges including: digital, analog and others.

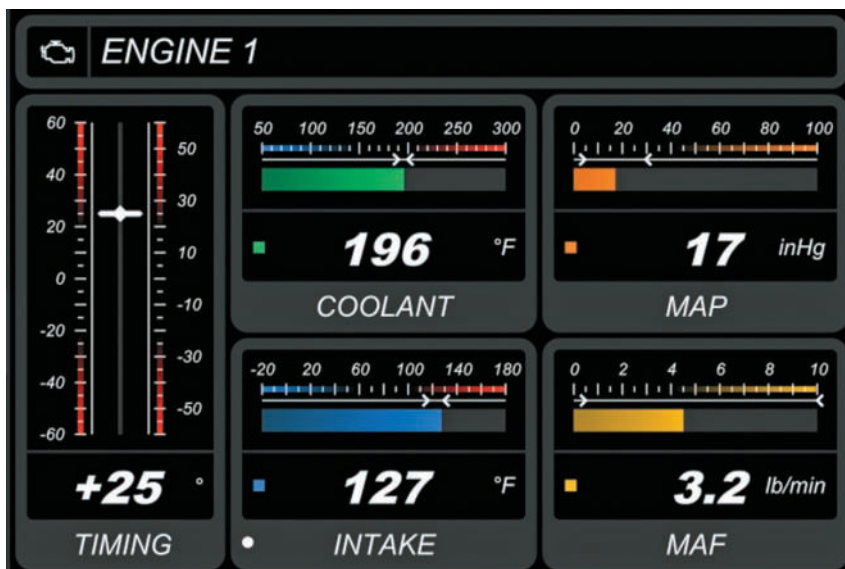
Race Track feature visually maps out a vehicle's location, acceleration, and braking as it's driven around the track. This allows drivers to visually analyze different laps to see how they performed from lap to lap. DashCommand even has an inclinometer that shows rolling angle and vehicle pitch for off-roading enthusiasts. There are screens that monitor fuel consumption as the vehicle is being driven, allowing drivers to improve their MPG as they drive. One of the most impressive features is DashCommand's ability to create customizable gauges in groups called dashboards. Broad categories include gauges for vehicle performance, fuel economy, and engine data.



If you're a gas mileage addict, Torque has your fix. These calculated values show instant mpg, average mpg, a bar graph showing mpg over time, fuel remaining in the tank, fuel range in miles, and fuel flow into the engine in gallons per hour.



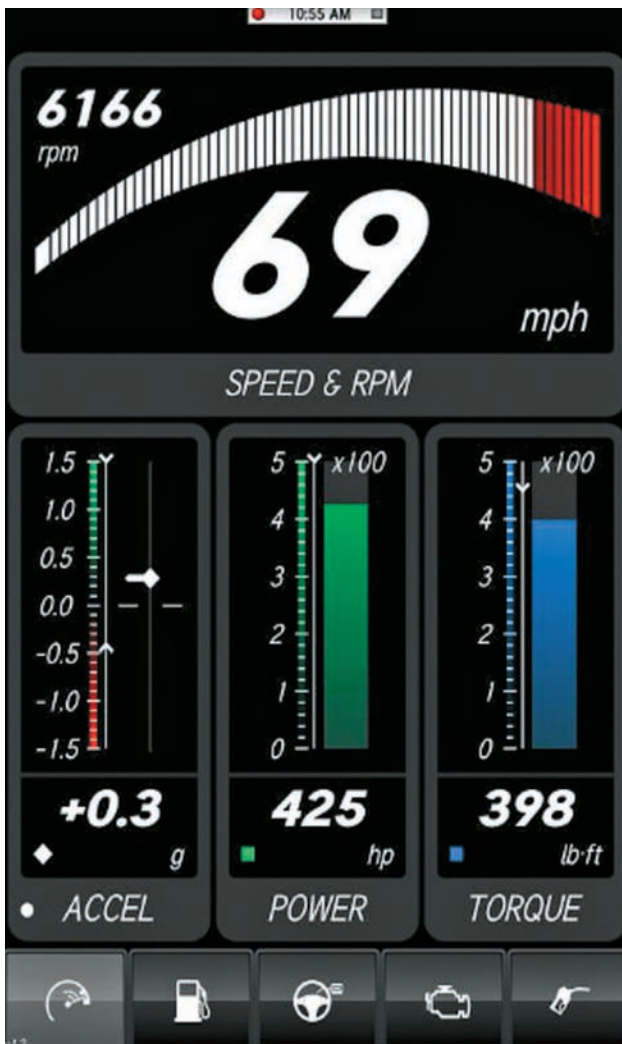
We hope this 2001 Ford Mustang is being driven on the track, as the indicated speed is over 120 mph. Time to distance (1/4, 1/2 mile, etc.) can also be displayed with a swipe of the screen.



One of many custom dashboards that can be created in DashCommand. Ignition timing, coolant temperature, intake manifold pressure, intake air temperature, and mass airflow in pounds per minute are just some of the possibilities.



Another DashCommand dashboard. This one shows calculated horsepower in the lower right corner.



Vehicle performance is quite impressive on this DashCommand screen. With the pedal-to-the-metal, calculated horsepower is 425, with engine torque at 398 ft-lbs. The vehicle's weight and the smartphones acceleration sensor and GPS locator figure into the engine performance numbers.



This DashCommand screen shows racetrack activity. The colored line indicates relative speed of the vehicle at various points on the track. This feature relies solely on the smartphone sensors; no OBD-II data is required to create this information.

Chapter 6

Automotive Detective Work



The same mechanical problems this vintage in-line six-cylinder engine on this old Ford was subject to (when it used to run), still occur in late model cars and trucks. Both early and late model engines use pistons, rings, valves, a head gasket, and intake and exhaust manifolds that all wear out or leak as miles rack up. The tried-and-true techniques that have worked for years to diagnose common engine mechanical problems still work today. Furthermore, when these techniques are applied to an engine on a late model vehicle, they can save lots of time that would otherwise be wasted chasing false OBD-II diagnostic trouble codes that are triggered by engine mechanical problems. *Courtesy Elwood's Auto Exchange*

While this book focuses on on-board computer systems (OBD-I and II), code readers, and scan tools, it's important to remember that what powers the majority of automobiles and light trucks driven today are four-stroke, gasoline-powered engines (apologies to owners with diesel-powered vehicles). While OBD-II on-board computer systems provide a wealth of information about emissions-related components that are operating

to reduce exhaust emissions, the same cannot be said for mechanical engine problems. A PCM cannot always set trouble codes for these. Although OBD-II diagnostic monitors all relate in some way (and perform in response) to what's coming out of an engine's exhaust, it is a simple limitation that, despite all their sophistication, these systems still rely on engines that can optimally burn air and fuel mixtures properly. Surprisingly, even if

something serious is out of whack with basic mechanical engine operation, a PCM still may not be able to figure out the problem in order to set appropriate DTCs.

Most professional technicians know that many drivability problems and numerous DTCs often do not actually reflect high-tech malfunctions (as a DTC might indicate), but rather, are something more basic or stupid. The issue may be of a mechanical nature, or the on-board computer system simply may not be able to detect or set a proper (or any) trouble code for. For example, when an engine misfires, a #P0300 multiple misfire diagnostic trouble code, or even a DTC indicating a specific cylinder misfire, could be triggered; however, the misfire might simply be caused by an mechanical engine problem rather than an electronic malfunction in an OBD-II system component. In such a case, a PCM is simply not programmed to, and therefore cannot, differentiate the cause, source, or nature of the problem. A technician could spend hours with a scan tool or code reader trying to figure out an electronically related reason why numerous DTCs have been set. After all that frustrating work on perfectly functioning electronic components, the technician might discover that an easy-to-fix mechanical vacuum leak was the source of the problem, or worse, a mechanical problem with the engine exists, like not-so-easy-to-repair bent valves or a leaking head gasket.

Consequently, potential problems with the more basic mechanical portions of an engine need to be separated out from computer-controlled engine management system components, or OBD II-related electronic system components. Then they can be investigated for proper operation, preferably before commencing a lengthy investigation into DTC-triggered potential malfunctions within specifically identified (or probable) electronic components. So with that caveat in mind, let's take a look at basic automobile engine operation and some simple tests that can be performed to quickly determine if an engine is mechanically sound. So, put on your thinking cap, and get ready to do a little automotive detective work.

Whether an engine has 4, 6, 8, or even 10 or 12 cylinders, the manner in which an engine creates power has not changed since the invention of the four-stroke-cycle engine in 1876. Nikolaus Otto, Gottlieb Daimler, and Wilhelm Maybach, all from Germany, were the first persons to discover and design a four-stroke method of burning gasoline in a piston-powered internal combustion engine. In 1886, Daimler went on to invent the world's first four-wheel vehicle to use an



Despite the presence of an OBD-II diagnostic system, all the high-tech electronics associated with this not-so-glamorous 1996 General Motors 3100 V-6 engine are, for the most part, unable to determine if the engine is in good mechanical condition. If the basic engine has serious problems, emissions can reach levels that will cause a PCM to set DTCs. Vacuum leaks, low compression, coolant leaks, and worn-out parts can all lead even experienced technicians down the wrong diagnostic path in pursuit of false trouble codes. Performing basic diagnostic engine testing helps separate OBD-II system problems and emissions-related electronic problems from more basic mechanical engine failures.

internal combustion engine. This vehicle was dubbed the automobile. In fact, the word automobile is derived from Nikolaus Otto's last name; the way in which this earliest four-stroke internal combustion engine operated was often called an auto (Otto) cycle.

FOUR-STROKE CYCLE

Understanding how an engine's four-stroke cycle works is a good starting point for understanding what to look for in an engine that's running as it's supposed to. Engine testing is relatively straightforward, and can be accomplished with simple tools like vacuum gauges or compression testers. However, vacuum gauge readings and compression testing are somewhat meaningless, unless one understands what's taking place inside a running engine. Understanding how a four-stroke cycle operates will help make sense of the mechanical tests that will be covered later in this chapter.

All four-stroke engines are in reality air pumps. The four-stroke cycle is the mechanical means used to pump air in and out of the engine. A four-stroke cycle is best conceptualized by using an example of a single-cylinder engine, like those found in small motorcycles

or lawnmowers. During a four-stroke cycle, a piston (connected to the crankshaft via a connecting rod) moves up and down inside a cylinder as the engine's crankshaft rotates. Each of these piston movements is considered a stroke—whether in an up or down direction. A four-stroke cycle begins with the piston at the top of the cylinder. There are two valves, an intake valve and an exhaust valve, which are operated by the engine's camshaft. The camshaft rotates at one-half the speed of the crankshaft. The intake valve starts to open to allow fresh air and fuel to be drawn into the cylinder at the same moment the piston starts moving downward. This phenomenon is known as the *intake stroke*. (See Figure 6-1). The camshaft then times the sequencing of the alternating opening and closing of the intake and exhaust valves to allow the four-stroke cycle to operate. This is known as *camshaft timing*, and it simply means that the valves will open and close in the correct timing in relationship to the movement of the piston and crankshaft. A spark plug then ignites the air and fuel mixture at exactly the correct moment during the four-stroke cycle to burn the air and fuel inside the combustion chamber.

Intake Stroke

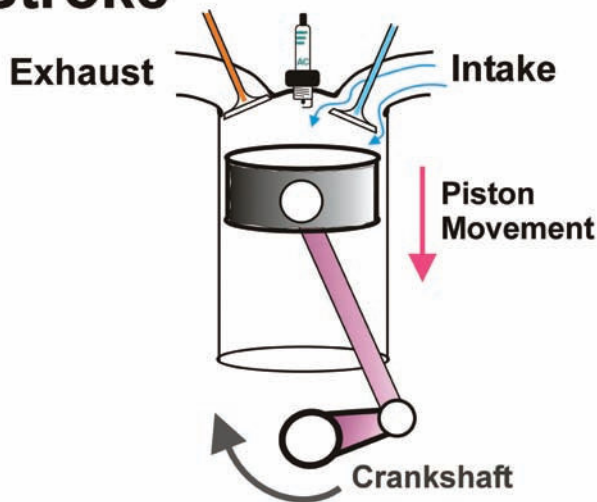


Fig. 6-1—The first stroke of a four-stroke auto ("Otto") cycle is the intake stroke. As the piston moves downward inside the cylinder, the intake valve is opened and air mixed with fuel is pushed into the cylinder by atmospheric pressure because a low pressure area was created by the rapidly moving piston. The intake stroke fills the cylinder with air and fuel, which will later be burned.

Once the piston is at the bottom of the intake stroke, the intake valve starts to close. The piston then starts to move upward and the intake valve closes completely. This is the beginning of the *compression stroke*, the second of the four strokes. The compression stroke squeezes or compresses the air/fuel mixture in order to make it more volatile so it can be more easily ignited by a spark plug. The amount that the air/fuel mixture is compressed is referred to as an engine's compression ratio. Compression ratios are expressed as a ratio representing the number of times the air/fuel mixture is compressed from its original volume. For example, if the compression ratio for a particular engine is 11:1, the mixture of air and fuel has been compressed 11 times its original volume by the time the piston reaches the top of the compression stroke. (See Figure 6-2.)

In the moment before the piston reaches the top of an engine's compression stroke, the ignition system sends a high-voltage spark to the spark plug, causing it to fire and ignite the air/fuel mixture. This sequence is the

Compression Stroke

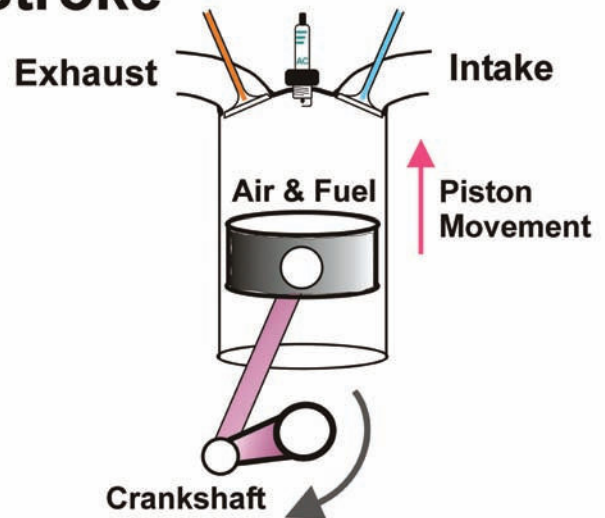


Fig. 6-2—A *compression stroke* follows directly after completion of the intake stroke in a four-stroke internal combustion engine. As the piston begins traveling upwards in the cylinder, both the intake and the exhaust valves are closed during the compression stroke. The piston compresses the air/fuel mixture as it pushes it upwards. Compressing the air and fuel mixture makes it more volatile or easier to burn. An air and fuel mixture will not simply ignite from just a spark from a spark plug if the air and fuel mixture is not compressed first. In a 10:1 compression ratio engine, the air/fuel mixture is compressed to nearly 10 times smaller than the volume of the cylinder.

Power Stroke

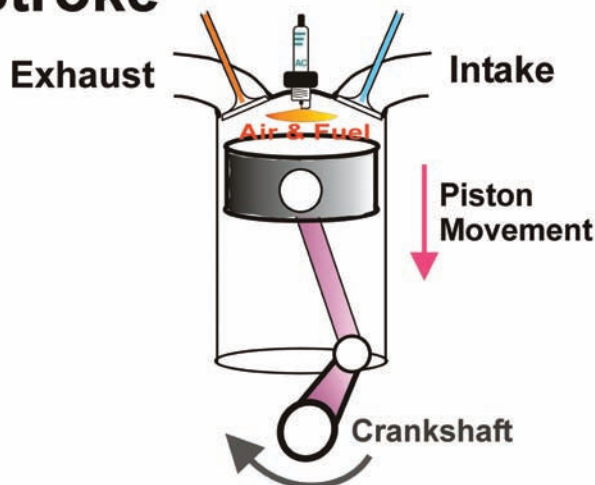


Fig. 6-3—The *power stroke* is the third in the sequence of piston strokes in a four-stroke cycle. Immediately before the piston reaches the top of its power stroke, the ignition system sends a high voltage spark to the spark plug. When the spark jumps the spark plug's air-gap, the combustion process is ignited or started. Heat from the burning air/fuel mixture then causes a sharp increase in cylinder pressure, which in turn places several tons of pressure on the top of the piston. The power stroke of a four-stroke cycle is the only stroke that produces work or power (or energy or heat, however you want to conceptualize it). The other three strokes, while essential to the auto cycle process, simply use up energy instead of producing it.

start of the *power stroke*, the third stroke in a four-stroke cycle. (See Figure 6-3.) The air and fuel mixture does not explode, but rather, burns at an even, controlled rate. The combustion of burning gases causes a rapid increase in heat to over 5,000° F inside the combustion chamber. This, in turn, causes the pressure inside the cylinder to build to several tons per square inch, all of which pushes down on the top of the piston. Since the piston is connected to the crankshaft via a connecting rod, the crankshaft rotates as a result of the piston moving up and down inside the cylinder. This action results in power, or torque, getting transmitted to the engine's flywheel. The flywheel is connected to whatever the engine was designed to power—a car's transmission, motorcycle, lawnmower, etc.

As the piston reaches the bottom of its *power stroke*, the exhaust valve starts to open, allowing the burned gases to escape from the cylinder. As the piston moves upward on the *exhaust stroke*, the exhaust valve opens all the way and the cylinder is cleared of exhaust gases,

Exhaust Stroke

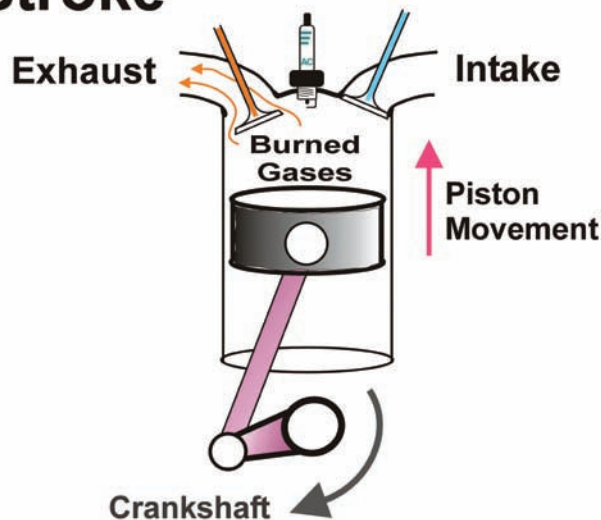


Fig. 6-4—The *exhaust stroke* is the last stroke that occurs in a four-stroke internal combustion engine. Once a piston reaches the bottom of the third or power stroke, the exhaust valve opens and the piston starts to move upward. The upward movement of the piston pushes the exhaust gases out of the cylinder. Just before the piston reaches the top of the exhaust stroke, the intake valve starts to open and the piston reverses its upward direction of travel so that it is now traveling downward, and the four-stroke cycle starts all over again with the intake stroke.

which is the conclusion of a four-stroke cycle in an internal combustion engine. (See Figure 6-4.) Then, just before the piston reaches the top of the exhaust stroke, the intake valve starts to open and the four-stroke cycle starts to repeat all over again. The four piston strokes of a four-stroke "Otto" cycle—*intake*, *compression*, *power*, and *exhaust*—are frequently known in automotive jargon by the much more colorful descriptive terminology of suck, squeeze, bang, and blow.

A four-stroke cycle takes two complete engine revolutions to complete—the *intake* and *compression* strokes comprise one full engine revolution, while the *power* and *exhaust* strokes complete another revolution. However, a four-stroke cycle occurs many times per second when an engine is running at high engine speeds. In fact, a single-cylinder engine turning 5,000 revolutions every minute (this phenomenon is called engine rpm) will complete a full four-stroke cycle 41.6 times every single second. Engines with multiple cylinders work in the same manner. Since all of the cylinders are connected

to a common crankshaft, each of the cylinders repeat the same four-stroke cycle every two engine revolutions—regardless of the number of cylinders an engine has, whether 4, 6, 8, 10, 12, or more.

ENGINE VACUUM

To visualize a four-stroke cycle occurring in a running engine, the process can be revealed with some simple, inexpensive tools. One of the most basic is a vacuum gauge, a tool that been around as long as the internal combustion engine. These tools are available at most auto parts stores for less than \$20. A quick test with a vacuum gauge will provide enough information about overall engine condition, and how that condition may relate to any OBD-II trouble codes that may be present within the PCM's memory. It's a good idea for anyone who has never used a vacuum gauge before to practice the test procedures outlined in this chapter before spending

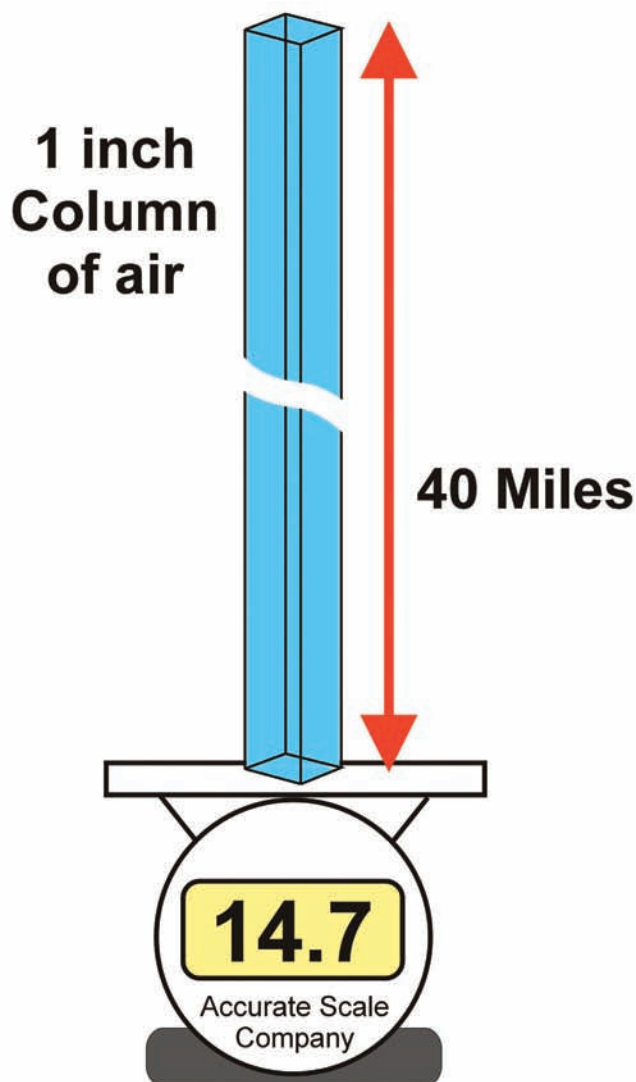
any length of time trying to determine what's wrong with a "problem" engine. All automotive technicians, whether professional or home mechanics, must be able to identify and understand what the test results will be for an engine with no mechanical problems, before beginning testing on an engine with something amiss. Consequently, being able to interpret vacuum gauge readings requires a fundamental understanding of how engines create vacuum. Thus, engine vacuum is an important concept to master, before tackling any significant testing on a malfunctioning engine.

Contrary to popular belief, the mixture of air and fuel that is consumed in the combustion process is not sucked into an engine, but rather, is instead *pushed* by atmospheric pressure. Here's an illustration of how this process works: Suppose a person is standing on a beach looking out at the ocean. That person has about 40 miles of atmosphere above him/her. The weight of the atmosphere pushing down on the earth creates atmospheric pressure, which is measured in pounds per square inch. Atmospheric pressure at sea level is 14.7 pounds per square inch pushing in all directions.

During an engine cylinder's *intake* stroke, the intake valve opens as the piston is moving down the cylinder. The movement of the piston increases the cylinder's volume faster than the opening of the intake valve allows atmospheric pressure to fill the cylinder; this process creates a vacuum (negative air pressure) inside the cylinder during the intake stroke. A vacuum is created whenever pressure inside the cylinder is lower than the surrounding atmospheric pressure. Air is pushed into the cylinder because relatively high atmospheric pressure flows into the lower negative air pressure inside the cylinder. How much the cylinder fills with atmospheric pressure is called volumetric efficiency, and on most engines it's around 85 percent of total cylinder filling, or more. Volumetric efficiency, or VE, almost never reaches 100 percent, because the intake valve restricts the amount of air that can fill the cylinder. Engines equipped with turbochargers overcome this limitation on cylinder filling, and are able to achieve greater volumetric efficiency because the turbocharger's air compressor pressurizes incoming intake air above atmospheric pressure, so the cylinder can fill to more than 100 percent of its volume. Depending upon the boost settings of a particular turbocharger, volumetric efficiency can actually top upwards of 120 percent. Engines with two intake valves (as compared to one intake valve) and tuned intake runners can also fill an engine's



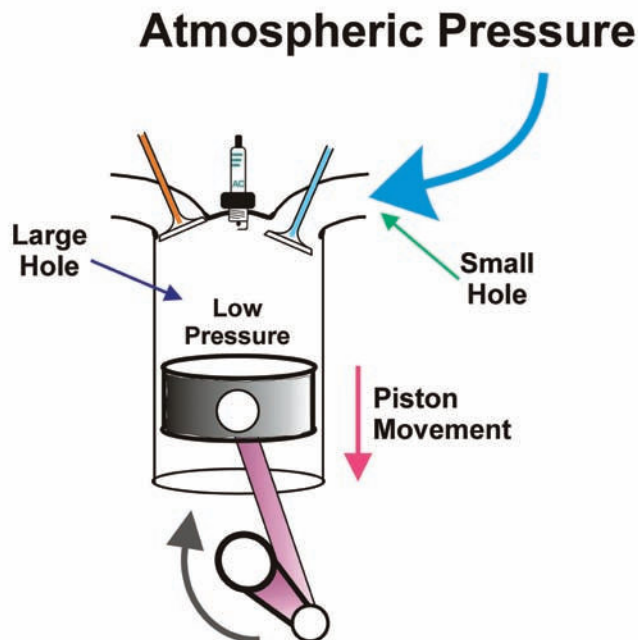
This is a compound vacuum/pressure gauge. The numbers on the inside scale (red and green ranges) represent inches of mercury, abbreviated as In.Hg. This scale is used for taking vacuum readings, and ranges from 0 to 30 inches. The numbers on the outside of the gauge (white numbers) form a scale representing centimeters of mercury, abbreviated as Cm.Hg. Notice that the white 0 range (where the needle is pointing) is large because 0 may vary slightly depending on the altitude the gauge is being used at, due to differences in barometric pressure. Numbered scales at the top of the gauge are for testing fuel pump pressure on carbureted vehicles.



Imagine a column of air, 1 inch square and 40 miles high. If a scale could be used to weigh the air in the column, it would weigh 14.7 pounds at sea level—the weight of the air at sea level is also known as barometric pressure. Since pressure from the weight of the atmosphere (air) pushes in all directions, barometric pressure is 14.7 lbs per square inch at sea level. If the scale were relocated to 10,000 feet above sea level, atmospheric pressure would drop because there is less air present above the scale since air is less dense at higher altitudes; thus, barometric pressure is lower. It's often confusing, and merely a coincident, that barometric pressure of 14.7 lbs per square inch is a similar number to the ideal air/fuel ratio of 14.7:1 (14.7 parts of air to one part of fuel).

cylinders close to 100 percent, since they also allow more air to flow into the cylinder at higher engine rpm.

Since air has to travel through a common intake manifold to get to the cylinders on a multi-cylinder engine, a constant vacuum is created inside the intake manifold. Thus, a vacuum gauge can be connected to the



One of the laws of physics states that an area of high pressure will always seek out an area of low pressure and flow into it. In the cylinder seen here, the piston is moving rapidly downward, thereby increasing the volume, or air space, of the cylinder above the piston. As a result of the relative size of the cylinder's volume compared with the diameter of the intake valve's opening, the incoming air cannot fill the cylinder with air fast enough to fill it completely, so a low pressure area is created inside the cylinder. The higher pressure of the outside atmospheric air is literally pushed down into the intake manifold, past the intake valve opening, and into the cylinder, with the atmospheric pressure basically trying to fill up the cylinder.

intake manifold in order to measure the pressure of the engine vacuum and to otherwise perform vacuum testing. Because vacuum readings are directly related to how well an engine seals against atmospheric pressure, taking vacuum readings at different engine operating conditions will provide an overall picture of engine mechanical health. This saves needless hours of scan tool/OBD-II testing on various trouble codes, only to subsequently discover the engine has a leaky intake manifold, bent valve(s), or is simply worn out from lack of maintenance, abuse, or high mileage.

ENGINE IDLE VACUUM TESTING

In order to perform vacuum testing with the engine at idle speeds, a vacuum gauge should always be connected directly to the intake manifold, or tapped into a vacuum line with a "T" fitting. Avoid vacuum lines that connect to canister or exhaust gas recirculation (EGR) valves, as they may carry vacuum signals lower than those produced by

engine vacuum. If that happens, vacuum test results may be misleading. For the same reasons, try to avoid vacuum lines that contain vacuum control valves or restrictors.

With the engine's speed maintained at idle and at normal operating temperature, a vacuum gauge needle should, more or less, register steady (depending on the number of cylinders the engine has). Vacuum readings on some four-cylinder engines may show a slightly pulsing needle due to camshaft timing that causes the intake strokes of individual cylinders to pulse the vacuum gauge needle. These types of vacuum readings can take place on engines with high-performance camshafts, even those with six or eight cylinders.

Vacuum gauge readings that are between 15 and 21 inches of mercury (In.Hg.) with a steady needle are in the normal range, and indicate an engine that is sealing properly. However, the needle may pulse slightly, especially if a four-cylinder engine is being tested. But this is normal, since the variable oscillation of the needle, or pulses, produced by testing on a four-cylinder engine represent the actions of a piston inside an individual cylinder during its *intake* stroke. The more cylinders present on an engine, the less the needle will pulse at idle because there are more intake strokes per engine

revolution. For this reason, normal needle movement for a V-8 is almost non-existent; while six-cylinder engines may produce very slight pulsing. A steady vacuum gauge needle confirms that all of the engine's cylinders are sucking in the same amount of air. The pressure drop for each cylinder within the intake manifold will be the same (thus, causing a steady needle gauge reading). A steady needle gauge reading confirms all of the cylinders are doing what they're supposed to do, i.e., all are sealing properly; and that all of the valves, piston rings, and head gasket(s) are not leaking. (See Figure 6-7.)

If a vacuum gauge needle is not steady, but rather, is wildly bouncing back and forth, this needle action suggests a serious problem probably exists within an engine. A pulsing needle could mean that one or more cylinder(s) is not contributing to the overall level intake manifold vacuum to the same extent as all the other cylinders, and is therefore, not doing its job properly or completely. In such an instance, further vacuum testing is required. If engine idle vacuum is steady, but lower than what would typically be expected for a normal range of 15 to 21 In.Hg., there could be several causes for this phenomenon. The most common and likely source of such a reading is an intake manifold vacuum leak. The presence of a vacuum leak in

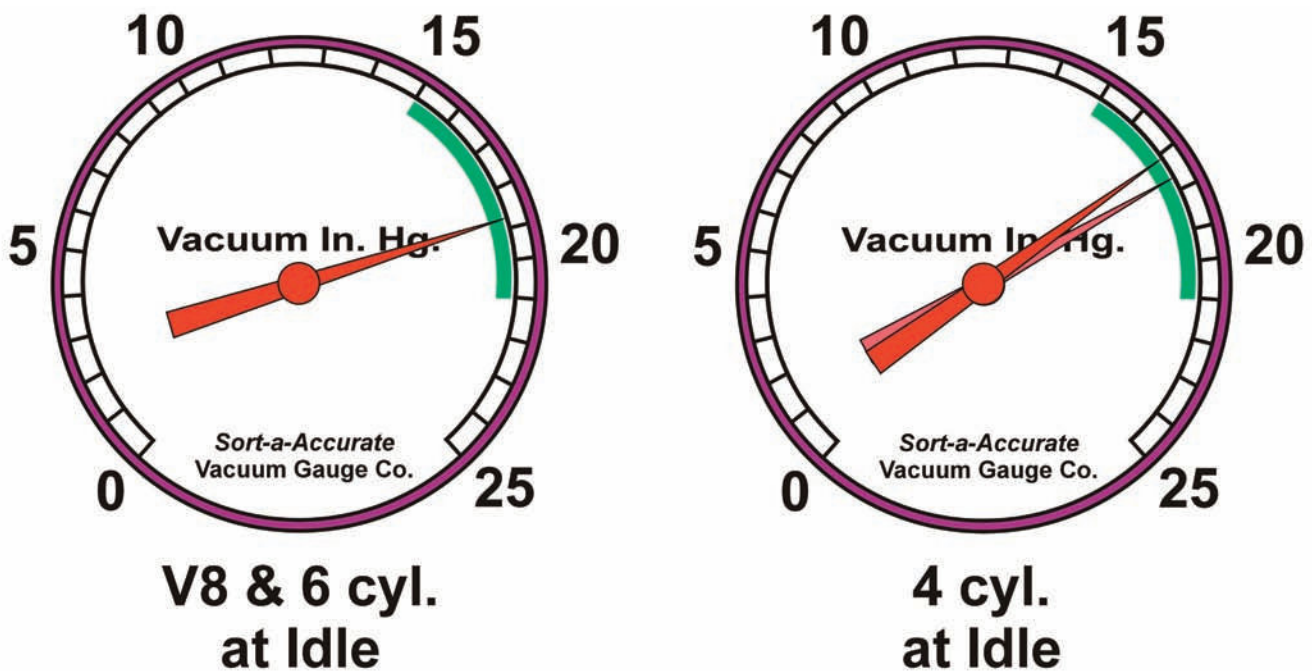


Fig. 6-7—An engine idle vacuum test confirms whether an engine is in good mechanical condition, or free from any vacuum leaks. At idle, an engine in good condition and with no vacuum leaks should produce a gauge reading on a scale of between 15 and 21 In.Hg. (inches of mercury) of vacuum. When connected to a V-8, V-6, or inline-6 cylinder engine, the needle on a gauge should hold steady. On certain four-cylinder engines, the needle may pulse slightly, which merely represents the actions of individual cylinders on their *intake* strokes.

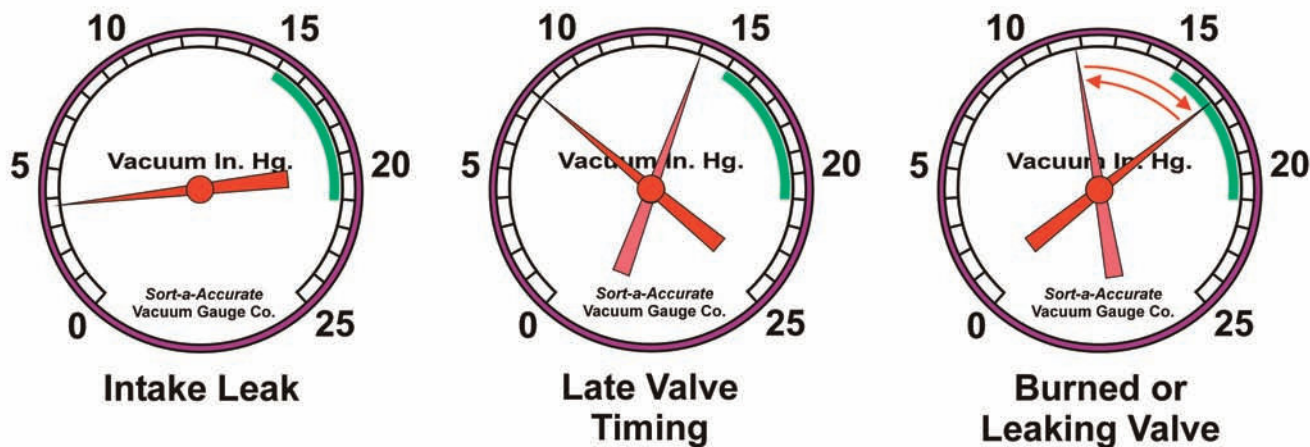


Fig. 6-8—All vacuum gauges show various engine conditions at idle. The vacuum gauge shown at the far left has a steady needle but a low reading, indicating that an intake manifold gasket or vacuum fitting is leaking, and thereby causing a lowering of engine vacuum. The needle on the center gauge is floating between 8 and 14 in.Hg. (inches mercury), and establishes what engine vacuum looks like on an engine with late valve timing caused by a slipped timing belt. The vacuum gauge on the far right of the figure reveals a steadily dropping, or pulsing, needle, thus confirming a burned or leaking valve, or head gasket problem.

an intake manifold could be a result of a poorly sealing gasket or could simply be a vacuum hose with a crack in it or one that has come loose. A vacuum leak would cause the pressure inside an intake manifold to rise closer to atmospheric pressure, thus lowering the vacuum gauge reading (remember the vacuum gauge will read “0” In.Hg. with no vacuum present).

Another cause of low vacuum readings is retarded ignition timing. However, retarded ignition timing is not usually a problem on OBD-II- equipped vehicles, since ignition timing is not adjustable (though on older vehicles with ignition distributors, this is a possibility that should be checked out). However, retarded camshaft, or valve timing, can be a problem on OBD-II vehicles and is typically caused by a timing belt that is worn out, causing it to jump a tooth or several teeth (and resulting in low vacuum readings). If a timing belt has slipped a tooth, or suffers from age and wear, the valves would be out of sync with an engine’s four-stroke cycle, which would invariably cause a low vacuum reading. On some engines, whenever a timing belt slips a tooth, the valves can come into contact with the tops of the pistons, resulting in bent valves that will fail to seal properly when closed. If this happens, and either the intake or the exhaust valve(s) do not seal properly, their respective cylinders will not be able to create the same vacuum pressure level as the other, unaffected cylinders produce. As a result, the unmatched or disproportionate pressure levels in all of the cylinders will cause the vacuum gauge needle to swing wildly back and forth at idle speeds. (See Figure 6-8.)

ENGINE VACUUM AT 2,500 RPM TESTING

Performing vacuum testing while holding the engine steady at 2,500 rpm can reveal several different types of engine problems. Engine vacuum readings at 2,500 rpm should be steady, regardless of the number of cylinders on an engine, provided there is nothing wrong with the engine. If the needle on a vacuum gauge bounces or pulses, then one or more cylinder(s) on the engine are not closing completely or sealing properly, which could be attributable to sticky, burned, or bent intake and/or exhaust valves, or a blown head gasket.

To test for worn piston rings or cylinders, or to simply examine overall engine condition, hold engine speed at a steady 2,500 rpm for 15 seconds while a vacuum test gauge is attached to the engine’s intake manifold. After 15 seconds, snap the throttle all the way open and then close it (simply letting go of the throttle will close it). When the throttle is held at 2,500 rpm, the test gauge needle should be steady; however, once the throttle is snapped open, the test gauge needle should instantly drop to 2 inches mercury or possibly even 0 In.Hg. After the throttle is let go, the test gauge needle should return to a high vacuum reading of around 25 inches Hg. It will then gradually taper off to the normal idle vacuum range of about 20 In.Hg. Typical needle readings such as these indicate a mechanically sound engine. However, if snapping open the throttle does not lower the vacuum reading to 2 In.Hg. or less, a restricted intake somewhere (usually a plugged air filter) is indicated. Conversely, if letting go of the open throttle doesn’t increase engine

vacuum by a range of at least two inches Hg above the reading obtained when engine speed was held steady at 2500 rpm, then worn-out piston rings or cylinders are most likely a problem. (See Figure 6-9.)

A good test for a plugged exhaust caused by either a vehicle being driven over a curb and denting the exhaust, or by a plugged-up catalytic converter, can be accomplished by holding engine speed steady at 2,500 rpm for 15 seconds, and then checking the vacuum gauge needle to see if it slowly drops (the vacuum gauge is connected to the intake manifold). A plugged catalytic converter will cause excessive exhaust backpressure to build up. If excessive exhaust backpressure exists, the vacuum gauge needle will slowly drop to a level of 5 In.Hg. or less. A plugged catalytic converter is the most common reason for this type of low vacuum reading at steady rpm of 2,500. (See Figure 6-9.)

A common misconception about ignition misfires is that they will cause a vacuum gauge's test needle to bounce wildly. This phenomenon is simply not true, since a vacuum gauge only measures an engine's ability to properly go through the four-stroke cycle and act as

an air pump as stated earlier. Consequently, if a cylinder has an ignition malfunction that results in an ignition misfire, the engine is still pumping air and fuel in and out of its cylinders, but it is no longer burning the air/fuel mixture in the specific misfiring cylinder. As long as the misfiring cylinder is still sealing during the four-stroke cycle, the presence of a misfiring cylinder will not greatly affect vacuum gauge needle movement. In fact, the only reason a vacuum gauge needle moves at all when there is a cylinder misfire would be as a result of an engine slowing down every time the specific misfiring cylinder fails to properly complete its *power* stroke.

CRANKING ENGINE VACUUM TESTING

A cranking engine vacuum test is a good method or indicator for determining the reason an engine won't start when both spark and fuel are present (testing for a no-spark condition or a no-fuel situation are covered later in this same chapter). The presence of either an excessively plugged-up catalytic converter or a slipped timing belt will not allow the engine to start. Timing belts on most vehicles are considered maintenance items that need to

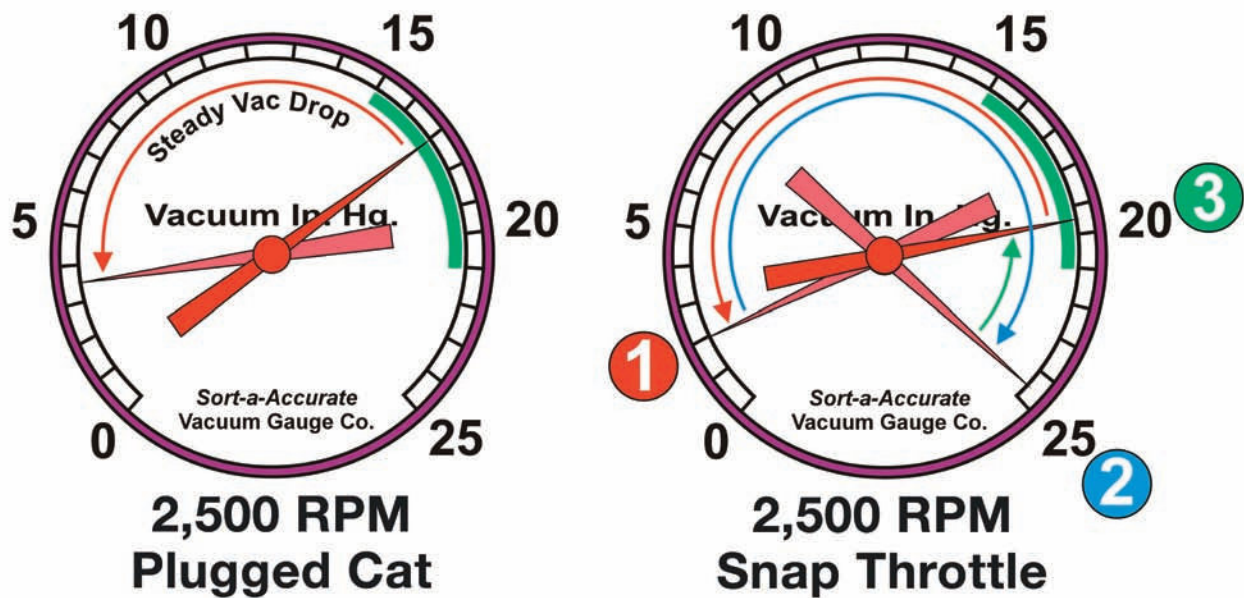


Fig. 6-9—The vacuum gauge on the left shows the levels of engine vacuum that are created by a plugged catalytic converter or other exhaust restriction. If engine speed is held steady at 2,500 rpm, but the vacuum needle slowly drops, a plugged catalytic converter or other exhaust restriction is definitely indicated as a problem. This happens because the exhaust restriction prevents exhaust gases from exiting the cylinder and raises cylinder pressure higher than normal, thus creating a high pressure, or low vacuum reading. The vacuum gauge on the right shows a healthy engine when the throttle is snapped open suddenly. On a healthy engine, when engine speed is held steady at 2,500 rpm, the needle is close to 20 in.Hg. (inches mercury), but when the throttle is snapped open suddenly, the needle drops from 20 inches mercury to 2 in.Hg. (position #1 on the right hand gauge). As soon as the throttle is closed with a tug on the throttle return spring, the needle quickly rises to 25 in.Hg. (position #2 in blue) The reading finally returns to the normal range of idle vacuum at about 20 inches mercury (position #3 in green).

be changed at recommended intervals (usually around 60,000 miles). Fortunately, on many newer vehicles, the timing belts are wider and last longer; maintenance intervals for belt replacement on some of these newer vehicles can be as much as 60,000 to 120,000 miles. However, as timing belts wear out, the teeth on the belt become rounded and can jump, or skip the corresponding teeth on the crankshaft or camshaft pulleys. This causes the camshaft's timing of the intake and exhaust valves to be "late" or retarded. Once the valve train is out of sync with the crankshaft, a four-stroke cycle can no longer occur properly, or at all, and this will affect the engine to the point where it will not start. While this may seem obvious, incorrect valve timing due to a slipped timing belt is the cause of many unnecessary replacements of parts, including batteries, starter motors, computers, spark plugs, fuel injectors, ignition modules, and other expensive components. The problems of slipped timing belts and plugged catalytic converters will both show up as no, or very low, vacuum readings during a cranking vacuum test. (See Figure 6-10.)

To perform a cranking vacuum test, make sure the vacuum test gauge is connected to an intake manifold vacuum source and that the throttle is closed. Then crank the engine over while watching the gauge. The test needle should pulse within a range of between 2 to 5 inches mercury (In.Hg.). Some engines may yield higher readings because of their specific valve timing and camshaft profiles. However, if engine cranking speed is normal (usually around 200 rpm) or higher, but the vacuum test reading is low or zero, this is an indication that the timing belt may have slipped. Performing a cranking vacuum test can be a bit tricky since other factors besides a slipped timing belt or plugged catalytic converter can also cause the absence of any cranking vacuum readings during the test. Keep in mind, a large leak in an intake manifold could also cause a zero cranking vacuum test reading; an initial visual inspection of vacuum hoses and the intake manifold before commencing the test is a good idea to eliminate this possibility right up front. The cranking vacuum test, and all vacuum testing, should be practiced on an engine that does not have a problem. To practice the cranking vacuum test the ignition of fuel system will have to be disabled to prevent the engine from starting during the test.

FINDING A VACUUM LEAK

As previously discussed, a steady, but low, vacuum gauge reading can be an indication of a vacuum leak. Leaks

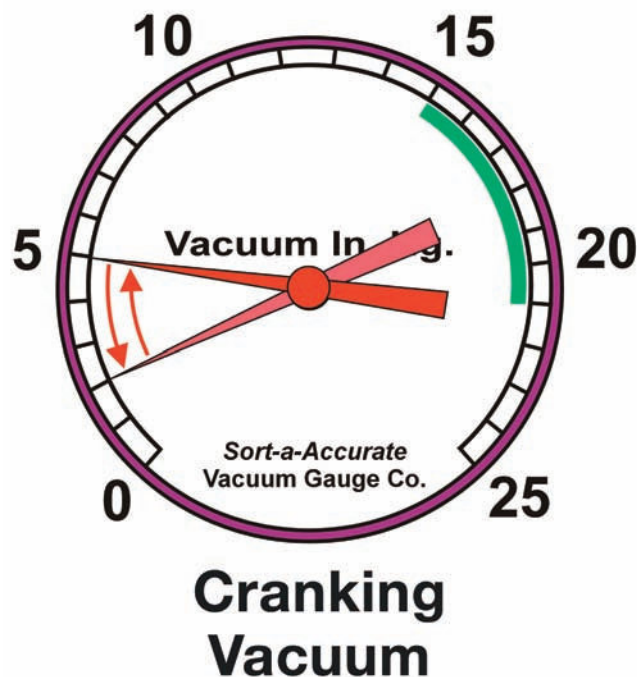
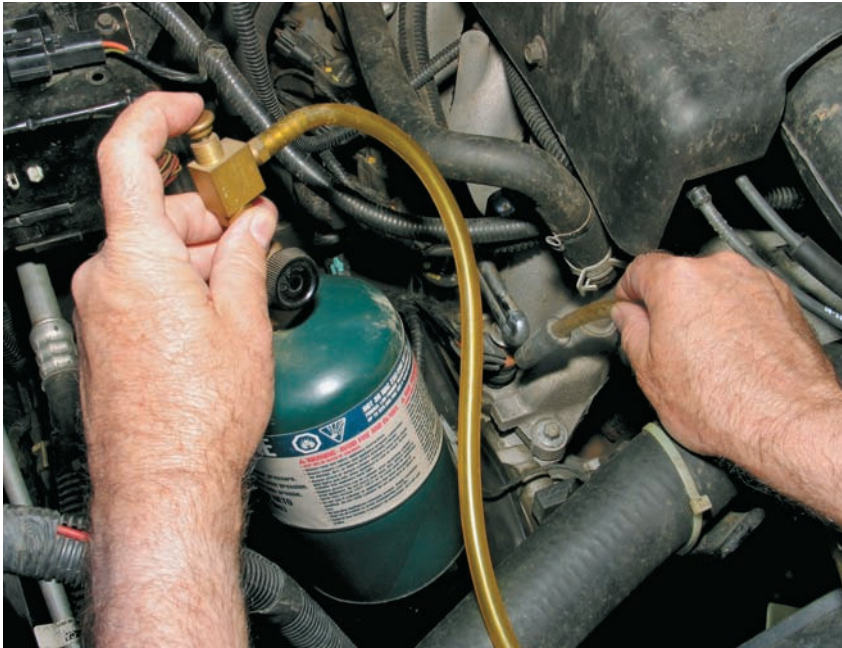


Fig. 6-10—Before performing a cranking vacuum test, the ignition system and/or fuel system must first be disabled. This will prevent the engine from starting and provide enough time to observe cranking vacuum readings. During testing, a healthy engine should display a steadily pulsing needle on the vacuum gauge that is within a range of 2 to 5 In.Hg. of vacuum. Since engine cranking speed is quite slow (only around 200 rpm), individual cylinder intake strokes can be seen on the gauge each time the vacuum gauge needle pulses. If a needle pulses are uneven, it most likely means one or more cylinders is failing to produce as much vacuum as the other properly functioning cylinders. A mechanical sealing problem is the most common cause of variance between cylinders and associated variable test readings.

can be caused by disconnected or cracked vacuum hoses, a loose vacuum fitting, or a gasket leak on an intake manifold's sealing surfaces. In view of the fact that there are hundreds of vacuum hoses under the hoods of most vehicles, and since an intake manifold may not always be easy to get to, finding a vacuum leak by visual means alone can often prove problematic at best, and impossible at worst. Following are two simple methods that can help technicians locate engine vacuum leaks.

The first method involves taking a two-foot section of $\frac{3}{8}$ -inch hose and using it as a low-tech type of stethoscope to listen for a vacuum leak. With the engine running and one end of the hose placed in one ear, the other end of the hose can be moved around various vacuum hoses and fittings, as well as the intake manifold, to listen for any possible vacuum leaks. A leak will sound like a hiss, and it will get louder as the end of the hose gets closer to the source or location of the leak.



With the engine running, a press on the button on this propane bottle will send a shot of flammable gas down the hose leading to the engine's intake manifold. If a vacuum leak is present (even a tiny leak), engine speed will momentarily change. Another method for detecting vacuum leaks via the use of propane is to monitor oxygen sensor voltage on a scan tool to watch for rapid voltage increases once the vacuum leak sucks up the propane. Caution! This test is potentially dangerous and should only be conducted with common sense. For example, if you can hear a spark plug wire arcing to ground, yet you still blast the area with propane, be forewarned that a fireball may ensue.

A more accurate method for finding vacuum leaks involves the use of propane gas. Take a propane bottle and connect a small section of hose to it. Then, with the engine running, crack open the valve on the propane bottle while directing the free end of the hose all over and around the vacuum hoses and fittings, as well as the intake manifold. Any vacuum leaks present will draw in the propane gas and cause a momentary change in engine rpm. An even better method would be to perform the same test but also use a scan tool connected to the vehicle. Then watch the front "upstream" O₂ sensor's output voltage for an instant voltage changes of up to 0.9 volts or higher. When the propane is sucked into the vacuum leak, the oxygen in the exhaust gas is reduced, causing the high O₂ sensor voltage reading. Remember that there is a time lag between when the O₂ sensors picks up the additional fuel and when the scanner displays the high voltage reading.

Caution: Remember that propane is a highly flammable gas that can cause severe burns and become explosive if used near heat in a non-ventilated space. Consequently, always use caution when performing tests that involve the use of propane. In addition, always use common sense when handling propane. For example, if you can hear a loose or disconnected spark plug wire arching to ground (it makes a snap, snap, snap sound) *do not* use propane to search for any vacuum leaks until the plug wire is repaired. If you disregard this, the result

might be a small fire or explosion, which would result in damage to a vehicle and potentially catastrophic injury to people. Thus, when using any type of fuel, common sense will help keep you safe.

COMPRESSION TESTING

If, during the performance of any engine vacuum test, the vacuum gauge needle starts to bounce wildly back and forth, there is a strong chance that one or more of the cylinders is not sealing or closing completely, or has other mechanical problems. Vacuum testing is not sophisticated enough to indicate which cylinder has the problem or is causing a particular problem, so other additional methods of testing are required. Of course, this assumption begs the question of why does it matter which cylinder is having a sealing problem if the engine has to be rebuilt anyway? While this sentiment is true to some extent, having more knowledge and information about why, and specifically where, the engine is failing to make a complete seal may help to determine whether a complete engine rebuild is necessary or not, or whether a simpler valve job, or even simpler head gasket replacement, might just as well do the trick. Of course, there are always those of us who just have to know which cylinder is failing to seal properly just so we can satisfy our compulsive mechanical tendencies.

Compression testing is a good way of identifying and confirming which cylinder is having a mechanical

problem. Compression testers are relatively inexpensive, and are available at most auto parts stores for around \$40. More expensive compression gauges are naturally more accurate, and also come complete with more adapters and accessories than standard models. Handheld compression testers designed to be held inside a spark plug hole are difficult to use and frequently don't produce consistent results. Compression testers fitted with hoses that screw into a spark plug hole are much easier to use and have better predictability in the accuracy department.

The first step in performing compression testing is to get the engine hot. This allows all of the internal engine



A remote starter switch makes compression testing easier to accomplish because the compression gauge can be viewed at the same time the starter is operating. With that, only one technician is needed to perform the test. The remote starter switch seen here was self-made from a plastic 35mm film container, a heavy-duty switch from Radio Shack, some flexible wire, and two alligator clips. Remote starter switches can also be purchased at auto parts stores and online.



The compression tester in the photo comes complete with two adapter hoses for use with different spark plug thread sizes. The compression gauge pictured has a quick disconnect attachment for the hoses. This gauge is capable of holding pressure readings until after the engine has stopped cranking, making it easier to record them. The Schrader valve shown on the side of the fitting is the exact same valve commonly used to fill tires with air. The purpose of a Schrader valve is to release the pressure built up by engine compression, thus returning the test gauge needle to zero after completion of a compression test.

parts to expand to their normal size, and to seal as well as they possibly can during the test. The next step is to remove all the spark plugs. On some vehicles this can be quite a project, sometimes even taking hours just to gain access to them. The fuel-injection and ignition systems must also be disabled. Usually the PCM fuse(s) or ignition fuse(s) can simply be removed to prevent these systems from operating. It's neither a good idea nor safe practice to have fuel injectors spraying fuel on open spark holes and ignition coils or cables. Doing so could create a high-voltage spark in an enclosed space (possibly leading to a fire or other damage).

Start the test by screwing a compression tester's hose into the first (#1) cylinder's spark plug hole. Next, hold the engine's throttle all the way open. You may want to temporarily block the throttle open because it must remain so during the entire compression test sequence. The open throttle allows the maximum amount of air to enter the engine during testing.

The next step involves how to crank the engine over. You can use a friend inside the vehicle to operate the starter motor via the ignition key, or you can use a remote starter switch. The best way to perform a compression test is to connect a remote starter to a starter solenoid. This way, a sole technician can control the starter motor

while simultaneously watching the test gauge. To start the test, the engine should be cranked over long enough so that the cylinder being tested goes through four complete compression strokes, which can easily be determined by watching the compression gauge needle as it pulses. Each pulse represents one full compression stroke. The numerical scale on most compression gauges represents pounds per square inch (psi). While the test gauge needle is being watched, compression numbers for the first and fourth strokes should be recorded. Repeat the test for all other cylinders. Needless to say, a vehicle's battery should be in good operating condition during compression testing, since it will have to crank the engine over a number of times. If the battery is weak, the last cylinders tested could display a lower range of numbers due to a slower engine cranking speed as the battery loses energy.

So, what exactly are the good and bad ranges of numbers that can be expected from compression testing? Some manufacturers have published cylinder compression numbers in their service manuals, and occasionally will also list minimum compression numbers and permissible variations between cylinders. As a general rule, the lowest compression test readings should still be within 75 percent of the highest reading possible for all the cylinders on the engine. For example, if the highest cylinder compression test reading yields 140 psi, the lowest reading should not be less than 105 psi (or 75 percent of 140 psi). Another general rule to remember is that if compression pressure is below the range of 85 to 100 psi in any one cylinder, that cylinder is worn out and the engine, unfortunately, needs to be rebuilt.

Here are some guidelines for interpreting compression test results:

- If compression increases steadily after all four compression strokes (remember the cylinder should go through four complete four-stroke cycles) of the four-stroke cycle, and is still within manufacturer's recommended specifications, or within 75 percent of the highest reading obtained for any one cylinder (when compared to all cylinder readings), then the cylinder being tested is good.
- If compression is low on the first compression stroke, and then gradually increases during the remaining three compression strokes, but still fails to reach the manufacturer's good or minimum permissible range of compression pressure, the piston rings and/or that specific cylinder being tested is/are probably worn out.
- If compression is low on the first compression stroke, and only increases slightly during all of the remaining compression strokes, the valves may be sticking or burned, or the piston rings may be broken.
- If compression is simultaneously low in two adjacent cylinders, suspect a blown head gasket, as it is likely leaking between both cylinders.
- If a compression test gauge reading ever yields a higher range of numbers than what is recommended in manufacturer's specifications, that cylinder(s) may have excessive carbon deposits in its combustion chamber, which are causing higher than desirable compression readings.



This compression gauge has a range from 0 to 300 pounds per square inch (the outside number scale on the gauge). The inside number scale is in kPa x 100, or kilopascals, for those technicians that are metrically inclined. The quick disconnect fitting at the bottom of the gauge allows various hoses with spark plug thread adapters to attach to the gauge. The Schrader valve on the right side of the gauge's quick disconnect fitting is used to release gauge pressure after the completion of each cylinder's compression test.

If it is determined that compression is low in any cylinder due to an inadequate piston ring sealing problem, a wet compression test can be performed to provide significant information about the condition of the piston rings. To perform a wet compression test, squirt a small amount (about one tablespoon) of engine oil into the specific cylinder being tested and then crank the engine over a few times to let the oil soak in for awhile. Then, repeat the compression test. If the compression number increases by 5 percent (usually about 15 psi), that cylinder probably has worn piston rings. However, if compression doesn't increase at all, the sealing problem is most likely in the cylinder head's valves or the head gasket seal. Bear in mind, a wet compression test won't work on engines with a horizontally opposed design, like those found on Volkswagen "Bugs," Porsches, and some Subaru models. Because cylinders are positioned on their sides in these vehicles, the oil added into the cylinder for a wet compression test won't be able to work its way completely around the piston rings, so they won't seal any better than they would when a dry compression test is performed.

BATTERY AND ELECTRICAL SYSTEM TESTING

Because all OBD-II systems are electrical in nature, it makes sense that the vehicle's battery and charging system should be operating properly before commencing any OBD-II testing. The PCM performs hundreds of electrical measurements that compare sensor signals to each other, and to reference voltage within the PCM itself. If the vehicle has battery- or charging-related problems, the PCM could set numerous false DTCs caused by electrical system issues. This is especially true if the vehicle being tested is experiencing a number of different DTCs that are all related to sensor signals or PCM output failures, since these could actually all be related to a bad battery or poorly operating charging system instead.

Now is an appropriate time to go over some basic battery and charging system tests. For more detailed test procedures on automotive electrical systems, please read the book *How To Diagnose and Repair Automotive Electrical Systems* by Tracy Martin, published by Motorbooks International. It will provide easy-to-understand procedures and explanations on the subject. This related automotive electrical book is available at the author's Internet website, www.tracyAmartin.com.

There are several methods available for testing a battery, and they range from using expensive, professional-grade

test equipment to using only a digital voltmeter in conjunction with an engine's starter motor. Regardless of which test is used, the vehicle's battery should be fully charged. Simply by using any digital voltmeter, a battery's state of charge can easily be determined. An *open circuit* voltage test can determine a car battery's state-of-charge, and whether the battery is conventional (utilizing filler caps to add water) or maintenance-free (no filler caps).

The most basic and frequently used test for determining a battery's state-of-charge is an *open circuit* voltage test. This test determines the relative state-of-charge of the battery for purposes of further testing. If a vehicle has recently been driven, its battery needs to rest for at least 10 minutes without any electrical load being placed on it before an open circuit voltage test can be performed. It is important to make sure all electrical loads are turned off before testing begins. To start the test, connect a digital voltmeter directly to the battery and then measure its voltage. See chart in Figure 6-11 to determine states-of-charge for any given voltage readings. If the battery's state-of-charge is less than 75 percent of its full capacity, the battery must be charged further before any additional battery or related OBD-II testing can occur. Battery chargers are available from Sears and most auto parts stores. After charging the battery, if voltage does not increase to 12.6 volts or higher, the battery should be replaced.

Battery Open Circuit Voltage

State of Charge	Battery Voltage
100%	12.65 or more
75% - 100%	12.45v
50% - 75%	12.24v
25% - 50%	12.06v
0% - 25%	11.89 or less

Fig. 6-11—Measuring *open circuit voltage* is an accurate method for determining a battery's state of charge. Before performing any testing of this nature, make sure all electrical loads are OFF before proceeding further. If a vehicle's battery has recently been charged, the surface charge will also have to be removed prior to any battery testing; this can be accomplished simply, by disabling the ignition or fuel system, and then cranking the engine over for about 15 seconds. Then let the battery rest for five minutes before testing for open circuit battery voltage.



Electrically loading the battery by cranking the starter motor over is a good method to test for battery starting capacity. With a digital voltmeter connected directly to the battery, crank the engine over for about 15 seconds. Record the voltage displayed just before the starter has stopped cranking the engine. If the voltage reading is 9.6 volts at 79° F, or higher, the battery is in good condition. The battery seen here shows 10.46 volts, which indicates it is in like-new condition.

Another battery test indicates how much cranking capacity a battery has available to start an engine. This battery load test stresses a battery by placing an electrical load upon it. The fuel-injection or ignition system will have to be disabled in order to perform this test. With one of these systems disabled the engine can be cranked over without starting. Typically, just removing ignition or PCM power fuses will prevent the ignition and/or fuel systems from operating, as will as removing the fuel pump fuse. To perform this test, connect a voltmeter to the battery and crank the engine for around 15 seconds. Next, watch the voltmeter reading just before the starter stops cranking—a good battery should have a minimum loaded voltage of 9.6 volts at 70° F. If testing is done in a cold climate (ambient temperature is around 40 F°), minimum voltage should read 9.3 volts. If loaded voltage is less than the minimum, the battery is weak or tired and well on its way to being the source of an engine starting problem. If the battery is bad, loaded voltage will drop way off (to less than 7 volts) within the first few seconds of engine cranking. A weak, old, or tired battery simply will not pass this test and should be replaced.

After testing a vehicle's battery, its charging system should be checked next. Again, a faulty charging system could cause the PCM to set false trouble codes. The following is a description of one of two available charging system tests: Leave the voltmeter connected to the battery as it was during the open circuit voltage

test, and replace whatever fuses were removed in order to perform the previous tests. Then start the engine. The battery should register charging-system voltage of at least 0.5 volts more than was produced by the open circuit voltage test performed earlier. Appropriate vehicle-specific service manuals will list correct ranges for charging voltages, though they are usually between 13 and 14.5 volts, though naturally there are some exceptions. In any event, if charging voltage exceeds 14.5 volts, or falls below 13 volts, the charging system needs to be checked further for potential problems. Over- or under- charging voltage conditions could possibly cause a PCM to set charging system related DTC(s), but don't count on it.

The final charging system test checks the condition of diodes inside the alternator. Diodes are solid-state one-way electrical valves, so if they start to leak AC voltage into a vehicle's DC voltage system, a PCM could set various false DTCs. To perform the last test, connect the red voltmeter lead from a digital voltmeter directly to the back of an alternator's output wire (usually the large wire on the back of the alternator). Next, set the scale on the voltmeter to read AC millivolts. AC voltage should not exceed .055 volts AC (55mV AC) with the engine running and several accessories turned on. However, if AC voltage is greater than 55mV, one or more diodes could be about to malfunction, so the alternator should be checked further, and possibly replaced.

IGNITION MISFIRE TESTING

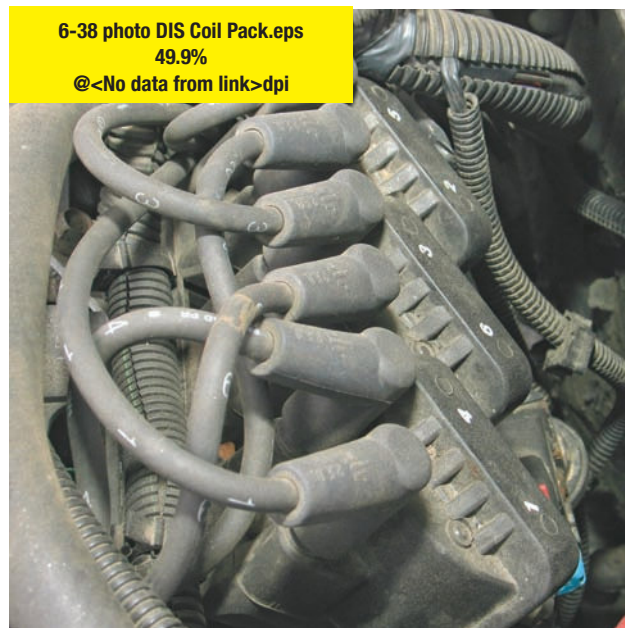
So far we've discussed how to diagnose basic mechanical engine problems that relate to cylinder sealing and compression. Another common problem that has existed since the invention of the automobile, and is still around today, is ignition misfire. To put modern ignition misfires and their related DTCs into perspective, let's take a look at some early ignition systems. Before 1975, automotive ignition systems were high-maintenance, requiring attention every 10,000 miles or sooner. Keep in mind, 10,000 miles in 1975 was a lot of driving mileage to rack up, as people tended to live closer to their work, and the interstate system of highways was not as extensive as it is today. Nevertheless, mechanical points, the condenser, distributor, spark plug wires and boots, and spark plugs all wore out or needed frequent adjustment.

With the introduction of more stringent emissions controls in the mid-1970s, especially those affecting the exhaust gas recirculation (EGR) system, spark plug energy had to be boosted considerably in order to reliably ignite lean air/fuel mixtures caused by EGR application at part throttle. Furthermore, the lean air/fuel mixtures that catalytic converters required in order to operate caused spark plug firing voltages that needed to be increased even further. The addition of catalytic converters to vehicles resulted in the creation of a chemical environment inside an engine's combustion chamber that served to increase a spark plug's air-gap resistance well beyond the range of what older ignition systems could provide (only about 20,000 volts). In fact, spark plug firing voltages could reach 50,000 volts or more on these early emission systems. In addition to the mechanical necessity for higher voltage outputs, the US federal government also mandated that ignition systems had to be maintenance-free for at least 50,000 miles.

Today, distributorless ignition systems equipped with coil packs and plug wires, as well as coil-over-plug systems that have no spark plug wires, can output voltages as high as 100,000 volts. These OBD-II-monitored ignition systems are almost maintenance-free since spark plug replacement intervals are often recommended at no less than 100,000 miles, and there are no associated adjustments that have to be made either, regardless of how many miles are on the odometer.

Despite their high reliability, ignition systems in use on OBD-II vehicles can still misfire. In fact, there are over 90 generic ignition system misfire-related OBD-II diagnostic trouble codes in existence. These trouble codes bear DTC numbers that start with the

prefix #P03XX (where XX is the cylinder number), and can be caused by the following: individual cylinder misfire, random misfires, knock sensors, crankshaft and camshaft position sensors, ignition coil primary/secondary circuits, and ignition timing reference DTCs.



By 1990, many manufacturers had replaced ignition distributors with coil packs like this one from a 1996 Pontiac. These systems were more reliable than earlier mechanical distributors, but they still used spark plug wires to transmit an ignition coil's high voltage energy to the plugs. Many of these systems have now been replaced by coil-over-plug systems that connect the ignition coil directly to the spark plug, a more advantageous design since there are no more spark plug wires that can wear out.

If a scanner tool detects that a PCM has set a #P0300 "random/multiple cylinder misfire detected" DTC, or a #P030X DTC where X represents a specific misfiring cylinder, the existence of the misfire should be verified before replacing expensive ignition parts. For example, on a coil-over-plug ignition system, if a #P0352 (Ignition Coil 'B' Primary/Secondary Circuit) code was set (this code is supposed to indicate a bad ignition coil), there is a simple test that can be performed to confirm which ignition coil has caused the DTC to be set. By swapping an ignition coil from the bad or potentially problematic cylinder with an ignition coil from a good or perfectly operable cylinder, the bad coil can be indirectly tested. If a new DTC is set again for that same bad cylinder, despite the fact its original coil is now no longer installed on it, it can safely be

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TURBOCHARGERS

Internal combustion engines, gas or diesel, are in their simplest form, air pumps. Air is pushed into an engine's cylinder via atmospheric pressure where fuel is added. The air/fuel mixture is ignited (via a spark plug on a gasoline engine and mechanical compression on a diesel engine) and burned. This causes a sharp rise in cylinder pressure pushing down on the piston that rotates the crankshaft. The exhaust valve opens and the piston pushes the burned waste gases out of the cylinder and the cycle begins all over again. Variable valve timing, long duration camshafts, tuned intake runners, and exhaust headers all have but one purpose—to increase the amount of air going into and out of the engine. When a higher volume of air in the cylinder is present, more fuel can be added and burned, creating greater power output. A turbocharger serves the same purpose as high-performance components—to increase the air density of the air entering the engine.

A turbo supercharger (the actual name of the device) is an exhaust-powered centrifugal air compressor that forces air into the engine by raising the intake manifold's air pressure—also called boost. A turbocharger's compressor is powered by recycling some of the heat energy that is normally lost to the engine's exhaust system. For example, exhaust gas temperature leaving the engine could be 1,200° F, but the exhaust temperature leaving the exhaust turbine of the turbo

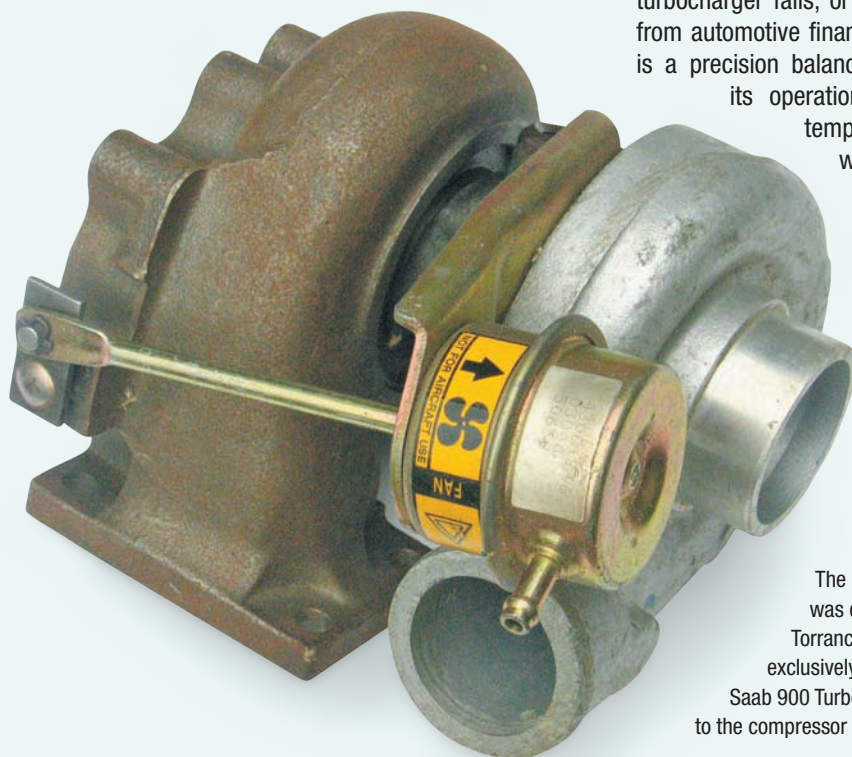
may be 700° F. This temperature drop of 500° F represents the energy recovered by the turbocharger and converted into mechanical energy to power the turbo's compressor. Turbos have been around since the 1940s on aircraft and diesel trucks. They became popular on automobiles in the mid-1980s, when gas crises encouraged many manufacturers to utilize them to give small displacement engines the power output of a larger engine, while getting the same fuel mileage as small engines. They were not a great success due to lack of technology, specifically, electronic fuel injection, which was in its infancy. With the advance of automotive electronics, including electronic fuel-injection and OBD-II systems, many manufacturers are again using turbo applications including Honda, Ford, General Motors, Kia, Nissan, Toyota, and others.

We'll take a quick look at what typically goes wrong with turbochargers and how to diagnosis the most common problems.

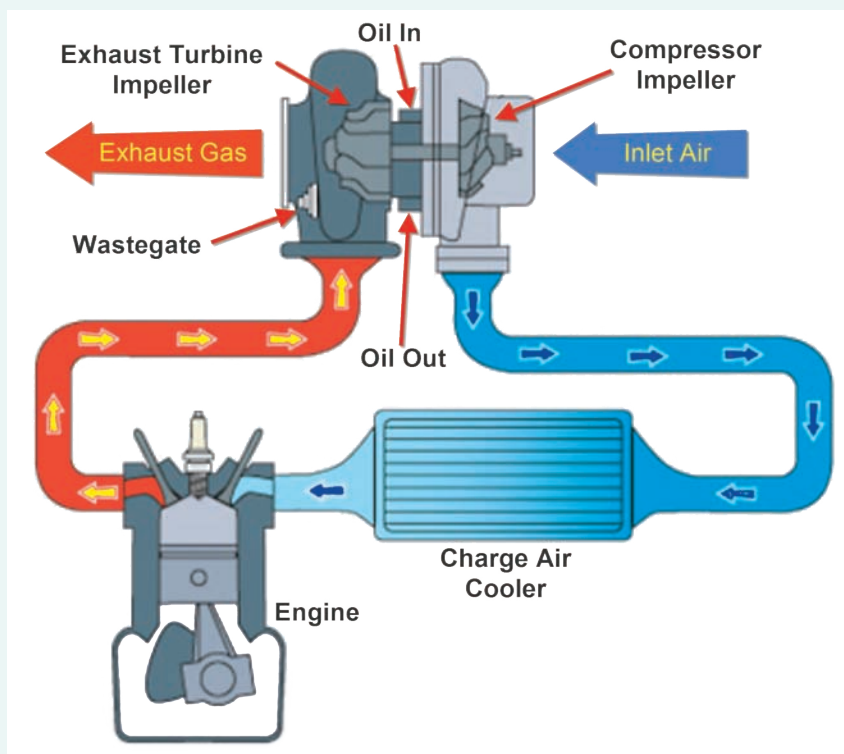
Most owners of turbocharged vehicles know something is wrong when their car lacks power on acceleration and/or does not product normal boost pressure (usually between 9 and 14 psi on most applications) at full throttle. These problems are too often blamed on the turbocharger, but around 80 percent of the time the turbo is not at fault and is replaced unnecessarily. After spending hundreds, if not thousands, of dollars for a new turbo, the same issues show up again. Finding the root cause of why a turbocharger fails, or doesn't perform, can save owners from automotive financial hardship. While a turbocharger is a precision balanced, high-tech piece of machinery,

its operation is simple. Engine exhaust gas temperature is converted into mechanical work, specifically, powering an air compressor. For this to take place, a turbo needs three things to function: 1) sufficient exhaust gas temperature, 2) a filtered air supply for the compressor, and 3) a clean oil supply and oil evacuation. We'll take a look at the last one first—the oil supply.

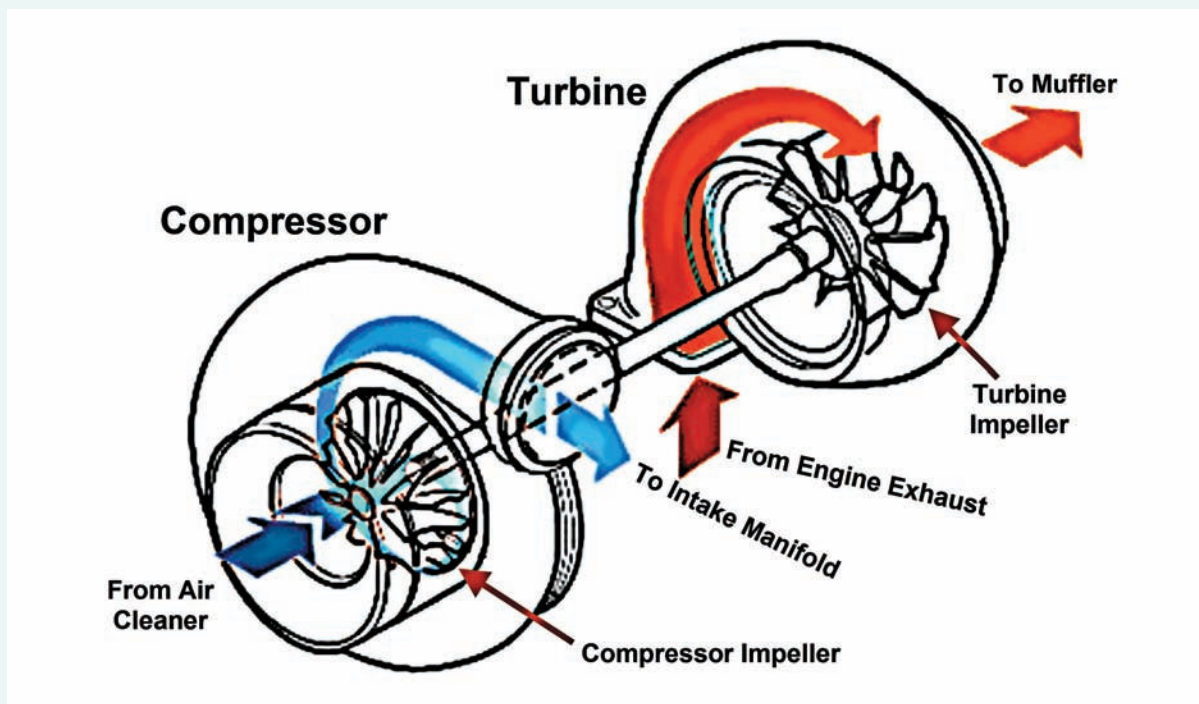
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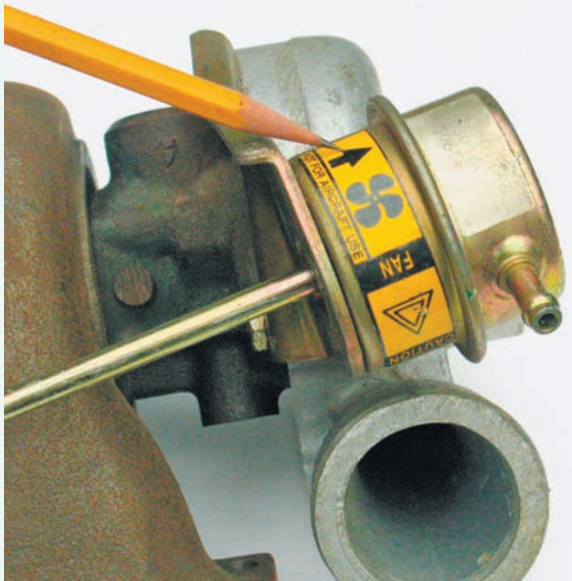
The Garrett AiResearch T3 turbocharger was developed at the company's facilities in Torrance, California, in the 1980s. The T3 was exclusively used for automotive applications—the Saab 900 Turbo is one example. The wastegate, attached to the compressor housing, controls boost pressure.



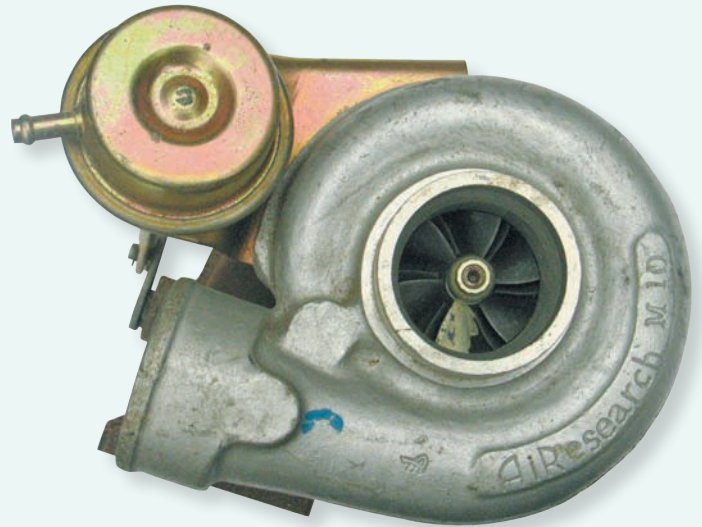
This drawing shows how a single-cylinder engine operates with a turbocharger. Air is fed into the engine where fuel is added. The air/fuel mixture is burned and exits the engine as hot exhaust gases. The waste exhaust gas is routed to the turbocharger's exhaust turbine where its energy is used to spin a shaft connected to a compressor. The compressor draws in air and boosts its pressure. During this process the air heats to over 200° F. The charge air cooler removes some of the heat and the cooler, denser, pressurized air is used by the engine to start the cycle over again.



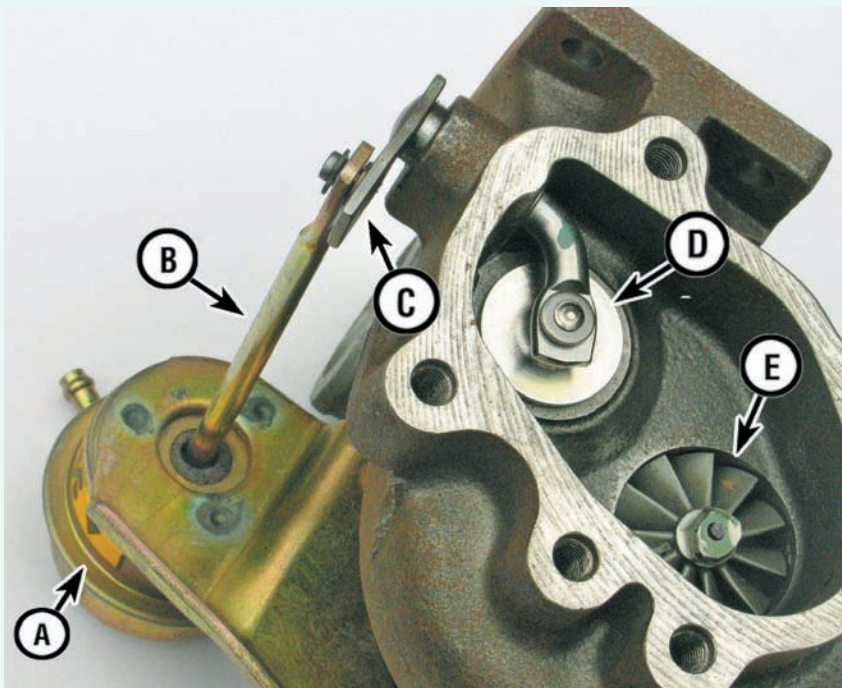
A turbocharger is an exhaust-driven compressor that uses some of an engine's wasted exhaust to power a centrifugal compressor. Often referred to as the "hot" and "cold" sides of a turbo, the compressor actually heats the compressed air. Charge air coolers, or intercoolers, are used to remove heat from the compressed air. Cooler air is denser and thus contains more oxygen that allows the engine to make more power.



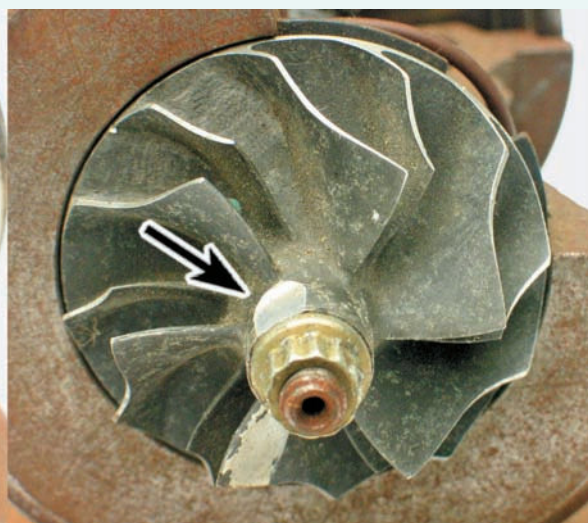
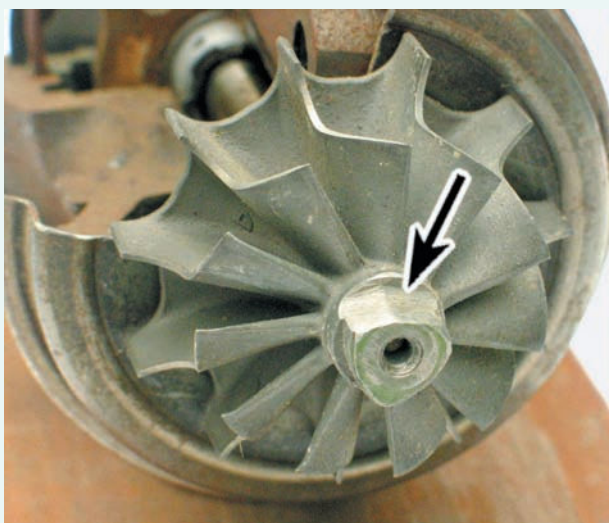
The T3's wastegate actuator has a diaphragm and spring inside. As intake manifold pressure increases, the actuator pushes on a rod that controls the wastegate valve. The wastegate has a label that states "Not for Aircraft Use," just in case someone wanted to bolt the unit to their Cessna's engine.



This is a T3 compressor and wastegate diaphragm actuator. The nipple on the wastegate is connected to the engine's intake manifold, where it senses manifold pressure and uses this signal to regulate turbocharger boost. The AiResearch name can be seen on the compressor housing.



These parts make up the mechanical boost control system: (A) The wastegate actuator diaphragm and control spring, (B) actuator rod, (C) the wastegate valve lever arm, and (D) the wastegate valve, which bypasses some of the engine's exhaust gas to control turbine speed and boost. When boost pressure is high, a hose connected between the intake manifold and actuator uses the pressure to push on the wastegate diaphragm to move the actuator rod. This action moves the lever and opens the wastegate valve in the turbine housing. When the valve opens, some of the engine's exhaust gas will bypass the turbine wheel, slowing the turbocharger's speed. (E) The exhaust turbine wheel where most of the engine's exhaust exits.



The T3's turbine wheel (left) shows where material was ground off in the balancing process. The compressor wheel (right) has a machined flat area where material was removed again to balance the wheel. Balancing a turbocharger is very precise, as the turbine shaft and compressor wheel on a T3 can spin at over 180,000 rpm at full throttle.

When Honeywell Turbo Technologies (formerly Garrett AiResearch Industrial Division) started mass producing turbochargers for the automotive market in the mid-1980s, there were an abnormally high amount of warrantee claims for turbo failure. Prior to this, turbochargers were considered a highly reliable, low-maintenance item that could typically go over 300,000 miles in diesel engine applications without any problems. What had changed? The answer turned out to be simple—the maintenance habits of automotive vehicle owners was vastly different from those of diesel fleet owners. Until the 1980s turbocharger production was almost exclusively for the diesel truck and heavy-duty, off-road vehicle market. Earthmovers, road graders, and 18-wheelers were owned by large companies. Skipping or taking shortcuts on maintenance with engines that cost upwards of \$40,000 is not cost effective. The maintenance schedules for these fleets of vehicles were strict in that they were performed on time and with quality parts (filters) and lubricants. This was not the case in the automotive market. The mindset of most owners of cars and light trucks regarding maintenance is “I’ll get around to it when I can.” or, “I don’t take my car to the shop unless there is something wrong with it.” While an engine may survive this lack of maintenance, a turbocharger does not.

TURBOCHARGER QUICK INSPECTION

When faced with a low boost, or an engine that lacks power in acceleration conditions, technicians are faced with a dilemma. Turbo performance affects engine performance,

and poor engine performance affects turbo performance. In this “chicken before the egg” scenario there is about an 80 percent chance that the turbocharger is *not* at fault. Engines that use a turbocharger are subject to all the things that can, and do, go wrong with engines that don’t use a turbocharger. For example, low compression in one or more cylinders caused by valves not sealing, and bad or worn piston rings will all affect engine, and thus turbo, performance. Bad fuel injectors, ignition system faults (misfires, bad spark plugs), and leaking intake manifold gaskets all will cause poor engine/turbo performance. This chapter on “Automotive Detective Work” covers many tests that can determine if the engine is working as it should.

Depending on how difficult the turbocharger is to get to, it may be easier to inspect it, and eliminate it as the cause of poor engine performance. Start by pulling the engine oil dip stick and look at what’s on the end. Is the oil dirty and/or looks like it hasn’t been changed in 12,000 miles? Does it have a milky, foamy, and/or cream-colored look to it? This could indicate an internal coolant leak. Does the end of the dipstick smell of gasoline? If so, it could be caused by worn piston rings, a leaking fuel injector, or other “rich” running problem. If any of these conditions are present, the bearings inside the turbo may have been damaged.

Remove the compressor inlet pipe and inspect the compressor wheel. Look for damage to the compressor blades (see Turbocharger Plumbing Leaks—Intake and Exhaust in this chapter). Using your thumb and forefinger, pinch the compressor wheel mounting nut and put

(continued)

pressure on it in any direction. There will be “play” in the shaft. This is normal. Rotate the wheel slowly with pressure applied. If you can feel the compressor blades rubbing on the compressor housing, the bearings are bad. A visual inspection of this condition will show a flat edge on the compressor blades where they rubbed on the housing. The compressor wheel should also turn freely without binding. This test works on the turbine/exhaust side of the turbo as well.

If a dial indicator is available, a somewhat more accurate bearing clearance check can be performed. With the dial indicator positioned against the shaft hub, bearing free play can be measured. Up and down shaft movement should not exceed 0.003 to 0.006 of an inch. End play (in and out movement) should be in the 0.001 to 0.003 range. These specifications are ballpark, and a factory service manual should be consulted for actual numbers.

TURBO OIL SUPPLY AND DRAIN

Dirty oil due to lack of regular oil changes, the wrong type of oil, low oil levels, and not changing the oil filter all contributed to the failure of many turbos. Turbochargers are especially sensitive to the condition of lubricating oil. The center housing rotating assembly (CHRA) contains the turbine wheel and shaft, compressor wheel, bearings, and seals. This assembly reaches rotation speeds of upwards of 130,000 rpm under full boost operation; the parts float on a thin film of engine oil.

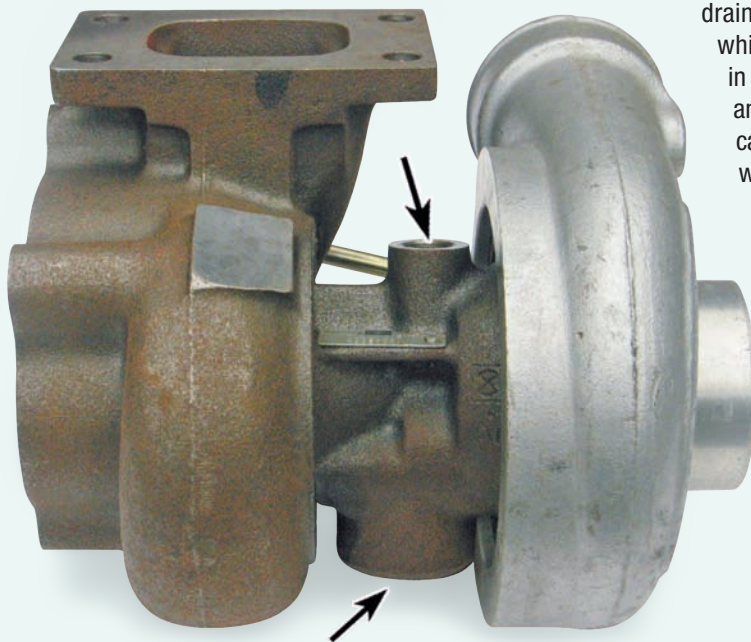
With tight clearances between the shaft, bearings, and center housing, and high surface speeds, it doesn't take much dirt or other contamination in the oil to cause the bearings to fail. Owners of turbocharged vehicles should read and follow the manufacturer's recommendations for oil change intervals, type of oil, and oil filter, or they may find out just how much a new turbocharger costs.

Getting clean, filtered oil into a turbo is important but getting it out is equally so. As oil circulates between the turbine shaft, bearings, and center housing, air gets mixed with the oil, causing it to turn into a substance that looks like brown whipped cream. The foamy oil uses gravity to flow down the oil drain at the bottom of the CHRA and into the engine's oil sump. Anything that prevents the gravity drain from functioning will cause the oil to remain in the CHRA; under this condition it may leak out into the compressor and turbine housings. Oil leaks are more common on the compressor side because that side of the turbo is constantly exposed to intake vacuum. If oil is present in both housings, but the turbo shows no signs of binding, wobble, or rubbing, remove the oil return line and check it for obstructions by passing a stiff wire through it.

Unmaintained crankcase venting systems (PCV valves) can also cause a turbocharger's seals to leak. Piston ring blow-by under full boost can cause turbo seal leaks if the crankcase vent system is partially clogged, especially from engine sludge in winter under cold operating conditions. This can cause positive pressure to build up in the crankcase, restricting the flow of oil from the turbocharger drain. Another cause of leaks is a dirty air filter, which will eventually cause a restriction resulting in a pressure drop between outside air pressure and the turbocharger compressor inlet. This can cause a partial vacuum, which is not an issue when the engine is under load and positive pressure exists at the compressor seal. But during idle, or low load conditions, this partial vacuum can cause oil to be sucked from the bearings, through the seal, and into the compressor housing.

TURBOCHARGER INTAKE AND EXHAUST PLUMBING LEAKS

Problems with the turbocharger intake plumbing: air filter, compressor inlet and outlet pipes, throttle body ducting, and intake manifold can all cause poor



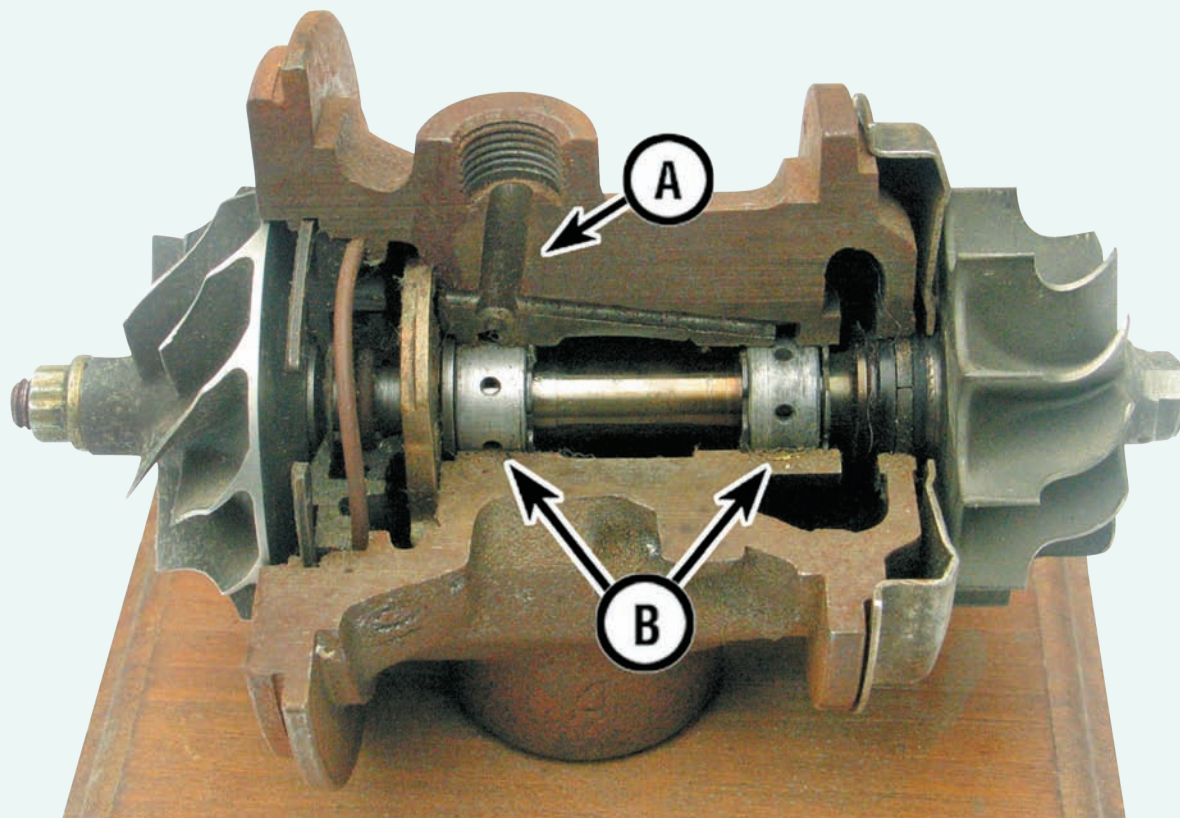
Seen here are the turbine housing (left), center housing, and aluminum compressor housing at right. The arrow at the top is the oil inlet where pressurized oil is fed into the center housing. The arrow at the bottom is the oil drain that is connected to the engine's oil pan, or sump.

engine performance and thus low boost from the turbo. In some cases these issues can damage the compressor impeller. An air leak between the air filter and the compressor inlet, or a damaged air filter, can allow small particles of dirt into the air stream going into the compressor. The particles, especially sand, will erode the edges of the blades on the compressor wheel. This looks like a saw-tooth abrasion on the edges of the compressor blades. The compressor blades should come to a sharp point where they change direction within the compressor housing. If these blade tips are rounded off, even slightly, this indicates dirty air entering the compressor housing. As the blades erode they lose efficiency and turbo boost will suffer.

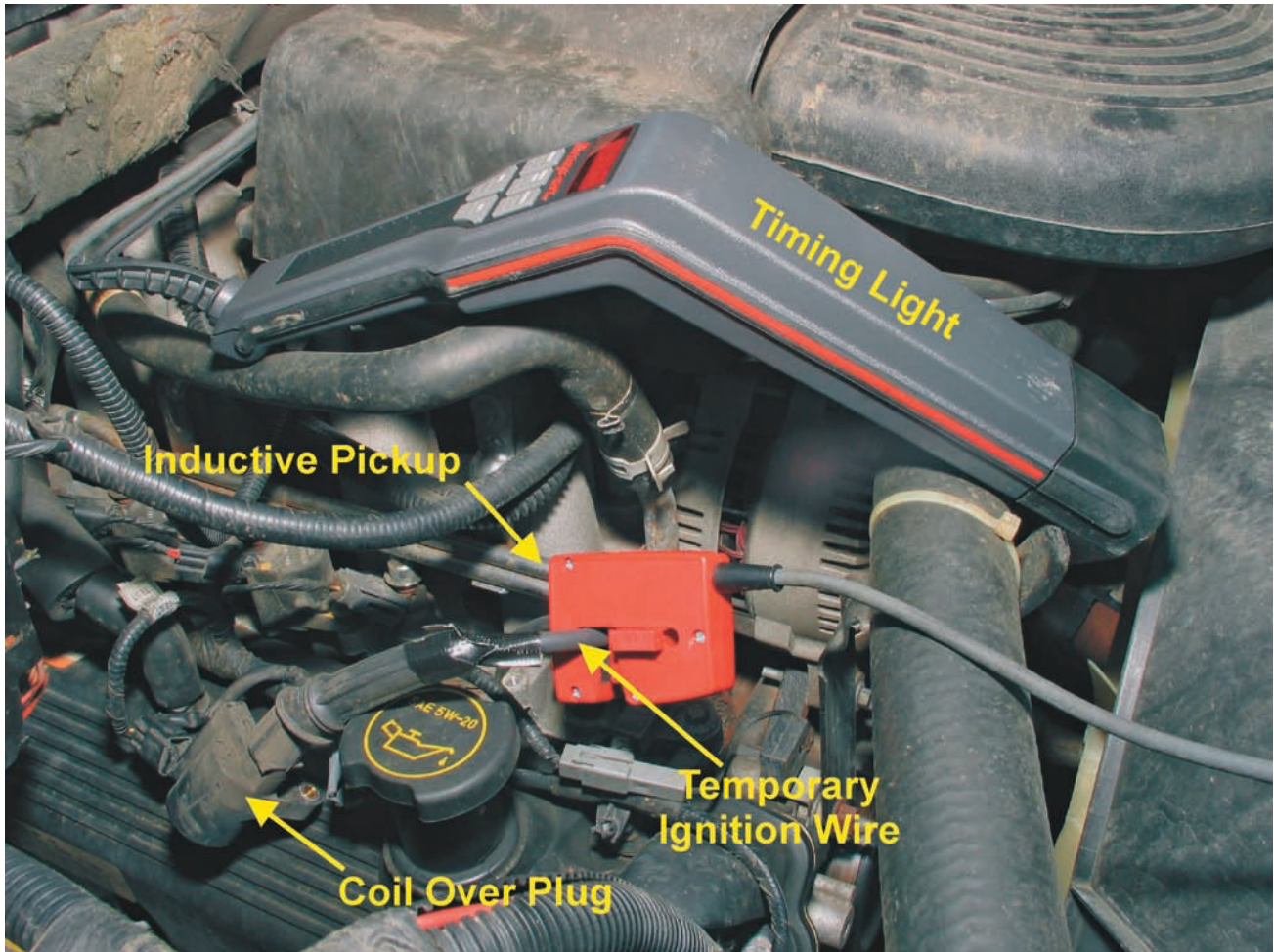
Exhaust leaks between the exhaust ports and the turbine inlet will not allow enough heat energy to enter the turbine. Boost pressure will be lower than normal. Another sensitive area is exhaust back pressure between the turbine outlet and catalytic converter. If the converter becomes clogged due to age or contamination, the excess back pressure in the exhaust system will reduce the amount of heat energy that the turbocharger can absorb to spin the compressor, causing low boost conditions.



The T3's exhaust turbine wheel is mounted in the exhaust housing of the turbocharger. The irregular shaped metal on the end of the turbine wheel is used to balance the shaft and turbine wheel. Material has been removed to achieve the correct balance.



In this cutaway of a T3 turbocharger (A) shows the oil galley from the oil inlet to the shaft bearings (B). The bearings are a full floating design in that there is a film of oil between the bearing and the turbine shaft, and the bearing and the center housing bore. Dirty oil will compromise the turbo bearings in a relatively short time, causing the shaft to wobble during operation—time for a new/rebuilt turbo.



Any type of inductive timing light can be used as a “poor-man’s” ignition scope. A coil-over-plug for one cylinder has been removed from this Ford truck, and a temporary ignition wire installed between the coil and spark plug. The timing light’s inductive clamp is then placed over the temporary wire. With the engine running, the flashing timing light is observed. If a misfire occurs, the human eye and brain are fast enough to visually register it. This little trick also works to discover injector misfires. To find an injector misfire, the inductive probe is clamped over one of the two wires going to a fuel injector. If the PCM skips a beat and fails to fire the fuel injector, a momentary pause in the flashing timing light will occur, letting a technician know that injector has misfired.

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assumed that the coil that was swapped out was good, and the wiring between the PCM and ignition coil, or the PCM itself, may be bad.

On all OBD-II vehicles equipped with coil-pack types of ignition systems, spark plug wires are still used, and still suffer from the same problems experienced by older vehicles with plug wires. Since voltage traveling through spark plug wires is so high, it tries to make its way to battery ground via a path of least resistance, instead of traveling to the intended spark plug. This cause misfires and can set OBD-II related trouble codes. Spark plug wires, terminals, and spark plug boot can all eventually wear out with age or otherwise become damaged; both conditions can cause arcing or voltage leaks.

When working on older OBD-I vehicles equipped with distributor caps and rotors, check the inside of every distributor cap for carbon tracking (which appears as shiny black lines). Additionally, green or white corrosion can form on rotor tips and distributor cap terminals. A distributor cap and rotor can be checked using an ohmmeter, but this method of testing will only confirm that connections are not open, not how well they will work under actual operating conditions. Consequently, while these connections may check out all right with a meter, they can subsequently break down under load, causing ignition misfires. Spark plug wires should be visually inspected for cracks, brittle insulation, or loose connections at the distributor cap or spark plugs. Spark

plug wires can also be checked using an ohmmeter, but resistance values vary widely between manufacturers, so be sure to consult an appropriate service manual for specific ohms per inch/foot values. Keep in mind that using an ohmmeter for resistance checking has limited value because it can only detect if a wire is not broken, not how well it will perform with high voltage flowing through it. For example, when an engine's throttle is wide open, engine compression increases to maximum, which in turn places added electrical resistance on the secondary circuit. This can cause a spark plug wire that previously checked out as good with an ohmmeter to turn bad and leak voltage to ground, and in the process, completely bypass the intended spark plug.

Using an inductive timing light to detect high voltage ignition misfires is one of several low-dollar methods that work on both coil pack and coil-over-plug ignition systems. Following is a brief explanation of how such a test works: When the pick-up clamp of a timing light is connected to a spark plug wire, the timing light will flash every time a spark is sent from the ignition coil to the spark plug. The human eye and a timing light act as a makeshift “poor man’s” ignition scope that allows a technician to visually detect misfires. To check for ignition misfires, connect a timing light to the coil wire between the coil and distributor cap on vehicles equipped with distributors, or to the spark plug wire on ignition systems fitted with coil packs. On coil-over-plug systems, the coil must be removed, and a temporary plug wire installed between the coil and plug in order to provide a place to connect a timing light for this test. Start the engine and point the timing light at your face. The flashes from the timing light should be steady.

If a misfire is bad enough, the flashes will skip or pause, indicating an ignition misfire. Now snap the throttle open momentarily and again watch if the light skips a few flashes. Sudden throttle opening should increase the resistance of the ignition circuit, which in turn should cause the coil to yield higher spark plug firing voltages. The increased voltage may cause a spark plug wire to go bad, or cause a coil or other ignition component to cause a misfire. If no misfire is detected with a timing light, but the engine is still obviously misfiring, move the inductive clamp of the timing light to each individual ignition wire (or temporary coil-over-plug wire) and repeat the test. Doing so will help isolate the component(s) causing the ignition misfire.

Another method for finding bad ignition wires requires a 12-volt test light and a spray bottle filled with water. Use the spray bottle to really soak the ignition wires and/or components, since water helps magnify any high voltage leaks from the ignition system. Connect the alligator clip of a 12-volt test light to battery ground and start the engine. Move the tip of the test light along all the ignition wires and around coil packs while listening to the engine. When the sharp tip of the test light is placed close to any wire or component that is leaking voltage, the high voltage will jump to the tip of the test light, causing the engine to misfire. A variation on this test requires it to be duplicated in the dark, preferably at night (CAUTION! Remember, having garage doors closed while an engine is running risks lethal carbon monoxide poisoning, which is undetectable by human senses.) In such a test, leaking high energy voltage can often be seen and sometimes heard (listen for a spark arcing to ground) whenever the misfire occurs.

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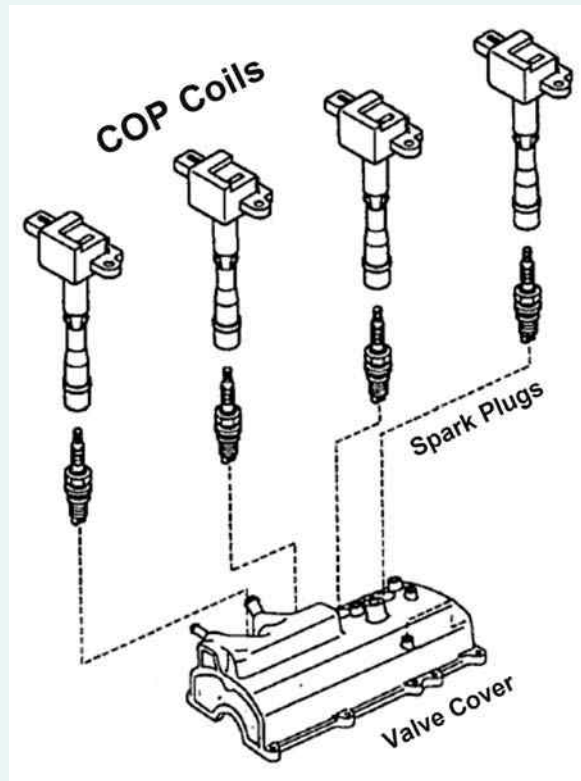


After spraying secondary ignition wires with water, a grounded test light can be used to find bad wires or spark plug boots. When the sharp tip of a test light is placed close to a leaky wire, the test light will attract high-voltage spark energy that culminates in a misfire. This test also works well in the dark, where leaking ignition wires that are shorting high voltage energy to ground can be readily seen.

COIL-OVER-PLUG IGNITION SYSTEMS

High-voltage spark plug cables, or wires, have always been factors in ignition misfires. As the high-tension wires break down due to heat, engine vibration, and old age, secondary ignition high voltage leaks through the wires to ground, causing ignition misfires. Distributorless ignition systems (DIS) that have been around since the mid-1980s use secondary spark plug wires that eventually wear out, causing secondary voltage shorts to ground. With as much as 60,000 volts in a DIS system trying to make its way to a spark plug, any path of least resistance to ground caused ignition misfires. While the material used for secondary spark plug cables stood up to high voltage, they still had issues with misfires. DIS ignition systems have largely been replaced with coil-over-plug (COP) systems that eliminate the secondary spark plug cables by placing ignition coils (one for each cylinder) directly over the spark plug. There is also a variant of COP called coil-near-plug, where a short secondary plug wire is used to connect the individual coils to the spark plug located near the ignition coil.

Besides eliminating long, bulky (and expensive) high voltage spark plug cables, placing individual ignition coils directly over each spark plug reduces ignition-caused radio frequency interference and reduces resistance along the electrical path between the coil and plug. The individual coils used in a COP system can be smaller, and lighter than in other systems, and use less energy to fire the spark plug.

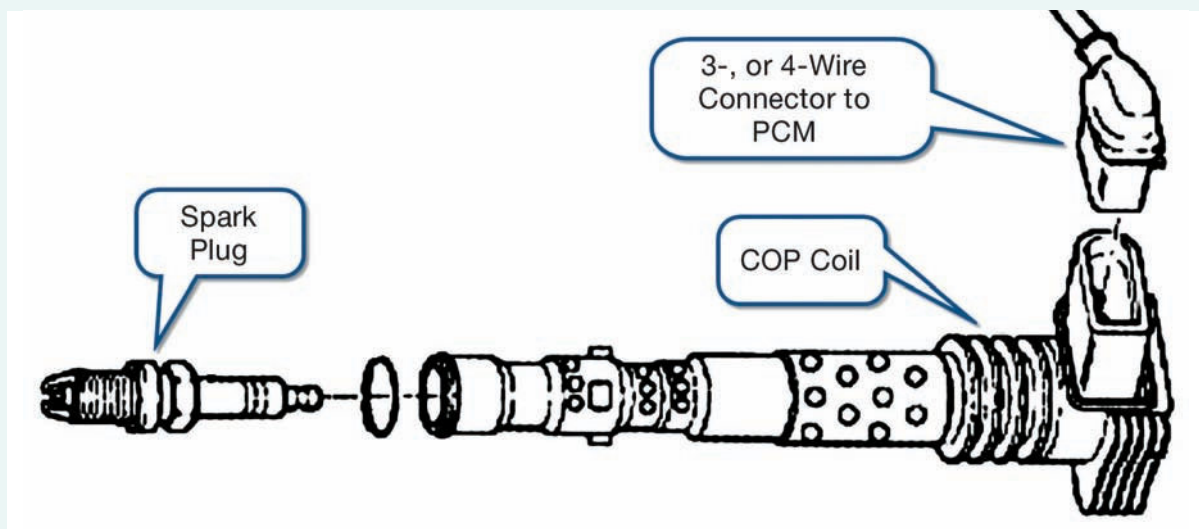


With individual coils mounted directly above the spark plugs, there are no more hard-to-maintain, high voltage ignition cables. A variant of COP coil placement is CNP, or coil near plug, by which a short section of ignition cable connects the individual coils to their respective spark plugs (not shown in drawing). Some late model GM V-8 engines have plugs that protrude from the side of the cylinder head, leaving no room for a COP arrangement.



This Nissan 2.4L four-cylinder engine uses coil-over-plug ignition. The four coils can be seen mounted at the top of the valve cover. The coil in cylinder number 3 is about to be removed as the mounting bolt has been taken out and the coil wire harness to the PCM has been unplugged.

From a performance perspective, having a separate coil for each cylinder gives the coil more time to recharge between cylinder firings and thus potentially produce higher spark voltage. Conventional ignition systems that used a single coil had to fire all the spark plugs twice for every revolution of the crankshaft in a four-cylinder engine, and four times for a V-8. With a multi-coil COP system, each coil only has to fire once every other revolution of the crankshaft. This provides more coil saturation time (ignition dwell) for a hotter spark, especially at higher rpm when firing times are greatly reduced. The resulting spark provides for fewer misfires, cleaner combustion, and better fuel economy. Additional benefits for COP systems include the engine's ability to use a greater amount of exhaust gas recirculation, or EGR that reduces oxides of nitrogen emissions. The COP's higher-voltage spark helps make the spark plugs more resistant to fouling, and allows for 100,000 mile plug change intervals.



This typical COP coil has a three-wire connector from the PCM. A fourth wire that is really the coil mount bolt (not shown) serves as a battery ground. An O-ring helps seal the coil in the valve cover. The end of the coil seals around the spark plug shell.

COP systems come in several different configurations. Toyota, Chrysler, Nissan, and other manufacturers have ignition coils mounted directly over the spark plug and use “pencil” style coils that extend down into recessed wells in the engine’s valve covers. On other applications, like GM’s Quad 2.2L Four, the individual coils are mounted in a cassette, or carrier, that positions the coils over the spark plugs. On late model Corvettes, Camaros, and other V-8s, a Coil-Near-Plug system is used because the spark plugs

protrude from the side of the cylinder head and there is no room to mount a coil on the end of each plug. These systems mount the individual coils on the valve cover and attach to the plugs by short plug cables.

DIS ignition systems used an electronic module that was part of the coil pack assembly to control the on/off switching of the coils. On most COP systems, the switching function is handled by the powertrain control module (PCM). The PCM receives a basic timing signal from the crankshaft position

(continued)



The COP coil on the left is from a Nissan 2.4L. center coil is manufactured by NGK and the right coil is made by Denso. Individual coils are priced anywhere from \$9 to \$90, with the OEM coils being the most expensive. They are also available in sets of four or six, depending on application.



COP coils do not have ignition module electronics contained within them. The PCM controls each coil providing power, ground, and a switching signal.

sensor to determine engine speed, firing order, and timing. The PCM also looks at inputs from the throttle position sensor, airflow sensor, coolant sensor, MAP sensor, and even the transmission to determine how much individual timing advance to provide for each cylinder's spark plug. The PCM is capable of making ignition timing adjustments between cylinder firings, which makes these systems very responsive to adapt to changing engine loads and driving conditions.

COP DIAGNOSIS

Modern ignition coils are highly reliable. However, they do sometimes fail. Coils used in COP systems run hot because of the high voltage that is constantly surging through them. Over time, the combination of high voltage and engine heat may break down the insulation between the coil windings, coil housing, or tower. If a coil problem is suspected, the coil's primary and secondary resistance can be measured

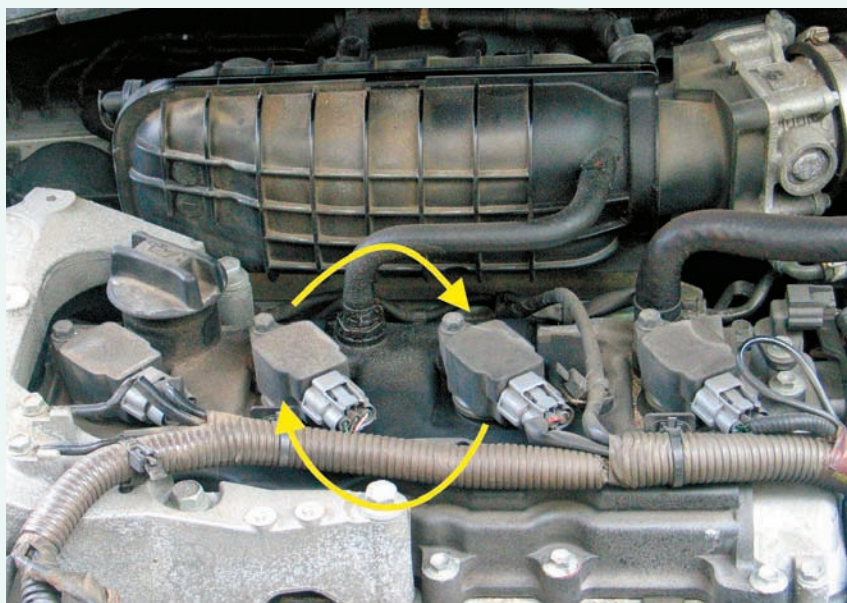
using an ohmmeter. If either is out of specifications, the coil needs to be replaced.

On CPO coils, the primary and secondary windings are insulated from one another and do not touch. The resistance of the primary winding is typically very low, usually less than a couple of ohms, and as low as 0.6 to 0.7 ohms on some systems. By comparison, the resistance of the secondary windings is quite high. COP coil secondary resistance can vary from 5,500 ohms to as much as 14,000 ohms. Before condemning a coil, look up the resistance specifications in a factory service manual for the specific coil that is being tested.

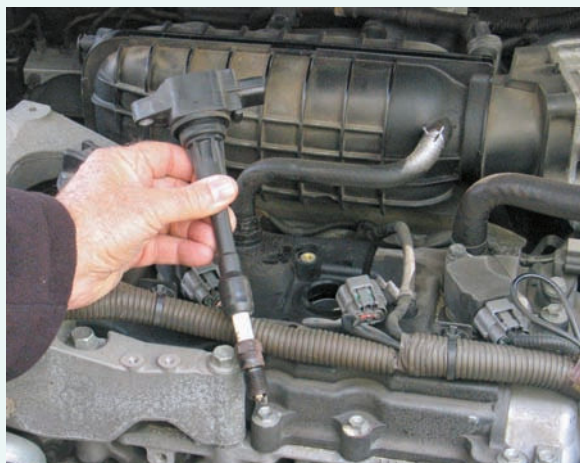
When the coil failed on a low-tech distributor ignition system, or only provided a weak spark, it would affect all the engine's cylinders. The engine may not start or it may misfire badly when under load. On a DIS waste spark system, where the coils provide spark to a pair of cylinders, the engine would barely run or not start at all. If a single coil fails on a COP system, it only affects one cylinder. Fortunately, on 1996 or newer vehicles the OBD-II system can detect cylinder misfires and identify the specific cylinder that has the misfire. A misfire code P0301, for example, would indicate a misfire problem in cylinder #1. A P0304 would indicate cylinder #4 and so on. A cylinder that is misfiring could have a number of causes for the misfire. A worn or fouled spark plug, a weak coil, a bad plug wire or connection (in the case of a DIS or CNP system), a dirty or dead fuel injector, or a loss of compression (burned exhaust valve or leaky head gasket) could all cause a cylinder to misfire. Further diagnosis is needed to isolate and identify the root cause. This is problematic on COP systems as they do not have spark plug wires. Further, secondary ignition scope patterns are not available unless some type of adapter or inductive pickup is used that fits on top of the coil.



One diagnostic procedure that has been consistent over time for ignition coils is measurement of electrical resistance. The COP coil's secondary and primary winding resistance can be checked to see if it matches factory specifications. On some coils the mounting bolt hole services as a ground, and resistance measurements are between the coils terminal (primary or secondary) and the mounting hole.



OBD-II misfire codes will indicate an individual cylinder at fault. A quick way to tell if the coil, or PCM signal to the coil, is not working is to swap coils between cylinders. If the misfire DTC follows the coil, it needs to be replaced. Never unplug a COP coil with the engine running; damage to the coil, PCM, or technician may result.



COP ignition systems make it hard to quickly check for a spark because the coil has to be removed from the cylinder head/valve cover. Place a spark plug into the end of the coil and lay it on the valve cover (make sure the plug is touching the cover). Start the engine and look for a spark at the spark plug; a spark indicates that the coil is operating.

Here is a quick way that the coil can be eliminated as the cause of the misfire. Imagine a DTC of P0303 has been set, indicating a misfire on cylinder #3. Assuming that it is not caused by fuel delivery, it could be the ignition system—the coil, signal from the PCM, or wires from the PCM to the coil could all be the cause. Remove the coil from cylinder #3 and swap it with another coil (doesn't matter which one). In our example, the coil will be swapped for the coil on cylinder #1. Reconnect both coils and start the engine and let it run for a short time. Read the codes set by the OBD-II system and see if the misfire code is now a P0301. If it is, then the coil that used to fire cylinder three is now causing a misfire in cylinder #1, indicating that the coil

is the problem. If the misfire code is still a P0303, then the PCM or wires connecting the coil to the PCM are at fault.

A word of caution: On all types of ignition coils when the electro-magnetic field collapses a high-voltage surge (could be as much as 100,000 volts) will try to go ground. If this voltage can't go to the spark plug it will find another path to ground. This could be back through the PCM driver circuit or through the insulation inside the coil itself. This scenario can be damaging to these parts. Never disconnect a plug wire or COP coil while the engine is running. This practice can also be a safety hazard. If the path of least resistance to ground is through the technician, it can be shocking—and time to dial 911.

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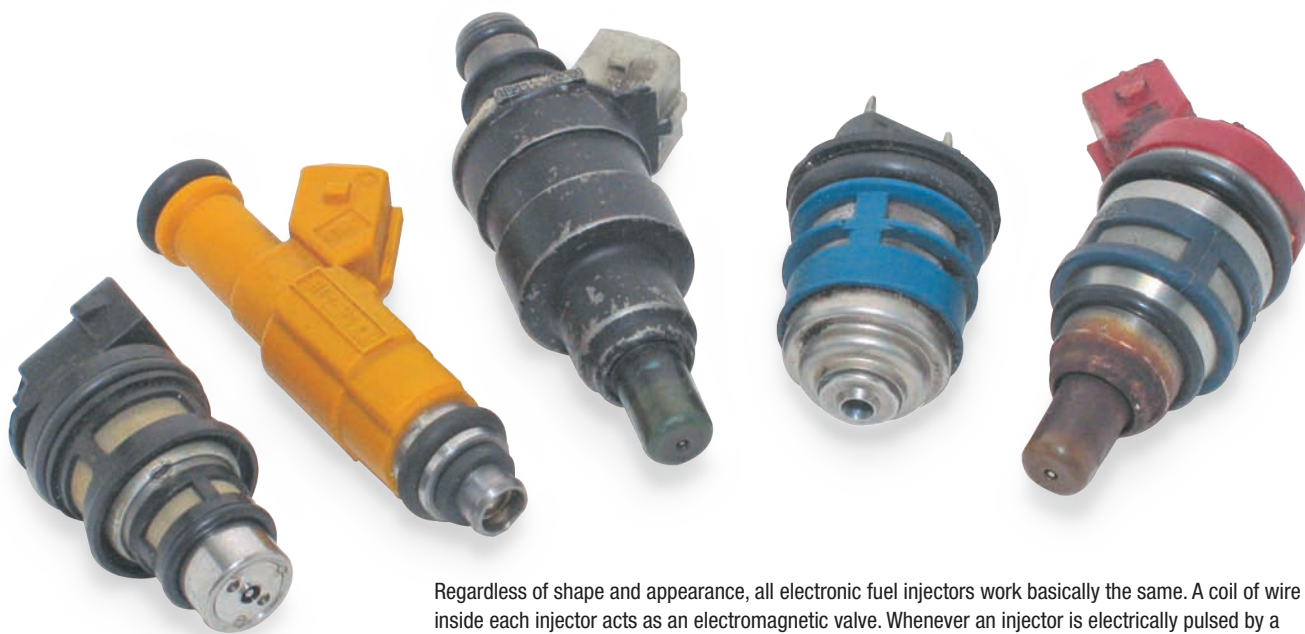
FUEL INJECTORS

Fuel injectors are simply nothing more than electrical solenoids controlled by a vehicle's computer. Inside each fuel injector is a coil of wire and moveable electromagnetic valve. When energized by an on-board computer, the coil of wire is transformed into an electromagnet, which causes the valve to open, thereby allowing fuel to be injected into the engine's intake manifold. A PCM controls the amount of fuel injected into the engine by varying the length of time the injectors are turned on. This is referred to as injector pulse width.

Fuel injectors and their circuits are fairly reliable on modern vehicles, but on those infrequent occasions when they do misbehave, OBD-II systems have as many as 100 DTCs that can be set to address injector circuit malfunctions. Much like ignition system components, fuel injectors are expensive to replace; consequently, just because a DTC has been set by a PCM doesn't mean a vehicle owner should rush right out and spend money on replacement parts or a costly repair. Just as individual ignition circuits or coils can cause a PCM to set ignition-related DTCs, a shorted injector can do the same thing. To verify if an injector, PCM, or wiring harness is the cause of an injector code problem, try swapping injectors and then check to see if the same diagnostic trouble code follows the injector to a different cylinder, or if it stays on the cylinder where the DTC was originally set. For

example, if a #P0204 DTC ("Injector Circuit/Open—Cylinder 4") is set, swap the injector from a different cylinder and install it into the #4 cylinder, and install the original injector from the #4 cylinder into the other cylinder from which the injector was removed. Then clear all DTCs. After performing an appropriate "drive cycle," check to see if the OBD-II fuel monitor has completed its scan for any possible DTCs again. If the same DTC has been reset, but this time shows up on the cylinder where the original injector from cylinder #4 was reinstalled instead, then it is obvious that the original injector from cylinder #4 caused the PCM to set the DTC, and not the wiring between the injector and PCM, or the PCM itself.

Another fuel injector test measures levels of electrical resistance using an ohmmeter. Such a test is called a fuel injector electrical resistance test. However, bear in mind these tests are not particularly sophisticated, in that electrical resistance readings will only confirm whether a specific injector's internal coil is not shorted to ground or open. Since resistance values vary widely between auto manufacturers, consulting an appropriate service manual for specific values is always a good idea. In fact, the only way to tell with certainty if an injector is actually working electrically is to use a lab oscilloscope to monitor the injector's pulse from a PCM. However, there are a number of simpler tests that



Regardless of shape and appearance, all electronic fuel injectors work basically the same. A coil of wire inside each injector acts as an electromagnetic valve. Whenever an injector is electrically pulsed by a PCM, the electromagnetic valve opens, allowing fuel to be injected into the engine's intake manifold. These electrical pulses are very short, lasting only a few thousandths of a second each.



To check for the presence of an injector pulse from a vehicle's PCM, a test light is used in place of a fuel injector. The pointy end of the test light is touched to one of the wires in the injector harness, and the alligator clip end is connected to a straight pin inserted into the other injector wire at the harness. As soon as the engine is cranked over, the test light will flash or pulse if an injector signal is present at the connector. This simple test confirms whether a PCM is sending out an injector pulse to individual fuel injectors.

will work and yield results most of the time. Those tests can be used to indirectly confirm whether an injector is operating properly, or at all. Following are brief descriptions of four simple tests that can be used to confirm the operating condition of a fuel injector. The first three tests verify that a PCM is, in fact, sending an injector pulse signal to the injector, while the last test checks for and confirms mechanical injector operation.

Test 1. Unplug the injector and connect a 12-volt test light between the two wires at the injector connector harness. Crank or start up the engine while watching the test light. If the test light flashes, the PCM is sending an injector pulse to that injector. (While a test light will work most of the time in this test, it's important to know the test will not work on all vehicles because some use a dropping resistor in the injector circuit that limits current going into the injector, to keep it from overheating. See Test 2.

Test 2. Instead of using a test light, use a noid light that is specific to the particular EFI system being tested. A noid light has a low-enough resistance to flash during the test, even when a dropping resistor is used. Noid lights are available from some auto parts stores and on the Internet for about \$20.

Test 3. Instead of a test light or noid light, this test uses an inductive ignition timing light to verify injector pulse. However, the method performed is the same as the one used to check for an ignition misfire. Clamp the timing light's probe around one of the wires going to the injector. Start or crank the engine and watch the timing light to see if it flashes—a flashing light provides confirmation that the PCM is sending an injector pulse to that injector.

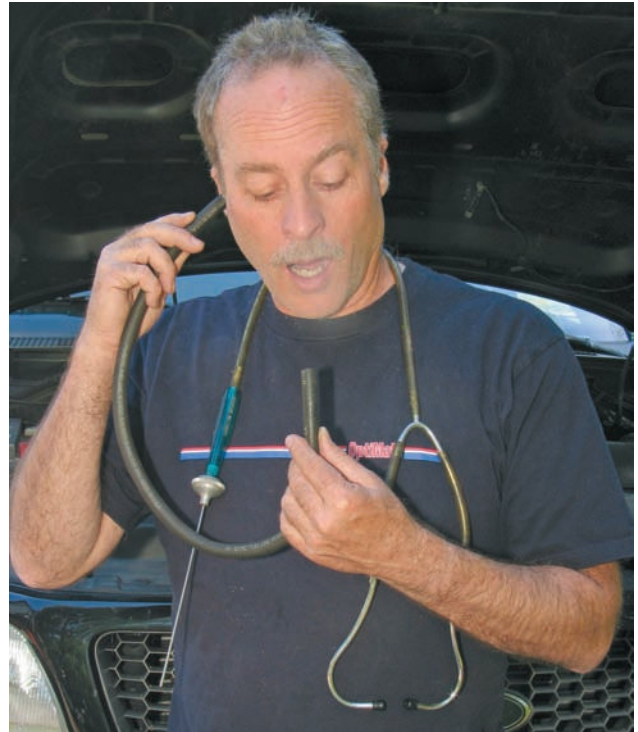
Test 4. This final test provides a low-tech method for confirming whether a fuel injector is receiving injector pulses from a PCM. Simply take a long screwdriver and



By removing the electrical connector from an injector and connecting a noid light to the injector's harness instead, an injector pulse from a PCM can be viewed once the engine is cranked over. Noid lights come with a variety of adaptors to fit many popular injector wiring harnesses. They are a better choice than a test light to allocate a PCM-generated injector pulse. Noid lights are available at many auto parts stores and online.



A mechanic's stethoscope (available at most auto parts stores) is used to listen to the operation of a fuel injector. If working properly, the injector should make a steady clicking sound and speed up in direct correlation with engine speed. If the PCM is not sending an injector pulse to the injector, or the pulse is intermittent, the stethoscope will allow the technician to hear this problem.



A short section of $\frac{3}{8}$ -inch hose can also serve as a satisfactory method for listening to a clicking fuel injector. Here, the author is speaking into the hose to test if the sound waves from his voice (like sound waves from a fuel injector) will travel through the hose into his ear—true science in action!

touch the end of it to a fuel injector and stick the handle end in your ear (no kidding!). If the injector is working, you should be able to hear a steady clicking from the injector as sound waves from opening and closing of the injector are transmitted through the screwdriver. A wooden dowel, mechanic's stethoscope, or even a simple piece of vacuum hose will also work for this test.

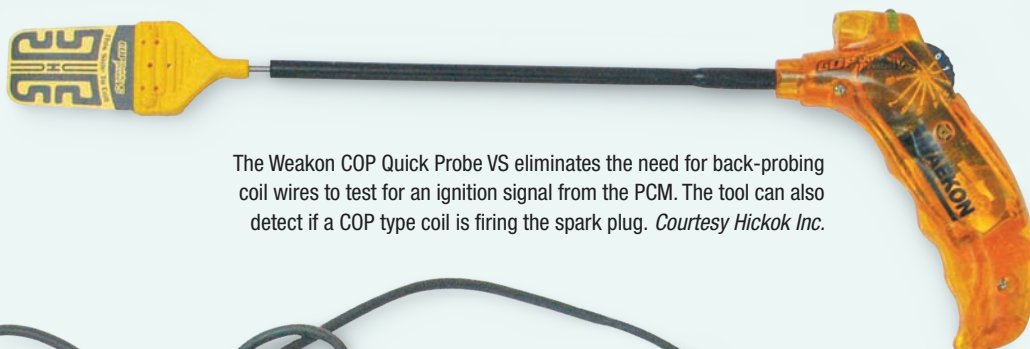
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TOOLS FOR DETECTING MISFIRES ON COP IGNITION SYSTEMS

With a few exceptions, COP ignition systems do not have spark plug wires, making analysis of secondary ignition voltage problematic. Ignition scopes that use kV (breakdown voltage) probes rely on having access to high-voltage spark plug cables for voltage signals. When COP was first introduced, many shops simply added temporary sections of secondary ignition wires between the ignition coil and spark plug. These extensions provided access for ignition kV probes and ignition burn time. Maximum kV voltage could be viewed on an ignition scope. Today, there are a couple of tools from the automotive aftermarket that allow kV readings, and other information, from COP systems. The COP Interceptor and the COP Quick Probe VS by Hickok/Waekon are two tools that provide an easy way to diagnose COP ignition issues.

These tools rely on magnetic field signals that the COP ignition coil generates each time it fires a spark plug. Both tools use an inductive/antenna probe placed on top of, or alongside, the COP coil.

The Quick Probe VS (p/n 76562) uses a seven-inch antenna probe. When the probe is placed on top of the ignition coil with the engine running, the user rotates a thumbwheel to adjust the probe's sensitivity until the tool's Super Bright LED kV strobe begins to flash. A green LED indicates sufficient spark plug arc duration. By observing these two LEDs a technician can determine if the coil is firing the spark plug consistently, intermittently misfiring, or not firing at all. With the engine running, the probe is moved from coil to coil to determine if they are all firing.



The Weakon COP Quick Probe VS eliminates the need for back-probing coil wires to test for an ignition signal from the PCM. The tool can also detect if a COP type coil is firing the spark plug. *Courtesy Hickok Inc.*

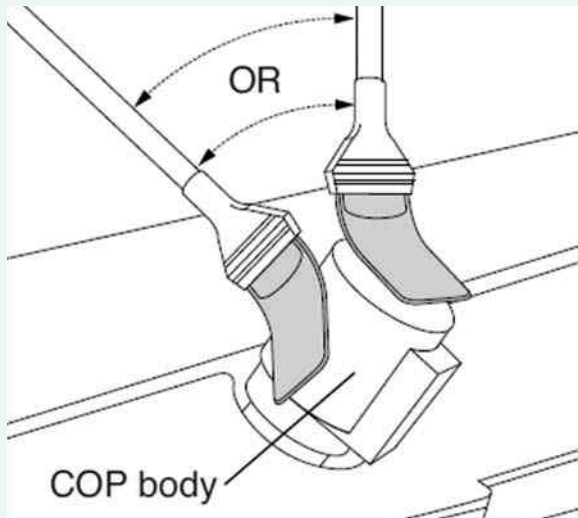


The Weakon COP Interceptor measures, displays, and saves each coil-on-plug's secondary ignition data in real time for detailed ignition analysis. Trend data can be displayed for visual verification of an intermittent misfire that may not trigger a DTC. *Courtesy Hickok Inc.*

In the case of a misfire, the tool makes quick work of determining which coil is at fault. The Quick Probe VS retails for \$139.98 and is available in auto parts stores, online, and Walmart.

The COP Interceptor provides more ignition-related information than the Quick Probe VS. In addition to indicating if the coil is firing the plug, the Interceptor also has an Auto-Set Gain calibration that adjusts the tool to provide accurate data for multiple types of COP ignition systems. The tool measures and records real-time kV breakdown voltage up to 30,000 volts, and mS arc/spark burn duration as they happen. It also features graphical and numerical data and saves up to eight cylinders of ignition data. It detects ignition misfires from engine idle speeds to 4,000 rpm. The Interceptor retails for \$345.95 but can be found for less on the Internet.

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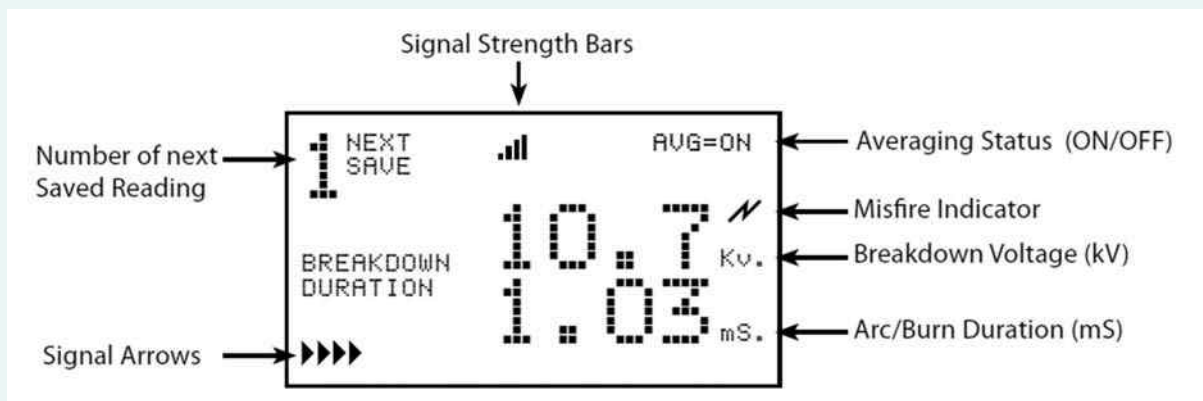


In most cases, the tester's signal pad probe is placed on top of the COP coil, but sometimes the side of the coil may provide a better signal. During use, make sure to keep the probe from touching any metal engine parts and the other COP coils. *Courtesy Hickok Inc.*

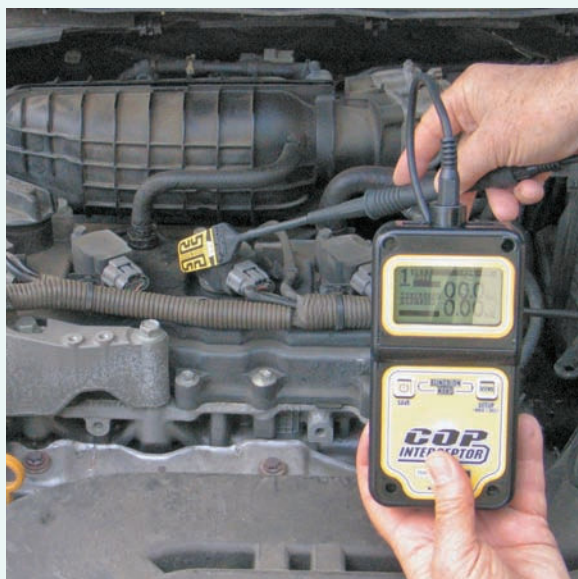
Breakdown voltage (kV) indicates the high voltage necessary to ionize the spark plug's air gap and initiate the spark. Each spark event is determined by spark plug gap, air/fuel mixture, combustion chamber turbulence, and the integrity of the secondary ignition circuit. The arc/burn duration (mS) indicates the time in milliseconds that the spark flows current across the spark gap. Spark duration is determined by coil type, dwell time (coil charge time), breakdown voltage, and the integrity of the primary ignition circuit.



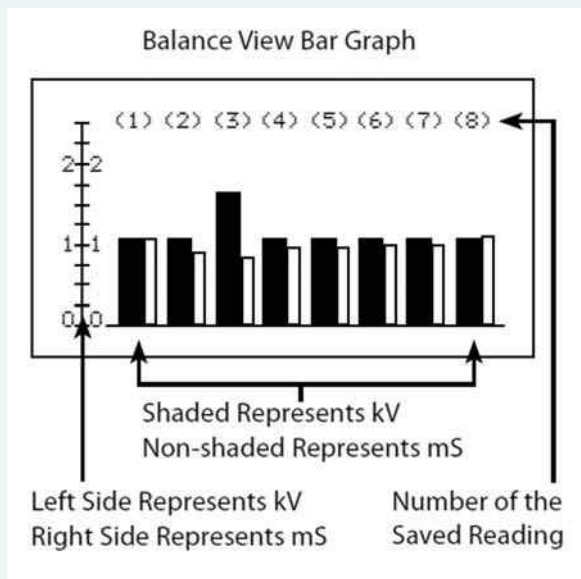
The Weakon Quick Probe VS is easy to use. Just hold the antenna probe on top of, or next to, the COP coil. With the engine running, adjust the sensitivity wheel until the tool's LED starts to flash. Move the probe from coil to coil to check if they are all firing their respective spark plugs. *Courtesy Hickok Inc.*



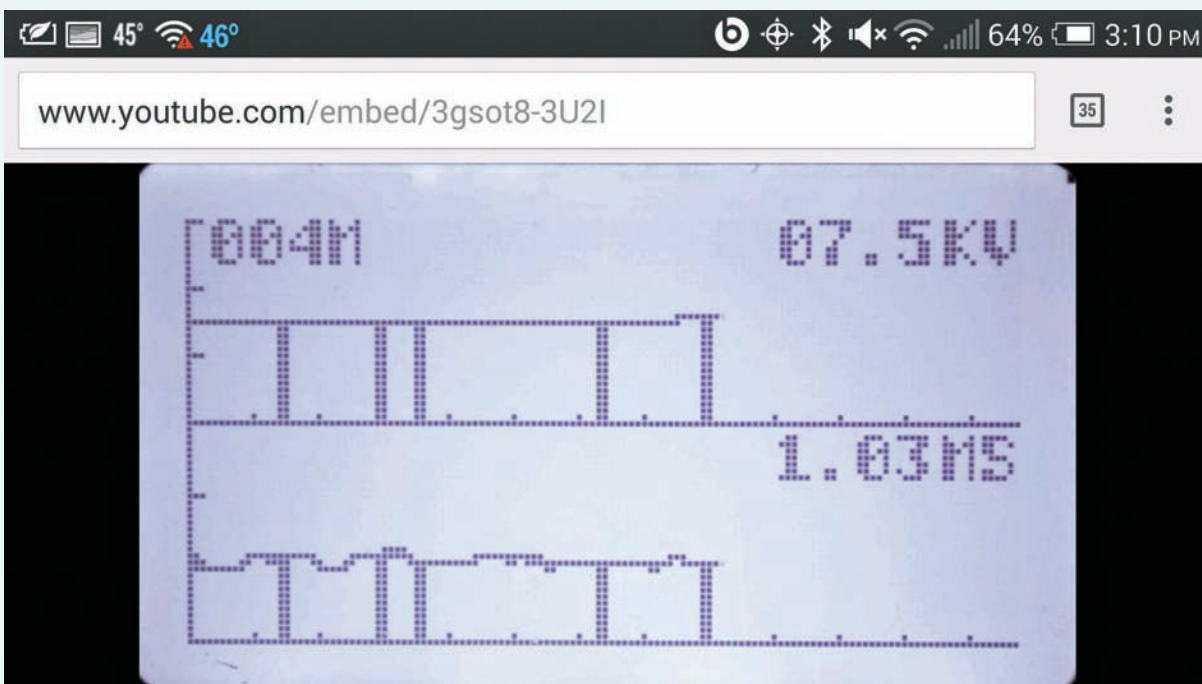
The Interceptor's main display screen provides several pieces of information about a COP ignition coil in operation. Starting at the top left: the saved reading, or cylinder number; signal strength from the COP coil; AVG=ON shows kV values averaged over 10 readings; 10.7kV is the voltage, in thousands of a volt, from the coil; 1.03mS is the plug burn time in milliseconds; a misfiring coil is indicated by the lightning bolt (to the right of the number 7); or misfire indicator. *Courtesy Hickok Inc.*



The Weakon COP Interceptor records ignition data when the probe is moved from coil to coil for later analysis. Spark kV as well as burn time can be displayed in a graphical format that makes it easy to determine the overall health of a COP ignition system. *Courtesy Hickok Inc.*



The Interceptor's Balance View shows the kV and mS readings for all cylinders in a bar graph format. Touching the left key function on the unit changes the view to show numerical values. *Courtesy Hickok Inc.*



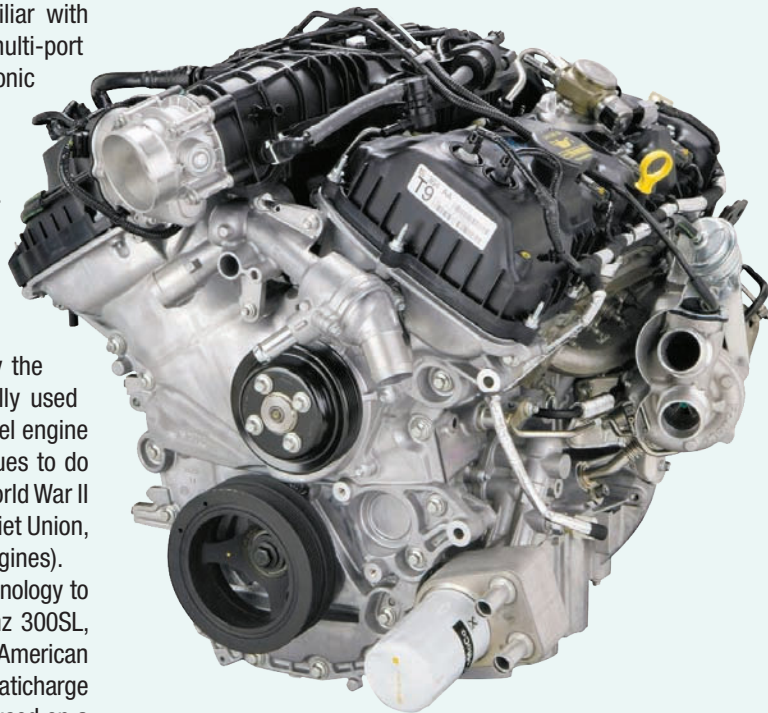
The Trend View shows ignition misfires in real time. A counter (upper left) displays counted ignition misfires up to 255M. The counter automatically zeros when the ignition signal stops for more than one second. Each misfire drops the kV and mS trend lines to "0" to show the misfire. *Courtesy Hickok Inc.*

GASOLINE DIRECT INJECTION (GDI)

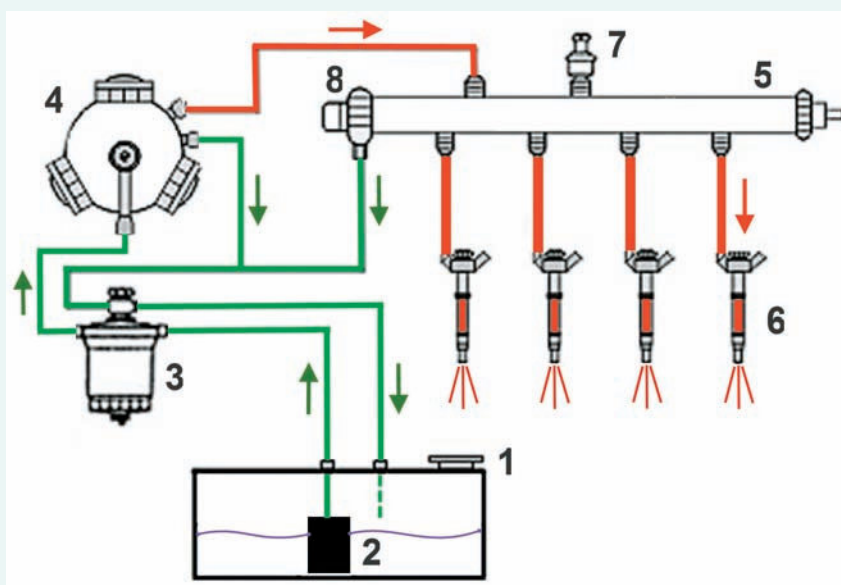
Most technicians who have been turning wrenches on automobiles since 1980 are probably familiar with several types of fuel injection. Throttle body, multi-port electronic fuel injection, and mechanical K-Jetronic injection systems have been widely used since that time, and even earlier. The “new kid on the block” is GDI (Gasoline Direct Injection). Also known as Spark Ignited Direct Injection (SIDI) or Fuel Stratified Injection (FSI), GDI is a generic name for this reintroduced technology.

Why reintroduced? Because like many automotive technologies, it has a useful history. The first GDI system was introduced in 1902 by the French inventor Leon Levavasseur, and eventually used on a V-16 aircraft engine. In the early 1920s, diesel engine technology also used direct injection and continues to do so today. GDI was widely used on aircraft in the World War II era by Germany (BMW and Daimler-Benz) the Soviet Union, and the United States (on some Wright aircraft engines).

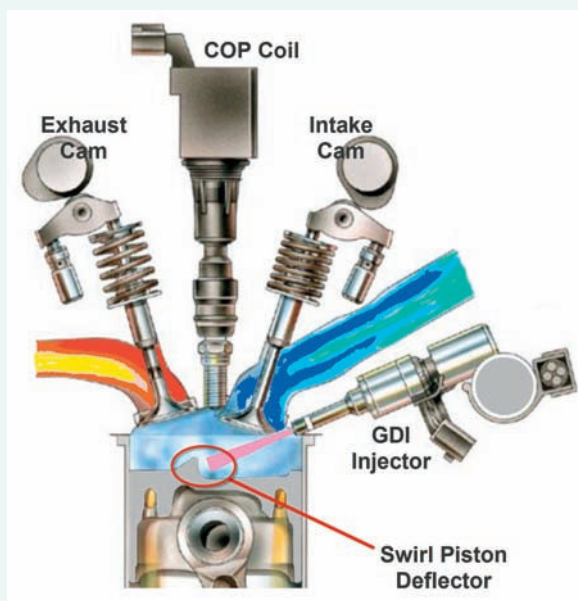
In 1955, Bosch adapted its diesel injection technology to create a crude GDI system for the Mercedes-Benz 300SL, the first production sports car to use fuel injection. American Motors Corporation (AMC) came up with the Straticharge Continuous Fuel-Injection (SCFI) system that was used on a 1973 AMC Hornet (a truly fine automobile). In the late 1970s, Ford Motor Company developed the PROCOT (programmed combustion) GDI system that was installed on a small number of Crown Victorias. All of these early GDI were expensive to manufacture and difficult to maintain. Further, the technology was not suited to the average family car or



This Ford 3.5L V-6 EcoBoost engine features independent variable camshaft timing and gasoline direct injection (GDI). It produces 365 horsepower at 5,500 rpm and 350 ft.-lbs. of torque between 1,500 and 5,000 rpm. This amount of power could only be possible with a sophisticated GDI system. Installed in a 2015 Ford Taurus SHO, it gives 17 mpg city and an astounding 25 mpg on the highway.



A typical GDI system schematic. Fuel under low pressure is indicated by green lines, with red lines indicating high fuel pressure. Fuel in the gas tank (1) is sent to the fuel filter (3) by the low pressure fuel pump (2) at about 50 psi. From the fuel filter, fuel moves to the high pressure, mechanical fuel pump (4) where it is pressurized to between 500 to 3,000 psi, depending on engine load. A pressure relief valve on the pump returns fuel to the tank. From the high pressure pump fuel travels to the common fuel rail (5). The injectors (6) spray the fuel directly into the engine's combustion chamber. A fuel pressure sensor (7) provides the PCM with fuel pressure information. The high pressure regulation valve (8) controls fuel pressure in the rail and returns fuel to the fuel tank.



Instead of placing the fuel injector in the intake manifold runner, GDI systems locate the injector directly in the combustion chamber. The piston has a swirl deflector that redirects the spray of fuel upward and directly at the spark plug for more efficient combustion. GDI injection systems use many different piston crown designs to assist in premixing the fuel cloud with the intake air charge.

the neighborhood mechanic's level of repair/diagnostic skills. More recently, Mitsubishi produced a 1.8L four-cylinder GDI engine, the same year that OBD-II was introduced—1996. Since that time, most automotive manufactures followed with their own version of GDI technology, right up to 2014, when General Motors introduced their 6.2L V-8 with variable valve timing, variable displacement, and a GDI fuel system.

Why GDI? There are several advantages that fit a familiar scenario within the automotive arena: increased fuel economy (between 8 and 22 percent, more than a similar engine with port fuel injection), high engine power output, and lower emissions can be provided with GDI technology. Because GDI has such precise control of the fuel directly injected into an engine's cylinders, engine designers are now offered numerous possibilities for improving fuel economy and power, and lowering exhaust emissions. Conventional engines, with fuel injection (and even carburetors) that vary the air/fuel ratio, and ignition systems that modify spark advance are technologies that many home technicians are familiar with.

The big difference between GDI and conventional fuel injection is that GDI uses several operating modes to inject gasoline directly into the engine's combustion chamber.



Delphi's GDI High-Pressure, Low Noise Fuel Pump is a single piston pump that is driven off the engine's camshaft. The pump can deliver fuel pressures from 420 psi to over 2,800 psi, and includes an integrated flow control valve (electrical connector). The pump can be used on large displacement engines and can operate at engine speeds of 7,500 rpm.

While terminology used by automobile manufacturers may differ, the three basic modes of GDI operation are: ultra-lean burn, stoichiometric (relating to chemical laws of energy), and full power—all characterized by air/fuel ratio. The ultra-lean burn mode, or stratified charge mode, is used for light-load operating conditions and constant road speeds. Fuel is injected into the combustion chamber during the latter stages of the compression stroke of the engine's four-stroke cycle, instead of at the beginning of the intake stroke. The air/fuel mixture can be as lean as 65:1 (lean mixtures on conventional EFI are in the 15:1 range). The fuel/air charge is placed near the spark plug, where it burns with decreased combustion temperatures, lower emissions, and heat losses, all resulting in more power. This ultra-lean mixture would be impossible to achieve with carburetors or conventional fuel injection.

The stoichiometric mode is used for moderate load driving conditions. The fuel charge is injected during the intake stroke and creates an air/fuel mixture (14.7:1) that is homogeneous (completely mixed air and fuel). This results in an optimum fuel burn where all the fuel and oxygen are consumed in the combustion process. The exhaust gas is fairly clean, and any hydrocarbons that do

(continued)



Delphi (left) and Bosch GDI fuel injectors. Because of the high fuel pressures involved (500 to 3,000 psi), these injectors require 60 to 90-volts to open. After the initial opening, the PCM switches voltage to 12 volts to keep the injectors open until they are turned off. Each time the injector is removed from the cylinder head, the Teflon seal on the end of the nozzle must be replaced.

escape the engine are further cleaned by the catalytic converter. The GDI full power mode (around 13: 1 a/f) is reserved for rapid acceleration and heavy engine loads. The air/fuel mixture is slightly richer than stoichiometric and is homogeneous in nature. In the power mode, fuel is injected during the engine's intake stroke.

ADVANCED GDI STRATEGIES

Today's GDI systems are only possible because of advanced computing power. In addition to controlling all the emission-related components, and throttle position, the PCM has to contend with the multiple modes of the GDI system. If that were not enough, the PCM also has to integrate GDI operation with other advanced engine systems. One of these systems is variable cylinder displacement, where an engine's companion cylinders are essentially turned "off" to save fuel. Variable engine displacement, combined with GDI, is a milestone in automotive technology. For example, disabling three cylinders on a V-6 engine requires an

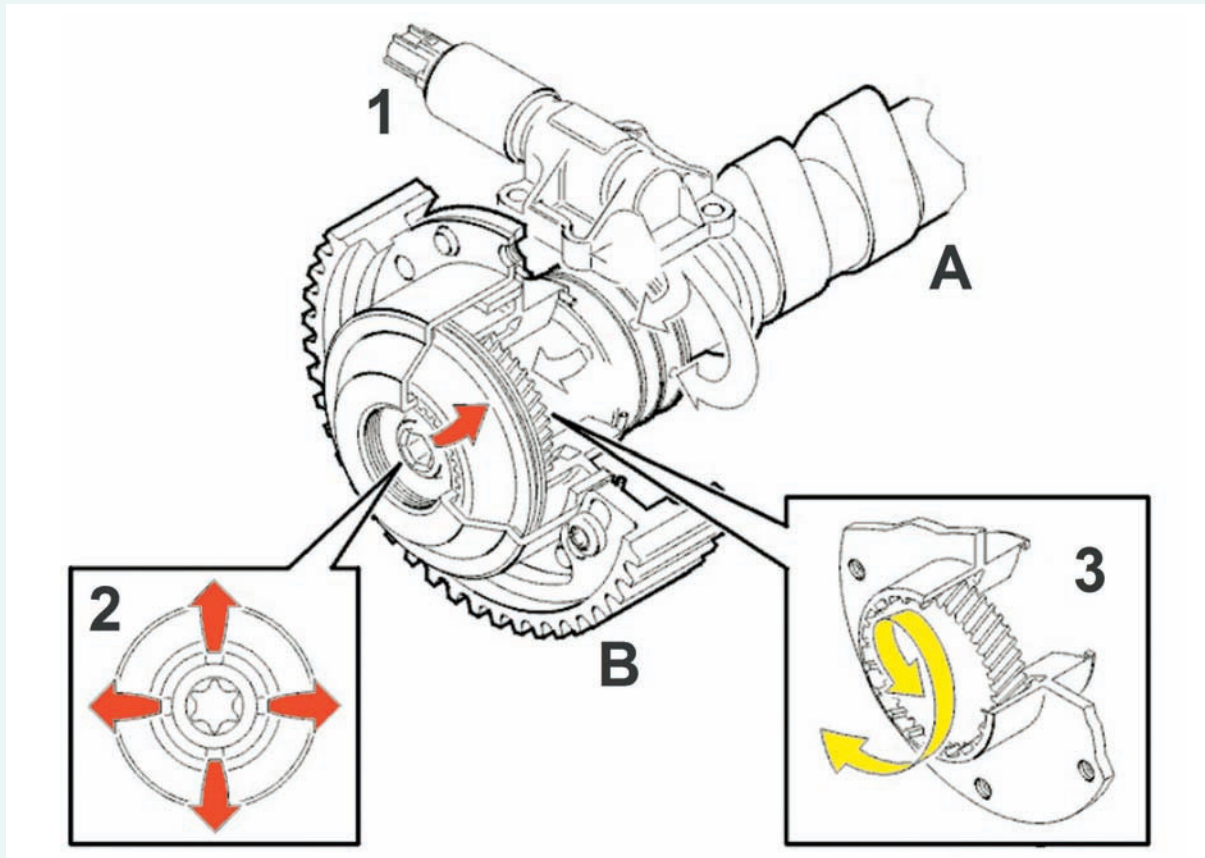
increase in throttle opening to supply air to the remaining three operational cylinders. The greater throttle opening lowers the intake manifold vacuum to those cylinders, resulting in a higher running compression pressure that produces more engine power at part throttle. During idle conditions, the higher running compression causes the air and fuel to be burned more efficiently. Fewer emissions are produced. To shut off specific cylinders, some variable displacement systems use a solenoid to unlock the camshaft followers on one bank of cylinders from their respective valve rockers. The cam followers float freely and the valve springs keep the valves closed. The pistons in these cylinders are still going up and down, but because there is no air entering the cylinder, there is no compression; the pistons are just along for the ride. When the driver steps on the gas pedal, the PCM turns the cylinders back on and the engine can produce full power. During variable displacement operation, the PCM changes the GDI injection timing and modes, along with controlling the throttle opening.

Variable valve, or camshaft, timing is another system that works in concert with GDI. Conventional intake and exhaust valves are operated by a camshaft(s) that controls when they will open and close in relationship to the crankshaft position. The resultant cam timing has a significant impact on the engine's power output. The drawback to the conventional systems is that the valve timing and lift (amount that valve is opened) is fixed for all engine rpm. The ideal camshaft timing/valve lift at idle is not suited for full power operation, and vice versa. Lower emissions at part throttle requires camshaft timing that will not be ideal for other operating conditions. Variable valve timing and lift allows engine performance to be improved over the entire rpm range, providing lower emissions and increased power output.

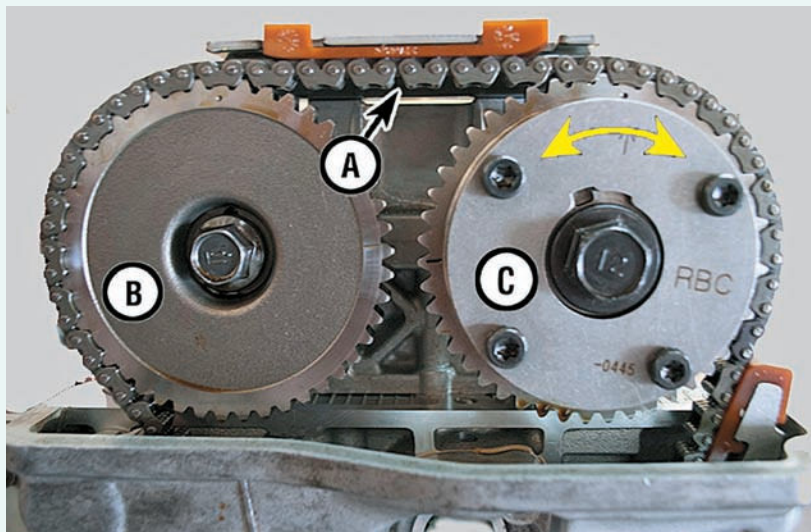
Variable valve timing can be accomplished in various ways. Some manufacturers use dual camshaft profiles and switch between the profiles via hydraulic actuators. Others use camshaft phase timing, where the cams are rotated forward or backward in relation to the crankshaft. The combination of variable valve timing and GDI offers automotive engineers a high degree of control over engine power, fuel economy, and emissions. A final improvement in engine efficiency, when combined with GDI, is turbocharging, covered earlier in this chapter.

The application of gasoline direct injection, combined with ancillary developments including variable cylinder displacement, turbocharging, variable valve timing and lift, advanced combustion chamber design, and wide-band air/fuel ratio sensors, results in smaller displacement engines that produce similar power to larger engines but have lower overall emissions and greater fuel economy.

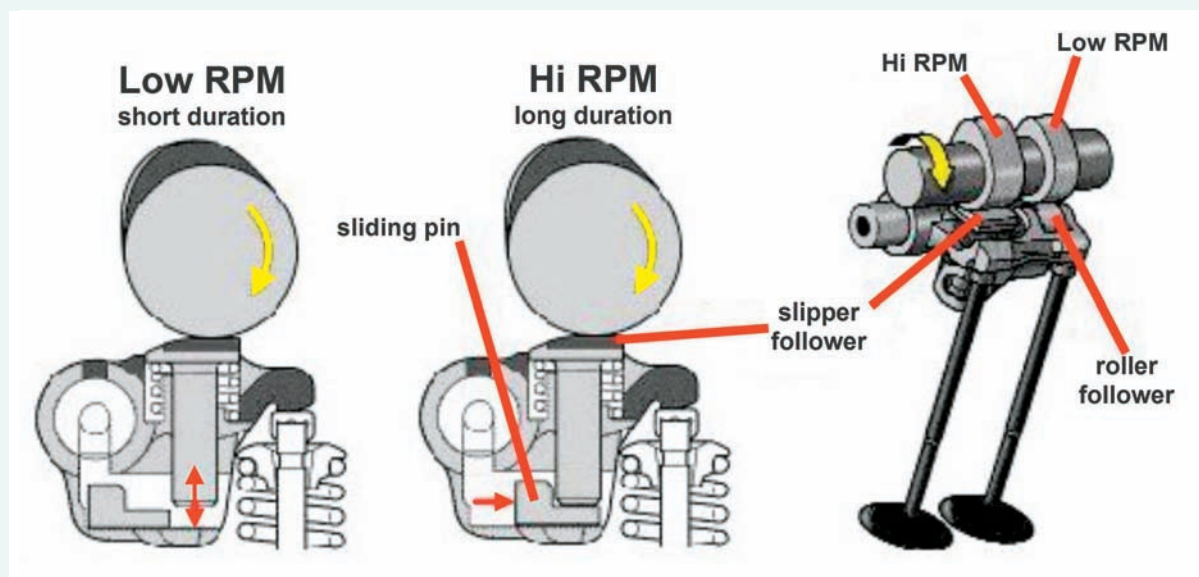
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Operation of typical variable camshaft timing. The camshaft (A) and cam timing sprocket (B) are turned by the timing belt—the same setup used on a conventional engine. The PCM controls the camshaft timing as follows: Variable cam timing is controlled by hydraulic oil pressure. The oil control valve (1) is opened and closed by the PCM. When the valve opens, oil pressure is sent into the camshaft actuator (2) where oil pressure pushes on a piston. This action causes the helical gear inside the cam actuator to rotate the camshaft (3). The ability to advance and retard the camshaft timing provides the engine's cylinders with increased volumetric efficiency, or fill rate.



This engine uses double overhead camshafts. The timing chain (A) is turned by the engine's crankshaft, which rotates the intake cam (B) and the exhaust cam (C). Depending on engine rpm, and load conditions, the PCM can cause the camshaft actuator on the exhaust cam to rotate independently from the cam sprocket (yellow arrow). This action provides the ideal valve timing for both high and low engine rpm operating conditions.



Honda's VTEC engines use variable camshaft lift that provides two different cam profiles. During low engine rpm operation, the short duration cam profile is used to increase torque. During high rpm/load operation conditions, the PCM switches the camshaft lift to the long duration profile by cycling a solenoid linked to oil pressure. The change in pressure operates a locking pin that binds the high rpm, long duration cam profile to the low rpm cam follower. Because the high rpm profile maximizes cylinder filling, the engine produces more power.

GDI ISSUES

GDI does have some operating problems that are unique. Carbon accumulation on intake valves, excessive camshaft wear on high pressure pump lobe(s), and low-speed pre-ignition plague some systems. Unlike multi-port fuel injection, where fuel injectors spray fuel directly, or close to the back sides of the engine's intake valves, GDI system injectors discharge fuel directly into the combustion chamber. With no fuel to wash away the carbon deposits on the backs of the intake valves, and their valve seats, those surfaces become clogged with carbon buildup, which results in engine misfires. Most of the carbon deposits come from the exhaust gas recirculation (EGR) system and the positive crankcase ventilation (PCV) system. If the deposits are significant, the cylinder head(s) and intake manifold may have to be removed to clean and resurface the valve seats.

Another issue with GDI systems is premature camshaft wear on the cam lobe that drives the high-pressure GDI fuel pump. Some of these cam lobe problems are caused by the manufacturer's choice of materials used for the camshaft and cam followers. Fortunately, these issues are usually repaired under new car warranties. If manufacturer-approved, application-specific engine oil is not used, the cam lobe that operates the fuel pump may wear rapidly.

When changing engine oil on a GDI engine, always follow the manufacturer's recommendations for the type and brand of oil to use.

Now, an issue that is not particularly common but does show up occasionally: Small displacement turbocharged GDI engines may exhibit detonation due to very small droplets of oil that pass through the piston rings, transform from a liquid state to a vapor, and spontaneously ignite due to the high combustion chamber temperatures. This phenomenon can cause mechanical engine damage by upsetting the carefully managed combustion process used in GDI engines.

GDI SAFETY

Working with multi-port fuel injection and gasoline can be a fire hazard, and the same is true with GDI systems. However, GDI has another potential safety hazard. Because the high pressure side of a typical GDI system reaches pressures of 500 to more than 3,000 psi, extreme caution must be taken when working on these fuel systems. A quick burst of fuel from a fuel line that is being disconnected at 3,000 psi can slice off a finger. Before repairing a GDI system, this high pressure must be bled off, or otherwise relieved. The high-pressure is located between the high pressure fuel pump discharge and fuel rail for the injectors.



To relieve fuel pressure some manufacturers recommend disabling the fuel pump with the bi-directional controls included with most scan tools, then starting and running the engine until it stalls. Other manufacturers use alternate methods for fuel pressure relief. The most common method of relieving fuel pressure is to remove the fuse or relay that controls the low pressure pump. Then start the engine and let it run until it dies. This procedure may not remove all of the high pressure in a GDI system, so a scan tool can be used to read pressure in the fuel rail. Always refer to a factory service manual for the proper and correct procedure for relieving fuel pressure on a GDI fuel system. Some manufacturers advise waiting at least two hours after pressure relief before opening up the high side of the system. In addition, for reassembly many manufacturers require that all O-rings and most of the high pressure steel fuel lines and high pressure fuel pump mounting bolts be replaced with original equipment as components are replaced or removed.

GDI DIAGNOSTICS

The typical GDI system can be divided into low and high pressure components. The low pressure side is similar, if not identical, to a multi-port EFI system. There is a low pressure lift pump located in the fuel tank. Some manufacturers use a pulse damper built into the low pressure line and even a service port for pressure testing. Low side fuel pressures are similar to multi-port injection and are in the range of 40 to 60 psi.

The high pressure side of GDI systems has a high pressure mechanical fuel pump that is powered by the engine's camshaft. Some V-6 engines use two high pressure pumps. These pumps must be "timed" when they are installed. They are capable of pressures from 500 to 3,000 psi, and contain an electric pressure regulator solenoid that is controlled by the PCM. There is also an internal pressure relief valve. During engine operation, the high pressure pump will make a clicking noise. Fuel rails used on GDI systems are made from stainless steel for strength and corrosion resistance. Fuel rails are often called a "common rail," much like those used on diesel engine injection systems. The fuel injectors are attached to the rail via special, one-time-use clips or retainers. There is no service port for pressure testing on the fuel rail. High pressure lines may use ball type, one-time-use fittings and should always be replaced when servicing.

The fuel rail is bolted directly to the cylinder head and is often "buried" under the intake manifold. Because the fuel pressure is so high, the average injector pulse width is 0.4ms (400 micro-seconds) as compared to multi-port

injection pulses that are in the 1.5ms to 3.5ms range. To work with the injectors, the high pressure pump must be able to react quickly to fuel delivery requirements. To achieve this, the pressure control solenoid can be cycled at 4,700 cycles per second. On some systems, the PCM will trigger low pressure pump operation when the engine is off for one second at a time—four to five times in a six-hour time period. This keeps pressure applied to the fuel inlet of the high pressure pump and prevents fuel vapors and air from entering the high pressure pump. If fuel vapors are present in the high-pressure pump the engine will not start until sufficient pressure is built up as the engine is cranked over. The PCM will not allow the ignition to operate until it senses enough pressure from the fuel pressure sensor.

The fuel injectors on a GDI system can be one of two types: solenoid (the most common) and piezoelectric. Because of the high pressures, 50 to 65 volts are required to initiate injector opening before voltage drops to 12 volts to keep them open. The Piezo injectors are a stack of crystals that open the injector valve and may use voltage as high as 105 volts to operate. Do not use noid lights or a 12-volt test light for testing injector signals from the PCM because shocking results may complicate your day.

The following are some common high pressure side service components and procedures: high pressure pump failure (use new bolts, seals, and gaskets), high pressure pump bucket cam follower wears out, injector failure (removal may require special tools), pressure sensor failure, de-carbonizing the intake manifold and intake valves. Many of the high pressure lines are a one-time-use, ball end fitting and must be replaced anytime they are loosened or removed. Use GDI PIDs for diagnostics as there are many more of them than those with port fuel injection systems. Use the scan tool's bi-directional controls to turn on/off components for testing and function. Pay attention to DTCs that are specific for GDI systems.

continued from page 154

NO-START CONDITIONS

In those instances when an engine cranks over but just won't start, there are some basic things any technician, regardless of skill level, can check or do before calling a tow truck. The first thing is obvious: use a code reader or scan tool to check if any DTCs have been set by the PCM. Diagnostic trouble codes are a good place to start any investigation into potential causes of a specific problem. They may provide valuable clues as to what the problem is, or where the malfunction is most likely located. At a minimum, trouble codes will reveal the system that has the problem. For instance, if any of the range of #P0350 to #P0362 diagnostic trouble codes are set, a problem with the vehicle's ignition

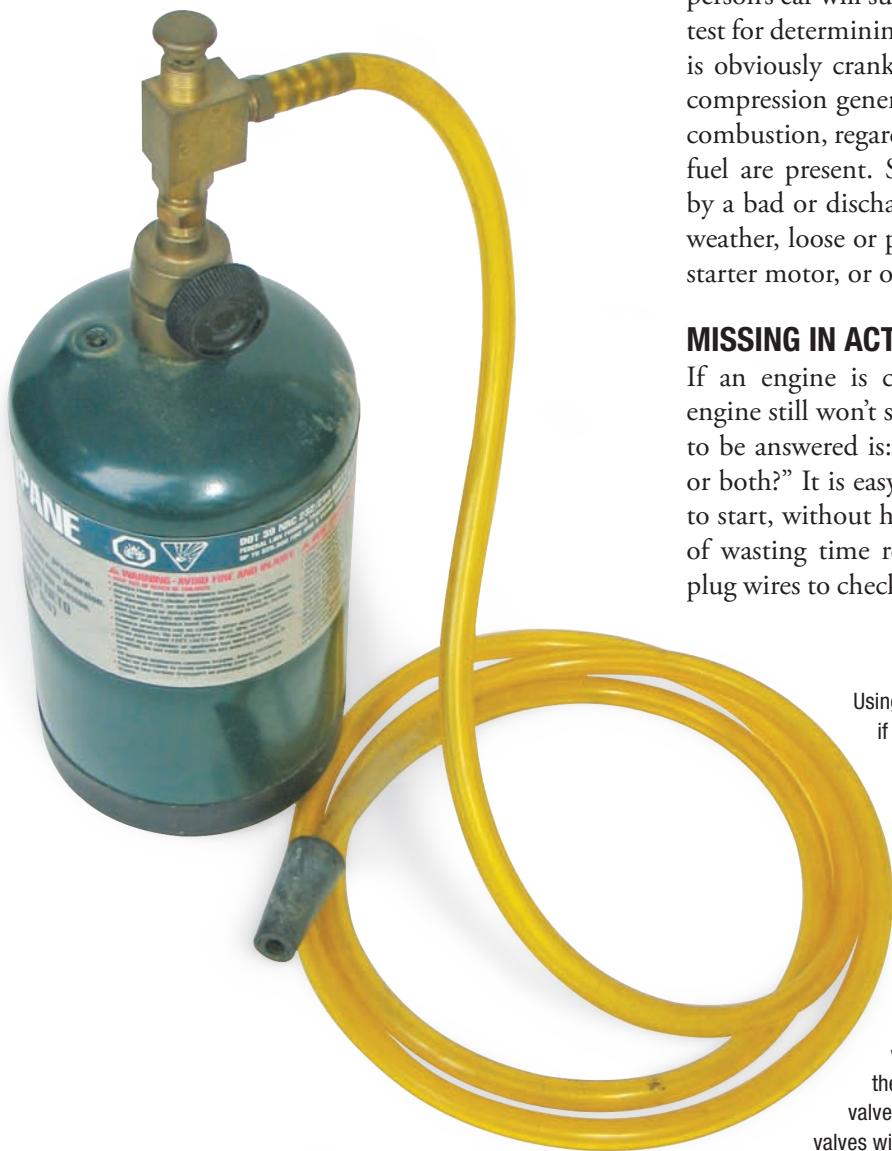
system is probably causing a no-spark condition. However, #P02XX fuel and air metering codes are also a possibility, so these should be checked. Moreover, remember that just because a code has been set by a PCM doesn't mean it's time to start replacing parts, at least not until it has been verified by other independent methods that a no-spark condition really does exist. Keep in mind, ignition system DTCs only provide a clue to the *source* of the problem, but not necessarily the answer.

As most technicians know, slow engine-cranking speed will prevent an engine from starting. Engine-cranking speed should typically be around 200 rpm, but engine speeds are actually difficult to measure at this level without special equipment. Fortunately, a person's ear will suffice, with some experience, as a basic test for determining engine-cranking speed. If an engine is obviously cranking slowly, there will be insufficient compression generated inside the cylinders to promote combustion, regardless of whether an ignition spark and fuel are present. Slow engine cranking can be caused by a bad or discharged battery, and aggravated by cold weather, loose or poor battery cable connections, a bad starter motor, or other mechanical engine problems.

MISSING IN ACTION—SPARK OR FUEL?

If an engine is cranking at normal speeds, but the engine still won't start, then the big question that needs to be answered is: "Is the engine missing spark or fuel or both?" It is easy to find out why an engine is failing to start, without having to take anything apart. Instead of wasting time removing ignition coils and/or spark plug wires to check for an ignition spark, try this simple

Using propane is a relatively safe way to determine if an engine has spark, but no fuel. This simple test bypasses the entire electronic fuel injection system. To perform the test, insert the hose from the propane bottle into the intake duct at the throttle body, then turn on the bottle's valve and crank the engine. If the engine starts and runs (even for only a few seconds), then the presence of an ignition spark is confirmed. The valve on the propane bottle shown in the photo is actually designed for automotive use, so it is equipped with a plunger at the top that instantly opens the valve. Propane flow is controlled via the round valve located at the top of the propane bottle (other valves will also work, but not as well).





test instead: Take a hose from a propane bottle and either snake it into the air cleaner or directly place it onto the throttle body. Then open the propane bottle's valve slightly while an assistant cranks the engine over. If the engine starts and runs, even for a few seconds, the ignition system is producing a spark.

In such an event, be sure to check for the presence of a full 12 volts at all fuses, as this could be a cause of no-fuel problems. Furthermore, if an engine doesn't start even after a shot of propane, a check for ignition problems is in order. Also be sure to check ignition/coil power-related fuses in addition to fuel-related fuses. Although a non-operational fuel pump won't necessarily cause a PCM to set a DTC, it is wise to check the #P0230 to #P0233 range of DTCs (all are related to fuel pump primary circuit operation) as a good first place to start an investigation into the cause of a no-fuel condition. Most vehicles' on-board-computers are programmed to allow a fuel pump to run for a few seconds to prime the fuel system after the ignition key is first turned on. Have an assistant turn the ignition key to "ON" while you place an ear to the open fuel tank filler hole—you should be able to hear the fuel pump running. However, bear in mind that not all vehicles may allow a fuel pump to run (check an appropriate vehicle service manual to verify this fact), so don't automatically assume something is wrong with the fuel pump if you don't hear it running.

Once it is verified that both spark and fuel are present in a combustion chamber, but an engine still won't start, use a vacuum gauge to check if cranking vacuum exists. Low or no cranking vacuum may indicate a significant leak in an intake manifold, or that camshaft timing is retarded—either of these can cause a no-start condition. (See Figure 6-10, page 133.)

If valve timing is suspected (one indication of no cranking vacuum), camshaft timing can be verified by inspecting the alignment marks on the crankshaft and camshaft. A service manual will have to be consulted to locate the timing marks and interpret correct engine valve timing alignment.

Finally, the absence of cranking vacuum can be caused by a plugged-up exhaust system, which can occur if a vehicle was driven over a curb and ended up with a smashed exhaust pipe or catalytic converter. To test for a plugged converter disconnect the exhaust pipe located between the catalytic converter and the engine; to accomplish this, simply loosen any exhaust connection sufficiently enough so that it will allow exhaust gases to bypass the catalytic converter. If the engine now starts and runs, the source of the problem has been discovered.

Another cause for a non-starting engine could be any related vehicle alarm codes. "Fuel enabled" or "alarm-" related diagnostic trouble codes are not generic OBD-II DTCs, but are instead, specific manufacturer's enhanced trouble codes. For example, any of the anti-theft-related diagnostic trouble codes could actually prevent a PCM from starting the engine. A PCM will do this simply by shutting off components like a starter motor, fuel injectors, or ignition coils. A specific example of this can be seen on certain Chrysler cars, where an enhanced manufacturer-specific OBD-II trouble code like "Fuel Enabled = NO" exists. On these vehicles, a PCM sometimes reacts in a manner consistent with having an alarm activated, even if no alarm exists on the vehicle in question. In such instances, the problem may actually be with the PCM itself, in that either a wrong PCM has been installed, or a specific PCM needs some updated programming.

Now that we've covered basic engine diagnostic procedures we'll move on to how to use a scan tool to diagnose basic OBD-II related problems and trouble codes. Chapter 7 discusses basic scanner operation, and puts what you know to practical use.



Chapter 7

Scanner Operation

This chapter, scanner operation, will discuss how to effectively use a scan tool to diagnose OBD-II related problems. For those of you who skipped chapter 6, “Automotive Detective Work” you will probably have to read it anyway because the engine in your car or truck is still after all just a mechanical air pump that has to seal and operate correctly. If there is a mechanical problem with the engine, the PCM will not have the ability to diagnose basic engine related problems like low compression, vacuum leaks, burned or bent valves, or blown head gaskets. In addition to engine mechanical problems, any issues with a weak or bad battery, or problems related to the charging system will cause unreliable diagnostic results from the PCM. These results may show up as multiple DTCs that seem to have no direct relation to each other. These types of DTCs may show up as sensor signal outputs that are way out of range and/or PCM output failures. Chapter 6 shows you how to separate OBD-II computer related issues from engine mechanical and charging system/battery problems. So before you tackle the “Service Engine Soon” light, and related diagnostic trouble codes, make sure the problem is not something simple that has been overlooked.

Start the diagnosis process by reading any DTCs that the PCM may have stored. If the vehicle is having drivability problems check for codes even if MIL is not on, as pending DTCs may be present. If the MIL is on, see if it also flashes at any time when the vehicle is being driven. The behavior of the MIL can provide clues as to what’s wrong. Also note when any drivability symptoms occur. Is the engine hot or cold? Does the vehicle have to be driven for a short or long period of time before the problem shows up? How long have the symptoms been present—did they happen right after someone else replaced a component or worked on the vehicle?

If there are any trouble codes stored in the PCM, check for freeze frame data. If your scan tool has the capability, print out freeze frame data and any codes scanned. If the scan tool or code reader cannot print these test results, write down the freeze frame. Don’t just read and then erase DTCs that are present in the PCM’s

memory. On most vehicles, when the codes are cleared so is all the freeze frame data. If you inadvertently lose this valuable information it may take considerably longer to correctly diagnose what’s wrong. Make a visual inspection of the engine compartment and look for anything that is obviously disconnected or damaged, including vacuum hoses and sensors. Especially pay attention to areas indicated by any DTCs that have been set by the PCM. For example, if one or more DTCs present are related to the EGR system operation, and you find a loose, cracked, or disconnected EGR vacuum hose you may have solved your problem. The PCM, and all of its inspection and maintenance monitors, can lead you in the general direction of where to look for a problem. Often, though, it does not provide specific enough information to get to the root cause of engine performance or emission related issues. Remember that with all its computing power and sophistication, the PCM is not as smart as you, so don’t let it take you in the wrong diagnostic direction and waste your time and money.

TROUBLE CODES, OBD-I VS. OBD-II

When a trouble code is present, OBD-II offers much more specific information related to the faulty system or component than earlier OBD-I systems did. For example, a trouble code 53 on an EEC-VI Ford from the mid-1980s was defined as “TPS” or throttle position sensor malfunction. Numerous problems and conditions could cause this code to be set including: disconnecting the sensor and then turning the ignition ON; a problem with the wiring harness or connectors between the TPS and the Electronic Engine Control unit (on-board computer); a bad computer; or a loose TPS sensor. Other possibilities include a misadjust throttle plate; electrical interference from secondary ignition wires; and last but not least, a bad throttle position sensor. Many a technician wrongly assumed that a Ford code 53 indicated that the TPS should be replaced, but more often than not, this did nothing to fix the underlying problem. Scanning trouble codes on an OBD-I system only provided very general clues,



While some of the throttle position sensors (TPS) in this picture are from older OBD-I systems, they still provide the same information as they do on newer OBD-II-compliant vehicles. Fortunately, when something goes wrong with a TPS on an OBD-II system, the numerous TPS-related trouble codes can help pinpoint where a potential problem lies.

and not much more, as to where to start looking for a drivability or emission related problems.

OBD-II has made drivability and emissions diagnosis much easier by providing more specific, detailed information when a malfunction occurs. In the case of the throttle position sensor, there are five generic OBD-II trouble codes and seven manufacture specific DTCs, all for the throttle position sensor and its electrical circuit. (See figure 7-1.) Using only the generic OBD-II TPS-related DTCs, the following information about the TPS and its electrical circuit is available: too high or low a TPS output voltage, or TPS range of output voltage does not match other sensor outputs. Even intermittent circuit problems can be pinpointed simply by reading these OBD-II generic TPS-related trouble codes.

The manufacturer-specific “P1” codes provide even more detailed TPS circuit information. A code P1121 is defined on a scan tool as “Throttle position sensor inconsistent with mass airflow sensor.” A look in a service manual reveals a more detailed code P1121 definition: “While the engine is running, the PCM detected that the TPS and the MAF sensor are not consistent with

their designated values. Check the Real Time data, TPS = < 4.82% @ a load of 55% or TPS = > 49.05% @ a load of 30%.” This means that the PCM has received a TPS signal that is less than 4.82 percent of the throttle opening with a calculated load value (from the MAF sensor) of 55 percent. Because the engine load value is high at 55 percent (the engine is working at 55 percent of its total capacity), the TPS should have been sending an output voltage signal to the PCM indicating that the throttle was opened considerably more than 4 or 5 percent. The other half of this code definition (TPS = > 49.05% @ a load of 30%) is the opposite of the first. The TPS output voltage signal to the PCM is indicating that the throttle is open 49.05 percent, but calculated engine load value is only 30 percent—far too low for the throttle being open halfway, or 49 percent. The TPS-related DTCs in this example are typical of the detail of diagnostic information that OBD-II systems provide via a scan tool or code reader. Always keep in mind that while the P1121 code could be caused by a bad TPS sensor, it could also be caused by a loose sensor or misadjusted throttle plate. The P1121 is a specific

OBD-II Generic Codes

DTC	Code Definition
P0120	Throttle/Pedal Position Sensor/Switch "A" Circuit
P0121	Throttle/Pedal Position Sensor/Switch "A" Circuit Range/Performance
P0122	Throttle/Pedal Position Sensor/Switch "A" Circuit Low
P0123	Throttle/Pedal Position Sensor/Switch "A" Circuit High
P0124	Throttle/Pedal Position Sensor/Switch "A" Circuit Intermittent

Manufacture Specific OBD-II Codes

P1120	Throttle Position Sensor "A" Out of Range Low <i>While the engine is running, the PCM detected the TPS voltage was below its designated spec.</i>
P1121	Throttle Positions Sensor Inconsistent with Mass Airflow Sensor <i>While the engine is running, the PCM detected that the TPS and the MAF sensor are not consistent with their designated values. Check the Real Time data, TPS = < 4.8% @ a Load of 55% or TPS = > 49.05% @ a Load of 30%.</i>
P1122	Throttle Position Sensor "A" in Range but Lower Than Expected <i>While the engine is running, the PCM detected the TPS to be below its designated spec.</i>
P1123	Throttle Position Sensor "A" in Range but Higher Than Expected <i>While the engine is running, the PCM detected the TPS to be above its designated spec.</i>
P1124	Throttle Position Sensor "A" Out of Self-Test Range <i>While the engine is running, the PCM detected the TPS to be out of its designated spec of less than 13.27% with KOEO, or more than 49% with KOER.</i>
P1125	Throttle Position Sensor "A" Intermittent <i>While the engine is running, the PCM detected the TPS to be out of its designated spec. Check the Real Time data, and do a wiggle test to look for intermittent changes in the output.</i>
P1126	Throttle Position Sensor Circuit <i>While the engine is running, the PCM detected the TPS to be out of its designated spec. Check the Real Time data, and do a wiggle test to look for intermittent changes in the output.</i>

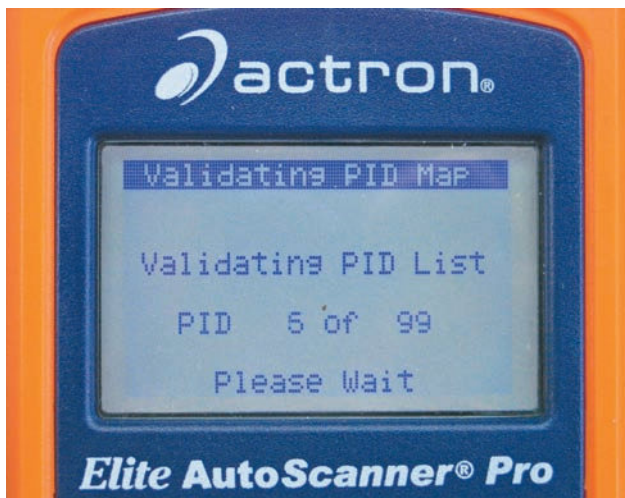
Fig.7-1—OBD-I systems usually only provide a single (or maybe two) trouble code(s) if anything is wrong with its system computer sensors. OBD-II has much greater diagnostic capabilities. The example seen here shows five generic DTCs and seven manufacturer-specific trouble codes—all for a throttle position sensor, or TPS. OBD-II provides this detailed level of diagnostic information to narrow down what is actually wrong with the TPS sensor, or its related electrical circuit.

clue, but *only* a clue, and not necessarily the ultimate answer to a drivability or emission-related problem.

LIVE DATA STREAM, OR PIDS

By checking the parameter identification (PID) information on a scan tool and comparing the PCM data values with a service manual, you can readily see when a sensor is out of range or inconsistent with other sensor inputs. For example, if the engine had just been

started and running for only a minute, the coolant temperature sensor (CTS) reading should be higher than the intake air temperature (IAT). Because the engine is running, the CTS should increase to normal operating temperature (over 200° F) within a few minutes at idle, or sooner after driving a short distance. If the CTS value was the same as, or only slightly higher than, the IAT, or if the coolant temperature was lower than the IAT, a problem would be indicated



When "View Data List" is selected from the main menu, this Elite AutoScanner Pro scan tool accesses the PCM and validates the PID (parameter identification) list. PIDs are nothing more than the data stream from the PCM and its various sensors. The vehicle that the scan tool was connected to had 99 PIDs available. *Courtesy Actron*

with the coolant sensor. Be careful when using generic, seat-of-the-pants sensor ranges and values, as these may vary widely between manufacturers, and even between model years and engine families from the same manufacturer.

WHERE TO FIND INFORMATION

In addition to scanning for DTCs and reading a vehicle's data stream, check for technical service bulletins (TSBs) from the manufacture of the vehicle you are working on. This is especially true if the MIL is on and there are no drivability issues. Often, trouble codes or other weird drivability problems are just a matter of updating the PCM's software with the latest "fix" from the factory. Reprogramming the PCM is typically done on new vehicles because the automotive engineers who design these systems don't always get things right the first time; after a model has a few thousand miles on the odometer, design flaws may show up. TSBs and other service information can be found in a variety of places. Sometimes you can find TSBs on the manufacturer's website, or on a discussion forum where owners of the same vehicle share technical information and tips and tricks for their favorite car or truck. Actron and AutoXray have a subscription website called CodeTrack, where do-it-yourself technicians can access specific information on OBD-II codes and TSBs. The website address for



This is the live data stream from the vehicle that this Actron scanner is connected to. By using the down arrow key on the scan tool, more PIDs, or sensor data, will be displayed. Comparing PID values to those found in a service manual is a good way to verify that sensor outputs are where they belong and that nothing is out in "left field," and causing a problem. For example, the engine in this vehicle has only been running for a few minutes. The coolant temperature sensor reads 20° higher than the IAT (intake air temperature) sensor, indicating that the sensor is functioning properly. *Courtesy Actron*

CodeTrack is www.codetrack.spx.com. Another good source of information is the International Auto Technicians Network (IATN). With over 50,000 member technicians, as many as 2,000 may log on to the website at one time—all sharing information and giving advice. The IATN website is located at www.iatn.net.

Finally, if you want to talk live to an actual technician about your specific drivability or OBD-II related problem, try the SCM Hotline. This resource currently supports a large number of professional and home technicians, and has quick access to technical data from the hotline's in-house database. Vehicle coverage includes foreign and domestic cars and light trucks (gasoline and diesel) from 1964 to present. The automotive systems that are covered include: engine performance, OBD-I/OBD-II diagnostics, climate control (HVAC), ABS braking systems, computer-controlled transmissions, supplemental restraint systems (air bags), and electronic body control systems. Information regarding OEM factory information, technical service bulletins, wiring diagrams, repair procedures, component locators, and other-service related information is available. The hotline can be reached at 800-847-9454, or on the Internet at www.AutoHotLineUsa.com

Jeep Grand Cherokee Technical Service Bulletin #18-40-98

18-40-98 -- HIGH IDLE RPM DURING DECELERATION

Date: 12/18/98

Model year(s): 1999

Description: THIS INFORMATION APPLIES TO VEHICLES EQUIPPED WITH 4.01L ENGINES BUILT PRIOR TO DEC. 18, 1998. Some vehicles may exhibit high idle RPM during deceleration and/ or parking lot maneuvers when the engine coolant temperature is greater than 103 c (217 f). The increased idle rpm will return to normal when the vehicle comes to a stop. Coolant temperatures greater than 103° C (217° F) are more noticeable in high ambient temperatures during stop and go traffic, or after towing.

Details: Using the Mopar Diagnostic System (MDS/MDS2) or the Diagnostic Scan Tool (DRB III®) with the appropriate Diagnostic Procedures Manual, verify all engine/transmission systems are functioning as designed. If Diagnostic Trouble Codes (DTC's) are present, record them on the repair order and repair as necessary before proceeding further with this bulletin. Make sure the cooling system is working properly and verify that the engine temperature sensor values are valid. If no other problems are found, reprogram the PCM following the proper Repair Procedure as outlined on page two of this TSB.

A typical TSB, or technical service bulletin. This one is for a Jeep Grand Cherokee with a 4.0L engine, built prior to December 18, 1998. The symptoms are a high engine idle speed when the engine temperature is above 217° F. In addition, the TSB states that idle speed will return to normal when the vehicle comes to a stop. The "Details" paragraph advises the use of a Mopar Diagnostic System or factory diagnostic scan tool (DRB-III) to verify that all systems are functioning as designed, and to read any DTC that are stored in the PCM. The repair procedure is to reprogram, or flash-update, the PCM. What the TSB doesn't state is that the only way to accomplish this is by use of a factory scan tool or diagnostic system. This TSB also illustrates that the causes of some drivability problems are not related to components that are broken or malfunctioning. In this case, a software update is the only way to "fix" the problem. Technicians unaware of this type of TSB could spend needless hours trying to find something wrong with the vehicle.

USING OBD-II DRIVE CYCLES AND DIAGNOSTIC MONITORS

As discussed in chapter 2, "OBD II, the On-Board System Monitor," OBD-II system monitors can be used to diagnose both emissions and drivability problems. There are two basic reasons for taking this approach. The first is that unlike OBD-I systems of the past, OBD-II is robust enough to do a pretty fair job of figuring out what is working (or not working) with the emissions systems that it monitors. Because many emissions-related systems and controls are closely associated with engine performance (fuel injection and ignition systems

are but two examples), these systems' ability to function properly will have a great effect on drivability and engine performance issues. OBD-II diagnostics have been designed, developed, and installed on all vehicles since 1996, so why not take advantage of their diagnostic capabilities? By allowing the OBD-II system to run all its inspection and maintenance (I/M), a technician can know for sure that everything is working as it should.

The second reason to use OBD-II for diagnostic work is its ability to turn off the malfunction indicator lamp (MIL) and to verify if any repairs were successful. Clearing trouble codes and turning off the MIL can

be accomplished using a scan tool or coder reader. However, if a component was replaced because a DTC was set, one of the best ways to know that the problem is actually fixed is to see if the vehicle's PCM can turn off the MIL all by itself.

Using the PCM to turn off the MIL has another advantage. Turning off the MIL using a scan tool can be a problem if the vehicle is directly driven to a state emission testing facility for a smog test. Here's why. When DTCs are cleared using a scan tool, or code reader, all I/M monitors are set to "not ready" or "incomplete." Most state testing programs require that most, if not all, I/M monitors be in a "ready" state to pass emissions testing. The vehicle will have to be driven enough random miles to cause the PCM to run all I/M monitors before the vehicle can pass emission testing. As an alternative to driving many miles, performing the manufacturer's specified drive cycle will speed up this process and set the I/M monitors to a completed, or ready, state sooner than by merely driving the vehicle.

By following a specific manufacturer's drive cycle to run all the continuous and non-continuous I/M monitors the OBD-II system, you can perform fairly extensive tests of fuel, ignition, and other engine-

management systems. Chapter 2 has an example of a generic OBD-II drive cycle, but the specific manufacturer's procedure is a better way to ensure that all the monitors will run. A scan tool, or code reader, connected to the OBD-II system can be used to see exactly when a particular monitor has been completed.

Many of these I/M monitors can be verified by reading data from a scan tool during the drive cycle. Needless to say, looking at the PIDs (live data stream) on the scan tool's display and watching the road at the same time is not a good idea or a very safe driving practice. Have a helper along for the ride when you perform drive cycle monitoring and testing. Drive cycles for General Motors, Ford, DaimlerChrysler, and European vehicles are discussed beginning on page 177. Some vehicles may require specific drive cycles instead of manufacture-generic drive cycles for their monitors to run. A service manual should be consulted to determine the exact drive cycle to be used.

GENERAL MOTORS DRIVE CYCLE

The General Motors drive cycle will test all the emissions-related components and their systems. This drive cycle tests various groups of I/M readiness monitors instead of individual monitors. Drive cycles of specific General Motors vehicles may be different than the one presented here. A service manual should be consulted for drive cycle procedures for specific models. Here is a generic drive cycle for General Motors vehicles.

1. **Cold start**—In order to be classified as a cold start, the engine coolant temperature must be below 122° F and within 11° F of the ambient air temperature at startup. Do not leave the key "ON" prior to cold starting the engine; if you do, the heated oxygen sensor monitor may not run successfully.
2. **Idle**—The engine must be running for two and a half minutes with the air conditioner and rear defroster turned on. These systems apply an electrical load to the alternator. In fact, the more electrical loads you can apply to the charging system the better for completing the OBD-II monitors. This will test and run monitors for the O₂ heater, passive air, ignition misfire, and purge-EVAP flow. If a closed loop is achieved, fuel trim will be tested.

continued on page 177



This Actron scanner displays the status of inspection and maintenance (I/M) monitors. The information verifies that the PCM has tested all of the emission systems on the vehicle. The display image was captured after the diagnostic trouble codes were last erased, or cleared by the scan tool. Monitors are indicated as "OK" when they have completed, "Inc" when not completed, and "n/a" when that system is not present on the vehicle. To get all the monitors to run, a complete manufacturer's drive cycle will have to be performed. *Courtesy Actron*



SCAN TOOL PID DIAGNOSTICS TECHNIQUES, MISFIRE DETECTION STRATEGY

The following section is used with the permission of Mandy Concepcion, who for the past 16 years has been involved in the diagnosis of all the different electronic systems found in today's vehicles. Mandy also produces an automotive technology DVD-Video series, writes auto repair books, develops automotive software, and designs OBD-II scanners, scopes, and other diagnostic equipment. The Misfire Detection Strategy is from Mandy's book, *Diagnostics Strategies of Modern Automotive Systems, Scan-Tool PID Diagnostics*. The book is available on Amazon.com. More information about Mandy can be found on his website, www.autodiagnosicsandpublishing.com.

INTRODUCTION

In recent years, the scan tool has become faster at processing data and more powerful in how it tracks and displays OBD-II information. It is the first tool employed at the start of the diagnostics process, and with good reason. The scanner is versatile, with many built-in features that no other piece of equipment can match. It is also the only tool that can provide a window into PCM inner operations and memory functions. In essence, it displays what the PCM is seeing, regardless of whether it is true or not. With the scan tool, a whole array of convenient and fast techniques can be employed to quickly analyze and diagnose many OBD-II related problems.

In the last couple of years, the term "PID diagnostic" (On-board diagnostics Parameter IDs) has been used to denote the ability to diagnose a problem by analyzing the serial data on a scan tool. In fact, given today's faster scanners, it is possible to perform a great deal of the diagnostics process while sitting inside the vehicle. This has given rise to the term "front seat diagnostics." As much as 70 percent of diagnostic work can be performed by the simple correlation of OBD-II signal data, with the rest employing actual manual testing.

Serial data communications has been around for a number of years. As far back as the early 1980s, domestic manufacturers were putting out vehicles with available scan tool data parameters. These early communication protocols were proprietary in nature, which made it harder for aftermarket equipment makers to design affordable scanners for the home technician. Although the need for an OEM scan tool is as important now as ever, a wide range of engine performance and emission faults can be quickly diagnosed by the use of generic PIDs. Many home technicians will load 20 PIDs into the display of their new scan tool and be disappointed at the slow rate of data transfer. At first glance, the data seems less than ideal for the purposes of diagnostics.

The generic OBD II protocol works on a request system, which means that the scan tool has to send a request to the PCM for each PID. This OBD-II-generic request operation contrasts with the OEM communications protocols that work using data packets, by which PID data is sent in bursts or packets—a much faster rate of data transfer. The rate of data transfer for generic OBD-II PIDs can be accelerated if the scan tool requests less data. With many scanners, requests for just three or four PIDs allow the PID data rate to be fast enough to see changes in OBD-II operating systems in close to real time, and allow its use as a diagnostic tool. By combining different and faster data PIDs to form a relationship, a signal correlation can be arrived at. For example, an EGR valve that is commanded on (manually or otherwise) should have an effect on MAP sensor values. A lack of MAP sensor response is a good indication of a defective or clogged EGR valve, since an opening EGR valve should create a drop in intake vacuum.

The same PID strategy is employed by the PCM when running drive cycles. Home technicians can use these techniques to their advantage when diagnosing an engine performance problem. Both OEM (enhanced) and generic information formats (PID data signals) will be implemented in the diagnostics strategies used for misfires. It is also worth mentioning that in order to attain maximum advantage with these techniques, the use of graphing software is highly recommended. A scan tool, laptop, or smartphone with graphing features can display a picture of PID values that can be understood more easily than just raw numbers.

IGNITION AND INJECTOR MISFIRES

With recent advancements in electronics, the design of modern electrical systems poses a real challenge to technicians. Gone are the days of simple electronic distributor-type ignitions, where a coil wiretap was all that was needed to obtain a secondary ignition pattern. Newer systems like DIS or COP are extremely hard to access in order to perform manual testing. The need for a better and quicker way to test these systems is obvious. The chart in Fig. 7-3 shows the relationship of ignition misfire to O₂ sensor freeze frame data. Freeze frame data is a snapshot of the relevant PIDs pertaining to the particular code set, taken at about one to two seconds after the code has set. The data seen here was gathered just before the code was set, and after. Freeze frame data cannot be used to detect fast-acting glitches, but it is useful in the analysis of slower-moving PIDs (fuel trims, ECT, TPS percentages, etc.). For OBD-II, the PCM holds a misfire code in memory

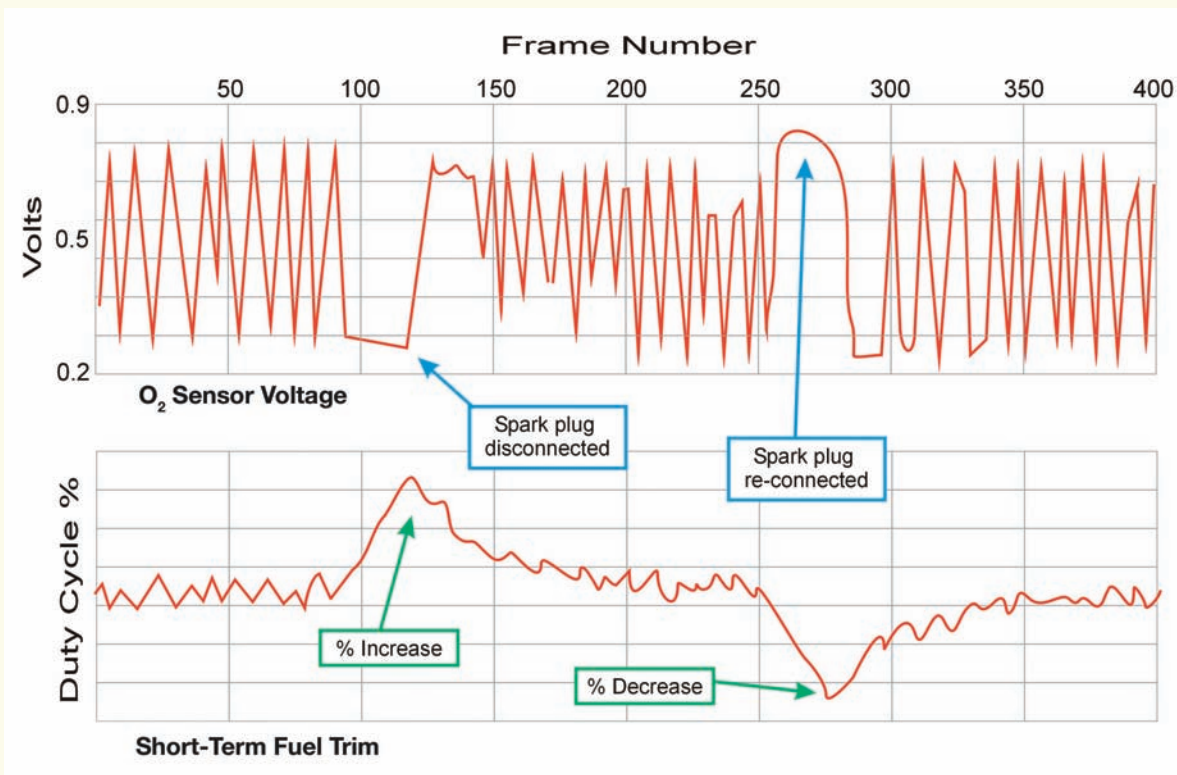


Fig.7-3—This chart shows the O₂ sensor voltage in relationship to a disconnected spark plug. The resulting misfire causes the O₂ sensor voltage to decrease, indicating a lean condition at the time of misfire. The PCM will add fuel to compensate for the phantom lean condition. When the spark plug is reconnected, the O₂ sensor voltage returns to normal values. The short-term fuel trim also increases when the plug is disconnected, indicating that the PCM has added more fuel. STFT returns to normal when the plug is reconnected.

for 80 engine warm-up cycles. In contrast, the PCM holds a non-misfire code for 40 warm-up cycles, so using PID for diagnosing misfires is an effective strategy. Because freeze frame data is erased when OBD-II codes are cleared, this should be the last step in the diagnostic process and should only be done after repairs have been made.

Two basic types of misfires can be detected using O₂ sensor data (PID) on a scan tool. These are: ignition/injector misfires and EGR-density misfires, which are the most common misfire faults. Malfunctioning triggering devices (camshaft/crankshaft sensors) cause a third type of misfire, which may necessitate the use of lab scope (oscilloscope) testing. But before delving into misfire diagnostics, keep in mind that not all misfires can be detected using O₂ sensor data. Minor misfires will be masked almost immediately by the PCM, as seen between frames 150 and 250 in Fig. 7-3. When a spark plug is disconnected (frame 100), the PCM will add fuel and the O₂ voltage will appear normal for a short time. The spark plug is reconnected at frame 250 and the O₂ voltage returns to normal values.

Ignition misfire on conventional distributor-type ignition systems is usually caused by defective secondary components—spark plugs, high voltage plug cables, plug boots, etc. Modern ignition systems that use DIS and COP technology make it extremely hard to get to any of the secondary components for testing. The nature of some of these systems, like COP and integrated ignition modules (module inside the coil), also renders some of the previously used secondary ignition analyzers useless. The proper diagnosis of these new ignition systems lies in carefully thought out OIB-II PID diagnostic procedures. By correctly analyzing the different serial data PIDs, a diagnostic conclusion can be arrived at without performing any major intrusive (manual) testing. When it comes to fuel control, an ignition misfire behaves exactly like a vacuum leak. During the misfire the O₂ sensor goes lean (low voltage), since the mixture consists of oxygen and unburned raw fuel. The O₂ sensor only senses the excess O₂ present in the exhaust, and cannot measure or account for the raw unburned fuel.

(continued)

The chart in Figure 7-3 shows the following: the O_2 sensor will go lean (low voltage) in the event of a secondary ignition misfire; the O_2 sensor will go lean in the event of an injector shutdown and misfire (clogged or electrically open injector coil). The chart also suggests that a misfire will occur if an injector is stuck in the open position, causing the O_2 sensor to go lean. This is a rich misfire caused when excess fuel is sufficient to extinguish the spark at the spark plug. The O_2 sensor will go rich (high voltage) in case of an excessive EGR flow misfire caused by an EGR valve that is stuck open due to carbon buildup. Because these gases are void of oxygen, the O_2 sensor perceives the diluted exhaust gases as being rich.

Secondary ignition misfire is by far the most common of all misfire problems. This misfire, caused by no spark at the spark plug, allows an excessive amount of raw fuel and oxygen into the exhaust system. The result is a low (lean) O_2 sensor voltage reading because of the excess oxygen in the exhaust. The O_2 sensor does not measure the raw fuel being thrown into the exhaust. It only senses the oxygen content, hence the low O_2 sensor voltage (lean) reading. A misfiring cylinder due to a secondary ignition problem will introduce raw fuel into the catalytic converter, and cause the converter to overheat. Also, the PCM will interpret the misfire as a lean condition and further enrich the mixture to compensate, adding even more fuel into the engine. A 5-gas analysis of this condition will result in a high oxygen content and high HC (raw fuel) content. Figure 7-3 shows an increase in short-term fuel trim when the spark plug is disconnected. When the plug is reconnected the STFT decrease and returns to a normal value.

On some vehicles, an overly compensating PCM will richen the mixture so much that the O_2 sensor will shift to a high voltage reading, thereby skewing the test results. A glance at the fuel trim PID will confirm whether the PCM has reached its full limit. In this case, a fuel trim reset might be necessary in order to run all the necessary diagnostic tests. Resetting the fuel trim to 0.0 percent will prevent the PCM from skewing the test results—for a short time.

A misfiring cylinder due to an inoperative or clogged fuel injector will also cause a lean O_2 sensor voltage reading. In fact, this condition will make the O_2 sensor voltage behave almost exactly as an ignition misfire. However, if a 5-gas analyzer is used in the diagnostic process, it will show a high O_2 content as well as low HC (raw fuel), which is indicative of an inoperative injector.

Although rare in today's systems, a fuel injector stuck in the open position will create a lean condition and positive fuel trim values. The excessive fuel from the faulty injector will not allow combustion to take place. When the exhaust valves open, raw fuel and unburned oxygen will enter the exhaust. The O_2 sensor will send a low voltage signal

to the PCM that will be interpreted as a lean condition, resulting in positive fuel trim numbers. In this case, a 5-gas analysis will show high O_2 and high HC. Some newer OBD-II engine control systems have an injector cut-off feature built into the PCM's programming. In the event of a misfiring cylinder, the PCM simply shuts down the misfiring injector. The reason for such a precaution is to save the catalytic converter from damage, since converters have to be warranted by law for 80,000 miles. In the event of a PCM injector cut-off, the end result is still the same: low O_2 sensor voltage. A cylinder that runs rich because of a dripping injector is not severe enough to cause a misfire, but it will have a low O_2 and high CO content in the exhaust. Such a case does not constitute a misfire and therefore the techniques in this section do not apply.

EGR MISFIRES

Misfires can also be caused by a malfunctioning EGR system. The EGR gases are inert and do not supply oxygen to the combustion process. The O_2 sensor will therefore interpret the EGR gases at low oxygen content, and produce a high voltage indicating a false rich condition. As a result, a misfiring engine caused by excessive EGR flow will have a high (rich) O_2 sensor reading and negative fuel trim numbers. This situation is exactly the opposite from the ignition misfire. The end result will be the PCM leaning the mixture even further to compensate for the falsely perceived rich condition.

Blocked EGR passageways on one bank of cylinders can create excessive EGR flow. This, in turn, can cause the MAP sensor output voltage to go high (speed/density system), and fool the PCM into sensing a bigger load placed on the engine than there actually is. This will cause the PCM to increase injector pulse in order to richen the mixture to compensate for the perceived engine loading. In dual cylinder-bank (V-type) engines, it is common to see only one bank with clogged EGR passages. In such cases, all the EGR gases will be redirected to the unclogged passageways in the other bank of cylinders and will cause a misfire. The bank with the misfiring cylinder(s) does not have clogged EGR passageways; any further diagnostics should be concentrated in the opposite bank.

Whenever disconnecting the EGR valve, it is always important to remember that the PCM will adjust A/F ratio according to its internal programming. The EGR gas flow pattern is already preprogrammed into the PCM fuel-injection-map. The PCM programming may take the EGR operation into account, regardless of whether it is working or not. It may be wrong to simply expect a correct fuel balance on an engine with a disconnected EGR valve. The PCM may still compensate for EGR flow even if there is no flow. By taking the EGR out of the picture, it becomes easier for

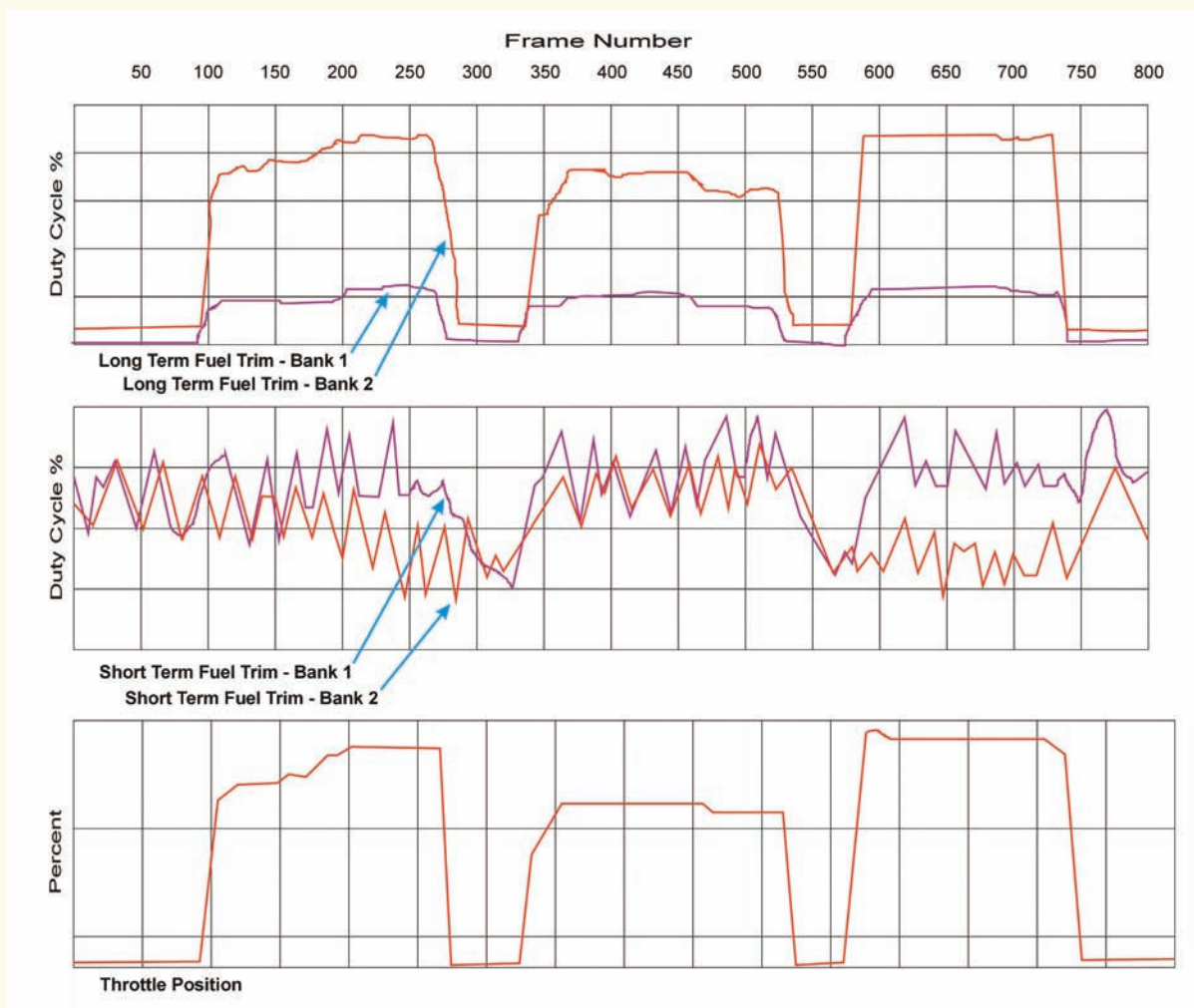


Fig.7-4—In this example showing a V-6 engine, the EGR ports on Bank 2 are clogged. This has caused all the EGR gases to flow into Bank 1, resulting in a misfire on two Bank 1 cylinders. The engine is being preloaded (stepping on the brake and gas at the same time), as can be seen by percent of throttle position in the bottom PID trace. Notice that the long-term fuel trim (LTFT) on Bank 1 is much lower than LTFT on Bank 2 each time the engine is loaded. The excessive EGR flow causes the PCM to reduce injector pulse to Bank 1, since it interprets the inert exhaust gases as a rich condition. This is a normal reaction by the PCM to the high load condition and EGR operation. The difference here is that there are no EGR gases flowing to Bank 2 because the EGR ports are blocked. With no EGR gases present in Bank 2 cylinders, the LTFT percent has been increased by the PCM due to a perceived lean condition.

the spark plugs to ignite, thereby hiding any possible misfiring cylinders.

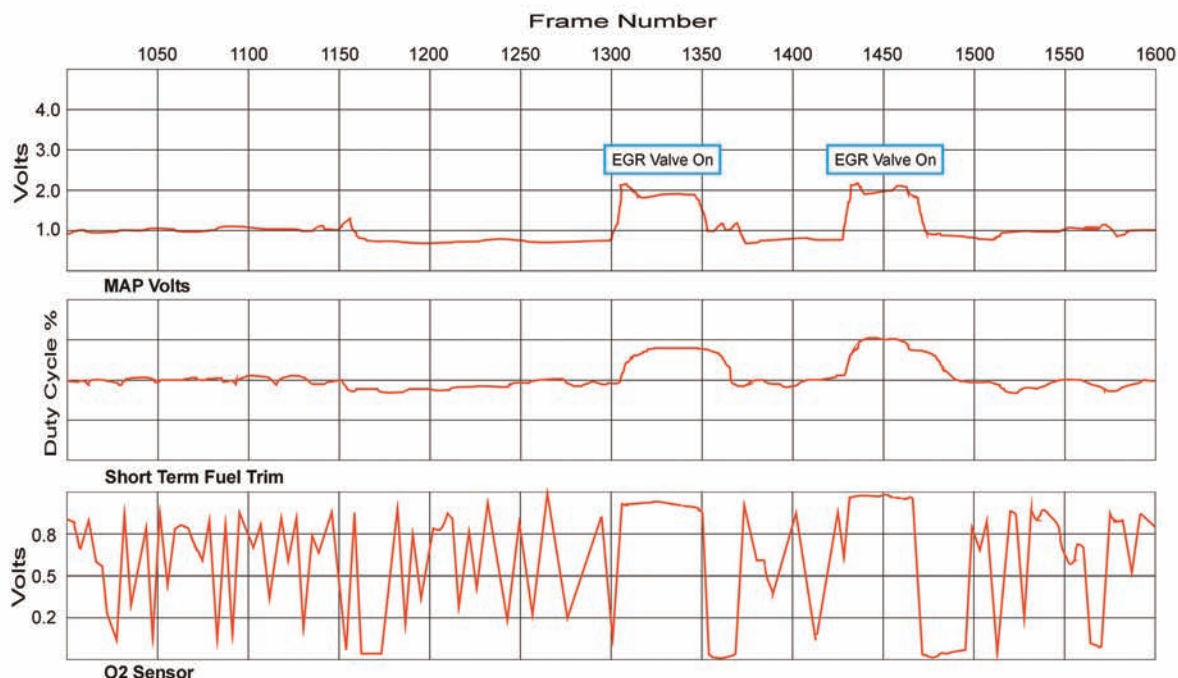
OBD-II MISFIRE CODE TYPES

OBD-II uses three categories of misfire codes: types A, B, and C. Type A sets the malfunction indicator lamp (MIL) to ON as a first trip fault. This type of “A” code is severely damaging to the catalytic converter, and for this reason will register on the first trip. The MIL light will flash off and on to warn the driver of a fault. The type B code is a two-trip code and will set the MIL to ON as a second trip fault. This code is less severe than Type A, and is considered less

damaging to the catalytic converter. Type C codes are not considered to be damaging to the converter, and will not turn on the MIL. This code will simply be stored in memory as a possible fault for future reference.

The OBD-II code type is particularly important when diagnosing misfire problems. Many fuel control systems now have what is called a “Misfire Alert Mode” built into their internal PCM programming. In the event that a non-catalyst-damaging DTC misfire code exists, the PCM misfire counter must reach a set value before displaying any changes on the scanner screen. In order to avoid long

(continued)



The EGR passageways are clogged in Bank 1, and all the EGR flow is directed to Bank 2. The chart shows MAP sensor voltage during excessive EGR flow in Bank 2. When the EGR valves opens, the MAP sensor sees a drop in manifold pressure and the MAP voltage increases. The PCM will interpret the higher MAP voltage as an indication that the engine is being loaded. The short-term trim will increase to add more fuel and the O₂ sensors will read a rich condition and produce a high voltage. Because the engine is not being loaded, and only the excessive EGR flow is taking place, the overly rich fuel mixture can eventually damage the catalytic converter.

delays in logging a particular misfire problem, the PCM can be forced into misfire alert mode. By putting the PCM in misfire alert mode, the PCM can immediately start logging in any presently occurring misfires. Since a non-catalyst damaging code is not severe enough to set a code, it will not show up on the misfire counter until the misfire alert mode is enabled. Running the engine at 2,000 to 3,000 rpm and disconnecting an injector will enable the misfire alert mode on most OIB-II systems. As soon as the MIL comes on, shut the engine off and then restart it.

CONCLUSION

To recap, the need for a PID-based diagnostic strategy becomes apparent when testing newer fuel control systems that are also equipped with COP or DIS ignition systems. These ignition systems make it difficult to obtain secondary ignition waveforms that can be used in diagnosis. OBD-II systems hold a misfire code for 80 warm-up cycles, as opposed to 40 for a non-misfire code. Because of this, there is a good chance that the misfire codes could be present. Erasing an OBD-II code should be the last step in the diagnostic process, as the freeze frame data will also be erased. Because freeze frame data is

set to one to two seconds after a fault has occurred, freeze frame data should not be used to detect fast-acting glitches in the fuel system.

Three types of misfires that can be detected using the O₂ sensor's PID information: ignition misfires, injector misfires, and EGR-caused misfires (these may only occur on speed/density fuel systems).

An ignition misfire leaves unburned oxygen in the cylinder. When the exhaust valve opens, the excess oxygen enters the exhaust system and causes O₂ voltage to decrease. The misfire that follows causes the O₂ sensor voltage to indicate a lean condition due to excessive oxygen in the exhaust gases. When an injector doesn't operate, there is no fuel to burn in the cylinder and the excess oxygen causes the O₂ voltage to decrease. Oddly enough, an injector that is stuck open and dumping fuel into the cylinder will also cause a lean condition. The excess fuel doesn't allow the cylinder to fire because excessive oxygen is present in the cylinder. In speed/density systems, excessive EGR flow will cause the O₂ sensor to go rich because the MAP sensor voltage will increase as the PCM thinks that the engine is being loaded.

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3. **Accelerate**—Turn off the air conditioner and all the electrical loads. Apply half throttle and accelerate the vehicle until 55 mph is reached. During this time, the misfire, fuel trim, and purge flow monitors will run.
4. **Hold steady speed**—Hold a steady driving speed of 55 mph for three minutes. During this time, the O₂ response, secondary air, EGR, canister purge, misfire, and fuel trim monitors will be performed.
5. **Decelerate**—Let off the accelerator pedal. Do not shift, or touch the brake or clutch. It is important to let the vehicle coast along, gradually slowing down to 20 mph. During this time EGR, purge, and fuel trim monitors will be run.
6. **Accelerate**—Accelerate the vehicle at $\frac{3}{4}$ throttle until 55 to 60 mph is reached. This step will run the same monitors as in step 3.
7. **Hold steady speed**—Hold a steady speed of 55 mph for five minutes. During this time the same monitors from step 4 will be performed again, only this time the catalyst monitor diagnostics will be performed as well. If the catalyst is marginal or the battery has been disconnected, it may take five

complete driving cycles to determine the state of the catalyst and to set its monitor to a complete, or read status.

8. **Decelerate**—This will perform the same monitors as in step 5. Do not press the clutch or brakes or shift gears during this last part of the General Motors drive cycle.

FORD DRIVE CYCLE

Ford Motor Company's OBD-II drive cycle differs from the General Motors cycle in that individual inspection and maintenance monitors can be run separately from the overall drive cycle. On many Ford vehicles, a manufacturer code, P1000 (EVAP system), will be set if all the I/M readiness monitors are not complete. Clearing the P1000 can be a bit tricky because the evaporative emission monitor test has to be completed before the PCM allows the P1000 to be cleared. The problem is that the EVAP monitor will only run during the first 30 minutes of engine operation from a cold start condition. There is an EVAP monitor bypass procedure but it amounts to letting the vehicle sit for eight hours before trying to run the monitors again. The following four procedures will prepare the vehicle for monitor testing and clearing the Ford P1000 DTC.

1. Most OBD-II monitors will complete more readily using a "steady foot" driving style during cruise or acceleration modes. Operating the throttle in a smooth fashion will minimize the time required for monitor completion. This will also minimize "fuel slosh" in the gas tank, and allow the EVAP monitor test to run successfully.
2. The ambient air temperature should be between 40° to 100° F. Altitude should be below 8,000 feet. (If it's too cold or hot outside, and testing takes place at high altitude, the P1000 won't go away.)
3. Fuel tank level should be between $\frac{1}{2}$ and $\frac{3}{4}$ full ($\frac{3}{4}$ full is better for testing).
4. Check the scan tool for any "Pending" DTCs. Any pending codes must be cleared and/or repaired before the P1000 will clear. After repairs, clear any trouble codes before proceeding.



General Motors drive cycles vary among its family of cars and light trucks. A service manual should be consulted for specific drive cycle procedures that apply to the OBD-II vehicle being tested.



When run correctly, Ford Motor Company's OBD-II drive cycle will clear any diagnostic trouble codes and turn off the malfunction indicator lamp, or MIL. The fuel tank should be $\frac{3}{4}$ full for the EVAP monitor to run successfully. The ambient air temperature should not be over 100° F or less than 40° F.

DRIVE CYCLE PROCEDURE

Note: The first two steps allow the PCM to go into "Monitor Entry" so it can begin testing. From this point on, all of the monitors can be tested, or you can test only specific monitors for the purposes of verifying repairs or turning off the MIL. It doesn't matter what order these monitor tests and their drive cycle criteria are performed in. However, to keep the PCM from setting a P1000 DTC, the EVAP monitor test should be run before the other monitors.

1. Connect the scan tool to the DLC, turn the ignition key "ON," but don't start the engine. Cycle the ignition key "OFF," then "ON." Clear all the DTCs if any are present.
2. Start the engine *without* turning the key to the OFF position (the key was left in the "ON" position from step 1). Let the engine idle for 15 seconds. Drive at 40 mph until the ECT (engine coolant temperature) sensor shows at least 170° F.
3. The EVAP monitor tests the EVAP system's ability to route vapors to the engine, where they can be burned and kept from escaping into the atmosphere. To initiate the EVAP monitor, the throttle position (as viewed on a scanner's PID display) needs to be between 40 to 60 percent and the fuel level sensor should read between 15 to 85 percent (this is why the gas tank should be $\frac{1}{2}$ to $\frac{3}{4}$ full). Avoid practicing for an autocross event as sharp turns will "slosh" the fuel around in the tank and make lots of fuel vapor. This could cause the monitor to fail the EVAP system test unnecessarily. To run the monitor, cruise at 45 to 65 mph for 10 minutes.
4. To run the heated exhaust gas oxygen, or HEGO monitor, cruise (steady driving) at 40 mph for up to four minutes. This monitor tests the internal oxygen sensors' electrical heaters. This monitor will probably run when performing step 2. Note: this step should be used only when the HEGO monitor needs to be run.
5. The catalyst monitor tests the catalytic converter's ability to store and release oxygen, plus its effectiveness at controlling exhaust emissions. To run the catalyst monitor, drive in stop-and-go traffic conditions. Make sure to include five different constant cruise speeds that range between 25 to 45 mph, all over a 10-minute driving period.
6. The EGR monitor tests the EGR system's ability to route exhaust gases into the intake manifold. To run the EGR monitor (exhaust gas recirculation) stop the vehicle and then accelerate to 45 mph at $\frac{1}{2}$ to $\frac{3}{4}$ throttle. Repeat this sequence three more times. Use your scan tool to determine throttle opening by watching the throttle position PID.
7. In addition to running the SEC AIR monitor, the secondary air (SEC AIR) test starts the comprehensive components monitor (CCM) for the idle speed control test. To run the secondary air monitor, stop the vehicle and let the engine idle with the transmission in drive (neutral if you have a manual transmission) for 2 minutes. The secondary air monitor tests the air pump and hoses for proper operation and leaks. Not all vehicles have this system.
8. The misfire monitor tests the ignition system's ability to fire the spark plugs under an engine load. To run the misfire monitor, stop the vehicle and then accelerate to 65 mph. Decelerate (close the throttle but don't step on the brakes) until a speed of 40 mph is reached. Stop the vehicle and repeat this procedure two more times.

DAIMLERCHRYSLER DRIVE CYCLE

DaimlerChrysler has specific drive cycles for their catalyst, EGR, oxygen sensor, oxygen sensor heater, and EVAP monitors. All other monitors use a different drive cycle. All DaimlerChrysler monitors are organized and prioritized by the Diagnostic Task Manager (software within the PCM). Monitors are run under specific operating conditions called enabling criteria. In particular, the EGR monitor will not run if to do so conflicts with other monitors. Further, the EGR monitor will be difficult to run if DTCs. The following are the drive cycles for each monitor.

All monitor drive cycle—Pre-conditioning requirements: the MIL must be off and the engine should be cold (no temperature is defined). Warm up the engine for five minutes until closed loop is achieved (monitor your scan tool for closed loop status). Drive the vehicle with a steady throttle between 40 to 60 mph for eight minutes. Stop and let the engine idle for three minutes. Drive the vehicle again (steady throttle) above 20 mph for two minutes. Stop the car and turn the ignition key off for 10 minutes (this runs the O₂ sensor heater monitor).

Note: The preceding drive cycle is limited and may not run all the monitors on all Chrysler vehicles. Better results can be obtained by running the monitor-specific drive cycles that follow.

Catalyst monitor drive cycle—Pre-conditioning requirements include: the MIL must be off, no DTCs present, fuel level is between 15 and 85 percent full ($\frac{1}{2}$ to $\frac{3}{4}$ in the tank), ECT should be above 70° F, the engine must have been running at least 90 seconds at a speed between 1,350 and 1,900 rpm. Let the engine idle for five minutes until it reaches closed loop status (monitor closed loop stats on a scan tool). Now drive the vehicle at a steady speed between 30 and 45 mph for two minutes. The catalyst monitor should run.

EGR monitor drive cycle—There are two different drive cycles for the EGR monitor. One for vacuum controlled EGR systems and another for electronically controlled systems.

The EGR (vacuum controlled) drive cycle has only one pre-conditioning requirement; the MIL must be off. Start the engine and let it idle for five minutes until it reaches closed loop status (watch a scan tool to monitor closed loop operation). Drive the vehicle at a



Chrysler uses an “All Monitor Drive Cycle” which, ironically, won’t run all the inspection and maintenance monitors. Using the monitor-specific drive cycles to run each monitor separately is a more effective method to run and complete all the monitors.

steady speed between 40 and 60 mph for eight minutes. The EGR monitor should run.

The EGR (electronically controlled) drive cycle has six pre-conditioning requirements: the MIL must be off, the MAP sensor must read between 0 and 60 kPa (kilopascals), and the ECT should be above 180° F. No pending misfire DTCs should be present (check these PIDs with a scan tool). Turn off the AC. Start the engine and let it idle for five minutes until it reaches closed loop status (watch a scan tool to monitor closed loop operation). Drive the vehicle using a steady throttle between speeds of 40 to 60 mph for two minutes. Let the engine idle for three minutes. The EGR monitor should run.

Note: The EGR monitor determines EGR flow based on a change in idle quality (when the EGR valve is open at idle, engine idle will be rough). Any conditions that cause an unstable idle (like running the AC, turning the steering wheel, or having the cooling fan[s] cycle on and off) may prevent completion of the EGR monitor.

EVAP monitor drive cycle—There are two different drive cycles for the EVAP monitor. One drive cycle is for the standard type of EVAP system, and another for systems that use a leak detection pump.

The EVAP (standard type) monitor has three pre-condition requirements: the MIL must be off, no EVAP

related DTCs should be present, and the fuel level should be between $\frac{1}{2}$ and full. The EVAP monitor may still run if the fuel level is between 15 and 85 percent (check fuel level sensor on scanner for this information). Start the engine and let it idle for five minutes until it reaches closed loop status (watch a scan tool to monitor closed loop operation). Drive with a steady throttle at speeds between 30 and 45 mph for two minutes. The EVAP monitor should run.

Pre-conditions for the leak detection pump type of EVAP system are the same as for the standard type. The vehicle must be cold (sitting overnight or at least eight hours). Start the engine and let it idle for four minutes. Drive in simulated stop-and-go traffic conditions for five minutes (use smooth accelerations and decelerations). Stop and let the engine idle for four minutes. The EVAP monitor should run.

Oxygen sensor monitor drive cycle—The only pre-condition requirement is that the MIL should be off. Start the engine and let it idle for five minutes, until it reaches closed loop status (watch a scan tool to monitor closed loop operation). Using a steady throttle, drive the vehicle at speeds above 25 mph for two minutes. Stop and let the engine idle for 30 seconds. Accelerate smoothly to a speed between 30 and 40 mph. Repeat the last step four times. The oxygen sensor monitor should run.

Oxygen sensor heater monitor drive cycle—There is only one precondition for this monitor: the MIL should be off. Start the engine and let it idle for five minutes until it reaches closed loop status (watch a scan tool to monitor closed loop operation). Shut the engine off for 10 minutes. The oxygen sensor heater monitor should run.

EUROPEAN DRIVE CYCLE

Since 2002, all automobile imports from Europe must meet the same standards as OBD-II vehicles made in the US. These imports use a system called EOBD, which is very similar to an OBD-II system. Following is a generic EOBD drive cycle that should work for verifying repairs and turning off the MIL for most European imports.

The PCM will start a drive cycle as soon as the engine is started (from either hot or cold conditions) and ends the drive cycle when the engine is turned off. To meet all the conditions that will allow all monitors to run and have a completed status, the following steps should be taken.

1. **Cold start**—For the PCM to recognize a cold start, the coolant temperature must be below 122° F (50°C) and within 42° F (6° C) of the ambient air temperature when the engine is started.
2. **Idle**—The engine should idle for two to three minutes with several electrical loads turned on, such as the rear screen defogger or heater blower fan. This will allow the oxygen sensor heater, misfire, and fuel trim monitors to run.
3. Accelerate the vehicle to a speed between 50 and 60 mph (80 to 96 kph). The misfire and fuel trim diagnostics will be performed.
4. The vehicle speed should now be held steady between 50 and 60 mph (80 to 96 kph) for about three minutes. The PCM will run the O_2 response, misfire, and fuel trim monitors.
5. At the end of this three-minute period (step 4), the accelerator pedal should be released and the vehicle allowed to decelerate to 20 mph (32 kph)



The European, or EOBD, drive cycle starts as soon as the engine is started, hot or cold, and ends when the engine is shut off. As with the domestic manufacturers' drive cycles, individual vehicles may use slightly different procedures. A service manual will provide details for testing specific brands and models of European imports.



without changing gears or using the brakes or clutch. Fuel trim diagnostics will again be run.

6. Accelerate the vehicle again to between 50 and 60 mph. The misfire and fuel trim diagnostics will be performed again as in step 3.
7. Hold the vehicle's speed steady at between 50 and 60 mph for about five minutes. The catalyst monitor will run. If the catalyst efficiency is low (the converter is worn out after many miles), or if the battery has been disconnected, it may take up to five complete drive cycles for the PCM to determine the effectiveness of the catalyst.
8. Finally, the vehicle should be decelerated, as per step five, and then stopped.

COMMON DIAGNOSTIC TROUBLE CODES AND THEIR CAUSES

The following are some of the more common generic OBD-II diagnostic trouble codes and their possible causes. After reading any stored DTC, but before replacing any parts, always check for manufacturer technical service bulletins, (TSBs). These documents provide a wealth of information and may have specific procedures for the trouble codes that are present on the vehicle being worked on. They also may indicate that a software update is required for the vehicle's PCM, or that a PCM replacement is the solution for various drivability issues. And they can suggest ways to keep the MIL and false DTCs from coming back to haunt the vehicle owner. If more information regarding generic and manufacturer-specific DTCs is needed, it can be found in a vehicle's service manual, or on the Internet. Also, generic OBD-II code definitions are in the Appendix of this book.

P0505: Idle control system malfunction—A DTC P0505 can be set for several reasons: the actual engine idle speed varies from the PCM's target idle speed, or the PCM can't control idle speed properly. Symptoms could include the following: too high, or too low an idle speed, stalling at idle, fluctuating idle speed, difficulty starting, and hesitation on acceleration. Some of the causes of lack of idle control are intake manifold vacuum leaks, dirty throttle body, dirty passages, bad idle air control (IAC) valve, faulty drive-by-wire throttle, or issues with

wiring or connectors. Also, the P0505 can be caused by problems with the EVAP or EGR systems. Many P0505 codes can be fixed simply by cleaning the IAC valve or throttle body and throttle plate. Some manufacturers may require an idle relearn procedure after work is done on the throttle body. These can be performed using a scan tool, or by following a relearn procedure outlined by the manufacturer.

P0455: Evaporative emission system leak detected (gross leak/no flow)—This code indicates a "gross" (large leak) in the EVAP system. "Did you remember to tighten the gas cap the last time you filled the tank?" If the gas cap was left off, or just loose, a P0455 DTC could be set by the PCM. Also, if an aftermarket gas cap is used, it may not seal as well as the original part, causing this code to be set. Other causes for large leaks include: a broken canister vent valve, disconnected vacuum or EVAP-system vent hoses, or a damaged vapor canister.

P0442: Evaporative emission system leak detected (small leak)—The same problems that caused a P0455 can cause this DTC to be set. Again, look for any EVAP system hoses that have cracked from old age, come loose, or been disconnected. Also, carefully inspect the gas cap for rubber O-rings or gaskets that are damaged or missing. Just as with the P0455, you are looking for a leak only this time, and the leak will be small.

P0440: Evaporative emission system—This code indicates that the EVAP system is not functioning, but not necessarily leaking. There are 20 generic OBD-II EVAP-related codes and many more manufacturer-specific EVAP trouble codes. The presence of any of these DTCs may provide additional specific information as to the cause of the P0440 code. Components to check include: gas cap, EVAP vent hoses, vacuum lines, canister vent valve, purge solenoid, and fuel lines.

P0420: Catalyst system efficiency below threshold, Bank 1, and

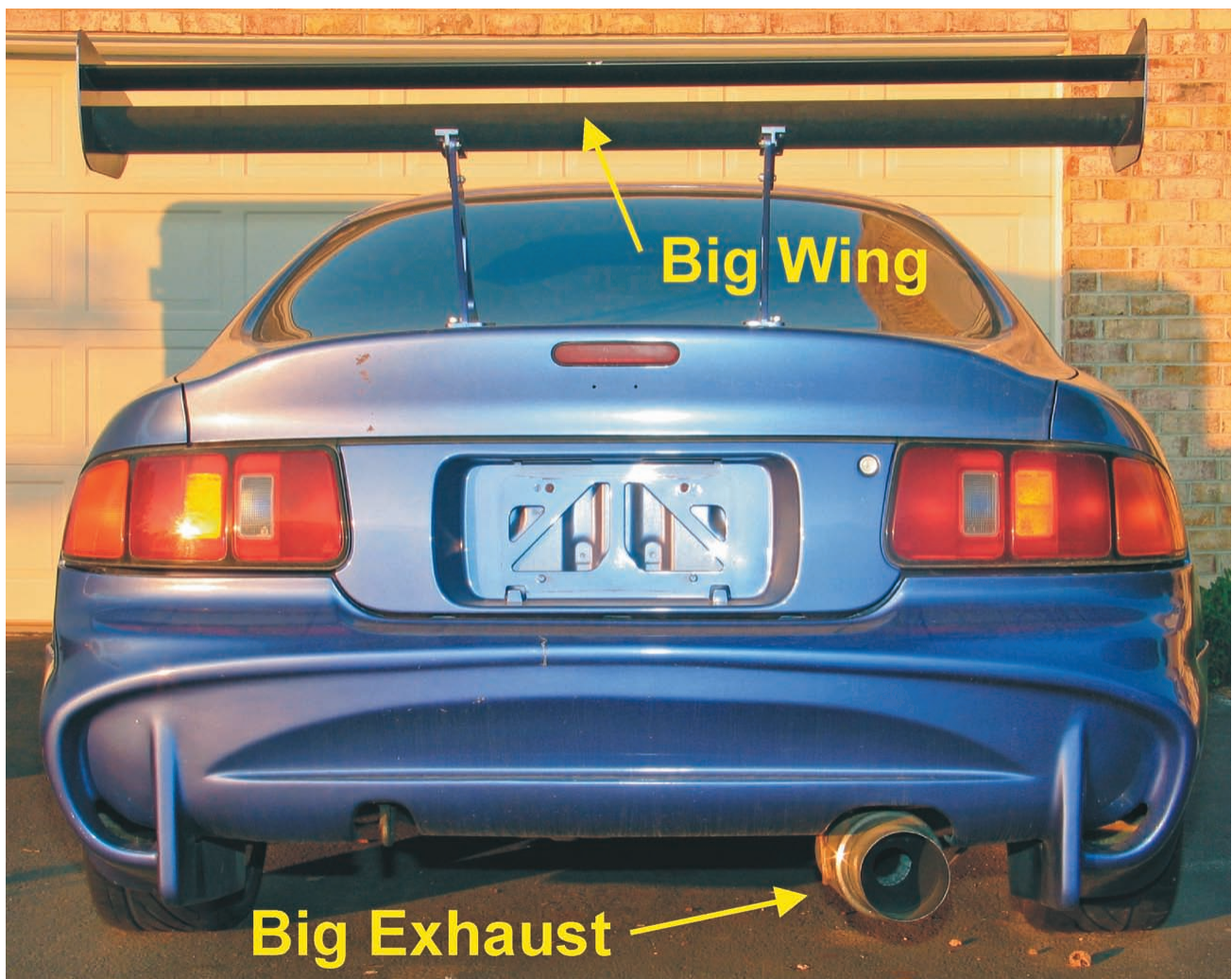
P0430: Catalyst system efficiency below threshold, Bank 2—The PCM will set these codes when one of the rear oxygen sensor output voltages varies between 0.2 and 0.6 volts. This indicates that the catalyst is no longer reducing exhaust emissions sufficiently. In addition to a catalyst that is worn out, other causes for these codes include: oxygen sensors, malfunctioning oxygen sensor

circuits (both up and down stream O₂ sensors), an exhaust system leak, or other exhaust damage. A software update for the PCM or new PCM should also be looked at as a possibilities for these codes. The reason is that some manufacturers have made the catalyst efficiency monitor (and the codes it produces for failures) a bit too sensitive. This causes the P0420/30 codes to be set even when the catalytic converter is working properly.

P0402: Exhaust gas recirculation flow excessive detected—P0402 sets when the PCM detects excessive EGR system flow when no or little flow is expected. Symptoms could range from a rough idle to no idle, and

hesitation to surging at cruise. Any of the following could cause a P0402 to be set: issues with the EGR vacuum valve, clogged catalytic converter, intake manifold leaks, dirty or clogged air filter, EGR valve stuck in open position, bad EGR temperature sensor, bad mass airflow sensor, and a damaged or missing EGR gasket.

P0401: Exhaust gas recirculation flow insufficient detected—Common causes of incorrect EGR flow include: a damaged/blocked EGR vacuum sensing hose, clogged EGR valve or exhaust hose, and EGR passageway plugged due to excessive carbon buildup. Also: defective EGR vacuum solenoid, no vacuum



Auto manufacturers design a certain amount of exhaust back pressure into their exhaust systems. Some exhaust gas recirculation (EGR) systems use a differential pressure sensor, sometimes referred to as differential pressure feedback exhaust (DPFE), to regulate EGR flow into the intake manifold during EGR operation. When an aftermarket, high-flow exhaust is installed, the DPFE never has enough exhaust back pressure to operate the EGR system correctly and the PCM may set EGR related DTCs. Seen here is a larger-than-stock exhaust system that could cause an EGR code to be set. The “Big Wing” keeps this hot rod stable at speeds over 200 mph—at least that’s what the owner told me.



signal to the solenoid, and no command from the PCM to the EGR vacuum control or electronically operated EGR valve. In addition, various EGR-related codes can be caused by low exhaust back pressure from certain high-flow exhaust systems installed by the owner.

P0400: Exhaust Gas Recirculation (EGR) Flow—The DTC P0400 can be set when the PCM detects that EGR gas flow is out of the expected range. EGR, or exhaust gas recirculation, is a system designed to reduce the amount of nitrogen oxides (NOx) in the exhaust gas. The EGR valve sends a small amount of exhaust gas to the engine's intake manifold to reduce the high combustion temperatures that are present during part-throttle conditions. In general, EGR valves are controlled by the PCM via a vacuum signal or an electrically operated EGR valve. The EGR valve is closed at idle and wide-open throttle, but open at part-throttle cruise conditions.

P0340: Camshaft position sensor Circuit A (Bank 1)—The signal generated by the camshaft sensor (CMP sensor) provides information regarding camshaft position in relationship to the crankshaft. The PCM uses this information to set ignition timing, control fuel delivery, variable valve timing, or variable camshaft lift operations. The DTC P0340 is set when the PCM can't detect a signal from the camshaft position sensor. This code could be caused by a bad camshaft position sensor, issues with the wiring or connectors, engine mechanical problems, or a problem with the PCM. A faulty CMP sensor can cause engine stalling, misfiring, or hard starting. A related DTC is P0345: camshaft position sensor circuit (Bank 2).

P0325: Knock sensor Circuit 1 (Bank 1)—The DTC P0325 can be set if the voltage signal from the knock sensor is out of the expected range. The knock sensor monitors engine detonation, or knock, and develops a low voltage signal. The PCM will retard the ignition timing until the knock is no longer present. The cause of the code could be a faulty knock sensor or a problem with wiring running from the sensor to the PCM. Most knock sensors operate on a bias voltage sent by the PCM to the sensor. Turn the ignition key on and check for this voltage on the knock sensor wire. The sensor's resistance value can be checked using an ohmmeter. Look up the correct resistance value in a factory manual.

P0300: Random or multiple misfire detected—Random or general ignition misfire can be caused by

primary and secondary ignition electrical problems. On vehicles that use a distributor, excessive cap and rotor wear will affect the entire ignition system, and cause random multiple misfires. Also, any malfunctions with fuel delivery, air metering, excessive exhaust gas recirculation, or an intake restriction can cause a cylinder(s) to misfire. The mechanical condition of the engine should not be overlooked, as leaking valves or compression problems can also cause misfires.

There are several seemingly unrelated causes for the P0300 random misfire code. If the vehicle was used for off-road activities (Jeeps, trucks, and SUVs) and the tires and wheels picked up lots of mud, the tires may become unbalanced. Also, if one of the wheel weights fell off, the tires can slip out of balance. These out-of-balance conditions cause vibration in the driveline. The vibration is transmitted to the engine's crankshaft, causing it to speed up and slow down. The PCM is not smart enough to tell the difference between a real ignition misfire and vibration from an out-of-balance wheel, or wheels, and could set a random misfire code. Also, imbalances in the driveshaft can cause the same false DTC problems.

P0301, 2, 3, 4, 5, 6, 7, 8: Cylinder "X" misfire detected—Misfire for cylinder "X" (X = any of the engine's cylinders) is commonly caused by primary and secondary ignition faults, incorrect fuel delivery, air metering, excessive exhaust gas recirculation, intake restriction, or engine mechanical problems. In addition, a vacuum leak at one of the port fuel injectors or an intake runner may cause one or more cylinders to misfire. The misfire is a response to a fuel mixture that is too lean.

P0170: Fuel trim malfunction (Bank 1)—Fuel trim malfunction (Bank 1) is set when the air/fuel ratio is either too lean or too rich. The more common reason is the "too lean" condition. A P0173 code has the same meaning except that it refers to Bank 2. Some manufacturers may call the code "Self adaptation out of limits," meaning that the long-term fuel trim number is too high. Common causes for this code that are related to an overly lean condition are: vacuum leaks, faulty PCV valve, leak in the crankcase ventilation system, low fuel pressure, bad mass airflow sensor, or faulty oxygen sensors. When installing a new mass airflow sensor, be sure that the air filter is installed properly, as the sand particles carried by unfiltered air can damage the sensor.

P0171 (Bank 1) & P0174 (Bank 2): System too lean—A “too lean” DTC for only one bank of cylinders can be caused by an intake port or fuel injector vacuum leak on one side of the engine. Also, a large vacuum leak may cause the PCM to set *both* codes (P0171 and P0174). Incorrect MAP or MAF sensor readings can also cause “lean” DTCs to be set. Low fuel pressure from an electric fuel pump circuit with high resistance, or one with a weak or tired fuel pump, will also cause overly lean fuel mixtures that may result in these types of “lean” DTCs.

P0172 (Bank 1) & P0175 (Bank 2): System too rich—Causes for a rich condition DTC from only one bank of cylinders include: poor fuel-injector spray pattern (bad injector), malfunctioning oxygen sensor for that bank of cylinders, and incorrect air metering from MAF or MAP sensors. A leak in the fuel pressure regulator diaphragm could cause *both* codes to be set because this condition allows all the engine’s cylinders to be too rich. In addition, malfunctioning oxygen sensors can cause too much fuel to be added to the engine, and thus set these diagnostic trouble codes.

P0106: Manifold absolute pressure/barometric pressure circuit range/performance—A manifold absolute pressure (MAP) sensor malfunction can send a false signal to the PCM that is out of range of what the PCM expects. This can be caused by a cracked, leaking, or loose MAP vacuum hose (some MAP sensors are connected directly to the engine’s intake manifold and don’t use a vacuum hose, but could leak nevertheless). Other possible causes: a bad electrical connection at the MAP sensor, and an “open” or short in the wiring harness between the MAP and the PCM. Any of the preceding may trigger this and other related MAP sensor codes, including: **P0105**, MAP circuit; **P0107**, MAP circuit low; **P0108**, MAP circuit high; and **P0109**, MAP circuit intermittent. When testing a MAP sensor and comparing its values with a mechanical vacuum gauge, or reading a scan tool display, make sure that the scanner and gauge are using the same units of measurement. MAP vacuum levels can be read in inches of mercury (In.Hg.), kilopascals (kPa), or pounds per square inch (psi).

P0130: O₂ sensor circuit (Bank 1, Sensor 1)—The fault code P0130 is set when voltage from the front O₂ sensor (Bank 1, Sensor 1) is out of range. This DTC could

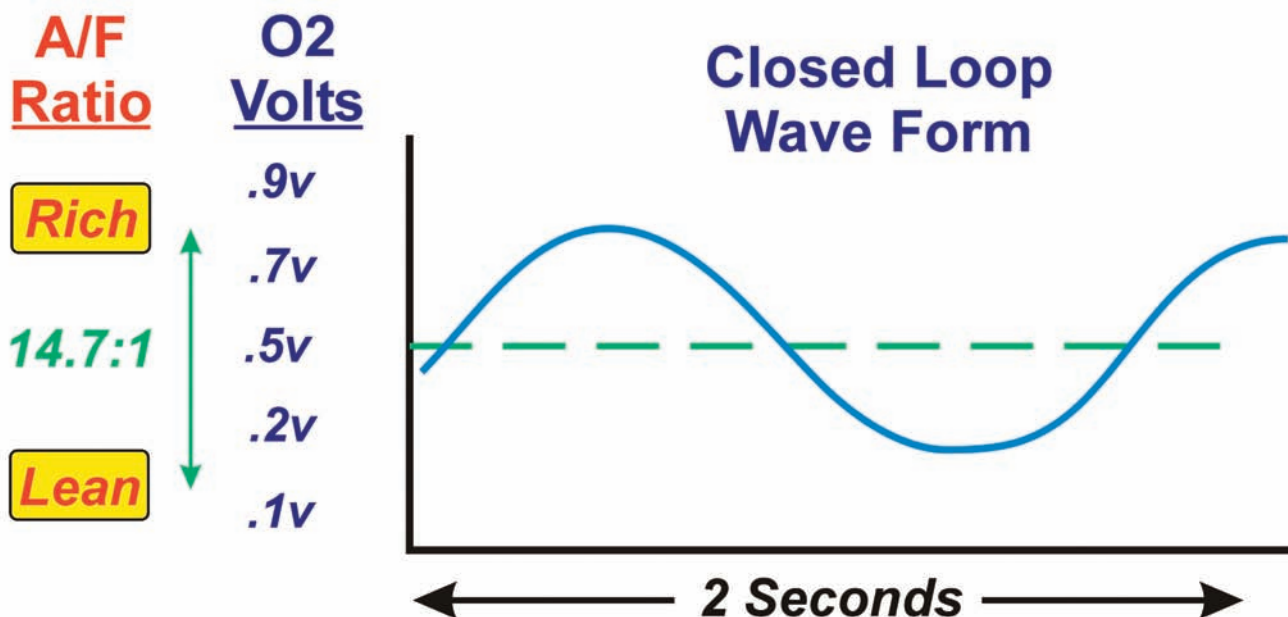
be caused by multiple problems, including: an open or shorted oxygen sensor circuit, faulty oxygen sensor, too lean or too rich an air/fuel ratio, intake leaks, and exhaust leaks. Oxygen sensors can be checked with a lab scope, digital voltmeter, or OBDII scan tool using Mode \$06. The DTC P0150 is the same as P0130 except that it is for the *front* oxygen sensor (Bank 2, Sensor 1).

P0132: O₂ circuit high voltage (Bank 1, Sensor 1)—If the signal voltage from the Bank 1 Sensor 1 oxygen sensor is over 0.9-volts the DTC P0123 may be set. Normal range for the oxygen sensor is 0.2 to 0.9 volts. The high voltage could result from several problems, including: the oxygen sensor’s signal wire has been shorted to a power source inside its wiring harness, too rich a fuel mixture, a bad ground, or moisture inside the connector. A P0132 can also be set by a faulty oxygen sensor. Some vehicle makes are sensitive to the use of an aftermarket oxygen sensor replacement instead of the OEM part; this could be the cause of a P0132. Before replacement, the O₂ sensor should be checked using a digital voltmeter, or a scan tool that can read the correct PIDs.

P0133: O₂ circuit slow response (Bank 1, Sensor 1)—This code can be caused by the oxygen sensor signal switching from low to high (lean to rich exhaust) too slowly, or if the voltage amplitude is out of the expected range. The code could be caused by several other reasons, including: a faulty oxygen sensor, sensor wiring problems, exhaust leaks, intake leaks, or a malfunctioning mass airflow sensor. The sensor should be checked using a scan tool or digital voltmeter. Another code, P0153, O₂ circuit slow response, is the same as a P0133 but indicates a fault in the front oxygen sensor on *Bank 2*, Sensor 1.

P0134: Oxygen (A/F) sensor no activity detected (Bank 1, Sensor 1)—The DTC P0134 indicates that no oxygen sensor activity is detected by the PCM. The code would be set if engine parameters, including engine temperature, rpm and other criteria, have been met and there is no resulting O₂ sensor activity. The sensor’s voltage should switch between 0.2 and 0.9 volts. This code is not common, so if other DTCs are set along with the P0134, those should be diagnosed first.

A simultaneous P0154 (Bank 2, Sensor 1) would indicate that the problem is probably not with either oxygen sensor, as it is highly unlikely that both would fail at the same time. Some conditions that could set *either* DTC are: a bad front O2 sensor, a bad air/fuel



This waveform shows an O₂ sensor switching between “rich” and “lean” air/fuel mixtures. Rich mixtures are indicated by sensor voltage readings above 0.5 volts, while readings below 0.5 volts indicate lean air/fuel ratios. The PCM analyzes the voltage signals from all the oxygen sensor 1 signals; if they are not what is expected, a DTC can be set. The oxygen sensor’s voltage range and response time can be checked using a digital voltmeter (scan tool voltage reads may be too slow for an accurate test). If propane is added to the intake manifold, the O₂ sensor voltage should immediately increase to 0.9 volts. If a vacuum leak is introduced at the intake manifold, the O₂ sensor voltage should immediately drop to 0.02 volts. If the response is slow, or does not reach voltage levels indicated in this test, the oxygen sensor is bad and should be replaced.

ratio sensor, and an “open” or short in the O₂ sensor signal circuit. Other possible causes: faulty wiring or connector, an “open” or short in the oxygen sensor heater circuit, vacuum leaks, lean air/fuel ratio, or a faulty PCM.

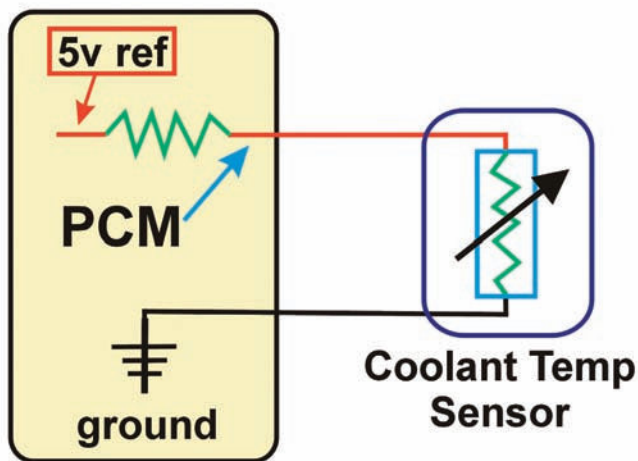
P0135: O₂ sensor heater circuit (Bank 1, Sensor 1)—OBD-II vehicles use heating elements that are integral to oxygen sensors. Because the sensors may be located some distance from the exhaust manifold, the heating elements provide a heat source to help the sensor reach its operating temperature. If the PCM detects an “open,” short, or excessive current draw from the heating element, a code P0135 may be set. The reason could be the sensor itself, or the sensor wiring or connectors. Low battery voltage, or a problem with PCM, can also cause this code. Other DTCs that are essentially the same as P0135 are: PO141 O₂ sensor heater circuit (Bank 1, Sensor 2); PO155 (Bank 2, Sensor 1); and PO161 (Bank 2, Sensor 2).

P0128: Coolant thermostat—This DTC indicates that the specified engine temperature was not achieved when

the engine was started, or that the coolant temperature is below the thermostat-regulating temperature. The PO128 often indicates a malfunctioning thermostat, or one that is stuck on the “open” position. A failed coolant temperature sensor (ECT), low coolant level, or other problem with the coolant system can also cause this trouble code to be set. A factory PCM flash program update designed to address the PCM setting the code may exist.

P0115: Engine coolant temperature circuit—A malfunction in the coolant sensor circuit can set this code. The trouble could be something as simple as an unplugged coolant sensor, or one with a poor electrical connection. In addition, the PCM may sense that the coolant temperature is too high, or low for an extended period of time, and set this DTC.

P0116: Engine coolant temperature circuit range/performance—The PCM can set this DTC because the coolant sensor’s voltage signal does not agree with other sensor input data. For example, if the engine has not been started for several hours, or overnight,



The PCM in an OBD-II system reads the coolant-temperature sensor's voltage at a point on the temp sensor's signal wire located just before an internal resistor (blue arrow). This variable voltage signal is interpreted by the PCM as engine temperature—the higher the engine's temperature, the lower the sensor voltage (many vehicles will read less than 1.0 volts when the engine is at normal operating temperature). On a cold engine that sat overnight, the coolant-temperature sensor's voltage will be around 3.5. A scan tool or digital voltmeter can be used to read coolant temperature sensor outputs. More information on how these sensors operate and how to diagnose them can be found in the book *Automotive Electrical Systems, Diagnosis and Repair*, by Tracy A. Martin.

and the air temperature sensor reads 50° F, the coolant sensor should have a similar (if not the same) reading. If the CTS (coolant temperature sensor) reads 120° F, or some other value that is out of line with the air temperature sensor, the PCM could set a “range/performance” code. If there is a problem with the vehicle's thermostat (stuck in the “open” position, for instance) the engine may take too long to reach normal operating temperature. The PCM knows how long the engine has been running and expects to see the CTS's input rise at a predetermined rate. If the thermostat was stuck open, the engine will take longer to warm up and the PCM may set this code.

P0117: Engine coolant temperature circuit low—The engine coolant sensor may be unplugged or its signal wire is broken somewhere between the sensor and the PCM. A scan tool may show the CTS temperature as very cold 0° F or below. A bad coolant sensor can also cause this low temperature condition, and prompt the PCM to set this code.

P0118: Engine coolant temperature circuit high—The engine coolant sensor may have a short in its signal

wire between the sensor and the PCM. This causes the signal to the PCM to indicate a very high temperature, usually above 250° F. A bad coolant sensor can also cause this high temperature condition, and prompt the PCM to set this code.

P0119: Engine coolant temperature circuit intermittent—A poor or loose connection at the coolant temperature sensor may set this DTC. The code could also be caused by a loose connector at the PCM or in a wiring harness. In addition, a bad coolant temperature sensor can cause an intermittent signal, as well as set this DTC.

P0011 (12, 14, 21, 23, 24, and 25): “A” or “B” camshaft position, timing over retarded/advanced, Bank 1 or Bank 2—Any camshaft- or crankshaft-related DTCs can be caused by timing belt issues. If the timing belt was installed incorrectly (off by one tooth or more), a no-spark condition may result, as well as the presence of these codes. The no-spark condition occurs the PCM is trying to prevent an intake backfire that could blow the air cleaner off. An intake manifold backfire can be caused by retarded camshaft timing. Not all OBD-II systems use the strategy.

In addition, if the timing belt has more than the recommended miles on it and needs to be changed, it can stretch just enough to cause one of these “timing over retarded” or “timing over advanced” trouble codes. A brand new timing belt is another possible cause for a slightly retarded or advanced camshaft. Some aftermarket timing belts are a couple of degrees short and need a few miles to stretch out. However, if the new belt also causes a no-spark condition, the engine will not run. Consequently, the timing belt will never stretch. The best solution is to use a factory timing belt.

P0016 (17, 18 and 19): Crankshaft position to camshaft position correlation (Bank 1 or Bank 2, Sensor A or Sensor B)—These trouble codes are similar to the previous DTCs in that they relate to camshaft timing issues. More specifically, these codes deal with crankshaft vs. camshaft timing, or correlation. The PCM is looking at the camshaft and crankshaft sensors and determining if the cam and crank are in the correct timing relation to each other. Take a close look at the timing belt. Is it past its useful service life? Does it need to be replaced as a maintenance item? Or is it

brand new and slightly too short? If so, it needs to be stretched by driving the vehicle for a few miles. These codes also may cause a no-spark condition.

Because of the extreme sensitivity of some OBD-II systems, anyone wishing to avoid these DTCs is usually better off with a timing belt from the vehicle manufacturer instead of the automotive aftermarket.

This chapter brings the book to a close. I hope that those of you who have stuck it out have learned

something about automobile emissions, electronic fuel injection, and on-board diagnostics. I learned a great deal while doing the research, and while writing it. If you have any comments or questions, please contact me via my website: www.tracyAmartin.com. Looking forward to hearing from you soon!



While researching this book, the author takes a moment to collect his thoughts. "The DLC was right where the service manual said it would be—next to the choke pull knob. But when I try to read the DTCs my scan tool says "No Communication, PCM Not Found." I wonder why the scanner can't find the PCM? Is it lost? Maybe I forgot to turn the ignition switch ON. Maybe this is one of those cars that uses that new CAN protocol and the scanner can't read the PIDs from the PCM." *Courtesy Elwood's Auto Exchange*

Sources

I would like to thank the following companies for help with images and information. Their kind assistance made this a better book from the technical as well as artistic perspectives. All of these automotive dealers and aftermarket manufactures offer great products and services for professional and do-it-yourself technicians alike. Contact information is listed for each company—check out their websites.



ACTRON®

Actron®, an innovator in quality automotive diagnostic tools and accessories, continues its 40-plus year tradition as a leading manufacturer of cost-effective, high-performance diagnostic and test equipment. From scan tools and code readers, to multimeters, battery testers, and timing lights, Actron has an automotive diagnostic tool for every level of user, from the DIYer to the professional technician. Actron's innovative products are the tools of choice for do-it-yourselfers. In December 2012, Actron became a Bosch brand and was integrated into the Automotive Service Solutions Business Unit of the Bosch Automotive Aftermarket Business Division.

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OTC is a major manufacturer and supplier of vehicle electronic diagnostic instruments, automotive fuel system maintenance equipment, special service tools, general-purpose tools, pullers, heavy-duty tools, shop equipment, and hydraulic components. The company markets its products through a global network of authorized aftermarket distributors, and serves a large number of car, truck, agricultural implement, construction, and marine manufacturers on an OEM basis.

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BOSCH

THE BOSCH AUTOMOTIVE AFTERMARKET DIVISION

The Bosch Automotive Aftermarket Division (AA) provides the aftermarket and repair shops worldwide with a complete range of diagnostic and repair shop equipment, as well as a wide range of spare parts—from new and exchange parts to repair solutions—for passenger cars and commercial vehicles.

The Bosch product portfolio includes products made as Bosch original equipment, as well as aftermarket products and services developed and manufactured in-house. More than 18,000 associates in 150 countries, as well as a global logistics network, ensure that some 650,000 different spare parts reach customers quickly and on time. In its “Automotive Service Solutions” operations, AA supplies testing and repair-shop technology, diagnostic software, service training, and information services. In addition, the division is responsible for the “Bosch Service” repair-shop franchise, one of the world’s largest independent chains of repair shops, with some 16,500 franchises. In addition, AA is responsible for more than 800 “AutoCrew” partners.

Additional information can be accessed at www.bosch-automotive.com.



AUTOMOTIVE DATA SERVICE (S.C.M. INC)

Technicians helping technicians.

Almost all repair shops have some kind of electronic service manuals. Our techs here at Automotive Data Service (A.D.S.) have helped technicians nationwide diagnose and repair all brands of automobiles and light trucks, with every conceivable problem, for 31 years. All of this information and knowledge is stored in our searchable database. Anyone can access the information through our hotline service. Having this type of information greatly increases shop performance and the ability to perform advanced diagnostics and services. Hard-to-find, real-word sensor specs are available. Visit www.SensorTests.com, “From Technicians for Technicians.” Use our Free Forum for all your diagnostic needs. Request sensor information or add to the database.

The A.D.S. hotline is open from 6 a.m. to 5 p.m. Pacific Standard Time, Monday through Friday. The A.D.S. Hotline offers you a place to turn to for all your automotive diagnostic needs.

Automotive Data Service

800-847-9454

www.SensorTests.com

www.AutomotiveDataService.com

Admin@AutomotiveDataService.com



SCANTOOL.NET, LLC

ScanTool.net, LLC is located in Phoenix, Arizona, in the heart of the Silicon Desert. The company was founded in April of 2002 with one goal in mind: to make an affordable, yet sophisticated, personal scan tool.

Today, we are proud to offer a complete line of PC-based scan tools, which cover all OBD-II-compliant vehicles, and sell for under \$150 (some for under \$100). Thanks to their open architecture, our scan tools are compatible with a wide range of software, including free and open-source diagnostic programs, as well as different hardware platforms, including Palm- and PocketPC-powered devices. We also sell adapters that interface with smartphones (Android and iPhone) applications.

About half of our sales are international, thanks in big part to our distributor network, which spans five continents, from Europe to Australia. If you would like to learn more about how your company can become a reseller, please visit the Distributors Wanted page.

ScanTool.net, LLC places a great emphasis on customer service and technical support. If you are not satisfied, we always try to settle the dispute in your favor, whether it be through repair, exchange, or refund. We are looking forward to doing business with you.

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Phoenix, AZ 85027
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www.ScanTool.net



AUTOENGINIUTY

Founded in 2002 by a computer hardware engineer who spent a great deal of his time tuning and racing his own cars, AutoEnginuity's purpose is to provide vehicle owners and independent service shops, the opportunity to diagnose and tune vehicles quickly and economically. Today we are the leading provider of PC/PDA-based scan tools in the world. We offer the most diverse coverage in any PC/PDA-based scan tool, in an easy-to-use user interface. You'll find that we update our product at a rate unmatched by our competitors and with quality to back up our performance. Not only do we make tools for cars, we race them, too. AutoEnginuity sponsors a BMW M3 race car. The car is piloted by the owner and maintained by our staff. The car is used in the research and development of some of our future products. The car is run in the Pro Auto Sports and SCCA Racing leagues. We are sponsoring members of IATN, AAIA, and ETI.

AutoEnginuity's customers include vehicle owners, independent service shops, and dealerships. Regardless of your mechanical skills, our tools will provide you with reliable information to service and tune vehicles quickly and accurately. What's more, our enhanced interface options offer coverage that rivals factory tools that professional mechanics require. Since our enhanced interface options are modular, you only need to purchase the coverage you need.

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HICKOK**WAEKON**

HICKOK-WAEKON

Hickok Incorporated has been in the business of developing and manufacturing tools for service technicians for over 100 years. Since 1984 the company has been a leader in diagnostic tools for automotive and mid-size truck technicians. We develop, manufacture, and market electronic and non-electronic diagnostic tool products in the USA. This includes products designed for automotive aftermarket service providers, tools designed specifically to OEM requirements, and products developed for the emissions testing industry. Additionally, the company develops and manufactures indicating instruments for aircraft, locomotive, and general industrial applications.

Our goal is to develop tools for service providers and technicians in the automotive and truck industries, providing them with the fastest possible return on investment based on time savings, increased accuracy, and accurate parts replacement for the owner.

Our products measure a broad range of parameters on the vehicle and provide the technician insights about the system operations to help them make a speedy and accurate diagnosis of the problem. They are designed to easily connect to the system or component that needs testing. Offering state-of-the-art capability at economic prices to enhance vehicle service profitability is what we do.

As new technologies emerge, the company actively researches and develops tools to aid technicians in the diagnosis and service of the components and systems these technologies drive. Hickok is fully committed to providing innovative, quality American designed and manufactured diagnostic equipment for years to come.

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AESwave specializes in the sales and support of handheld electronic systems diagnostic equipment. For over 20 years we have provided pre-sale advice and after-purchase support for a full range of tools across many brands for every diagnostic situation including: driveability; lab scopes; multimeters; scan tools; smoke machines; circuit testers; reprogramming and resetting; flash and TPMS tools; hybrid diagnostics; CAT-III rated tools; and training books, DVDs, and seminars.

In the early 1990s, the founder of ASEWave, Jorge Menchu, helped launch the automotive lab scope revolution from Fresno, California, with a kit of homemade test leads, DOS-based software, a book, and diagnostic strategies created specifically for automotive diagnosis.

Twenty years later, Jorge is a nationally recognized industry expert and president of Automotive Electronics Services, Inc. (AESwave), which specializes in the sales and support of automotive diagnostic equipment. Each day, thousands of technicians, educators, trainers, engineers, and technical writers use products and strategies developed at AESwave.

AESWave

www.aeswave.com

5465 East Hedges Avenue

Fresno, CA 93727-2279

877-351-9573



AUTOMOTIVE DIAGNOSTICS AND PUBLISHING

In 2003 Automotive Diagnostics and Publishing was founded by Mandy Concepcion. The goal was to provide integration, custom-gear training, repair software, and equipment for the automotive repair community. The pace of modern automotive technology is almost incomprehensible to most people outside the industry. Our company understands that and engages primarily in the development of features and information, rich content training, repair, and equipment products. Integration, which is now the center of many of our efforts, is the ability for smart applications/programs to talk to each other and come up with solutions that would otherwise be impossible to detect.

As a wholesale operation to schools and tool houses, we develop, test, and manufacture all of our dedicated PC-based software, interface boxes and training DVDs, books, and CD-ROMs. We also run and operate a Nationwide Web-Based Techline Service. Our Integrated Scan-1 and Internet Techline Service are technologies created at our California facility. Our job is to help repair shops solve faults that are difficult to solve. This way we can stay current with all the newer systems and recurrent problems out in the field. The company also engages in training on-demand, tailored to the specific needs of each shop using the Scan-1 and Techline Internet service. Our on-demand training programs can range from equipment usage (scanners, oscilloscopes, GMM, signal generators as well as our own PC Based equipment), OBD-II strategies, tracing network faults, factory antitheft, ABS systems, electronic transmissions, to how to advertise your repair shop on the Internet.

Automotive Diagnostics and Publishing

www.autodiagnosticsandpublishing.com

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sales@autodiagnosticsandpublishing.com

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KEPLINGER'S AUTOMOTIVE CENTER

In February of 1968 my career in the automotive repair industry began when I opened Williamsport Shell, a gas station with two service bays. Soon after opening I realized that if I wanted to succeed as an independent repair shop, I needed additional training from the basics of what I already knew, and so began a 40-year journey to learn how to repair automobiles—a journey that has no end. Allen Test Products, Catonsville Community College, and numerous after-hour automotive seminars provided just some of the training for me and the technicians who worked for me.

I spent 27 years running the service and repair stations for Shell and Exxon. During that time I was twice elected to represent Baltimore area Exxon dealers at Exxon corporate headquarters in Houston, Texas. In 1994 I opened a repair-only shop in a leased building and ran that business for five years.

Due to the success of the business, and my expanding customer base, I couldn't take care of all the customers who wanted service in the current building so in 1999 I built a 10-bay service center—Keplinger's Automotive Center, located in Hagerstown, Maryland. We work on all makes and models of cars and trucks and have six technicians, including two of my sons. If you're in the area, and need service for your vehicle, please stop by.

Larry C. Keplinger
Keplinger's Automotive Center
10218 Sharpsburg Pike
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ELWOOD'S AUTO EXCHANGE

Elwood's Auto Exchange is located in Smithsburg, Maryland, on Route 64. Established in 1950, Elwood Grimm's first junked car is this 1953 Willys Aero Lark, which has been parked right outside the old farmhouse ever since they opened for business. Elwood's has cars and trucks (even a few motorcycles) from the 1940s to present in various states of salvage. Nestled in rural Maryland farmland, the yard covers 53 rolling acres packed full of old, and not so old, cars and trucks.

According to William Smith, the company historian, Elwood's is famous, or infamous, depending on whom you talk to. It seems that President Lyndon Johnson and the first lady, Ladybird Johnson, were on their way from Camp David, located in the Catoctin Mountains a few miles away, to church in Hagerstown. As the Presidential motorcade passed the junkyard, Ladybird asked that they stop. She got out of the limousine and marched up the dirt road to Old Man Grimm's office and gave him a piece of her mind regarding the unsightliness of the wrecking yard, and how it ruined the beautiful landscape. This was in 1963, and in

1965, the Highway Beautification Act was passed by Congress. This legislation authorized federal funding for the removal of billboards and the cleaning up of junkyards along interstates and other highways. So we have Elwood's to thank for having wrecking yards located away (or at least hidden) from major highways.

Elwood's was a great place to take many of the photographs for this book. If I needed a photo of a crank sensor from a late-model Chevy. I would just walk along the rows of cars until I found one with the front end ripped off. I bent down and got the shot I needed. Images like this would be extremely difficult to get from a running automobile, as there is no way to even get a camera close to some of the components I took pictures of. I thank Elwood's for letting me photograph their great selection of cars and trucks. They are open seven days a week, from 8 a.m. to 5 p.m.

Elwood's Auto Exchange
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Smithsburg, MD 21783
301-739-7159



APPENDIX A

Domestic OBD-I and OBD II Applications

This table shows the various onboard engine management systems used by domestic auto makers and emphasizes how different they all were until OBD-II in 1996.

GM Onboard Diagnostics

System	Years Used	Description
OBD-I Control	1981–1995	Most vehicles used the 12-pin ALDL (Assembly Line Data Link) located Module under the dash on the driver side. Some 1994–1995 vehicles used the 16-pin OBD-II (J1962) data link connector (DLC) but use the Historical application software. Refer to the vehicle's Vehicle Emission Control Information label.

OBD-II Control	1994*–Present	Complies with OBD-II regulations and uses the J1962 DLC.
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Module

- *OBD-II system is used on certain 1994–1995 vehicles equipped with a 2.2L, 2.3L, 3.8L, 4.3L, or 5.7L engines.*

Ford Onboard Diagnostics

System	Long Name	Years Used	Description
MCU Control Unit	Microprocessor	1980–1991	Used in police vehicles containing carbureted engines. Uses the MCU DLC.
EEC-IV	Electronic Engine Control Fourth generation	1984–1995	Most Ford vehicles equipped with North American engines. Uses the EEC-IV DLC.
MECS Control System	Mazda Electronic	1988–1995 Uses MECS 6-pin and 17-pin DLCs.	Vehicles equipped with Mazda-sourced engines.
EEC-V	Electronic Engine Control Fifth generation	1994*–present	Complies with OBD-II regulations and uses the OBD-II J1962 DLC.
PTEC Electronic Controller	Powertrain	2000–present	Complies with OBD-II regulations and uses the OBD-II J1962 DLC.

- *EEC-V OBD-II system used in 1994–1995 vehicles equipped with a 3.8L or 4.6L engine.*

Chrysler Onboard Diagnostics

System	Long Name	Years Used	Description
SMEC	Single Module Engine Controller	1989–1990 DLC and has bidirectional capability.	Used a 6-pin Serial Communication Interface (SCI)
SBEC	Single Board Engine Controller	1989–1995	Used two types of DLCs; a 6-pin (SCI) and 6-pin LH series.
OBD-II	Powertrain Control Module	1995–present	Uses OBD-II J1962 DLC connector.
JTEC	Jeep/Truck Engine Controller	1996–present	JTEC system is used on light-duty trucks and Jeeps.

APPENDIX B

Vehicle Manufacturer Contact Information for OBD-II

Domestic Vehicles	Web Site Address	Phone Number
General Motors		
Chevrolet	www.chevrolet.com	1-800-551-4123
Pontiac	www.pontiac.com	1-800-551-4123
Oldsmobile	www.oldsmobile.com	1-800-551-4123
Buick	www.buick.com	1-800-551-4123
Cadillac	www.cadillac.com	1-800-333-4CAD
Saturn	www.saturn.com	1-800-553-6000

Domestic Vehicles	Web Site Address	Phone Number
Ford		
Ford	www.ford.com	1-800-392-3673
Lincoln	www.lincoln.com	1-800-392-3673
Mercury	www.mercury.com	1-800-392-3673
Chrysler		
Chrysler	www.chrysler.com	1-800-348-4696
Dodge	www.dodge.com	1-800-348-4696
Plymouth	Not Available	1-800-348-4696
Eagle	Not Available	1-800-348-4696

(continued)

Domestic Vehicles	Web Site Address	Phone Number	Domestic Vehicles	Web Site Address	Phone Number
European Vehicles			Asian Vehicles		
Audi	www.audi.com	1-800-544-8021	Acura	www.acura.com	1-800-999-1009
Volkswagon	www.vw.com	1-800-544-8021	Honda	www.honda.com	1-800-999-1009
BMW	www.bmw.com	1-201-307-4000	Lexus	www.lexus.com	1-800-255-3987
MINI	www.mini.com	1-201-307-4000	Scion	www.scion.com	1.866.70.SCION
Jaguar	www.jaguar.com	1-800-4-JAGUAR	Toyota	www.toyota.com	1-800-GO-TOYOTA
Volvo	www.volvo.com	1-800-458-1552	Hyundai	www.hyundai.com	1-800-633-5151
Mercedes-Benz	www.mercedes-benz.com	1-800-367-6372	Infiniti	www.infiniti.com	1-800-662-6200
Land Rover	www.landrover.com	1-800-637-6837	Nissan	www.nissanusa.com	1-800-NISSAN1
Porsche	www.porsche.com	1-800-PORSCHE	Kia	www.kia.com	1-800-333-4542
Saab	www.saab.com	1-800-955-9007	Mazda	www.mazda.com	1-800-222-5500
			Daewoo	www.daewoo.com	1-822-759-2114
			Subaru	www.subaru.com	1-800-SUBARU3
			Isuzu	www.isuzu.com	1-800-255-6727
			Geo	Not Available	Not Available
			Mitsubishi	www.mitsubishi.com	1-888-MITSU2004
			Suzuki	www.suzukiauto.com	1-800-934-0934

APPENDIX C

Just like many drivers don't feel that all traffic regulations and laws apply to them, auto manufacturers take this same view when it comes to the location of their OBD-II diagnostic link connectors, or DLCs. Here is a chart that illustrates hiding places for some of the nonstandard, but allowed, locations for the DLC.

Nonstandard Locations for DLC

Manufacturer	Model(s)	Year(s)	DLC Location
Acura	CL	1997-1998	Under dash, passenger side near center console
Acura	CL	1999	Uncovered, above shifter
Acura	RL	1999-2000	Center console, forward of shifter behind cover
Acura	TL	1996-1998	Center console, behind ashtray
Acura	TL	1999-2000	Behind center dash/console, below stereo, near seat heater control at left
Acura	Integra	1996-1999	Under dash, passenger side near center console
Acura	NSX S2000	1999-2000	Under dash, passenger side near center console
Acura	RL	1996-1998	Front of center console, passenger side
Audi	A4, A4 Avant,	1996	Center console, behind rear sliding ashtray cover
Audi	A6	1996-1997	Center console, behind front tray
Bentley	All	1996-2000	In glove box, behind cover
BMW	3 Series	1996-2000	Behind left side of lower left dash but covered by panel.
	5 Series, M3		Turn slotted screw ¼ turn to open
BMW	7 Series	1996-2000	Behind center dash/console, under stereo controls
BMW	X3, M Roadster	1996-2000	Behind passenger side of center dash, console
BMW	Z3	1996-2000	Behind cover, under dash on passenger side
Ferrari	All	1996-2000	Very high under dash, driver's side near center of car
Ford	Bronco	1996	Under dash, slightly right of center
Ford	Trucks, F-Series		Covered
Ford	Thunderbird	1996-1997	Under dash, slightly right of center covered
Honda	Accord	1996-1997	Behind ashtray, center console
Honda	CR-V, Prelude	1997-2000	Under dash, passenger side near center
Honda	Del Sol, Insight	1996-2000	Under dash, passenger side near center
Honda	Odyssey	1996-1998	Behind passenger side of center dash/console
Honda	Prelude	1996	Uncovered, above shifter
Hyundai	Accent	1996-1998	Right center dash, in coin holder
Land Rover	Defender	1997	Left center of dash, under tray
Land Rover	Range Rover	1996-2000	Under right dash, behind cover
Lotus	Espirit	1997-2000	Under cover, above right center of dash/console
Porsche	All	1996	Behind center dash, toward left side
Rolls-Royce	All	1996-2000	In glove box, behind cover
Toyota	Prius	2000	Behind right center dash/console
Toyota	Previa	1996-1997	Behind cover, right side of instrument cluster
Volvo	850	1997-1998	Center console, behind coin holder, forward of shifter
Volvo	All except 850	1998-1999	Behind right side of center console near hand brake
Volvo	S40, V40	2000	Behind cover, left center dash/console
Volvo	C70, S70, V70	2000	Behind cover, center console forward of shifter
Volkswagen	Cabrio	1996-1998	Behind right center dash, to right of ashtray
Volkswagen	Eurovan	1996-early 1999	Under cover, right of instrument cluster, behind wiper control lever
Volkswagen	Golf, Jetta	1999	Behind right center dash
Volkswagen	Passat	1996-1997	Under cover, right of instrument

Glossary—OBD-II Automotive Terminology

ACT	Air Charge Temperature sensor, measures air temperature entering the engine.	EGR	Exhaust Gas Recirculation, valve that meters exhaust gas into intake manifold to be reburned.
AFM	Airflow Meter, mechanically measures volume of air entering the engine.	EI	Electronic Ignition, generic description of any distributorless ignition system.
ALDL	Assembly Line Data Link, GM connector for reading codes engine data. See DLC.	EPA	Environmental Protection Agency, Federal Government.
		EVAP	Evaporative System, controls fuel vapors from the fuel tank.
BARO	Barometric Pressure sensor, measures altitude or atmospheric pressure.	Fuel Trim	Adjustment made by the PCM as needed to add or remove fuel from its basic fuel map.
BCM	Body Control Module, controls accessories and functions other than the engine and transmission.	HC	Hydrocarbons, unburned fuel from the combustion process
BOO	Brake On/Off switch, tells the PCM when the brakes are being applied.	HEGO	Heated Exhaust Gas Oxygen sensor, same as EGO but with an electric heating element.
BUS	The electronic circuits (hardware) that connects a scanner to an OBD-II system.		
CCM	Comprehensive Component Monitor, one of 12 OBD-II diagnostic monitors or tests.	IAC	Idle Air Control, air passages that bypass the throttle are adjusted by the PCM control idle speed
CO	Carbon Monoxide, an odorless poisonous gas that is a product of incomplete combustion.	IAT	Intake Air Temperature sensor, same as ACT, MAT.
CO2	Carbon dioxide, an inert gas that is a byproduct of the combustion process.	KS	Knock Sensor, generates an electrical signal to tell the computer when detonation occurs.
CAN	Controller Area Network, a communication protocol that is mandatory by 2008 for OBD-II.	LED	Light Emitting Diode, solid state device (light) used as an indicator light.
CAT	Catalytic Converter, mounted in the exhaust to control HC, CO, and NOx from the exhaust.	MAF	Mass Airflow sensor, used by the PCM to measure the amount and density of intake air.
CKP	Crankshaft Position sensor, measures the rotational speed and position of the crankshaft.	MAP	Manifold Absolute Pressure sensor, measures intake manifold vacuum to sense engine load.
CMP	Camshaft Position sensor, monitors camshaft position, used for cylinder identification.	MAT	Manifold Air Temperature sensor, same as ACT and IAT.
CTS	Coolant Temperature Sensor, monitors engine coolant temperature.	MIL	Malfunction Indicator Lamp, controlled by the PCM, to warn driver of impending doom.
		MPI or MPFI	Multiport Fuel Injection, EFI system with one injector per cylinder.
DI	Distributor Ignition, uses a conventional distributor with internal electronics.	NOx	Oxides of Nitrogen, pollutant that occurs when the combustion temperatures are too high.
DIC	Data Information Center, data display located in the dash, center, or overhead console.	O2	Heater An electric heating element integral to the O2 sensor.
DICM	Driver Information Center Module, same function as DIC.	O2	Sensor Measures exhaust gas oxygen content in the engine's exhaust.
DIM	Dash Integration Module, controls memory seats, mirror tilt steering wheel, radio memory.		
DIS	Distributorless Ignition System, uses remote ignition module and coil pairs or coil over plug.	PCV	Positive Crankcase Ventilation, directs crankcase gases into the intake manifold.
DLC	Data Link Connector. Diagnostic Link Connector, same as ALDL.	PCM	Powertrain Control Module, onboard vehicle computer, see ECM.
DMM	Digital Multimeter, solid state multimeter for measuring volts, amps, ohms, and others.	PFI	Port Fuel Injection, individual fuel injector for each cylinder, see MPI or MPFI.
DPFE	Differential Pressure Feedback EGR, Ford acronym for EGR valve flow sensor.		
DTC	Diagnostic Trouble Code, the number(s) stored in the PCM to indicate a malfunction.	TBI	Throttle Body Injection, EFI system that uses one or two injectors for the entire engine.
DVOM	Digital Volt-Ohmmeter, see DMM above.	TPS	Throttle Position Sensor, measures throttle opening or angle.
ECT	Engine Coolant Temperature sensor, same component as CTS.	TCC	Torque Converter Clutch, applies a mechanical lock between the engine and auto transmission.
EEPROM	Electronically Erasable Programmable Read-Only Memory.		
EFE	Early Fuel Evaporator Valve, helps warm up intake manifold with exhaust gas.	VSS	Vehicle Speed Sensor, measures vehicle road speed.
EGO	Exhaust Gas Oxygen sensor, measures amount of oxygen in the exhaust flow.	WOT	Wide Open Throttle, pedal to the metal.

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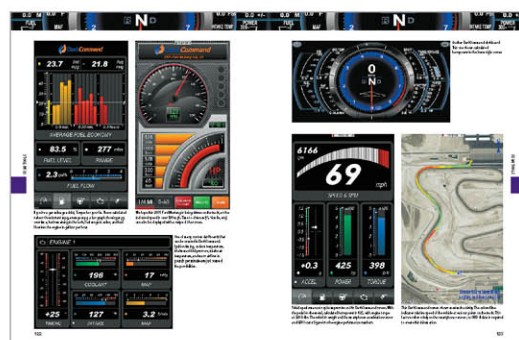
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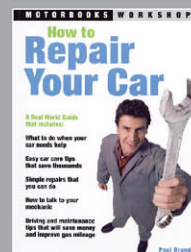
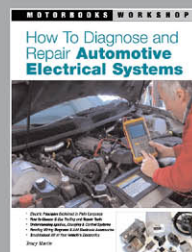
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