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AUTOMOTIVE COMPUTER CONTROL SYSTEMS

William L. Husselbee

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Automotive Computer Control Systems

Fundamentals and Service

11/18

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William L. Husselbee

Rogue Community College
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*To my wife, Laurie, whose patience, understanding, and
clerical assistance made this project possible.*

PREFACE

Automotive repair technicians are now faced with what is probably the greatest challenge since the introduction of the automobile—the testing and repairing of the microcomputer engine control systems found on automobiles. The computerized system has all but replaced a number of basic engine control functions that were once handled by mechanical or pneumatic automatic devices. The change to microcomputer engine control systems resulted from emission and fuel economy standards that the vehicle manufacturers had to meet.

To people working in the field, computerized control systems may seem very complex and difficult to understand, requiring the skill of an electronics expert more than an automotive technician. However, this is not true. Although computerized systems are complicated and often require different methods of diagnosis and repair, they are all fixable. As with any other automotive system, common sense, logic, and a knowledge of how the system functions are the most important tools the technician can have.

This textbook is designed to provide that knowledge. It is arranged to guide the reader through computerized engine control systems from the basic operating principles to the testing and repair of the complex systems used in modern automobiles and light trucks. The chapters are arranged in the order they should be studied, the early chapters providing the groundwork for the later ones. The first four chapters, for example, deal with the need for electronic engine control systems, electrical fundamentals, electronic fundamentals, and automotive computers. Without mastering this information, the rest of the text will be difficult to comprehend.

Chapter 6 deals with shop tools and procedures. This information is introduced before any material on the subsystems under microcomputer control are discussed. The reader will, therefore, be ready to use correctly the various types of equipment called for to test subsystem and microcomputer circuits and components. These circuits and

components are usually very expensive, and the improper use of test equipment or an inaccurate diagnosis can quickly destroy them.

Chapters 7 through 17 break down the computerized engine control system into smaller units, or subsystems. Before the advent of microcomputer control, these were all considered to be separate engine systems. A chapter on the design and operation of a particular subsystem is followed by one on how to troubleshoot it for malfunctions. In these later chapters, special emphasis is placed on the use of diagnosis charts and step-by-step procedures along with such basic test equipment as the voltmeter and the ohmmeter. In the ignition service chapters, scope pattern diagnosis of the various systems is clearly explained.

Chapters 18 through 23 provide data on specific, computerized engine control systems produced by Ford, General Motors, and Chrysler. Each system is covered fully, enabling the reader to form a complete picture of system design and function. Such an understanding should make the diagnosis easier. Because most imported systems are similar in design and operation to those presented in Chapters 18 through 23, only typical domestic computerized engine control systems are covered in this book.

Each of the system theory chapters is followed by one on service. The service chapters cover detailed procedures for troubleshooting and repairing typical systems, including how to access service codes and properly use driveability, quick, and pinpoint test procedures. If the technician is not fully aware of what a particular test is attempting to measure, what the normal readings should be, and what conditions cause abnormal results, a correct interpretation of diagnostic procedure directions can be difficult.

In designing this book, the author assumed that the reader was already familiar with the basic principles of internal combustion gasoline engines and their fuel, lubricating, and cooling systems. Therefore, these principles are not explained in this

text. Moreover, this textbook is not intended to replace manufacturer's manuals or aftermarket technical service publications. This book supplements these materials by providing additional information about how the systems are designed and operate, and practical instruction about how to interpret the manufacturer's service and testing procedures.

SAFETY PRECAUTIONS

This text contains various general and specific safety precautions that must be read and understood in order to minimize the risk of personal injury or damage to the vehicle or its components from incorrect service procedures. The author could not possibly know, evaluate, and advise the service industry of all the conceivable ways in which service or repair may be carried out or of the many possible hazardous consequences of an unorthodox method. Accordingly, anyone who uses any service procedure must first satisfy himself or herself that the use of a procedure will neither jeopardize personal safety nor damage the vehicle. When in doubt as to how to use a given tool or piece of equipment, or how to perform a given service procedure, always refer to the appropriate manufacturer's instructions or vehicle service manual.

TEACHING AIDS

This text incorporates a number of teaching aids. Each chapter is preceded by a number of objectives that spell out what the reader should know or be able to do after reading and studying a given chapter. In addition, all chapters have self-check and review sections at their conclusion to assist the reader in determining how well he or she remembers the material in the chapter. All the self-check and review questions or statements are based on chapter objectives and are keyed to the sections from which they come.

Although they are not actual Automotive Service Excellence (ASE) test questions, the review questions or statements found in service Chapters 7, 9, 11, 13, 15, 17, 19, 21, and 23 are similar in format. ASE questions are generic in nature, while the ones presented in these chapters test the reader's knowledge of a system specific to a single make of automobile. ASE is a nonprofit institute that prepares, ad-

ministers, and grades tests for the voluntary certification of automotive, heavy-duty, and auto body technicians. ASE certification is the most valuable credential available to service technicians because (1) the ASE tests are tough and passage of any one of the specialized area tests demonstrates that a technician is among the elite of his or her profession and (2) ASE credentials are recognized throughout the nation.

Each chapter has a generous number of illustrations. They help in explaining components or systems as well as service procedures. And each illustration has a brief explanation that ties it to the text material.

ABOUT THE AUTHOR

The author has 31 years of experience in the industry in the following areas: automotive machinist, automobile mechanic, service advisor, tune-up technician, automotive instructor, and technical writer. This experience is reflected in the practical approach to the subject matter along with the content and design of this book. Finally, the author is an ASE certified master automotive technician and a member of the National Association of College Automotive Teachers (NACAT) and California Automotive Teachers (CAT).

ACKNOWLEDGMENTS

The author wishes to thank Chrysler Motors Corporation, Ford Motor Company, Sun Electric Corporation and General Motors Corporation for the use of material and illustrations in this text.

The author must also express appreciation to the reviewers whose comments and criticisms have greatly enhanced this book: William M. Dempsey, National Institute for Automotive Excellence; Max J. Morley, Anchorage Community College; Rick Escalambre, Skyline College; Ted Nicoll, Central Missouri State University; and Steve Stillwell, Central Piedmont Community College.

Also, the author would be grateful for information from readers on errors or omissions in this book.

William L. Husselbee

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Automotive Computer Control Systems

NEED FOR ELECTRONIC CONTROL OF ENGINE OPERATION

OBJECTIVES

After reading and studying this chapter, you will be able to

- explain the function of engine controls.
- describe the differences between primary and secondary engine controls.
- explain the three harmful emissions that an engine produces.
- describe what an information processor does and the drawbacks to mechanical or pneumatic types.
- explain how electronic engine controls can increase engine power, improve vehicle driveability, reduce emissions levels, and improve fuel economy.

1-1 PRIMARY ENGINE CONTROLS

Automobile engines have always had a number of primary control devices. Basically speaking, *primary engine controls* are mechanisms used to regulate the operation of the power plant so that it can function in an efficient and predictable manner. For example, the carburetor is a control that governs the engine's air/fuel ratio and speed, while the distributor directs ignition system operation and spark timing (Fig. 1-1).

Over the years, the automobile industry has used hydraulic, mechanical, and pneumatic controls. By the mid-1960s, these controls had become quite sophisticated. However, the only electrical primary control, used before the mid-1970s, directed the operation of the ignition system.

Factors Relating to the Control of Engine Operation

When viewing the control of engine operation, there are four factors to consider: (1) power, (2) vehicle driveability, (3) emission levels, and (4) fuel economy. Before the mid-1960s, the automobile industry designed and produced vehicles with controls that promoted the first two factors, power and driveability. This was due primarily to the public's taste and driving habits.

As a result, the majority of automobiles at that time were large, heavy, and equipped with high horsepower engines that produced a lot of power and provided great vehicle driveability. But these engines consumed a lot of fuel and produced high emission levels.

However, neither of these problems was of much concern then. After all, fuel was cheap and

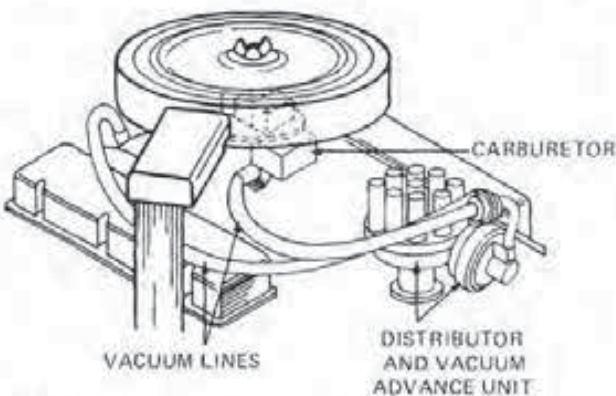


FIGURE 1-1
Primary engine controls, the carburetor and distributor.

MODEL YEAR	HYDROCARBON (HC)		CARBON MONOXIDE (CO)		OXIDES OF NITROGEN (NO _x)	
	CALIFORNIA	FEDERAL	CALIFORNIA	FEDERAL	CALIFORNIA	FEDERAL
1978	0.41	1.5	9.0	15.0	1.5	2.0
1979	0.41	0.41	9.0	15.0	1.5	2.0
1980	0.39	0.41	9.0	7.0	1.0	2.0
1981	0.38	0.41	7.0	3.4	0.7	1.0
1982	0.38	0.41	7.0	3.4	0.4	1.0
1983	0.38	0.41	7.0	3.4	0.4	1.0
1984	0.38	0.41	7.0	3.4	0.4	1.0
1985	0.38	0.41	7.0	3.4	0.7	1.0
1986	0.39	0.41	7.0	3.4	0.7	1.0
1980 (No Control)		10.5		64		4.1

FIGURE 1-2
Federal vehicle emission requirements in grams per mile.
(Courtesy of Chrysler Motors Corp.)

readily available. Moreover, although recognized as a problem, harmful engine emissions were not as yet subject to strict controls.

During this era, vehicle designers and engineers also did not have to concern themselves with complicated primary engine controls. Engines operated well on relatively rich mixtures that were rather simple to maintain. The basic hydraulic, mechanical, and pneumatic controls built into the carburetor and distributor, which had been in service for years, still remained adequate for the job.

In fact, there is one main reason it took so long for electronic controls to be adapted to the automobile engine. The automobile industry was reluctant to give up a well-understood and well-defined primary control technology to embark on the potentially risky program of implementing the use of electronics.

Legislated Emission Standards

But in the late 1960s and early 1970s, the third factor, emission levels, entered the picture. California and the federal government, responding to ever increasing levels of airborne pollution, began to pass emission control standards for motor vehicles. Figure 1-2 shows federal and California emission standards, using 1978 as a base. Notice that for 1980 and 1981, emissions standards decrease sharply the allowable limits.

As a result of the new standards, automobile manufacturers embarked on a program of federally mandated change. For the first time, auto companies had to seriously consider emission levels during engine operation. These standards have been effective in curbing high emission levels of motor vehicles by forcing manufacturers to adjust engine calibrations by leaning air/fuel mixtures, altering spark timing, and even redesigning the power plant itself.

1-2 SECONDARY ENGINE CONTROLS

In addition, the industry installed additional devices when it became apparent that the primary ignition and fuel system controls were insufficient to reduce emission levels alone. Therefore, these *secondary engine controls* were primarily for the purpose of further reducing harmful emissions and operated either mechanically, pneumatically, or electrically.

Typical secondary engine controls or systems installed on vehicles include the

- positive crankcase ventilation (PCV) system,
- air injection system,
- exhaust gas recirculation (EGR) system,
- transmission controlled spark (TCS),
- evaporation emission control (EEC) system,
- catalytic converter system, and
- thermostatic air cleaner (TAC).

Types of Emissions Controlled

These devices reduce three of the harmful emissions produced by an automobile engine. These include hydrocarbons, carbon monoxide, and nitrogen oxides, all three of which are under federal control standards.

Hydrocarbons (HC) are the chemicals that make up gasoline. They are made of different combinations of hydrogen (H) and carbon (C). Hydrocarbon emissions are the product of unburned gasoline from blow-by gases, unburned gasoline from the engine crankcase, fuel evaporation losses, or a misfire condition within a cylinder (Fig. 1-3). The misfire can result from a mechanical, electrical, or air/fuel ratio problem. The latter is characterized by a portion of the charge being too rich or too lean to burn at all.

Carbon monoxide (CO) is a gas consisting of carbon and oxygen. This colorless, odorless, poisonous gas is the product of the combustion process within the engine (Fig. 1-4).

During ideal combustion, the carbon and hydrogen in the gasoline combine with oxygen from the air, releasing heat energy and forming various chemical compounds. If the combustion is perfect, the exhaust gases consist of carbon dioxide (CO_2) and water (H_2O), neither of which is considered harmful in the atmosphere.

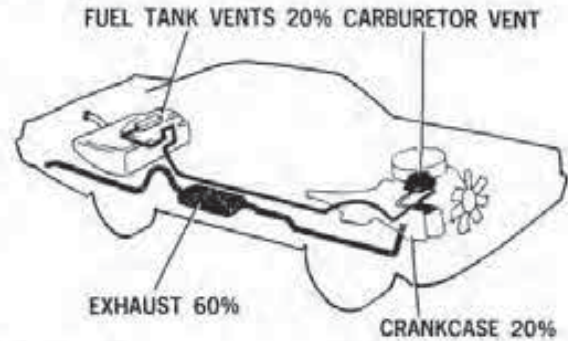


FIGURE 1-3

Sources of hydrocarbon emissions from an automobile. (Courtesy of Chrysler Motors Corp.)

Unfortunately, combustion in the internal combustion engine is not perfect. Consequently, in addition to the CO_2 and H_2O , the exhaust contains a quantity of CO. The problem becomes worse whenever the air/fuel ratio is richer than about 15:1 because there is less oxygen present in the charge to complete the combustion process. The lack of oxygen decreases the conversion of carbon to carbon dioxide.

Therefore, carbon monoxide levels are very dependent on the air/fuel ratio. This, in turn, depends to a great extent on the calibration of the carburetor. The leaner the mixture the carburetor provides, within a certain range, the more oxygen there is available to reduce CO emissions.

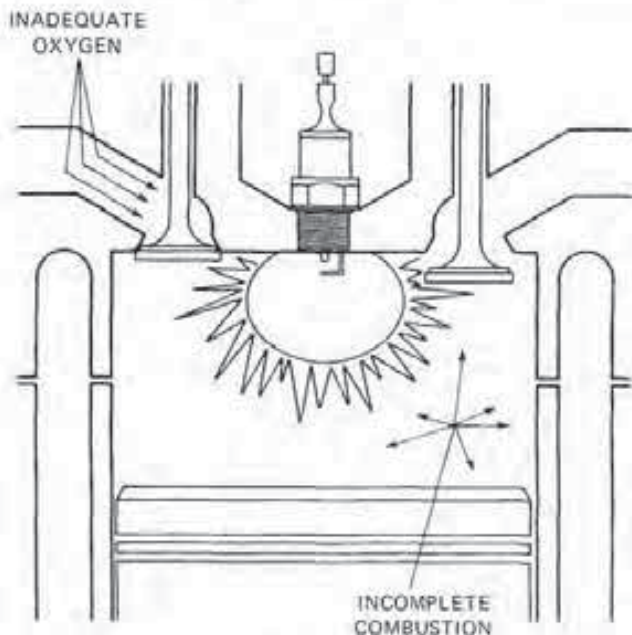


FIGURE 1-4

Carbon monoxide is the result of incomplete combustion.

Nitrogen oxides are gases consisting of nitrogen from the atmosphere that combine with varying amounts of oxygen under the high temperature and pressure conditions found in the internal combustion engine (Fig. 1-5). The high temperatures necessary to form NO_x , above $2,500^\circ\text{F}$, only occur during some phases of engine operation. (Note: NO_x is the symbol representing any combination of nitrogen and oxygen. The x symbolizes any number of oxygen atoms in the gaseous compound.)

When an engine is operating, atmospheric air moves through the carburetor where it mixes with fuel before entering the engine. Under normal conditions, the combustion process consumes the oxygen from the air, while the nitrogen passes out of the exhaust virtually unchanged.

However, during the combustion process, temperatures may exceed $4,500^\circ\text{F}$. At temperatures above about $2,500^\circ\text{F}$, nitrogen oxides form very rapidly from the nitrogen and oxygen in the air. Consequently, the formation of NO_x is dependent on temperature. Any variable that causes an increase in temperature above about $2,500^\circ\text{F}$ will increase NO_x emissions.

Effect of Emission Control Standards on Vehicle Driveability

Engine power was lost and vehicle driveability did suffer slightly as a result of leaner mixtures, timing recalibrations, internal engine changes, and the addition of the early types of secondary controls. These negative effects were in opposition to the

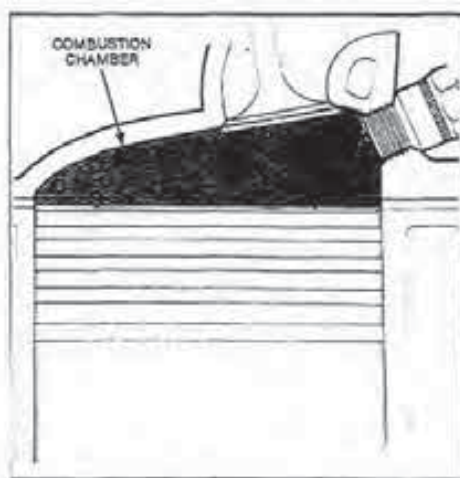


FIGURE 1-5
Nitrogen oxides form in the combustion chamber under high temperature and pressure.

MODEL YEAR	MPG	IMPROVEMENT OVER 1974
1978	18.0	50%
1979	19.0	58%
1980	20.0	67%
1981	22.0	83%
1982	24.0	100%
1983	26.0	116%
1984	27.0	125%
1985	27.5	129%
1986	27.5	129%

FIGURE 1-6
Fuel economy standards. (Courtesy of Chrysler Motors Corp.)

public's passion for big, fast automobiles. Vehicle driveability includes everything that the driver expects from a properly operating engine, such as easy starting (hot or cold), acceptable smoothness at idle, good acceleration in all speed ranges, instant response, and full power.

But manufacturers still considered their hydraulic, mechanical, pneumatic controls adequate for the task because driveability was not all that bad. Moreover, it was always possible to make an engine larger to compensate for the power loss. Finally, despite the fact that the larger, recalibrated emission-controlled engines of this period used more fuel, the operating costs were still within the range of most people. Therefore, there was still no need to make any basic changes in the primary engine controls.

1-3 LEGISLATED FUEL ECONOMY STANDARDS

In the early 1970s, another large problem occurred that directly affected the driving public and the automobile industry. This, of course, was the fuel shortage, which caused gasoline prices to skyrocket.

To reduce the use of fuel, the federal government mandated fuel economy standards, or requirements, to all vehicle manufacturers (Fig. 1-6). Federal fuel economy standards are based not only on a single automobile but also are stated in terms of average rated miles per gallon (mpg) fuel consumption for all production models by a manufacturer in any given year. It is a somewhat complex requirement that is based on the measurement of the fuel used during a prescribed, simulated, standard driving cycle that includes city and highway operation.

The mileage of any vehicle depends on many things, including size, shape, weight, and how it is driven. The best mileage is achieved under a steady

cruise condition; for example, on a highway. Good mileage is not a characteristic of city driving, with its many starts and stops. A combination of city and highway driving is used to determine the typical fuel mileage of a vehicle.

The standard itself is known in the automotive industry as the *Corporate Average Fuel Economy (CAFE)*. Beginning with the 1978 model year, CAFE standards began at 18.0 mpg and gradually increased through 1986, when the industry was supposed to meet a 27.5 mpg requirement. This represents a 129 percent decrease in fuel usage from typical 1974 model vehicles.

The *Environmental Protection Agency (EPA)* monitors these fuel economy requirements. To do this, the EPA groups automobiles by model, engine size, number of cylinders, catalyst use, fuel system, and sales area (49 states or California). However, because identical engine and drive train combinations are used in many different models, the EPA does not actually test every possible combination.

As a result of the CAFE standards, the automotive industry, for the first time, had to consider fuel economy during engine operation as well as power, vehicle driveability, and emission levels. To do this, engineers had to design smaller engines for little vehicles.

Moreover, these new engines had to operate closer to the *stoichiometric*, or ideal, air/fuel ratio of 14.7:1, regardless of the usual changes in load, acceleration, and other operating conditions. As a result, the conventional engine control systems were pushed to the limit of their capacity. The only solution available was a shift from the conventional to electronic control systems.

1-4 ELECTRONIC CONTROL SYSTEM

One of the most important developments in the automotive industry has been the shift to electronic engine control systems. The contemporary, fully computerized control system constantly adjusts fuel, ignition, and emission controls during various driving conditions. The result is improved engine performance, better driveability, increased fuel economy, and lower emission levels.

Conventional Control Systems are Information Processors

To understand why the shift to electronic control has become necessary, let's take a look at the inher-

ent limitations of a few conventional primary and secondary controls and then see how a computer overcomes them. All types of engine controls are *information processors*. That is, the control receives input information from the operating engine, processes it, and finally produces a specific output, which modifies the power plant's performance.

In what manner the control processes the information and how much it alters engine performance depends on its designer. In any case, the control comes very close to duplicating the human decision-making process by responding as the designer would to the information provided.

In addition, the action of the control is automatic. This means the device, if working properly, will process the information exactly the same way each time to produce a given change.

The centrifugal and vacuum advance units are primary controls found on a conventional distributor. Both of these devices are automatic information processors that use input data from the engine. The centrifugal advance is strictly a mechanical processor, while the vacuum unit is a pneumatic/mechanical processor. However, both units advance the ignition timing according to a given input signal.

The centrifugal advance (Fig. 1-7) uses an engine speed input signal from a spinning distributor shaft that is driven by the camshaft. The processor portion of the control consists of two flyweights of a given mass that pivot on a bracket attached to the distributor shaft and two springs. The low and high speed springs are of a calibrated tension and resist the outward movement of the flyweights due to centrifugal force.

In operation, the centrifugal advance receives the input speed signal from the engine in the form of the spinning distributor shaft. This signal causes the two flyweights within the processor to move out-

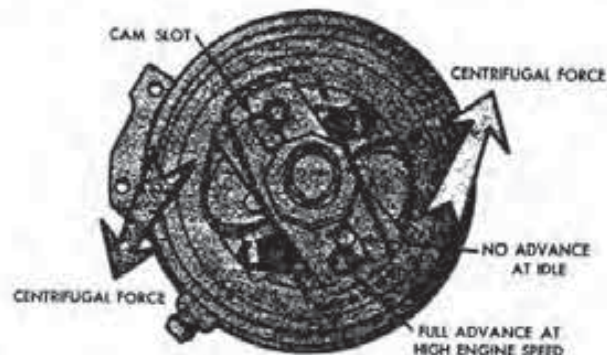


FIGURE 1-7
Typical centrifugal advance mechanism. (Courtesy of Ford Motor Co.)

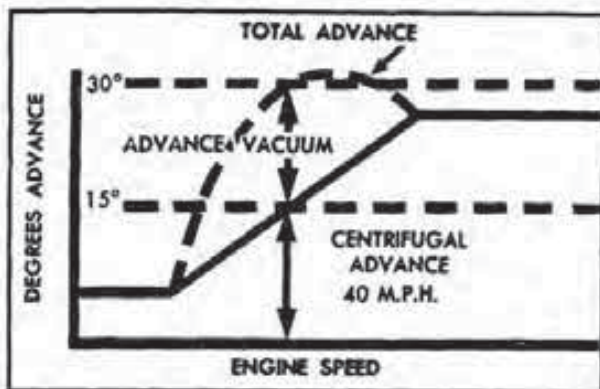


FIGURE 1-8
Timing advancement provided by the centrifugal and vacuum control units. (Courtesy of Delco Remy)

ward on their pivots due to the action of centrifugal force. The low-speed and then, in turn, the high-speed spring resist the movement of the flyweights as the distributor shaft accelerates.

At given speeds, the flyweights do move outward against spring tension. As they do, they advance the ignition timing by rotating the cam of point-type distributors, and the reluctor, armature, or timer core of electronic units. This movement is the output change that modifies the operation of the engine itself.

The amount of timing advance depends on how the processor—the weights and springs—react to the input signal. If the shaft speed (input signal) is low, there will be little or no advancement of the timing. On the other hand, with a high distributor shaft speed, the weights extend full outward in their respective travel, and the engine receives the maximum advancement built into the control. Between these two extremes, the timing will vary according to engine speed (Fig. 1-8).

The vacuum advance unit, on the other hand, uses a changing ported vacuum as the input signal to the processor. The processor itself consists of its housing, diaphragm and rod, and a spring (Fig. 1-9). The housing attaches to the outside of the distributor and has two chambers. One chamber vents directly to the atmosphere; the other connects via a line or hose to a carburetor-ported vacuum source.

The diaphragm is a piece of flexible material that is stretched between the two chambers to seal one from the other. The center of the diaphragm is reinforced with a round metal disc, where a push-pull rod attaches. The other end of the rod connects to a moveable plate that pivots within the distributor assembly.

One end of the calibrated spring bears against the center of the diaphragm; the other end is against the housing wall. The tension of the spring resists any movement of the diaphragm and rod as it reacts to changes in the ported vacuum.

When the engine is running at part-throttle conditions, there is a ported vacuum input signal at the carburetor nipple. Since one side of the diaphragm connects via a hose to the nipple, the ported vacuum acts on the spring side of the diaphragm. At the same time, atmospheric air pressure bears against its opposite side. With low pressure on the spring side and atmospheric pressure on the other side, the diaphragm moves over within the chamber against the tension of the spring.

The diaphragm movement causes the rod to move the plate within the distributor assembly a number of degrees on its pivot. This action (the output change) advances the timing by opening the points sooner in a contact system, or by advancing the position of the reluctor, armature, or pole teeth within the pickup coil of an electronic system.

When the ported vacuum is very high, the diaphragm assembly (the processor) provides the greatest amount of timing change (see Fig. 1-8). The timing advance provided by the unit varies from maximum at a high-ported vacuum to zero at idle.

Figure 1-10 illustrates a secondary engine control system consisting of the exhaust gas recirculation (EGR) control valve and a coolant control valve. The EGR valve itself is a pneumatic/mechanical, automatic-type processor that contains a diaphragm and calibrated spring. The diaphragm has a stem that attaches to a valve. The valve opens and closes passages leading from the exhaust to the intake manifold.

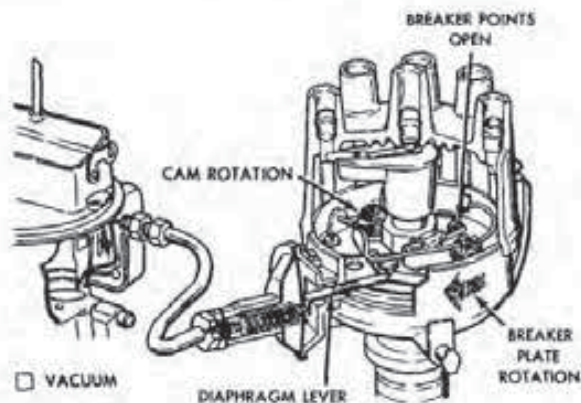


FIGURE 1-9
Common type of vacuum advance mechanism. (Courtesy of Ford Motor Co.)

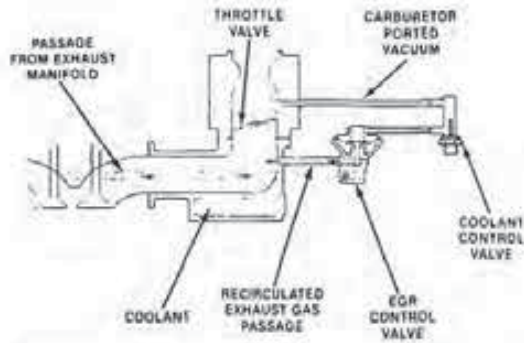


FIGURE 1-10
Typical exhaust gas recirculation (EGR) system. (Courtesy of Chrysler Motors Corp.)

The engine input signal to the EGR control processor is the ported vacuum. This signal varies from zero at idle to an intake manifold vacuum at moderate throttle settings. The signal also is near zero during wide-open throttle acceleration.

The input signal to the processor acts on the diaphragm. If the signal is strong enough to overcome spring tension, the diaphragm opens the EGR valve. Valve position, or the output change, is determined by the strength of the ported vacuum signal in opposition to the tension of the calibrated spring.

This system also has a second information processor, the coolant control switch (Fig. 1-11). The input signal to this device is coolant temperature. The temperature acts on a wax pellet or bimetallic sensing unit that operates a vacuum switch within the processor.

If the engine is cold, the sensing element allows the vacuum switch to close. This cuts off the ported vacuum signal to the EGR valve, so it cannot react to the ported input vacuum signal. When the engine is at normal operating temperature, the sensing element expands and opens the vacuum valve. At this point, the input signal can act on the EGR control valve.

Limitations to Automatic Processors

There are a number of drawbacks to automatic processors. First, the units are very inflexible. To change the manner in which one of these devices manages or processes input information, its hardware must be modified. For example, to alter the advance curve of a centrifugal unit, the mass of the flyweights or tension of the springs must be changed.

Second, most automatic processors use only one input signal. In the case of the centrifugal advance, the signal is the rotating distributor shaft.

The vacuum advance and EGR control valve both act on the varying strength of a ported vacuum signal.

Third, a mechanical or pneumatic/mechanical processor produces only one output change that affects engine performance. In the case of both of the advance controls mentioned earlier, the output change was an alternation in the engine's ignition timing. The EGR control valve, on the other hand, regulated the amount of exhaust gas recirculation used to reduce nitrogen oxide emissions.

Fourth, these devices do not respond instantaneously. In other words, a mechanical processor uses too much time to process the input information before actually making a change in some performance factor. As a result, it is basically impossible for the engine to operate as efficiently as it could.

Finally, a mechanical or pneumatic processor is adversely affected by wear. Even with the same input information provided, a worn part can cause the processor section of the unit to produce the wrong output change or become inoperative. This, of course, results in poor engine performance or increased emissions.

Electronic Information Processors

In order to meet increasingly stringent federal emission and fuel economy standards, automobile manufacturers had to develop different types of engine controls to overcome the inherent problems with automatic processors. Through the use of electronic controls, the various systems of the engine can be controlled very accurately. An electronic control system uses a number of *sensors* that detect and relay input information regarding changes in engine performance and emission levels. This information is fed to a microcomputer, which is an electronic information processor called by such names as the logic module, electronic control unit, and electronic

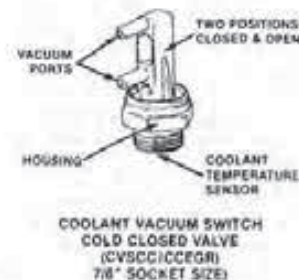


FIGURE 1-11
Thermostatic vacuum switch. (Courtesy of Chrysler Motors Corp.)

control assembly (Fig. 1-12). In any case, the input signals allow the microcomputer to monitor all engine operating conditions.

The sensors relay input information to the microcomputer by means of electrical signals. The computer processes the signals and then makes a decision regarding what system or systems need to be turned on or off. It then instantly directs electrical output signals to one or a number of control devices or actuators. Obviously, the system uses more than a single input signal and can produce multiple output changes that affect engine performance or emission levels.

When the computer signals an actuator, it turns a certain engine system on or off. This action

very precisely controls engine operation. This, in turn, promotes vehicle driveability, decreases harmful emissions, and increases fuel economy.

There are other benefits of the electronic control system. For example, it has fewer moving parts that could wear, which allows the system to retain its calibration almost indefinitely. In addition, the system is very flexible. Because it uses electronic processors, the system can be modified through programming changes to meet a variety of different vehicle and engine combinations. In other words, critical quantities that describe an engine can be easily changed by altering data stored in the computer's memory.

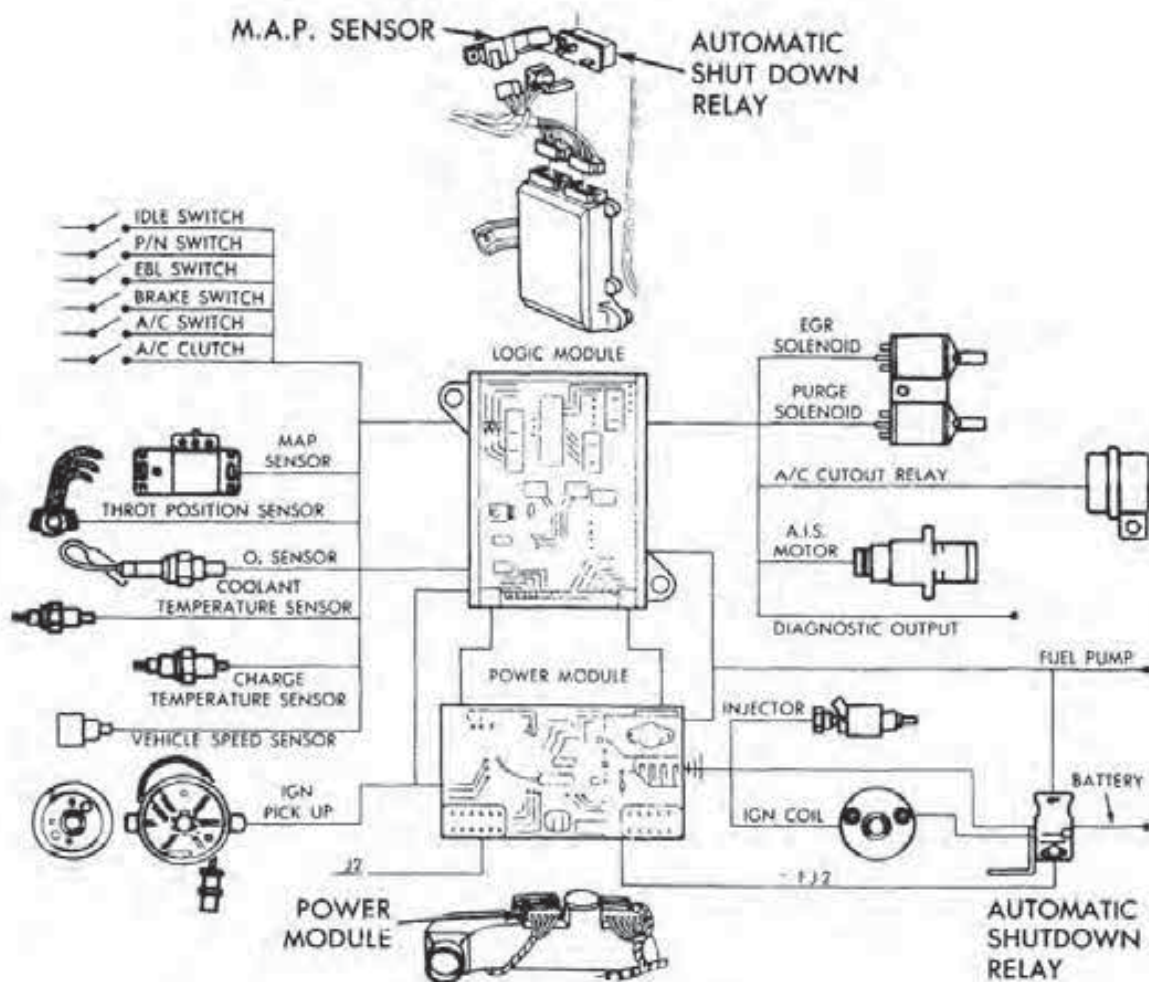


FIGURE 1-12

Typical electronic control system uses various sensors to provide input data to the computer. (Courtesy of Chrysler Motors Corp.)

CHAPTER REVIEW

The following two sections will assist you in determining how well you remember the material contained in this chapter. If you cannot complete a statement or question, refer back to the section marked in brackets that contains the material.

SELF-CHECK

1. What do engine controls do [1-1]?
2. Briefly describe how electronic controls overcome the problems inherent in mechanical or pneumatic devices [1-4].
3. What is the difference in function between primary and secondary engine controls [1-2]?
4. Where does NO_x originate [1-2]?
5. Explain the drawbacks to mechanical or pneumatic controls [1-4].
4. Secondary controls reduce what factor [1-2]?
 - a. fuel economy
 - b. emission levels
 - c. engine performance
 - d. both a and c
5. High CO emissions can be the direct result of [1-2]
 - a. a rich air/fuel mixture.
 - b. a lean air/fuel mixture.
 - c. a leaking vacuum hose.
 - d. both b and c.
6. The output signal from a microcomputer goes to a [1-4]
 - a. receiver.
 - b. sensor.
 - c. actuator.
 - d. transformer.
7. A signal that comes from an engine sensor to a processor is known as [1-4]
 - a. an input signal.
 - b. a processor signal.
 - c. an output signal.
 - d. a sensor voltage.

REVIEW

1. Electronic processors can handle how many input signals [1-4]?
 - a. one
 - b. two
 - c. three
 - d. four or more
2. The carburetor is which type of engine control [1-1]?
 - a. primary
 - b. secondary
 - c. processor
 - d. none of these
3. Wear has what effect on a mechanical information processor [1-4]?
 - a. may cause it to become inoperative
 - b. may throw it out of calibration
 - c. both a and b
 - d. neither a nor b
8. Who monitors the CAFE standards [1-3]?
 - a. auto industry
 - b. EPA
 - c. vehicle manufacturers
 - d. both a and c
9. Mechanical processors produce how many output changes [1-4]?
 - a. seven
 - b. five
 - c. three
 - d. one
10. NO_x is formed above what engine temperature [1-2]?
 - a. $2,000^\circ\text{F}$
 - b. $2,500^\circ\text{F}$
 - c. $3,000^\circ\text{F}$
 - d. $3,500^\circ\text{F}$

ELECTRICAL FUNDAMENTALS

OBJECTIVES

After reading and studying this chapter, you will be able to

- explain the basic structure of matter and the atom.
- describe the electron theory of current flow in a conductor.
- explain the differences in current, voltage, and resistance.
- identify and use the various forms of Ohm's law.
- identify the various types of electrical circuits used on motor vehicles.
- describe the effects of magnetism on non-magnetic and magnetic materials.
- explain how electromagnets are formed.
- describe electromagnetic induction of voltage in a conductor.
- explain the function and design of mechanical, automatic, and electromagnetic switches.
- describe circuit resistors, protection devices, and diagram symbols.

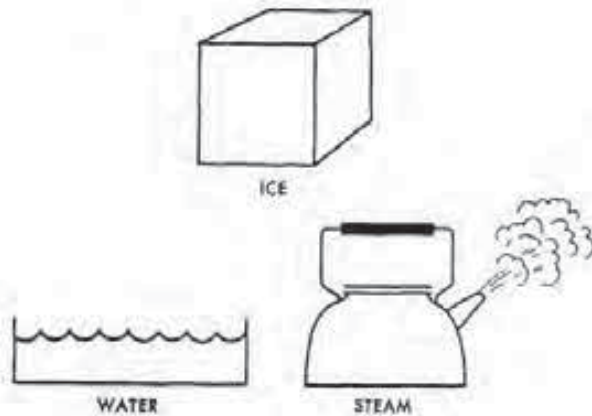


FIGURE 2-1
Three forms of matter: solid, liquid, or gas. (Courtesy of Delco Remy)

The modern automobile incorporates a vast amount of electrical and electronic equipment used to operate the engine, vehicle lighting, and varied accessories. This equipment has become very complex over the years, resulting in many mechanics dropping out of automotive service. As a result, there is a wide gap between technicians who understand electrical fundamentals and those who know very little about the subject.

The point here is that as the automotive industry moves farther away from mechanical or pneumatic controls and closer to using all electrical and electronic units, it becomes more important for all technicians to have a working knowledge of basic electricity. Although Chapter 2 is not a complete course in itself, it does provide the basic theory behind the operation of the electrical equipment found on the automobile. Moreover, the information provided prepares the reader for the more sophisticated electronic data presented in Chapter 3.

2-1 STRUCTURE OF MATTER AND THE ATOM

Although electricity itself is still somewhat of a mystery, its practical use has been known for over 100 years. *Electricity* is an invisible force that behaves according to definite rules and produces predictable results and effects. People have learned how to produce, store, use, and measure electricity, but no one knows exactly what it is. Scientists have a theory, the electron theory, that explains the nature of electricity fairly well. However, it is difficult to understand because electrons cannot be seen or easily illustrated.

Matter

In order to understand what an electron is and how it behaves, let's first briefly examine the composition of matter. *Matter* is anything that has weight and occupies space. For instance, the air that we breathe, the food that we eat, and the chair or sofa on which we sit are all forms of matter—that is, they all have weight (mass) and occupy space.

In addition, matter is not always in the form of a solid; it can be a liquid or a gas (Fig. 2-1). Thus, ice, water, and steam are examples of matter in all three forms. The actual differences in the appearance of forms of matter depend basically on two things: (1) the composition of the molecule, and (2) its physical arrangement within the object itself.

Molecule

A *molecule* is the smallest particle into which matter can be divided but still retain its original physical properties. For example, if a scientist divided a grain of salt in two and then divided each subsequent grain again and again until the division was as fine as possible, the smallest particle still retaining all the properties of salt would be a molecule. This salt molecule would be almost one-millionth of an inch in diameter and would need to be enlarged about 100 times before it could be seen in a microscope.

Molecular Arrangements

As mentioned, science classifies matter by its molecular arrangement into three forms: a solid, liquid, or gas (Fig. 2-2). In a solid form of matter such as a block of ice or a piece of steel, the molecular arrangement is rigid. That is, all molecules are very close to each other and have a strong attraction for one another. This arrangement resists any attempt to change the object's physical shape. For this reason, solid objects are, for practical purposes, not compressible.

In a liquid such as water, the molecular arrangement is not as rigid as the solid material. The molecules in this case do move somewhat in relation to one another or have less attraction for each other. This particular property allows the liquid to conform to its container's shape. Furthermore, the distance between the molecules in a liquid remains relatively close; consequently, it is also not compressible by normal means.

A gas such as steam has molecules that are far apart and move about at high speeds. Moreover, the

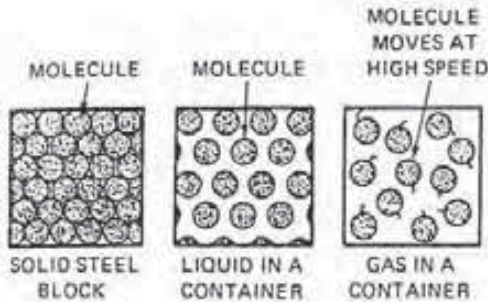


FIGURE 2-2
Molecular arrangement of a solid, liquid, or a gas. The molecule is represented by the circles within the object.

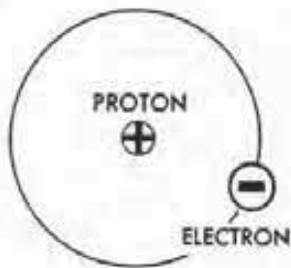


FIGURE 2-3
Hydrogen atom. (Courtesy of Delco Remy)

molecules can move freely in relation to one another and tend to repel each other. These factors give a gas its expansion quality; yet it is compressible by normal means because of the distance between the molecules.

Atoms

Molecules are composed of tiny building blocks called *atoms*. An atom can exist alone or in combination with other atoms to form millions of different forms of matter. An atom that exists alone is known as an *element*, and scientists are aware of over 100 of these atoms or elements on the atomic scale. Hydrogen, copper, and gold are good examples of elements. To signify all these elements, each one has an assigned letter or letters to represent it, such as H for hydrogen and O for oxygen.

In addition, each element differs from the one

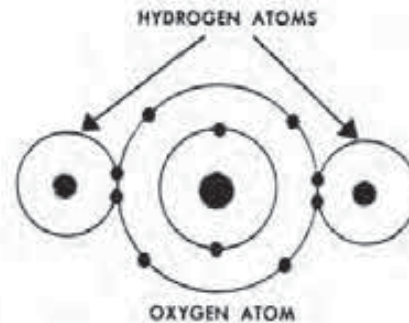


FIGURE 2-4
Atoms combine to form a molecule of water. (Courtesy of Delco Remy)

preceding it on the atomic scale by the addition of one proton and one electron. Hydrogen, for example, is one of the simplest of all atoms; it is number 1 on the atomic scale and has one proton and one electron (Fig. 2-3). Copper, on the other hand, is number 29 with 29 protons and 29 electrons.

If two or more atoms combine chemically, they form a molecule (Fig. 2-4). For example, if two atoms of hydrogen (H_2) combine with one atom of oxygen (O), they form water (H_2O). Both kinds of atoms are gases, but they form a liquid when combined under proper conditions.

Structure of the Atom

According to the electron theory, the atom itself is further divisible into even smaller particles known as *protons*, *neutrons*, and *electrons* (Fig. 2-5). These particles are the same within different atoms, and the different properties of matter such as hardness, softness, toughness, fragility, conductivity, or non-conductivity occur because of the number and arrangement of these particular particles.

Both protons and electrons have a type of electrical charge—the proton, positive (+), and the electron, negative (-). The neutron has no electrical charge but adds weight to the atom.

The particles also have a definite placement within the atom. The protons and neutrons are tightly bound together to form the center or nucleus of the atom, much as the sun does in our solar sys-

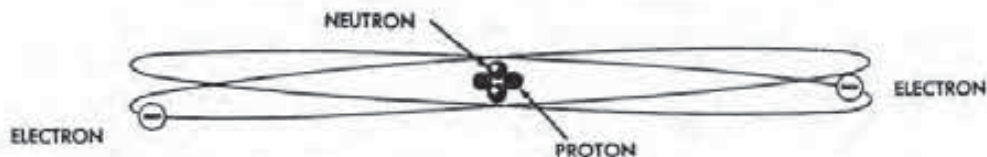


FIGURE 2-5
Structure of the atom. (Courtesy of Delco Remy)

tem (Fig. 2-6). The electrons, on the other hand, turn in one or more orbits around the nucleus, much as the Earth, Venus, Mars, and other planets rotate around the sun. The electrons are held in their orbits by the positive-charged nucleus. Moreover, if electrons approach each other, they are repelled because of the similar charge, while still maintaining their orbital position around the nucleus.

This interaction between the electrons and the nucleus or between the electrons themselves is the result of basic laws of electricity. These laws are

1. Unlike charges attract one another.
2. Like charges repel one another.

2-2 ELECTRON THEORY

The *electron theory* states that a flow of electricity, or current flow, is the movement of electrons between atoms within a conductor. To understand this statement, it is first necessary to explain the differences between a good conductor and an insulator, or nonconductor.

Conductors

For purposes of explanation, let us examine the makeup of a good electrical conductor, the copper atom (Fig. 2-7). Within this atom are four orbital paths for the electrons. In the innermost orbit, closest to the nucleus, are 2 electrons. The second orbit contains 8, while the third orbit has 18. The electrons in these three orbits are known as *bound electrons* because they are held tightly in their respective positions by the unlike charge of the protons within the nucleus.

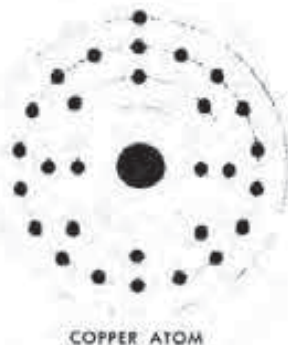


FIGURE 2-7
Structure of the copper atom. (Courtesy of Delco Remy)

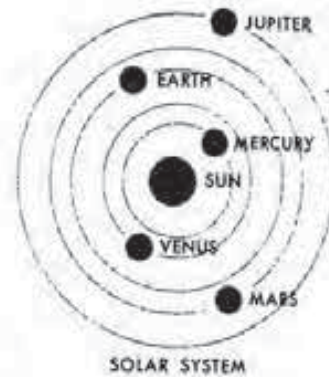


FIGURE 2-6
Solar system. (Courtesy of Delco Remy)

The fourth orbit has only 1 electron, which is commonly known as a *free electron* because it can become dislodged from its orbit rather easily (Fig. 2-8). Since this electron is further from the nucleus, its negative attraction to the positive-charged nucleus is reduced.

If a copper atom loses an electron, it takes on a more positive charge because it has more protons (29) than electrons (28). Before the electron was lost, the atom was electrically in balance, having the same number of protons and electrons.

In any conductor with free electrons, the atoms are usually so close together that their orbits overlap. *Electron drift* occurs when an electron dislodges from one atom in a conductor and moves to an outer orbit of another. As long as the conductor is not connected into a live electrical circuit, the pattern of electron movement remains random. If an atom in one place loses an electron, another one, from somewhere else, takes its place. This is due to the extra positive charge exerted by the atom that has lost its electron. Finally, since the movements are random, the total of all the electrical charges of all the atoms in the conductor remains in balance.

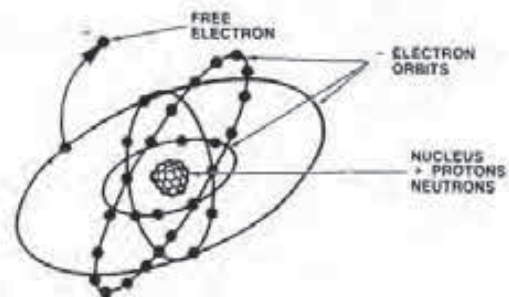


FIGURE 2-8
Free electron of a copper atom dislodged from its orbit. (Courtesy of Chrysler Motors Corp.)

Current Flow

If the free electrons are somehow organized to drift in one direction, the result is called an *electric current* or *current flow*. In order to have this organized current flow, something must force the free electrons from their orbits. Friction, heat, magnetism, or chemical activity are all examples of forces that can expel electrons from their orbital paths.

In the automotive electrical system, current flow is due to the action of the battery or alternator. These devices produce *electromotive force* (EMF), which literally means electron moving force, or the difference in electrical pressure that causes the electrons to flow from atom to atom in a given direction within the conductor.

For the present, we will use the battery as the device that causes electron flow in the conductor. The battery itself has two terminals, one positive and one negative. The positive terminal, through chemical action, has a net *positive charge*, or an abundance of protons. The negative terminal, on the other hand, has an excess of electrons or a *negative charge* (Fig. 2-9). Simply speaking, the battery chemically produces an electrical imbalance or a difference in pressure (EMF).

If you connect a copper wire, which contains billions of atoms per square inch, between the two terminals of a battery, electrons will flow from negative to positive. Figure 2-9 shows this action within the copper conductor. Although this conductor contains billions of copper atoms, all having free electrons, the diagram only shows a few atoms and the movement of negative charges between them.

The electron closest to the positive terminal of the battery is drawn out of orbit and passes into the net positive charge of the battery. Remember, unlike charges attract one another.

This atom, therefore, now has a net positive charge because it has one less electron. As a result, the atom attracts an electron from an adjacent atom. This action, in turn, attracts an electron from the next atom and so forth.

In addition, at the opposite end of the conductor, the negative battery terminal applies a push on



FIGURE 2-9
Flow of electrons in a copper conductor placed between two battery terminals. [Courtesy of Delco Remy]

the electron in the first atom because like electrical charges repel each other. The result of both the attracting and repelling actions is the forced movement of the electrons through the wire from the negative end toward the positive side.

This flow of current continues as long as the unlike positive and negative charges remain at the two terminals of the battery and there is an uninterrupted path, or circuit, between the two. However, when there is neither an excess of electrons at the negative terminal nor an excess of protons at the positive, a balance of electrical charges exists, and electron flow will cease.

Nonconductors

A *nonconductor*, or *insulator* (like rubber, wood, bakelite, and porcelain), is said to have bound electrons. These substances have five or more electrons in their outer orbits, that cannot be easily dislodged from their respective positions. Consequently, these materials cannot normally carry a current of electricity. In other words, they have high anti-electric properties, or *dielectric strength*.

2-3 ELECTRICAL CURRENT, VOLTAGE, AND RESISTANCE

When discussing electricity, there are three basic factors: current, voltage, and resistance. These terms are basic to the understanding of electricity and its effects within the complex electrical and electronic systems of the automobile.

Current

As mentioned, the flow of electrons in a conductor is known as a current of electricity. The measurement for current flow is in *amperes* (A). One ampere is an electric current of 6.24 billion, billion electrons (6.24×10^{18} electrons) passing a given point in a conductor in 1 second (Fig. 2-10). A smaller unit of current flow is the *milliampere* (mA), which is $\frac{1}{1,000}$ of

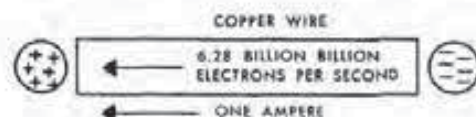


FIGURE 2-10
Measurement of current flow. [Courtesy of Delco Remy]

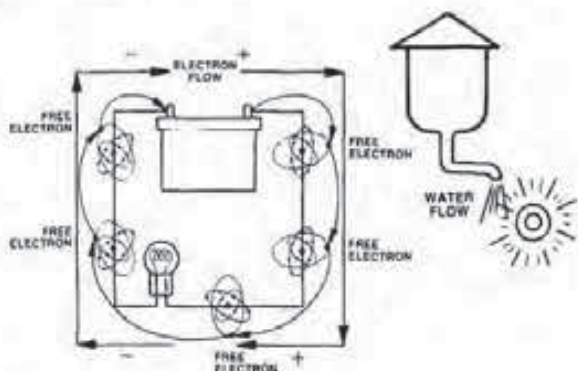


FIGURE 2-11
Electrical current compared to water flow. (Courtesy of Chrysler Motors Corp.)

an ampere. Thus, current is the rate of electron flow and is measurable in amperes or electrons per second. It is this current flow through a conductor that performs the work of operating the electrical units in the automobile—for example, the starter motor, headlights, and the ignition system.

When electrons flow along a conductor to an electrical unit, their effect on it is instantaneous. Although the electrons themselves do not travel more than a few inches a second, the electrical energy applied to one end of a circuit is transmitted to the unit on the other end at the speed of light (186,000 miles per second).

Current is comparable to the flow of water in a pipe. In fact, comparing current to water flow is undoubtedly the easiest and quickest way to explain this and all factors dealing with electricity. Current flow is the movement of electrons through a conductor (wire) just as water flow is the movement of liquid through a pipe (Fig. 2-11). As mentioned, an ampere is the electrical measure for current flow, while gallons per minute is the measurement for the rate of water moving through a pipe.

Voltage

Another term more commonly used to represent EMF, or electrical pressure, is *voltage*. Electrical pressure is measured in volts and is what frees the electrons to create current flow within a conductor.

The amount of voltage depends on the difference in electrical charges, either positive or negative, existing at each end of the conductor (Fig. 2-12). The greater the charges are at each point, the higher the voltage. In other words, the greater the lack of electrons at the positive terminal and the greater the excess of electrons at the negative terminal, the higher the voltage will be.



FIGURE 2-12
Voltage exists between two unlike electrical charges. (Courtesy of Delco Remy)

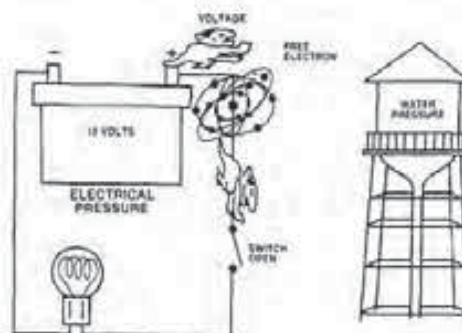


FIGURE 2-13
Both a battery and a water tower provide pressure. (Courtesy of Chrysler Motors Corp.)

Voltage is a potential force and can exist even when there is no current flow within a circuit. The vehicle battery, for example, may have a potential of 12.6 volts between its positive and negative terminals. This pressure is there even if there are no current-consuming devices connected across its terminals. Consequently, voltage can exist without current flow, but current flow cannot occur without the push of voltage.

In one regard, the battery and a water tower have something in common in that they both provide pressure (Fig. 2-13). The battery is a source of electrical pressure due to its internal chemical action; the tower provides water pressure due to the action of gravity on the weight of the liquid in the tank. In other words, battery voltage is simply electrical pressure. It is this potential that pushes the electrons through the wire in a complete circuit, just as the pressure at the outlet of the tower forces the water through the pipes in a plumbing system.

Resistance

Electrical resistance is opposition to the flow of electrons, and all electrical conductors offer some resistance (Fig. 2-14). Basically, resistance is the result of each atom resisting the removal of an electron due to the electron's attraction to the nucleus, and due to collisions of countless electrons as they move through the conductor. These collisions cause resistance and create heat in the conductor itself.

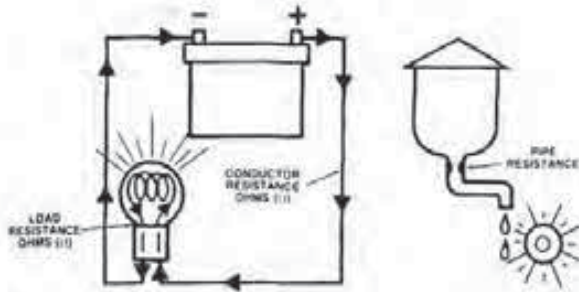


FIGURE 2-14
Resistance reduces current flow. (Courtesy of Chrysler Motors Corp.)



OHM'S LAW: $\frac{E}{I \times R}$

$E = IR$ (VOLTAGE = AMPERAGE TIMES RESISTANCE)
 $I = E \div R$ (AMPERES = VOLTAGE DIVIDED BY RESISTANCE)
 $R = E \div I$ (RESISTANCE = VOLTAGE DIVIDED BY AMPERES)

FIGURE 2-15
Ohm's law defines electrical behavior. (Courtesy of Chrysler Motors Corp.)

Several other factors increase or decrease resistance. For instance, the size of the wire also affects resistance. A small wire causes more resistance to current flow than a larger one of the same material, in much the same way a small pipe in a water system offers more opposition to liquid flow than a large pipe.

In addition, the length of the wire and the material from which the manufacturer makes it affect resistance. A shorter wire offers less resistance than a long one, and good conductor material provides less resistance than poor conductor material. Manufacturers use metals like copper, aluminum, and silver for conductors because they offer low resistance.

Resistance, therefore, is the only real difference between good conductors and good insulators. Any material that is an extremely poor conductor is usually a good insulator. In other words, an insulator is a material that offers enough resistance to prevent the flow of current.

The basic unit of measurement for resistance is the *ohm* (Ω). One ohm is the resistance that will only allow one ampere to flow in a circuit with a pressure of one volt.

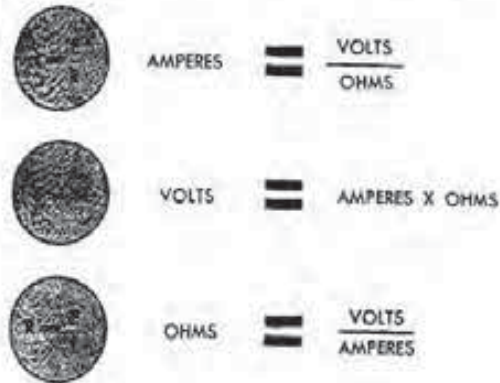


FIGURE 2-16
Three equations derived from Ohm's law. (Courtesy of Delco Remy)

2-4 OHM'S LAW

In the early 1800s, the scientist George S. Ohm formulated a law that links voltage, current flow, and resistance within a basic electrical circuit (Fig. 2-15). Ohm found that the current in a circuit is directly proportional to the applied voltage and inversely proportional to the resistance in the circuit. In simpler form,

1. When resistance goes up or down, current flow decreases or increases, assuming the voltage remains the same.
2. When voltage goes up or down, current flow increases or decreases, assuming the resistance stays the same.
3. When resistance goes up, current flow decreases, assuming voltage remains the same.
4. When resistance goes down, current flow increases, assuming voltage remains the same.

Ohm's law can be expressed as an equation showing the relationship among current flow (I), voltage (E), and resistance (R). The equation is $E = I \times R$, or voltage equals amperage times resistance. This simply means that one volt will push one ampere of current through one ohm of resistance.

Since Ohm's law is an equation, you can write it three different ways. Consequently, if you know two factors about a circuit, you can calculate the third or unknown by using one of the following equations (Fig. 2-16):

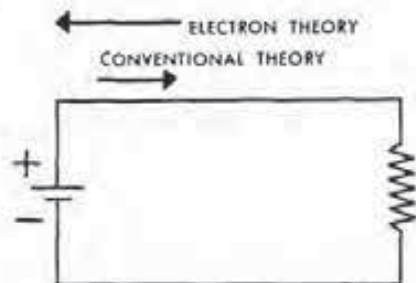


FIGURE 2-17

Two theories of current flow in a circuit. (Courtesy of Delco Remy)

1. Amperes equal volts divided by ohms.
2. Volts equal amperes times ohms.
3. Ohms equal volts divided by amperes.

To use the equations, simply substitute the values in amperes, volts, or ohms, and solve for the missing value.

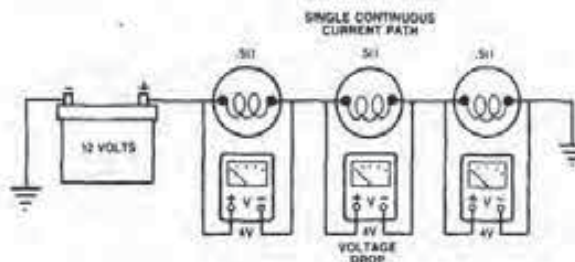
2-5 ELECTRICAL CIRCUITS

As mentioned, batteries and alternators apply electrical pressure and cause current to flow through a circuit from the high-pressure side to the low-pressure side, or from negative to positive. However, there must be a complete *circuit* or pathway (made up of wires or other conductors) in order for the current to flow. If for some reason a wire is broken or disconnected, it loses its completeness, or *continuity*, and current flow stops abruptly.

Automotive circuits are not all alike, and electricity does not behave exactly the same in the different types of circuits. Therefore, it is important that the technician understand the basic types of circuits, and how volts, amperes, and ohms behave in each one.

Simple Circuit

The easiest way to explain the basic circuits is through the use of a battery (the power source), some wire (the conductor), and one or more electrical lamps or other devices that serve as resistance units. In the *simple circuit*, current flows from the battery, through the lamp or resistor, and back to the battery via the conductor (Fig. 2-17).



$$\text{TOTAL RESISTANCE} = .5\Omega + .5\Omega + .5\Omega = 1.5\Omega$$

FIGURE 2-18

In a series circuit, there is only one path for current flow. (Courtesy of Chrysler Motors Corp.)

However, most automotive circuits have more than one lamp or resistance unit and use the vehicle body and frame as the circuit from the resistance unit to the negative side of the battery. This forms a single-wire circuit.

There are two ways to describe current flow in any circuit, using either the conventional theory or the electron theory (see Fig. 2-17). In the conventional theory, current flows from the (+) terminal of the battery, through the circuit, to the (-) terminal of the battery. The electron theory states that current flow is from the (-) terminal of the battery, through the circuit, to the (+) terminal of the battery.

Either theory is usable. *This text utilizes the conventional theory in its remaining explanation of electrical circuits and devices because it is more popular and easier to use on automotive single-wire circuitry.*

Series Circuit

In a *series circuit*, two or more lamps or resistance units connect in such a way that there is only one continuous path for current flow (Fig. 2-18). Since within a series circuit all the current must flow through each resistance unit, the current flow is always the same everywhere. This is always true regardless of the number of resistance units connected in series into the circuit.

There are four important things to remember about the series circuits. First, there is only one path for current to flow. Second, the sum of all voltage drops in the circuit is equal to battery voltage. Third, the total resistance in a series circuit is equal to the sum of all the resistances. Finally, an opening in any part of a series circuit, or resistance device, stops the current flow throughout the entire circuit.

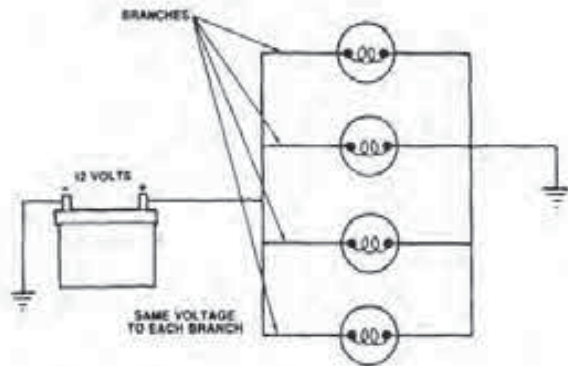


FIGURE 2-19
Parallel circuit provides several paths for current flow. (Courtesy of Chrysler Motors Corp.)

Parallel Circuit

In a *parallel circuit*, the lamps or resistance units connect in such a way that there is more than one path for current flow (Fig. 2-19). This simply means that part of the current flows through one lamp and part of it moves through the other resistance units. Should any of the paths become open, current will still continue to flow through the other branches and operate the resistance units.

Also in this type of circuit, the voltage drop across each resistor is equal to the voltage of the battery since there is a separate path for current to flow through each lamp. This means that the voltage across each resistance unit is the same.

If any of the resistance values in a branch is different, current through each lamp is not the same. Current always flows through the path of least resistance. Finally, the total current flow in the parallel circuit is equal to the sum of all the currents flowing in each of its branches.

The total resistance in a parallel circuit is always less than that of the smallest resistance unit in the circuit. This is explained by the fact that there is less resistance to current flow when a number of branches are in a circuit to provide for electron movement than when only one path is available.

Series-Parallel Circuits

The automobile has many series-parallel circuits. In a *series-parallel circuit*, the resistance of a lamp, load device, rheostat, or switch is in series between the battery and the branches of the parallel circuit. This has the effect, in most cases, of dropping the voltage to the lamps in the parallel paths.

Figure 2-20 illustrates a typical series-parallel

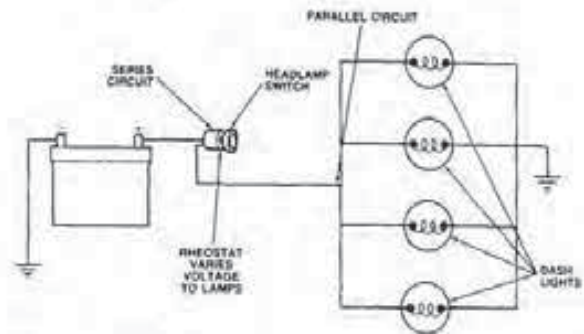


FIGURE 2-20
Typical series-parallel circuit. (Courtesy of Chrysler Motors Corp.)

circuit. Notice in the drawing that the headlamp switch can open or close the circuit to the lamps and also change the resistance in the series portion. In other words, the switch can control current flow, or the rheostat can vary the voltage to the parallel circuit branches.

An opening in the series portion of the circuit will stop all current flow. However, an opening in one of the parallel branches will stop current flow along the affected pathway but not in the total circuit.

Open Circuit

There are two other types of electrical circuits, open and short. An *open circuit* indicates a break or loss of continuity somewhere within the circuit so that there is no longer a complete or continuous path for the current to flow through.

The opening may be the result of a break in a wire, loose connection, defective switch, defective resistance unit, or no ground. Moreover, the opening can be located on either side of a resistance unit. An opening in a series circuit stops current through the entire circuit (Fig. 2-21).

The effect of an opening in a parallel circuit depends on the location of the break. If the break is in the circuit feed or control switch (series portion of the circuit), current flow stops in all the branches.

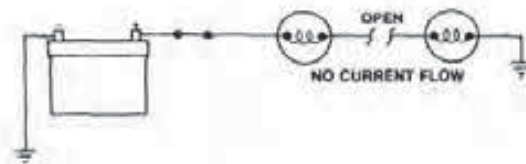


FIGURE 2-21
Open in a series circuit. (Courtesy of Chrysler Motors Corp.)

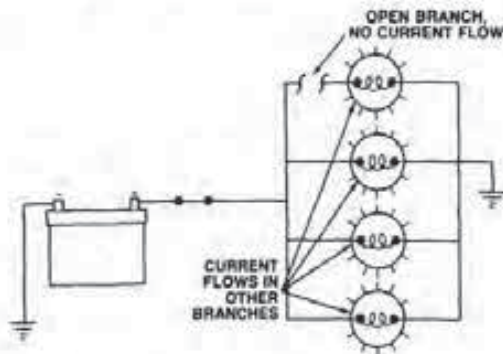


FIGURE 2-22
Open in a parallel circuit. (Courtesy of Chrysler Motors Corp.)

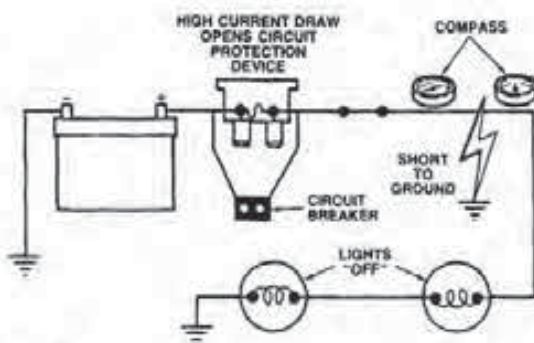


FIGURE 2-23
Typical short circuit to ground. (Courtesy of Chrysler Motors Corp.)

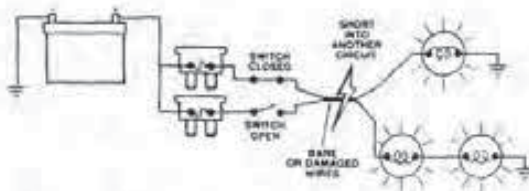


FIGURE 2-24
Short into another circuit. (Courtesy of Chrysler Motors Corp.)

However, an opening in an individual branch only stops the current flow along the affected path. The current flow in the other branches will not be affected by the opening (Fig. 2-22).

Short Circuit

A *short circuit* is a continuous path for current flow that interrupts or bypasses its intended course through the circuit. One type of short is directly to ground, while others may be into another circuit (Fig. 2-23).

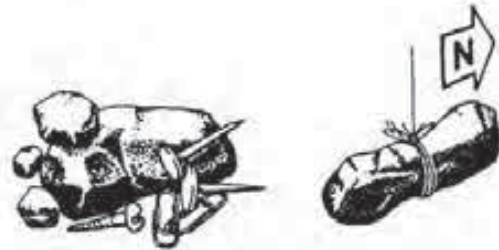


FIGURE 2-25
Magnetic effects of lodestone. (Courtesy of Delco Remy)

With a *short to ground*, the current bypasses the resistance unit. This reduces the total resistance in the circuit and causes a large amount of current flow. As a result, a fuse blows, circuit breaker cycles open and close, or the fusible link opens.

A *short into another circuit* usually results from two bare wires touching or from a damaged wiring harness (Fig. 2-24). Often this situation creates an additional branch of a parallel circuit. Since current always follows the path of least resistance, the majority of the current flows in the branch with the smallest amount.

Moreover, a switch closed in one circuit energizes other circuits that should at the moment be deactivated. If the circuit with the closed switch is a series type circuit, it now becomes parallel. Since the parallel circuit has less resistance than the series, additional current flows, which may open the circuit protection device.

2-6 MAGNETISM

The principle of magnetism became the basis for the navigation compass over 1,200 years ago. The discovery of the effects of magnetism was the result of observing how fragments of iron ore called lodestone attracted other pieces of iron (Fig. 2-25). It was also noticed that a long piece of this particular ore, if suspended in air with a string, would align itself so that one end always pointed to the North Pole of the earth. Therefore, this end of the lodestone became known as its north (N) pole, and the opposite end as the south (S) pole.

Magnetic Fields

Further study of the bar magnet showed the existence of an invisible attractive force that exerted itself on bits of iron or iron filings even though they were some distance away. Although mysterious,

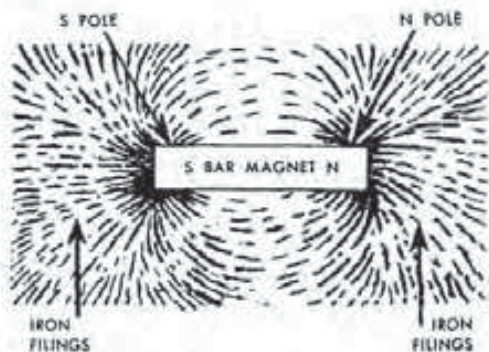


FIGURE 2-26
Effects of the magnetic field around a bar magnet. (Courtesy of Delco Remy)

this phenomenon makes it very clear that some form of force exists in the space close to the magnet.

The force that fills this space around the magnet and into which iron filings attract is known as a *magnetic field*. The field is nothing more than invisible lines of force that come out of the N pole and enter the S pole (Fig. 2-26).

You can see the effects of these magnetic lines of force by sprinkling iron filings on a piece of paper resting on top of a bar magnet. If you lightly tap the paper by hand, the iron filings line up to form a clear pattern around the bar magnet. The pattern also shows that these lines of force heavily concentrate themselves at the N and S poles of the magnet and then spread themselves out into the surrounding air between the poles. The concentration or the number of lines at each pole is equal, and the attractive force on the filings at each pole is the same (see Fig. 2-26).

Fundamental Law of Magnetism

There is a fundamental law that deals with magnetism. This law states that *unlike poles attract one another, and like poles repel each other*.

Figure 2-27 demonstrates this fundamental law. In the upper portion of the illustration are two magnets placed so that the N pole of one and the S pole of another are close together. In this situation, the magnetic lines of force leaving the N pole of the right-hand magnet enter the S pole of the left-hand one, creating an attractive force since all lines of force are in the same direction. As a result, the adjacent N and S poles do attract each other, and the attractive force increases as the two magnets move closer together.

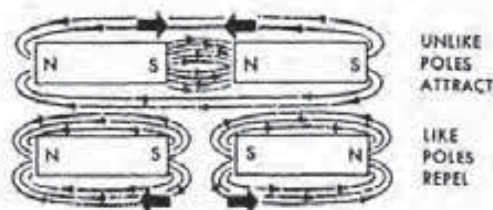


FIGURE 2-27
Fundamental law of magnetism. (Courtesy of Delco Remy)

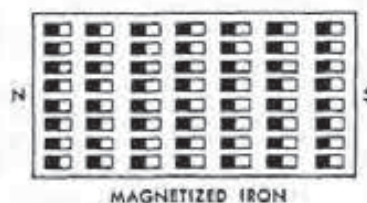


FIGURE 2-28
In a natural magnet, the molecules are in alignment. (Courtesy of Delco Remy)

The lower diagram shows two magnets lying end-to-end with both their S poles adjacent to one another. In this instance, the lines of force from both magnets move in opposite directions. As a result, the adjacent poles repel one another.

Note: In understanding this magnetic principle, it is helpful to know a rule that says that lines of force never cross one another. While this statement is not theoretically correct, it has often been found effective in explaining this phenomenon.

Theory of Magnetism

Although no one knows exactly what magnetism is, there is a theory that tries to explain what it is and how it exerts a force field. The theory implies that a magnet, like all matter, is formed of molecules. The molecules in a magnet are lined up in such a way as to make their electrostatic fields work together in one direction (Fig. 2-28). When a material has no magnetic properties, the molecules are thought to be arranged in a random manner.



FIGURE 2-29
Inducing magnetism into an iron bar. (Courtesy of Delco Remy)

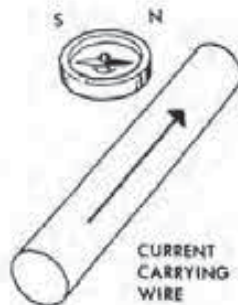


FIGURE 2-30
Compass shows the magnetic field to be at a right angle to the conductor. (Courtesy of Delco Remy)

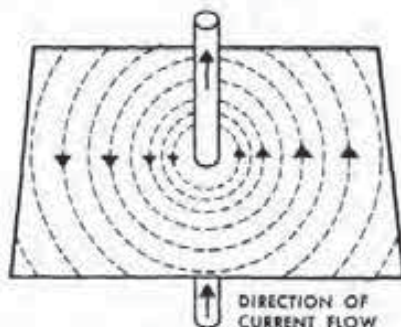


FIGURE 2-31
Shape of the magnetic field around a current-carrying wire. (Courtesy of Delco Remy)

Magnetic and Nonmagnetic Materials

Iron is one of the better-known magnetic materials. However, most permanent magnets are manufactured from alloys because softer metals do not retain magnetism for very long. A few of the most common alloys are nickel-iron and aluminum-nickel-cobalt.

A number of materials are nonmagnetic because they do not exhibit any magnetic properties. A few of these nonmagnetic materials are wood, paper, glass, copper, and zinc.

Formation of a Magnet

You can convert an iron bar into a magnet in a number of ways. One method, for example, is to stroke the iron bar with a magnet. Since the molecules within the magnet are in alignment, the pull of unlike poles and the push of like poles align the molecules in the iron bar. Producing a magnet in this way is known as magnetic induction.

A second method also uses magnetic induction. However, this time the iron bar is positioned in a strong magnetic field (Fig. 2-29). The lines of force from the magnet itself pass through the iron bar; this action aligns the molecules in the bar. As a result, the iron bar becomes a magnet as long as it remains in the magnetic field. If you remove the field of force and the bar's composition is such that it retains some of the induced magnetism, it becomes a permanent magnet.

2-7 ELECTROMAGNETISM

A magnetic field always exists around a current-carrying conductor. Such a field of force is always at right angles to the conductor (Fig. 2-30). If you hold a compass over a wire, for instance, the needle turns so that it is crosswise (at a right angle) to the wire. Since the only thing that attracts the compass needle is a magnetic field, it is obvious that the current flowing in the wire created a force field around itself. This reveals the connection between magnetism and electricity.

You can observe the nature of the magnetic field around the conductor by positioning a piece of cardboard over the wire, as shown in Fig. 2-31, and then sprinkling iron filings on the cardboard. The iron filings align themselves to indicate a clear pattern of concentric lines around the conductor. In addition, the circles appear more concentrated near the wire than further out. Finally, although the iron filings on the cardboard piece only show the pattern in one plane, remember that the concentric lines of force extend over the entire length of the current-carrying conductor.

Magnetic lines have a certain direction and change this direction whenever the current flow in the conductor reverses itself (Fig. 2-32). When the current flow is away from the reader, the N pole of the compass needle points in the direction shown in the upper illustration. On the other hand, when current in the wire flows in the opposite direction (toward the reader), the N pole of the compass re-

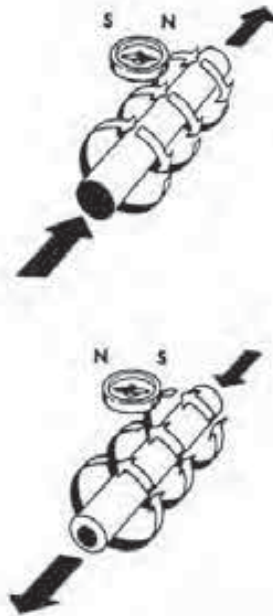


FIGURE 2-32
Whenever the current flow reverses in a conductor, the magnetic lines change direction. [Courtesy of Delco Remy]

verses and points in the opposite direction. This action results because the compass needle always has a tendency to align itself so that the magnetic lines from the conductor enter its S pole and leave the N pole.

You can determine the actual direction by which the magnetic field encircles a wire by using the right-hand rule (Fig. 2-33). With the right hand, grip the wire so that the thumb extends in the direction of current flow. As shown in the illustration, your fingers will encircle the conductor in the direction of the magnetic field.

Note: The use of the right-hand rule, in this case, is necessary if you are using the conventional theory of current flow.

Force Strength

As the current through the conductor increases, the number of lines of force (strength of the magnetism) grows (Fig. 2-34). If (as shown in the upper illustration) you move the compass a distance away from the wire, the compass needle reaches a place where it is no longer affected by the conductor's magnetic field. If you then increase the current flow through the conductor (note the lower illustration) without moving the compass, its needle responds to indicate the presence of an increased magnetic field. This action indicates that the number of lines of force in the



FIGURE 2-33
The right-hand rule can be used to determine the direction of the lines of force around a wire. [Courtesy of Delco Remy]

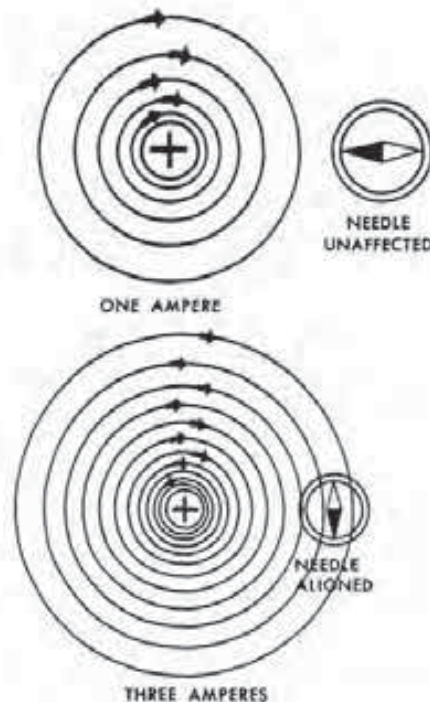
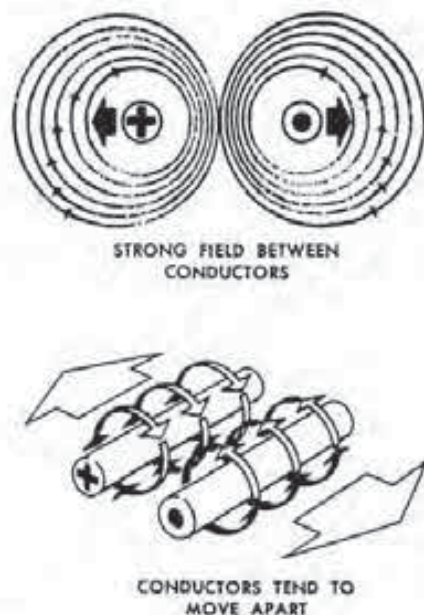


FIGURE 2-34
An increase in current flow within the wire creates a stronger magnetic field. [Courtesy of Delco Remy]

area around the wire grows as current through the wire increases. In other words, additional current flow creates a stronger magnetic field around the conductor.

When two adjacent, parallel conductors carry current flow in opposite directions, the movement of the magnetic field is clockwise around one wire and counterclockwise around the other (Fig. 2-35). In this situation, the lines of force concentrate themselves between the two conductors and spread out

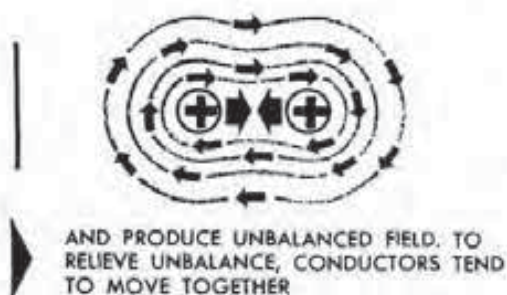
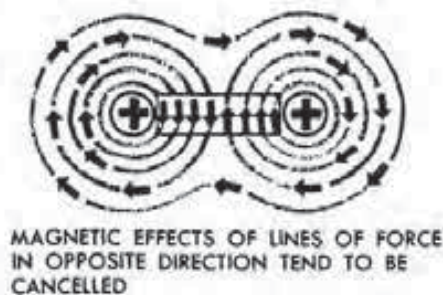
**FIGURE 2-35**

A current-carrying conductor moves from a strong to a weak magnetic field. (Courtesy of Delco Remy)

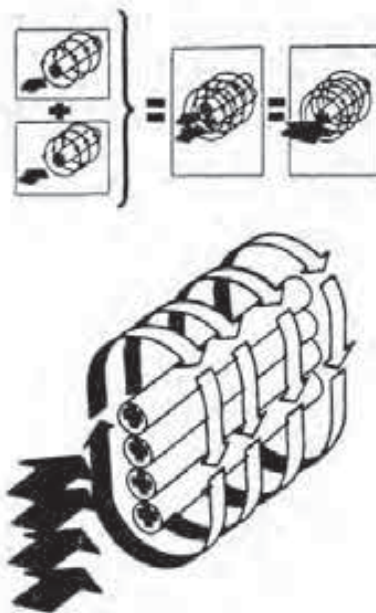
into space on the outside of them.

The lines of force between the two conductors move in the same direction; this forms a concentration of lines or a strong magnetic field. Under these conditions, the two wires tend to move apart. In other words, a current-carrying conductor tends to move out of a strong field into a weak one.

However, a different situation exists when two parallel conductors carry equal current flow in the same direction (Fig. 2-36). In this case, a magnetic field, clockwise in direction, forms around each wire with the magnetic lines between them opposing each other in direction. As a result, the magnetic field between the conductors cancels out, leaving essen-

**FIGURE 2-36**

If their current flow is in the same direction, adjacent conductors tend to move together. (Courtesy of Delco Remy)

**FIGURE 2-37**

Two or more adjacent wires with the same current flow increase the magnetic field. (Courtesy of Delco Remy)

tially no field in this area. This causes the two wires to move toward each other, that is, from a strong field to a weak one.

As mentioned, the magnetic field around a current-carrying conductor grows in intensity as current flow through it increases. However, there is another way of achieving the same result. For instance, two wires lying alongside each other, each carrying current in the same direction, create a magnetic field equivalent to one conductor carrying twice the current flow (Fig. 2-37). The reason for this is that when several more conductors are side-by-side, the magnetic effect increases as the lines from each wire join around all of them.

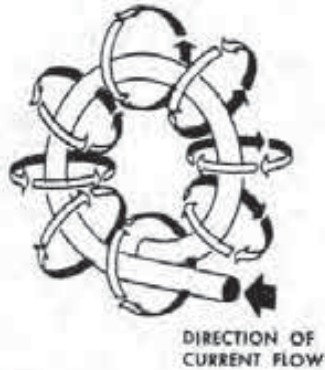


FIGURE 2-38
When a loop of wire carries current flow, the lines of force concentrate inside the coil. (Courtesy of Delco Remy)

Electromagnetism in Coils

When you form a straight, current-carrying wire into a single loop (Fig. 2-38), it has the same magnetic field surrounding it as when it is straight. But in this instance, all the lines of force enter the inside loop of the wire on one side and leave from the other side. These lines of force, therefore, concentrate themselves inside the loop. Consequently, this single loop of wire forms a basic electromagnet that has polarity.

When the current-carrying wire is wound into a number of loops or turns to construct a coil (Fig. 2-39), the resulting magnetic field is the sum of all the single loop fields added together. This has the same effect as several conductors, side-by-side, carrying current in the same direction.

Moreover, with the lines of force leaving the coil at one end and entering it at the other, a N and S pole form at the ends as in the bar magnet. If the coil is wound over a material such as iron, the assembly becomes a useful electromagnet.

The addition of this iron core greatly increases the strength of the magnetic field at the N and S poles (Fig. 2-40). The reason for this is that air is a very poor conductor of magnetic lines, while iron is a very good conductor. Relatively speaking, the use of iron in the coil's core increases the magnetic strength by about 2,500 times over a coil with an air core.

The strength of the magnetic poles within the electromagnet is directly proportional to its current flow and the number of turns of wire (Fig. 2-41). For example, both an electromagnet having one ampere flowing through its 1,000 turns of wire and another one having 10 amperes flowing through 100 turns have 1,000 ampere-turns, which is a measurement of their magnetic-field strength. In other words, the at-

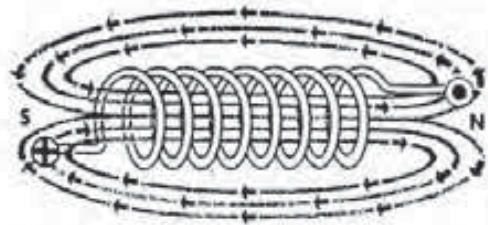


FIGURE 2-39
The magnetic field of a coil grows by increasing the number of loops or turns. (Courtesy of Delco Remy)

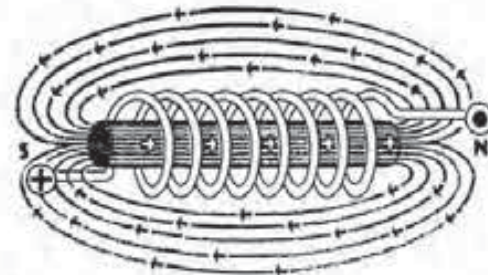


FIGURE 2-40
Using an iron core increases the field strength of the coil. (Courtesy of Delco Remy)

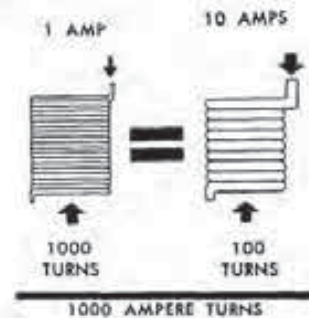


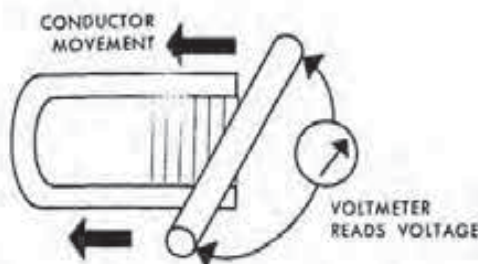
FIGURE 2-41
The total strength of an electromagnet depends on the current flow and the number of coil turns. (Courtesy of Delco Remy)

traction of other magnetic materials placed within the fields of both these coils is the same.

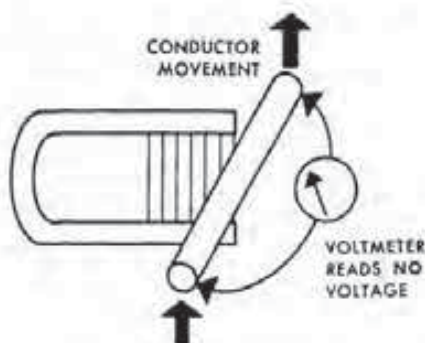
Electromagnetic Induction

When any conductor moves through a magnetic field, its lines of force induce a voltage into the wire. This basic principle is known as *electromagnetic induction*. Figure 2-42 shows this point very well. When the straight wire moves across (cuts through) the magnetic field of the horseshoe magnet, the attached sensitive voltmeter registers a small induced voltage.

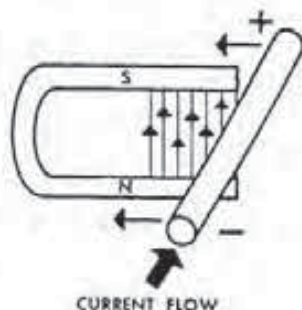
However, if the conductor moves parallel with

**FIGURE 2-42**

Moving a conductor through a magnetic field induces a voltage into the wire. (Courtesy of Delco Remy)

**FIGURE 2-43**

Moving the wire parallel to the field induces no voltage in the conductor. (Courtesy of Delco Remy)

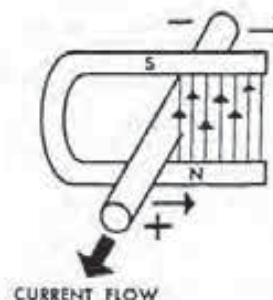
**FIGURE 2-44**

Voltage polarity of the conductor as it moves through the magnetic field. (Courtesy of Delco Remy)

the lines of force, it cannot induce a voltage in the wire (Fig. 2-43). In other words, the wire must cut across the lines of force in order for the field to induce voltage in it.

As mentioned, voltage (EMF) has polarity; that is, it has (+) and (-) poles. Also, current flow is always from (+) to (-) according to the conventional theory, or from (-) to (+) according to the electron theory.

A wire cutting across a magnetic field also becomes a source of electricity, and therefore it must also have a (+) and (-) pole, just like a battery.

**FIGURE 2-45**

Reverse polarity of the same conductor as it passes back through the field. (Courtesy of Delco Remy)

However, unlike the battery, the wire's polarity can change at its end. The polarity depends on the relative direction of conductor movement through the magnetic field or the direction of the field travel itself.

Figures 2-44 and 2-45 illustrate this point. Figure 2-44 shows a straight conductor moving to the left across the magnetic field. With this direction of movement, the magnetic lines strike the wire on its left side, the leading edge. This induces voltage in the conductor and causes current to flow in it away from the reader.

When the direction of the motion of the wire reverses (Fig. 2-45) and moves toward the right, the right side of the conductor becomes the leading edge. Consequently, the induction of voltage reverses, and the resulting current flow is toward the reader. This means that the voltage polarity at the wire ends has reversed itself.

If instead of moving the wire to the left, as shown in Fig. 2-44, the magnetic field moves to the right across a stationary conductor, the same voltage induction and current flow occur. The same holds true for moving the field to the left across a wire. In each case, the leading side of the conductor and the magnetic-field direction are unchanged. In other words, voltage induction in a conductor can occur by moving it across a stationary magnetic field or moving the field across a stationary wire. It really does not matter which, as long as there is relative movement between the two.

Methods of Inducing Voltage

Basically, there are three ways to create voltage through the principle of electromagnetism: (1) by moving a wire through a magnetic field, (2) by self-induction, and (3) by mutual induction. A direct current (DC) generator produces voltage by moving a

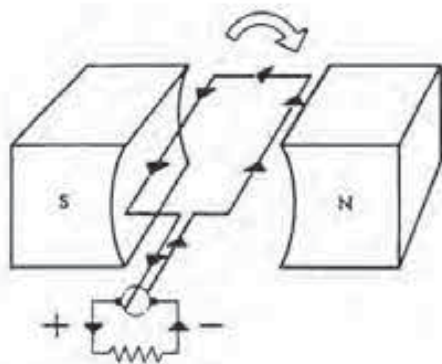


FIGURE 2-46
Basic DC generator. (Courtesy of Delco Remy)

number of wires across a stationary magnetic field (Fig. 2-46). This illustration shows a basic type of DC generator, where a single turn of wire rotates between the N and S poles of a magnetic field.

In the position shown, current flows within the loop, as indicated. Due to the voltage induced into the turn of wire, there is polarity at the two commutator segments attached to the wire ends. The current can then flow through the brushes, riding on the commutator and out into the external circuit.

Note: The generator, due to its design, is able to produce voltage even if no current passes out of it and into an external circuit.

The alternator is another application of the principle of induced voltage (Fig. 2-47). But in this instance, the magnetic field cuts across a stationary wire in order to produce voltage and then current flow. The basic alternator has a rotating magnetic field that cuts across a stationary conductor mounted on a frame. As you can see with the rotating field position in Fig. 2-47, current flows through the conductor with the voltage polarity as shown.

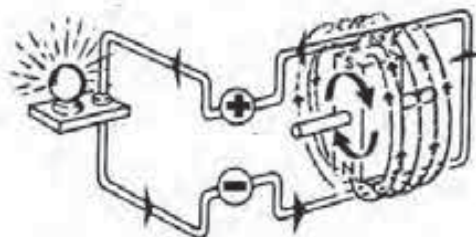


FIGURE 2-47
Basic alternator. (Courtesy of Delco Remy)

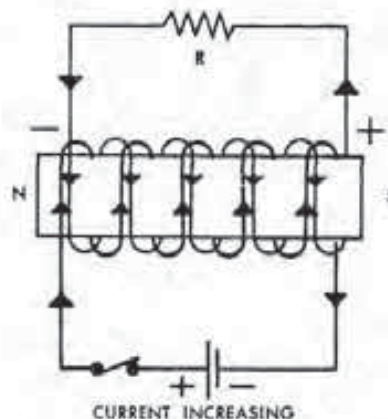


FIGURE 2-48
Mutual induction in the second coil when the circuit to the first coil is closed. (Courtesy of Delco Remy)

around the wire, which expand and contract as current flow increases or decreases, these magnetic lines cut across the conductor itself and thereby induce a voltage within it. The condition for inducing the voltage has been met because there is relative motion between the field and the conductor.

Mutual Induction

If a magnetic field produced by current flow in one electromagnetic coil cuts across the windings of a second coil, the field from the first coil induces a voltage in the second. This induction of voltage in one coil as a result of electromagnetism from another coil is known as *mutual induction*. Figure 2-48 shows this principle of mutual induction in a circuit where a second winding is wound around an iron core. The windings of the first coil are then wrapped around those of the second.

With this arrangement, when the switch closes, current begins to flow in the first coil, causing its magnetic field to expand and cut across the windings of the second coil. This action causes a voltage induction in the second coil and current flow

Self-Induction

Self-induction, or *inductance*, is voltage generation in a conductor when current flow in the wire itself changes. In the two previous illustrations, an external magnetic field produced voltage in a wire as it moved through the conductor. In the self-induction process, no separate field is necessary. Instead, the magnetic field created by a changing current flow in the conductor induces voltage in the wire itself. Thus, the wire's own magnetic field causes this self-induction of voltage.

Since the current flow, to start with, creates a magnetic field in the form of concentric circles

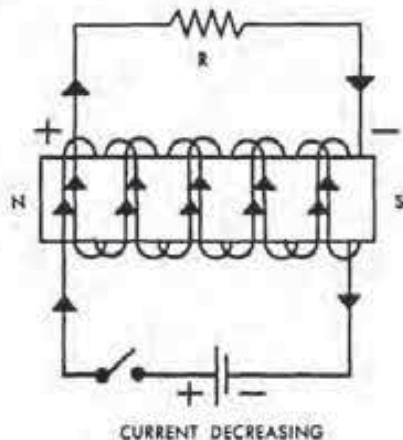


FIGURE 2-49
Mutual induction in the second coil when the circuit to the first coil is open. (Courtesy of Delco Remy)

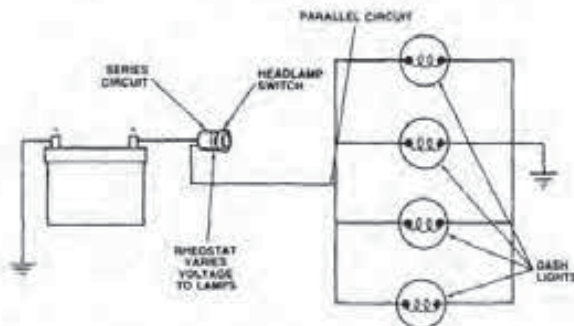


FIGURE 2-50
Manually operated headlamp switch. (Courtesy of Chrysler Corp.)

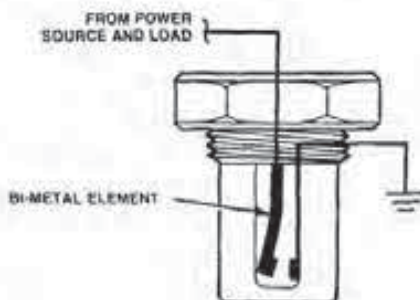


FIGURE 2-51
Typical coolant temperature switch. (Courtesy of Ford Motor Co.)

through the resistor in the direction shown.

Similarly, when the switch opens (Fig. 2-49), the sudden decrease in the current flow in the first coil causes its magnetic field to shrink and pass through the windings of the second coil once more.

This also induces a voltage with an opposite polarity in the second coil, so the direction of current flow through the resistor reverses itself. In either case, the windings of the second coil become a source of voltage that can provide a source of current flow to an external circuit.

2-8 ELECTRICAL CONTROL DEVICES

All electrical systems contain a number of control devices. These regulate the flow of current from the battery to the various circuits of a vehicle. The most common types of control devices are the switch, relay, solenoid, and resistor.

Manual Switches

Electrical switches are used to open, close, or direct the flow of current in a circuit. A switch has contacts made of special metal alloys. These metals resist burning and corrosion by small electrical arcs that form as the switch opens and closes.

Many of the switches found on the automobile operate manually (Fig. 2-50). This means that the driver must manipulate a control knob on the switch to operate a given circuit. The control knob, through a rod or linkage, then closes or opens the contact points. When the points close, the positive side of the battery is connected into the circuit and current flows.

Manual switches are used to operate such circuits as the starter; ignition; headlights; radio or tape player; air conditioner and heater; windshield wiper and defogger; and power seats, windows, or door locks.

Automatic Switches

An *automatic switch* is also a device that opens or closes a circuit. However, in this case, the points within the switch are controlled by a material or mechanism activated by heat, pressure, or vacuum.

When the contacts are closed in this type of switch, they can also connect a circuit to the positive side of the battery. But in many cases, the closed points complete the ground (–) portion of the circuit back to the battery.

Typical examples of automatic switches are coolant temperature (Fig. 2-51), low oil pressure warning, vacuum, and brake warning lamp.

Relays

A *relay* is an electromagnetic type of switch that uses a small amount of current to trigger the flow of a large amount of current. The relay is usually used in circuits carrying high current flow, where long, large wires are expensive and awkward to use. Examples of relays found on automobiles are the horn, starter, radiator electric fan, air conditioner, power window, and fuel pump.

A typical relay consists of an electromagnetic coil and a pair of contact points (Fig. 2-52). The coil consists of many turns of fine wire wound around a laminated soft iron core. One end of the coil connects to the positive side of the battery. The other connects to one of the horn switch contacts. When closed, the horn button, or switch, will complete the ground portion of the relay coil circuit.

One of the relay points attaches to a movable armature arm that mounts above the electromagnetic coil. A spring hinge maintains the arm and the contact point in the open position when there is no current flowing in the coil. The stationary contact attaches to a wire that carries the heavy current flow from the battery to the horn itself.

When the driver depresses the horn button, it completes the ground circuit and a small amount of current flows through the coil. It, in turn, forms a strong electromagnet that attracts the armature arm down to close the two contact points. A heavy current can now flow to the horn.

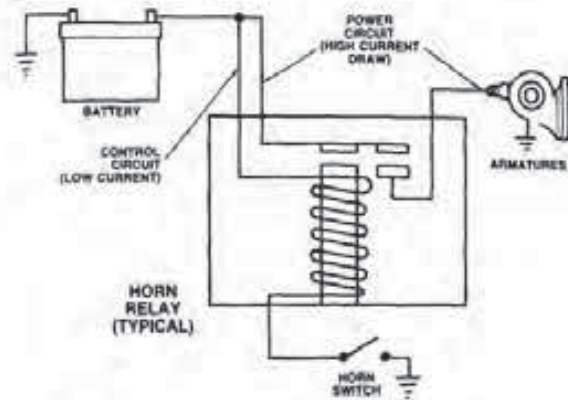


FIGURE 2-52
Schematic of relay construction. [Courtesy of Chrysler Motors Corp.]

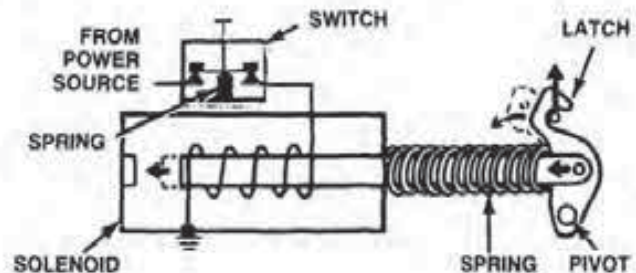


FIGURE 2-53
Luggage compartment solenoid schematic. [Courtesy of Ford Motor Co.]

Solenoids

A *solenoid* is an electromagnet with a movable instead of a fixed iron core. The solenoid can have two basic functions. First, it can be used to convert electrical current flow into mechanical movement to do some type of work. Second, the solenoid can act as a relay to close a second set of contact points to control a heavy current flow.

Figure 2-53 illustrates a typical solenoid that is used to operate a luggage compartment latch. Solenoids of a similar design are also used as actuators for a number of applications in electronic control systems. The solenoid shown consists of a set of windings and a core. One end of windings connects to ground and the other to the battery positive terminal via the manual switch contacts.

The core is a piece of iron that slides into the air gap inside the windings. Over one end of the core fits a return spring that keeps it extended when the

coil is de-energized. This end of the core also attaches to the latch, which can pivot back and forth.

When the manual switch is pressed in, current flows through the windings of the solenoid, energizing the coil. The coil now becomes an electromagnet that pulls the core inward. This action pulls on the latch, releasing the luggage compartment lid.

When the switch is released, current ceases to flow in the solenoid circuit. As a result, the coil loses its electromagnetism, and the spring moves the core outward, resetting the latch in the closed position.

Solenoids that operate under a heavier load usually have two windings (Fig. 2-54). The heavy set (known as the primary or pull-in) is necessary to help pull the core into the coil. The lighter windings, called the hold-in or secondary windings, can maintain the core in place once it is drawn in.

In operation, current flow from the battery passes through both sets of windings and to ground. This produces a large enough magnetic field to pull the core into the air gap.

As the core bottoms in the solenoid, it contacts

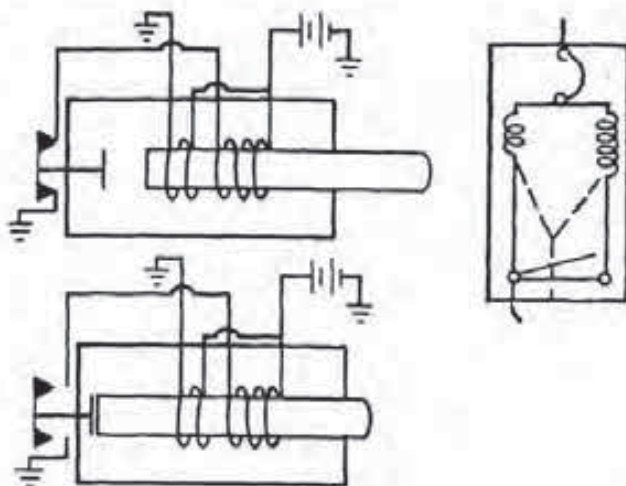


FIGURE 2-54
Diagram of a compound-wound solenoid. (Courtesy of Ford Motor Co.)

a switch that opens. This action breaks the ground circuit for the pull-in windings. As a result, there is a reduction in current flow through the solenoid. However, the reduced flow through the hold-in windings is enough to produce sufficient magnetism to hold the core in position.

Resistors

A *resistor* is an electrical component used to limit current flow and thereby voltage in a circuit as needed. Resistors (Fig. 2-55) are conductors spe-

cially constructed to introduce a measured amount of electrical resistance into a given circuit. However, some other circuit components use built-in resistance to produce heat, light, or both, such as cigarette lighters and light bulbs.

Resistors in common use in automotive circuits are of three types: (1) fixed value, (2) stepped or tapped, and (3) variable. A *fixed value resistor* is one designed to have only one rating that should not change. Resistors of this design are used for controlling circuit voltage and thus current flow. Common applications for this type are the ignition resistor and the carbon units used in ignition modules, radios, or computers.

A *tapped or stepped resistor* is designed to have two or more fixed values, attached by connecting wires to several taps on the resistor block. A typical example of this type of device is the blower motor resistor.

The *variable resistor* is designed to have a range of resistances available through two or more taps and a control. The headlight switch rheostat is an example of this type of resistor. This unit has two tap connections, one on the fixed end of a resistor and one attached to a sliding contact that rides on it. Turning the switch control moves the sliding contact away from or toward the fixed end of the resistor. This has the effect of increasing or decreasing the resistance in the dash light circuit that the rheostat controls.

There are two other types of variable resistors, the potentiometer and the thermistor. These devices are covered in Chapter 4.

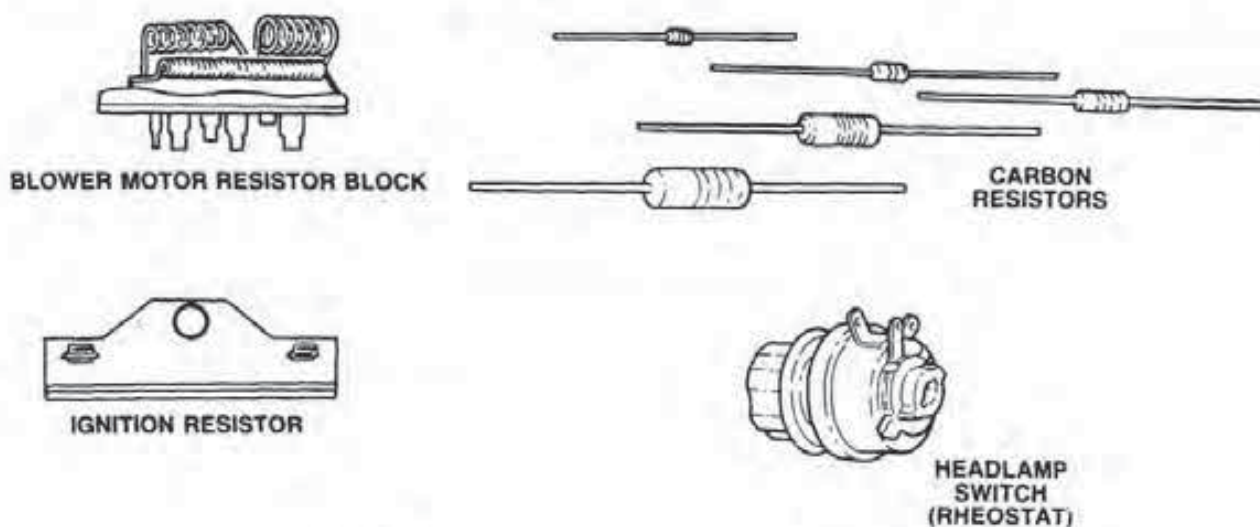


FIGURE 2-55
Automotive type resistors. (Courtesy of Chrysler Motors Corp.)

Circuit Protection Devices

Automotive electrical circuits have some kind of protective device. This device safeguards the circuit from damage when an overload causes too much current to flow. The excessive current would otherwise cause the wiring to heat up, possibly melting the insulation and maybe causing a fire. The common types of protection devices are the fuse, fuse link, and circuit breaker (Fig. 2-56).

The fuse is the most common form of circuit protection used in automobiles. Several types of fuses are used by manufacturers; they include the glass tube style and the plastic blade design. The glass tube style contains an element strip of metal with a low melting point. If an excessive current flows through the circuit with either style of fuse, the fuse element melts at the narrow portion, opening the circuit and preventing damage to the electrical component.

A fuse is designed to carry a specified maximum current flow and to blow when this value is exceeded. The maximum fuse current flow is marked on the fuse in amperes (A). *A blown fuse must always be replaced with one that has the same design and current-carrying capacity. Do not, for example, replace a 15A fuse with a 20A fuse.*

A fuse block or panel serves as the common connection point for a number of wires or wiring harnesses. Fuses are inserted between the connecting points of the wires. This design protects each circuit against electrical overloads and also groups the fuses in a convenient location.

Some wiring harnesses are equipped with a *fusible link* to protect them against damage in the event of a short in a main feed circuit. The link itself (see Fig. 2-56) is a short length of wire smaller in gauge than the conductor in the circuit it protects. The link is installed in the conductor, usually close to the power source. In addition, the fusible link wire is covered with thick, nonflammable insulation.

If a circuit overload occurs, the link will melt, causing the circuit to open. Moreover, the heat from the overload usually causes the link's insulation to smoke or blister.

Fusible links are replaced by cutting them out of the conductor and installing a replacement of the same rating. *Do not replace a blown link with standard gauge wire. Only fusible-link-type wire with hypalon insulation must be used or damage to the electrical system will occur.*

Some special electrical components and wiring harnesses are protected by *circuit breakers*. These circuits (such as the headlights or wipers) may some-

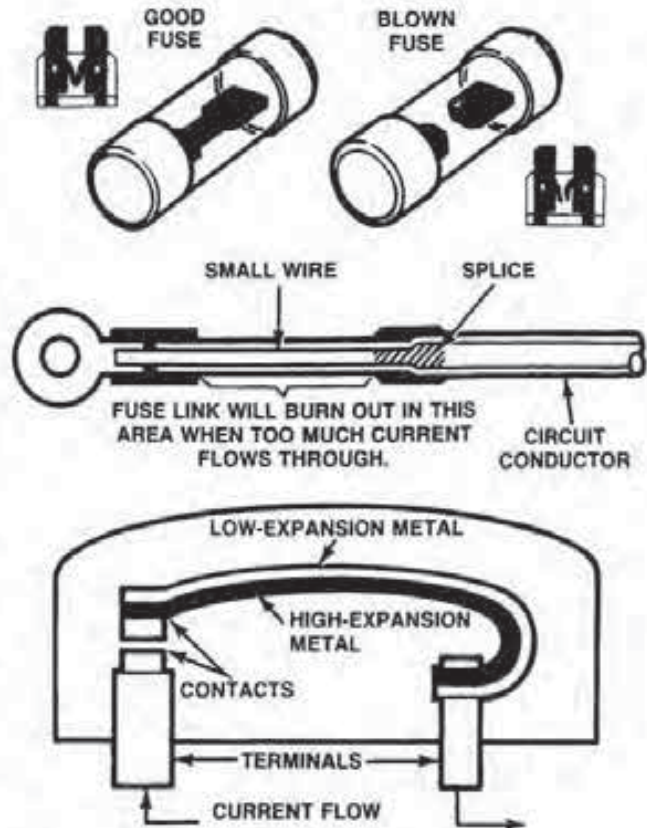


FIGURE 2-56
Circuit protection devices. (Courtesy of Ford Motor Co.)

times undergo a temporary overload, yet they must have power restored rapidly. A fuse and fuse link are no good in these cases because they may not be readily available for replacement. A circuit breaker can be mounted in a fuse block or in-line with a particular circuit. Also, like fuses, circuit breakers are rated by their ampere-carrying capacity.

A circuit breaker consists of a set of contacts controlled by a strip made of two kinds of metal bonded together. Each strip of metal has a different coefficient of expansion.

When an overload occurs and excessive current flows through the bimetallic strip, it heats up and bends due to the uneven expansion of the two metals. This action very quickly opens the contact points and the circuit.

With no current flowing, the bimetallic strip cools and straightens out, closing the contact points. This once again closes the circuit. If the overload is continuous, the circuit breaker will cycle open and closed until the source of the problem is corrected. If the overload is removed, the breaker will remain closed, and the circuit will continue to function in a normal manner.

This type of breaker is called *self-resetting* because it automatically reconnects the power to the circuit after protecting it against an overload. *Manually resettable circuit breakers* are also sometimes used. On this type, a button will pop out of the circuit breaker case, indicating the points have opened. To reset this breaker design, it is simply a matter of pushing in the button.

Keep in mind that just replacing a fuse, fusible link, or resetting a circuit breaker does nothing toward remedying the problem that caused the overload. Indeed, the action may be fruitless because the fuse or breaker will again blow as soon as the circuit is switched on. *Always repair the source of the overload before restoring the circuit protection device.*

2-9 WIRING DIAGRAMS AND SYMBOLS

Each year, all vehicle manufacturers issue wiring diagrams for the electrical system found on each of their production vehicles (Fig. 2-57). A *wiring diagram* is a graphic representation of the components and conductors within the electrical system. These diagrams are incorporated into the service manual for the particular vehicle. In addition, publishers

such as Chilton, Motors, and Mitchell Manuals provide wiring diagrams for domestic and imported vehicles.

In either case, a diagram is as informative as a road map once you understand the numbers and symbols shown on it. Without a diagram, diagnosis and repair of electrical circuits would be almost impossible; with one, you can make your way quickly to where you need to go to locate the source of a problem.

In this chapter and others, you will see a type of diagram that shows actual components connected by conductors. This is known as a *pictorial diagram*, and is a crossbreed between the actual likeness of a component and what is shown on a true *schematic diagram*. Pictorial diagrams are useful in training because they relate the familiar to the unfamiliar. Schematic diagrams, on the other hand, are more informative. They usually show component internal electrical paths and squeeze more information into a smaller space.

Diagram Symbols

All parts of wiring diagrams have symbols that represent the actual physical parts used in the system.

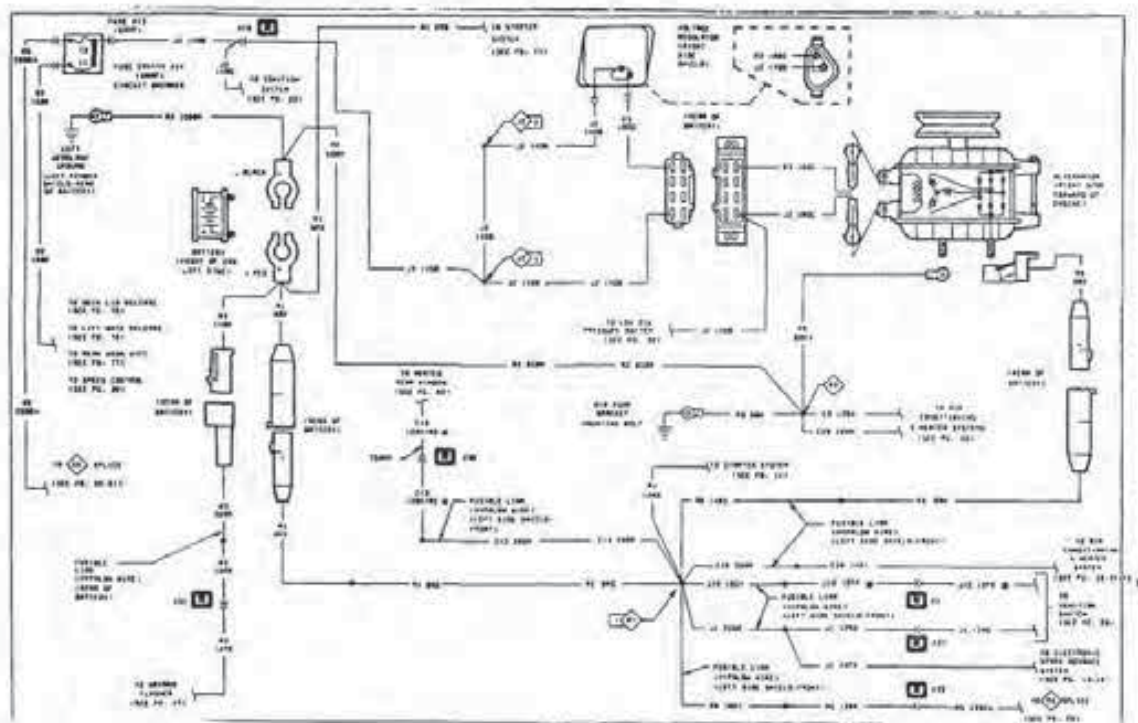


FIGURE 2-57
Typical wiring diagram. (Courtesy of Chrysler Motors Corp.)

	POSITIVE		CONNECTOR
	NEGATIVE		MALE CONNECTOR
	GROUND		FEMALE CONNECTOR
	FUSE		MULTIPLE CONNECTOR
	CIRCUIT BREAKER		DENOTES WIRE CONTINUES ELSEWHERE
	CAPACITOR		SPLICE
	OHMS		SPLICE IDENTIFICATION
	RESISTOR		OPTIONAL WIRING WITH WIRING WITHOUT
	VARIABLE RESISTOR		THERMAL ELEMENT BI-METAL STRIP
	SERIES RESISTOR		Y-WINDINGS
	COIL		DIGITAL READOUT
	STEP UP COIL		SINGLE FILAMENT LAMP
	OPEN CONTACT		DUAL FILAMENT LAMP
	CLOSED CONTACT		LED LIGHT EMITTING DIODE
	CLOSED SWITCH		THERMISTOR
	OPEN SWITCH		GAUGE
	CLOSED GANGED SWITCH		TIMER
	OPEN GANGED SWITCH		MOTOR
	TWO POLE SINGLE THROW SWITCH		ARMATURE AND BRUSHES
	PRESSURE SWITCH		DENOTES WIRE GOES THROUGH CROMMET
	SOLENOID SWITCH		DENOTES WIRE GOES THROUGH 10 WAY DISCONNECT
	MERCURY SWITCH		DENOTES WIRE GOES THROUGH 25 WAY STEERING COLUMN CONNECTOR
	DIODE OR RECTIFIER		DENOTES WIRE GOES THROUGH 25 WAY INSTRUMENT PANEL CONNECTOR
	BI-DIRECTIONAL ZENER DIODE		

FIGURE 2-58
Common wiring diagram symbols. (Courtesy of Chrysler Motors Corp.)

In some cases, the symbol looks just like the part, and other times, it's rearranged to fit more easily into the diagram and keep it simple.

There are wide variations in the use of automotive electrical symbols. Some companies use their component drawings for some units and standard symbols for others (Fig. 2-58). Moreover, the component's basic internal circuit is sometimes shown, while in other cases, symbols are used all of the time.

Figure 2-58 is a legend of the various symbols

and their descriptions provided by Chrysler Corporation as an aid in following its diagrams. Other manufacturers provide the same type of information in their service manuals.

Become very familiar with the symbols used on the diagram with which you are going to work. These symbols represent the components, wires, and connectors exactly the way you will find them in the circuitry of that particular vehicle. You will find more information on reading diagrams in Chapter 5.

CHAPTER REVIEW

The following two sections will assist you in determining how well you remember the material contained in this chapter. If you cannot complete a statement or question, refer back to the section marked in brackets that contains the material.

SELF-CHECK

1. Explain the purpose of a relay [2-8].
2. What determines the classification of matter [2-1]?
3. What factors determine the strength of an electromagnet [2-7]?
4. According to the electron theory, what is current flow [2-2]?
5. What is the basic law of magnetism [2-6]?
6. Current flow can be compared to what [2-3]?
7. What are the three forms of the equation for Ohm's law [2-4]?
8. Describe the basic difference between a series and a parallel circuit [2-5].
9. What is the difference between a fixed and tapped resistor [2-8]?
10. Explain the purposes of pictorial and schematic diagrams [2-9].
3. The use of an iron core increases the strength of an electromagnet about how much [2-7]?
 - a. 1,000 times
 - b. 1,500 times
 - c. 2,000 times
 - d. 2,500 times
4. Electrons that are easily lost from their orbits are known as [2-2]
 - a. drift electrons.
 - b. bound electrons.
 - c. balance electrons.
 - d. free electrons.
5. What is a natural magnetic material [2-6]?
 - a. lodestone
 - b. steel
 - c. iron
 - d. aluminum
6. Electrical pressure can also be called [2-3]
 - a. voltage.
 - b. EMF.
 - c. both a and b.
 - d. neither a nor b.
7. To find the amount of amperes in a circuit, which form of Ohm's law should you use [2-4]?
 - a. $I = E \times R$
 - b. $I = E \div R$
 - c. $E = I \times R$
 - d. $R = E \div I$
8. Which type of circuit has the same current flow through all the resistance units [2-5]?
 - a. parallel
 - b. series
 - c. series-parallel
 - d. both b and c
9. A headlight circuit usually has what type of protection device [2-8]?
 - a. fuse
 - b. fusible link
 - c. fuse and link
 - d. circuit breaker
10. How many electrons does a copper atom have in its outer orbit [2-1]?
 - a. 1
 - b. 7
 - c. 9
 - d. 13

REVIEW

1. The electromagnet with a movable core is called [2-8]
 - a. a relay.
 - b. a solenoid.
 - c. an ignition coil.
 - d. a tapped resistor.
2. The nucleus of an atom is formed of [2-1]
 - a. protons and neutrons.
 - b. electrons and protons.
 - c. neutrons and electrons.
 - d. none of these.

11. What factor changes the direction of the lines of force around a conductor [2-7]?
 - a. increasing its resistance
 - b. reversing the current flow through it
 - c. decreasing its resistance
 - d. increasing the applied voltage
12. Bakelite is what type of material [2-2]?
 - a. semiconductor
 - b. conductor
 - c. resistor
 - d. insulator
13. Like magnetic poles [2-6]
 - a. attract each other.
 - b. are neutral toward each other.
 - c. repel one another.
 - d. do none of the above.
14. Which type of circuit has a voltage drop equal to the battery across each resistance unit [2-5]?
 - a. parallel
 - b. series
 - c. series-parallel
 - d. none of the above
15. According to Ohm's law, if voltage remains the same and resistance is increased current will [2-4]
 - a. increase.
 - b. decrease.
 - c. remain the same.
 - d. do none of the above.
16. The measurement for current flow is the [2-3]
 - a. volt.
 - b. ohm.
 - c. volt-ohm.
 - d. ampere.
17. An electrical control that performs mechanical work is the [2-8]
 - a. switch.
 - b. solenoid.
 - c. coil.
 - d. fusible link.
18. A lack of electrons exists at which battery terminal [2-2]?
 - a. positive
 - b. negative
 - c. neither terminal
 - d. both terminals
19. If a battery connected into a circuit has a difference in electrical charges at its terminals, what will occur [2-3]?
 - a. voltage
 - b. current flow
 - c. both a and b
 - d. neither a nor b
20. A shorted circuit can cause what condition [2-5]?
 - a. decrease in current flow
 - b. increase in current flow
 - c. no change in current flow
 - d. increase in system voltage

Chapter 3

ELECTRONIC FUNDAMENTALS

OBJECTIVES

After reading and studying this chapter, you will be able to:

- explain the structure and operation of a semiconductor.
- describe the function, design, and operation of a standard, zener, and light-emitting diode.
- explain the purpose, structure, and operation of a transistor.
- describe the function, design, and operation of a capacitor.
- identify and know the purpose of an integrated circuit.
- describe a microelectronic chip and know its purpose.
- explain basically how a memory cell can store information.

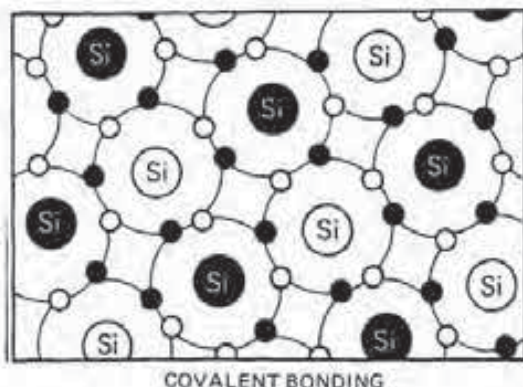


FIGURE 3-1
Crystalline silicon is an excellent insulator. (Courtesy of Delco Remy)

Years ago, the term *electronics* meant a study of the behavior of electrons in vacuum tubes and the devices (radios and televisions) that used them. Now the word has come to mean the flow of electrons through a radio tube or its equivalent. The equivalent in this instance means electron flow through semiconductors such as diodes and transistors.

Semiconductors have been especially important to the development of alternators, ignition systems, computerized engine controls, and other solid state equipment. *Solid state* refers to any device that uses transistors, diodes, and other components made from semiconductors. To understand the electronic equipment presented in later chapters in this text, it is necessary for the reader to have a basic understanding of the structure of semiconductors and how they are formed into diodes, transistors, and integrated circuits.

3-1 SEMICONDUCTORS

A semiconductor, as a form of matter, falls somewhere between a conductor and a nonconductor. In other words, it is a material that is neither a good conductor nor a good insulator. The difference is due primarily to the number and arrangement of electrons and the way in which atoms are joined.

Structure of a Semiconductor

As mentioned, materials that have atoms with less than four electrons in the outer orbit are good conductors and those having five or more are good insulators. Atoms with exactly four electrons in the outer orbit are neither good conductors nor good in-

sulators; however, they do form good semiconductors. *Silicon* and *germanium* represent materials of this type, with silicon the most predominantly used material for semiconductors in automotive circuits. For this reason, the following discussion will concentrate on silicon-based semiconductors.

When a number of these silicon atoms are combined chemically in crystalline form, the result is called *covalent bonding*. This means that the electrons in the outer orbit of one atom join with those in the outer orbit of another atom (Fig. 3-1). In effect, each atom has eight electrons in its outer orbit, four of its own and four shared with another silicon atom. This makes the material a good insulator because there are no free electrons.

But when certain other materials are added to the highly refined silicon crystal in very controlled amounts, the resultant mixture is said to be *doped*. The doping elements are often called *impurities* because their addition to the semiconductor makes its original base material impure. As a result of the doping, the silicon material is no longer a very good insulator, and it possesses some unusual electrical properties.

N Material. If silicon, for example, is slightly doped with an element such as phosphorus, arsenic, or antimony (also in crystalline form) at a ratio of 1 part to 10,000,000 parts of silicon, the result then becomes an *N material* (Fig. 3-2). Each of these doping materials has five electrons in its outer orbit. When phosphorus is combined with the silicon, covalent bonding does occur. However, in this case, there is one electron left over. In other words, there will not be enough space for the ninth electron in the shared outer orbits of the phosphorus and silicon atoms.

This electron is free and can be made to move through the entire material very easily. Any material having extra electrons is called negative or *N*

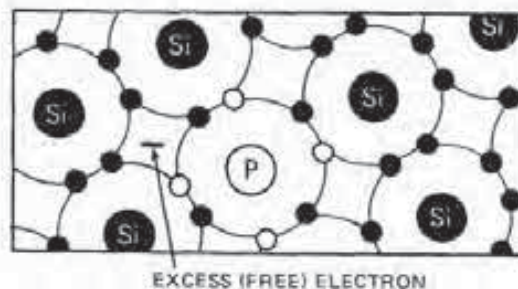


FIGURE 3-2
Using phosphorus to dope silicon leaves a free electron in silicon's outer orbit. (Courtesy of Delco Remy)

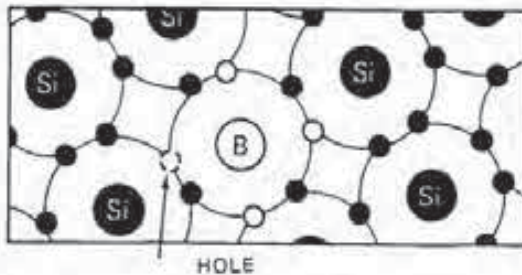


FIGURE 3-3
Using boron to dope silicon creates a hole in silicon's outer orbit. (Courtesy of Delco Remy)

material. That is, the material already has excess electrons that will repel additional negative or attract more positive charges.

P Material. On the other hand, when silicon is doped with impurities such as small particles of boron or indium crystals, it then becomes a *P material* (Fig. 3-3). Both of these doping materials have three electrons in their outer orbits. So when covalent bonding occurs between the silicon and atoms of the doping material, there is a deficiency of one electron needed to fill the shared outer orbit.

The resultant void is called a *hole*. A hole is the absence of an electron required to fill an atom's outer orbit. While the electron has a negative charge of electricity, the hole can be considered a positive charge of electricity. Materials of this type are known as positive or *P materials* because they will attract a negative or repel an additional positive charge.

Semiconductor Operation

To better understand the operation of a semiconductor, consider the extra electron in the *N material* as a negative ($-$) charge, and the hole in the *P material* as a positive ($+$) charge. The hole can move from atom to atom in the same way an electron can due to the influence of electromotive force (EMF).

Figure 3-4 illustrates current flow in an *N-type material*. By connecting a battery and a resistor into a circuit with the material, current flows. This flow is the movement of the excess or free electrons through the material and is very similar to what occurs in a good conductor, a copper wire. The negative side of the circuit pushes electrons through the semiconductor, and the positive side attracts the free electrons.

The movement of holes and electrons in a *P-type material* is shown in Fig. 3-5. When voltage is

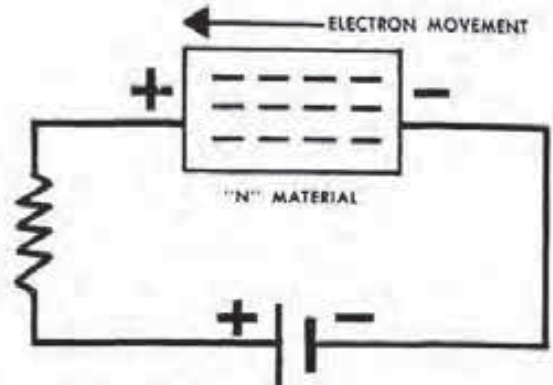


FIGURE 3-4
Electron flow in a circuit with *N-type material*. (Courtesy of Delco Remy)

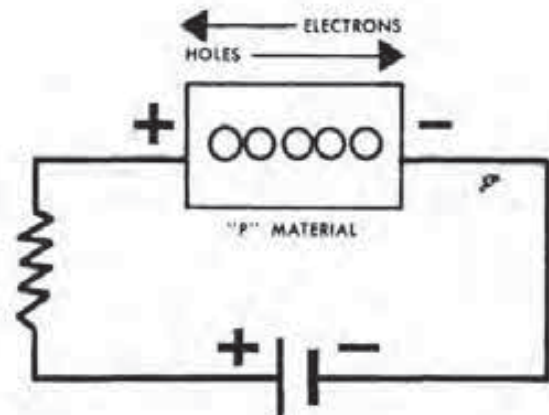


FIGURE 3-5
Movement of electrons and holes within the circuit with *P-type material*. (Courtesy of Delco Remy)

applied to the material, it produces a directed pattern of holes and moving electrons. As mentioned, current (according to the electron theory) is the movement of electrons from negative to positive. But current in the *P-type semiconductor* is looked on as movement of the positively charged holes from positive to negative just like current flow is described in a good conductor using the conventional theory. In other words, the hole effectively moves from atom to atom in one direction, just like an electron travels from atom to atom in the opposite direction.

Figure 3-6 further illustrates this hole movement. Notice how the positive battery terminal in diagram 1 attracts a negative electron from one of the covalent bonds within the *P material* into the hole next to the terminal (i.e., unlike charges attract

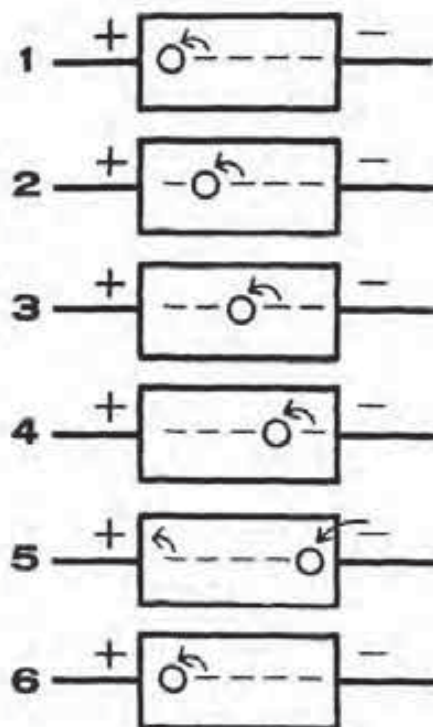


FIGURE 3-6
Movement of holes within a P-type material. (Courtesy of Delco Remy)

one another). Similarly, the negative battery terminal repels an electron through its connection.

This movement of an electron leaves behind a hole (diagram 2). The positively charged hole has, in effect, moved to the right or toward the negative terminal of the battery. Another electron will then move in to fill this hole, creating yet another hole nearer the negative terminal.

This process continues in this manner as the hole moves to the right. Finally, the hole arrives in the vicinity of the negative terminal of the semiconductor (diagram 5). At this time, the hole again is filled by an electron that leaves the negative terminal, while the positive terminal removes an electron from the semiconductor. In diagram 6, the positive terminal repels a hole into the semiconductor, and the process is then ready to repeat itself all over again as described above.

As mentioned, this continuous movement of the holes from the positive to the negative terminal can be considered as current flow in a P-type material. And this action can only occur when voltage causes the electrons to shift around in the covalent bonds.

However, it is important to note that the hole movement only occurs within the semiconductor,

while electrons flow through the entire circuit. Finally, the theory of hole movement affords an easier way to understand how diodes and transistors operate.

3-2 DIODES

As stated, the N- and P-type materials are both semiconductors. As such, they can conduct current flow in some applications, while in others they act as insulators. The first practical, production-line use of N- and P-type semiconductor materials in the automotive industry was in the construction of diodes for use in the alternator. In the alternator, diodes are used to rectify current from AC to DC for use in the charging system. Later, of course, the diode was extensively used in ignition modules and computerized engine control systems.

Diode Function

A *diode* is an electronic component that allows current to pass through itself in one direction only, like a one-way valve, because the unit offers low resistance in one direction only. A diagram and symbol for the diode are shown in Fig. 3-7. Notice that the arrow in the symbol points in the direction of hole movement, or current flow using the conventional theory.

Typical Diode Construction

Manufacturers construct a diode by changing silicon crystal into N-type and P-type materials and forming the two together. The process of forming the two types of material involves not just a mechanical union, but a carefully controlled manufacturing technique that creates and joins the two parts in a diffusion process. *Diffusion* is a process by which particles of the impurities and the silicon intermingle as a result of thermoagitation.

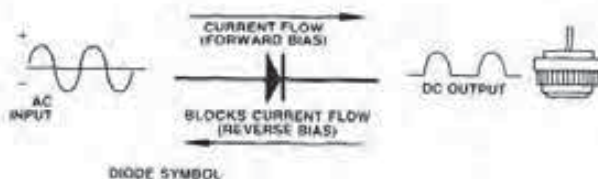


FIGURE 3-7
Typical automotive diode. (Courtesy of Chrysler Motors Corp.)

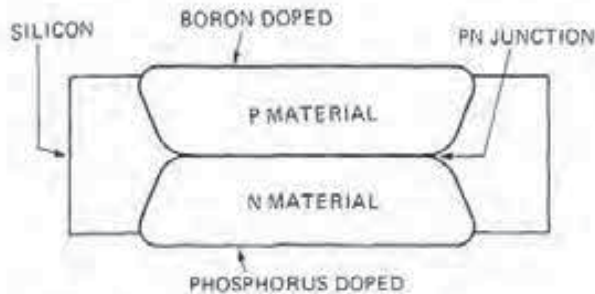


FIGURE 3-8
Diode wafer design.

The process itself involves a wafer of silicon about 0.007 inch thick and 1-½ inches in diameter. The wafer is first painted on one side with a solution containing phosphorus pentoxide and on the other side with one containing boric oxide. Next, the painted, or doped, wafer is positioned into a furnace containing a hydrogen atmosphere at 1,200°C. Under these conditions, the compounds phosphorus pentoxide and boric oxide are chemically drawn together. This produces boron and phosphorus, which diffuse into the silicon to form P-type and N-type materials respectively (Fig. 3-8). The internal area of the diode where the P-type and N-type materials meet is known as the *junction*.

The manufacturer then plates the wafer to facilitate the soldering of electrical connectors before breaking it up into smaller pieces. This sizing operation is necessary to incorporate the diode into a given electrical circuit.

Diode Operation

There are three phases of diode operation: static, forward bias, and reverse bias. During the *static phase*, the diode is not connected into an electrical circuit (Fig. 3-9). When P-type and N-type materials are formed into a diode, an attraction exists between the free electrons and holes. It would seem then that the N material's free electrons would drift across the junction area and fill the holes within the P material.

This action does occur, but only to a very limited extent. As a few electrons from the N material do drift toward the junction, they leave behind charged particles called positive ions. An *ion* is an atom having a deficiency or excess of electrons. These positive ions exert an attractive force on the remaining free electrons to prevent them from crossing the junction.

In a similar manner, a few holes from the P material cross the junction. When they do, the holes leave behind negative ions, which exert an attractive

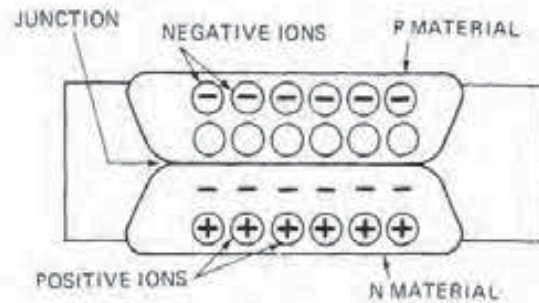


FIGURE 3-9
Static diode operation.

force on the remaining holes to prevent them from crossing the junction. The net result is a balanced condition with a deficiency of electrons and holes at the junction area. The electron and hole drift, in effect, is an insignificant amount and does not measurably affect diode operation.

When a diode is connected into a circuit with a battery and a resistor, as shown in Fig. 3-10, the situation changes. As indicated, the diode is connected into the circuit with the negative side of the battery connected to the N-type material and the positive terminal attached to the P-type material. This is known as a *forward-bias connection*. *Biasing* is the application of voltage to the two doped semiconductor materials.

With this type of connection, the negative terminal of the battery will repel electrons into the N-type material, and the positive terminal will repel the holes into the P-type material. The electrons moving into the N-type material satisfy the positive ions that had been holding other electrons away from the junction. With this restraining force satisfied, electrons at the junction move across and on through the circuit.

As electrons move across, they leave behind positively charged holes in the N material, which at-

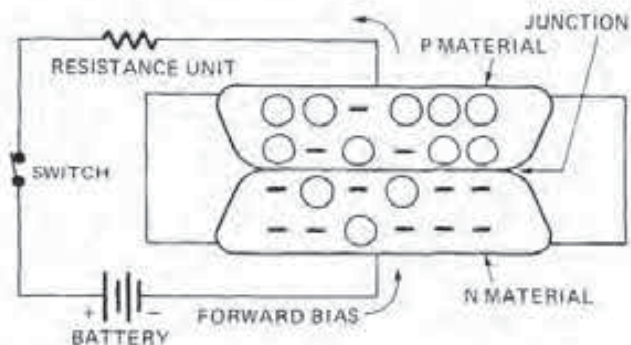


FIGURE 3-10
Diode operation in a forward-bias connected circuit.

tract more electrons from the negative battery terminal. At the same time, the free electrons that moved into the P material continue to be attracted toward the positive battery terminal, leaving behind holes in the P-type semiconductor at the junction.

In a similar manner, the additional holes entering the P material from the positive terminal satisfy the negative ions that had been holding the holes away from crossing the junction. With this restraining force also satisfied, holes at the junction move across and through the N material.

As the electrons move from the N to the P material, the battery continues to inject electrons into the N-type and attract electrons from the P-type material to maintain a given rate of electron movement. Thus, there is current flow: holes in one direction and electrons in the other.

An important factor to note, however, is that in order for an appreciable amount of current to flow through the diode, there must be a concentration of holes in the P material near the junction, and a concentration of electrons in the N material near the junction. This is necessary because in order for electrons to move into the P material, there must be holes present at the junction into which the electrons can move. In other words, if there are no holes present, the electrons have no place to go in the material. Consequently, there can be no flow.

Depending on its design, a diode can only withstand a given amount of forward-bias voltage and current flow. If the forward current flow is too strong or flows for too long a period, the doped materials can be damaged or destroyed.

Figure 3-11 illustrates a diode installed into a circuit using *reverse-bias connection*. In this case, the positive terminal of the battery attaches to the N-type material, while the negative connects to the P-type semiconductor.

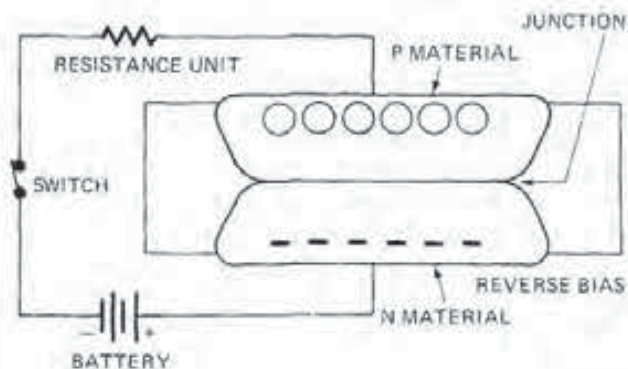


FIGURE 3-11
Diode operation in a reverse-bias connected circuit.

As shown, the positive battery terminal attracts the electrons away from the junction area in the N-type semiconductor. The negative terminal attracts the holes away from the junction area of the P-type material. As a result, the electrons and holes merely drift away from the junction area. Therefore, the electrons do not enter the circuit to create current flow.

With the junction area void of holes and electrons, there can be no appreciable current flow. In effect, the diode has a very high electrical resistance created at the junction area. Consequently, when the diode has a reverse-bias connection into a circuit, it blocks current flow. In other words, the diode permits current flow in one direction by acting as a conductor, but it stops current flow in the opposite direction by operating as an insulator.

However, because the diode is not a perfect insulator, a small amount of reverse current leakage does occur. But this amount is usually too small to consider.

Diode Performance Curve

Figure 3-12 shows a typical diode performance curve that illustrates the current flow for both forward- and reverse-bias voltages. Note how as the forward-bias voltage goes up, the forward current flow tends to increase very rapidly.

The curve in the lower left portion of Fig. 3-12 shows that a current does flow when a reverse voltage is applied to the diode. The magnitude of the reverse current is very small, and it increases very little until the breakdown or maximum reverse voltage is reached.

One of the most common ways to rate a diode is in terms of its *peak inverse voltage (PIV)*. This

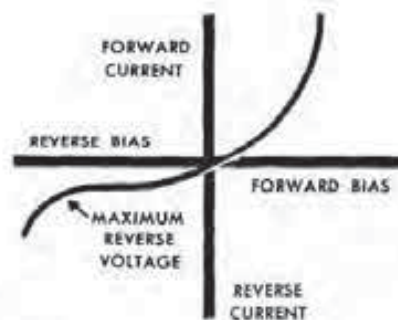


FIGURE 3-12
Diode performance curve. (Courtesy of Delco Remy)



FIGURE 3-13
Symbol for a zener diode. (Courtesy of Delco Remy)

refers to the amount of reverse-bias voltage the diode can withstand before breaking down and permitting excessive reverse current flow. A diode can withstand a reverse-bias voltage below its PIV rating indefinitely.

However, higher reverse current caused by increased reverse voltage above the PIV rating can quickly damage the diode. At a voltage above the PIV rating, the covalent bond structure of the semiconductor breaks down. This is followed by a rapid increase in current flow, which overheats and ruins the diode. Typical safe values for a given diode may be 2 or 3 amperes of forward current flow and less than 0.001 ampere of reverse current.

Zener Diode

A *zener diode* is a specially designed unit that will satisfactorily conduct current flow in the reverse direction. A symbol for this diode is shown in Fig. 3-13. The primary feature of this kind of diode is that it is very heavily doped during its manufacture. The process provides a large number of extra current carriers (electrons and holes). This allows the zener diode to conduct current in the reverse direction without damage; that is, as long as the zener is used in a properly designed circuit. Zener diodes are usually found in some form of voltage control circuitry.

The doping process is carefully controlled so that this diode type will only conduct reverse current if the voltage is higher than a specific level. For instance, a given zener diode may have a design to only conduct current if the reverse voltage is more than six volts. At any reverse voltage below six volts, the zener acts as a normal diode and does not conduct reverse current flow.

At six volts and above, the zener diode conducts reverse current flow with no damage to the doping materials within the semiconductors; that is, if the current flow is kept within specified limits. In the example given, the diode's *breakdown* or *zener voltage* is six volts.

Light-Emitting Diodes

A *light-emitting diode (LED)* is one made of a specially doped crystal that glows when current passes through it. When the two doping materials gallium and arsenic are formed with the silicon crystal, an interesting thing occurs within the semiconductor under forward-bias voltage. When a hole and an electron meet, they are neutralized as electrical charge carriers. As this occurs, electrical energy is released as light. If these diodes are arranged in geometrical shapes and then the current flow is turned on and off through selected units in a pattern, the result is a lighted LED display, as used in some automotive instruments.

3-3 TRANSISTOR

As mentioned in the last section, diodes can control the direction of current flow as well as the amount and polarity of voltage applied across all or a portion of a circuit. However, diodes cannot increase, or amplify, current or circuit voltage.

Electronic systems for such applications as voltage regulators, ignition modules, radios, and microcomputers usually require current or voltage amplification in order to develop sufficient power to perform given functions. The *transistor* (Fig. 3-14) is a semiconductor device that can perform this amplification. In addition, the transistor can work like a relay in electronic systems to switch a high-current circuit on and off using a voltage signal across a low-current circuit.

Transistor Design

Manufacturers usually form an individual transistor by adding a section of N- or P-type material to the PN junction used for diodes. This design results in either the PNP or the NPN transistor (Fig. 3-15). Notice that in each transistor the outer layers are the same kind of material (either P or N), and the



FIGURE 3-14
Typical transistor. (Courtesy of Chrysler Motors Corp.)

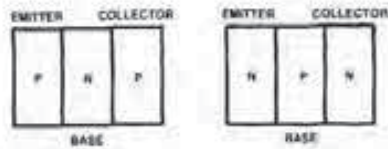


FIGURE 3-15
PNP and NPN transistors. [Courtesy of Chrysler Motors Corp.]

center layer is opposite. The name *transistor* comes from the words *transfer* plus *resistor* because this device transfers signals across the resistance of either two P or two N materials.

The three components of the transistor are the *base*, *emitter*, and the *collector* (see Figs. 3-15 and 3-16). When the transistor is part of an integrated circuit, the base is known as the *gate*, the emitter as the *source*, and the collector as the *drain*. In any case, the emitter and the collector are the outer layers and the base is the inner layer.

Notice also in Fig. 3-16 the arrowhead on each of the transistor symbols. The arrow is always on the emitter side and points in the direction of the hole or conventional current flow.

Figure 3-17 illustrates the design of a conventional, nonintegrated transistor. The three parts of the transistor are doped and constructed differently to affect the amount of current through the different areas. The base is thin and doped with a minimum number of carriers (holes or electrons), depending on transistor design. Moreover, attached around the base is a metallic ring, which will connect into an external electrical signal circuit. The signal applied to the base circuit controls the operation of the transistor.

The emitter is the thickest section of the transistor. The emitter is doped more than any other part in order to provide the maximum number of carriers.

The collector is not as thick as the emitter. In addition, this area is doped less. Therefore, it has fewer majority carriers (electrons in the NPN or holes in the PNP transistor). This design allows a reverse current flow when bias voltage is applied.

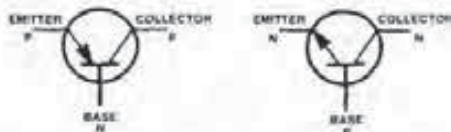


FIGURE 3-16
Transistor symbols. [Courtesy of Chrysler Motors Corp.]

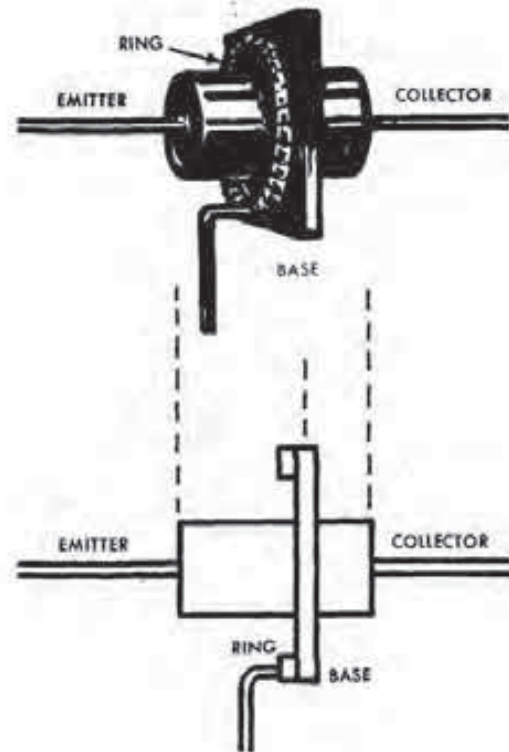


FIGURE 3-17
Design of a conventional transistor. [Courtesy of Delco Remy]

The conventional transistor is encased in a metal container (see Fig. 3-14) that protects it from damage. Also, the container is evacuated to prevent stray molecules of air from entering and interfering with the transistor's operation.

Transistor Operation

The transistor described above is *bipolar* in that the unit uses both holes and electrons as current carriers. In other words, current flows with positive and negative polarity in different circuits. The emitter always supplies the majority current carrier (either electrons or holes), and the collector receives them as long as the transistor is turned on, or conducting.

With this in mind, let's examine the operation of a typical NPN transistor. There are, in fact, two PN junctions, one between the emitter and base and the other between the base and the collector. Therefore, bias voltage can be applied to two different places.

If we apply forward-bias voltage to the emitter-base junction (negative terminal of the battery attached to the N emitter and positive terminal to the P base), a small current flows as within a simple PN

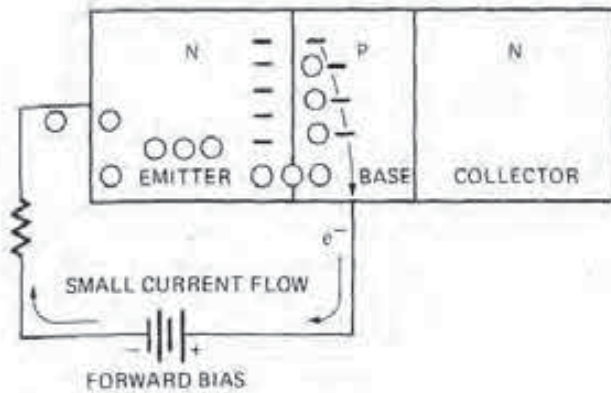


FIGURE 3-18
Forward-bias voltage applied to the emitter-base junction.

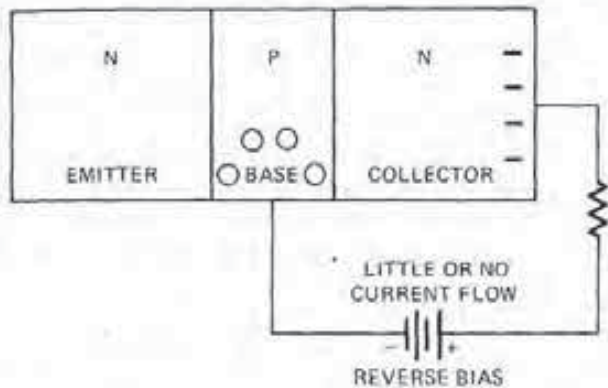


FIGURE 3-19
Reverse-bias voltage applied to the base-collector junction.

diode (Fig. 3-18). Holes move from the P base material toward the negative battery terminal through the N material. Electrons, on the other hand, move from the N material through the P base material to the positive battery terminal. However, excess free electrons do accumulate in the P base material. This is due to the overall reduction in available holes as a result of the doping process.

If we now apply a reverse-bias voltage to the base-collector circuit, current cannot flow (Fig. 3-19). Again, the PN junction acts like a diode with the voltage polarity reversed. In this case, the positive terminal of the battery attracts electrons away from the PN junction, while the negative terminal pulls the holes away from the junction. As a result, no current can flow.

In order to get the transistor to conduct and amplify current, let's assume the N-type emitter is at a zero volt potential. If we apply a low forward-bias voltage of three volts across the emitter-base PN junction, the result will be electron flow from the emitter into the base and hole movement in the op-

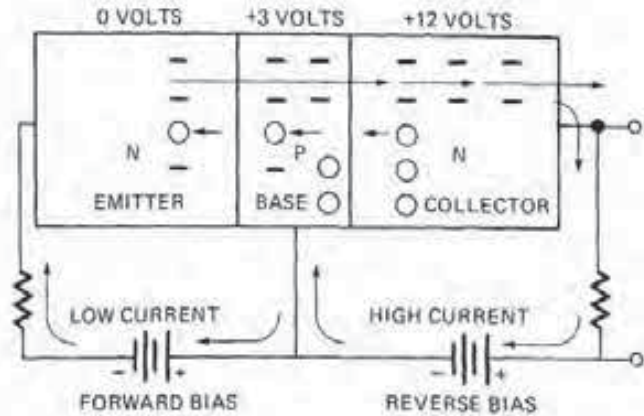


FIGURE 3-20
Small emitter-base current controls a larger flow through the emitter and collector.

posite direction. Even at the low applied voltage, there are extra electrons that gather in the base. Remember, the base has fewer holes than the emitter due to their different doping ratios.

Now, let's see what occurs when we apply a higher reverse-bias voltage of 12 volts to the collector (Fig. 3-20). This action causes a reverse bias across the base-collector PN junction. Consequently, high positive voltage on the collector terminal attracts electrons away from the base-collector PN junction, so little or no electrons should actually flow between the base and the collector. However, there is the matter of the extra electrons that have gathered in the base due to the forward-bias voltage on the emitter-base PN junction. They can now pass through the base and into the collector as they move toward the high positive voltage terminal of the battery.

As you can see, by itself, the reverse-bias voltage of 12 volts across the collector-base PN junction would not cause electron flow between the emitter and collector because there is high resistance. Therefore, almost no current flows through the circuit and the transistor is considered off.

But by applying the forward-bias voltage across the emitter-base PN junction, emitter electrons mass in the base and will flow easily into the collector toward the higher positive voltage source. In other words, resistance is reduced and the transistor turns on. The overall electron flow is forward from a low (-) potential at the emitter to a high (+) potential at the collector.

Note: The voltage examples used here are purely arbitrary; the actual applied voltages are a design consideration for each transistor application.

The time required for the emitter-base current to reach the maximum value designed to turn the transistor on is called *saturation*. Depending on design factors, a transistor can turn on and off (go from cutoff to saturation) in less than one millionth of a second.

The example of the NPN transistor shown in Fig. 3-20 clearly points out how the unit controls current flow through its parts and that a small voltage and current flow across one junction can regulate a larger current flow through the entire device. In the PNP transistor, the voltages and flow of electrons and holes are reversed, but the operating principle is the same.

Transistor Gain

The ratio between input and output power is known as *transistor gain* and is a design factor of the unit itself. Suppose, for example, that the forward-bias voltage across the emitter-base PN junction in Fig. 3-20 is supplied by the pickup coil within a distributor. This low voltage and current flow represent a fraction of a watt of electrical power, but are the input power for the transistor.

The larger voltage and current flow between the emitter and collector represent several watts of power, enough to energize the ignition coil. This then is the transistor's output power.

If the input power fluctuates between $\frac{1}{10}$ watt and $\frac{3}{10}$ watt (100 to 500 milliwatts) and the transistor gain is 100 to 1, the output power between the emitter and collector will fluctuate between 1 watt and 5 watts. This is plenty of power to energize the ignition coil in response to a low input voltage and current flow from the distributor pickup coil.

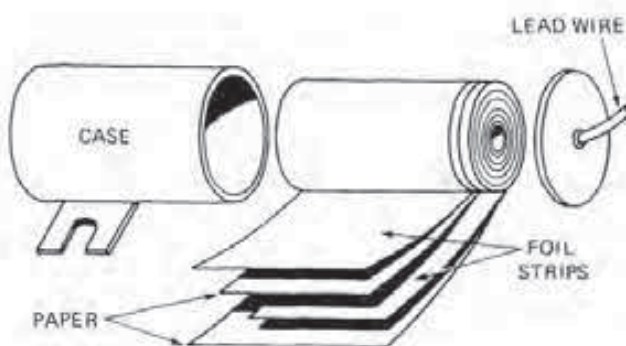


FIGURE 3-21
Design of a fixed capacitor.

3-4 CAPACITORS

Automotive electrical and electronic systems require the use of capacitors. A *capacitor* can serve a number of different functions in either or both types of circuit. For example, a capacitor will store voltage; therefore, it slows down any change in circuit voltage. In a given circuit, capacitors are often used to absorb voltage changes and thus act as shock absorbers. If a high voltage pulse is applied to a circuit, the capacitor absorbs it before the resulting increase in current flow can damage other parts of the circuit.

In addition, a capacitor is used as a short-circuit shunt to cause current flow to stop quickly when a circuit is opened. This is one of the tasks of capacitors that are used in ignition circuits.

Finally, a capacitor can store a high voltage charge and then discharge it quickly when connected across a circuit. In this way, the capacitor holds the charge until it can be transferred to and used by another part of the same or another circuit.

Fixed Capacitor Design

There are two designs of capacitors in use, the fixed and variable. A typical *fixed capacitor* consists of two long conductive foil strips, called plates, usually made of metal such as aluminum, zinc, steel, or copper (Fig. 3-21). Between each foil roll is an insulator. The insulator might be nothing more than the air in the space between the rolls, or it may be some nonconductive material such as mica, ceramic, glass, paper, or plastic. The insulation itself is known as a *dielectric*.

The foil strips and insulators are usually about eight feet in length, and the manufacturer rolls these components into a tight, round, cylinder-shaped bundle. However, during this process, the foil strips are offset so that one edge of one strip protrudes past the insulation on the top end of the assembly, and the edge end of the other plate extends past the insulation on the bottom side.

These exposed edges provide the electrical contact points for the two plates. The manufacturer flattens these edges before installing the roll into the metal housing, or case. With this arrangement, the bottom on the case contacts the foil edge and grounds it. The other foil edge provides the contact point for the insulated lead wire at the top of the case. Finally, to provide additional insulation, wax or oil is drawn into the case, and the entire unit is sealed.

Capacitance

The unit just described has an electrical property known as *capacitance*. Capacitance is the capacity, or ability, of two conducting surfaces to store an electric charge, or voltage, when separated by an insulator. The capacitor has this ability.

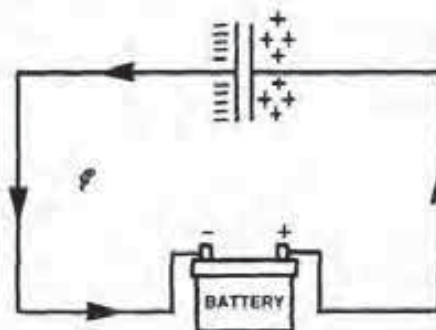
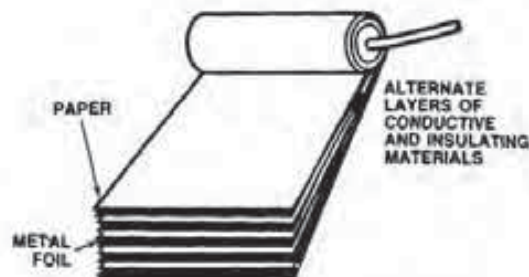
Capacitors are also called *condensers*. This term developed because electric charges collect, or condense, on the plates of the capacitor much like water vapor collects and condenses on a cold drinking glass.

The property of capacitance exists due to the electrical principle that unlike charges (+ and -) attract each other. This leads to the assumption that there is a field of electrical energy, or potential voltage, between any two oppositely charged points or surfaces. This is called an *electrostatic field* because the charges do not move. In other words, the charges are stored on the two plates in a form of static electricity.

When a capacitor is connected into an electrical circuit, the plate attached to the lead wire has a positive polarity, or excess of holes (Fig. 3-22). The ground plate has a negative charge, or an excess of electrons. Consequently, an electrostatic field exists between the two plates due to the opposite charges. The field will not be present if the capacitor is disconnected from the electrical circuit. Finally, the capacitance of a fixed condenser is a physical property, and this value will not change in any circuit. However, there are factors that affect its capacitance.

Factors of Capacitance. Capacitance is regulated by three factors. First, the larger the surface area of the plates, the greater the capacitance will be. This is because more electrons and holes can collect on larger plates than smaller ones. Second, the closer the plates are to each other, the greater the capacitance is because a stronger electrostatic field exists between the charged bodies. Third, the insulating qualities of the dielectric affect capacitance. The capacitance of a condenser is higher if the dielectric is a very good insulator.

Fixed Capacitor Ratings. A fixed capacitor (Fig. 3-23) is rated in units called *farads* (F). One farad is a very large charge, and a capacitor rated at one farad may be the size of a hot water heater. A smaller unit, the *microfarad* (μF) is used to describe the electrical capacity of fixed automotive capacitors. A microfarad is one-millionth (0.000001) of a farad.



THE CAPACITOR CHARGES TO THE SOURCE VOLTAGE

FIGURE 3-22
Capacitor plates charge to the source voltage. (Courtesy of Chrysler Motors Corp.)

Fixed Capacitor Operation. In order to understand the operation of a capacitor, consider the circuit illustrated in Fig. 3-24. Since the capacitor plates are insulated from each other, it would seem that no current will flow in the circuit. This is indeed the case, *except* at the instant of time when the switch is closed. When this occurs, the voltage across the capacitor plates will suddenly change from 0 to 12 volts.

When the switch closes, electrons will leave the battery and congregate on the capacitor's negative plate, as shown. This plate will have an excess of electrons. At the same time, holes will leave the (+) battery post and cause the other capacitor plate to have a positive charge. It is important to note that the electrons and holes flow through the circuit and not through the insulating material separating the two capacitor plates.



FIGURE 3-23
Symbol for a fixed capacitor.

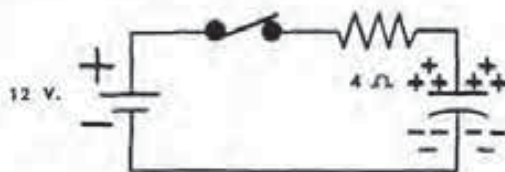


FIGURE 3-24
Capacitor storing a charge. (Courtesy of Delco Remy)

As the two plates become negatively and positively charged, a voltage appears across the capacitor. The voltage is the direct result of the difference in the charges between the two plates. As more and more electrons accumulate on the negative plate and holes on the positive plate, the stored capacitor voltage approaches that of the battery. When stored voltage equals battery voltage, electron flow will stop.

If the switch is suddenly opened, the charge of voltage on the capacitor will remain. The accumulated charge represents stored energy.

Theoretically, a capacitor will hold its charge indefinitely. But actually, the charge slowly leaks off the capacitor through the dielectric. The better the dielectric, the longer the capacitor holds the charge.

By adding another switch to the basic circuit, the voltage stored in the capacitor can be used to send current through a resistance unit (Fig. 3-25). When the new switch is closed, a momentary surge of current flows through the resistance unit. Flow will continue until the voltage across the plates decreases to zero. At this point, the capacitor is completely discharged.

As mentioned, the characteristic of a capacitor to act initially like a short circuit when a sudden difference in circuit voltage is applied across its plates makes it suitable to temporarily store electrical energy that would otherwise damage electrical components. To illustrate this point, consider an ignition circuit (Fig. 3-26) in which a capacitor connects across the distributor contact points.

When the contacts separate, a high voltage is induced in the ignition coil primary winding because

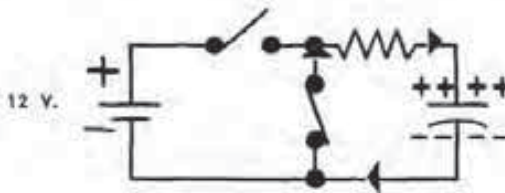


FIGURE 3-25
Capacitor voltage charge used to cause current flow through a resistance unit. (Courtesy of Delco Remy)

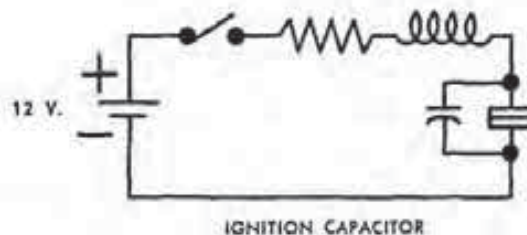


FIGURE 3-26
Ignition capacitor. (Courtesy of Delco Remy)



FIGURE 3-27
Symbol of a variable capacitor.

of self-inductance. This high voltage causes the capacitor plates to charge when the contacts first separate. The capacitor, in this manner, acts initially like a short circuit, and current flows into the capacitor to minimize arcing at the contact points.

Variable Capacitors. As mentioned, the fixed capacitor can be used in both electrical and electronic circuits. When used in electronic circuitry, the capacitor is a small ceramic unit with short wire leads that are soldered into a circuit.

Electronic circuitry can also use a *variable capacitor*, one in which its capacitance can be changed (Fig. 3-27). This is usually accomplished by changing or altering the distance between the plate areas.

Figure 3-28 illustrates a special leaf-type adjustable capacitor used exclusively in some electronic circuits. The variable capacitor, in this case, is used to *tune a circuit*, causing it to oscillate or vibrate at a certain frequency. In the example shown, the coil, resistor, and capacitor form what is called a basic *tank circuit*—one that will surge back and forth at a certain frequency if an alternating current signal is impressed across the input leads.

The variable capacitor, or tuner in this case, is charged until the circuit picks up the *tiny input signal* and begins to oscillate at that frequency. When the right frequency is reached, the circuit will be aided in one direction. Then, when the current stops flowing into the capacitor, it will begin discharging back out into the circuit in the other direction. If the unit is set at the wrong capacitance, the circuit vibrates too fast or too slow, and will be opened by the incoming signal. Circuits of this type are used to detect radio frequency.

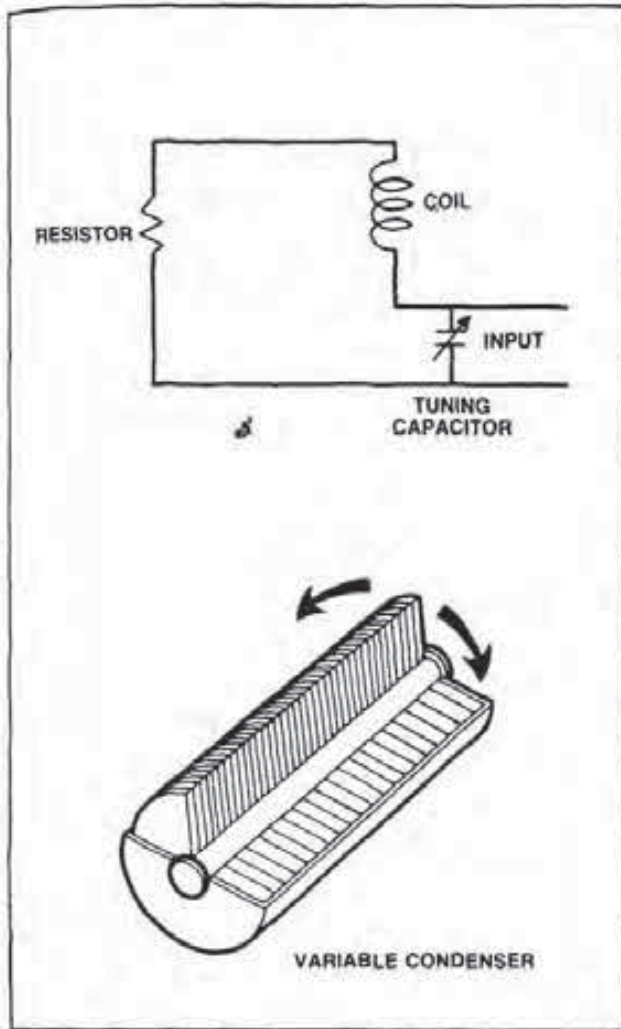


FIGURE 3-28
Variable capacitor and circuit. (Courtesy of Ford Motor Co.)

Printed Circuit Boards

Along with the transistor came another innovation, namely the printed circuit board. A *printed circuit* (PC) board provides a means of securing and connecting solid state electronic component circuits (Fig. 3-29). Due to the smaller component size of transistors, less strength is needed to support them physically and less of a support framework is necessary to contain the average circuit. Therefore, as the components got smaller, the need for a better way to cross-connect them on a chassis became more evident. As a result, the printed circuit started appearing wherever transistors were being used.

The typical circuit board is made of an insulating material. The underside of a board contains an etched conductor, which connects the various termi-

nals of the electronic components into the circuits. The circuits represent a map of conductors, flowing from component to component just as wire conductors do. The components are attached to the board terminal connectors soldered to the etched conductors at appropriate locations.

Rigid circuit boards are used in such components as ignition modules, voltage regulators, and microcomputers. Another type of printed circuit, a flexible, flat-conductor version, is used on many instrument panels.

Note: Printed circuit boards must be handled with care to avoid bending or physically damaging them. A loose electronic component or a cracked or damaged board will result in a nonfunctioning electrical circuit.

3-5 INTEGRATED CIRCUITS

The electronic devices presented so far have been individual components. Engineers classify these as *discrete devices* because each one is made separately with wire leads for connecting it into a given circuit. Most of the early solid state devices were of the discrete type, such as those used in alternator installations. A number of discrete devices are still used in many automobile systems, especially in the ignition, charging, and headlight circuits that require large amounts of electrical power.

While these discrete devices are quite small, they are enormous compared to the modern, sophisticated integrated circuit. An *integrated circuit* (IC) is a very complex electronic circuit that can contain thousands of transistors and other devices. These are all formed on a tiny $\frac{1}{4}$ -by- $\frac{1}{4}$ -inch chip of silicon that is about the thickness of a thumbnail. Consequently, the circuits and electronic devices are usually so small they cannot be examined without the help of a microscope (Fig. 3-30).

Through the use of IC chips, the size and power requirements of electronic components have been drastically reduced. Moreover, the reliability of integrated circuits is much greater than any other type of electronic construction.

Although integrated circuits were expensive to produce in the 1960s and early 1970s, their cost is now only a fraction of what it was then. This is the result of improvements made in construction and mass production processes. Finally, integrated circuits are found in automotive electronic voltage regulators, ignition modules, microcomputers, instrument clusters, and voice alert and navigation systems.

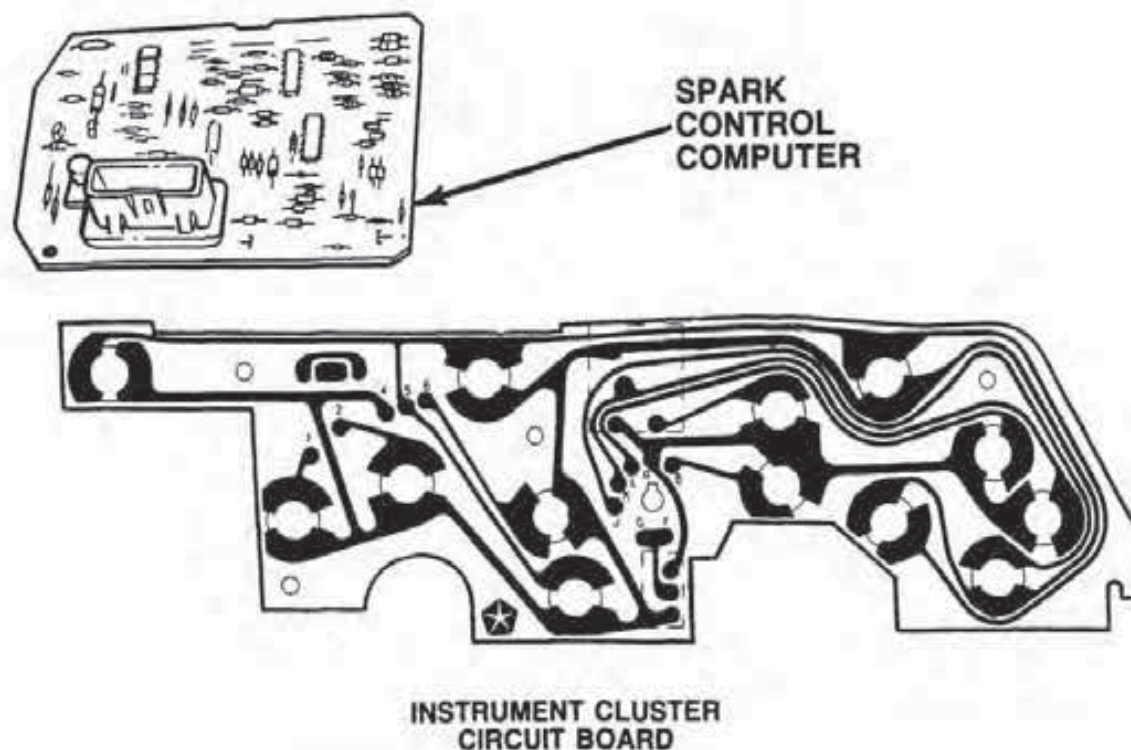


FIGURE 3-29
Typical circuit boards. (Courtesy of Chrysler Motors Corp.)

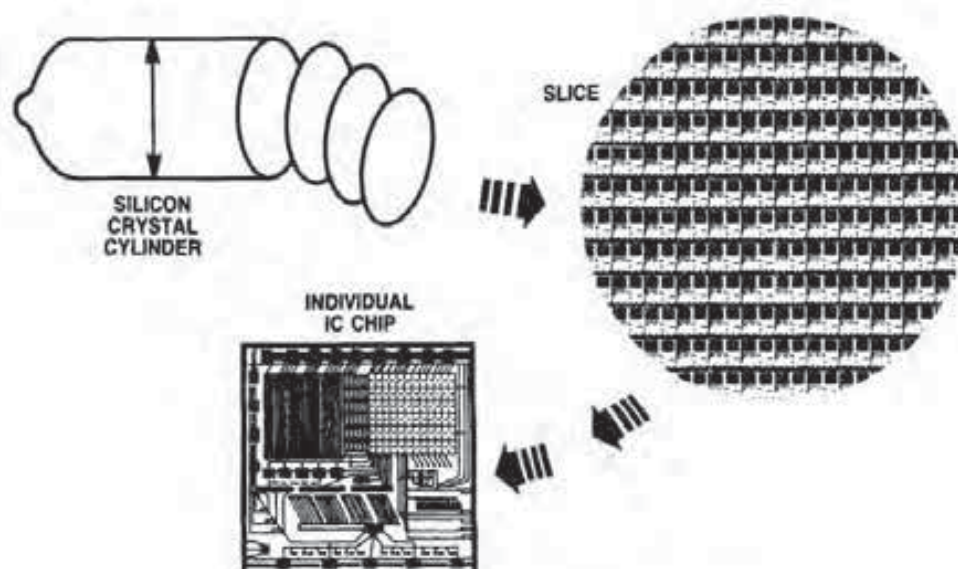


FIGURE 3-30
Individual IC chip. (Courtesy of Chrysler Motors Corp.)

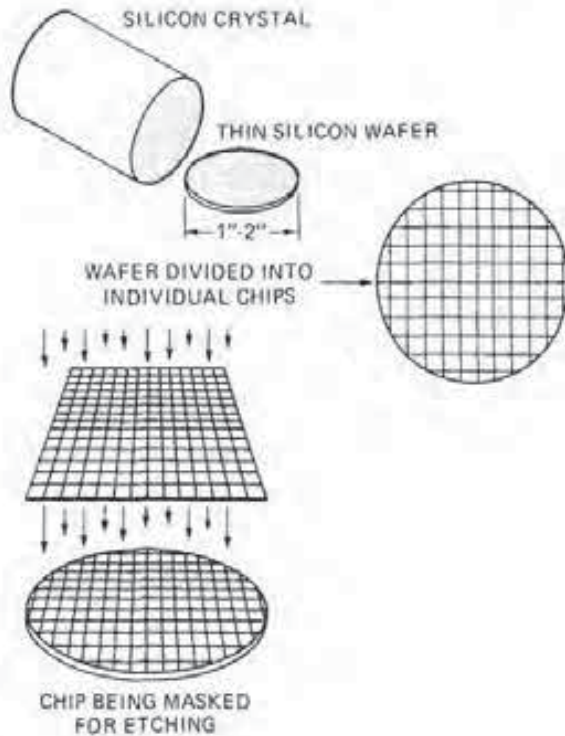


FIGURE 3-31
Cutting and screening the wafer.

Typical Manufacturing Process

Integrated circuits are made by photochemically etching circuit patterns on a silicon wafer and then depositing various conductive and insulating materials through a diffusion process. This actual procedure often requires more than 100 separate steps. However, the following is a simplified version of the process to provide you with a basic idea of how it is done.

To begin with, a silicon crystal of the desired type is grown in a very special environment. For our purposes, the crystal is the P-type and will be used to develop a high speed N-MOS chip.

After a one-inch to two-inch wafer is sliced off, its surface is divided into separate areas, each of which will be a separate chip (Fig. 3-31). This way, 25 or more chips can be made at the same time on a two-inch slice. Next begins a number of steps that involve using a screen or mask to control the etching process and the application of chemical and gases to the surface of the silicon wafer.

To illustrate the first part of this process, examine Fig. 3-32. In this diagram, you see the chip area for a single N-MOS transistor located on the wafer. Diagram (a) shows a cross section of the P-type silicon wafer as it appears after being sliced off

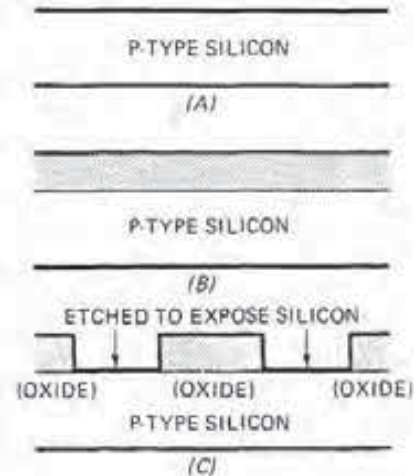


FIGURE 3-32
Forming the drain and source areas of the transistor.

the roll. Diagram (b) illustrates its appearance after the application of an oxide layer to one surface of the wafer. Diagram (c) shows the use of masks to photochemically etch the oxide to remove places on it that will become the drain (collector) and source (emitter) of the transistor.

The exposed areas are now treated with a gas mixture of atoms and subjected to a high temperature. This process changes the makeup of these areas into N-types within the P-type structure (Fig. 3-33a).

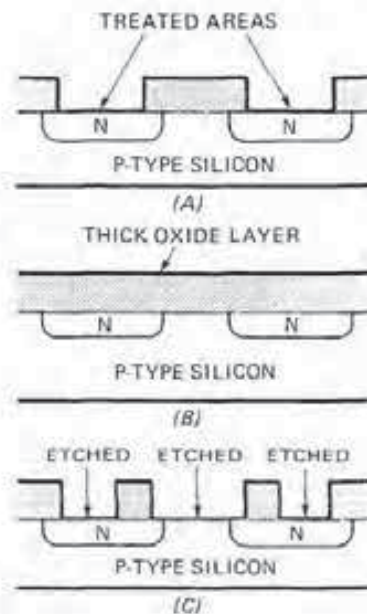


FIGURE 3-33
Creating the N-type areas in the P structure.

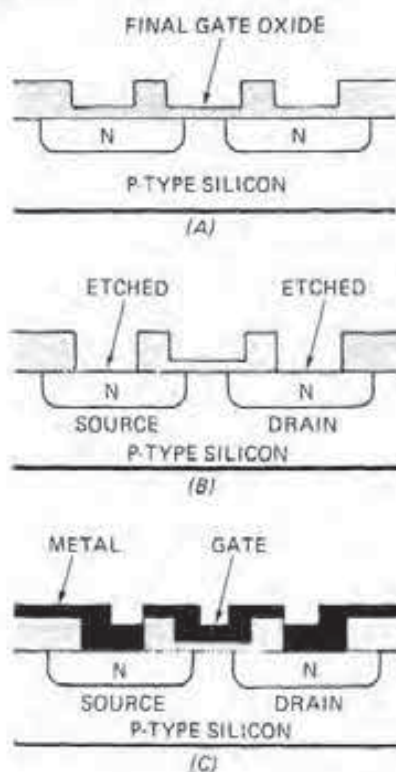


FIGURE 3-34
Completing the source, drain, and gate areas.

A thick oxide layer is then applied quickly to stabilize the entire surface area and protect it from contamination (Fig. 3-33b). This process is going on in every location and on every chip on the entire wafer.

For a second time, the oxide layer is selectively etched away (Fig. 3-33c). This action exposes the N areas and the area between them.

Oxide is once again applied quickly, but in a thinner layer (Fig. 3-34a). This coating is necessary to seal the area under the gate only. However, one area cannot be coated without layering the others as well. The next step is to etch away the oxide for the last time, exposing the N areas (Fig. 3-34b).

As a final step, metal contact material is applied to the N areas and the gate (Fig. 3-34c). Notice in diagram (c) that neither the source nor the drain contact material touch the gate.

Operation of an IC Transistor

Now that we have a completed IC transistor, let's see how it operates (Fig. 3-35). In order for electrons to flow between the source and the drain, a positive charge must be applied to the gate directly over the

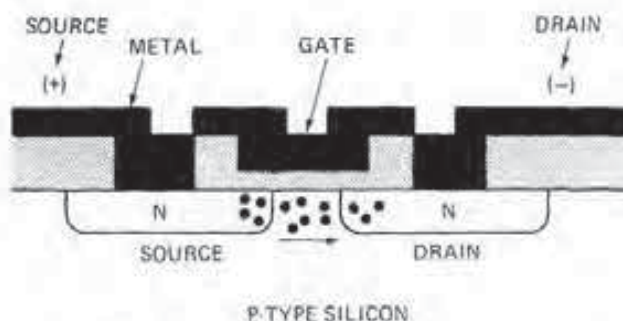


FIGURE 3-35
Operation of an IC transistor.

space shown. With the positive charge applied, electrons mass at the gap between the source and the drain. Current flows between the two, toward the positive charge at the drain.

Memory Cells

A *memory cell* is a device designed to store information electronically. Figure 3-36 illustrates a memory cell that has many of the same features as the IC transistor just discussed. The one main difference is that the memory cell has a floating gate.

If a small positive voltage is applied to the memory cell drain and a large positive charge to the control gate, electrons will be drawn up into the floating gate as shown in the example. The presence of these gate electrons represents either an off (0) or on (1) signal.

The floating gate electrons remain in place even after the power is turned off. In other words, the cell remembers the signal. The cell is erased by applying a large negative charge to the control gate and a small positive voltage to the drain.

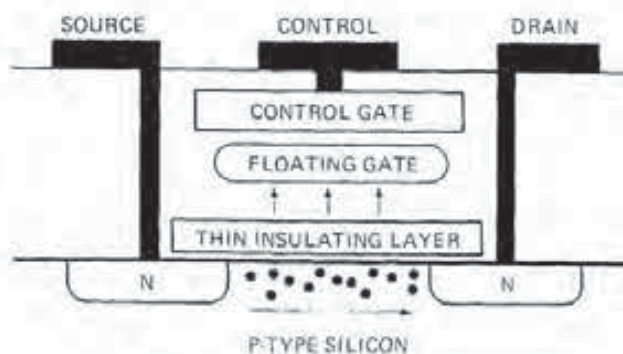


FIGURE 3-36
Memory cell design.

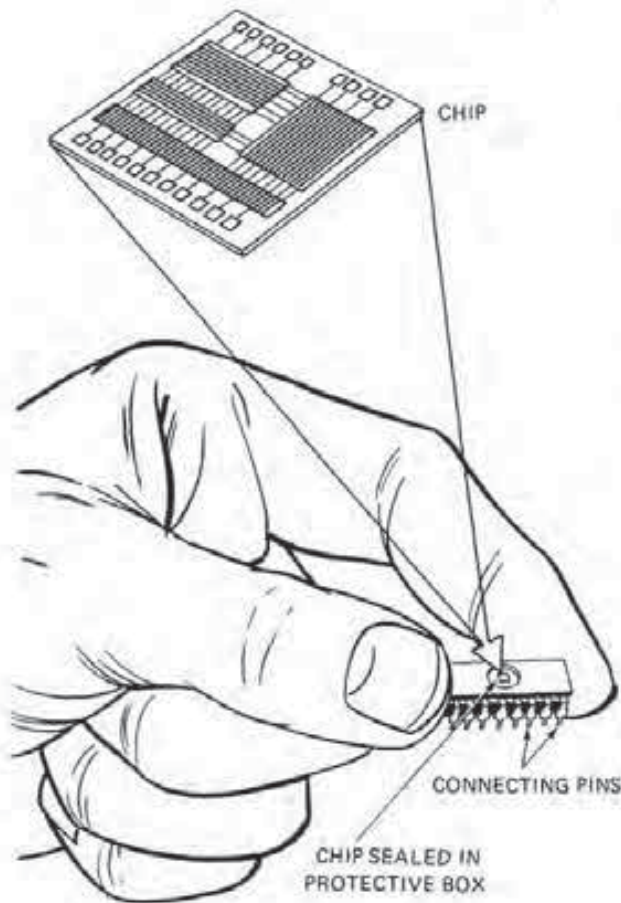


FIGURE 3-37
Typical IC package installation.

Typical IC Installation

After the IC is formed, it is installed into a package device similar to the one shown in Fig. 3-37. The protective box has rows of small metal connecting pins along its edges. These provide the electrical connections when the assembly is plugged into a larger circuit.

If an IC is combined in a package with one or more discrete devices, the result is a *hybrid circuit*. Many automobile systems have used and continue to use this kind of circuit. But as more and more functions are packed into a single IC, the need for discrete diodes, resistors, and capacitors is decreasing.

CHAPTER REVIEW

The following two sections will assist you in determining how well you remember the material contained in this chapter. If you cannot complete a statement or question, refer back to the section marked in brackets that contains the material.

SELF-CHECK

1. What is the difference between a circuit with a discrete device and the IC [3-5]?
2. In relation to semiconductors, what is covalent bonding [3-1]?
3. Explain the functions of a capacitor [3-4].

4. Describe what is meant by forward and reverse biasing [3-2].
5. Explain the functions of a transistor [3-3].

REVIEW

1. What is the name for the electronic device that can store information [3-5]?
 - a. memory cell
 - b. IC transistor
 - c. capacitor
 - d. transducer

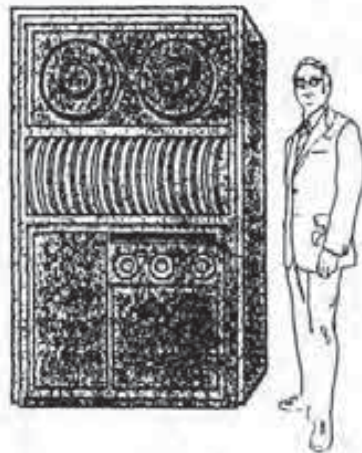
2. What is the term used to designate the semiconductor doping material [3-1]?
 - a. dielectric
 - b. impurity
 - c. bonding agent
 - d. covalent material
3. Leaf-type capacitors are found in what type of circuit [3-5]?
 - a. electric
 - b. electronic
 - c. hydraulic/electric
 - d. hydraulic/electronic
4. The movement of holes in a semiconductor can be compared to what type of current flow [3-1]?
 - a. conventional
 - b. electron
 - c. forced
 - d. magnetic
5. How many transistors can be formed on a single IC chip [3-5]?
 - a. one
 - b. five
 - c. ten
 - d. more than ten
6. An N material has less [3-1]
 - a. electrons.
 - b. holes.
 - c. protons.
 - d. neutrons.
7. The ability of a device to store an electrical charge is called [3-4]
 - a. voltage.
 - b. capacitance.
 - c. current.
 - d. charging.
8. What is the name given an electronic check valve [3-2]?
 - a. memory cell
 - b. LED
 - c. transistor
 - d. diode
9. What is placed between the plates of a capacitor [3-4]?
 - a. insulator
 - b. dielectric
 - c. both a and b
 - d. neither a nor b
10. A diode contains what type(s) of semiconductor material [3-2]?
 - a. N-type
 - b. P-type
 - c. both a and b
 - d. neither a nor b
11. What is transistor gain [3-3]?
 - a. the ratio between input and output power
 - b. the ratio between the number of different current carriers in the material
 - c. the ratio between base and emitter power
 - d. the ratio between base and collector power
12. If a diode is forward biased, what is the direction of hole flow [3-2]?
 - a. - to +
 - b. + to -
 - c. either a or b
 - d. neither a nor b
13. What portion of a transistor is used to turn the device on and off [3-3]?
 - a. collector
 - b. emitter
 - c. base
 - d. both a and b
14. A transistor is made from what type(s) of semiconductor material [3-3]?
 - a. two layers of P and one of N
 - b. two layers of N and one of P
 - c. both a and b
 - d. neither a nor b
15. A zener diode controls electron flow in how many directions [3-2]?
 - a. one
 - b. three
 - c. four
 - d. two

AUTOMOTIVE MICROCOMPUTERS

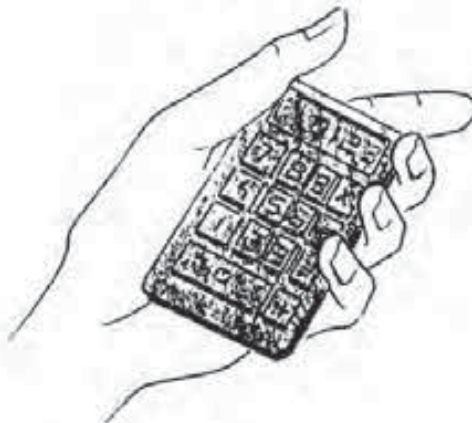
OBJECTIVES

After reading and studying this chapter, you will be able to

- describe the function and basic design of a microcomputer.
- explain the difference between analog and digital input signals.
- describe the design and operation of a potentiometer, thermistor, and voltage-generating input sensors.
- explain how analog signals are converted to digital.
- describe the three types of computer memory.
- explain the function and design of computer output devices.
- describe how a microcomputer controls both open and closed loop engine operation.



TYPICAL COMPUTER OF THE
1950'S



HAND-HELD
CALCULATOR

FIGURE 4-1
Early computer and a microcomputer within a calculator.
[Courtesy of Ford Motor Co.]

Ever since the first electronic calculators were built in the 1940s, the computer has proven itself to be an extremely flexible and reliable tool. With the advances in computer technology over the last 20 years, this tool has been used to perform an increasing number of tasks, including many on the automobile.

The first units were so large that one computer filled an entire room. These computers used vacuum tubes to control the flow of electrical signals. Moreover, a single computer contained thousands of these tubes. Consequently, these systems produced large amounts of heat and were prone to breaking down.

As mentioned in the last chapter, today it is possible to produce miniature electronic circuits with the same amount of computing power. These miniature devices are called microcomputers. While large computers are used in business, industry, government research centers, and university laboratories, microcomputers are now a component part of microwave ovens, hand-held calculators, wrist watches, and automotive engine control systems.

A common hand-held calculator now has the same computing power as a large computer of the 1950s (Fig. 4-1). However, the microcomputer in the calculator multiplies five times faster, adds ten times quicker, uses $\frac{1}{100,000}$ the amount of power, and requires $\frac{1}{16,000}$ as much space as this full-size unit.

4-1 MICROCOMPUTERS

A *microcomputer* is an electronic device that controls other electrical or mechanical units either to perform work or provide information. A microcomputer performs work by controlling the operation of such automotive components as solenoids and relays. The unit provides information by controlling a display such as an electronic speedometer or fuel gauge. In any case, the microcomputer performs these functions by receiving, processing, and sending out electrical voltage signals.

The microcomputer is often referred to as the brains of an electronic engine control system. In this situation, the device receives information on vehicle operation and then decides how and when vehicle performance should be changed. Of course, a microcomputer does not think any more than a solenoid or relay. The microcomputer just passes small electrical voltage signals from one circuit to another.

However, these signals pass through the microcomputer circuitry at an extremely rapid rate and in a predictable and logical manner. In fact, the typical unit is capable of receiving information, making a decision, and acting on it in less than one-tenth of a second. Because of this, the microcomputer is capable of controlling electrical and mechanical devices with great precision.

Computers, Microcomputers, Processors, and Microprocessors

When dealing with computerized engine control systems, a number of terms have become part of the language, including computer, microcomputer, proc-

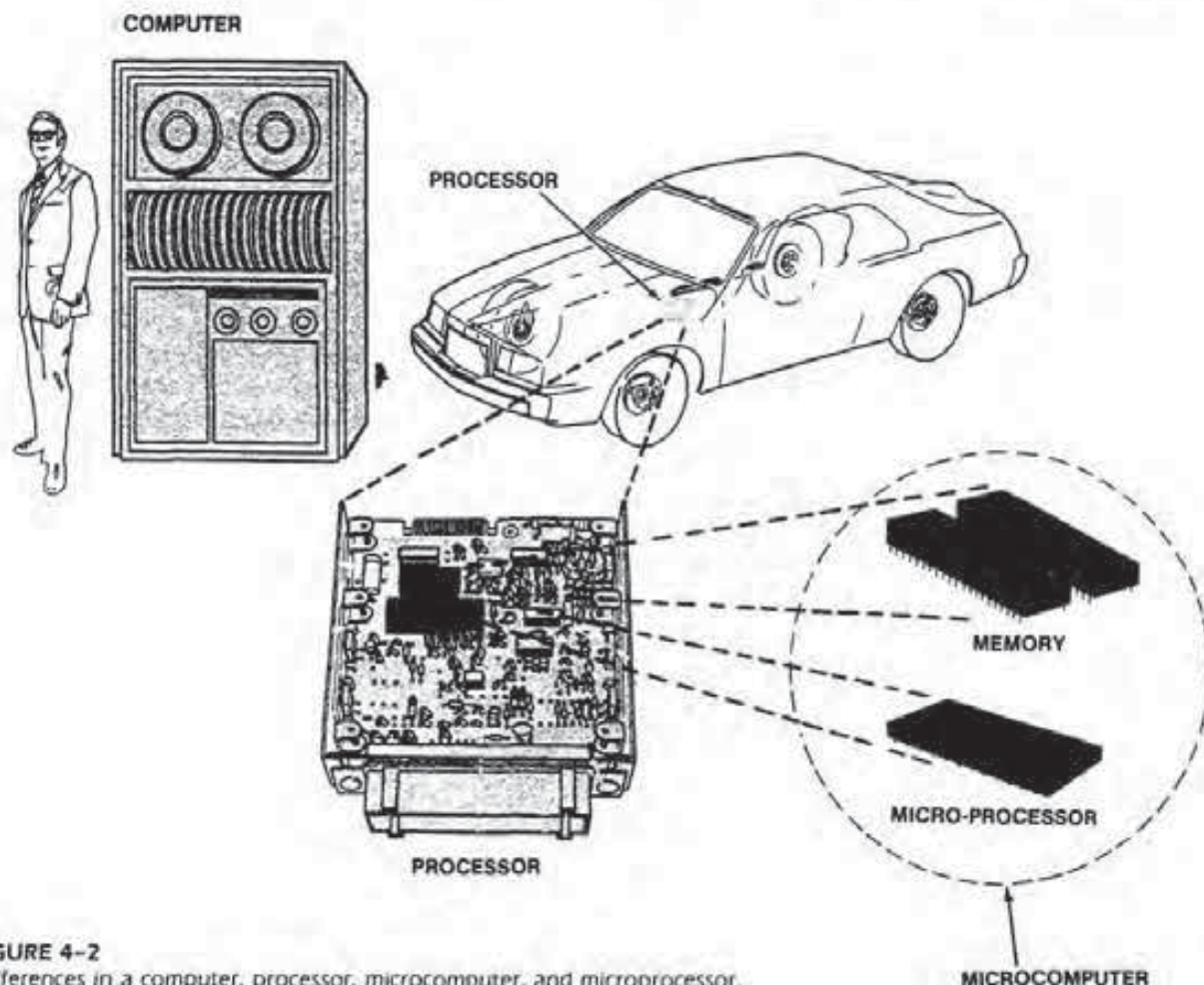


FIGURE 4-2
Differences in a computer, processor, microcomputer, and microprocessor.
(Courtesy of Ford Motor Co.)

essor, and microprocessor. Unfortunately, even experts have a difficult time agreeing on just what these terms mean. In other words, a computer to one person is a microcomputer to another. Hopefully, the definitions in this section will clear up the meaning of these terms.

A *computer* is a large assembly of electronic components (Fig. 4-2). A computer is not portable, and it is used to handle vast amounts of information or to control large operations. On an automotive assembly line, for example, computers are used to control robotic assembly equipment.

A *microcomputer*, on the other hand, is much smaller. In addition, the unit is portable and can easily fit into an automobile. Normally, the automobile microcomputer is built into a small box known as the *processor*. When the lid is taken off the processor, you can see a number of electronic parts inside it that make up the microcomputer.

The *microprocessor* is the heart of the microcomputer. This unit performs the calculations and

controls microcomputer operation.

Automotive processors, as used with engine control systems, are also called a number of other names by various manufacturers, including electronic control unit (ECU), electronic control module (ECM), electronic control assembly (ECA), and spark control computer (SCC).

Microcomputer Types

A microcomputer may be either analog or digital. An *analog microcomputer* operates on signals of varying voltage levels. The *digital microcomputer* requires voltage signals with a constant value.

The digital microcomputer is generally considered to be more accurate. Therefore, almost all electronic engine control microcomputers are of the digital type. A few notable exceptions are the early Cadillac electronic fuel injected processor and the early Chrysler spark control computer.

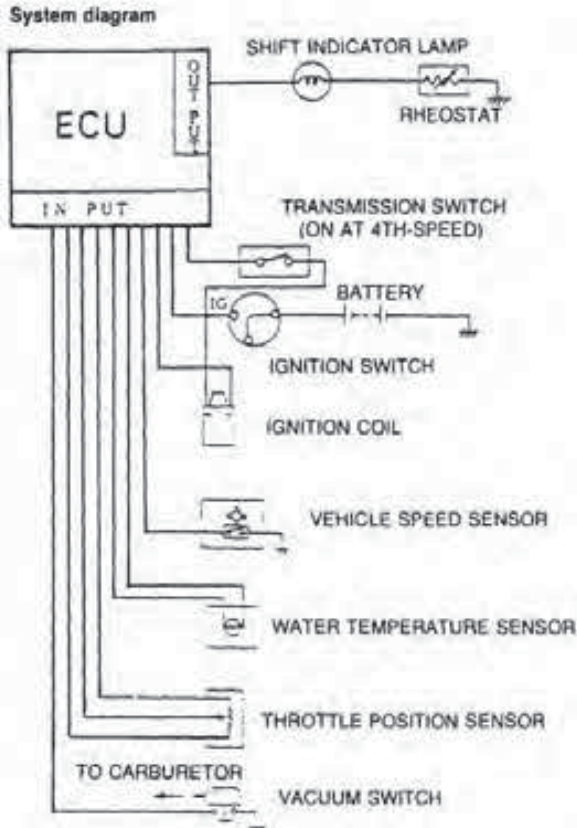


FIGURE 4-3
A number of sensors and switches provide input signals to the microcomputer. (Courtesy of Chrysler Motors Corp.)

4-2 MICROCOMPUTER INPUT SIGNALS

In order for the engine control microcomputer to perform its function, it has to receive a number of input signals from sensors and switches (Fig. 4-3). These signals provide information that the microcomputer will use in its decision-making process. The signals can be either analog or digital, both of which have distinct characteristics.

Analog Signals

An *analog signal* is one that varies continuously. This means that the signal can be any voltage within a given range. In other words, at any point in time, the voltage value of the analog signal may be high, low, or any value in between. In an engine control system, the analog signal provides information to the microcomputer about an operating condition that is constantly changing over a certain range.

Figure 4-4 illustrates an example of an analog signal. The signal begins at 0 volts and then increases toward +5 volts. After reaching a maximum of +5 volts, the signal begins to decrease until it drops to 0 volts again. By graphing the change in voltage, a *DC analog waveform* is created.

Most automotive sensors produce a DC analog waveform. The only exception to this is a magnetic sensor such as a distributor pickup coil. It produces an *AC analog waveform* (Fig. 4-5). In this situation, voltage is induced in the pickup coil first toward the positive and then toward the negative end, as shown.

Digital Signals

A *digital signal* is one that has only two values. That is, the voltage is either on or off (Fig. 4-6). The graph in the illustration shows how the voltage values change as the switch is operated. The graph begins with the signal off, which indicates the voltage is at 0 volts.

When the switch turns the signal on, the graph shows the voltage value increase to 5 volts. But note that the change from 0 volts to 5 volts is very abrupt. Turning the switch off again causes an abrupt drop in voltage from 5 volts to 0 volts.

Thus, by graphing the changes in voltage, the *DC digital waveform* is created. Because of the abrupt changes in voltage, the final waveform has sharp corners and looks like a square. For this rea-

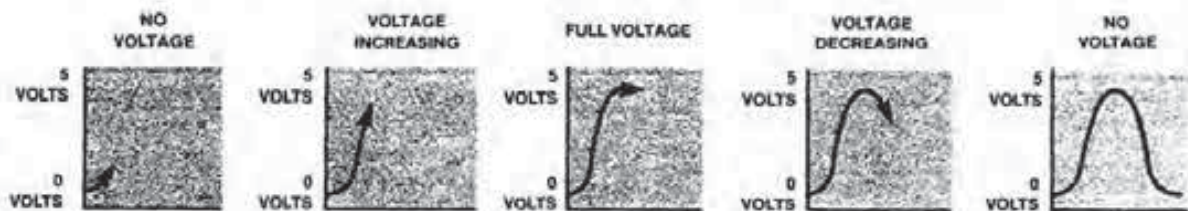


FIGURE 4-4
DC analog signal. (Courtesy of Ford Motor Co.)

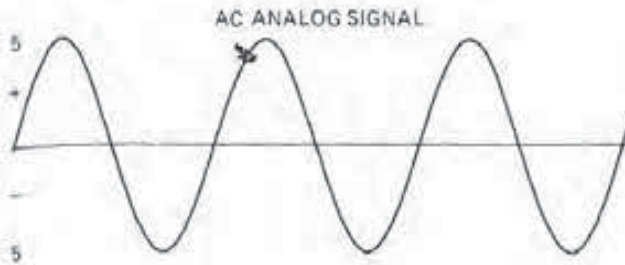


FIGURE 4-5
AC analog signal.

son, this type of waveform is also called a *square wave*.

By turning a switch either on or off rapidly, the waveform of the signal produced begins to look like the one illustrated in Fig. 4-7. Notice that the switch is off for slightly over the first second, on for part of the second, and off a portion of the third. But during the fourth and fifth seconds, the switch remains on; and for the sixth and seventh seconds, the switch is turned off.

The only engine sensor that can by itself produce a digital signal is one that uses a Hall-effect switch, such as Ford's profile ignition pickup (PIP). However, microcomputer integrated circuitry actually consists of thousands of tiny switches. As these are turned on and off, they can produce waveforms that are similar to the one shown in Fig. 4-7.

Binary Code

Because a digital signal varies between two values, the state of the signal can be described as being either on or off, or the voltage can be described as either high or low. Moreover, digital signals can be assigned a numeric value. For example, a signal that is on can be represented by 1 (one) and an off signal by 0 (zero).

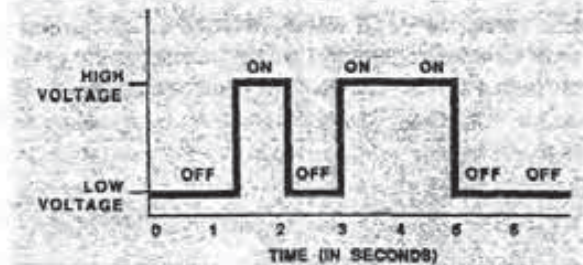


FIGURE 4-7
Typical digital waveform. (Courtesy of Ford Motor Co.)

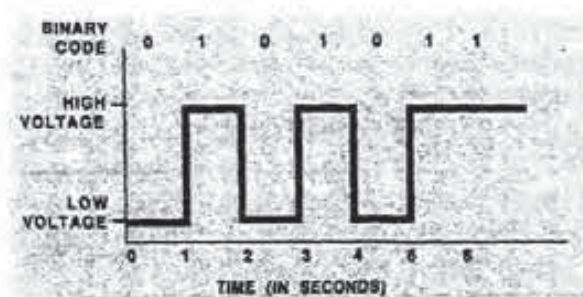


FIGURE 4-8
Binary code. (Courtesy of Ford Motor Co.)

This system of assigning a numeric value to voltage signals is known as *binary coding* (Fig. 4-8). The word *binary* means two values. The two values in the binary code system are 1 and 0.

Furthermore, each 0 and each 1 is known as a *BIT* of information from the term *binary digit*. Eight bits together are known as a *BYTE*, which forms a word in computer language. A word, therefore, contains any combination of eight binary code bits: eight 1s, or five 1s and three 0s, or two 1s and six 0s, and so on.

Binary code is used inside a microcomputer and between it and any electronic device that under-

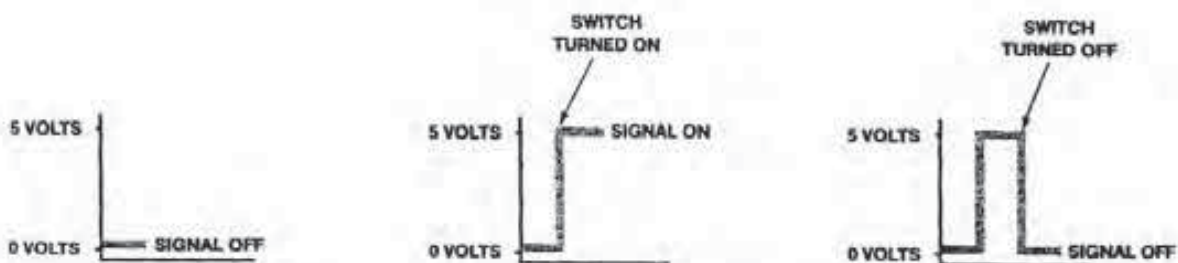


FIGURE 4-6
DC digital signal. (Courtesy of Ford Motor Co.)

stands binary code. Letters, numbers, and conditions are then represented in this binary code by a given series of 1s and 0s, and then transmitted as such. By stringing together thousands of bits, microcomputers can communicate and store an infinite variety of information. Therefore, any data that can be represented in binary code can be processed by the microcomputer.

Since the microcomputer is very good at working with numbers, it is able to perform calculations at an extremely rapid rate. Information is transmitted in binary code by switching voltage on and off at a very rapid rate (i.e., thousands of times per second).

4-3 MICROCOMPUTER INPUT SIGNAL SOURCES

As mentioned, in order for a microcomputer to perform its function, it must have input information. Sensors in an engine control system provide this input. Automotive engine sensors are typed by the manner in which they relay input signals to the microcomputer. The most common types of sensors are the potentiometer, switch, thermistor, detonation, and voltage-generating.

Reference Voltage

Before discussing sensors, it is important to understand what reference voltage is and how it is produced. *Reference voltage* is a constant voltage that is supplied by the microcomputer to some of the sensors. These sensors must have this reference voltage in order to produce an input signal. The sensor types that use reference voltage are the potentiometer, switch, and thermistor.

A voltage regulator inside the microcomputer supplies the reference voltage (VREF) of between 5 volts and 9 volts to these sensors (Fig. 4-9). The sensors, in turn, change the voltage level in proportion to some factor relating to engine operation. The resulting input signal is then relayed back to the microcomputer for processing.

Potentiometer

The *potentiometer* is a sensor that converts mechanical motion to a voltage value. The potentiometer is used to signal the position of such components as the throttle and exhaust gas recirculation (EGR)

valves or the movement of a diaphragm operated by atmospheric pressure or a vacuum.

Typical potentiometer-type sensors in use in engine control systems are the throttle position sensor (TPS), vane airflow sensor, and EGR valve position sensor.

The typical potentiometer-type TPS consists of a resistance material, wiper, and three connectors. Full reference voltage is supplied to the first connector, which is located on one end of the resistance material. The second connector provides a signal return (ground) for the resistor through the processor. The third signal voltage connector is located on the end of the wiper arm (see Fig. 4-9). The tip of the wiper contacts the resistor material.

As the wiper arm moves along the resistance material in response to changes in throttle valve angle, the voltage at the signal connector will increase or decrease. For instance, with the throttle plate fully open (i.e., at 80 to 85 degrees) the voltage signal to the processor is nearly 5 volts, or reference voltage (Fig. 4-10). However, as the throttle plate closes (angle decreases), the signal voltage drops until it reaches about 0.5 volt at closed throttle (i.e., a 0 degree angle).

In the throttle position sensor and in the other potentiometer-type units, the signal voltage increases or decreases by changing the resistance between the reference voltage connector and the wiper arm connector. With the throttle plate fully open, for example, the wiper assumes a position on the resistor that produces the least amount of resistance between the two connectors. At closed throttle, on the other hand, there is maximum resistance between the two connectors. The total resistance then changes between the two points as the wiper moves along the resistor.

Switches

A switch is also frequently used to signal the microcomputer, indicating the position of a component. However, in this case the signal voltage has only two values, high and zero, indicating that the switch is either closed or open.

Typical examples of switches used for this purpose include the neutral safety switch, the brake on/off switch, the clutch engaged switch, the key-on switch, and the air conditioning clutch switch.

Figure 4-11 illustrates a typical circuit of a switch-type sensor, a clutch engaged switch (CES). In this installation, an electrically conductive blade moves between two contacts. When the switch is

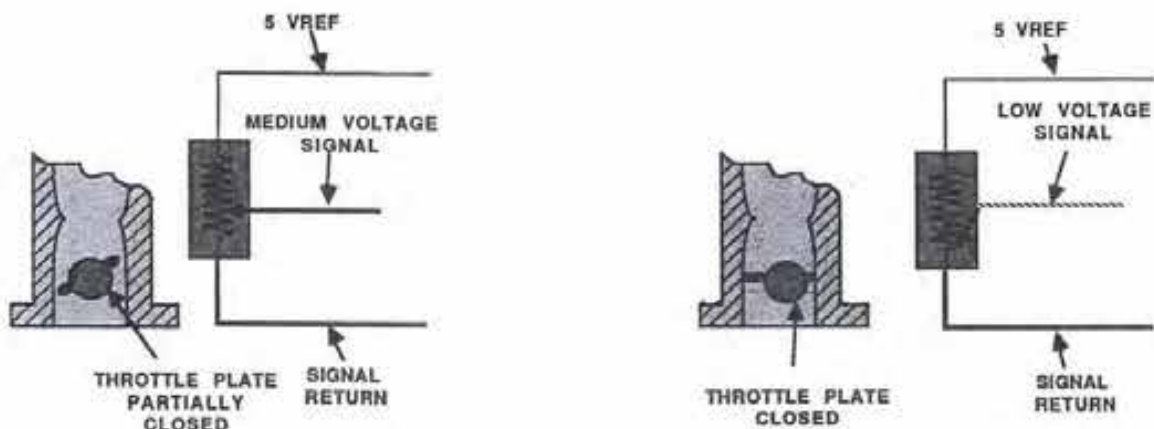
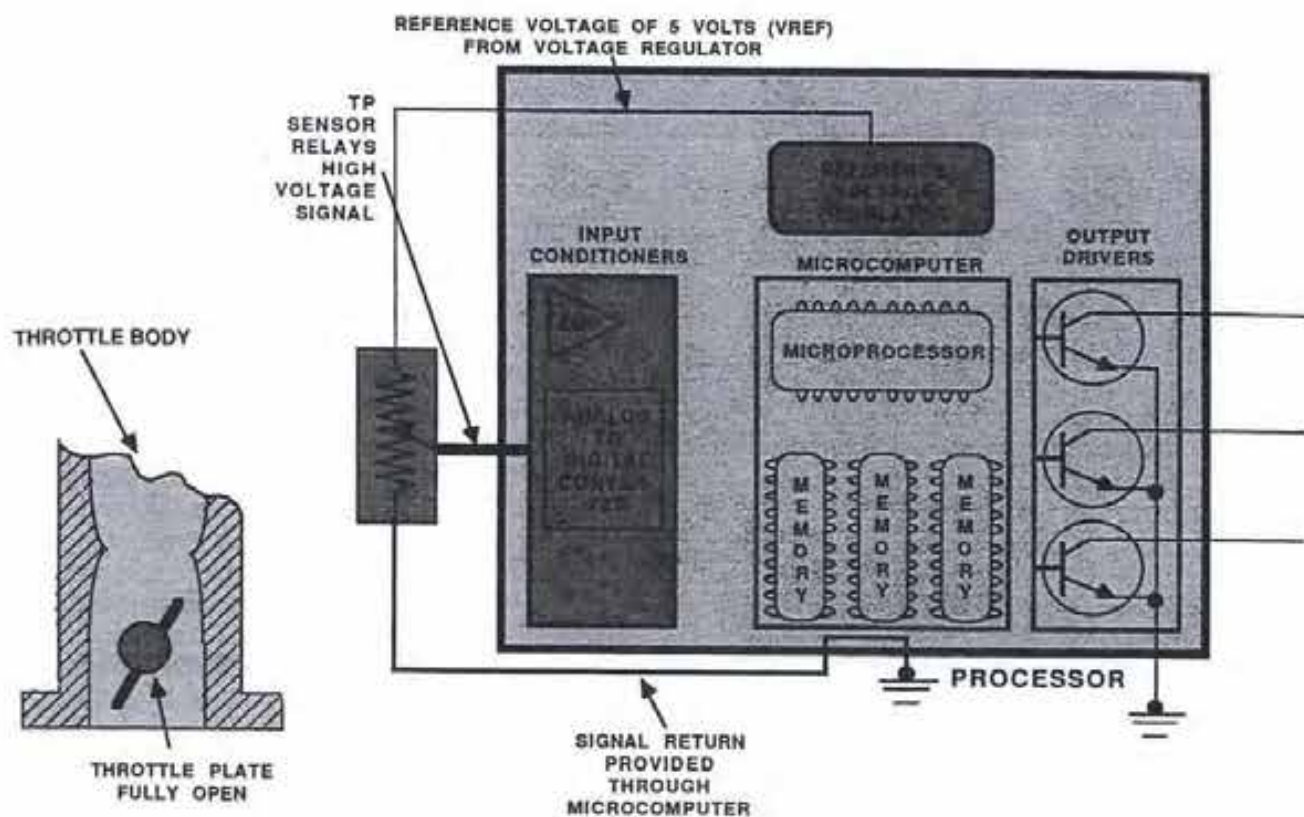


FIGURE 4-9
Schematic of the reference voltage source and a throttle position sensor. (Courtesy of Ford Motor Co.)

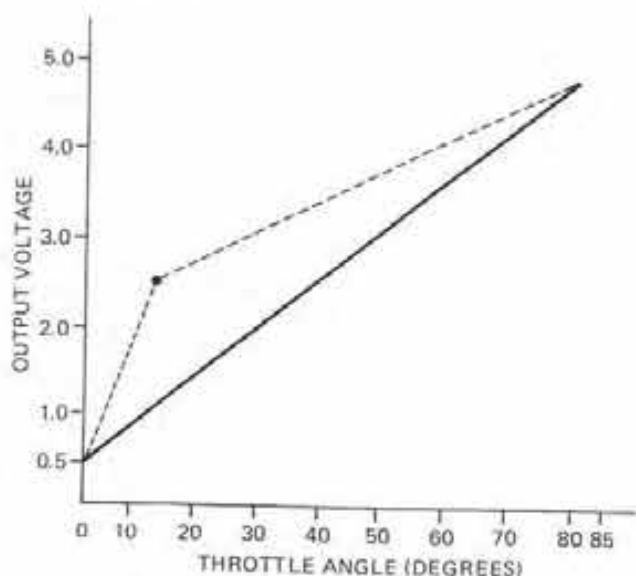


FIGURE 4-10
TPS voltage curve.

closed, the blade touches both contacts and current flows through the switch. In this case, the signal voltage to the microcomputer will be less than one volt because current flows through the switch to ground at the processor.

When the clutch pedal is released, the CES switch opens, as shown in Fig. 4-11. In this case, current cannot flow through the switch to the processor ground. Consequently, current flows through the signal voltage connector at a potential of nearly five volts.

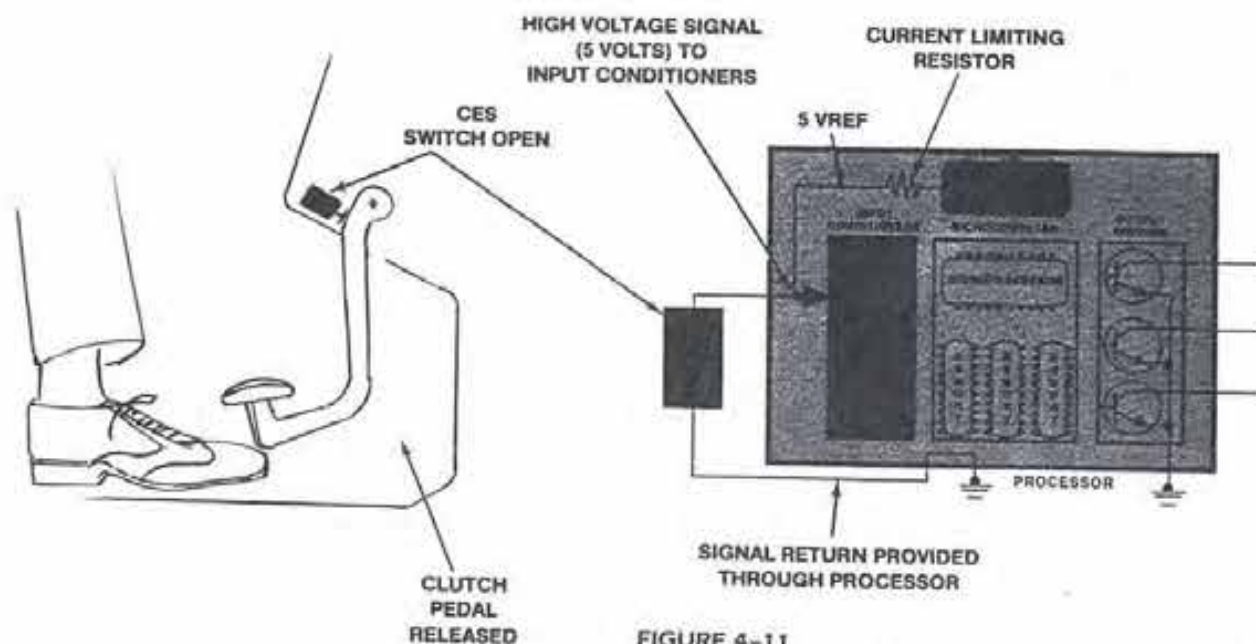


FIGURE 4-11
Typical switch schematic. (Courtesy of Ford Motor Co.)

Thermistors

A *thermistor-type sensor* is a device that converts temperature into a voltage signal. That is, the unit develops a voltage signal in proportion to changes in temperature. A thermistor device is made of a semiconductor material, the resistance of which varies as its temperature increases or decreases. In other words, the thermistor is a form of variable resistor. As shown by the curve in Fig. 4-12, the resistance of the thermistor decreases as its temperature goes up. Conversely, its resistance increases as the temperature decreases.

A thermistor-type sensor is therefore used to measure such things as engine coolant, air cleaner, intake manifold, or passenger compartment temperatures. Typical thermistor-type sensors are used in computerized engine control systems to measure engine coolant temperature, charge temperature, and vane air temperature.

Figure 4-13 is a schematic of an engine coolant temperature (ECT) sensor circuit. Notice the ECT is represented on the diagram by the variable resistor symbol. Moreover, like any type of thermistor, the ECT has two connections. The top connection provides the reference voltage from the processor; a ground circuit is provided through the processor via the lower connector.

A special signal line branches off the reference voltage line to provide the ECT input signal back to the processor. As the resistance of the thermistor

increases or decreases, this input signal changes. The microcomputer then uses this voltage signal to determine changes in engine temperature.

When the engine is cold, the resistance of the ECT sensor is high (see Fig. 4-13). As a result, a high voltage input signal is routed back to the processor. But as engine temperature increases, the resistance of the ECT sensor decreases, and more current flows through the sensor to ground. This action decreases the ECT input signal to the processor (Fig. 4-14).

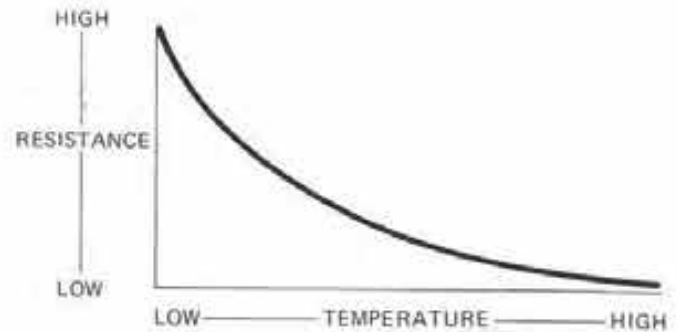


FIGURE 4-12 Thermistor temperature versus resistance curve.

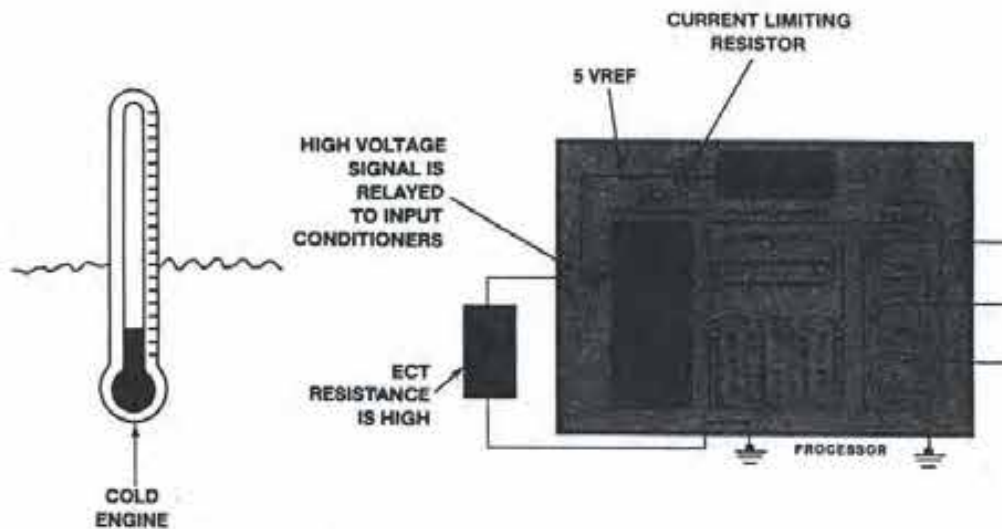


FIGURE 4-13 Typical engine coolant temperature (ECT) circuit with the engine cold. (Courtesy of Ford Motor Co.)

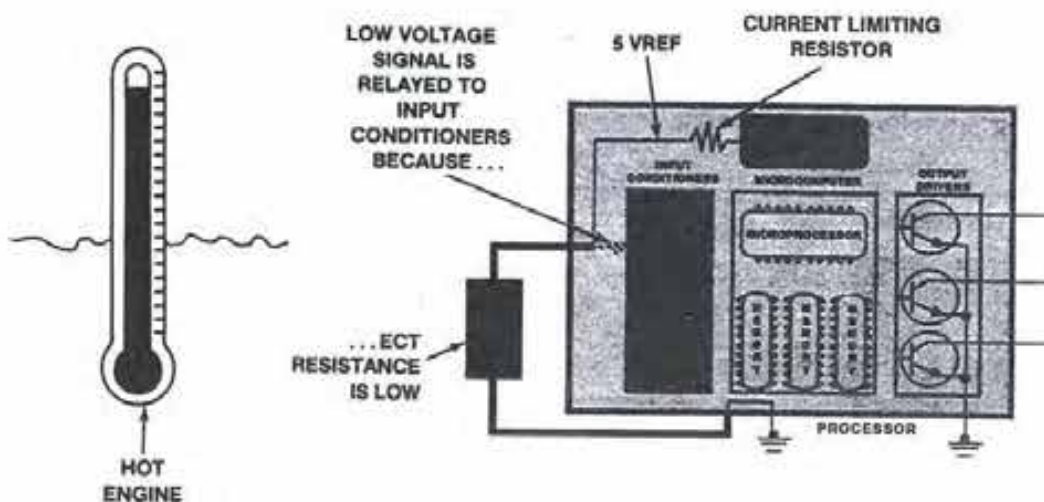


FIGURE 4-14 Typical ECT circuit with the engine hot. (Courtesy of Ford Motor Co.)

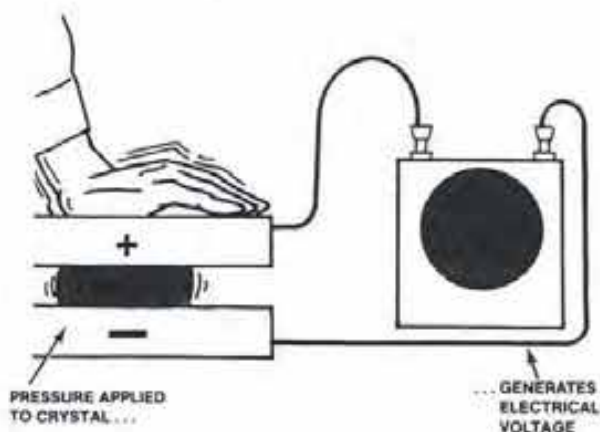


FIGURE 4-15
Design and operation of a piezo-electric sensor. (Courtesy of Ford Motor Co.)

Voltage-Generating Sensors

A *voltage-generating sensor* is not supplied with a reference voltage. Instead, the sensor generates its own signal for use by the processor. This type of sensor uses a variety of means to create the input voltage signal. In some of these sensors, a certain type of quartz crystal is used to generate voltage. Others utilize electrically conductive materials or electromagnetic principles to generate the voltage.

The types of devices that are voltage generating include the detonation sensor, exhaust gas oxygen sensor, distributor magnetic pickup sensor, and Hall-effect switch.

Detonation Sensors

A *detonation sensor* is a *piezo-electric device* that converts vibration or motion into an electrical voltage. This type of sensor is commonly used to monitor the vibrations resulting from engine detonation, or spark knock.

A typical piezo-electric sensor consists of a special quartz crystal sandwiched between two electrically conductive electrodes (Fig. 4-15). As pressure is applied to the crystal, a voltage is generated between the two electrodes.

Figure 4-16 illustrates this device as it appears in a schematic of a detonation or knock sensor. The knock sensor threads into the engine block or intake manifold where it can detect engine vibrations. (The engine block or intake manifold also forms the sensor ground return circuit.) The voltage signals produced by the sensor as a result of these vibrations are then relayed back to the processor in the form of voltage signals.

The typical engine produces many kinds of vibrations during normal engine operation. For this

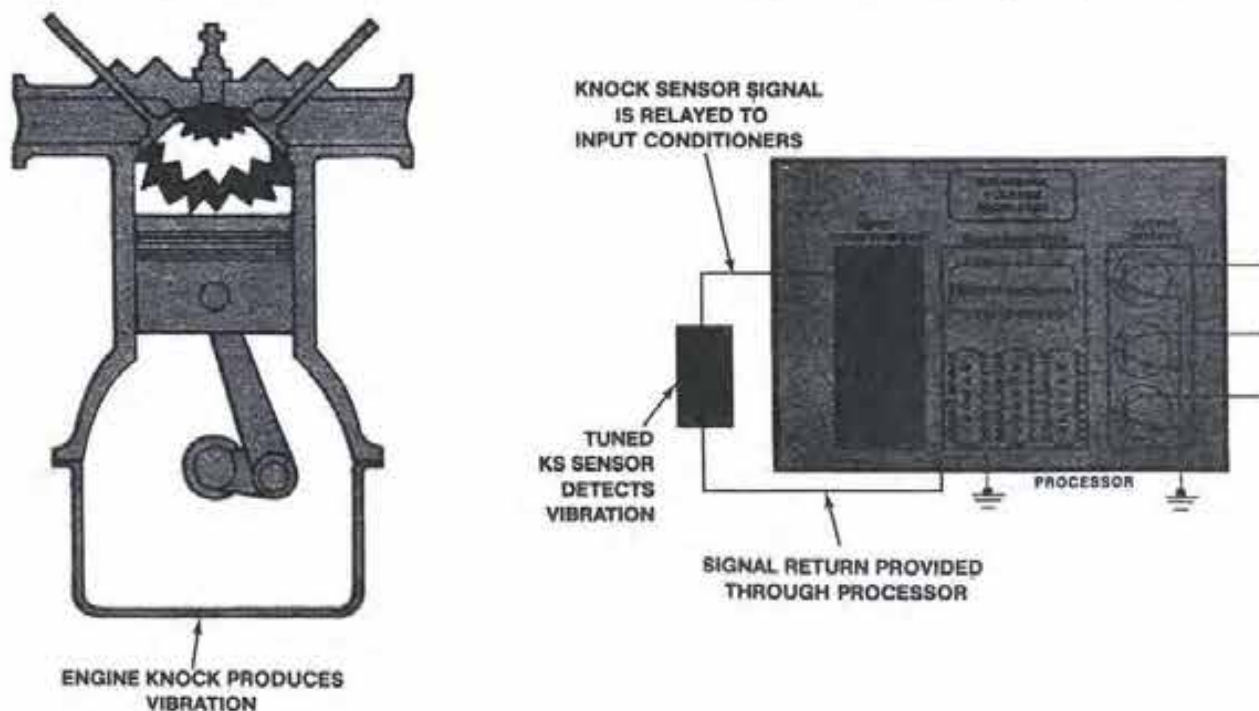


FIGURE 4-16
Typical detonation sensor circuit. (Courtesy of Ford Motor Co.)

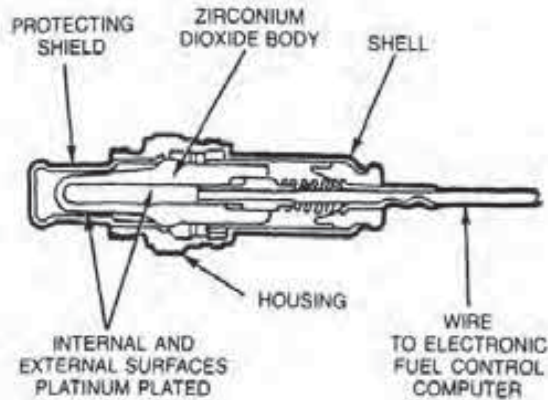


FIGURE 4-17
Typical oxygen sensor. (Courtesy of Chrysler Motors Corp.)

reason, a knock sensor is tuned to respond only to the type of vibrations produced by detonation.

In operation, the vibrations are transmitted via the engine block or intake manifold to the knock sensor where they place pressure on the quartz crystal inside the sensor. This results in a voltage signal that is passed back to the processor as input. The more severe the vibrations, the higher the voltage signal will be.

Exhaust Gas Oxygen Sensor

The *exhaust gas oxygen sensor* develops a voltage signal based on the amount of oxygen present in the exhaust gases (Fig. 4-17). The resulting input signal is used by the microcomputer to determine an engine's air/fuel ratio.

The exhaust gas oxygen sensor typically threads into the exhaust manifold that also forms the ground side of its circuit. The sensor detects the presence of oxygen in the exhaust gases and then produces a variable voltage, according to the amount that is present at any given time. A high concentration of oxygen (lean air/fuel ratio) in the exhaust causes the sensor to produce a low voltage signal (Fig. 4-18). On the other hand, a low concentration of oxygen (rich air/fuel mixture) produces a high voltage signal.

Figure 4-19 illustrates the construction of a typical oxygen sensor. A zirconium dioxide thimble is located in the tip of the sensor, as shown. Exhaust gases can enter the tip through slots, and air can pass into the body of the sensor through an air intake opening. This design permits exhaust gas to contact the outside of the thimble while air touches its inside surface.

Both the inside and outside surfaces of the

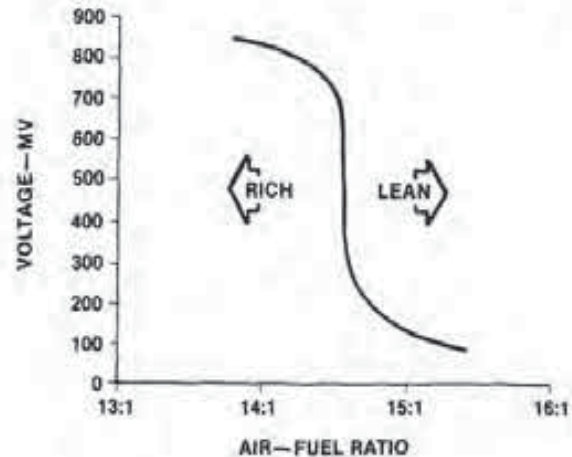


FIGURE 4-18
Oxygen sensor output voltage curve. (Courtesy of Chrysler Motors Corp.)

thimble are plated with platinum electrodes. The inside surface of the thimble forms the negative electrode; the outside is the positive.

In operation, the zirconium dioxide material attracts negatively charged ions of oxygen. These negative ions collect on both the inside and outside surfaces of the thimble. Since there is more oxygen in air than in the exhaust gas, the air side of the thimble connects more negative ions than the exhaust side does. This difference in the number of negative ions creates an electrical potential (i.e., voltage) between the air and exhaust sides of the thimble.

When there is a low concentration of oxygen on the exhaust side of the thimble (a rich mixture), a high voltage is generated between the two electrodes. On the other hand, a high concentration of oxygen on the exhaust side of the thimble (a lean mixture) produces a low voltage (Fig. 4-20). In either case, the sensor relays the resulting voltage signal to the processor.

Magnetic Pickup Sensors

Magnetic sensors are used to monitor the position and speed of the crankshaft and provide this information by generating a voltage signal to the microcomputer. The microcomputer uses the signal to determine such factors as ignition timing and fuel injection periods. There are two principal types of magnetic sensors, the magnetic pickup and the Hall-effect sensor.

A typical magnetic pickup consists of a wire coil and a permanent magnetic core (Fig. 4-21). The permanent magnet is necessary to create a magnetic field in and around the wire coil.

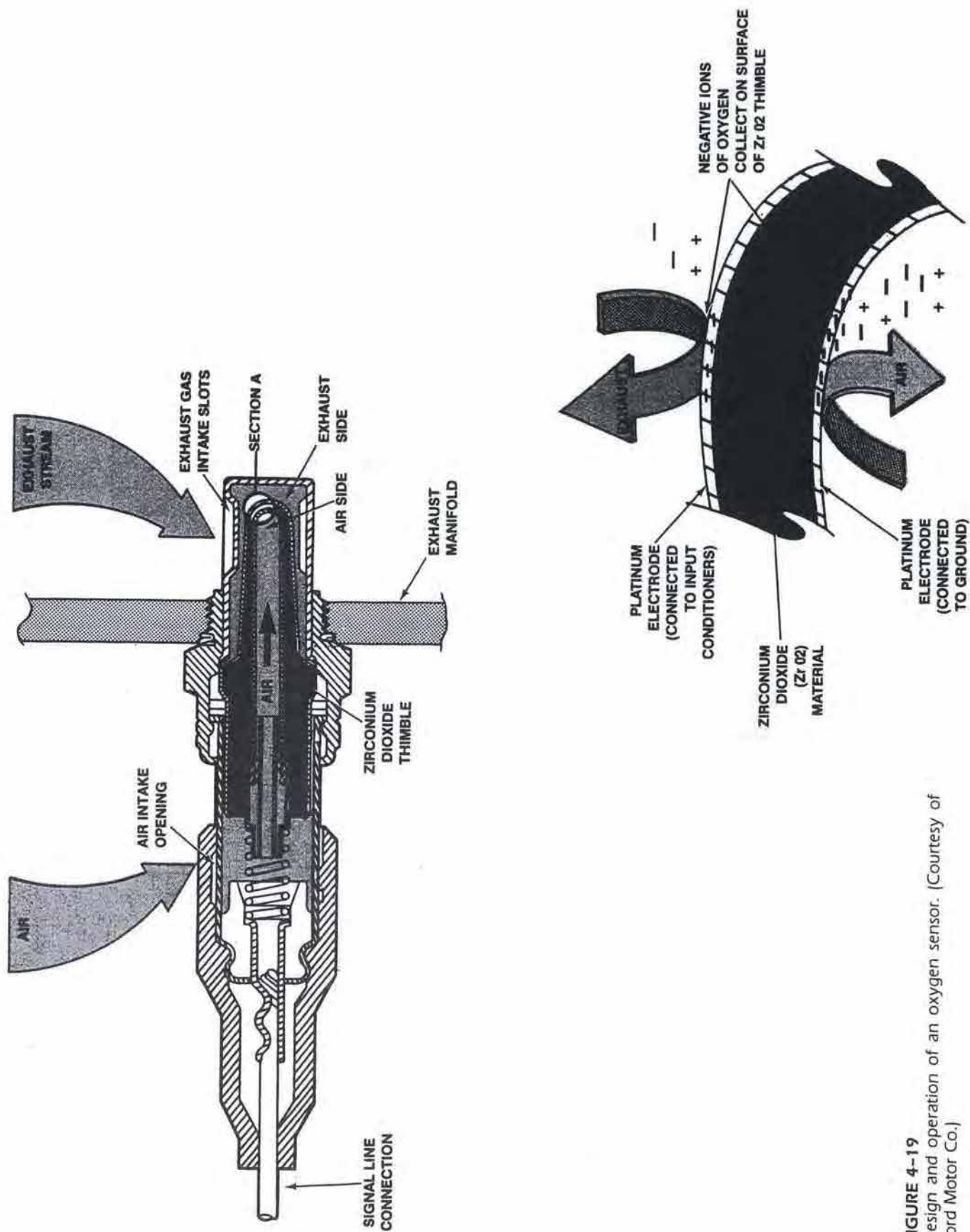


FIGURE 4-19
Design and operation of an oxygen sensor. (Courtesy of
Ford Motor Co.)

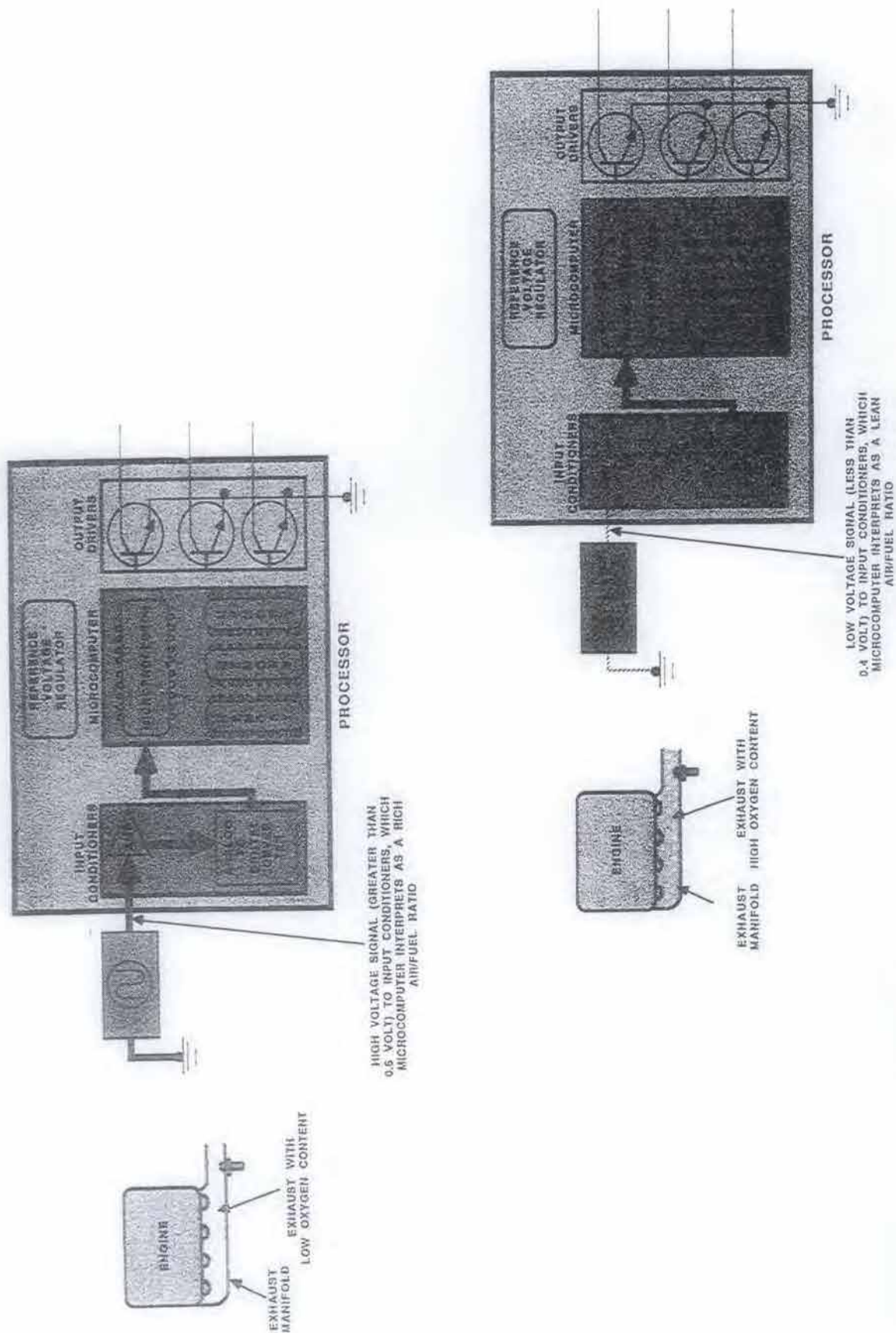


FIGURE 4-20
Sensor input signals during low and high oxygen content in the exhaust gases. [Courtesy of Ford Motor Co.]

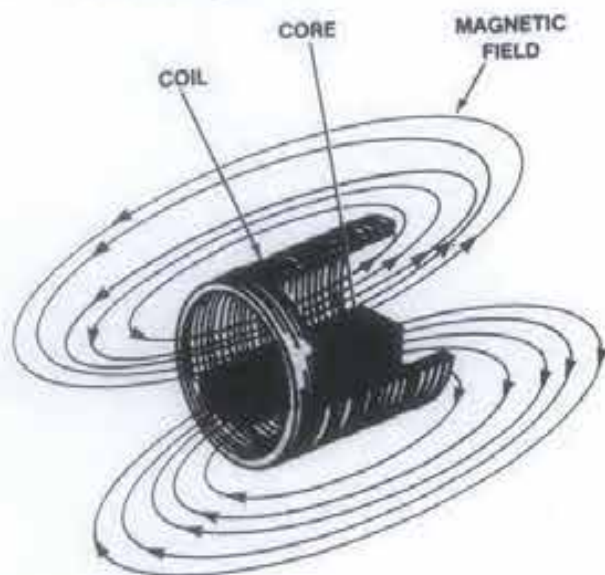


FIGURE 4-21
Typical magnetic pickup design. (Courtesy of Ford Motor Co.)

When a metallic object disturbs the strength of the magnetic field, an electrical voltage is generated in the wire coil. The resulting AC analog voltage signal is then relayed to the microcomputer.

A crankshaft position (CP) sensor is an example of a magnetic pickup (Fig. 4-22). The CP sensor is mounted in a bracket on the engine block. The tip of this sensor contains the magnetic pickup assembly.

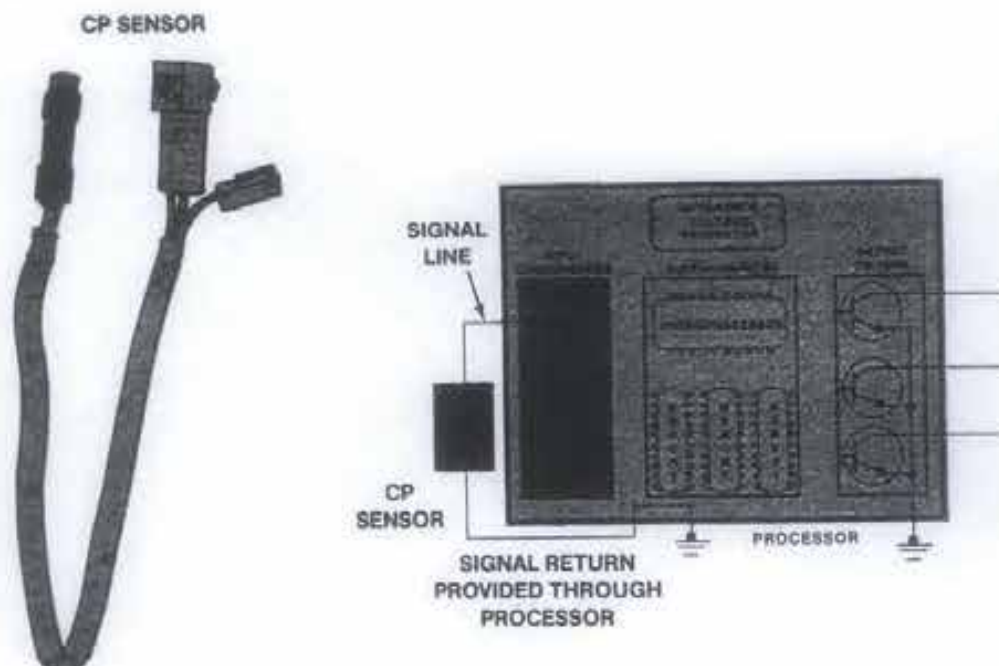


FIGURE 4-22
Schematic of a magnetic pickup circuit. (Courtesy of Ford Motor Co.)

bly. The metallic object used to disturb the magnetic field is in the form of a pulse ring that is mounted on the crankshaft. Additional information on the CP and distributor pickup type sensors is presented in Chapters 6, 8, and 10, which discuss ignition.

Hall-Effect Sensors

The *Hall-effect sensor* performs the same function as the magnetic pickup mentioned above. However, this sensor provides the signal using a different principle and produces a DC digital signal to the microcomputer. Because it produces a digital signal, which is very accurate, the use of Hall-effect sensors has become very popular with manufacturers.

A Hall-effect sensor can be located within the distributor or be an external device. Figure 4-23 illustrates a Ford profile ignition pickup (PIP) sensor that is of the Hall-effect design. The PIP sensor consists of a rotary vane cup and a Hall-effect switch. The rotary vane cup is positioned at the top of the distributor shaft. In addition, the cup has a set of vanes around its edge, one for each engine cylinder.

The Hall-effect switch is located in the distributor base. The switch contains a permanent magnet on one side, a Hall element (a gallium arsenate crystal) on the other, and two metal plates called magnetic field concentrators. The Hall-effect switch and the rotary cup are positioned so that their vanes

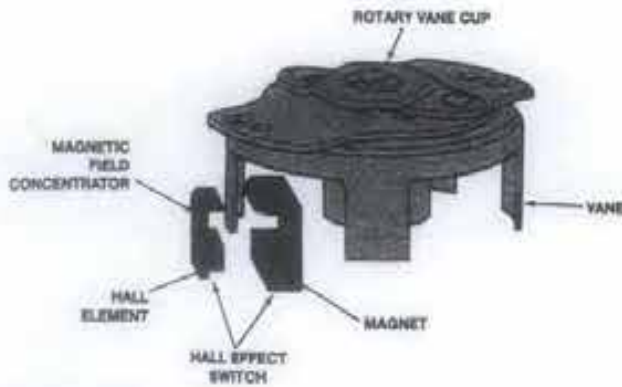


FIGURE 4-23
Typical Hall-effect sensor design. (Courtesy of Ford Motor Co.)

pass through the switch gap as the distributor shaft turns.

The Hall-effect element has three electrical leads (Fig. 4-24). The battery supplies 12 volts to one lead. The second lead is connected to a ground circuit. The third lead supplies the signal to the microcomputer.

The Hall-effect switch uses the effects of magnetism to generate a voltage in its crystal. The main difference between the Hall-effect switch and the magnetic pickup sensor is that the crystal in the Hall-effect switch has a voltage applied to it in a given direction. If the magnetic field passes through the Hall element with voltage applied to it, a signal is generated in the third wire attached to the crystal. This signal is then relayed to the microcomputer. Additional information about the design, operation, and specific applications of Hall-effect sensors can be found in Chapters 6, 8, and 10.

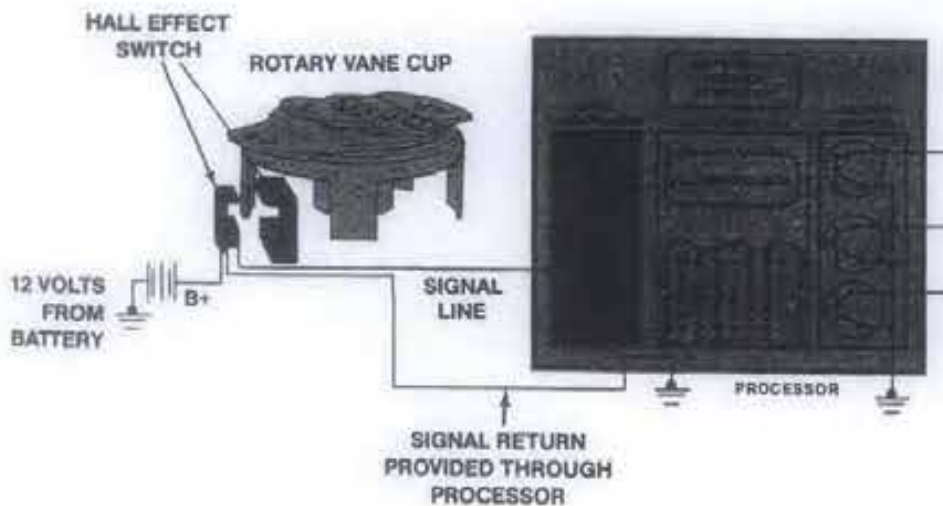


FIGURE 4-24
Hall-effect switch circuit. (Courtesy of Ford Motor Co.)

Input Conditioning—Amplification

As mentioned, a microcomputer requires certain types of input voltage signals in order to function. However, as pointed out in this section, input devices produce a wide range of voltage signals. In other words, the signal may be small, large, analog, or digital. Depending on its basic design, most signals must be prepared by special *input conditioning* or *interface circuits* before the microcomputer can use them to process information. The circuits also have a second function. That is, they protect the delicate electronic components in the microprocessor from high voltages that can occur in electrical circuits. There are two principal types of input conditioning processes, (1) amplification and (2) analog-to-digital conversion.

Some sensors like the oxygen sensor and magnetic pickup produce a very weak signal. The oxygen sensor, for instance, produces less than a one-volt signal. Such small signals require amplification, or strengthening, before they can be used by the microcomputer. Figure 4-25 shows the schematic symbol for an *amplifier*, which strengthens a small input signal before it is relayed to the microcomputer.

Analog-to-Digital Conversion

As mentioned earlier, a digital microcomputer must have input signals in DC digital form before it can process information. The simple reason for this is that in these units, the assembly of thousands of tiny switches can have only two states, on or off. That is, the switches are either closed or open. This

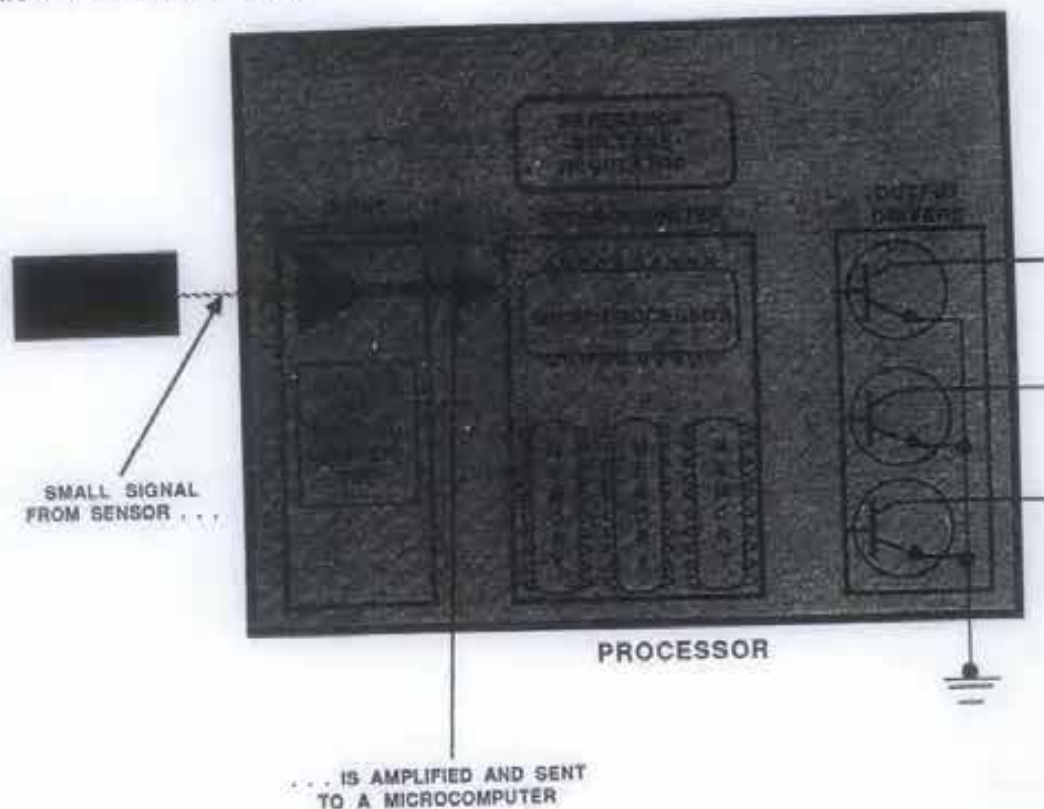


FIGURE 4-25
Typical signal amplifier. (Courtesy of Ford Motor Co.)

requires the input of digital, binary-coded 0 or 1 signals.

If all sensors produced digital signals, the microcomputer could use them to begin its processing function without any intermediate steps. However, many sensors provide a variable analog signal, that cannot be used by a digital microcomputer without converting it. This form of signal conditioning is called *analog-to-digital conversion*, or *A/D conversion*. This task is performed by the analog-to-digital converter (Fig. 4-26).

During the conversion process, voltages from a sensor are classified into different ranges (Fig. 4-27). In the example shown, the three ranges are: 0 to 2 volts, 2 to 4 volts, and 4 to 5 volts. Each voltage range is then assigned a numeric value: 0 to 2 volts = 1, 2 to 4 volts = 2, and 4 to 5 volts = 3.

These numeric values are then assigned a binary code: 1 = 01, 2 = 10, and 3 = 11.

Each analog signal is sampled at regular intervals during the process of conversion. In sampling, the A/D converter takes a picture of the analog signal and determines its voltage at that moment in time. In our example, the voltage is 5 volts.

This voltage is assigned a numeric value of 3. This figure is then translated into a binary code of

11, which, in turn, is relayed to the microcomputer as a digital signal.

In some installations, the microcomputer controls electrical devices that respond to analog signals. In this case, the microprocessor will have a digital-to-analog signal conditioner or interface to change the signals back.

4-4 PROCESSING INFORMATION

Before discussing how the microcomputer processes input signals and makes decisions, let's examine its basic structure and the function of its basic components.

Microcomputer Construction

A microcomputer, or processor, consists of two primary components, the microprocessor and memory (Fig. 4-28). The microprocessor is the part in which all the logical decisions are made. In other words, it is the thinking or calculating portion of the microcomputer.

The microprocessor is the *hardware* package of

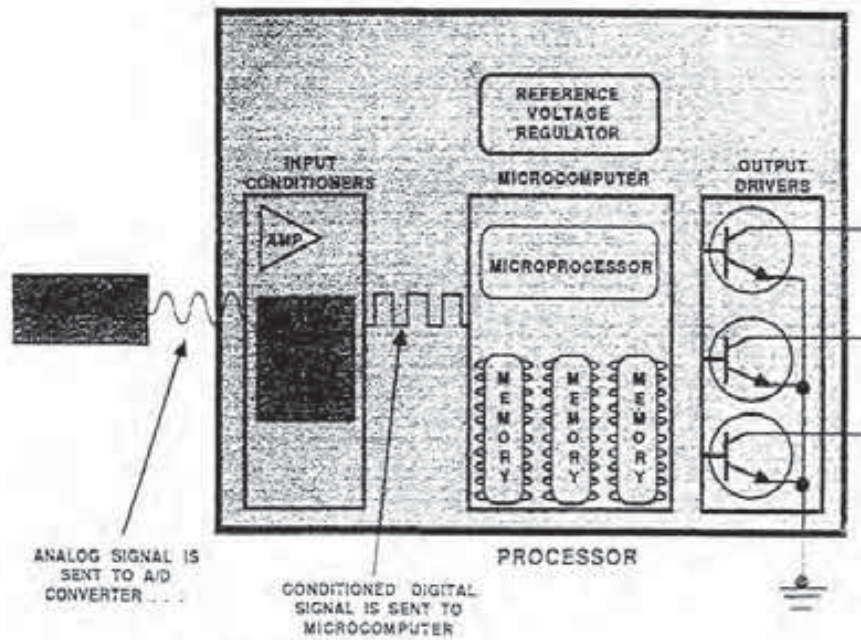


FIGURE 4-26
A/D converter. [Courtesy of Ford Motor Co.]

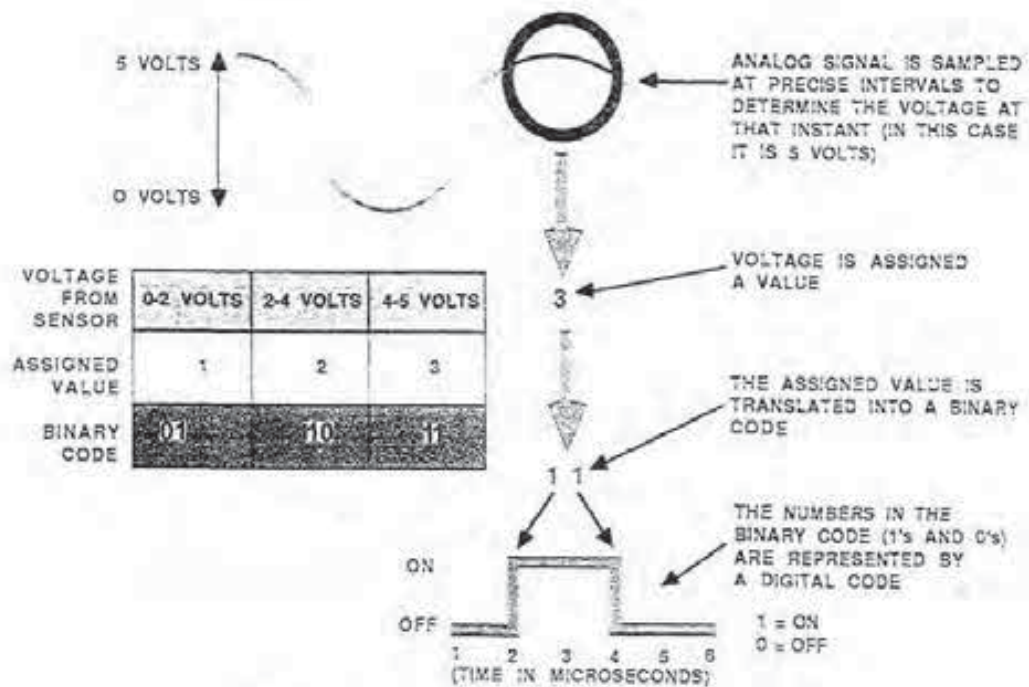


FIGURE 4-27
Analog-to-digital conversion. [Courtesy of Ford Motor Co.]

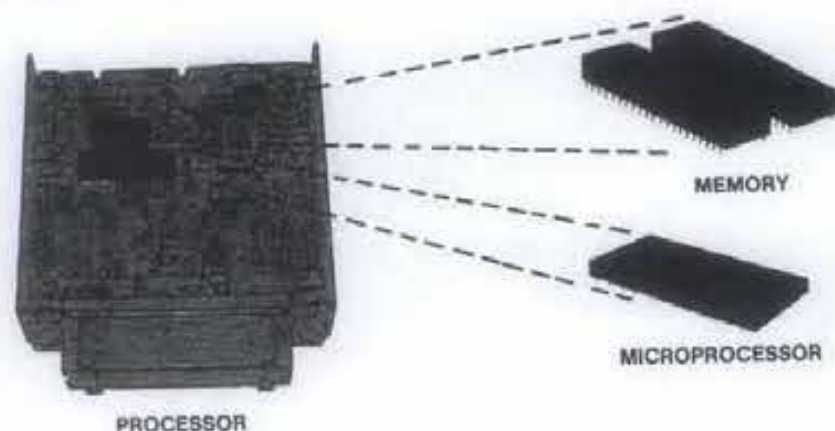


FIGURE 4-28
Processor design. [Courtesy of Ford Motor Co.]

the microcomputer. The unit can only make the decisions or take the actions that are programmed into its circuitry. In other words, the microprocessor can only function according to a built-in program. A *program* is a set of instructions or procedures that the unit follows. The instructions may tell the microprocessor when to retrieve input from a sensor, how to process that information, and when to activate an output device. Consequently, the program guides the microprocessor as it makes decisions.

In order to make accurate decisions, the microprocessor needs as much information as possible. The microprocessor obtains this information from the input sensors or from memory. *Memory* holds the programs and other data, such as vehicle calibra-

tions and information, that the microprocessor refers to in performing calculations. The microprocessor works with memory in two ways. First, the microprocessor can read, or access, information from memory. Second, it can change information in memory by writing new data.

Memory makes up the *software package* of the microcomputer (Fig. 4-29). Changes can be made to the software to alter the microprocessor operation without redesigning it. Just keep in mind, the hardware processes the software. For this reason, manufacturers can use the same microprocessor on a family of vehicles but have different software packages tailored to the particular engine, transmission, vehicle weight, and accessory configuration.

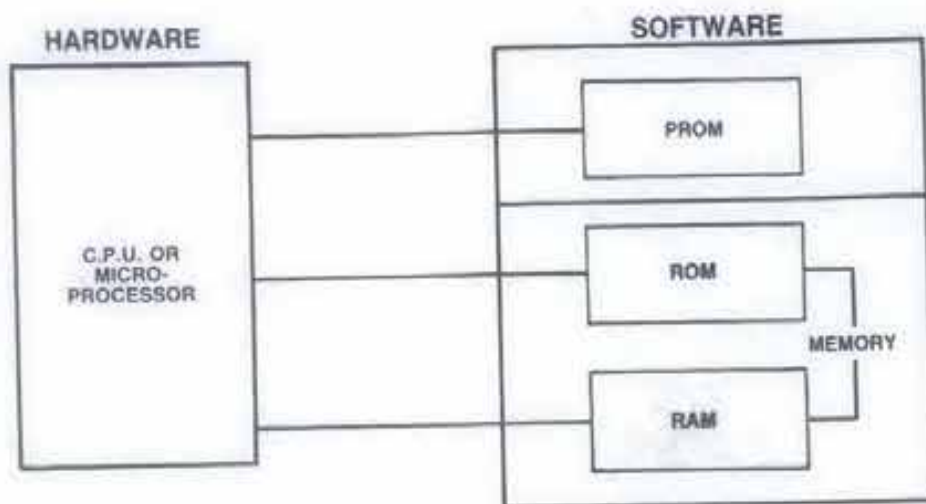


FIGURE 4-29
Hardware and software packages. [Courtesy of Chrysler Motors Corp.]

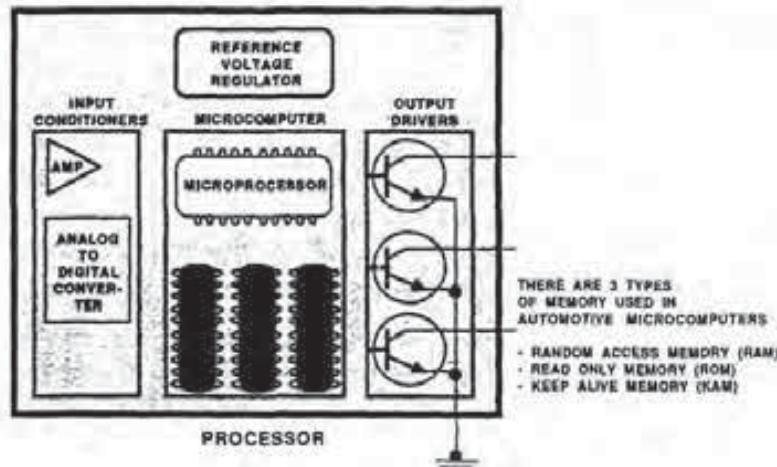


FIGURE 4-30
Processor with three types of memory. (Courtesy of Ford Motor Co.)

Types of Memory—PROM

As shown in Fig. 4-29, this microcomputer uses two types of memory that are stored in the *PROM* (*programmable read only memory*). They are RAM and ROM. Some types of information in these memory areas are constantly being updated and changed. Other pieces of data are permanent; that is, they must always be available to the microcomputer.

RAM. Information that is to be stored temporarily is directed to a type of memory device known as random access memory (RAM). Random access means that the microprocessor can retrieve information from any RAM location in any order. Moreover, the microprocessor can write, read, and erase information from RAM.

One characteristic of RAM is that if the ignition switch is turned off, the information in RAM is erased. When the vehicle is operated again, information is again written into RAM. RAM is used to store information from sensors, calculation results and other data that are subject to constant change.

ROM. Permanent information is stored in read only memory (ROM). The microprocessor retrieves information from ROM as needed. As its name implies, the microprocessor can only read information from ROM; it cannot erase or write information into ROM.

ROM contains information that is necessary for the vehicle systems to operate. The two types of information stored in ROM are the calibration tables and the look-up tables.

Calibration Tables. The *calibration tables* contain information about a specific vehicle. For example, the tables for one type of engine will contain such data as the number of cylinders, cylinder displacement, and the intake and exhaust valve sizes. The calibration tables for another vehicle engine will contain completely different information. For this reason, the information stored in the calibration tables *matches the microcomputer to a given engine/vehicle configuration*.

Look-Up Tables. The *look-up tables* contain standard information about how a vehicle should perform. These tables are used for *all vehicles*. An example of information stored in the look-up tables is the ideal oxygen content of the exhaust of an engine that is at normal operating temperature and at cruising speed. This datum is compared to the input signal coming from the oxygen sensor to determine if a change in the air/fuel ratio is necessary.

Information is programmed into ROM as the memory device is being constructed. Therefore, this information can never be erased, even if the system is turned off or the battery is disconnected from the processor.

KAM. Some microcomputers have a third type of memory known as keep alive memory (KAM) (Fig. 4-30). KAM has many of the same characteristics as RAM. Information, for example, can be written into KAM and can be read or erased from it. Unlike RAM, data in KAM are not lost when the ignition key is turned off. However, if battery power is disconnected from the processor, information in KAM is erased.

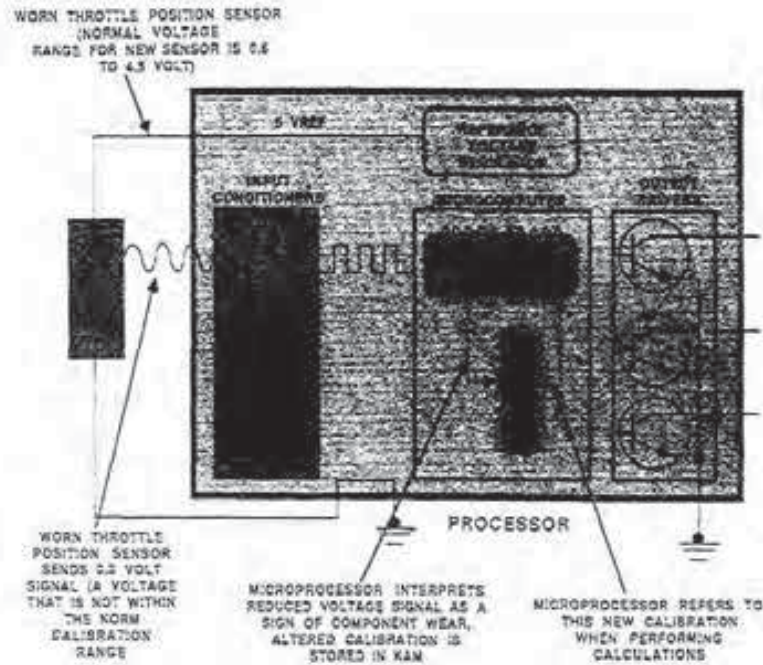


FIGURE 4-31

Example of adaptive strategy. (Courtesy of Ford Motor Co.)

KAM has permitted the development of adaptive strategies used in a number of current electronic engine control systems. Adaptive strategy is the ability for a microcomputer to learn from past experience. Adaptive strategy allows a microcomputer to correct for wear and aging of some parts in a system.

The information that the microcomputer learns during vehicle operation is stored in KAM (Fig. 4-31). KAM retains data on component calibrations so they will not be lost when the engine is turned off.

When the microcomputer executes adaptive strategy, it monitors the input signals from the system components. If the microcomputer detects any signs of age or wear in a calibrated part, it executes the necessary corrections to maintain system performance. If the signal from a sensor should be very erratic, the microcomputer may even ignore the input.

For a microcomputer with the adaptive strategy feature, a short adjustment or learning period will occur (1) on a new vehicle, (2) when the battery has been disconnected during normal use (disconnecting the battery from the processor causes the information in KAM to be lost), and (3) when a component is disconnected or replaced.

If a part is replaced, it is possible for vehicle performance to actually deteriorate because the new

component will be treated by the processor as if it were still aged or inoperative. In other words, during the learning period (usually under five miles), some vehicles could exhibit abnormal drivesability conditions such as surge, or high or low idle speeds.

Information Storage and Retrieval

Each type of microcomputer memory consists of a number of data locations. Each location contains one piece of information. Moreover, each memory location is assigned a number called an *address* (Fig. 4-32). Addresses are in binary code and are numbered sequentially starting with zero. The microcomputer uses the addresses to retrieve information and to write data into memory.

During processing, the sensors relay information to the microprocessor, but it may not be possible for the unit to process all this data immediately. In other words, some information has to be stored. To store the data, the microprocessor writes it into memory by specifying an address and then sending the data to that location.

The microprocessor can retrieve information stored in memory by reading the data. The microprocessor does this by specifying the memory loca-

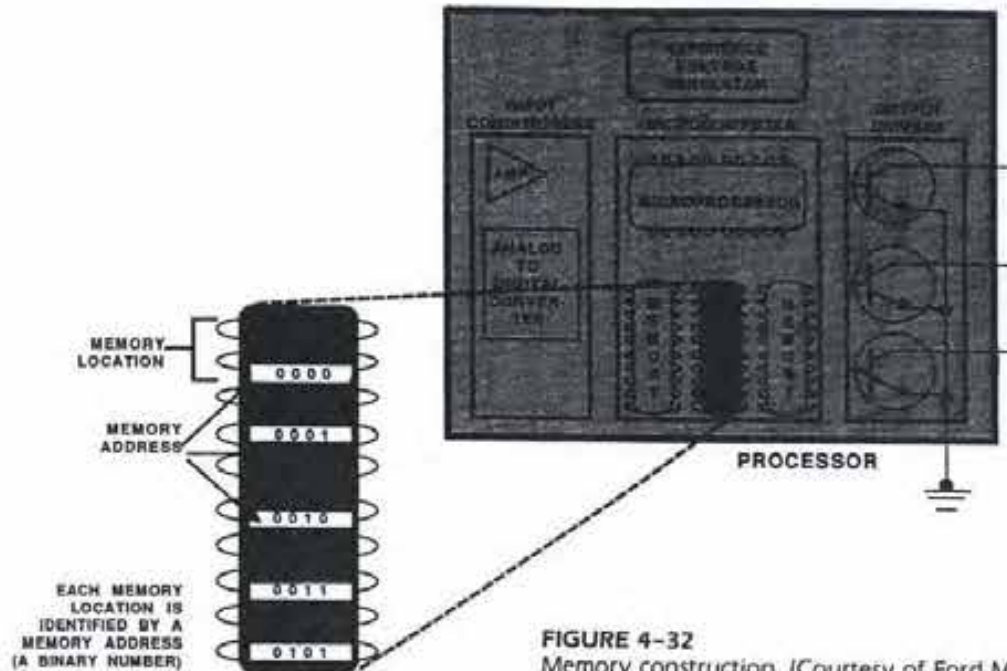


FIGURE 4-32
Memory construction. (Courtesy of Ford Motor Co.)

tion (address) and requesting that the information be sent.

When that particular memory location sees that it is being addressed, it sends a copy of the stored information to the microprocessor. The original data stays in the memory location and can be accessed later if necessary.

Microcomputer Clocks

Microcomputers contain some form of *clock generator* that provides constant steady pulses, each the length of one bit (Fig. 4-33). The microprocessor and the memories watch these clock pulses while they are reading or sending data, which lets the components know how long each voltage pulse (representing a bit) is supposed to last. This is how the microcomputer components can distinguish between a 01 and a 0011 binary code.

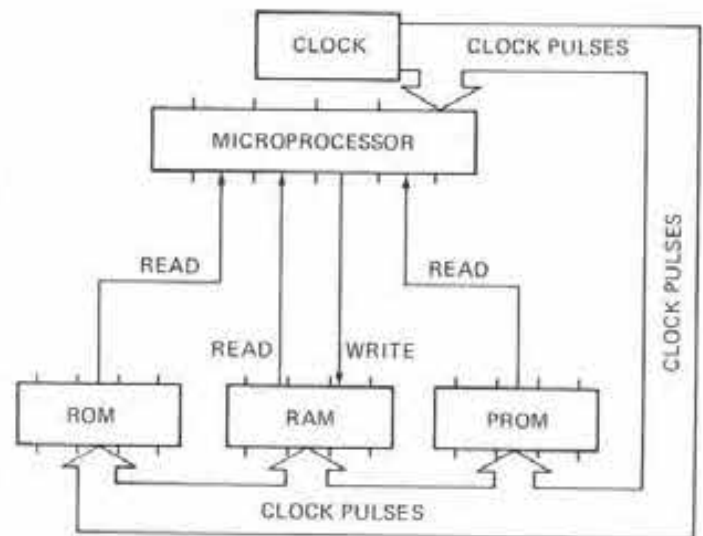


FIGURE 4-33
Microcomputer clock.

Data Links

Microcomputers send and receive digital signals through what are called *data links*. Some data links transmit data only in one direction, that is, from one device to another (Fig. 4-34). Other types of data links can transmit both ways, from one device to

another and back again. In some cases, the microcomputer may send signals to several devices over one data link. In this situation, the microcomputer is programmed to recognize each bit by its place in the data stream. This is how the microcomputer knows where to send or store a bit of information.

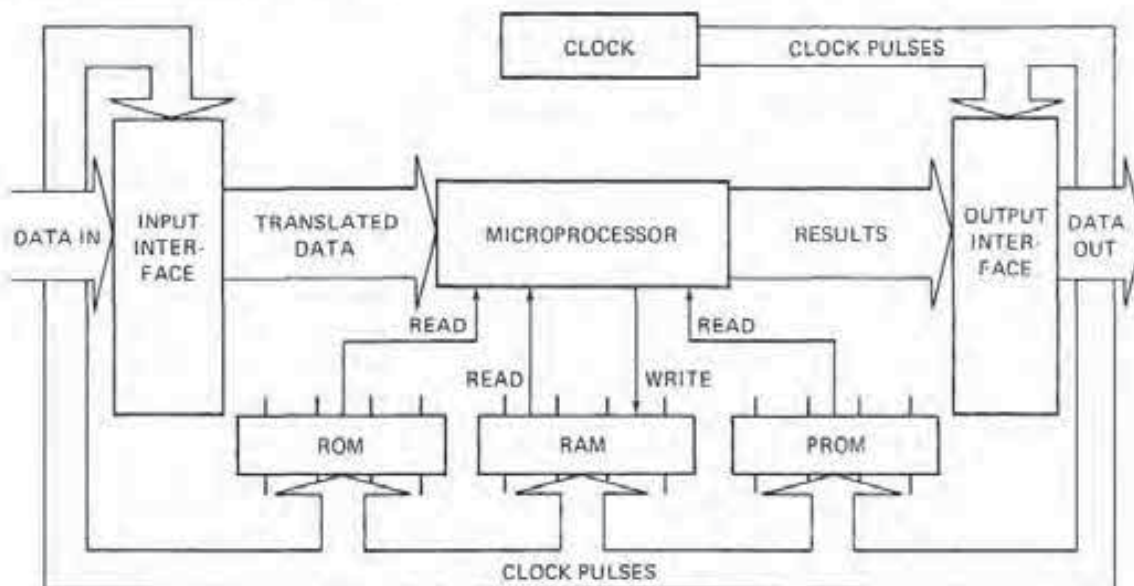


FIGURE 4-34
Microcomputer data links.

4-5 MICROCOMPUTER OUTPUT DEVICES

Thus far, this chapter has discussed how a microcomputer receives data about vehicle operating conditions from a variety of sensors. In addition, the design and operation of some of these sensors and how their analog signals are converted to digital has been explained.

It is now time to consider output, the third stage of microcomputer operation. Operational control of output devices involves either some form of actuator (Fig. 4-35) or an information display.

The microcomputer receives and processes input signals as programmed. The unit must then make a decision about engine operating conditions and act. To put the decision into action, the microprocessor issues commands in the form of voltage signals (usually digital), which, in turn, energize the output device.

Output Drivers

Before looking at different types of actuators, let's see just how a microprocessor energizes them. After a decision is made, the microprocessor relays a digital voltage signal to an output driver, which, in turn, completes an electrical ground circuit to an actuator (Fig. 4-36). Therefore, the output drivers do not supply voltage to the actuators. Their voltage is supplied by the battery.

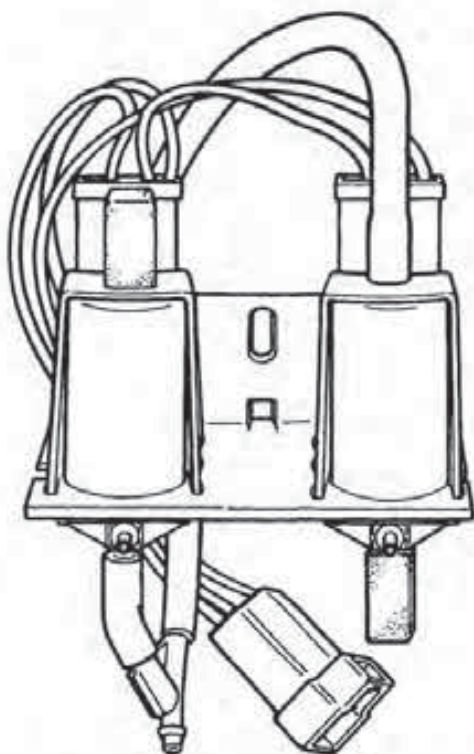


FIGURE 4-35
Typical output actuators in the form of solenoid-operated vacuum valves. (Courtesy of Chrysler Motors Corp.)

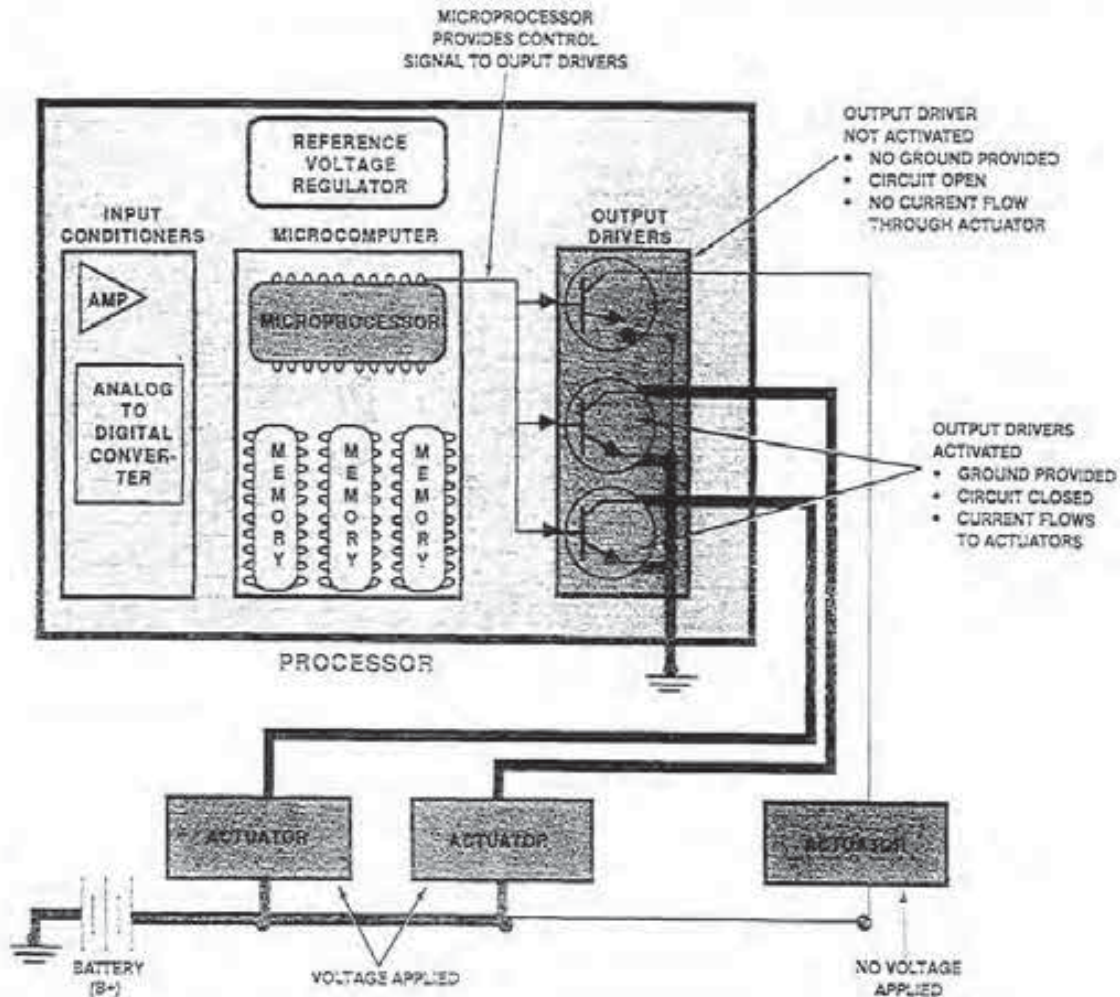


FIGURE 4-36
Output drivers energize the actuators. (Courtesy of Ford Motor Co.)

Output drivers are electronic switches (transistors); the ones shown in Fig. 4-36 are the NPN type. The microprocessor turns the output drivers on and off by directing a voltage signal to its base or gate circuit.

With a voltage signal on the gate circuit, the driver turns on. This action completes the actuator ground circuit, and current flows through it. If the microprocessor turns off the gate signal, the actuator ground circuit is broken, and no current flows. Thus, by using the output drivers to turn the actuators on and off, the microprocessor provides output control.

Actuators

An *actuator* is a device that converts electrical current into some form of mechanical motion using elec-

tromagnetism. There are three principal types of actuators in use: the solenoid, relay, and motor. Using these three devices, the microcomputer can control just about any portion of an engine control system.

Solenoids. As explained in Chapter 2, a solenoid uses electrical current through a coil of wire to create an electromagnetic field. This field, in turn, pulls a metal plunger into an air core inside the coil. A spring is used to push the plunger back out of the core when no current is flowing through the coil.

There are many types of solenoids used in electronic engine control systems. These include EGR control and vent solenoids, air diverter and bypass solenoids, canister purge and carburetor vent solenoids, and carburetor mixture-control solenoids.

Figure 4-37 illustrates the operation of a typical solenoid-operated vacuum valve. When the mi-

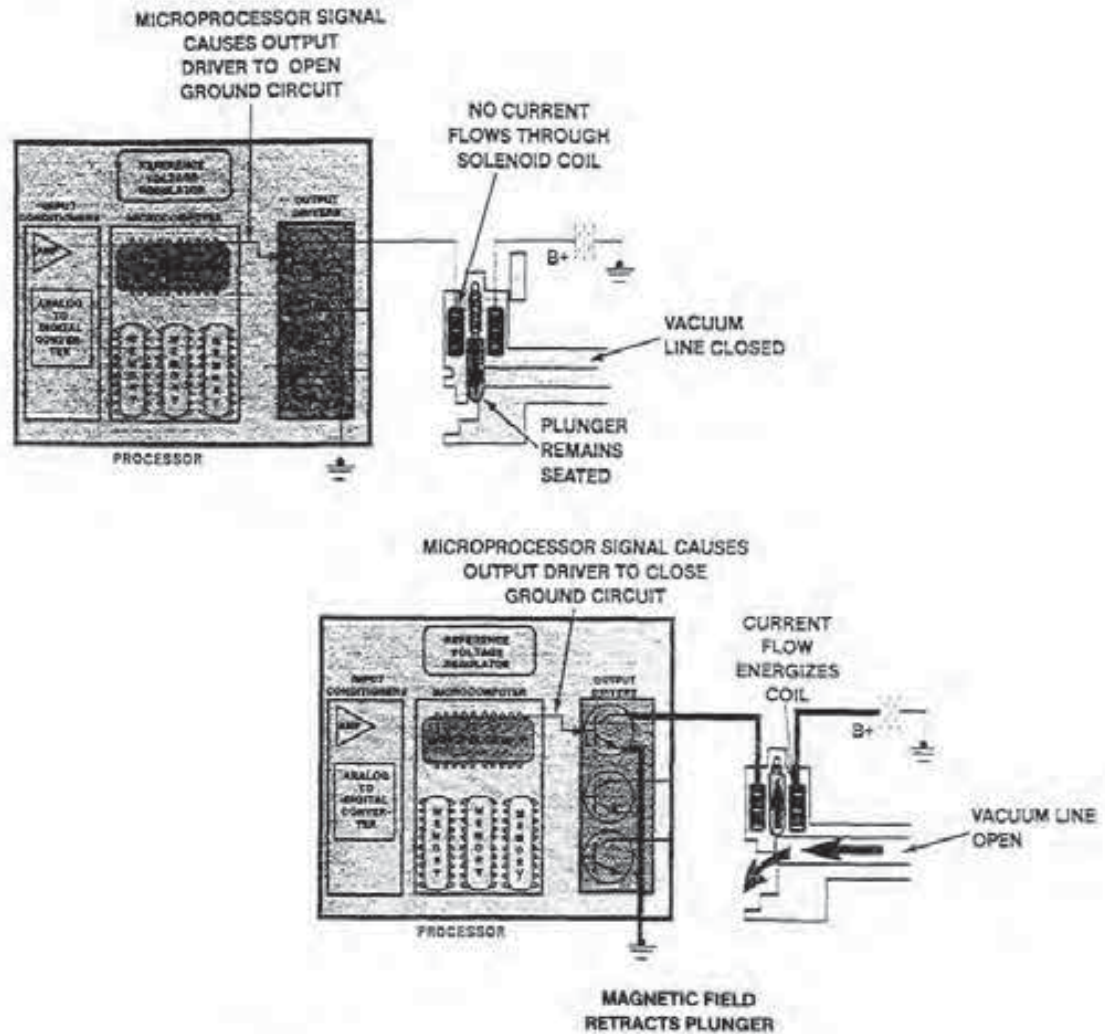


FIGURE 4-37
Operation of a solenoid-type actuator. (Courtesy of Ford Motor Co.)

croprocessor does not provide a positive voltage signal to the output driver, it opens, as shown. As a result, no current flows through the solenoid coil. There is no magnetic field created, and the spring holds the plunger valve against its seat. This effectively blocks the vacuum signal.

Whenever the microprocessor directs a positive voltage signal to the gate of the output driver, it closes. Electric current now flows through the solenoid coil windings and to ground via the output driver. This action creates a magnetic field that attracts the plunger into the air core. With the plunger valve off its seat, the vacuum passage is now open.

Relays. As mentioned also in Chapter 2, a relay is an electrical device that uses a small current to control the flow of a second, larger current. To perform

this task, the relay has a wire coil, relay switch, and two circuits, a control and power. Current through the control circuit is used to govern the electron flow through the power circuit. This circuit then delivers current to another component. In Fig. 4-38, this part is a cooling fan motor.

In operation, the microprocessor either directs or stops a digital signal to the gate of an output driver, which controls the ground circuit for the relay. Without a positive signal on the gate, the output driver remains open. As a result, current cannot pass through the relay coil and to ground via the driver. With the relay control circuit open, so is the power circuit. Therefore, the cooling fan is not energized and will not run.

When the microprocessor provides a positive signal to the gate, the driver turns on and completes

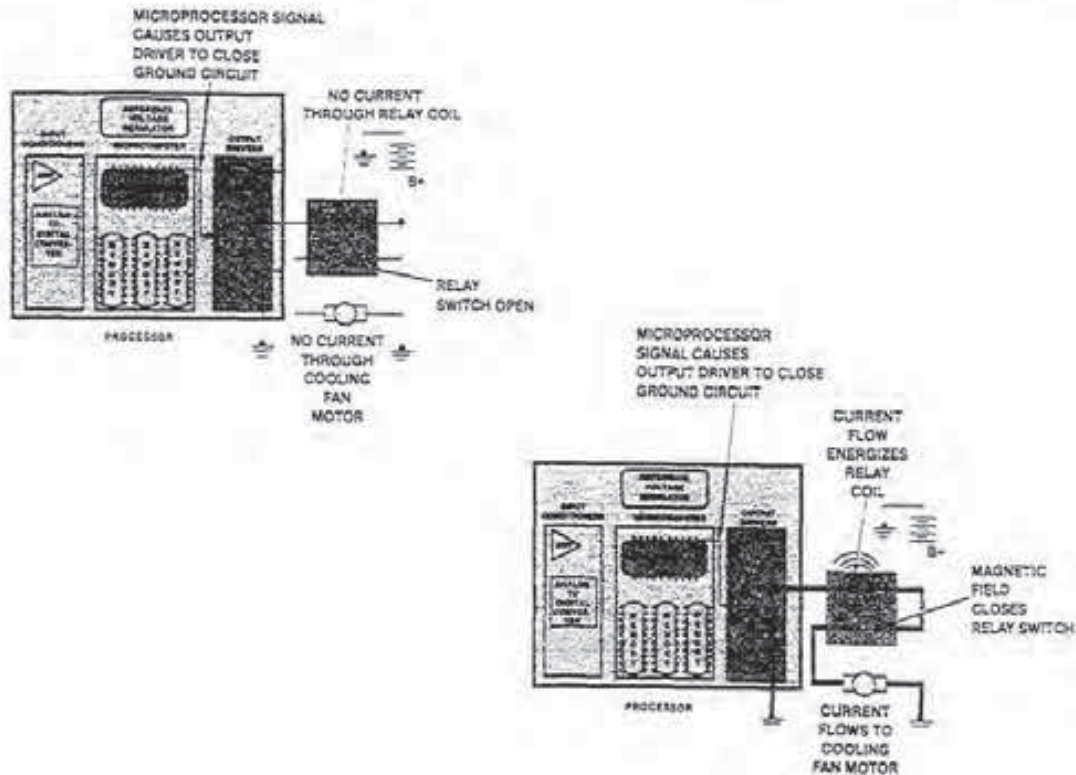


FIGURE 4-38
Design and operation of a relay-type actuator. [Courtesy of Ford Motor Co.]

the ground for the relay control circuit. With current now flowing through the coil, it creates a magnetic field that causes the relay switch to close. Current now can flow through the power circuit to the cooling fan, and it begins to operate.

Motors. Most electronic engine control systems incorporate an electric motor to control idle speed. The basic function of the *idle speed control* (ISC) motor is to regulate engine speed during all periods of closed throttle operation (Fig. 4-39). The motor performs this function during cold and hot operating conditions and compensates for additional accessory loads placed on the engine that can affect idle speeds. In addition, the ISC will adjust the idle speed whenever abnormal engine-operating temperatures are encountered.

The ISC is a reversible motor that adjusts idle speed by changing the throttle opening. It does this by acting as a moveable idle stop. The microprocessor, via the appropriate driver, energizes the ISC motor to either raise or lower engine speed, thus maintaining the correct idle required for a particular operating condition.

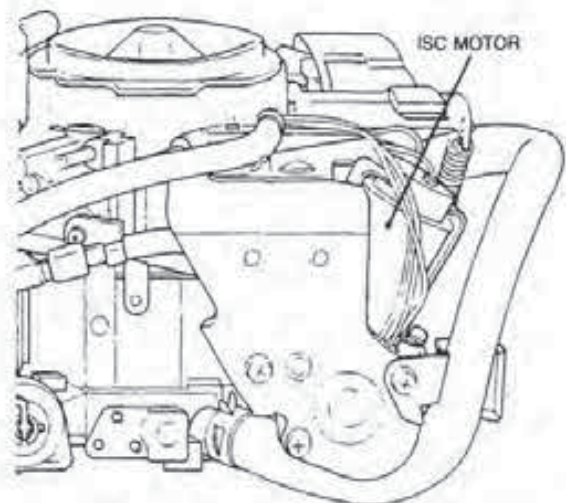


FIGURE 4-39
Typical idle speed control motor. [Courtesy of Chrysler Motors Corp.]



FIGURE 4-40
Typical output display. (Courtesy of Chrysler Motors Corp.)

Displays

The microprocessor controls a display by sending a digital signal to it. A *display* is a solid state device that contains the circuitry to decode digital signals. The decoded information appears on the display (Fig. 4-40).

The digital signal from the microprocessor carries data to the display in the form of a binary code. Figure 4-41 shows how the binary digital signals transport information. In the example, the numbers to be displayed are 1, 2, and 3. The microprocessor represents these numbers by relaying to the display the specific binary code, as shown. These signals are then decoded and displayed. Note in Fig. 4-41 that the output drivers have no function whenever the microcomputer output is used for display.

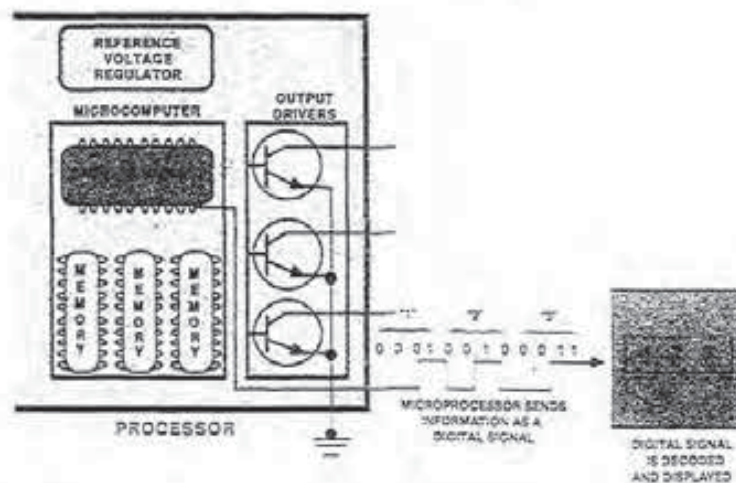


FIGURE 4-41
Data sent to a display as a binary code. (Courtesy of Ford Motor Co.)

4-6 MICROCOMPUTER OPEN AND CLOSED LOOP CONTROL

The microcomputer used in engine control systems performs its functions by following three stages of operation. First, it receives input. Second, it processes that input, and third, it provides output.

Open Loop Control

The microcomputer three-stage operating sequence is referred to as *open loop control* (Fig. 4-42). In open loop control, the microcomputer has no means of directly measuring the results of its output. In other words, it has no way of determining how effective the output has been in changing system performance.

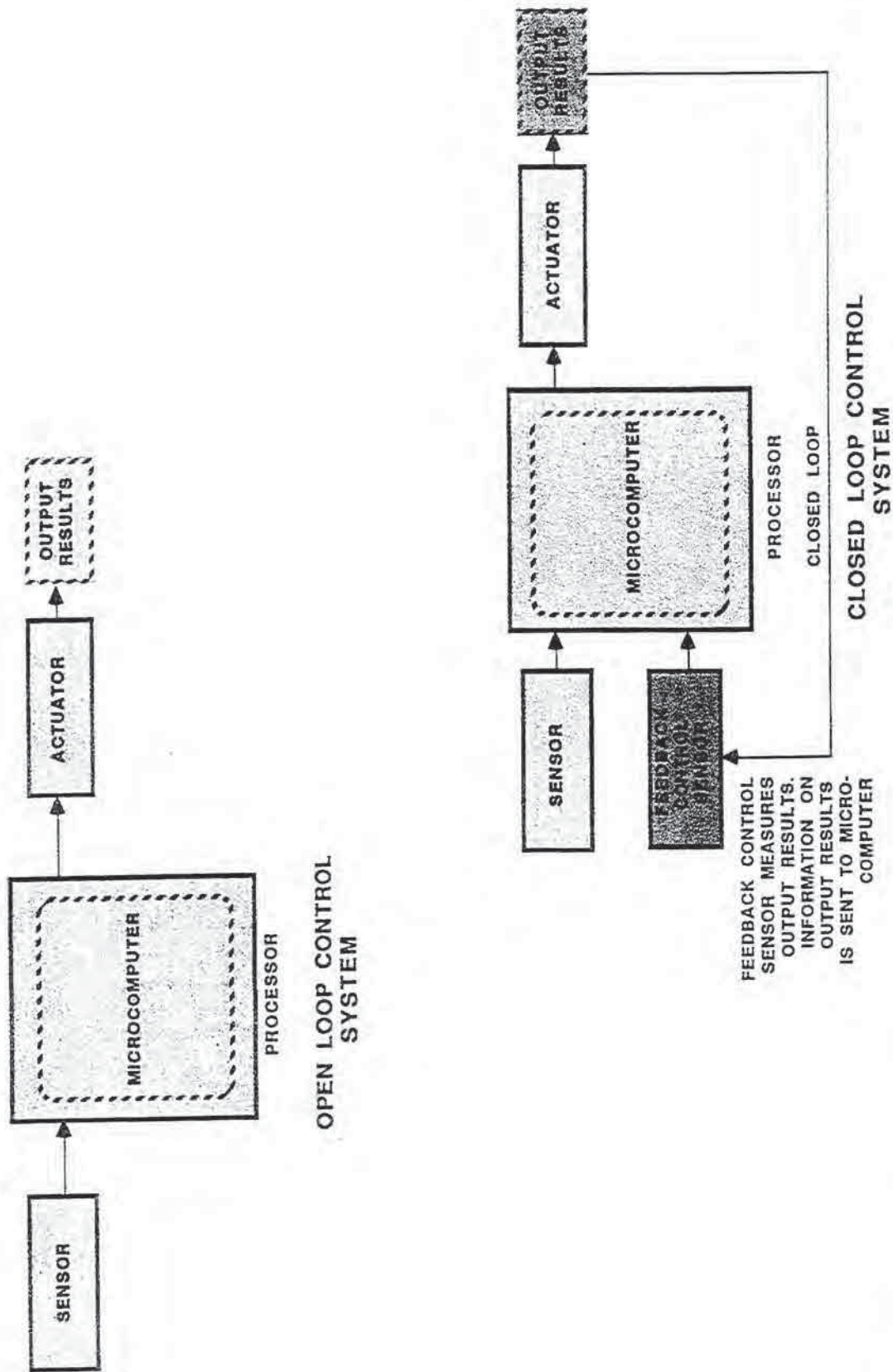


FIGURE 4-42
Open and closed loop microcomputer systems. (Courtesy of Ford Motor Co.)

CHAPTER REVIEW

The following two sections will assist you in determining how well you remember the material contained in this chapter. If you cannot complete a statement or question, refer back to the section marked in brackets that contains the material.

SELF-CHECK

1. What are the four stages of operation a microcomputer follows during closed loop [4-6]?
2. What is a microcomputer [4-1]?
3. Explain how an output driver energizes an actuator [4-5].
4. Explain the difference between analog and digital signals [4-2].
5. What is a microcomputer program [4-4]?
6. Explain what reference voltage is and where it comes from [4-3].

REVIEW

1. If the oxygen sensor is inoperative, the microcomputer cannot provide what type of operation [4-6]?
 - a. open loop
 - b. closed loop
 - c. start-up mode
 - d. acceleration mode
2. What is the name given the box that contains the microcomputer [4-1]?
 - a. microprocessor
 - b. processor
 - c. computer
 - d. memory
3. What is the most common type of output actuator design [4-5]?
 - a. motor
 - b. relay
 - c. solenoid
 - d. display
4. A microcomputer performs work by controlling the operation of what device(s) [4-1]?
 - a. solenoid
 - b. relay
 - c. both a and b
 - d. neither a nor b
5. If a microcomputer can learn from past experience, it has what is known as [4-4]
 - a. adaptive strategy.
 - b. interfacing logic.
 - c. limp-in strategy.
 - d. learning strategy.
6. How long does it take a microcomputer to act on input information [4-1]?
 - a. $\frac{1}{2}$ second
 - b. $\frac{1}{4}$ second
 - c. $\frac{1}{10}$ second
 - d. $\frac{1}{15}$ second
7. Information about the engine in a given vehicle is stored in which memory [4-4]?
 - a. RAM
 - b. ROM
 - c. RIM
 - d. EOM
8. A distributor magnetic pickup coil produces what type of signal [4-2]?
 - a. AC digital
 - b. DC digital
 - c. DC analog
 - d. none of these
9. What is considered to be microcomputer software [4-4]?
 - a. its memory
 - b. its microprocessor
 - c. its sensors
 - d. its output actuators
10. What is the term used to describe the assigning of a numeric value to a voltage signal [4-2]?
 - a. a bit
 - b. binary code
 - c. a bite
 - d. none of these
11. That sensor that relays information to the microprocessor concerning crankshaft position and speed is the [4-3]
 - a. magnetic pickup coil.
 - b. Hall-effect switch.
 - c. PIP sensor.
 - d. all of these.

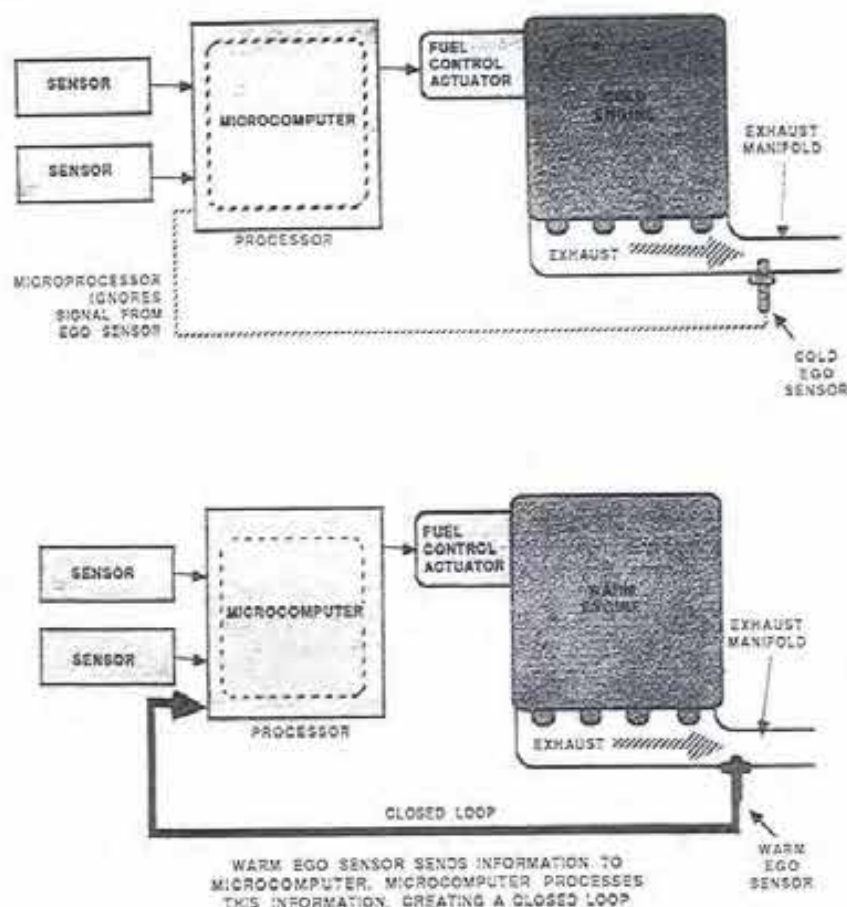


FIGURE 4-43

Open and closed loop system operation. [Courtesy of Ford Motor Co.]

Closed Loop Control

Current engine control microcomputers have a fourth stage of operation called *feedback*. When a microcomputer uses feedback, it is said to be operating in closed loop. In this situation, a feedback control sensor is used to measure the results of the microcomputer output to determine how effective it has been. In this way, a system can be controlled very closely. By adding the feedback control sensor to the open loop system, it becomes closed loop.

The oxygen sensor is a feedback control sensor. It measures the amount of oxygen present within the exhaust gas and relays this information to the microcomputer. With this information, the microprocessor can signal a mixture control solenoid or

the injectors to adjust the air/fuel ratio to achieve the proper level of oxygen.

When an engine has just started and is still cold, the oxygen sensor signal is not usable until the exhaust temperature reaches about 570°F (300°C). Until then, the microcomputer ignores the signal from the oxygen sensor, and the system operates in open loop (Fig. 4-43).

When other conditions are met and the oxygen sensor is at operating temperature, it signals the microcomputer with air/fuel mixture information. The microcomputer processes this data and makes changes in the mixture as necessary. Therefore, when the microcomputer is processing and acting on information from the oxygen sensor, the system is operating in closed loop.

12. A Hall-effect switch produces what type of signal [4-2]?
 - a. AC analog
 - b. DC analog
 - c. AC digital
 - d. DC digital
13. Which device is mainly responsible for determining an engine's air/fuel ratio [4-3]?
 - a. oxygen sensor
 - b. detonation sensor
 - c. park/neutral switch
 - d. clutch switch
14. What is the device that converts mechanical motion into an electrical signal [4-3]?
 - a. thermistor
 - b. potentiometer
 - c. switch
 - d. oxygen sensor
15. What effect does temperature have on a thermistor's resistance [4-3]?
 - a. Its resistance goes down as its temperature increases.
 - b. Its resistance goes up as its temperature decreases.
 - c. both a and b
 - d. neither a nor b

TEST EQUIPMENT AND PROCEDURES

OBJECTIVES

After reading and studying this chapter, you will be able to

- describe the function, design, and use of analog and digital voltmeters.
- explain the function, design features, and use of analog and digital ammeters.
- describe the function, design, and use of analog and digital ohmmeters.
- explain the function and how to use test lights and jumper leads.
- describe the purpose of a compression tester, vacuum gauge, vacuum pump, tach/dwell meter, timing light, oscilloscope, and exhaust gas analyzers.
- explain the function of the ignition module tester, STAR tester, breakout box, and aftermarket microcomputer system testers.
- describe the information found on or in emission decals, wiring diagrams, vacuum diagrams, diagnostic charts, and service manuals.
- explain the safety rules that pertain to general automotive maintenance and testing.

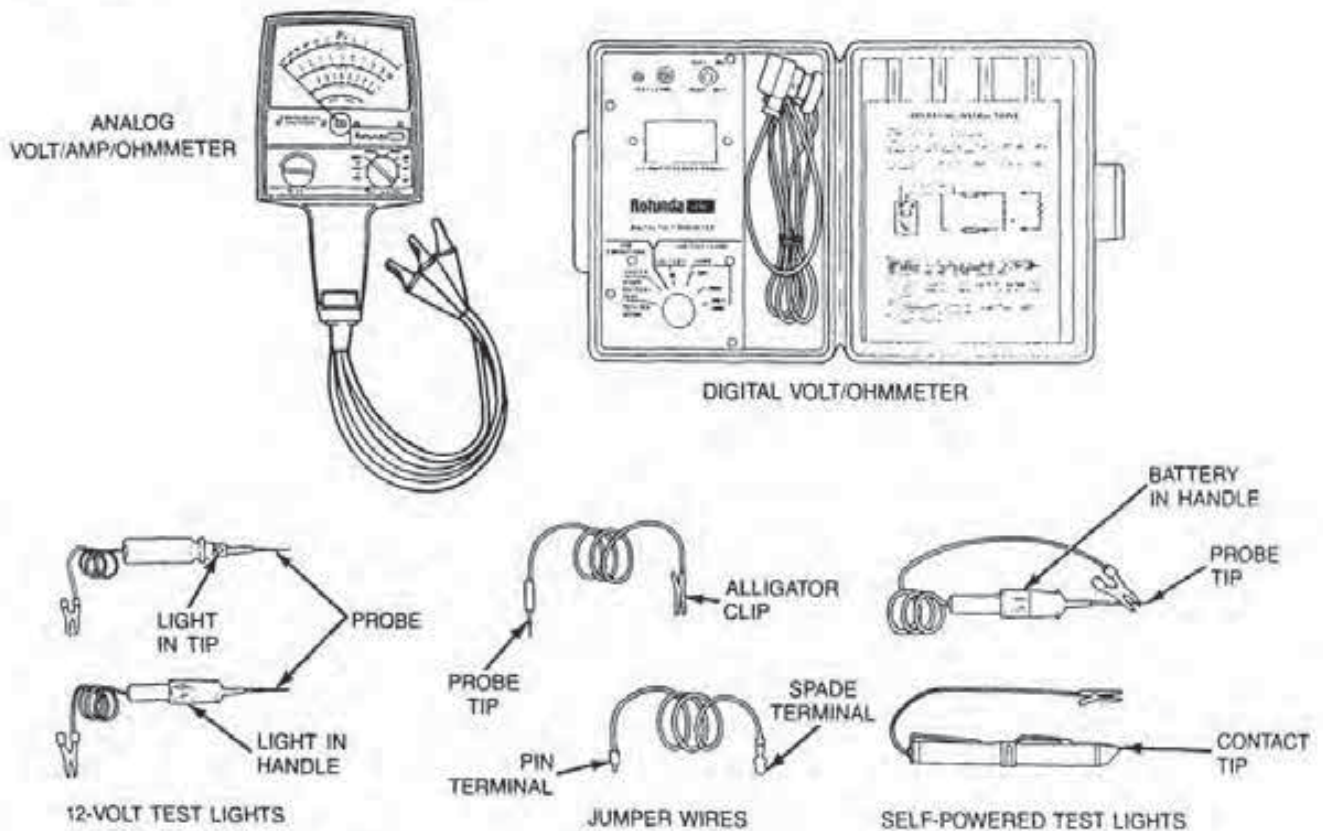


FIGURE 5-1
Typical electrical test equipment. (Courtesy of Ford Motor Co.)

The contemporary automobile has one or a number of microcomputers like those described in the last chapter. These microcomputers consist of electronic components and thus have no moving parts. Theoretically, a microcomputer should last the life of the vehicle, provided nothing external happens to damage its circuits, processor, or memory chips.

While it is true that the controls of a microcomputer-based engine should last longer than similar mechanical types, the microcomputer is extremely sensitive to electrical voltages and cannot tolerate careless or haphazard testing or service procedures. An inexperienced person can literally do major electronic circuit damage looking for a minor problem by either using the wrong type of equipment or connecting up test leads incorrectly.

Therefore, to safely troubleshoot these microcomputer systems requires the technician to be very familiar with the purpose and operation of the testing equipment available (Fig. 5-1). Through the proper use of these tools and information found on electrical diagrams, vacuum schematics, and diagnosis guides found in the various service manuals, the technician can develop the proper approach for identifying a problem and isolating the cause of a malfunction.

5-1 ELECTRICAL TEST INSTRUMENTS

Many of the testers used to measure voltage, current flow, and resistance are sold in a variety of models, and any working model will be adequate for making simple tests. However, when the value of the reading obtained is critical to the diagnostic procedure, accuracy becomes very important. Consequently, make sure the meter used has sufficient quality and accuracy to make the measurement required.

Types of Basic Meters

For automotive electrical system testing, there are two basic types of meters in use, the digital readout and the analog (Fig. 5-2). The *digital readout meter* uses solid state circuitry (a small microcomputer) that converts a measurement taken to a numerical value. In other words, the output of the meter circuitry is in the form of numbers in digital form displayed on a screen. This instrument is the most accurate of the two types.

Features of a typical digital meter include automatic range adjustment, automatic polarity adjust-

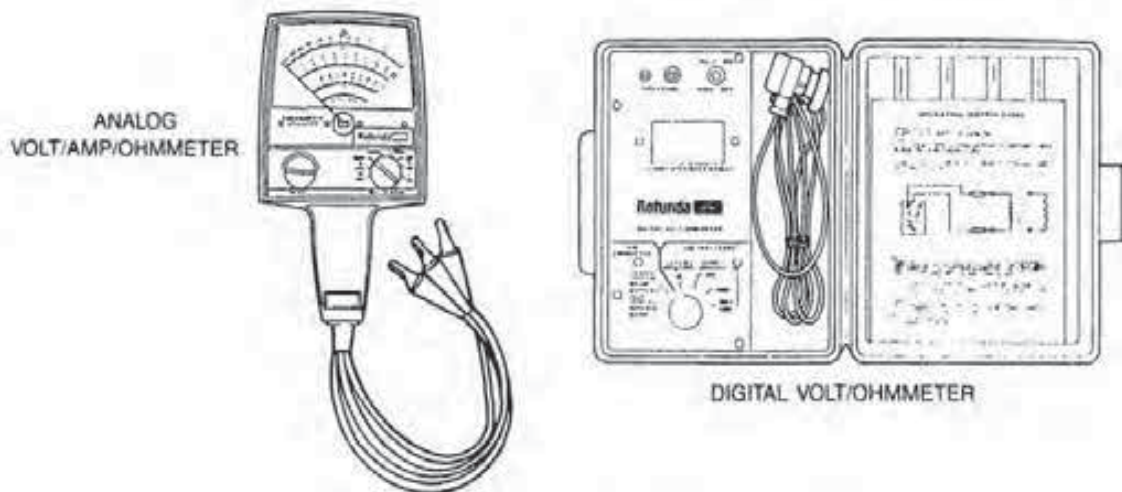


FIGURE 5-2
Digital and analog meters. [Courtesy of Ford Motor Co.]

ment, and accuracy to several decimal points. This last feature is very important when testing computerized system components because some measurements have such a low value that they just cannot be obtained accurately by reading the needle position on a scale.

The *analog meter* shows the actual measurement using a needle that moves across a scale. In the case of an analog voltmeter, the movement of the needle on the scale is in proportion to the actual voltage measurement being taken. If the meter is of the permanent magnet type, it is very durable and accurate enough for most general automotive electrical testing. *However, it should not be used to test components of computerized engine control systems.*

Many meters are multipurpose. For instance, the digital meter illustrated in Fig. 5-2 can measure both voltage and resistance. The analog meter is able to measure voltage, amperage, and resistance.

Basic Analog Meter Design

All analog meters use the same type of mechanism to indicate the value of voltage, amperage, or resistance. This mechanism is called a *D'Arsonval*, or *moving coil movement*, which uses a magnetic field to force a coil to rotate inside the meter (Fig. 5-3). The movement consists of a permanent magnet, moveable coil, and needle. The coil is made of several turns of wire carefully insulated and wound on a rectangular aluminum frame. The aluminum is non-magnetic and permits the fast collapse of the magnetic field when the coil is de-energized.

The coil attaches to an indicator needle and pivots on jeweled bearings. Two hairsprings hold the coil in its zero position and also carry the current

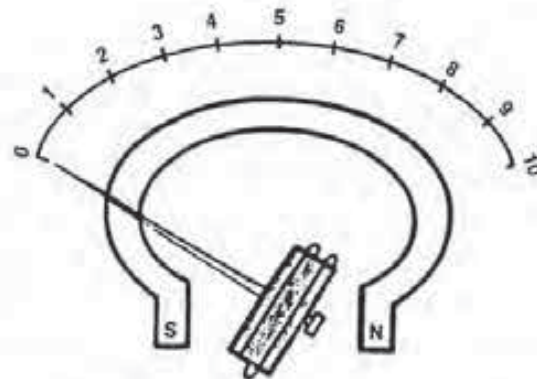


FIGURE 5-3
D'Arsonval movement. [Courtesy of Ford Motor Co.]

flow to the coil. Meter calibration is usually accomplished by increasing or decreasing tension on the needle through these springs.

At rest, with no current flowing through the windings of the coil, the needle is pushed to zero by spring force. When a current is applied, the coil becomes an electromagnet, operating within a second magnetic field produced by the permanent magnet.

Figure 5-4 illustrates what occurs when current passes through the moveable coil. With current flowing, the coil becomes an electromagnet with the polarity shown. Since like magnetic poles repel, the coil turns the pointer across the scale in proportion to the current flow through it.

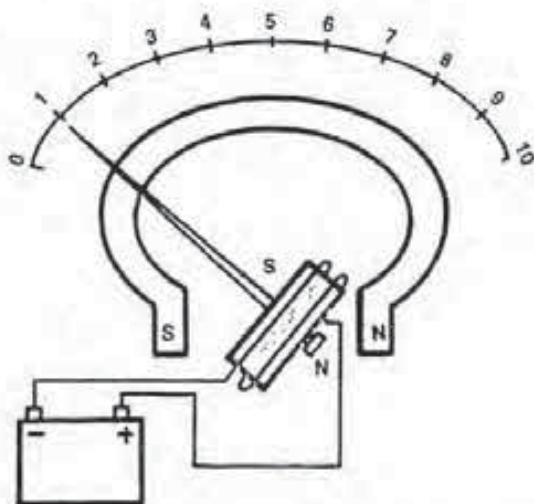


FIGURE 5-4
Current flow deflects needle. (Courtesy of Ford Motor Co.)

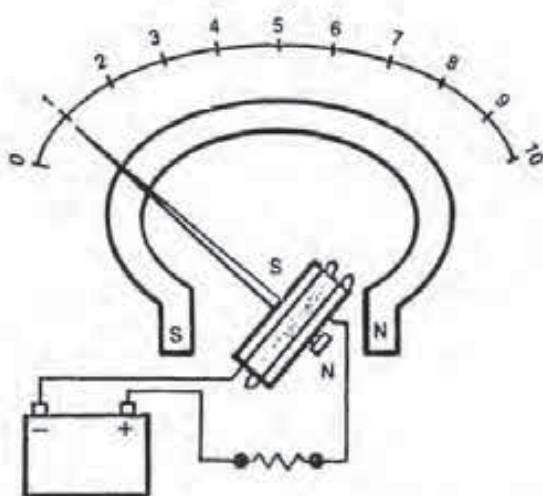


FIGURE 5-5
Basic analog voltmeter design. (Courtesy of Ford Motor Co.)

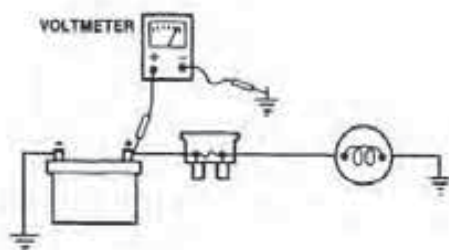


FIGURE 5-6
Voltmeter connected in parallel. (Courtesy of Chrysler Motors Corp.)

5-2 VOLTMETERS

A *voltmeter* is a device used to measure electromotive force (EMF), or voltage, in an electrical circuit. Voltmeters are used to measure such things as the EMF available at a circuit's voltage source, the voltage available at any point in a circuit, the voltage drop caused by a load service within a circuit, and circuit continuity, or completeness.

Analog Voltmeter Design

The basic analog meter illustrated in Figs. 5-3 and 5-4 is made into a voltmeter by simply connecting it across a voltage source. However, to bring the needle movement within the range of the voltage being measured, a resistor must be inserted in the line to the needle movement (Fig. 5-5). Analog voltmeters have as much as 1,000 ohms per volt resistance in the coil circuit. This allows for very slight current flow through its windings.

Digital Voltmeter Resistance

Testing most computerized engine control systems requires the use of a digital voltmeter with a high input *impedance (resistance)* rating of 10 megohms or higher. This means that the digital voltmeter has a minimum of 10 million ohms of internal resistance. A typical analog meter has only about 10,000 to 12,000.

Many microcomputer circuits have high resistance values that control the current flow. During a test, placing the leads of an analog meter, with its lower internal resistance, across a high resistance microcomputer circuit could easily cause a short. In other words, the meter's circuit offers an easier electrical path than the one being tested. The resulting excessive current flow can damage a microcomputer component.

Voltmeter Applications

A voltmeter is always connected across a circuit to read available voltage (Fig. 5-6). This is called a *shunt* connection. In this case, little current will flow through the voltmeter due to its internal resistance.

As you can see in Fig. 5-6, the voltmeter is connected so that it parallels the existing circuit. In other words, the positive voltmeter lead connects to the (+) side of the circuit and the negative lead to the (-) side. Reversing the leads will cause the me-

ter needle to move downscale and possibly damage it. Moreover, for greatest accuracy when using a voltmeter, select a voltage range so that the meter reading is in the mid-scale position whenever possible.

A voltmeter can also be used to measure the voltage drop across a load device or conductor. *Voltage drop* is the using up of voltage, caused by the current flow through a resistance unit. Moreover, any increase in either resistance or current flow will intensify the voltage drop.

To check the amount of voltage drop, connect the voltmeter leads across the points to be measured (+ to + and - to -). The voltmeter should now sense and display the voltage drop across the resistance unit as long as current is flowing in the circuit (Fig. 5-7).

5-3 AMMETER

The *ammeter* is a device that measures the amount of current flowing in a circuit. The instrument can determine if current is in fact flowing (i.e., the circuit has continuity), or if the flow is excessive due to a short in the circuit. In any case, the meter measures the flow in amperes or amps.

Ammeter Design

To make a simple analog voltmeter into an ammeter, a low-voltage internal shunt resistor is added across the terminals of the meter coil (Fig. 5-8). The external leads also connect to the shunt. The shunt resistor protects the small meter coil from excessive current flow.

The resistance of the shunt resistor is very low but high enough to act as a low-resistance internal conductor in parallel with the meter movement. Therefore, the meter coil has to handle and react to only a small part of the current flow in a given circuit.

Many ammeters have a knob or switch that moves shunt resistors of different values into parallel with the meter coil. This changes the proportion of the current flow through the coil and creates different ranges of amperage values that the meter can safely measure.

Ammeter Applications

The ammeter is always connected into a circuit or in series; it is never connected across components (Fig.

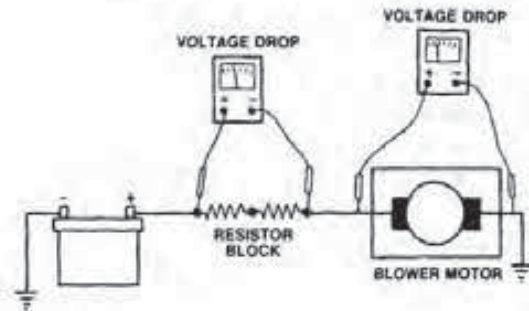


FIGURE 5-7
Voltmeter connected to measure voltage drop. (Courtesy of Chrysler Motors Corp.)

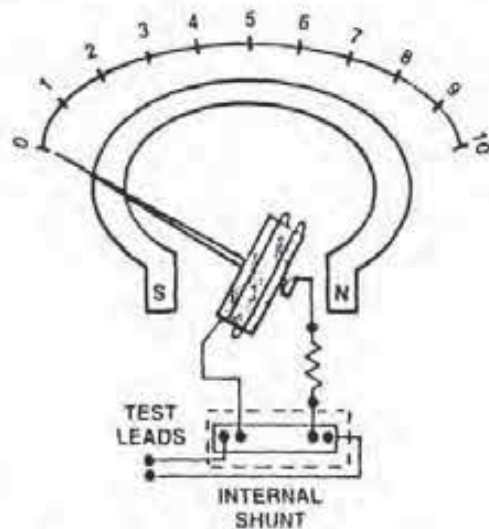


FIGURE 5-8
Ammeter basic design. (Courtesy of Ford Motor Co.)

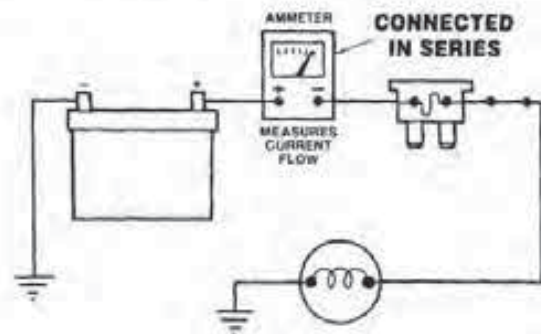


FIGURE 5-9
Ammeter connected in series with a circuit. (Courtesy of Chrysler Motors Corp.)

5-9). If the meter is connected across a component, its resistance is eliminated. In this case, the circuit current flow is shunted around the component. As a result, the meter may burn up due to excessive internal current flow.

In addition, never use an ammeter in a circuit that is carrying more current than the meter is designed to handle. It is all right in such a situation to use external shunts to lower the current flow to within the meter's range. Finally, always use the leads that are supplied with the ammeter since they form a critical part of the design makeup of the unit.

The use of an ammeter in testing components or circuits of computerized engine control systems is very limited. However, some manufacturers do call for the use of an ammeter for adjustment of certain components that are in sensitive circuits. In this situation, never use an ammeter with high resistance for this purpose. Adjustments made with such a meter in the circuit will be faulty because the total circuit resistance will change when the meter is disconnected.

Ammeters suitable for this purpose have an internal resistance of only about 0.01 ohm. This provides less than a 0.1 voltage drop across its leads with 10 amperes of current flowing in the circuit.

5-4 OHMMETER

An *ohmmeter* is an instrument that measures the resistance (in ohms) of a load device or conductor. The design of an ohmmeter's movement in an analog unit is somewhat different from that for a voltmeter or ammeter (Fig. 5-10). The ohmmeter still uses a D'Arsonval movement, but it also has a separate power source plus a resistor connected in series with the coil.

When the ohmmeter leads are connected together, as shown in Fig. 5-10, or to a device being tested, current from the meter's power source flows through the circuit and moveable coil. The power source can be either a small battery or alternating current. Because the source voltage and the meter's internal resistance are known, the current flow through the coil is determined by the resistance of the load device being tested. As a result, current flow through the meter coil is indicated on the meter scale as a resistance measurement.

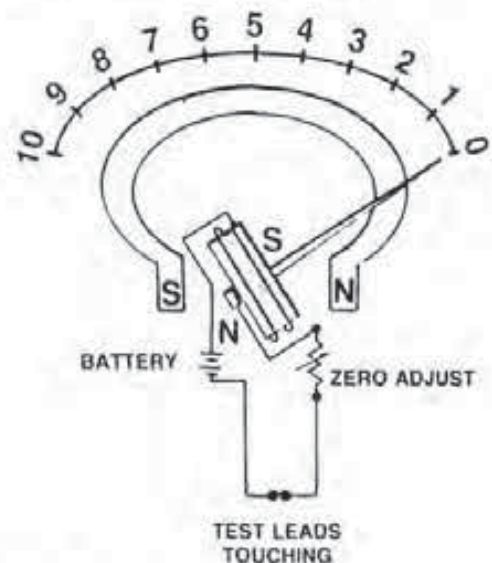


FIGURE 5-10 Ohmmeter design. (Courtesy of Ford Motor Co.)

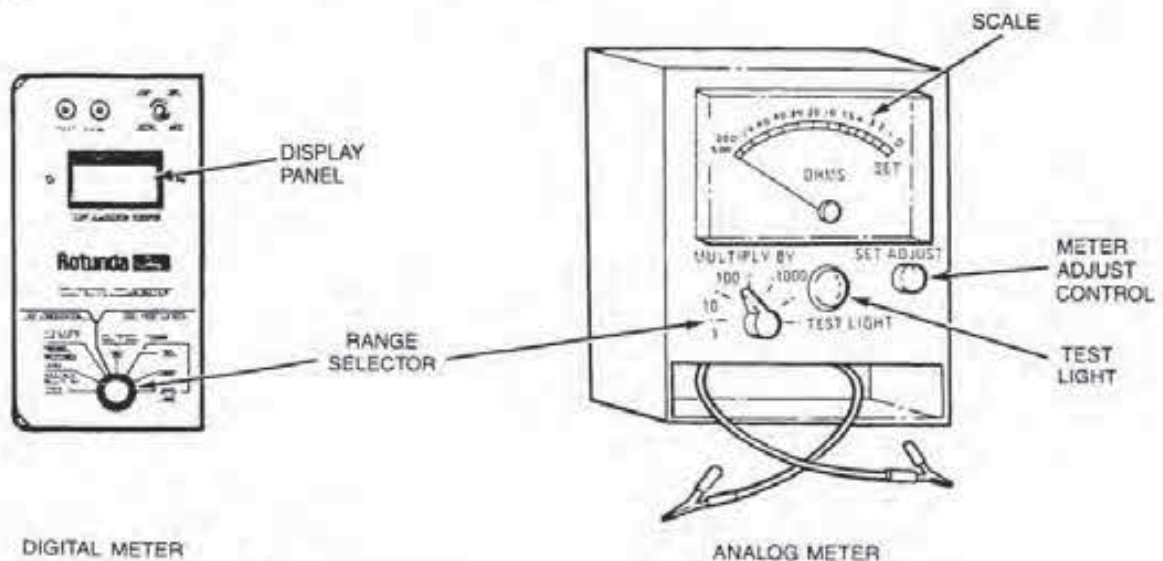


FIGURE 5-11 Design of digital and analog ohmmeters. (Courtesy of Ford Motor Co.)

Notice in Fig. 5-10 that the Ohm scale reads from right to left, just opposite to the one on either the voltmeter or ammeter. The needle, when the meter is not in use, rests against the left or full-scale side. The logic of the system is that when the leads are not connected to a circuit, the needle indicates *infinite resistance*, or a full-scale reading clear to the left. When the leads are connected together, the meter should read *zero resistance*, and the needle should be clear to the right.

Like voltmeters and ammeters, the ohmmeter usually has several scales to read from. A range selector switch determines which scale the operator will use for test purposes (Fig. 5-11). The lower the selector position number the operator can use, the more precise will be the reading taken.

The switch itself inserts different ranges of resistance into the coil circuit. The actual resistance shown on the meter scale is multiplied by the range selector number. For example, if the range selector knob is set at 100 and the needle points to 2, the resistance reading is 200 ohms.

Ohmmeter Calibration

Before using most ohmmeters, the meter needle has to be zeroed, that is, *calibrated to read zero* in any selector range used. This is due to the fact that the voltage of the battery inside the meter will weaken with age and change with temperature. Even the AC voltage used in some meters can vary.

To calibrate an ohmmeter in a given range, connect the two test leads together. The meter should read zero resistance. If it does not, move the calibration, or set adjust, knob until the needle indicates zero ohms. The meter will now provide accurate test measurements.

Digital Ohmmeter

On a digital ohmmeter, the resistance measured is converted inside the unit to a numerical output that is shown in the display window. Digital meters are self-calibrating and therefore do not have an adjusting knob (see Fig. 5-11). Digital meters also have various ranges just like the analog units.

Some microcomputer engine control systems require the use of a digital ohmmeter with at least 10 megohms impedance for testing purposes. The reason for this is that most analog meters use a 9-volt battery as their power source. This is a higher voltage than that supplied by the microcomputer to a number of resistance units or circuits. If an analog

meter is used to test a low-voltage circuit such as this, its internal power source is too high. This can result in excessive current flow, which can cause a resistance unit or microcomputer circuit to burn out.

Ohmmeter Applications

When measuring resistance with an ohmmeter, the load device or conductor has to be isolated by disconnecting it from the circuit. *It is imperative that no circuit current be flowing through the device being tested, or the ohmmeter will be damaged.*

To measure the resistance of a typical resistance unit, the leads of the ohmmeter are connected across the item (Fig. 5-12). This type of connection looks similar to the parallel connection used with a voltmeter. However, because there is no system voltage applied to the ohmmeter, it is not really a parallel circuit.

Instead, the self-contained voltage in the ohmmeter creates current flow through a circuit that consists of the meter movement and the resistance unit being tested. Thus, the ohmmeter provides a complete series circuit.

An ohmmeter reading can pinpoint a high-resistance or a low-resistance problem. If the ballast resistor reading in the example shown in Fig. 5-12 is very high or indicates infinity, the unit has high resistance or is open. A reading of zero shows continuity but no measurement of resistance. The resistor in this case is shorted out.

A reading between zero and infinity is the unit's actual resistance to current flow. To determine the actual resistance of the device, multiply the scale reading by the selector knob number.

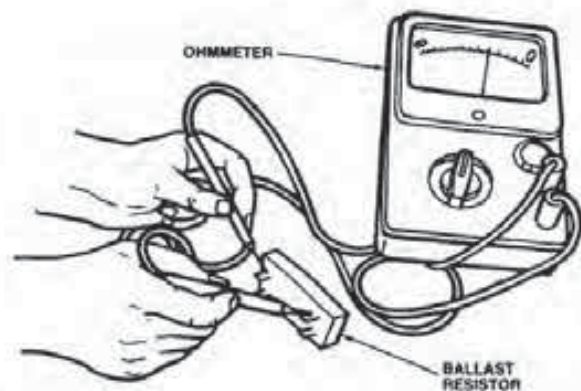


FIGURE 5-12
Testing resistance with an ohmmeter. (Courtesy of Chrysler Motors Corp.)

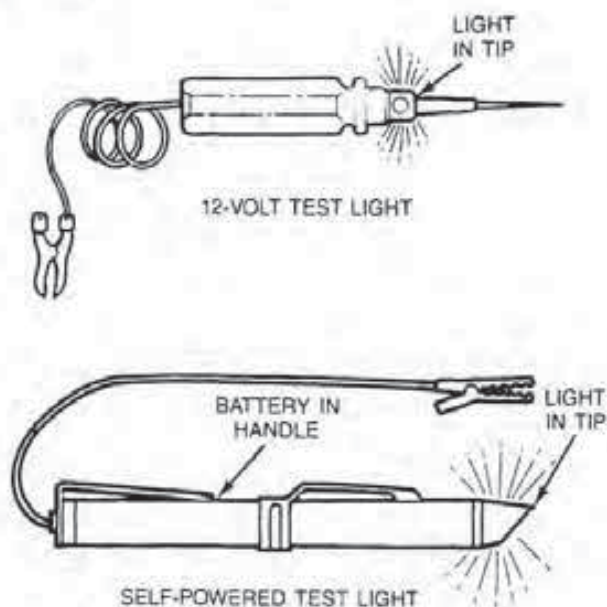
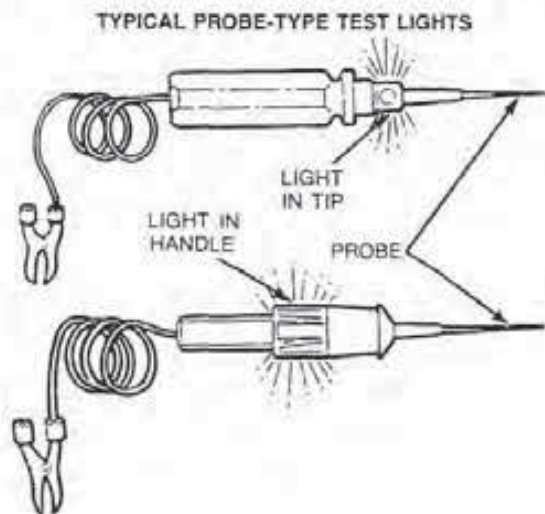


FIGURE 5-13
Test light continuity testers. (Courtesy of Ford Motor Co.)

5-5 CONTINUITY TESTERS AND JUMPER LEADS

There are three different kinds of continuity testers. The most accurate but most expensive is the ohmmeter, described in the last section. The other two are the 12-volt test light and the self-powered test light (Fig. 5-13). These units light up when there is continuity in a circuit or a component is being tested.

FIGURE 5-14
Types of 12-volt testers. (Courtesy of Ford Motor Co.)



12-Volt Test Light

The 12-volt test light checks for electrical power in any given point in a circuit by illuminating. If the bulb does not light during a test, the circuit is open, and no current is flowing.

Moreover, once you are familiar with the brilliance of the test light bulb in a normal circuit, high resistance can be recognized by its effect on lamp intensity. As the current drops in a circuit due to high resistance, the test light bulb will glow less brightly.

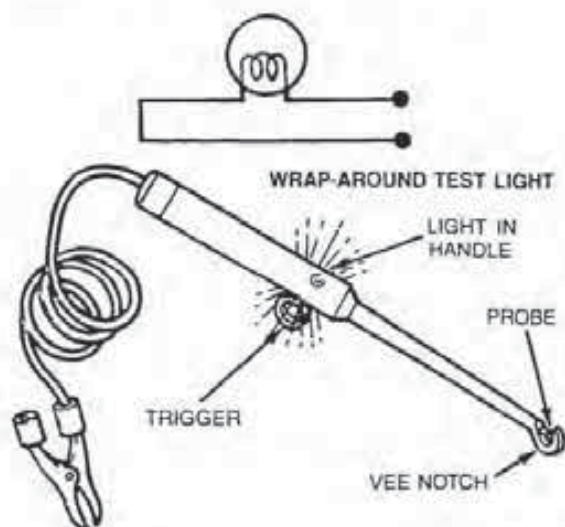
The 12-volt test light depends on the vehicle's battery to power the circuit during a test. Therefore, the battery must be charged sufficiently, or the test results may indicate high circuit resistance.

12-Volt Test Light Design

Manufacturers produce 12-volt testers with different bulb locations and tip designs (Fig. 5-14). Thus, the testers can be used on different types of installations, such as connectors, bare wires, insulated wires, or even wires within harnesses.

Most test lights have a sharp probe tip that can be inserted through the wire insulation for testing. It is important to keep the probe tip sharp to minimize the damage to wire insulation.

To check the tester before use, briefly touch the clip to one battery post and the probe tip to the other; the bulb should burn brightly. A 12-volt tester is not sensitive to the polarity of the battery or a circuit and can be connected with either the tip or clip on a ground. However, the alligator clip is considered the ground side of the tester.



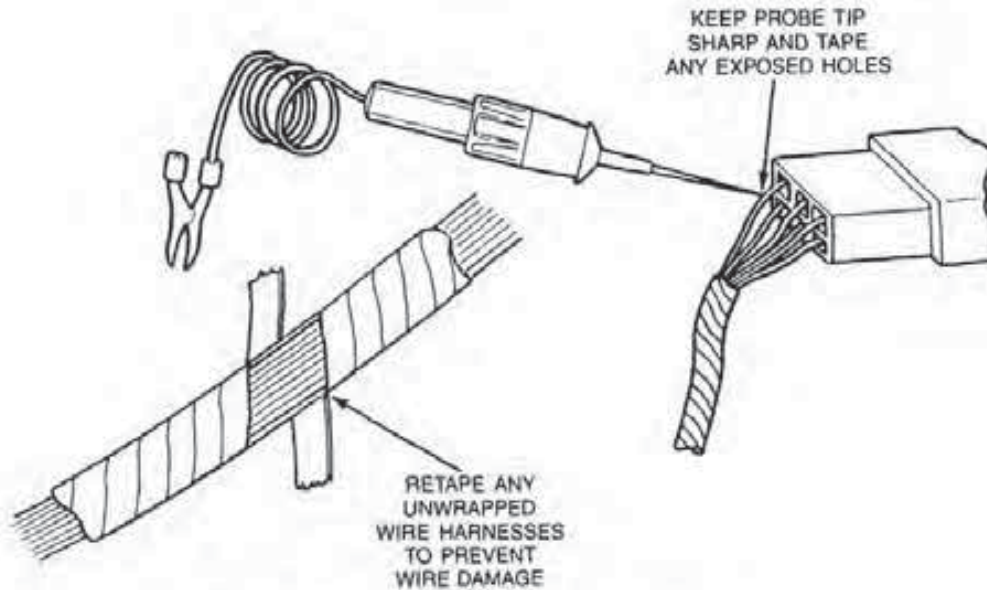


FIGURE 5-15
Typical 12-volt tester usage. (Courtesy of Ford Motor Co.)

12-Volt Test Light Applications

To use the tester to check a particular circuit, attach the alligator clip to a good ground, and then use the tester tip to probe the wire or terminal (Fig. 5-15). If the test light burns, the circuit has power. If the test light does not glow, the circuit is open. To locate the opening, move the test light successively back up the circuit toward the battery or power source until its bulb lights.

When the test is complete, make sure to tape all the holes in the insulation or cover the damaged areas with nonacetic Room Temperature Vulcanizing (RTV) compound.

Caution: Do not use a test light tip to probe electronic ignition or secondary coil cables. Moreover, never pierce wiring on microcomputer-controlled systems unless specifically instructed to do so.

A 12-volt test light can be substituted for a blown fuse to locate the cause of a short to ground (Fig. 5-16). In this case, the test light limits the current flowing in the circuit. If the light continues to burn with all the load devices in the circuit disconnected, there is a short to ground. The various harness connectors should then be unplugged one at a time, working back from the farthest load device in the circuit, until the light goes out. When the light quits burning, the short will be located somewhere between the last unplugged connector and the previous one.

Self-Powered Test Lights

The *self-powered test light* differs from the 12-volt unit in that the former carries its own battery as the source of power (Fig. 5-17). Its primary use is to test for continuity through a component or part of a circuit. However, the light can also be used to check for shorts to the vehicle body or frame.

Since the self-powered light carries its own power source, whatever unit is being tested has to be isolated from the vehicle battery so there is no voltage present. If this tester is connected to 12 volts, the 1- $\frac{1}{2}$ volt bulb will burn out.

The self-powered test light serves a dual purpose. It can be used to check for either an open or a short circuit when power is isolated from the circuit. The self-powered test light glows any time it is connected to a complete circuit (Fig. 5-18). However,

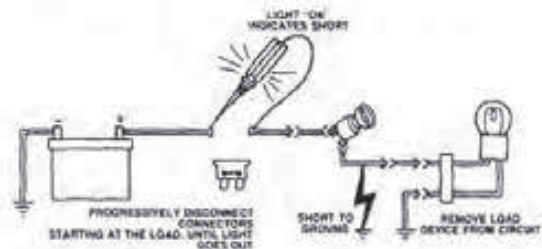


FIGURE 5-16
Test light used to locate a short to ground. (Courtesy of Chrysler Motors Corp.)

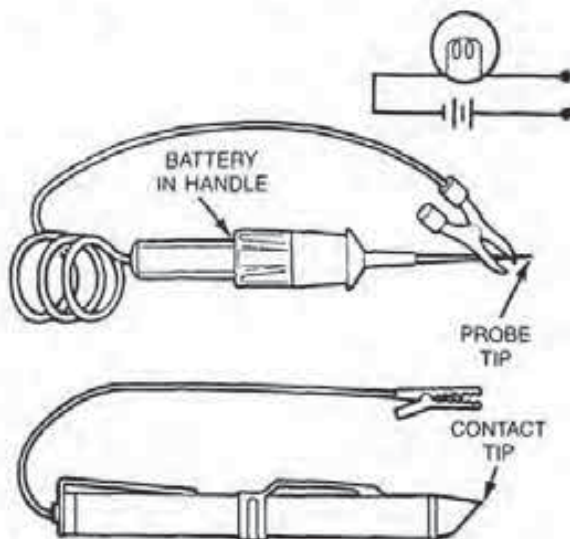


FIGURE 5-17
Typical self-powered test light. (Courtesy of Ford Motor Co.)

the light will not burn, due to its low voltage, if the circuit or load devices have too much resistance.

Caution: Do not test microcomputer circuits and components that operate on milliamperes. The current from the self-powered test light will damage them.

Jumper Leads

A *jumper lead* or *wire* is the simplest type of electrical troubleshooting tool (Fig. 5-19). Jumper leads allow the technician to temporarily bridge a suspected opening or break in a circuit. Technically then, a jumper lead is also a simple continuity tester.

The jumper lead is nothing more than a length

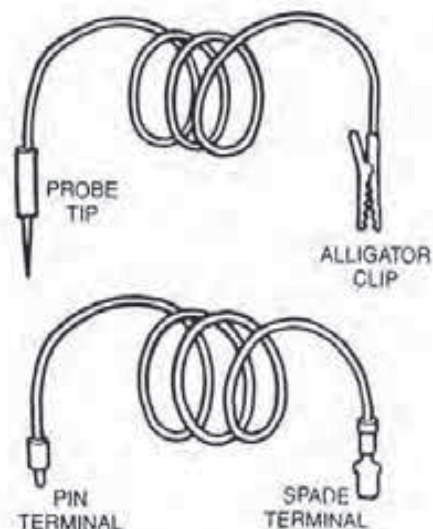


FIGURE 5-19
Typical jumper leads. (Courtesy of Ford Motor Co.)

of wire with a probe tip, various types of wiring clips, or connector terminals installed on either end, as shown in Fig. 5-19. As an aid to troubleshooting, it is a good idea to have several jumper leads available with different end configurations.

The jumper lead in use bypasses a portion of a circuit (Fig. 5-20). In this example, the jumper lead is used to bypass a switch and apply power directly to the load device. If there is power to the switch, and if the circuit works properly with the jumper lead in place but does not work with it removed, the switch is open.

Jumper leads can be used for several other purposes. For instance, the lead can be used to provide a good ground for a circuit or load device. In addition, jumper leads can be used to bench test a load device to confirm its proper operation.

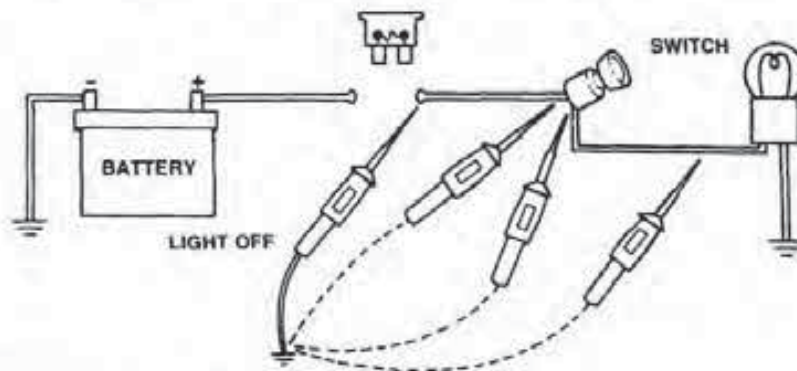


FIGURE 5-18
Using the light to check for an opening or for continuity. (Courtesy of Chrysler Motors Corp.)

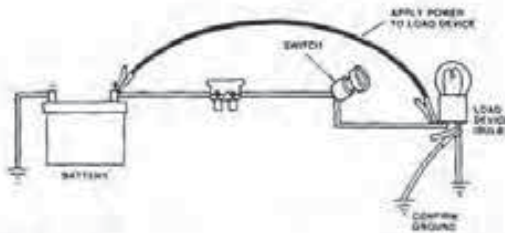


FIGURE 5-20
Jumper lead used to bypass a portion of a circuit. (Courtesy of Chrysler Motors Corp.)

Caution: Be careful when handling a positive (+) jumper lead. If it touches a ground, it will cause a short. Moreover, never use a jumper lead to bypass a load device. This will cause excessive current flow in the circuit, which will overheat the wire or open a fuse, circuit breaker, or fusible link.

5-6 ENGINE PERFORMANCE TEST EQUIPMENT

Before discussing the different types of test equipment used to check electronic circuitry, it is important to stress that most computerized engine control malfunctions are *not* due to problems in the microcomputer. In other words, the cause of the problem is most likely one or a number of simple items related to engine performance, such as a fouled spark plug, open plug wire, disconnected or leaking vacuum hose, burned valve, or a dirty carburetor, to name a few. Any one of these will give a microcomputer a faulty input signal in one way or the other. Therefore, its output signal to any number of actuators cannot be correct, and further malfunctions develop.

For this reason, this section reviews the various types of test equipment used to check systems or components relating to engine performance. These include the compression tester, vacuum gauge, vacuum pump, timing light, spark tester, tach/dwell meter, oscilloscope, and exhaust gas analyzers.

Compression Tester

A *compression tester* is an instrument that measures the ability of a piston to compress the air/fuel mixture within the cylinder. An engine requires good and equal compression pressure in all cylinders for two reasons. First, if compression pressure leaks

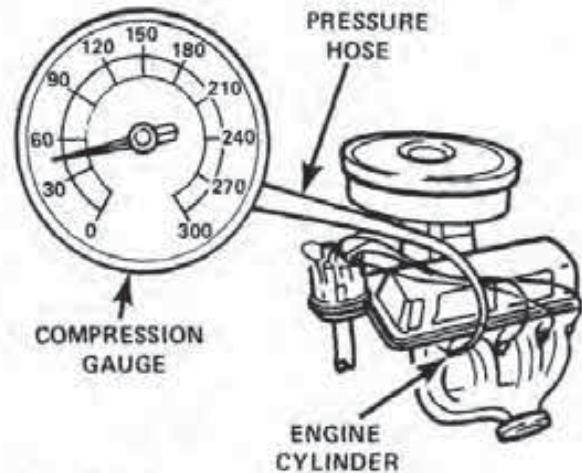


FIGURE 5-21
Gauge used to measure the amount of cylinder compression. (Courtesy of Chrysler Motors Corp.)

past worn rings or valves or around the head gasket or spark plug, engine power is lost.

Second, low or no cylinder compression causes excessive amounts of air to enter the exhaust, which interferes with normal microcomputer operation. During feedback operation, the microcomputer monitors the air/fuel mixture by measuring the remaining oxygen in the exhaust gases via the oxygen sensor. If there is excessive air remaining in the exhaust due to low compression or any type of misfire, the microcomputer senses excess oxygen and will enrich the air/fuel ratio. This compounds the problem of a loss of engine power by over-enriching the mixture to the remaining good cylinders.

A typical compression gauge for gasoline engines (Fig. 5-21) is able to measure high pressures of up to 300 pounds per square inch (psi), or 2,067 kilopascals (kPa). For a diesel engine, the gauge has to read up to 800 psi (5,512 kPa). The most accurate gauge design has a threaded adapter that fits into the spark plug hole. A hose connects the adapter to the gauge.

Another gauge design has an extension fitted with a flat or tapered rubber tip that fits into the spark plug hole. This gauge is used by holding the tip firmly into the plug hole during the test. Consequently, the gauge is harder to use and is usually not as accurate.

Vacuum Gauge

A *vacuum gauge* is a device that measures the ability of a piston to create a low pressure or vacuum within the cylinder and intake manifold (Fig. 5-22).

CHECK FOR LEAKS WITH A VACUUM GAUGE

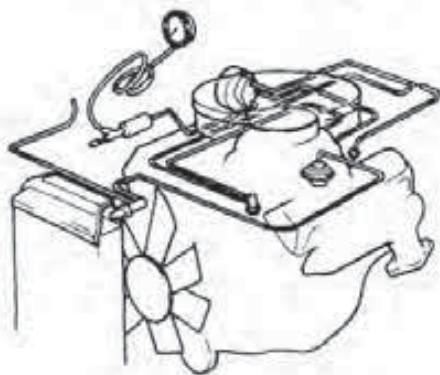


FIGURE 5-22
Typical vacuum gauge installation. (Courtesy of Chrysler Motors Corp.)

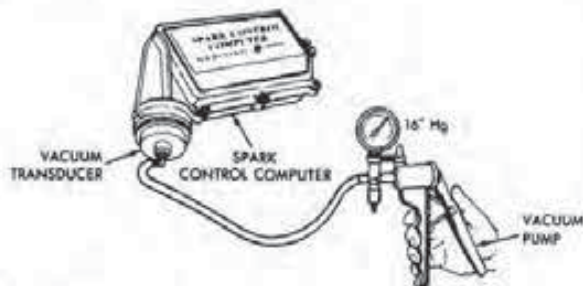


FIGURE 5-23
Vacuum pump. (Courtesy of Chrysler Motors Corp.)

The manifold vacuum, although used to operate a number of pneumatic devices, is necessary primarily to provide a pressure differential between the atmosphere and the cylinder. This is needed to force the air/fuel mixture, via the intake manifold, into all the cylinders. If a loss of vacuum occurs due to a leak, not only is the movement of the mixture to the cylinders affected, but the air/fuel ratio is also leaned out.

The vacuum gauge has a scale with divisions marked off in inches of mercury (Hg), ranging from 0 to 30 inches Hg (0 to 76 millimeters Hg). The movement of the needle on this scale indicates the difference in pressure between the atmosphere and what is in the intake manifold.

All gauge readings are dependent on altitude and must be adjusted for areas above sea level. For example, with every 1,000 feet (305 meters) above sea level, the vacuum gauge reads low by 1 inch (25.4 millimeters) Hg. In this situation, 1 inch Hg will have to be added to any gauge reading taken in order for it to be accurate.

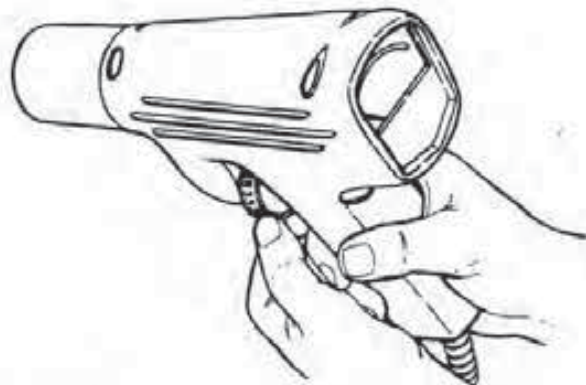


FIGURE 5-24
Power timing light. (Courtesy of Chrysler Motors Corp.)

Vacuum Pump

The *hand-operated vacuum pump and gauge assembly* (Fig. 5-23) is a very useful tool. This device can test the serviceability of most pneumatic controls such as a vacuum transducer, delay valve, vacuum motor, or vacuum advance diaphragm with the unit on or off the vehicle.

The pump shown in Fig. 5-23 consists of a vacuum gauge, vacuum pump, and release trigger. The gauge connects externally via a hose to the component being tested and internally to the vacuum pump. The gauge dial scale is marked off from 0 to 30 inches Hg and 0 to 76 millimeters Hg.

The vacuum pump is inside the main housing. The pump handle mechanically activates this pumping mechanism. It, in turn, evacuates the air from the test component, thus creating a partial vacuum.

The release trigger has one important function. That is, it vents all or part of any vacuum built up by the pump into the atmosphere. Therefore, by coordinating the movements of the pump handle and trigger, the technician can easily pump up a specific amount of vacuum within a unit.

Power Timing Light

The *power timing light* (Fig. 5-24) is used to test and set the initial ignition timing and to quickly check the action of the advance devices. In other words, this unit can measure the amount of spark advancement provided by the mechanical and vacuum advance mechanisms or the electronic control unit. This particular light is powered by the vehicle battery and has an inductive pickup that usually clamps around the number one spark plug cable.

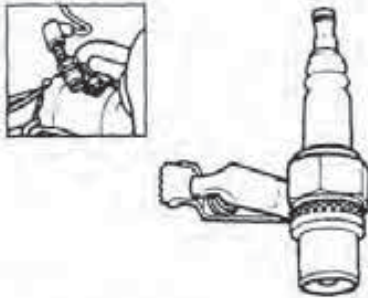


FIGURE 5-25
Spark tester. (Courtesy of Ford Motor Co.)

The light assembly also has a timing advance meter and control knob. The advance meter is built into the back of the light and has a scale with degree markings that are used to measure the exact amount of spark advancement.

The knob controls the electronic timing unit within the light, so it can make the light flash before or after the spark plug fires. By doing so, the action of the electronic timing light makes it appear that the crankshaft timing mark moves backward along the engine degree scale in relation to knob rotation.

Using this light, and with the engine operating at a specified speed, the technician can bring the timing mark back into alignment with the initial timing indication on the degree scale. The meter on the light shows the exact amount of spark advancement for which the light has compensated. The light then lets the technician read the total spark advancement much more accurately than possible by just viewing the timing mark movement of the engine degree scale.

Spark Tester

A *spark tester* is a device that is used to check the secondary output voltage of the ignition system without removing a spark plug from the engine. The tester (Fig. 5-25) lets a technician see if the ignition coil can create enough energy to arc across a very wide gap, yet the tool does not allow the system to operate open circuited.

This is important for two reasons. First, electronic ignition systems can produce very high voltages when open circuited. If a technician holds the coil wire too far away from a ground while testing output voltage, he or she can receive a shock if the cable's insulation is defective.

A number of manufacturers do not want their ignition systems operated open circuited because this can damage the coil or other components. A typ-

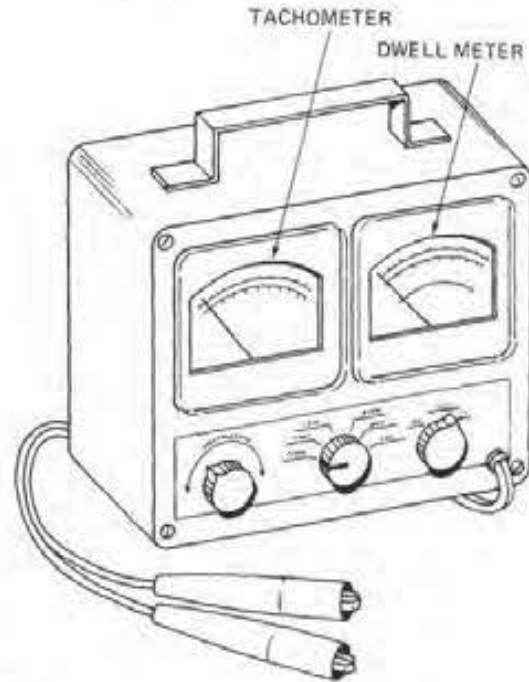


FIGURE 5-26
Typical tach/dwell meter.

ical example of this problem can occur in a General Motors high energy ignition (HEI) system. An open secondary circuit can cause a high voltage surge. Moreover, in its attempt to reach a ground, the voltage surge will pass through the integral ignition module and destroy it.

The tester, which is grounded via the alligator clip, prevents excessively high secondary voltage by supplying a large but calibrated gap opening between two plug electrodes. The coil has to produce high voltage to bridge the air gap but not enough to cause damage.

Tach/Dwell Meter

A *tach/dwell meter* is an instrument that combines both a tachometer and a dwell meter into a single unit (Fig. 5-26). Both of these instruments are special types of analog voltmeters. For test purposes, the unit is connected to the ignition primary circuit. With the engine operating, the primary circuit provides an on-off-on voltage signal to the meter. The meter's internal circuitry converts this signal to a varying amount of current flow through the D'Arsonval instrument coil.

The tachometer scale has divisions to show engine speed in revolutions per minute (rpm). As engine speed varies, the primary circuit's on-off-on

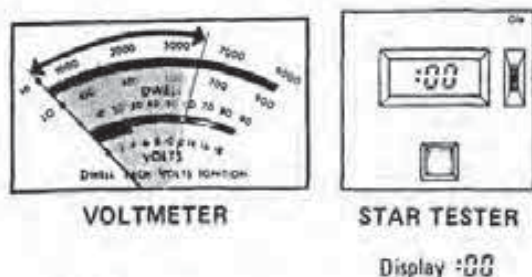


FIGURE 5-27
Use of a dwell meter or voltmeter to read service codes.
(Courtesy of Ford Motor Co.)

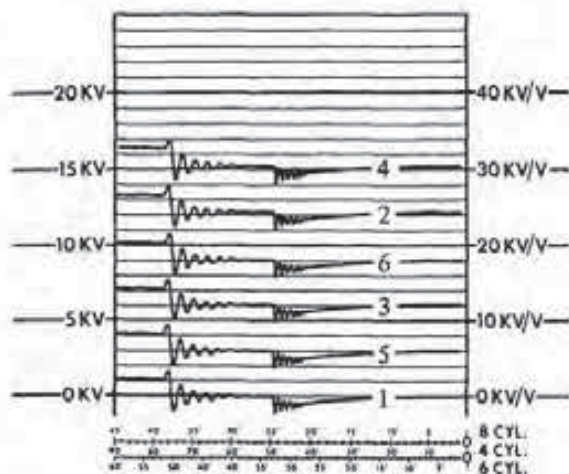


FIGURE 5-28
Typical oscilloscope screen. (Courtesy of Sun Electric Corp.)

voltage signal changes. Consequently, the tachometer needle moves to a different location on the engine speed scale.

The dwell meter scale has markings that show degrees of distributor shaft rotation. The position of the dwell meter needle then indicates, in terms of degrees of distributor shaft rotation, just how long current is allowed to flow in the ignition primary circuit. In the conventional contact point ignition system, dwell is determined by the opening and closing of the points. In electronic systems, dwell is determined by circuitry in the ignition module, or by the microcomputer in a number of computerized engine control systems.

The dwell meter is also used now for several other types of tests. For example, General Motors and some other manufacturers specify the use of a dwell meter to test the operation of mixture control and other solenoids that operate continually with varying duty cycles. The *duty cycle* is the percentage of solenoid or component on-time during an on-off cycle.

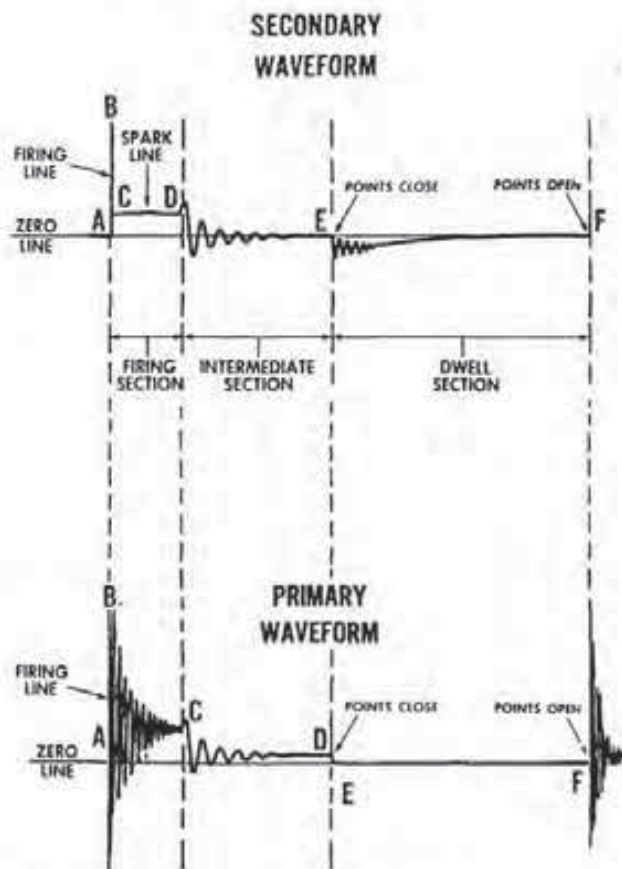


FIGURE 5-29
Secondary and primary waveform patterns of a conventional ignition. (Courtesy of Sun Electric Corp.)

In addition, some manufacturers specify the use of a dwell meter or an analog voltmeter to read service codes stored in microcomputer memory (Fig. 5-27). In this case, the meter is used in place of an automatic readout unit like a STAR tester. The dwell meter or voltmeter indicates a service code as pulsing movements of the instrument needle. A code 24, for example, registers as two fast needle pulses, a two-second pause, and then four additional fast needle pulses. Normally, about a four-second pause separates service codes when more than one is in microcomputer memory.

Oscilloscope

The *oscilloscope* is an instrument designed to aid in diagnosing ignition system malfunctions. Through its proper use, the technician can readily locate abnormal conditions within the ignition system by comparing the patterns observed on the scope screen (Fig. 5-28) with those of a trace from a nor-

mal operating system. In addition, the oscilloscope can indicate malfunctions in the alternator and often other abnormal conditions such as a high combustion chamber temperature, high pressure, or an incorrect air/fuel ratio.

The oscilloscope itself converts the complex electrical voltages developed during the ignition cycle into a graph-like picture. This picture (waveform pattern) represents all phases of the ignition cycle at the same instant they occur in the operating cycle (Fig. 5-29). The waveform permits accurate observation of the factors affecting ignition system operation that were once assumed in theory only. Moreover, since a properly operating ignition system provides a characteristic pattern, any deviation from it indicates some type of malfunction.

Each part of the waveform represents a specific phase of ignition system operation. For the purpose of understanding it, a pattern is divided into three sections: (1) the firing, (2) the intermediate, and (3) the dwell.

An oscilloscope screen can display both secondary and primary patterns (see Figs. 5-28 and 5-29). To do this, the screen is laid out in kilovolts (kV) to permit accurate voltage measurements. Each vertical division at the left side of the screen represents 1 kilovolt (1,000 volts). Each mark at the right side represents 2 kV.

The secondary waveform is more informative for showing overall ignition system operation than the primary pattern. However, ignition system problems that affect the intermediate or dwell section of the pattern will be indicated in both types of waveforms. Therefore, a primary pattern is basically used to permit a scope test when secondary circuit connections are not accessible, observe point conditions or actions of switching transistors, and provide a dwell pattern of greater clarity at the discretion of the operator.

With either type, the waveform is a picture of voltage in relationship to time. All vertical movement of the trace represents voltage—one polarity when the trace is above the zero kilovolt line and the opposite when it is below this line. Therefore, an oscillating pattern above and below the zero line represents AC voltage. Any vertical trace can be measured by comparing it to the graduations on the scope screen.

Horizontal movement of the trace represents time. On newer scopes, this is measured by screen markings in milliseconds. On older models, the divisions were in terms of distributor shaft degrees of rotation.

Figure 5-29 illustrates the ideal waveform for

a conventional ignition system. The patterns for electronic systems are similar, but there are some differences. Patterns for electronic systems can be found in Chapters 6-11.

Exhaust Gas Analyzers

There are three types of *exhaust gas analyzers* in use, the two-, three-, and four-gas models. The two-gas (infrared) analyzer is built for use on vehicles without catalytic converters. The three- and four-gas units are designed for use on all vehicles.

An *infrared analyzer* is a precise instrument for measuring the carbon monoxide (CO) and hydrocarbon (HC) levels in a vehicle's exhaust (Fig. 5-30). The analyzer operates on the principle of passing a single beam of infrared light through a gas sample taken from the tailpipe. The beam is chopped by a rotating wheel containing optical fibers that derive a signal proportional to the percentage of CO and HC in the sample. These data are electronically processed to separate the carbon monoxide and hydrocarbon signals and apply them to analog-type meters on the analyzer console.

The sample is usually taken via a probe inserted into the tailpipe. However, some vehicles with catalytic converters have a probe access hole in front of the converter to permit the use of this analyzer. In either case, the probe connects to the analyzer through a sampling hose and water trap that removes moisture.

The analyzer measures CO content as a percentage by volume. For instance, a one percent CO reading means that one percent of the total volume of exhaust gas is CO. Some of the most likely causes of excessive CO levels are the carburetor idle mixture is set too rich, the carburetor circuitry is malfunctioning, the choke is malfunctioning or misadjusted, the air cleaner is clogged, the air pump is inoperative, the positive crankcase ventilation (PCV) system is inoperative or clogged, the idle speed is below specifications, the initial timing is incorrect (over advanced), or the emission control devices are inadequately maintained.

HC levels are measured in parts per million (ppm) by volume. For example, a reading of 100 ppm indicates that for every million parts of exhaust gas, 100 parts are HC. Some of the most common causes of excessive HC readings are the cylinder compression is low, there are vacuum leaks, the ignition timing is incorrect, the carburetor is out of adjustment (too rich or too lean), the emission control devices are improperly maintained or adjusted, the spark

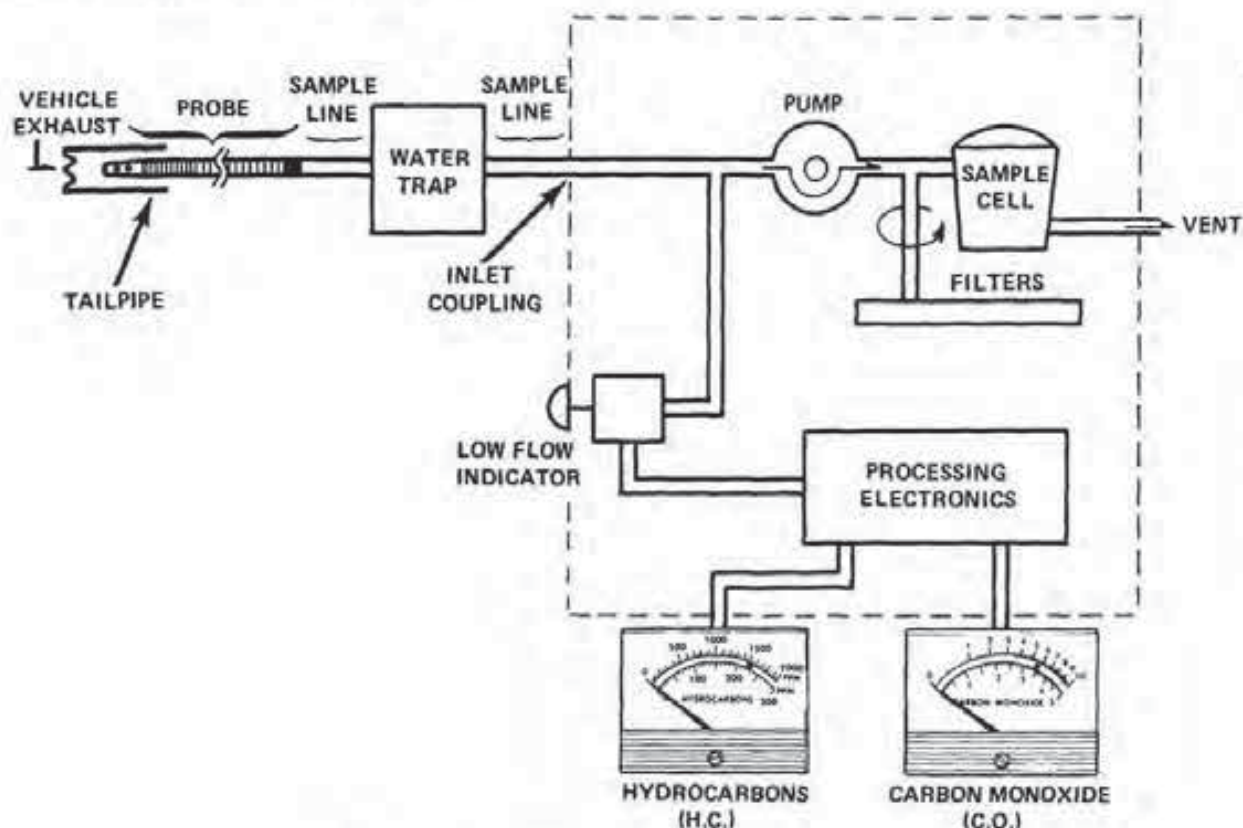


FIGURE 5-30
Typical infrared analyzer design. (Courtesy of Chrysler Motors Corp.)

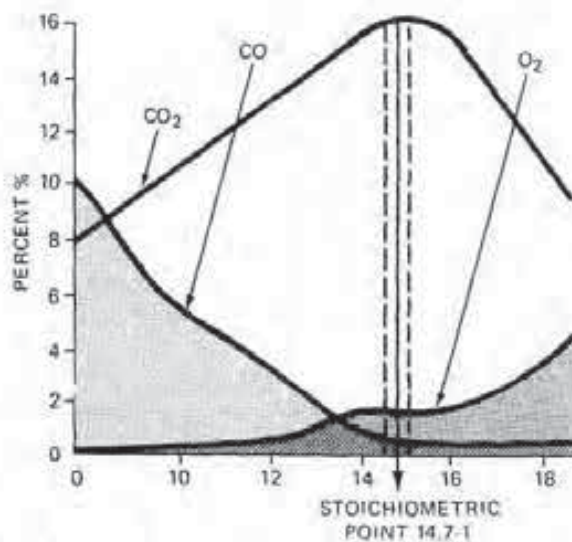


FIGURE 5-31
Oxygen and carbon dioxide levels are indications of the air/fuel ratio.

plugs are fouled, the secondary ignition cable is broken or defective, the distributor cap is cracked, there is a faulty valve or valve train component, or worn rings or valve guide seals are causing excessive oil consumption.

A *four-gas analyzer* has the ability to measure not only HC and CO levels but also oxygen (O₂) and carbon dioxide (CO₂) levels. A *three-gas analyzer* measures HC, CO, and O₂. These analyzers provide the only method now available for checking the air/fuel ratio of vehicles with catalytic converters that have no access plugs. The problem here stems from the ability of the catalytic converter to reduce the HC and CO emissions to acceptable levels even when the carburetor is set incorrectly. In other words, the HC levels do not increase if the carburetor mixture is set too rich or lean because the converter oxidizes the excessive hydrocarbons. If the air/fuel ratio is set too rich, CO levels do increase, but they are not as high as they would be on a pre-catalytic converter vehicle.

However, O₂ and CO₂ levels are also indicators of the engine's air/fuel ratio (Fig. 5-31). For example, the O₂ level in the exhaust increases signifi-

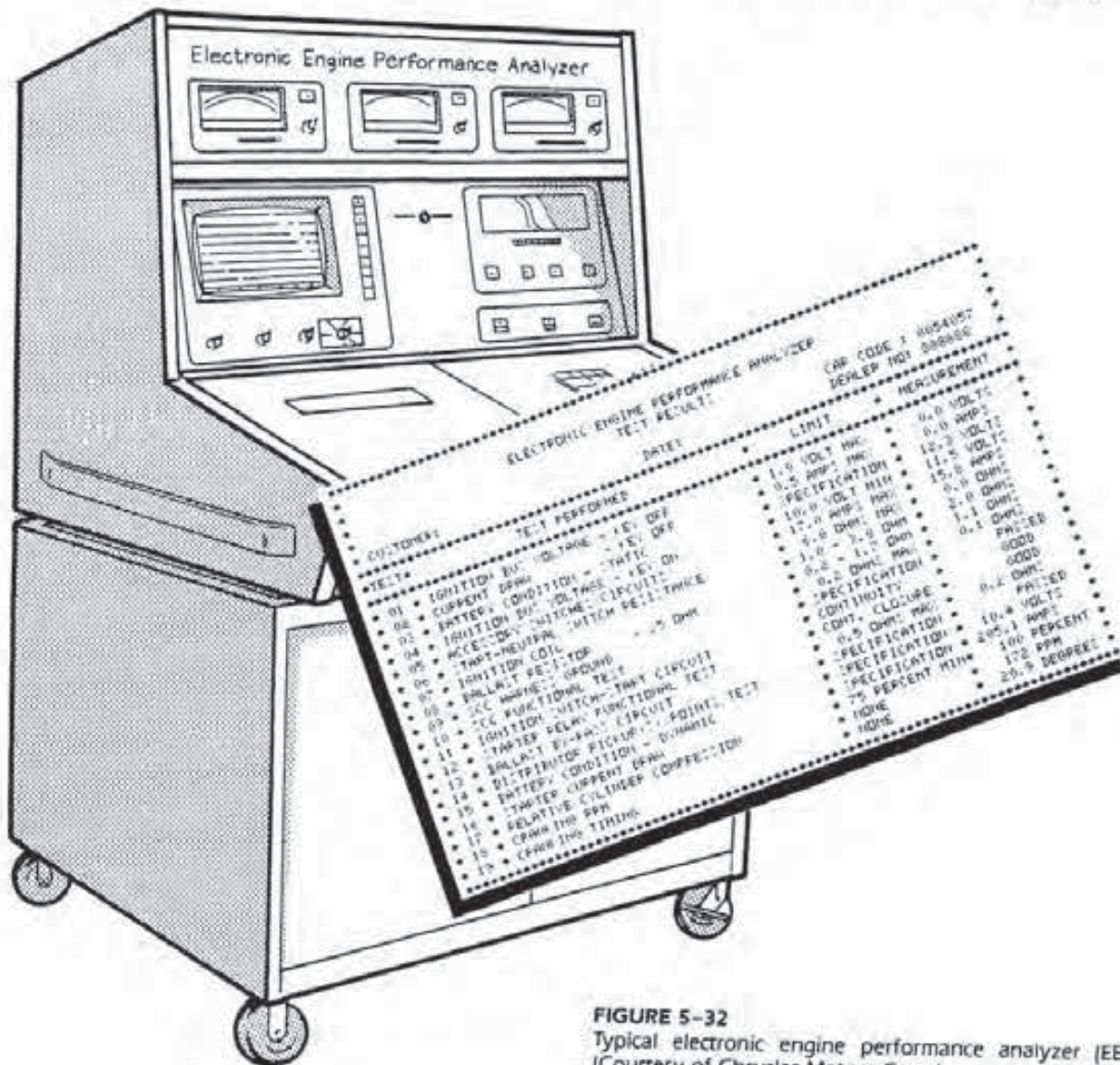


FIGURE 5-32
Typical electronic engine performance analyzer (EEPA).
[Courtesy of Chrysler Motors Corp.]

cantly when the air/fuel ratio becomes leaner than 14.7:1. A ratio of 14.7:1 is the *stoichiometric point* or *ideal ratio* at which gasoline burns most efficiently. Therefore, the O_2 level is an excellent indicator of a lean air/fuel ratio.

The CO and O_2 levels can be used to check catalytic converter action. If the O_2 level is above 0.5 percent, the converter is receiving enough oxygen to function. If the CO level is above 0.5 percent, with an O_2 reading of 0.5 percent, the converter is usually not oxidizing the carbon monoxide.

Carbon dioxide levels in the exhaust increase as the air/fuel ratio becomes lean, up to the 14.7:1 ratio. When the air/fuel ratio becomes leaner than 14.7:1, the CO_2 levels decrease.

Electronic Engine Performance Analyzers

A number of equipment manufacturers are producing an *electronic engine performance analyzer* (EEPA). As the complexity of the automobile increases, diagnosis becomes a larger and tougher job. The EEPA was developed to keep pace with the engineering advances that are a result of government regulations and customer needs.

These EEPA machines (Fig. 5-32) are the most up-to-date diagnostic tools available. An EEPA uses computer technology to precisely test engine electrical and performance-related components in a fraction of the time required for traditional testing.

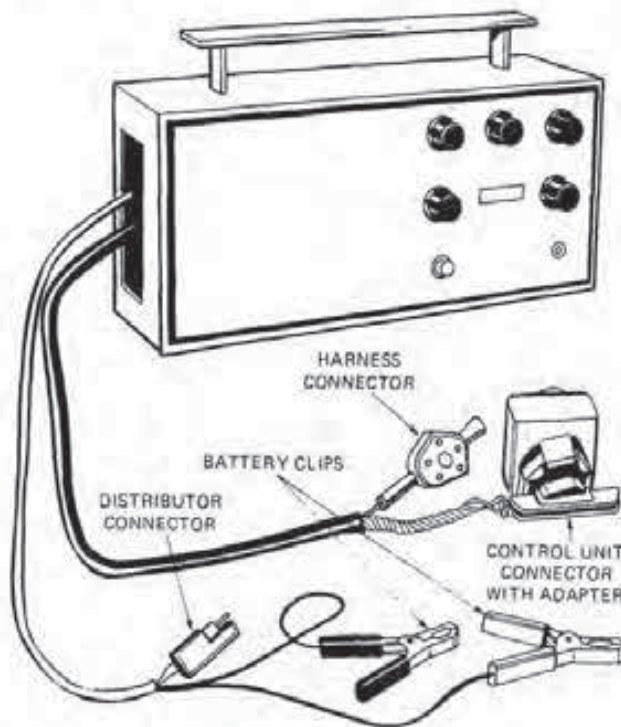


FIGURE 5-33
Typical electronic ignition tester.

One advantage of most EEPA units is that they are easily updated. New model information can be stored in microcomputer memory as it becomes available. Moreover, the modular design of most analyzers gives them the capability of having new functions and tests added as they become available.

Most EEPA units have the same types of instrumentation we have discussed so far. That is, their consoles contain an oscilloscope, voltmeter, ammeter, ohmmeter, tachometer, gas analyzer, and power timing light. These instruments can be used individually by the operator to locate a specific problem, or they can all function as part of a test sequence.

The programmed microcomputer test is performed by the analyzer in a logical sequence. Troubleshooting then becomes very consistent, as the same test methods are used for each vehicle.

Another advantage of these analyzers is that they have a built-in printer. It prints out the results of the programmed test and suggested diagnoses for those components that do not meet specifications. A copy of this report can be used during the writing of the repair order or given to the customer to show him or her how the vehicle is operating.

Electronic Ignition Testers

A few vehicle manufacturers produce a tester for use on their electronic ignition systems (Fig. 5-33). A tester such as this is used to check the operation of the entire system or to test a number of components off the vehicle. The battery clips shown in Fig. 5-33 are used only during off-vehicle testing. Lights on the face of the tester indicate whether components are faulty or serviceable.

There are also a few aftermarket module testers in use. These devices do not check the system on the vehicle but run a number of tests on the ignition module to determine if it is still serviceable. The advantage to the aftermarket tester is that it is usually capable of checking the modules of most current electronic ignition systems in use.

5-7 MICROCOMPUTER ENGINE CONTROL SYSTEM TESTERS

As mentioned, most microcomputer engine control systems have the ability to store service or trouble codes in memory. These codes can be retrieved and read through the use of an analog voltmeter, a dwell meter, or some type of readout tool or scanner. These instruments can be produced for a given microcomputer system or can test a number of systems.

Figures 5-34 and 5-35 illustrate two readout instruments. The first is a self-test automatic readout (STAR) tester used by Ford on its MCU and some EEC-IV systems. The second is a diagnostic readout tool used by Chrysler Motors Corporation



FIGURE 5-34
STAR tester. (Courtesy of Ford Motor Co.)

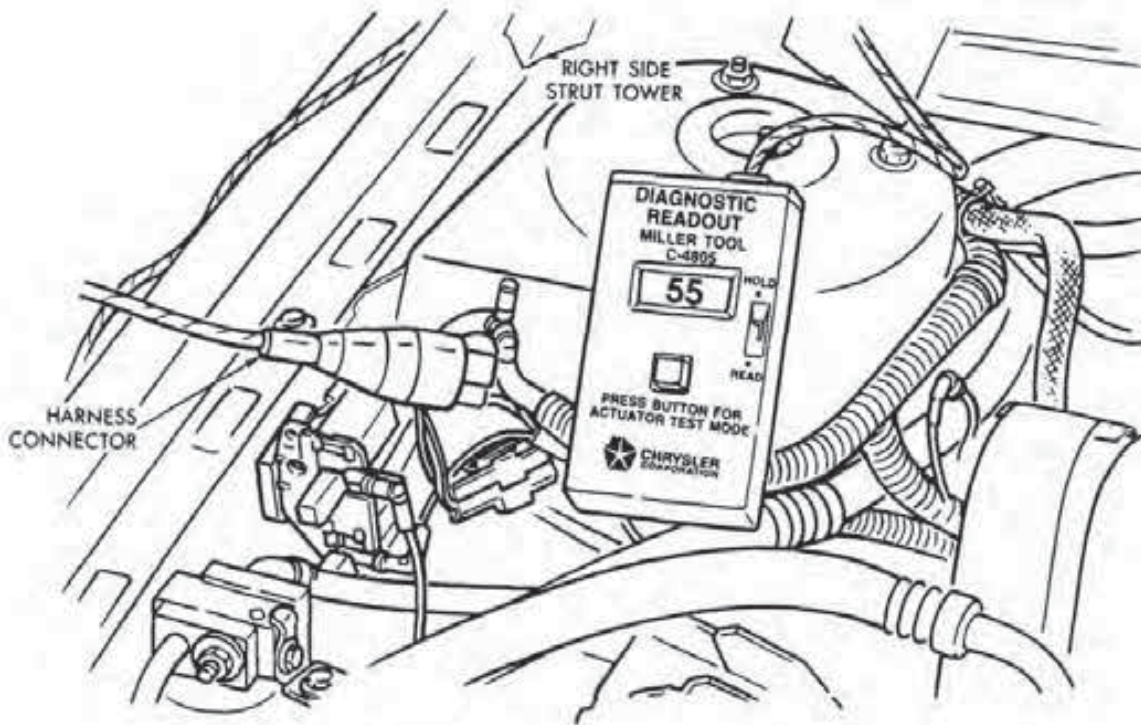


FIGURE 5-35
Diagnostic readout box. (Courtesy of Chrysler Motors Corp.)

on a number of systems.

In both examples, the instrument connects into a system harness connector. Each instrument will then display a service code in a digital format, which will provide valuable information during the troubleshooting of the applicable system.

When a service code appears, it indicates that the microcomputer has recognized an abnormal signal in the engine control system. The service code indicates the results of a failure but does not always identify the failed component. In other words, based on the service code, a technician may need to perform further testing.

Aftermarket Testers

A number of aftermarket testers are available that can check a number of different microcomputer systems. For instance, the Monitor 2000 uses a number of plug-in software cartridges in order to troubleshoot 1981 to current General Motors, Chrysler, and Ford vehicles. The tester is also adaptable to an IBM Personal Computer for data display purposes.

The TIF 1600 on-board computer scanner/printer uses a card to program the unit to fit a certain microcomputer system. This scanner can then

run over 100 different tests and take all sensor readings at the same instant. With this device, the technician can evaluate the operation of a vehicle even while driving at varying speeds. The unit also provides a printout for comparing data taken before and after a repair has been made.

Breakout Box

A *breakout box* (Fig. 5-36) is a special diagnostic tool used on Ford's EEC-IV engine control system. The box has both a male and female connector, which permits the installation of the tester between the microcomputer and its wiring harness.

Located on the face of the tester are a series of numbered pins. Each pin connects into a certain circuit within the system via the wiring harness. With this arrangement, the technician can use a digital volt-ohmmeter to check voltage or resistance in various circuits or components of the system as called for by pinpoint tests in the service manual.

CAMS and OASIS

CAMS and OASIS are two rather unique diagnostic tools available to some dealership technicians. Al-

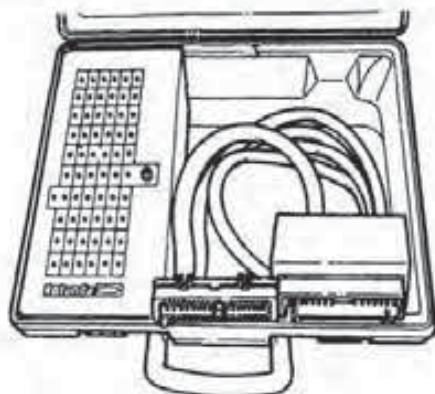


FIGURE 5-36
Breakout box. (Courtesy of Ford Motor Co.)

though both of these systems have been in use for a number of years now, not all dealership service departments have them.

CAMS. General Motors, in cooperation with Electronic Data Systems and IBM Corporation, developed the *Computerized Automotive Maintenance System (CAMS)*. CAMS is a computer-based network diagnostic tool that connects the service-bay technician to some very sophisticated equipment. The system was first set up for Buick dealerships, but it is now used to some extent by Chevrolet, Pontiac, and GMC agencies. Cadillac and Oldsmobile will also soon be on-line with this system.

CAMS consists of a mainframe computer and a service-bay processor terminal (Fig. 5-37). The host mainframe computer for Buick is located in Flint, Michigan. This computer is an IBM 4381 with

enough memory to record every detail of every electronic system Buick has made since 1981, along with each detail of every service procedure necessary to repair them. The service-bay processor is an IBM PC/AT with a touch-control video screen and a printer. The processor hooks up to the vehicle's *assembly line communication link (ALCL)*, a plug with an umbilical harness that connects the on-board computer to CAMS.

In use, CAMS automatically analyzes data from the vehicle's computer, engine circuits, and sensors, and provides a printout of the results. CAMS then interprets the information and guides the technician through a test sequence to locate the cause of the problem. Guidance takes the form of step-by-step instructions that include schematics of the vehicle's wiring harness. The technician can also use the system's manual mode of operation to locate malfunctions.

CAMS backs up the technician in three other ways. First, at a touch of a menu, vehicle specifications, service manuals, and factory service bulletins can be made available. Second, information fed into CAMS by the technician is transmitted to the host computer. Engineers from design, manufacturing, and service study problem situations in order to correct design flaws and offer field repair tips. This eliminates the need for easily lost service bulletins. Third, technicians with an unusual vehicle problem can share it using the *Echo system*. The Echo system allows the technician to share the same information seen on the CAMS' screen with an engineering specialist at the technical assistance center in Flint. Consultations by phone provide immediate feedback aimed at solving the problem.

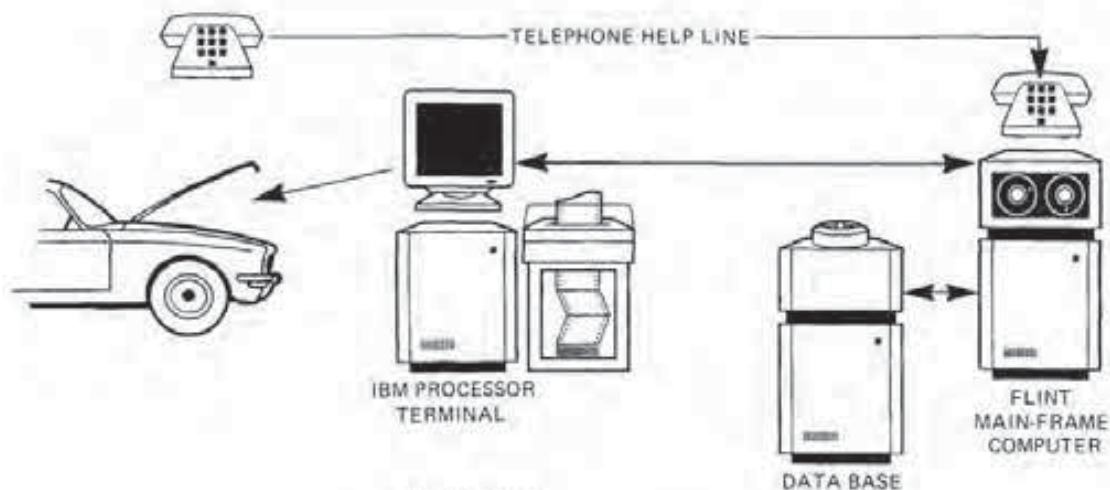


FIGURE 5-37
CAMS design and operation.

OASIS. *OASIS (On-line Automotive Service Information System)* is Ford's factory-direct communication system. OASIS is a keyboard terminal presently found in the service bays of many dealerships. The system involves a direct computer link with a mainframe computer in Dearborn, Michigan.

OASIS is primarily used for transmitting service information, such as the latest service bulletins on new techniques. To receive information, the technician identifies the vehicle and then enters a trouble code. Shortly thereafter, index numbers for applicable technical service bulletins appear on a printout. Many of these numbers are accompanied by a short abstract of the bulletin contents.

OASIS then lists possible corrective measures for the problem. The technician can then use these measures or refer to the suggested technical reference material for guidance in performing the vehicle repair.

5-8 SPECIFICATIONS, DIAGRAMS, AND DIAGNOSIS CHARTS

A technician will quickly find out that a substantial part of the process of repairing computerized engine control systems involves locating and following reference materials. These materials may be in the form of service manuals, service bulletins, driveability test procedures, electrical and vacuum diagrams, or quick and pinpoint test guides. In any case, in order to find and use data from these publications, the technician must be able to correctly identify the vehicle, engine, and emission control package. This is accomplished through the use of VIN numbers, and engine and emission control decals.

VIN Numbers

All cars and light trucks built since 1968 have a *vehicle identification number (VIN)* visible through the windshield on the driver's side (Fig. 5-38). The VIN is considered to be a combination model, part, and serial number for a specific vehicle. It is the starting point for accurate vehicle identification for any service or repair job. Most VIN plates are on the left side of the instrument panel, inside the base of the windshield.

Vehicle identification numbers adhere to a form standardized by S.A.E. For 1968-1980 vehicles, the VIN standard permits up to 15 digits of data. However, most vehicle manufacturers use 11 to 13 letters or numbers. The first 5 to 8 letters or numbers indi-

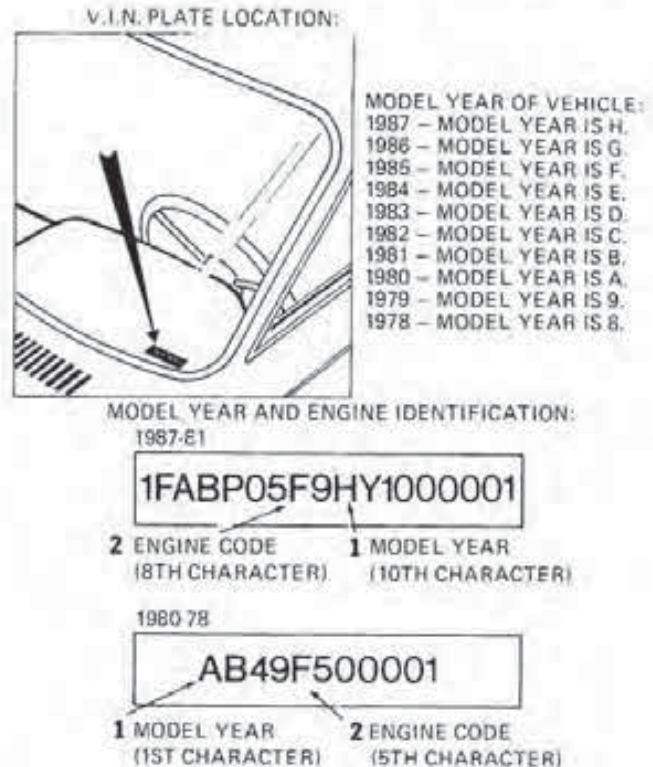


FIGURE 5-38
Typical VIN numbers.

cate the car line, the series, the body type, the engine type, the model year, and the manufacturer's assembly plant. The last 6 digits represent the serial number of a vehicle that was built in a specified assembly plant. S.A.E. expanded the VIN to 17 digits for the 1981 model year to include codes for the company, country of origin, and restraint system, and a check digit that prevents altering the VIN (see Fig. 5-38).

Manufacturers are free to use different letters or numbers in various positions on the VIN plate for various items. About the only thing that is uniform is the last six digits that represent the assembly sequence number. This arrangement makes it impossible to memorize any of the letter and number code combinations used by the manufacturers. However, there is no need for this because reference manuals will indicate which digit to check whenever there is a need to determine specific information about a vehicle for the purpose of ordering parts or locating specifications or procedures.

Engine Decals

Some manufacturers, particularly Ford, install a decal on the engine (Fig. 5-39). This decal contains an

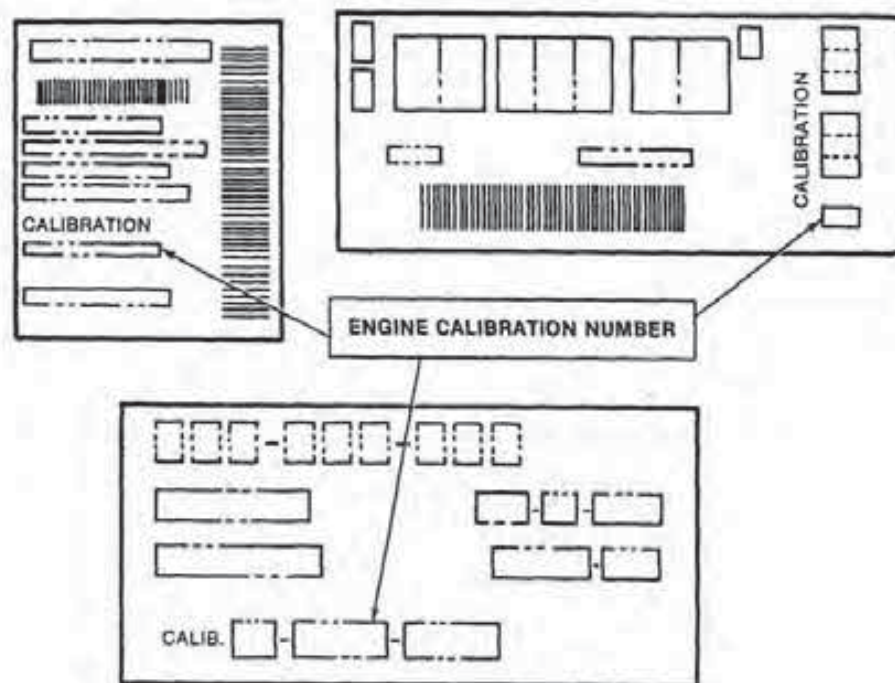


FIGURE 5-39
Engine label. (Courtesy of Ford Motor Co.)

engine code and data specifying its displacement, when and where it was built, its sequence number, and most importantly, its calibration code. The calibration code identifies what ignition system is used on the engine and the layout of its vacuum system, both of which can vary when the same power plant is used for a number of model years and vehicle configurations. Additional information on calibration codes can be found in Chapter 7, section 7-1.

Emission Decals

Now that you are aware of the importance and location of the various identification numbers and codes, let's examine some reference source materials supplied to a technician. These include emission decals,

vacuum diagrams, electrical diagrams, and test guides. Federal law requires each automobile manufacturer to install an *emission control decal* in the engine compartment of every vehicle (Fig. 5-40). This decal gives the engine size and lists a few of the basic tune-up specifications and instructions along with some of the emission control devices used on the vehicle. The specifications may include the initial ignition timing, the curb idle speed, the enriched rpm, the fast idle speed, the exhaust emission limits, the spark plug type and gap, and the engine calibration code (for Ford vehicles).

Because manufacturers often change engine calibrations or introduce new engine/vehicle configurations in the middle of the year, information in the service manual is not always up to date. Therefore,

	VEHICLE EMISSION CONTROL INFORMATION			IDLE SETTINGS: TIMING = 16° BTC ±2° CURB RPM = 750* ±100 ENRICHED RPM = 850* FAST IDLE RPM = 1600* Adjust fast idle RPM on step 2 This vehicle was not designed conversion to meet emission sta ated above 4000 feet altitude. *NOTE: On a new vehicle (und
	ENGINE = 318 Cu. In.	FD-318-2-CA	FAMILY	
	EVAPORATIVE FAMILY E-7			
	THIS VEHICLE CONFORMS TO U.S. E.P.A. REGULATIONS APPLICA- BLE TO 1978 MODEL YEAR NEW MOTOR VEHICLES AND IS CERTI- FIED FOR SALE AT ALTITUDES AT OR BELOW 4000 FEET			

FIGURE 5-40
Typical emission control decal. (Courtesy of Chrysler Motors Corp.)





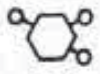

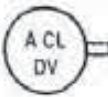






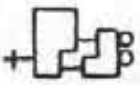







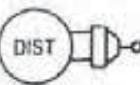





 A CL BI MET	AIR CLEANER BI-METAL SENSOR	 IVV	THERMACTOR IDLE VACUUM VALVE	 VCV 2-PORT	VACUUM CONTROL VALVE (ALSO CALLED A PORTED VACUUM SWITCH OR PVS)
 A CL CWM	COLD WEATHER MODULATOR (IN AIR CLEANER)	 MAN VAC	MANIFOLD VACUUM FITTING	 VCV 3-PORT	
 A CL DV	AIR INLET DOOR VACUUM MOTOR (ON SNORKEL)	 PURGE CV	CANISTER PURGE CONTROL VALVE	 VCV 4-PORT	
 ACV	THERMACTOR AIR CONTROL VALVE	 SA-FV	FUEL-VACUUM SEPARATOR	 VDV	VACUUM DELAY VALVE
 ALT COMP	ALTITUDE COMPENSATOR	 SOL V	SOLENOID VACUUM VALVE	 VOTM	VACUUM- OPERATED THROTTLE (KICKER) MODULATOR
 ANTI BF	ANTI-BACKFIRE VALVE	 TK	THROTTLE KICKER	 VRDV	VACUUM RETARD DELAY VALVE
 CARB	CARBURETOR	 TVS	THERMAL VACUUM SWITCH	 VRESER	VACUUM RESERVOIR
 DIST	DISTRIBUTOR (VACUUM ADVANCE)	 VAC SW	VACUUM SWITCH	 VREST	VACUUM RESTRICTOR
 EGR	EXHAUST GAS RECIRCULATION VALVE	 VCKV	VACUUM CHECK VALVE	 VVVAC	THERMACTOR VACUUM VENT CONTROL VALVE

FIGURE 5-42
Vacuum diagram symbols. (Courtesy of Ford Motor Co.)

source for the distributor. The E port on the carburetor provides the vacuum signal to the exhaust gas recirculation (EGR) valve. The P port on the carburetor provides a ported vacuum source to purge the vapor canister. The manifold vacuum port supplies the vacuum to operate the remaining pneumatic components of the system.

In many cases, the components of the system are shown by symbols (Fig. 5-42). The symbols are again graphic representations of a particular part, and they may vary somewhat among manufacturers. The ones shown in the example are also identified by symbol code letters such as A/CL BI MET for air cleaner bimetal sensor.

To illustrate the use of a diagram, follow the hose routing for the EGR system shown in Fig. 5-41. The first hose connects the EGR valve itself and the EGR/Ported Vacuum Switch. From it, a second hose runs to the Thermostatic Vacuum Switch. Finally, a third hose connects the TVS to the E port on the carburetor. The hoses mentioned may be single or formed into a vacuum harness consisting of a number of hoses attached to some form of connector or fitting.

Electrical Wiring Diagrams

An electrical wiring diagram like its vacuum counterpart is a graphic representation. But in the case of a wiring diagram, it can illustrate all or just a small portion of a vehicle's electrical system (Fig. 5-43).

Years ago, before the electrical system of the automobile became so complex, it was common to see one diagram or maybe two for the whole vehicle. However, this is not the situation now. Today, in vehicle service manuals and aftermarket technical books, diagrams are provided for particular sections, systems, and even individual components found on the vehicle. Moreover, these diagrams may be situated in a number of locations throughout a given reference book. However, the manual index, or in some cases a step in a given troubleshooting procedure, will advise you of which diagram to use.

As mentioned in Chapter 2, a wiring diagram contains a number of symbols. The symbols may be standard ones used throughout the industry or especially developed by a particular manufacturer. In any case, you must become familiar with the symbols before attempting to use a circuit diagram.

When using the electrical diagram, look at it as a road map, with the power source as the starting point. The wiring represents the different roads or

paths to follow until you reach your destination, that is, the component that is malfunctioning. Of course, the main power source is the vehicle battery. But in a typical electrical circuit, the source may be a switch, fuse panel, or even a microcomputer, because they all receive power from the battery. The darkened blocks in Fig. 5-43 show the power sources in this particular circuit diagram.

In diagnosing a certain problem in a circuit, the first step is to determine if there is power at the source when there should be. If there is, the next logical move would be to determine via a voltmeter or test light if power exists at the component that is malfunctioning. Power to a component indicates continuity in the circuit. In this case, the component is probably defective or there is a grounding problem.

If the component is not receiving power, you will have to backtrack along the wiring until you locate the break. This again is best accomplished through the use of a voltmeter or test light.

Caution: Make sure you always use the testing device recommended by the manufacturer when tracing for an opening in a circuit. In microcomputer systems, it is very possible to damage an electronic circuit if the wrong tool is used.

Driveability Test Procedures

When attempting to locate the cause of either a no-start condition or a driveability problem, it is mandatory that you use a *driveability test procedure, quick, or pinpoint test guide*. A procedure or test guide provides a systematic, step-by-step method of checking the function of each engine control system to determine if it is operating as designed. Moreover, if a particular system or component is found to be malfunctioning, the procedure set forth will guide you to where the problem is or instruct you to proceed using a completely different test sequence.

All manufacturers provide guides or procedures for their vehicles. They are normally found in the vehicle service manual or in a special driveability test procedure booklet. In either case, do not attempt to troubleshoot an engine control system without following a guide, and never skip any of the specified steps. Improper diagnosis can cause damage to the microcomputer or system components or lead to the replacement of nonfaulty parts.

Figure 5-44 illustrates a typical driveability test procedure. Notice that this is Test 3, designed to check battery-sensing circuit voltage when a ser-



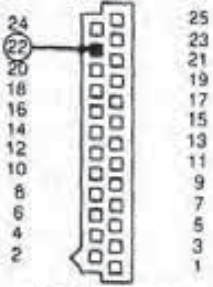
TEST 3	STEP A	CHECKING BATTERY SENSING CIRCUIT (CODE 16)	
PROCEDURE		TEST INDICATION	ACTION REQUIRED
<ul style="list-style-type: none"> Turn the ignition switch off. Disconnect the black connector from the logic module. Connect a voltmeter to cavity No. 22 of the logic module black connector and ground. 		<ul style="list-style-type: none"> Voltmeter should read within one volt of battery voltage. 	<ul style="list-style-type: none"> Voltage okay, replacing the logic module. <p>CAUTION: Before replacing the logic module, make sure the terminal in cavity No. 22 is not crushed so that it cannot touch the logic module pin.</p>
 <p>LOGIC MODULE BLACK CONNECTOR VIEW FROM WIRE END</p>			<ul style="list-style-type: none"> 0 volts, repair the wire of cavity No. 22 for an open circuit to the wiring harness splice.

FIGURE 5-44
Driveability test procedure. [Courtesy of Chrysler Motors Corp.]

vice Code 16 is stored in microcomputer memory. The left two columns of the procedure provide the step-by-step test sequence and an illustration to assist in pinpointing cavity No. 22. The right two columns provide test indications and show what the technician should do if voltage is or is not okay.

Quick and Pinpoint Test Guides

Let's now look at another method of testing for malfunctions that is used by Ford Motor Company. It involves the use of two test guides, the quick and pinpoint. A *quick test* (Fig. 5-45) is a functional test of the system to detect hard fault codes. A *hard fault* code is caused by a problem that is continuous, not intermittent.

The quick test guide basically tells a technician how to obtain trouble codes, but it does not describe any procedure for diagnosing problems other than those requiring just a part replacement. Instead, it provides test results in the left column and informs

the technician which pinpoint test to use. For example, if a Code 21 is stored in memory, the quick test refers the technician to Pinpoint Test Step DE1.

A *pinpoint test guide* (Fig. 5-46), on the other hand, describes how to locate the cause of the code. Each pinpoint test guide has three columns of information. The left column provides the step-by-step procedure, the center provides the test results, and the right indicates the action to take.

5-9 GENERAL SAFETY PRECAUTIONS

As you read through this text, you will come across some italicized material entitled notes and cautions. Each of these has a specific purpose. *Notes* provide added information to help you either understand the design and operation of a system or component or complete a particular procedure. *Cautions* are warnings given to prevent errors that could cause personal injury or damage to the vehicle.

3.1 KEY ON, ENGINE OFF SELF-TEST	
<ul style="list-style-type: none"> Using the On Demand Service Codes from Key On, Engine Off Quick Test Step 3.0 follow the instructions in the Action To Take column in this Step. When more than one service code is received, always start service with the first code received. Whenever a repair is made, REPEAT Quick Test. <p>NOTE: Before proceeding to the specified Pinpoint Test, read the instructions on how to use the Pinpoint Tests at the beginning of the Pinpoint Test section.</p>	
RESULT	ACTION TO TAKE
ON DEMAND SERVICE CODES	
15	▶ REPLACE processor. REPEAT Quick Test.
21	▶ GO to Pinpoint Test Step DE1 .
22	▶ GO to Pinpoint Test Step DF4 .
23	▶ GO to Pinpoint Test Step DH1 .
24	▶ GO to Pinpoint Test Step DB1 .
31	▶ GO to Pinpoint Test Step DL40 .
51	▶ GO to Pinpoint Test Step DE10 .
53	▶ GO to Pinpoint Test Step DH20 .
54	▶ GO to Pinpoint Test Step DB10 .
61	▶ GO to Pinpoint Test Step DE20 .
63	▶ GO to Pinpoint Test Step DH30 .
64	▶ GO to Pinpoint Test Step DB20 .
81	▶ GO to Pinpoint Test Step UA1 .
82	▶ GO to Pinpoint Test Step UA1 .

FIGURE 5-45
Quick test. (Courtesy of Ford Motor Co.)

TEST STEP		RESULT	ACTION TO TAKE
DE1	SERVICE CODE 21: CHECK ENGINE OPERATING TEMPERATURE		
<ul style="list-style-type: none"> • Run engine for 2 minutes at 2,000 rpm. • Check that upper radiator hose is hot and pressurized. • Rerun Quick Test. 		Vehicle stalls	Do not service code 21 at this time. REFER to diagnosis by symptoms.
		Code 21 present	GO to DE2 .
		Code 21 not present	SERVICE other codes as necessary.

FIGURE 5-46
Pinpoint test. (Courtesy of Ford Motor Co.)

Although certain procedures require specific precautions, there are also many general safety practices that you must follow. These practices are summarized below.

1. Most technicians are not aware of the need to protect microcomputer systems against damage from static electricity. Static charges of as low as 30 volts can destroy expensive electronic circuitry. Voltages much higher than this are carried on the surface of humans without their knowing it is there. The best method of preventing microcomputer damage is to drain the charge and provide a static-free work area. This can be accomplished easily by using 3M's static protection kit. This kit includes two different-sized wrist bands, a flexible static-dissipating work surface mat, and a ground cord that connects the wrist band and mat together while grounding them to the vehicle frame.

2. Always wear safety glasses in any area or for any job where an eye hazard exists.

3. When working under a raised vehicle, always install safety stands.

4. Make sure the ignition switch is always in the off position unless otherwise required by a given procedure.

5. Flammable liquids and combustible materials are always present in an automotive repair facility. You can minimize fire hazards by not smoking in a shop area.

6. Operate the engine only in a well-ventilated area to avoid the danger of carbon monoxide.

7. To prevent serious burns, avoid contact with hot metal parts such as the radiator, exhaust manifold, muffler, catalytic converter, and tailpipe.

8. To avoid injury, always remove watches, rings, loose hanging jewelry, and loose clothing before beginning work on a vehicle.

9. Keep your hands and other objects clear of the radiator fan blades. Electric cooling fans can start to operate at any time by an increase in underhood temperatures, even though the ignition switch is in the off position. Therefore, care must be taken to ensure that the fan motor is completely disconnected when working under the hood.

10. Set the parking brake when working on a vehicle. Also, if the vehicle has an automatic transmission, set it in park. Finally, place 4-by-4-inch or larger wood blocks at the front and rear surfaces of at least two tires to provide further restraint against inadvertent vehicle movement.

11. Keep yourself and your clothing away from moving parts, especially the fan and belts, when the engine is operating.

12. Never start an engine when someone is under the vehicle or leaning into the engine compartment. Also, do not start an engine with tools or parts lying on the air cleaner.

13. Never choke an engine with your hand over the carburetor.

14. Never pour gasoline into a carburetor when starting an engine or when an engine is operating.

CHAPTER REVIEW

The following two sections will assist you in determining how well you remember the material contained in this chapter. If you cannot complete a statement or question, refer back to the section marked in brackets that contains the material.

SELF-TEST

1. What is a static protection kit and why is it needed [5-9]?
2. Describe the basic difference between analog and digital meters [5-1].
3. Why are vehicle identification numbers and calibration codes important [5-8]?
4. Describe the four uses of a voltmeter [5-2].
5. Describe how aftermarket scanners are programmed to fit any microcomputer system [5-7].
6. Where is the location and what is the function of the ammeter shunt resistor [5-3]?
7. Describe what occurs to microcomputer operation if engine performance is poor [5-6].
8. What is the basic design difference between an analog ohmmeter and either a voltmeter or ammeter [5-4]?
9. How does the 12-volt test light and the self-powered test light differ [5-5]?
3. When diagnosing a microcomputer system malfunction, the technician must follow [5-8]
 - a. a driveability test procedure.
 - b. quick and pinpoint tests.
 - c. both a and b.
 - d. neither a nor b.
4. Which type of test instrument is the most accurate [5-1]?
 - a. digital
 - b. analog
 - c. test light
 - d. test lead
5. When attempting to trace an electrical circuit problem on a diagram, always begin at the [5-8]
 - a. malfunctioning load device.
 - b. power source.
 - c. starter motor.
 - d. alternator.
6. How are the leads of a voltmeter connected into a circuit to read its available voltage?
 - a. across the circuit
 - b. so the meter parallels the existing circuit
 - c. both a and b
 - d. neither a nor b
7. Every new automobile must have what type of decal [5-8]?
 - a. emissions decal
 - b. engine decal
 - c. fuel economy decal
 - d. load decal
8. What causes voltage drop in a circuit [5-2]?
 - a. current flow through a resistance unit
 - b. a charging system malfunction
 - c. a malfunctioning battery
 - d. a faulty starter

REVIEW

1. What procedure should be used to prevent a vehicle from accidentally moving in the shop [5-9]?
 - a. set the parking brake.
 - b. Place the transmission in park.
 - c. Block the wheels.
 - d. Do all the above.
2. Which meter type has the D'Arsonval movement [5-1]?
 - a. digital voltmeter
 - b. analog voltmeter
 - c. digital ohmmeter
 - d. none of these
5. The STAR tester is used on which Ford system [5-7]?
 - a. MCU
 - b. EEC-II
 - c. EEC-IV
 - d. both a and c
10. How is the ammeter connected into a circuit [5-3]?
 - a. in series
 - b. in parallel
 - c. in series-parallel
 - d. none of these

11. Which type of gas analyzer will function on any vehicle [5-6]?
 - a. two-gas
 - b. four-gas
 - c. both a and b
 - d. neither a nor b
12. An ohmmeter that can be used to test micro-computer circuits must have [5-4]
 - a. high internal resistance.
 - b. low internal resistance.
 - c. an external power source.
 - d. no power source.
13. Which ignition pattern is most commonly read on a scope [5-6]?
 - a. secondary
 - b. primary
 - c. both a and b
 - d. neither a nor b
14. What must be done before using an analog ohmmeter to test the resistance of a part [5-4]?
 - a. The unit must be disconnected from the circuit.
 - b. The ohmmeter must be calibrated.
 - c. both a and b
 - d. neither a nor b
15. Which test instrument can be used to check service codes stored in microcomputer memory [5-6]?
 - a. analog voltmeter
 - b. dwell meter
 - c. automatic readout box or scanner
 - d. all of these
16. What does an infinity reading on an ohmmeter mean [5-4]?
 - a. There is so much resistance it cannot be read on the scale.
 - b. There is so little resistance it cannot be read on the scale.
 - c. There is power to the component being tested.
 - d. none of these
17. What is the function of a power timing light [5-6]?
 - a. to check initial timing
 - b. to measure the amount of total timing advancement
 - c. both a and b
 - d. neither a nor b
18. How can a 12-volt test light be connected to a circuit ground [5-5]?
 - a. with its alligator clip
 - b. by its probe tip
 - c. both a and b
 - d. neither a nor b
19. What test instrument checks the piston's ability to create a low-pressure area [5-6]?
 - a. compression tester
 - b. vacuum gauge
 - c. vacuum pump
 - d. both b and c
20. How is a jumper lead used as a diagnostic tool [5-5]?
 - a. to bypass a portion of a circuit
 - b. to bypass a circuit load device
 - c. to remove the resistance from a powered circuit
 - d. none of these

FORD ELECTRONIC IGNITION SYSTEMS

OBJECTIVES

After reading and studying this chapter, you will be able to:

- explain the negative characteristics associated with standard ignition systems.
- describe the basic design and operation of the Ford transistorized ignition system.
- describe the design of Ford's solid state ignition system.
- identify and know the function of the components of a Duraspark I ignition system.
- describe the design of a Duraspark II ignition system.
- identify and know the function of the components of a Duraspark III ignition system.
- describe the basic design and operation of magnetic-pulse and Hall-effect trigger circuits.
- identify and know the function of the parts of a thick-film integrated (TFI) ignition system.

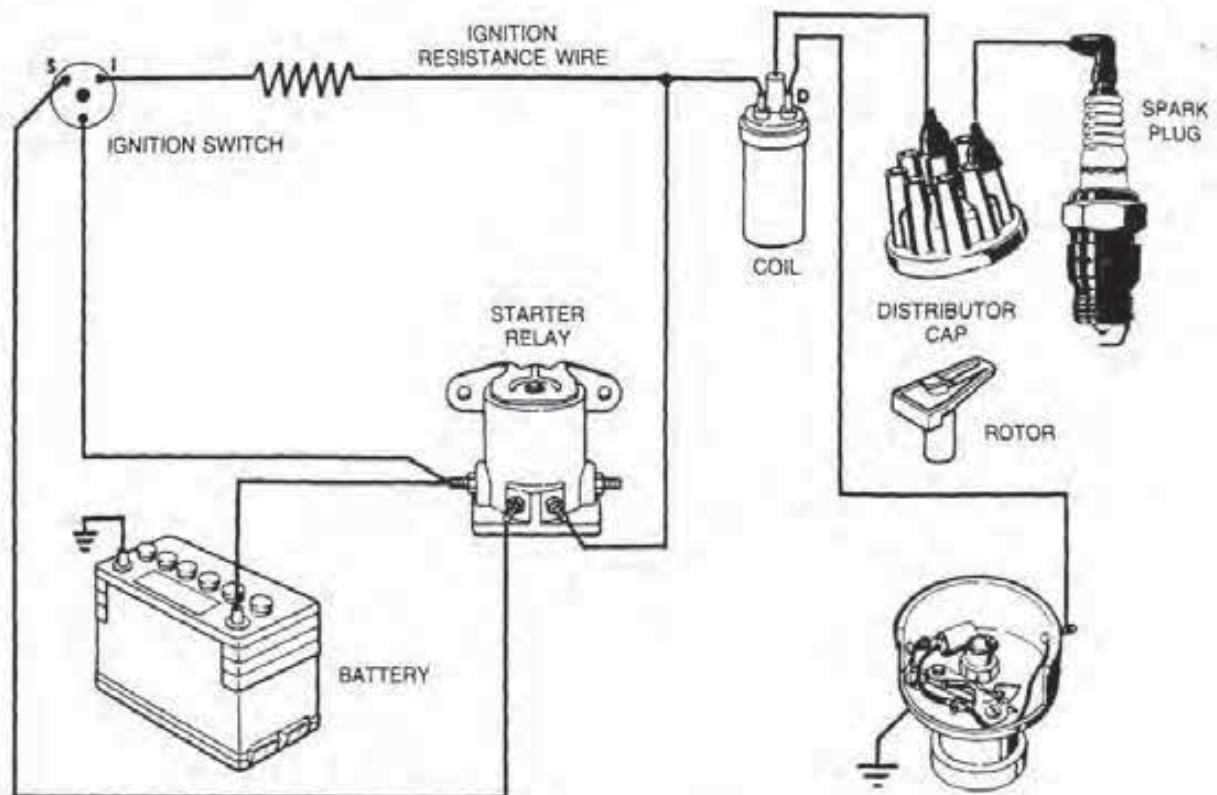


FIGURE 6-1
Standard contact point ignition system. (Courtesy of Ford Motor Co.)

Although the standard contact point ignition system has served the automotive industry well since 1912, it no longer appears on contemporary automobiles. In its place, Ford and the other vehicle manufacturers are using some form of electronic ignition system. The underlying reason for this changeover was the imposition of federal emission standards beginning in the late 1960s. These standards mandated the effective control of nitrogen oxides (NO_x), hydrocarbons (HC), and carbon monoxide (CO).

As the years went by, the standards became more strict. This forced manufacturers to install various emission control systems and to lean out air/fuel mixtures during certain phases of engine operation. However, the engine still had to deliver sufficient power to meet driveability requirements.

It was not long before engineers found that the old standard system could no longer meet ignition requirements. The answer was an electronic ignition system that would respond faster and provide spark plug firing with a precision and intensity that never existed before. To fully understand why electronic systems are far more efficient, let's review some of the negative characteristics associated with standard ignition.

6-1 NEGATIVE CHARACTERISTICS OF STANDARD IGNITION SYSTEMS

The breaker point ignition system (Fig. 6-1) has four inherent negative qualities that curtail its continued use on emission-controlled engines. These include (1) insufficient output voltage, (2) a tendency for voltage decay at high engine speed, (3) an increased maintenance requirement, and (4) a fixed amount of built-in timing advance. Although some of these problems can overlap, each will be discussed separately for purposes of clarification.

Insufficient Available Output Voltage

It is a well-known fact that nonemission-controlled engines require less ignition coil output voltage at idle to create an arc across the plug electrodes. There is a good reason for this. The spark plugs on these engines only require a gap of about 0.035 inch (0.88 mm) because the relatively rich air/fuel mixture at idle creates a rather good current-carrying conductor. As a result, operating voltages at idle are lower. Of course, the available output voltage of the system had to be much higher than this to meet ignition

demands during high engine loads and speeds.

Enter the emission-controlled engine with its leaned out air/fuel mixture at idle. This mixture contained fewer conductive gasoline particles. Consequently, many manufacturers increased spark plug gaps to accommodate a larger quantity of fuel.

The larger gap has the effect of increasing the required system voltage necessary to initiate the arc between the spark plug electrodes. With a higher voltage requirement at idle, the available system voltage must also be increased or voltage reserve will be too small. *Voltage reserve* is the difference between required voltage and available voltage. If voltage reserve is too small, the spark plugs will begin to misfire under heavy engine loading and high speeds. This produces higher emission levels and reduces fuel economy.

Voltage Decay at High Engine Speeds

Voltage decay is a reduction in available system voltage at high engine speeds. To understand this concept, let's review the term *dwell* as it relates to breaker points and coil operation. *Dwell* is the number of degrees of distributor shaft rotation in which the contact points of a standard system remain closed (Fig. 6-2). Dwell is very important because during this period, current flow from the battery through the primary side of the coil must produce a strong electromagnetic field around the primary and secondary coil windings. When this field reaches its full magnetic strength, it is called *magnetic saturation*.

However, magnetic saturation does not occur instantaneously due to *self-induction*, which is the induction of a counter voltage into the coil windings as current passes through them. The reason for this occurrence is that as current passes through each winding, it creates a magnetic field consisting of expanding concentric circles that move outward from the wire. These magnetic circles cut across a section of an adjacent winding before the current can reach that point. The magnetic circles induce a *counter voltage* in the winding, or one tending to cause current flow in an opposite direction to that from the battery (Fig. 6-3). This action resists the flow of current through the entire coil that produces the magnetic field.

Actually, the current cannot flow that way because the battery is already forcing electrons through every turn of the windings in the opposite direction (Fig. 6-4). However, there is this tendency for induced current flow in a reverse direction by the magnetic field as it builds up. As a result, it is harder for the electrons from the battery to move

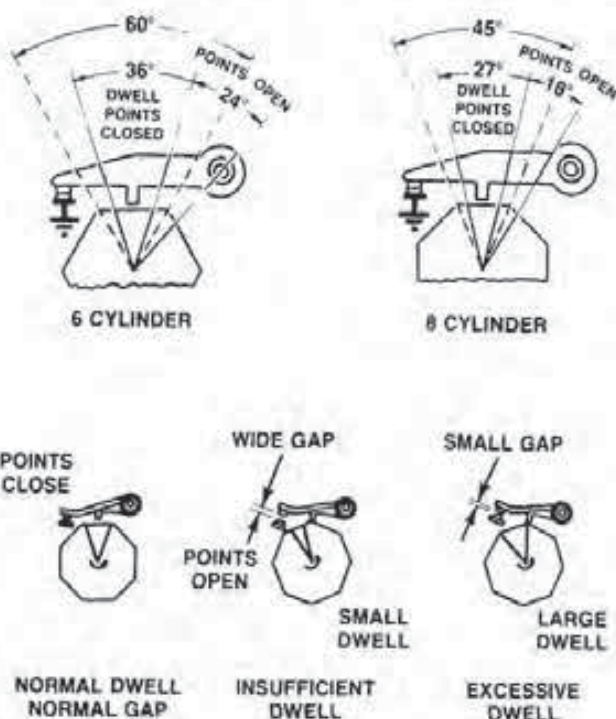


FIGURE 6-2

Dwell is the number of degrees the distributor shaft turns with the points closed. (Courtesy of Ford Motor Co.)

through the primary coil windings. The magnetic field of every winding produces this tendency on an adjacent coil turn, thereby resisting the passage of additional current through the entire unit.

Thus, a period of time is necessary for the battery to overcome this effect and increase the amount of current to the maximum, as determined by the

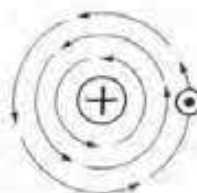


FIGURE 6-3

Effect of the magnetic field from one winding on an adjacent winding. The plus mark indicates the direction of current flow from the battery. The dot shows the direction of current flow due to the induction of a counter voltage.

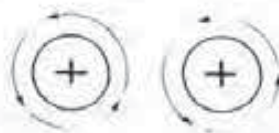


FIGURE 6-4

Battery forces the current to flow through all the windings in one direction.

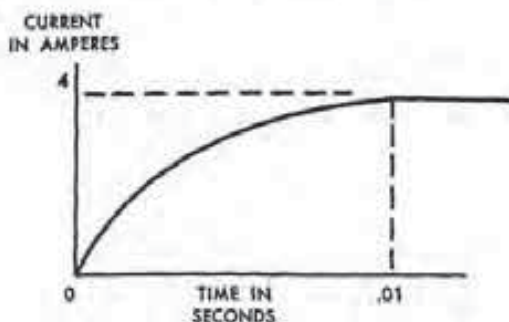


FIGURE 6-5
Graph of the coil build-up time and current flow.

total resistance in the primary coil circuit. This interval is commonly referred to as the *dwell period* or *build-up time* and is only a fraction of a second (Fig. 6-5). In this illustration, a time lag of 0.01 second occurs before the current value reaches four amperes with the contact points closed. This exceedingly short time period makes the situation appear unimportant, but it has always created problems for engineers who design ignition systems.

During idle and low engine speeds, the dwell period is of long enough duration for the primary coil to produce the strong field, resulting in a more than adequate available secondary coil voltage as the points open. At higher engine speeds, a different situation exists. Although point dwell remains constant, there is less time for the primary coil build-up. In other words, the points open and close much faster at high speeds, but their closed period, in degrees, remains the same. As a result, there is a reduction in the strength of the magnetic field produced by the primary coil, which reduces available output voltage, or decay. Coil reserve is therefore lower, increasing the tendency for spark plug misfires.

However, with electronic controls replacing the use of contact points, the dwell period can be lengthened as necessary. This, of course, provides a more constant coil output even at high engine speeds.

Increased Maintenance Requirement

The standard contact point ignition system does require frequent inspection and service or it will begin to malfunction. Although the spark plugs normally need attention at given intervals, they tend to become fouled more easily due to problems with the contact points. The main part of the system that has to be checked most often and that usually wears out the fastest is the contact point assembly.

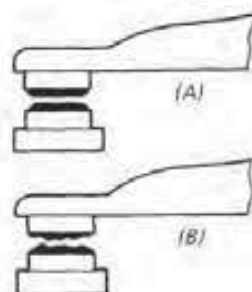


FIGURE 6-6
(A) Normal point-open condition. (B) Badly eroded and pitted points.

There are a number of reasons for this. First, since the contact points open mechanically by means of a rubbing block riding on the distributor cam, there is opportunity for wear. As the rubbing block wears down, the dwell period increases (see Fig. 6-2). Increased dwell would seem to increase the efficiency of the system, but this is not the case. The lengthened dwell period over the specified amount has the effect of retarding ignition timing and causing increased point arc. The retarded timing is the result of the points opening later than they should. The excessive point arc is due to the increased magnetic field created by a lengthed dwell period. When the points open in this situation, the self-induced voltage in the primary windings is higher than it should be. Therefore, the condenser cannot absorb the higher voltage level, resulting in arcing at the points.

Second, because the contact points are an electrical switch, they are subjected to arcing during both opening and closing periods. This tends to erode away the point surfaces. The points arc slightly as they close due to the one ampere to four amperes of battery current passing through the contacts on the way to the coil.

As the points open, the magnetic field around the primary coil collapses. This not only induces 30,000 volts to about 50,000 volts in the secondary coil due to mutual induction, but generates 250 volts to 450 volts in the primary coil due to a form of self-induction. This latter voltage has a polarity that attempts to keep current flowing across the opening points.

The condenser is in the primary circuit to temporarily absorb this primary voltage so the points can open without arcing and the magnetic field around the primary coil can collapse quickly. The problem here is that there is no single condenser capacity that is right for all phases of ignition system operation. Consequently, arcing of the points is a

constant problem that eventually leads to complete deterioration of the point material (Fig. 6-6).

As the surfaces burn away, the dwell period decreases because the contact points stay open longer. This action advances the ignition timing and causes voltage decay at high engine speeds. Therefore, the spark plugs begin to misfire and foul.

The third maintenance problem with contact points deals with their alignment, spring tension, and adjustment. After installation, the contact point surfaces must be parallel, and at least 90 percent of the surface area should mate with the points closed. If not, the points fail prematurely due to arcing.

If spring tension is too weak after installation, the points will bounce. *Point bounce* is a condition in which the points pop back open after closing, and it usually occurs at higher engine speeds. The end result is high-speed spark plug misfire.

If spring tension is too great, the rubbing block, cam lobe, and distributor shaft bushings will wear out prematurely. This causes the timing dwell to vary not only over a period of time but also from cylinder to cylinder.

There are two methods of adjusting contact points. The first requires the use of a dwell meter and is the most accurate method. The second and most common adjustment procedure is to measure the space between the open points with a feeler gauge (Fig. 6-7). However, this method is not too reliable for several reasons. First, the technician has to be sure the rubbing block is centered on the high point of the cam at the beginning of the procedure, which is not always an easy thing to do. Second, each technician's feel on the gauge is different, so it is easy to set the points either too close together or too far apart. In either case, the dwell period is affected as is total ignition system performance.

It should be obvious after this discussion that the best way to improve ignition system performance is to find a way to get rid of the contact points. Basically, this is one of the main differences between standard and electronic systems. The former uses contact points to control primary coil current flow; whereas, the electronic systems use a switching transistor for more reliable, maintenance-free operation.

Fixed Built-in Timing Advance

Ignition timing is a major factor in both fuel economy and driveability. It is also a critical factor in the control of harmful exhaust emissions.

As mentioned in Chapter 1, there are two fixed

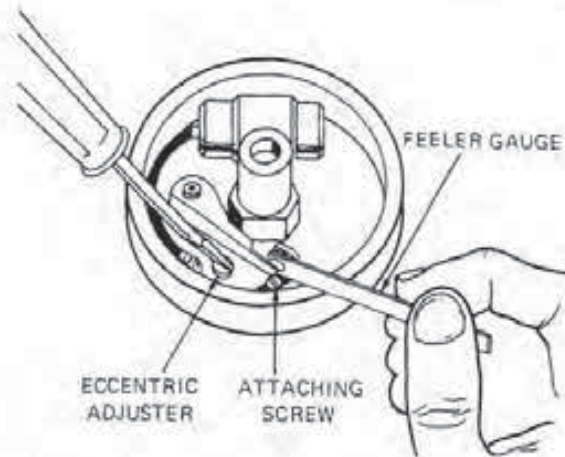


FIGURE 6-7

Adjusting contact point opening with a feeler gauge.

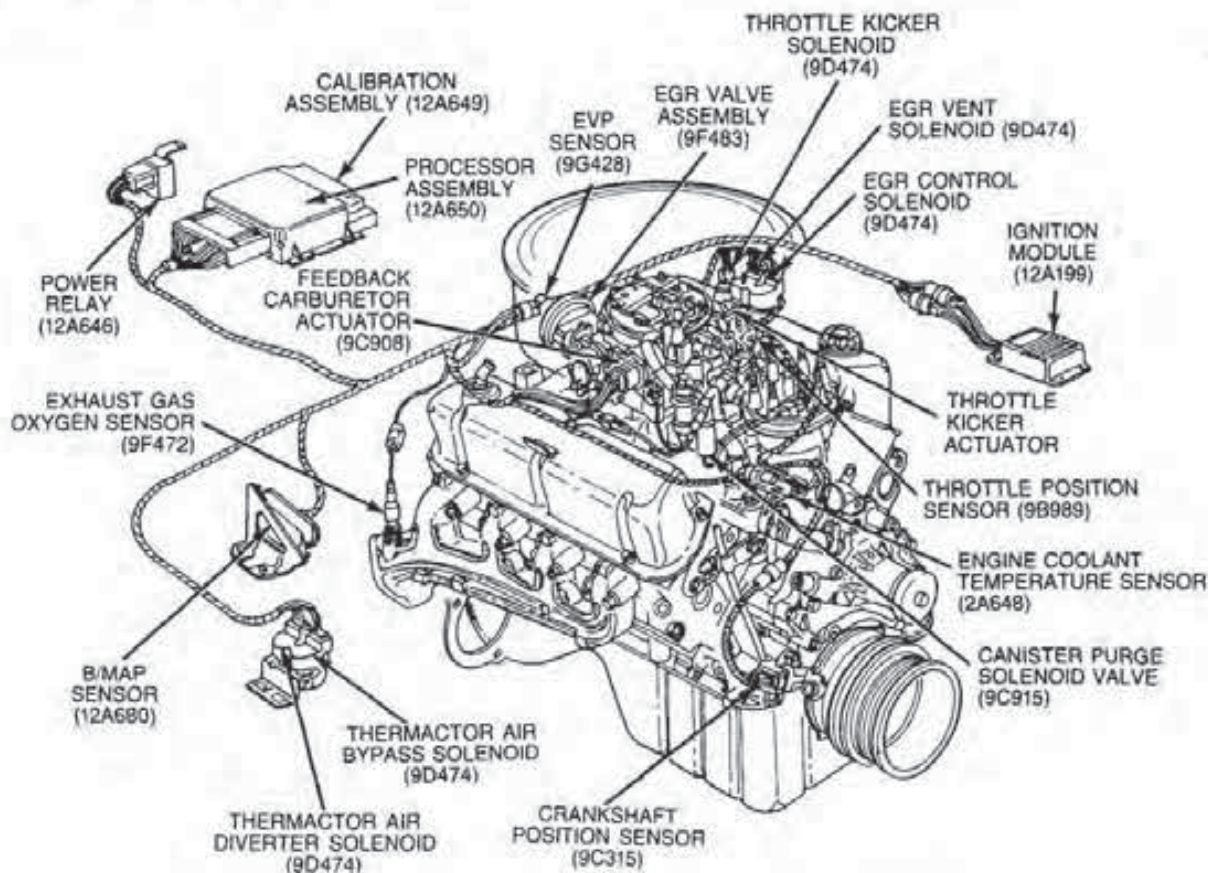
types of timing advance mechanisms built into the standard and many electronic ignition distributors. The mechanical advance alters ignition timing relative to engine speed. The vacuum unit advances the timing to match engine load conditions.

With both of these mechanisms, the amount of advance is fixed by the design of the unit itself. In other words, each unit can only advance the timing a given amount to correspond to certain conditions. For instance, the mass of the counterweights and spring tension determine at what engine speed and by how much the mechanism will ultimately advance the timing.

Often neither of these mechanisms can respond quickly enough to changes in engine operating conditions. The timing may be automatically advanced too much or too little during a given engine operating phase. This can cause engine hard starting, loss of power, pinging, excessive fuel consumption, increased emissions, and poor driveability.

Computer-controlled ignition timing can overcome this response problem by not being completely dependent on speed and load input signals. The computer can therefore adjust the timing to meet the greatest need during any driving condition. For instance, following a cold start, timing may be advanced to enhance driveability. During light load operation, with a partially warmed-up engine, timing can be retarded slightly to hasten engine warm-up and reduce exhaust emissions. Finally, during acceleration or wide-open throttle operation, timing may be advanced for maximum torque output.

An electronic timing system consists of a processor and a number of sensors (Fig. 6-8) that work together to determine more exactly the ignition timing needs of an engine. The sensors monitor such items as throttle position, engine vacuum, air and

**FIGURE 6-8**

Typical computerized engine control system with electronic spark control.
(Courtesy of Ford Motor Co.)

coolant temperatures, and engine speed. The sensors then relay this information to the computer.

The computer has integrated circuits programmed to interpret this information and calculate the proper timing for each firing cycle. Because of the extreme speed of the computer, the timing is updated many times each second.

6-2 FORD TRANSISTORIZED IGNITION SYSTEM

The Ford transistorized ignition system was offered as optional equipment on high-performance engines from 1963-1967. This system was Ford's first attempt at remedying the electrical and mechanical shortcomings of the standard contact point ignition system. The main advantages of the system are a hotter spark, more precise timing, longer point life, and a faster primary circuit switching speed than was ever possible with contact points.

A schematic of a transistor system is shown in

Fig. 6-9. The contact points are attached to the transistor instead of being connected in series with the primary windings of the coil. The contact points control the operation of the transistor within the amplifier.

The switching transistor switches the primary coil current on and off. When the contact points are closed, the transistor conducts, and current flows through the primary windings and the magnetic field expands. With the points open, the transistor stops conducting current flow, and the magnetic field around the primary coil collapses. This induces a high voltage in the secondary windings and an arc at the spark plug electrodes.

The ignition coil of this system is designed to draw a peak primary current of 12 amperes. The larger current passing through the coil primary windings produces a much higher secondary voltage and a much hotter spark at the plugs, even at high engine speed.

Ordinary contact points would burn out in a short time if they carried 12 amperes of current flow.

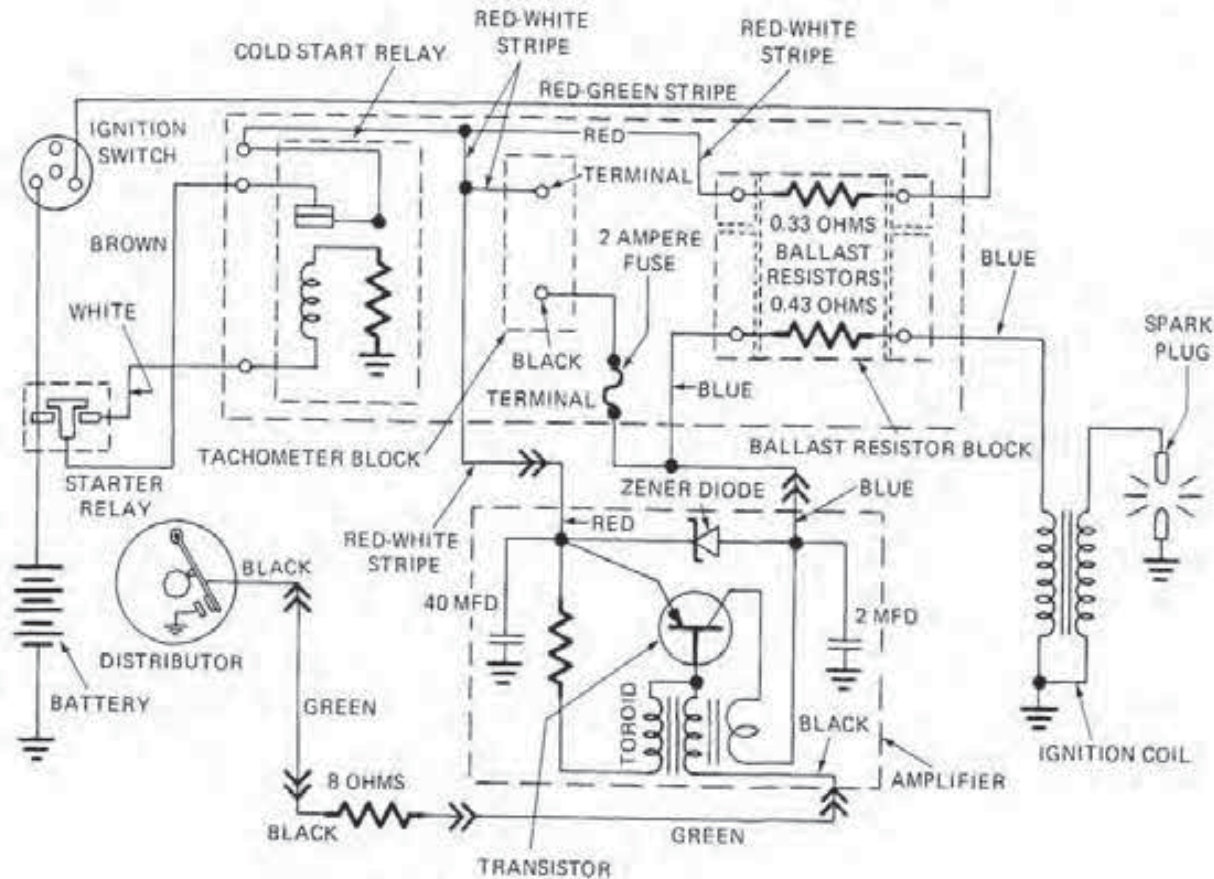


FIGURE 6-9
Schematic of a Ford transistorized ignition system.

However, the switching transistor can easily handle this current. The points in this system are only required to handle about 0.5 ampere to control the switching transistor; this lower current flow means longer point life. In fact, with such a small amount of current, pitting of the contact point surfaces is eliminated, and point life is extended to 40,000 miles (64,374 km) or more as long as the rubbing block does not wear out.

There is no condenser installed in the distributor. Instead, it is incorporated into the amplifier assembly. In addition, the capacity of the condenser is 2 microfarads; the capacity of the condenser in a standard system is about 0.25 microfarad.

This system also utilizes a ballast-resistor relay assembly that is enclosed in a fiber cover. This unit mounts in the engine compartment of a vehicle and contains a dual ceramic ballast resistor, a tachometer connector block, and a cold-start relay.

The tachometer connector block is necessary to attach a dwell meter or tachometer into the system. *These instruments must not be connected to the system by any other means, or inaccurate readings or*

damage to the circuit may result. Note the two-ampere fuse in the lead to the tachometer block. It helps protect the transistor from improper use of test equipment.

During starting, the cold-start relay bypasses the 0.33-ohm resistor if battery voltage drops below 10.5 volts. In this situation, full available voltage is then applied to the system to ensure a sufficient spark at the plugs for starting the engine.

6-3 FORD SOLID STATE IGNITION SYSTEM

In 1973, Ford Motor Company installed its first solid state ignition on some Mark IV models. In 1974 the system became optional equipment on the LTD models and some medium trucks. By 1975, it became standard equipment on all passenger vehicles and medium trucks under 10,000 pounds of gross vehicle weight (GVW).

The solid state ignition system is designed to

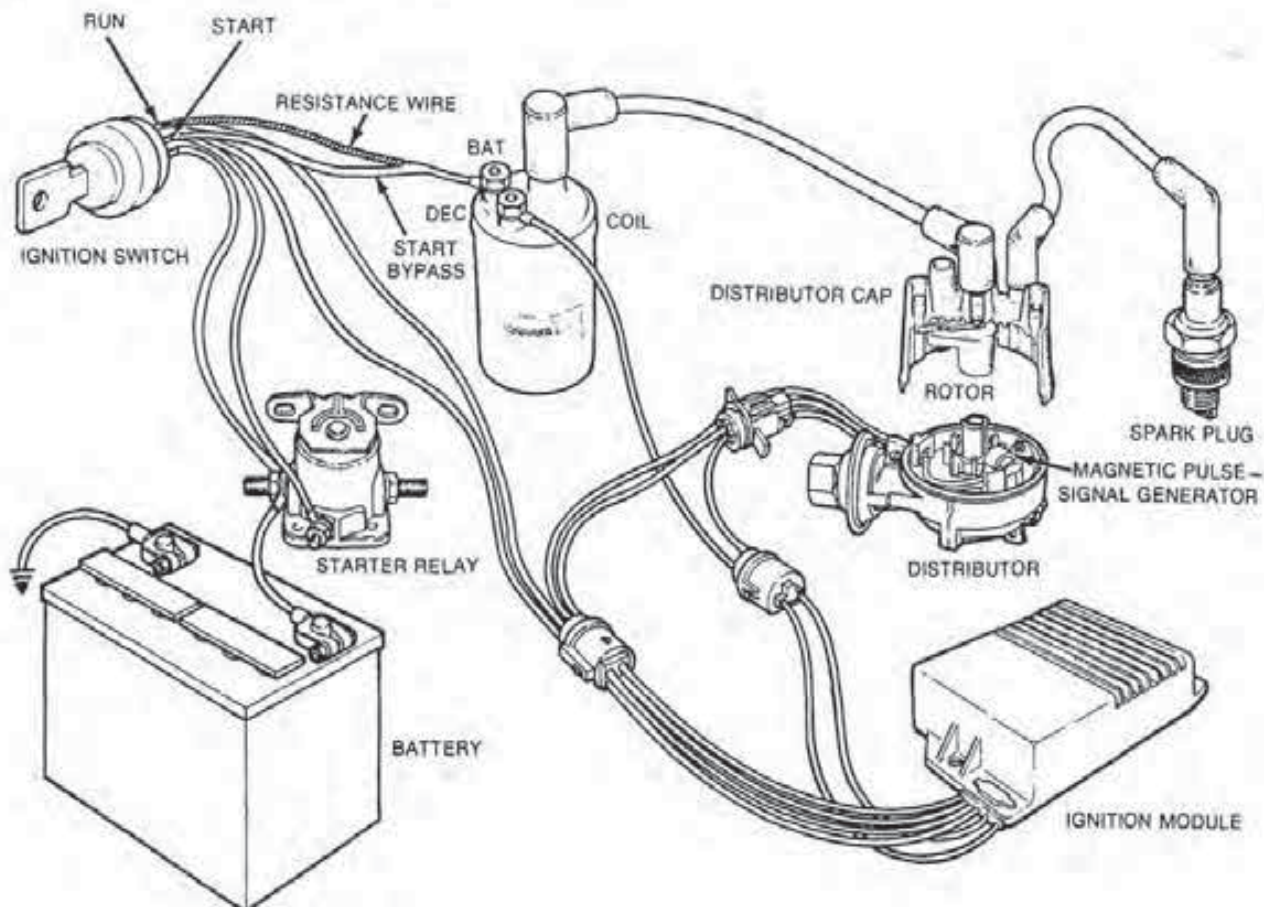


FIGURE 6-10
Components of the SSI system. (Courtesy of Ford Motor Co.)

eliminate deterioration of spark quality, which occurs in the standard system with wear or maladjustment of the contact points; to extend maintenance intervals even beyond those associated with the transistorized system; and to provide a more intense and reliable arc at the spark plugs for every firing impulse in order to ignite the lean mixtures needed for the control of emissions.

SSI System Design

The solid state ignition (SSI) system consists of a coil, rotor, distributor cap, secondary wires, module, and magnetic-pulse type distributor (Fig. 6-10). The coil is essentially the same one used on prior standard systems. However, the SSI coil has a blue case or tower, and the markings on the primary terminals are different. The negative (-) terminal is changed to DEC. A wire attached to this terminal leads into a harness from the ignition module. The wire from the ignition switch to the coil's BAT terminal has

the same resistance of that used with a standard system, 1.30 ohms to 1.40 ohms.

The rotor and cap are black in color and made the same as those used in standard systems. The secondary cables also are the same 7-mm, hypalon-insulated material used in the prior system.

The *ignition module* (Fig. 6-11) is simply an electronic switching circuit. This unit turns the primary circuit current off and on in response to voltage pulses received from the magnetic-pulse distributor.

The module has seven electrical leads formed into two harnesses. The connector attached to the end of each harness permits easy replacement of the distributor pickup coil or the module itself.

The color coding for the electrical module leads is as follows.

Note: The color coding of the wires shown below are for the leads directly attached only to the ignition module. The colors of the wires in the connecting harness may or may not be the same.

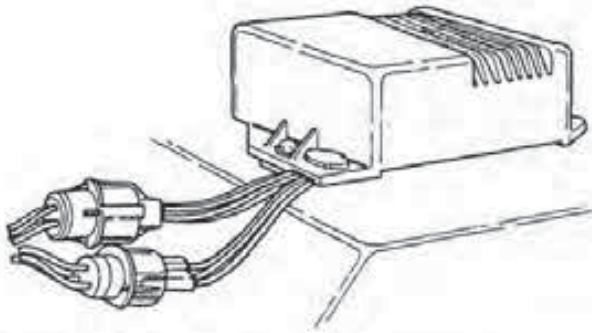


FIGURE 6-11
SSI ignition module. (Courtesy of Ford Motor Co.)

1. The green lead carries primary current from the coil's "DEC" terminal to the ignition module.
2. The black lead carries primary current flow from the ignition module to the ground connection in the distributor.
3. The orange and purple leads connect to the pickup coil within the distributor; they transmit voltage pulses from the pickup coil to the ignition module.
4. The red lead connects to the "RUN" terminal of the ignition switch. It provides the battery voltage and current flow to the module when the ignition switch is in the "RUN" position.
5. The white lead attaches to the "START" terminal of the ignition switch or to the "I" terminal of the starter relay. In either case, the lead carries battery current to the ignition module control circuits when the ignition switch is in the "START" position.
6. The blue lead attaches to the "BAT" terminal of the coil. This wire serves to bleed off any excessive voltage pulses that may occur in the module.

The magnetic-pulse distributor consists of a centrifugal and vacuum advance mechanism, an armature, and a magnetic pickup assembly (Fig. 6-12). The centrifugal advance mechanism is located under the fixed base plate and operates in the same manner as a similar device found in the standard ignition system distributor. The main and only difference is that the mechanism turns the armature ahead in the direction of distributor shaft rotation instead of point cam.

The vacuum advance attaches to the outside of the base casting and, with one exception, operates like a similar unit on a standard distributor. The dif-

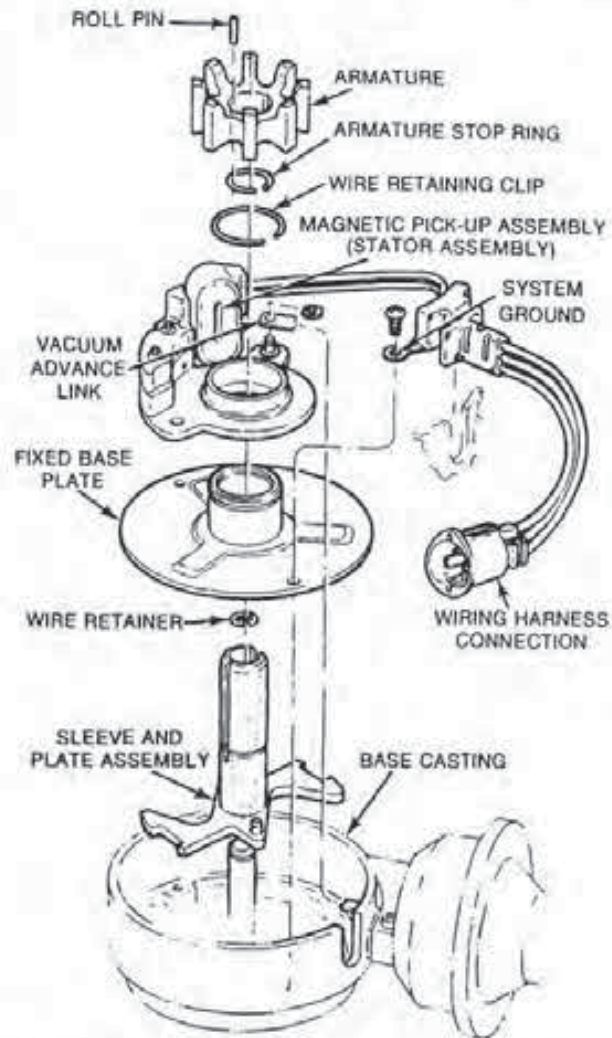


FIGURE 6-12
Design of the SSI distributor. (Courtesy of Ford Motor Co.)

ference is that this vacuum advance moves the magnetic pickup assembly in a direction opposite to distributor shaft rotation instead of the breaker plate.

The armature is a snug fit over the distributor shaft and is secured to it by a roll pin. The armature itself is made of ferrous metal (i.e., containing iron) that has low magnetic reluctance and, therefore, high permeability. The armature has teeth, projections, or spokes, one for each cylinder of the engine.

The magnetic pickup assembly consists of a coil and a weak, permanent magnet. The coil consists of a number of turns of fine insulated wire wrapped around the magnet. The magnet provides a fixed stationary magnetic field. If the strength (magnetic flux) of this field changes, it will induce a small voltage in the pickup coil. If no magnetic lines of force cut the coil, there will be no voltage induction.

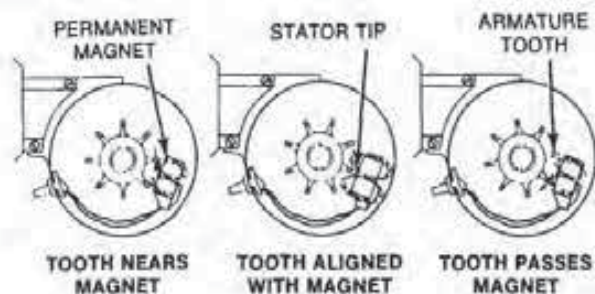


FIGURE 6-13
Operation of a magnetic-pulse generator. (Courtesy of Ford Motor Co.)

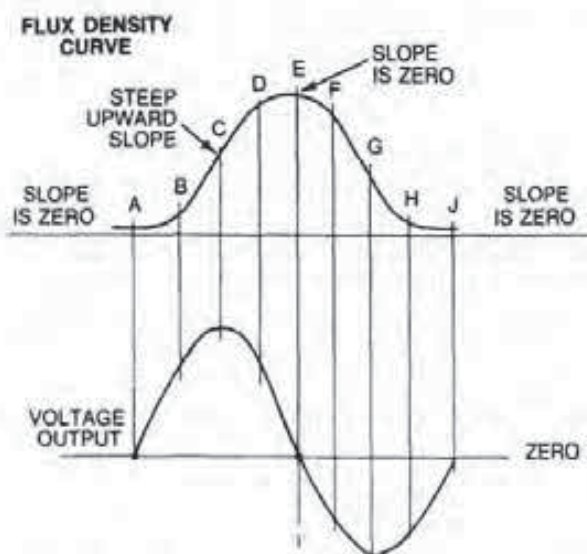


FIGURE 6-14
Voltage curve across pickup coil. (Courtesy of Ford Motor Co.)

Solid State System Operation

As the armature rotates with the shaft, the strength of the field of the permanent magnet varies (Fig. 6-13). When one of the teeth of the armature approaches the magnet, it reduces the reluctance, or magnetic resistance, near the field. This expands the magnetic field out of its normal position, causing the lines of force to cut the windings of the pickup coil. The field strength becomes strongest when the air gap is smallest, and the tip of a tooth is directly across from the magnet. The varying magnetic field induces a voltage in the pickup coil that is proportional to the rate of change of the field.

Figure 6-14 illustrates the voltage curve across the pickup coil as one armature tooth passes it. As the tooth passes by, it detours the magnetic

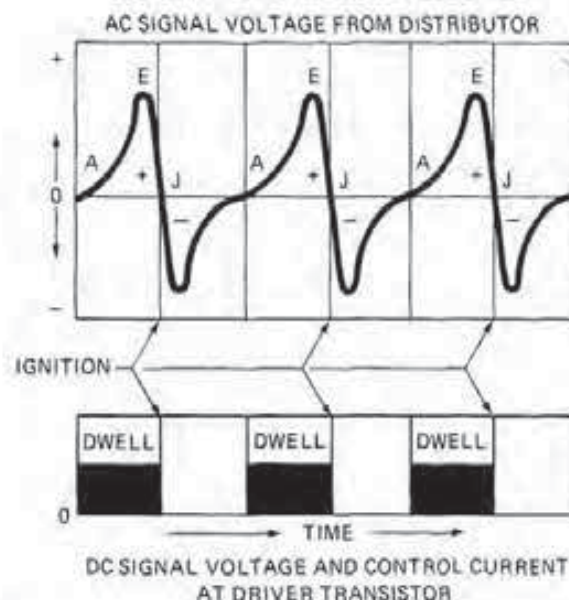


FIGURE 6-15
Electronic circuit converts AC pulses from the pickup coil to square wave DC pulses.

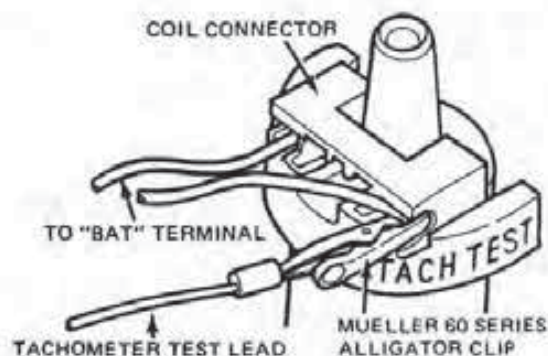


FIGURE 6-16
Ignition coil connector. (Courtesy of Ford Motor Co.)

lines of force from the permanent magnet inside the pickup coil. This changes the density of the lines of force through the coil. As mentioned, this generates a voltage proportional to the number of lines that are shifting at any particular instant. This is represented by an upward, positive voltage line from A to E.

At E, the armature tooth is directly across from the magnet. Even though the magnetic field strength is strongest at this point, the rate of change in the magnetic field density is zero at this point. That is why the voltage drops from positive to zero at J.

As the tooth passes the permanent magnet, a negative voltage is produced. The induced negative voltage is shown on the lower diagram and is due

to the collapse of the magnetic field to its original position.

As the pickup coil voltage induced by one tooth changes to negative polarity, another tooth approaches the magnet. This starts another positive voltage pulse in the pickup coil.

In the SSI system, both the positive and negative (AC) voltage (analog) signals are applied to the ignition module. *A circuit in the Duraspark III system converts these AC signals to DC square wave (digital) pulses (Fig. 6-15).*

In either case, the induction of a positive voltage in the pickup coil turns on the driver transistor. This closes the circuit to the primary coil, and current flows through its windings (the dwell period). However, at positive zero voltage, the transistor is turned off. During this time there is a collapse of the primary coil's magnetic field and the induction of high voltage in the secondary coil windings. The white boxes following those in black depict the dwell periods and represent the transistor-off periods for modules using DC square wave signals.

As the distributor turns faster and the frequency of the AC signal to the module becomes greater, the time span between positive voltage (transistor-on) pulses becomes shorter. The ignition module has built-in timing circuits that maintain optimum coil build-up times between these pulses. In effect, the module tailors the dwell to produce a secondary voltage output from the coil that is constantly high.

1975 Solid State System Modifications

In 1975, there were no changes that altered system operation. There were, however, some design changes.

The ballast resistance was slightly reduced to 1.25 ohms to 1.35 ohms. This increased the current flow through the primary windings in order to raise the secondary available voltage at the plugs. The internal components of the ignition module were upgraded to handle the increased primary current flow. In addition, a new blue material was used for the distributor cap and rotor to insulate them from leakage due to higher secondary voltage. The ignition module connectors were altered in order to prevent the use of 1974 modules in 1975 systems.

A new, polarized coil, primary circuit connector was used in order to prevent the installation of the leads in reverse polarity (Fig. 6-16). Also, the DEC terminal of the coil connector was changed to read TACH TEST. This new connector permits a tachometer test lead having an alligator clip to be installed

onto the distributor electronic control terminal without removing the connector. In addition, silicone insulation was used on some ignition cables to compensate for increased engine compartment heat on emission-controlled engines.

1976 Solid State Ignition System Modifications

In 1976, there were again no major changes in the basic operation of the system (Fig. 6-17). However, there were a few design changes.

Due to internal improvements within the ignition module, the blue overload shunt lead was no longer required and thus eliminated. The ignition module now has six leads instead of seven. The ignition module connectors were revised to reflect the reduction from seven to six leads. The use of silicone-insulated ignition cables was applied to more vehicles.

6-4 FORD DURASPARK I IGNITION SYSTEM

In 1977, Ford altered the basic SSI system to increase its available secondary voltage. Along with a number of design changes, Ford also changed the name to the Duraspark ignition system. There have been three variations of this system so far, each operating in a manner similar to the solid state system just discussed.

The Duraspark I system was used only in California from 1977-1979 on the 5.0-liter engine (Fig. 6-18). The system produced a much higher secondary voltage than the Duraspark II design, which is discussed in the next unit.

Coil Design

The higher secondary voltage is accomplished through the use of a high output coil. This special coil contains windings that have a much lower resistance, thus permitting a higher current flow. The core of the coil is also designed to accept a much higher magnetic charge from the higher current.

The ballast resistor is eliminated, so the system uses a full 12 volts across the primary windings. As a result, there is not only a speeding up of the build-up time but also an increase in the strength of the magnetic field around the primary windings. This has the effect of producing a much higher voltage in the secondary coil.

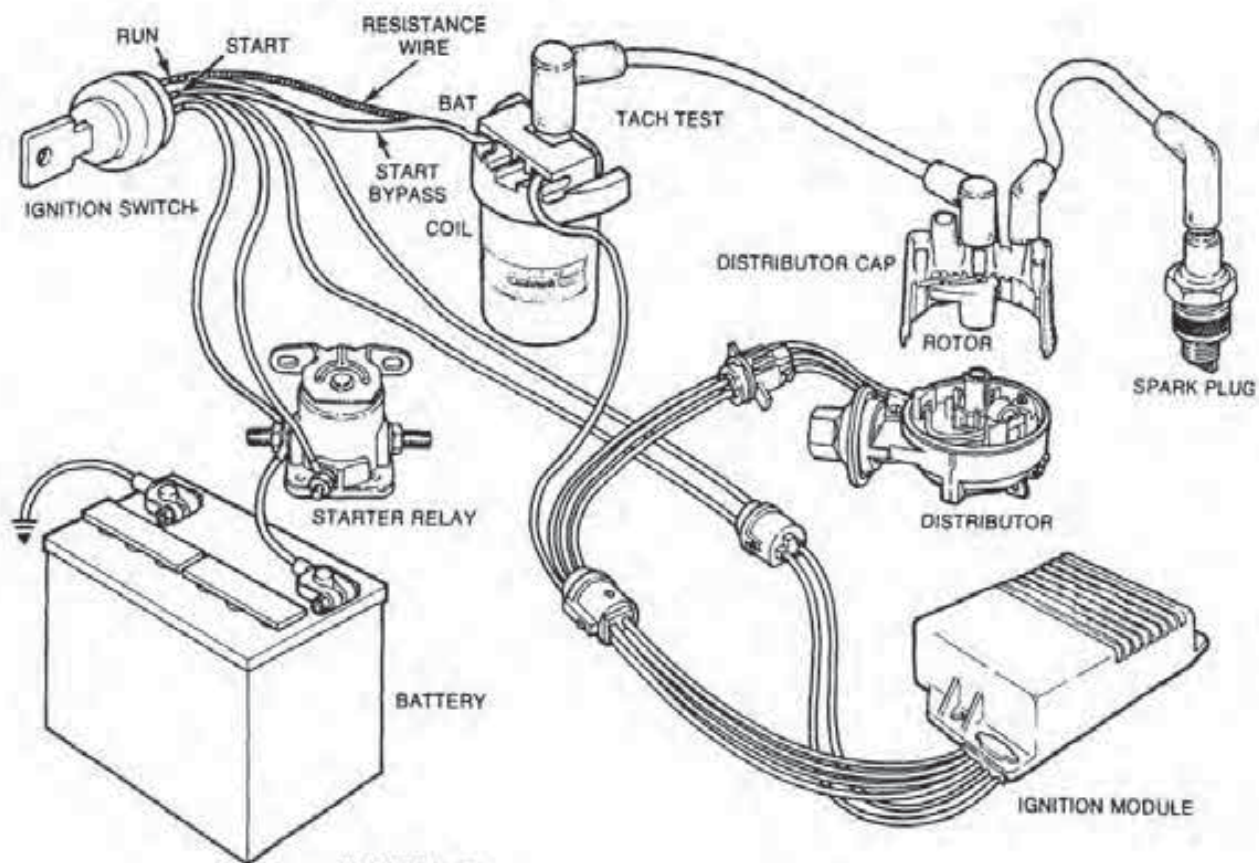


FIGURE 6-17
Design of the 1976 SSI system. (Courtesy of Ford Motor Co.)

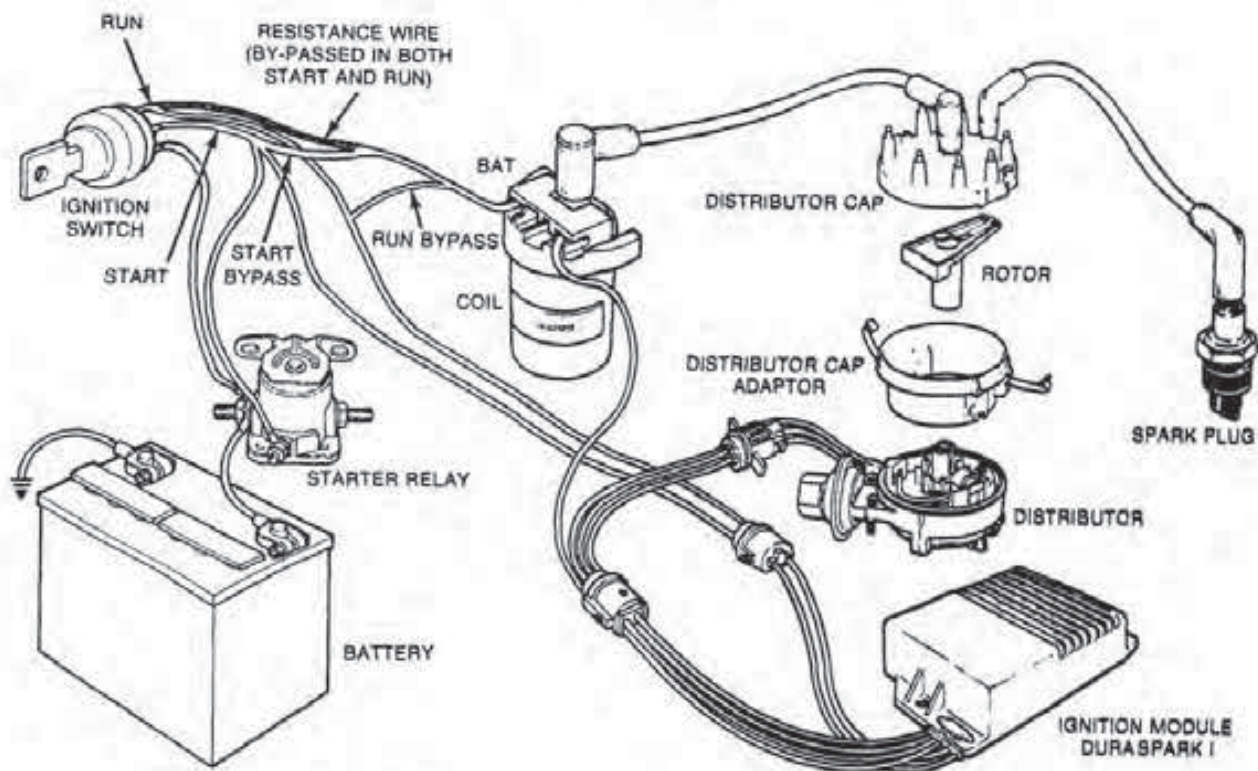


FIGURE 6-18
Design of the Duraspark I system. (Courtesy of Ford Motor Co.)

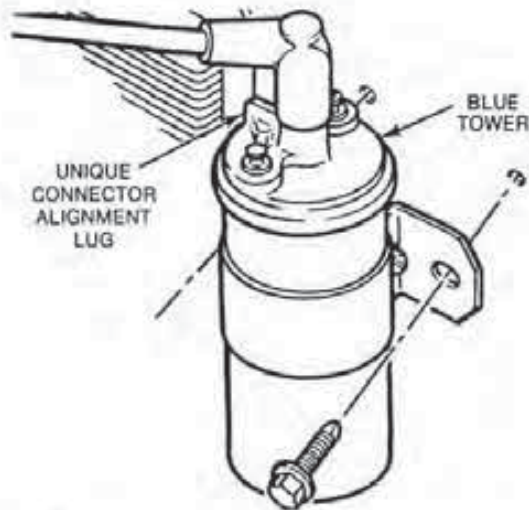


FIGURE 6-19
Duraspark I coil has an alignment lug. (Courtesy of Ford Motor Co.)

The coil has a unique alignment lug on the blue coil tower (Fig. 6-19). This prevents the coil from being attached to the harness of a basic solid state ignition system.

Design of the Cap and Rotor

To insulate the increased secondary voltage, a new, larger distributor cap with male-type spark plug contacts is used (Fig. 6-20). This, of course, requires a longer and higher rotor. The increased space between the cap cable contacts reduces the chance for arcing between adjacent inside terminals, or from the rotor to the wrong terminal.

To fit the larger cap and rotor to the distributor body, an adapter collar is installed between the body and the cap. Also, the distributor body uses centrifugal and vacuum advance units similar to those on a solid state ignition distributor.

Design of the Ignition Cables and Spark Plugs

The ignition cables are insulated with silicone, as indicated by the blue color, to resist higher engine compartment temperatures caused by the emission control systems. Furthermore, to insulate against the loss from leakage due to increased secondary voltage, the ignition cable size is increased from 7 mm to 8 mm.

The spark plugs used with the Duraspark I system are not the same as those used with SSI. The plugs themselves have a -6 suffix, and they are set to a wider gap.

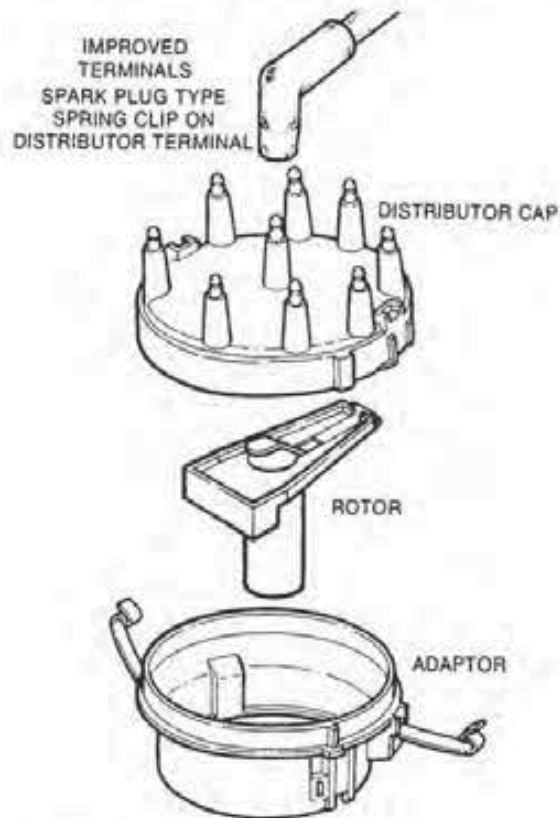


FIGURE 6-20
Cap and rotor used on Duraspark systems. (Courtesy of Ford Motor Co.)

Design of the Module

In the Duraspark I system, spark intensity is greatly increased, especially at higher engine rpm. If the coil were permitted to run with the same dwell control (maximum build-up time) as in the basic SSI system, the coil would, at lower rpm, overcharge and overheat. For this reason, the module of this system has a special current control.

This circuit senses the current flow in the primary windings just prior to each discharge of the coil. If the sensor reads more than a full charge within the coil, it delays the turn on of the primary circuit for the next dwell cycle of the coil. On the other hand, if the sensor reads a less than full charge, it turns on the primary circuit slightly sooner for the next dwell cycle.

This action holds the time during which the primary circuit is on to the period needed to fully charge the coil for every discharge. In this way, the module constantly tailors the length of the dwell to the requirements of the system and to engine speed. Dwell then varies with respect to the degrees of crankshaft rotation but remains relatively constant with respect to actual coil build-up time.

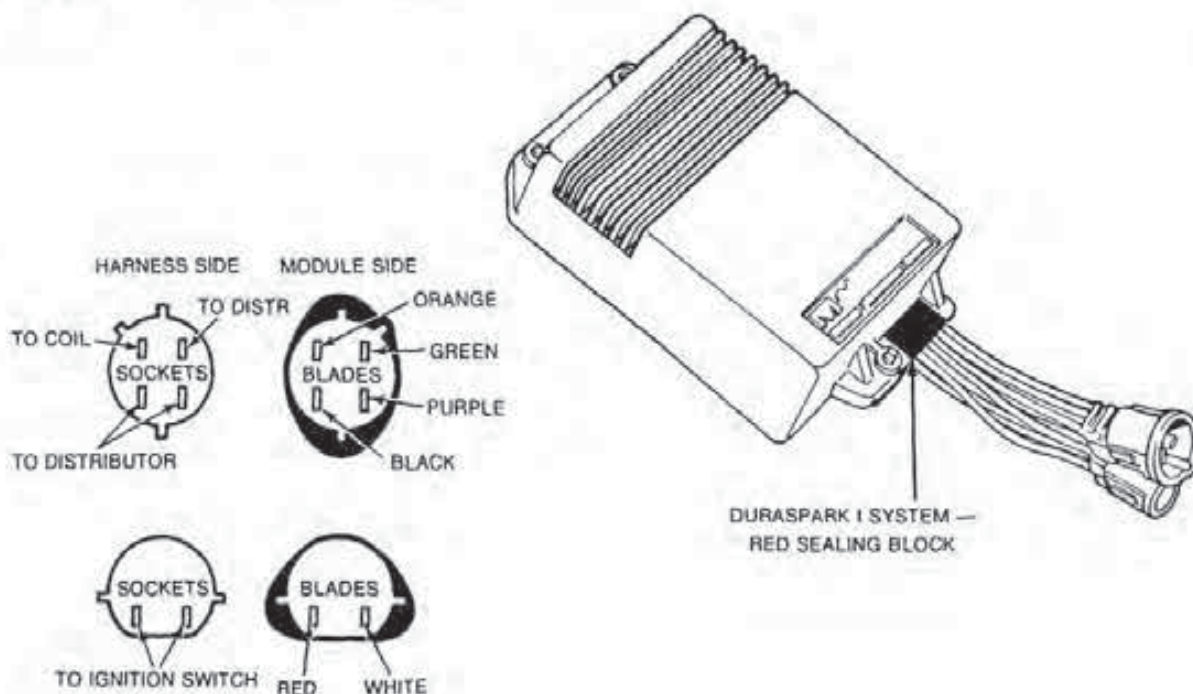


FIGURE 6-21
Module used on a Duraspark I system. (Courtesy of Ford Motor Co.)

The current-control circuitry also shuts off the primary current flow if the engine stalls. Therefore, the ignition switch must be turned to start in order to shift the module back into the operating mode.

In appearance, the module is identical to the basic SSI unit. It has the same six leads. However, the sealing block through which the leads enter the module is red in color. The block for the SSI module is blue. In addition, to prevent an interchange with other system modules, the connector keyway on the Duraspark I module is different. Figure 6-21 illustrates the Duraspark I module for 1977-1979.

6-5 FORD DURASPARK II IGNITION SYSTEM

Ford also developed the Duraspark II system in 1977 and used it much more extensively than Duraspark I (Fig. 6-22). The Duraspark II system produces a higher voltage than SSI but less than Duraspark I. The system uses the same distributor, cap, rotor, and ignition cables as Duraspark I. The system uses the SSI coil and spark plugs, but the gaps are increased on some models.

Ballast resistance is decreased from the 1.25 ohms to 1.35 ohms used with the 1975-1976 SSI system to 1.05 ohms to 1.15 ohms. This permits an increase in primary current that substantially raises the secondary available voltage. However, the mod-

ule required upgrading to handle the increased flow of primary current.

1978 Duraspark II Modifications

In 1978, the Duraspark II underwent a number of modifications. An electronic engine control system (EEC-II) was introduced on 5.0-liter (302 CID) V-8 engines installed in Versailles automobiles. This system covers a number of other engine functions and will be discussed in another chapter. In addition, dual-mode ignition modules and sensors were installed on some models that were manufactured for certain geographical areas.

Dual-Mode Ignition for Duraspark II Systems

There are two types of dual-mode ignition systems in use (Fig. 6-23). One system is for altitude compensation, while the other is for economy calibration. Both use the same ignition module.

The altitude system provides compensation on some vehicles that normally operate at altitudes above 4,000 feet (1,219 meters). On these installations, the carburetor is set lean for operation at a higher altitude with a normal spark advance setting. Below the specified altitude, a barometric pressure switch within the system provides an input signal to

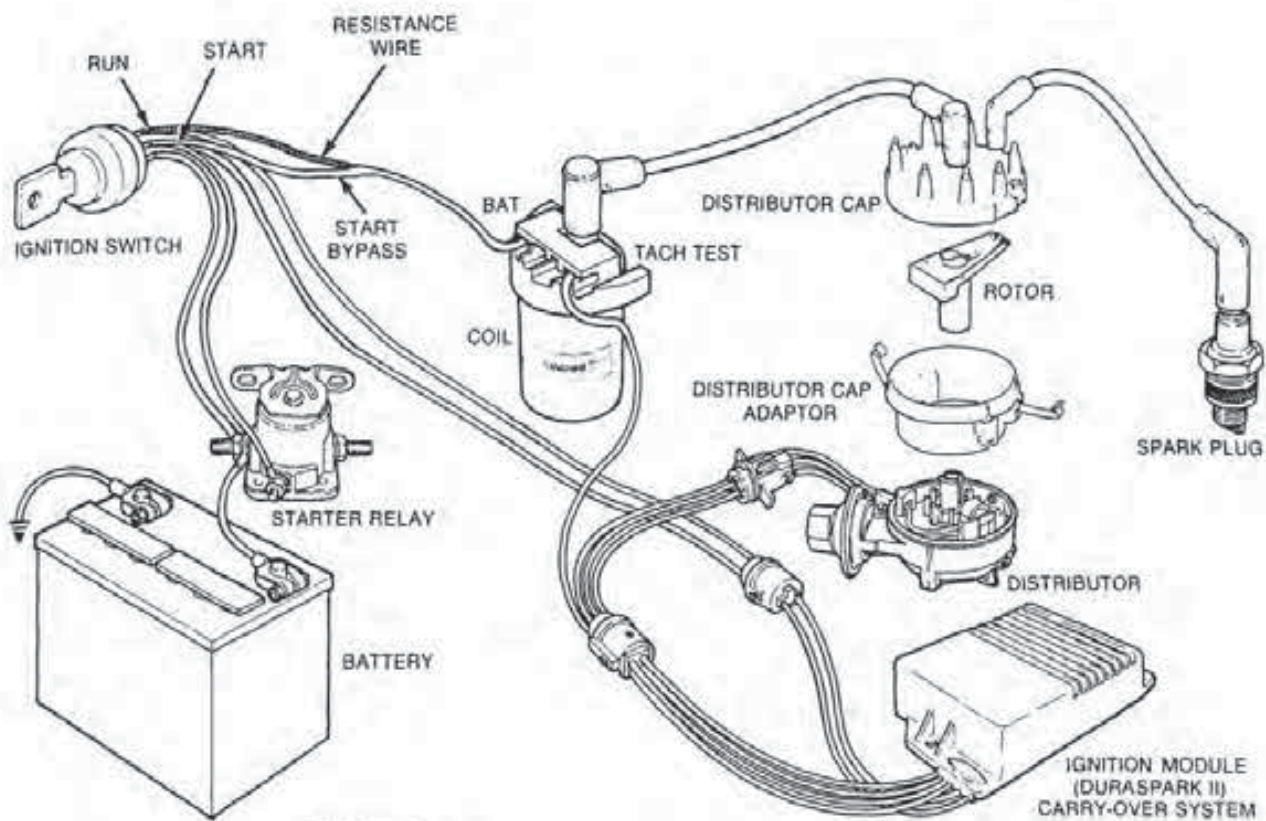


FIGURE 6-22
Design of the Duraspark II system. (Courtesy of Ford Motor Co.)

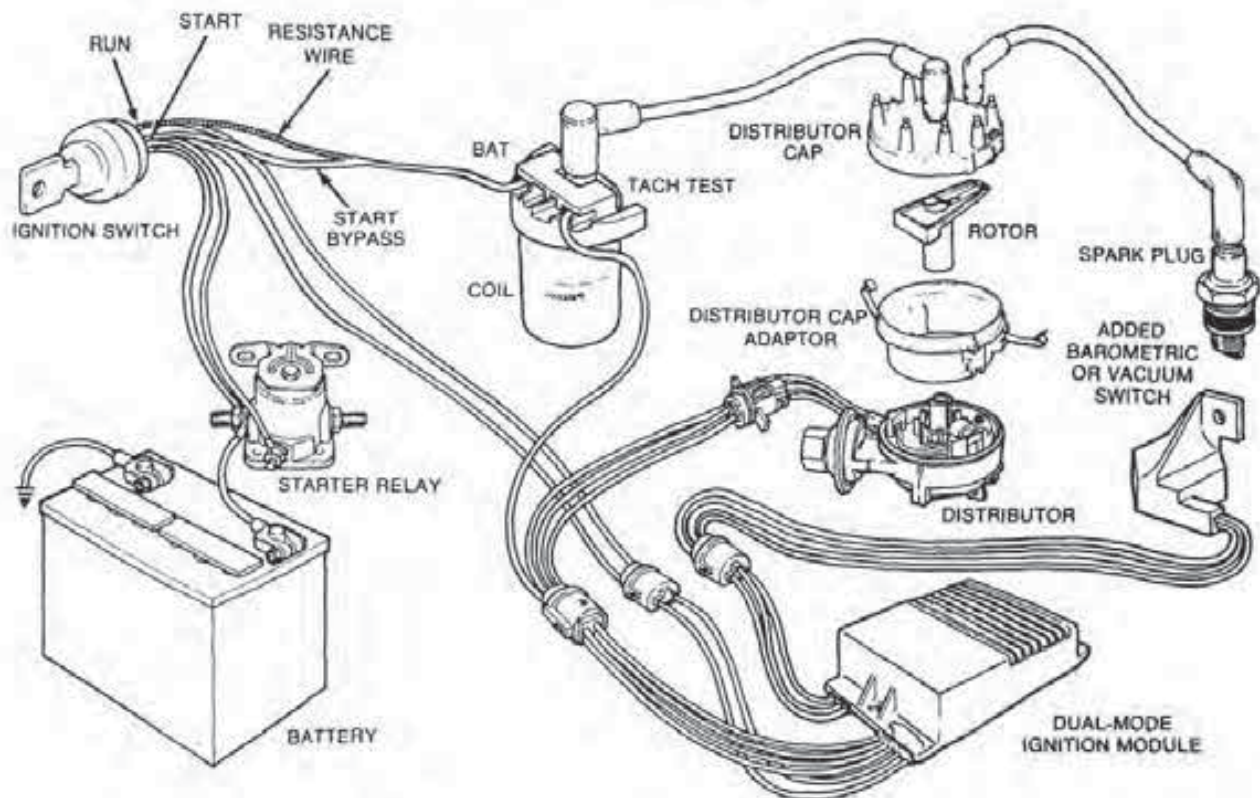


FIGURE 6-23
Dual-mode, Duraspark II system. (Courtesy of Ford Motor Co.)

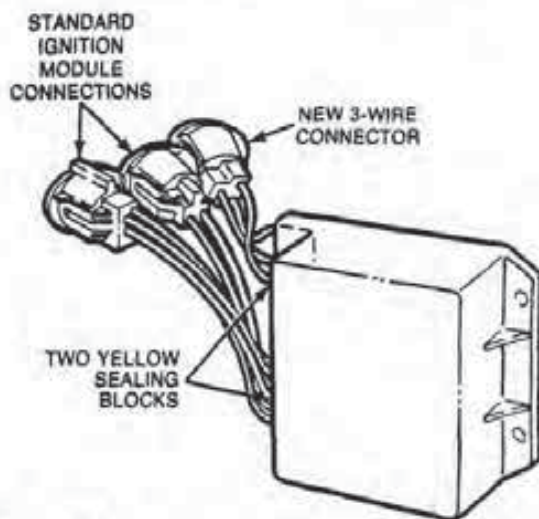


FIGURE 6-24
Dual-mode, Duraspark II ignition module. [Courtesy of Ford Motor Co.]

the ignition module. This causes the module to retard the spark timing by three to six degrees to prevent detonation from the overly lean mixture at lower altitudes.

The economy system provides calibration on a number of vehicles that operate at altitudes of sea level to 3,000 feet (914 meters). In this case, the carburetor is also set lean, while the initial spark timing is advanced for the greatest economy under a light engine load (cruise conditions). When the driver opens the throttle for acceleration or hill climbing, a vacuum switch senses the drop in engine vacuum and provides an input signal to the module. The module then retards the spark timing by three to six degrees to prevent detonation. This is in addition to the normal retard caused by a loss of vacuum to the vacuum advance during acceleration.

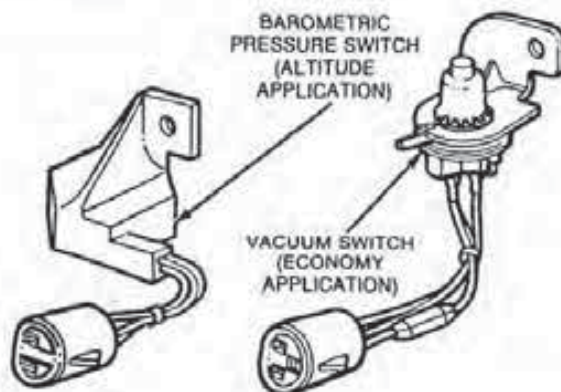


FIGURE 6-25
Barometric and vacuum switches for the dual-mode ignition system. [Courtesy of Ford Motor Co.]

The system itself consists of all the Duraspark II components plus a special ignition module. The module has three extra leads, making nine in all, and has yellow sealing blocks (Fig. 6-24). Either the barometric pressure switch or the vacuum switch (Fig. 6-25) may be plugged into these three extra leads on the module. In other words, the same module serves both the economy and altitude compensation applications. When the barometric or vacuum switches are not activated, the ignition module and the system operate in a normal manner.

There is one thing to remember about dual-mode installations. *When checking or adjusting initial spark timing, the barometric or vacuum switch must be unplugged from the module.*

1979 Duraspark II System Modifications

The Duraspark II underwent a number of modifications in 1979. An electronic engine control system (EEC-II) was installed with Duraspark II on Fords with the 5.8-liter (351W CID) V-8 engines built for use in California only. Mercury models with the same engine used the same arrangement in all 50 states. The EEC-II system will be discussed in a later chapter.

In addition, in non-turbocharged 2.3-liter engines with an automatic transmission, a cranking retard circuit was built into a special ignition module (Fig. 6-26). This retard feature is only actuated dur-

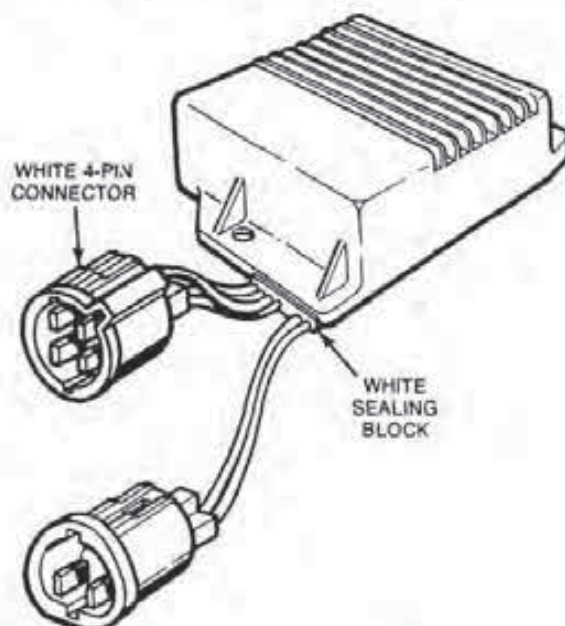


FIGURE 6-26
Cranking retard module. [Courtesy of Ford Motor Co.]

ing engine start-up by the slow rpm signal from the distributor's magnetic pickup. The signal activates a circuit in the ignition module to retard ignition timing up to 18 degrees to improve engine starting.

The ignition control module with the cranking mode is easily identified by the white four-pin connector in place of a black one. Also, the unit has a white sealing block where the wires from the connectors enter the module. The module is not functionally interchangeable with other units.

Universal Ignition Module

In 1981, Ford released a universal ignition module (Fig. 6-27). This unit is similar to the cranking retard module. However, it has a programmable run-retard feature in a smaller, compact Duraspark module. The module can be identified by a yellow grommet plus an extra three pin connectors.

The run-retard function may be programmed by an external switch. The switch changes resistance combinations inside the module to determine the actual amount of timing compensation the module will make for altitude and economy. The module switch may also be used as a variable control in a closed loop system.

6-6 FORD DURASPARK III IGNITION SYSTEM

In 1978, Ford developed the Duraspark III system to be used only in conjunction with electronic engine control systems. The ignition module used with Duraspark III is similar in appearance to those on the other Duraspark systems. However, some of the electronic circuitry has been eliminated in the new unit. This circuitry is no longer necessary because the processor assembly, or electronic control assembly (ECA), in an electronic engine control system performs these functions instead of the ignition module (Fig. 6-28).

Another unique feature of the Duraspark III system is the elimination of the centrifugal and vacuum advance mechanisms from the distributor. Consequently, engine timing is not controlled by the distributor as in prior systems but by the ECA. The only task that the distributor performs is the distribution of secondary voltage from the coil to the spark plugs. The ECA signals the ignition module when to break the coil primary circuit, which generates the secondary high voltage at the coil.

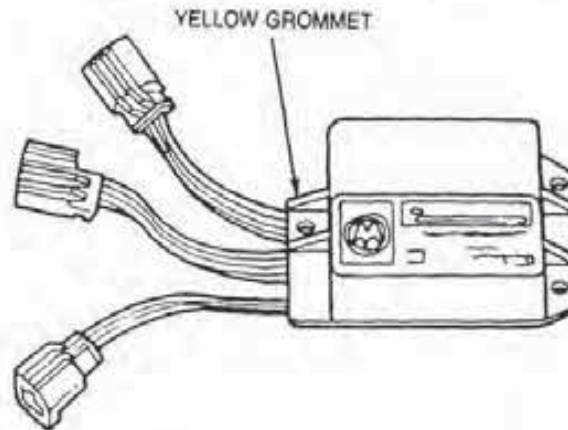


FIGURE 6-27
Universal ignition module. (Courtesy of Ford Motor Co.)

Design and Operation of the Crankshaft Position Sensor

The Duraspark III distributor contains no pickup coil and armature. But in order for the ECA to control ignition timing, it has to receive information about when each piston reaches the top dead center (TDC) position within the cylinder. To accomplish this action within the Duraspark III system, Ford introduced a *crankshaft position (CP) sensor*. This device senses crankshaft position that directly relates to piston location within the cylinder.

The CP sensor on the Duraspark III system, as used with some EEC-I systems, mounts on the rear of the engine block (Fig. 6-29). The tip of the sensor contains a permanent magnet and a coil of wire.

The CP sensor is secured in place by a retaining clip and screw. An O-ring, near the tip of the sensor, seals the lower opening in the rear of the engine block. Once the sensor is locked in place, no field adjustment is necessary.

In place of the armature used with Duraspark distributors, this system has a *pulse ring*. This device does the same task as the armature, just a little more accurately. The ring itself is formed of steel approximately $\frac{1}{4}$ inch (6.35 mm) thick, and has four equally spaced lobes 90 degrees apart (Fig. 6-30). The assembly presses onto the rear end of the crankshaft.

Pulse ring position on the crankshaft is critical because it establishes engine reference timing. Ring placement is such that one of its lobes is positioned on the crankshaft 10 degrees in advance of the TDC point. This determines the engine reference (basic) timing at 10 degrees before top dead center (BTDC).

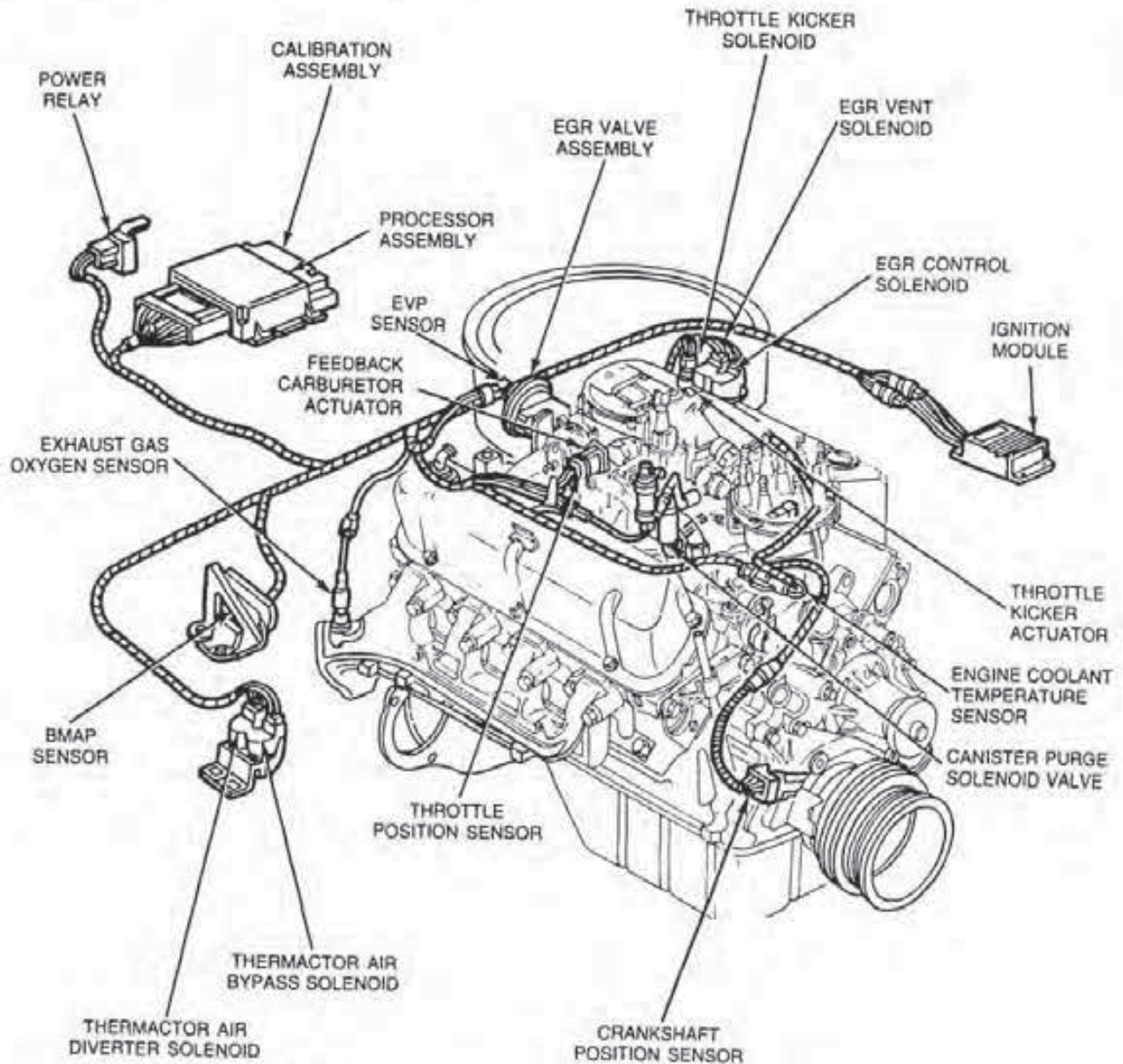


FIGURE 6-28
Duraspark III ignition used with an electronic engine control system. (Courtesy of Ford Motor Co.)

Moreover, once the pulse ring is pressed on during crankshaft manufacturing, it can never be removed or adjusted. Since the crankshaft rotates twice to each distributor shaft rotor revolution, only four lobes are necessary for V-8 engine ignition.

The CP sensor aligns with the crankshaft pulse ring. The sensor identifies the actual position of the crankshaft through the pulse ring lobe. In other words, the CP sensor coil, magnet, and ring operate like a distributor pickup coil and armature in previous systems to produce an AC sine wave signal.

In operation, as the crankshaft rotates, the in-

dividual pulse ring lobes approach and finally align with the sensor tip. This action produces the AC voltage signal to the ECA for analysis (Fig. 6-31). The CP voltage pulses determine crankshaft position, while its signal frequency provides engine rpm information.

The ECA is the control center for the system. It interprets and decodes the electrical input pulses from the CP sensor. The ECA uses this crankshaft position and rpm data for spark timing and ignition advance calculations. This eliminates the need for a distributor centrifugal advance mechanism. The

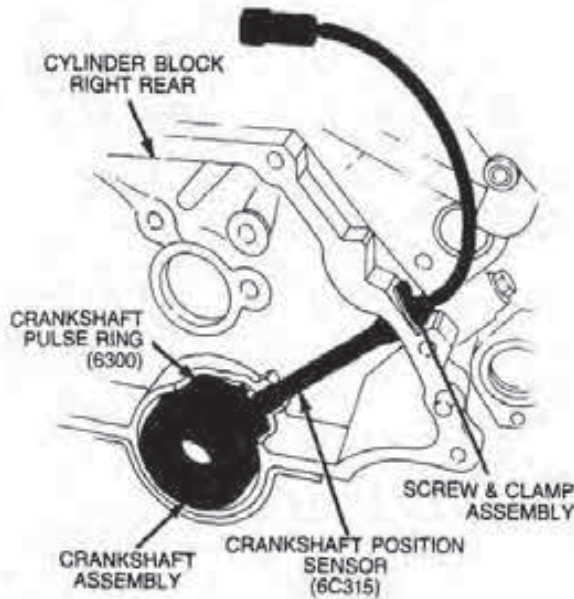


FIGURE 6-29
EEC-I, Duraspark III CP sensor and pulse ring. (Courtesy of Ford Motor Co.)

ECA also has input data from sensors that read engine vacuum as well as many other engine conditions. Therefore, there is no longer any need for a distributor vacuum advance mechanism.

The ECA has a circuit that converts the AC sine wave signal to the DC square wave pulse. This produces very precise information on crankshaft position for spark timing, and on rpm data for timing advance. However, the ECA directs this DC signal to the ignition module during a positive zero voltage signal from the CP sensor (see J of Fig. 6-14). When you consider the facts, it is not surprising that the ECA can then put out an extremely accurate ignition timing signal to the ignition module regarding when to open the primary circuit.

Function of the Duraspark III Ignition Module

The Duraspark ignition module actually opens the primary coil circuit. The resulting collapse of the field induces high voltage in the secondary windings of the coil. As the crankshaft turns faster and the frequency of the AC signal from the CP sensor becomes greater, the time span between pulses becomes shorter. The ignition module has built-in timing circuits that maintain optimum coil charging time between pulses. In effect, it is like the early modules that tailored the dwell (coil-on) time to produce a constant, high, secondary voltage.

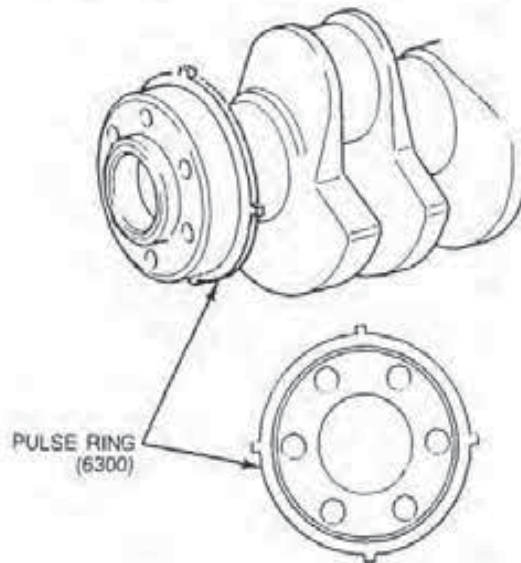


FIGURE 6-30
Design and location of the pulse ring. (Courtesy of Ford Motor Co.)

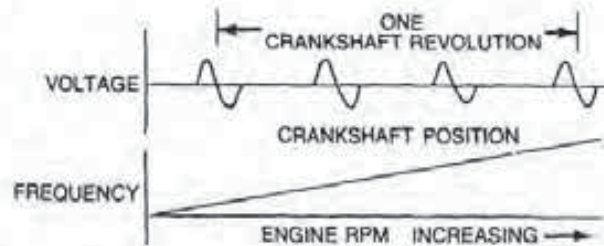


FIGURE 6-31
CP voltage pulses and frequency. (Courtesy of Ford Motor Co.)

If for any reason there is a failure in the ECA, the system goes into a *default mode*. In this mode, the engine operates with no additional spark advance, other than initial timing, regardless of sensor input signals. The vehicle can be operated until repairs are made, but engine performance is poor.

Bi-Level Rotor and Distributor Cap

Since the ECA used with the EEC-I system allows up to 30 degrees of ignition advance, Ford redesigned the distributor rotor and cap for the Duraspark III distributor. The new design allows for the additional advance capability without a problem of crossfire or need for a mechanical advance mechanism.

In early distributor designs, the cap firing order followed the circular path of the rotor. However, in the Duraspark III distributor, upper and lower

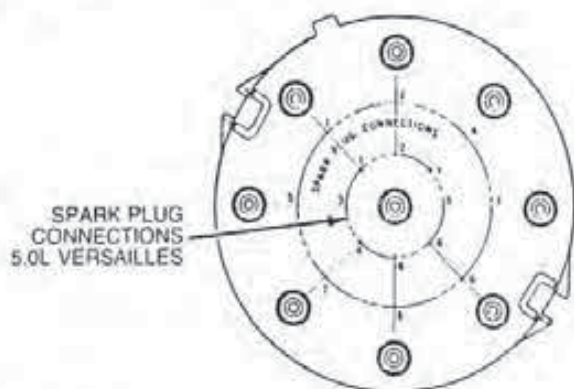


FIGURE 6-32
Inside view of the distributor cap. (Courtesy of Ford Motor Co.)

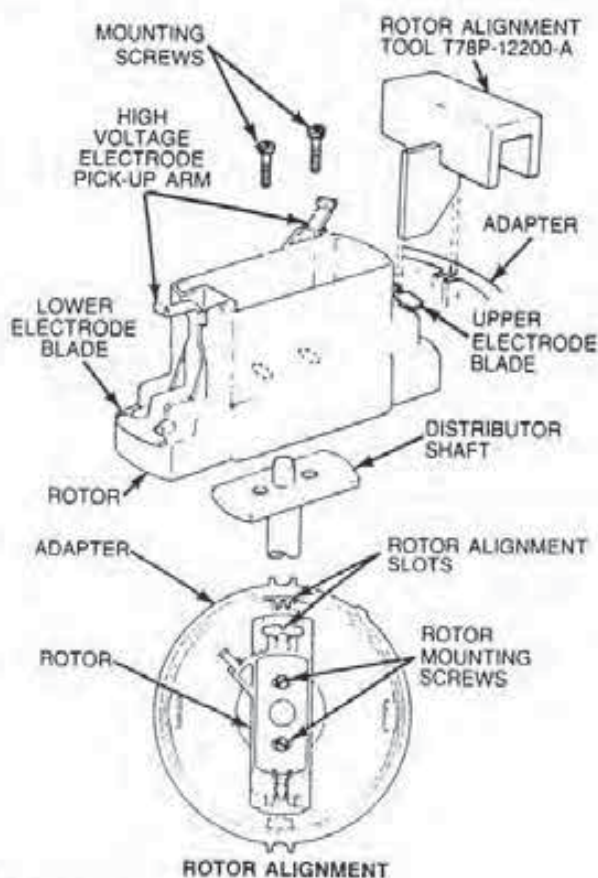


FIGURE 6-33
Duraspark III rotor. (Courtesy of Ford Motor Co.)

electrodes fire alternately in a pattern that jumps from one side of the cap to the other (Fig. 6-32).

In other words, the bi-level rotor and distributor cap have two separate levels of secondary voltage distribution (Figs. 6-33 and 6-34). As the rotor turns, one of the pickup arms aligns with one spoke of the distributor cap's center electrode plate. This

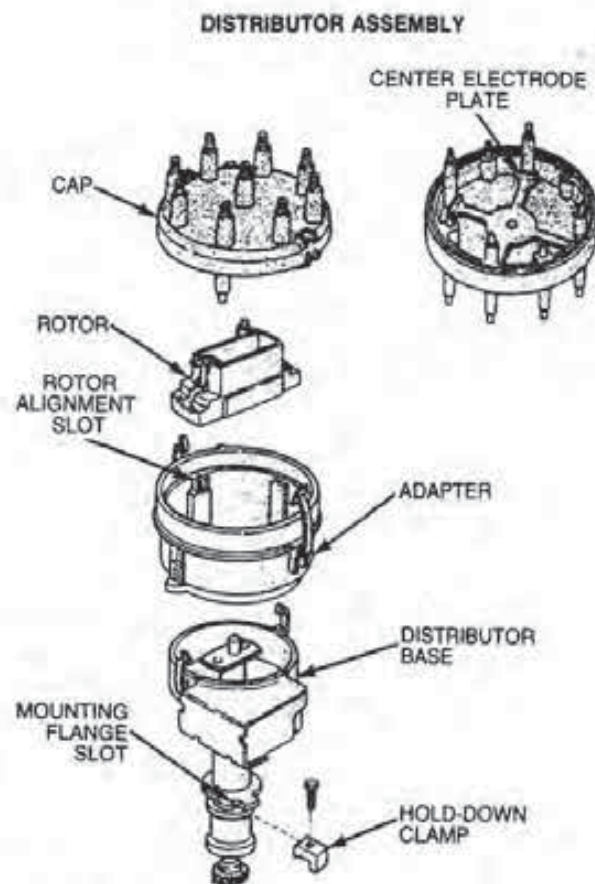


FIGURE 6-34
Duraspark III distributor. (Courtesy of Ford Motor Co.)

allows the high voltage to transfer from the plate, through the rotor, and then to the distributor cap, plug wire, and finally to the appropriate spark plug.

The relationship between the distributor base and the engine are important for proper dispersing of high voltage. For this reason, the Duraspark III distributor secures to the engine using a special type of slotted, hold-down flange and clamp.

The housing and cover on the side of the distributor case (Fig. 6-34) provide an enclosure for a future miniaturized version of the ignition module. Units with this design are known as *universal distributors*.

1979 Modifications to the Duraspark III System

In 1979, Ford introduced the EEC-II system. This brought about a few changes in the Duraspark III system, mainly to the location of the CP sensor and pulse ring.

The CP sensor, even though it operates the

same, has a different location and design. The sensor is now located in the front of the engine block, down near the crankshaft, instead of in the rear of the engine (Fig. 6-35). It also has an extra connector, which is necessary for shielding against electrical interference that can cause false or improper signals.

In addition, the pulse ring, instead of being mounted to the rear of the crankshaft, is moved to the front (Fig. 6-36), where it is pressed onto the crankshaft vibration damper. Once the pulse ring is installed onto the damper during manufacturing, it can never be removed or adjusted.

As in the EEC-I system, a default mode is used if there is a failure in the system. However, for EEC-II, this condition is known as *limited operational strategy (LOS)*.

Finally, the EEC-II system allows a timing advance of up to 36 degrees. The distributor continues to use the bi-level rotor can cap.

1980 Modifications to the Duraspark III System

In 1980 Ford introduced the EEC-III system. The only ignition system change is in the rotor and cap (Fig. 6-37). The second generation of bi-level distributor is designed not only to handle increased amounts of timing advancement but also for improved serviceability. The revised design allows rotor replacement without requiring rotor realignment.

The new rotor is also a bi-level design, but instead of being rectangular in design, it is cone-shaped. The center electrode of the distributor is also redesigned.

6-7 FORD THICK-FILM INTEGRATED-I IGNITION SYSTEM

Ford introduced its Thick-Film Integrated-I (TFI-I) ignition system in 1982 for 1.6-liter engines without an electronic engine control system. Electronically, its operation is very similar to Duraspark II. One major difference is that the TFI-I module is mounted directly into the base of the universal distributor assembly (Fig. 6-38). This arrangement eliminates the requirement for a wiring harness and connectors between the module and the distributor. The TFI-I module is also much smaller than a Duraspark unit. These factors combine to reduce the size of the entire TFI-I system.

A modified pickup coil and armature are used; therefore, the system does not have a CP sensor. The

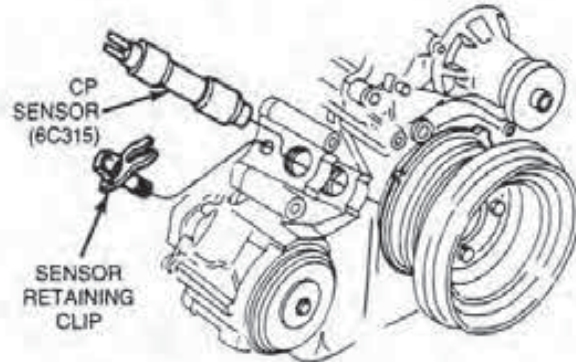


FIGURE 6-35
Location of the CP sensor in EEC-II systems. (Courtesy of Ford Motor Co.)

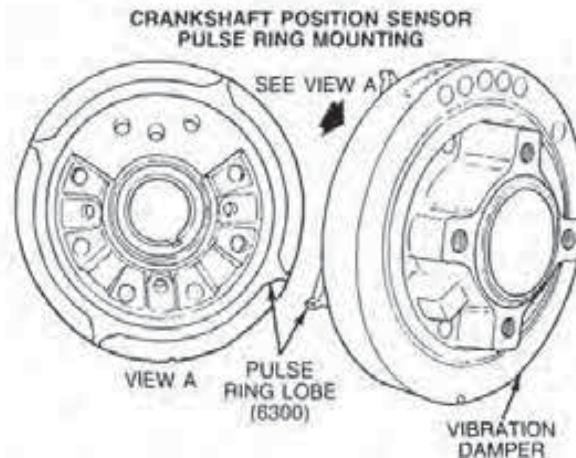


FIGURE 6-36
Location of the CP sensor in EEC-II systems. (Courtesy of Ford Motor Co.)

TFI-I module opens and closes the circuit to the primary coil windings using an AC sine wave signal. The unit opens the circuit when the pickup coil produces a positive zero voltage.

Since the system does not operate in conjunction with an electronic engine control, ignition advance and retard functions are performed by vacuum and centrifugal advance mechanisms.

Another significant difference between the TFI-I and early Duraspark systems is that the former does not have a ballast resistor. This allows more current to flow through the primary windings, thus producing a higher voltage in the secondary.

TFI-I also features a different type of coil, known as the *E coil* (Fig. 6-39). This coil takes its name from the E-shape of the laminations making up its core. The E-core coil has a higher energy transfer because the laminations provide a closed magnetic path.

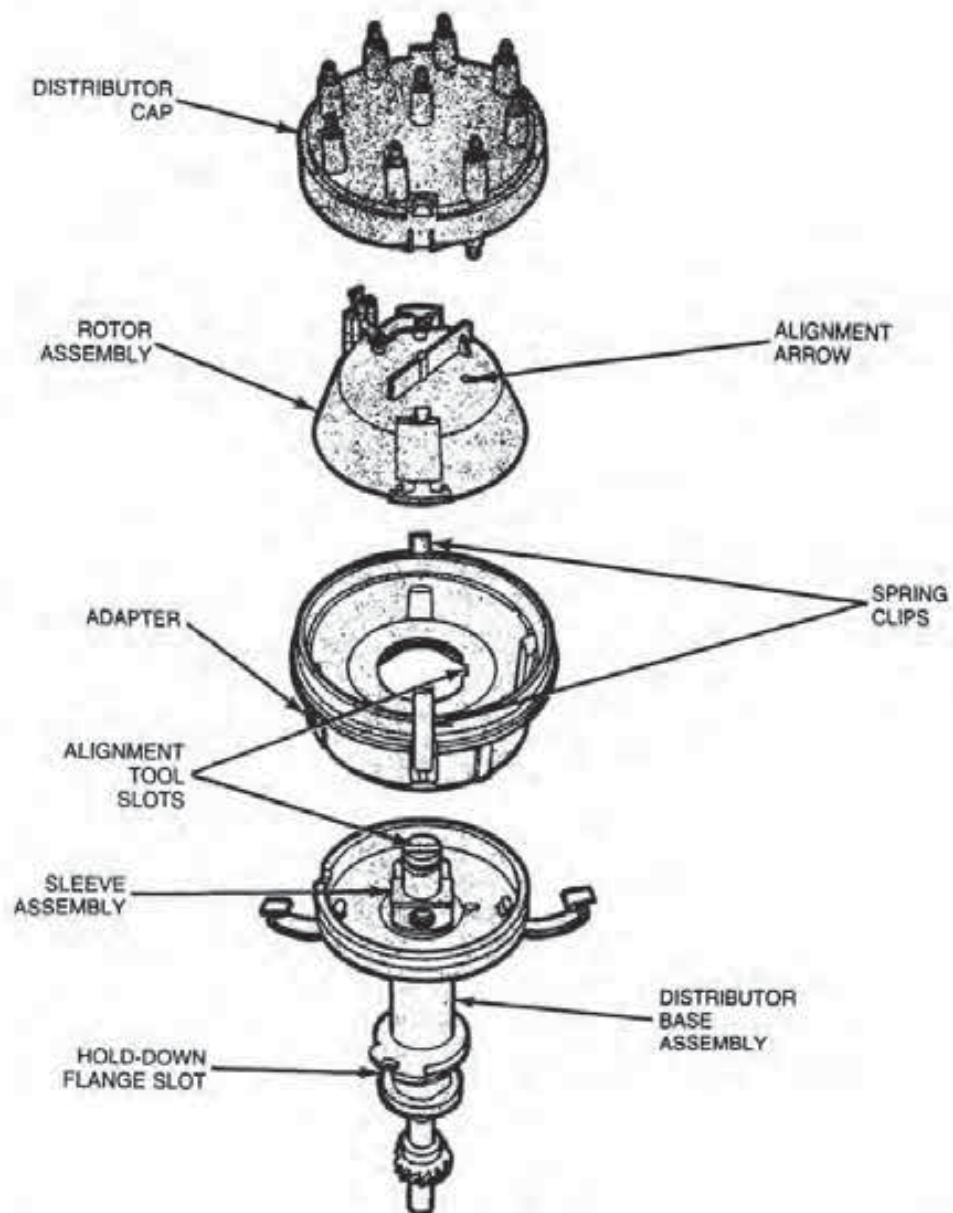


FIGURE 6-37
Second-generation distributor assembly. (Courtesy of Ford Motor Co.)

The TFI module requires a crank-mode signal for starting. For this reason, vehicles with TFI-I ignition cannot be push-started.

1983 TFI-I Modification

The 1983 TFI-I ignition has a slightly different rotor than the 1982 system (Fig. 6-40). The 1982 rotor's solid electrode is replaced by a unit with a two-pronged tip. This eliminates the need for silicone grease on the electrode to reduce radio noise. Also, if the rotor requires replacement, rotor alignment is not necessary. The early style rotor and the two-pronged unit are not interchangeable.

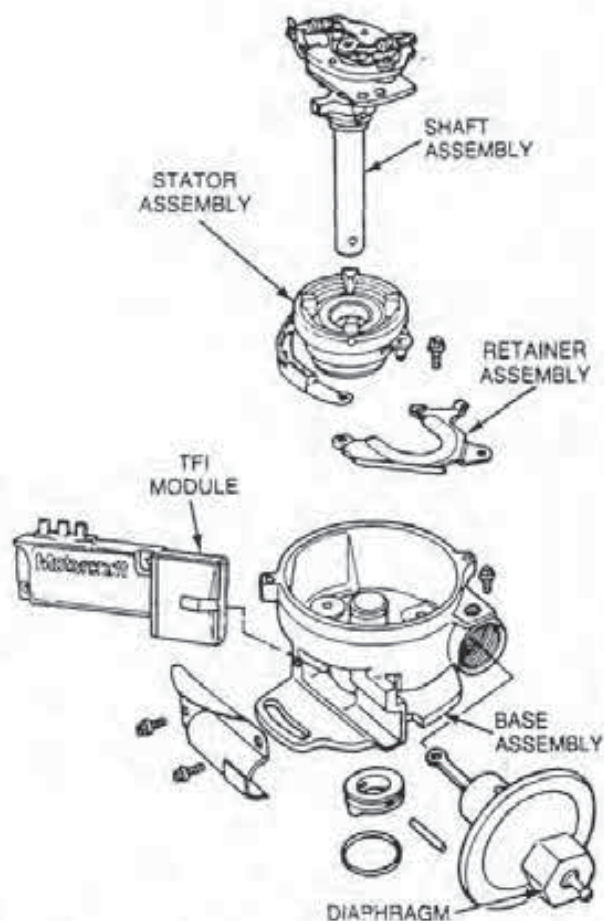


FIGURE 6-38
Exploded view of TFI distributor and module assembly.
(Courtesy of Ford Motor Co.)

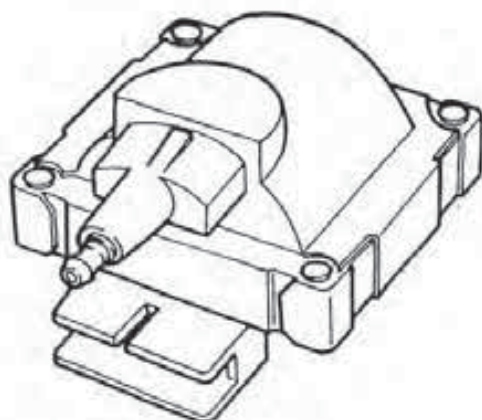
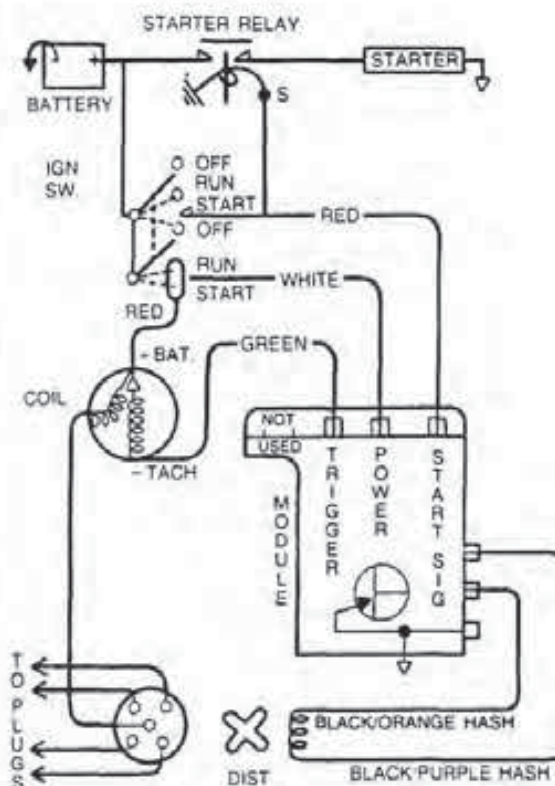


FIGURE 6-39
TFI, E-core coil. (Courtesy of Ford Motor Co.)

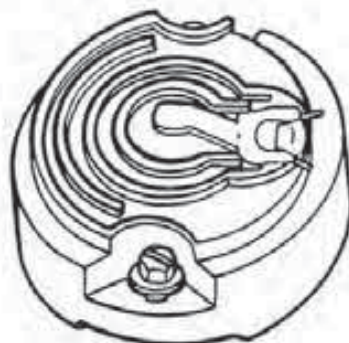


FIGURE 6-40
TFI, two-pronged rotor. (Courtesy of Ford Motor Co.)

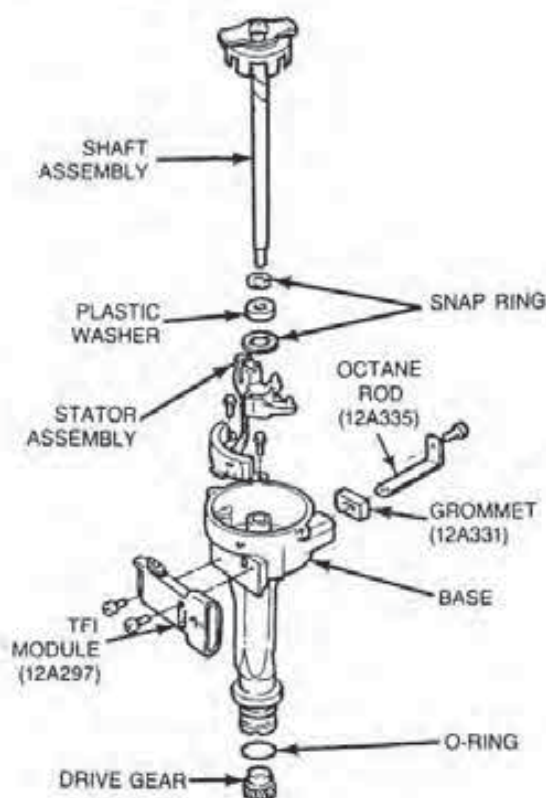


FIGURE 6-41
TFI-IV distributor. (Courtesy of Ford Motor Co.)

6-8 FORD TFI-IV IGNITION SYSTEM

In 1983, Ford introduced a TFI-IV ignition and the EEC-IV system. The TFI-IV module mounts onto the universal distributor in the same manner as in the TFI-I system (Fig. 6-41). A modification in the TFI-IV module circuitry provides for push-starting the vehicle.

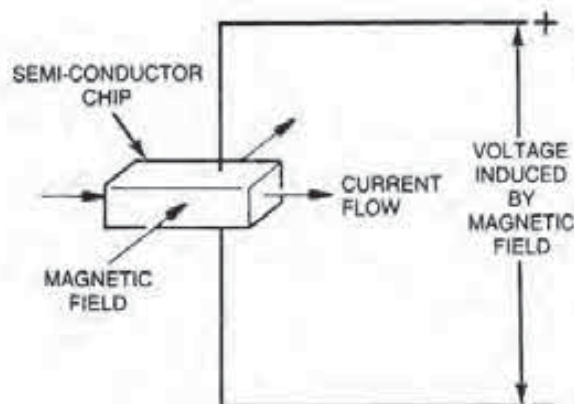


FIGURE 6-42
Hall effect. (Courtesy of Ford Motor Co.)

TFI-IV Distributor Design

The TFI-IV universal distributor, unlike its TFI-I counterpart, contains no advance mechanisms (Fig. 6-41). Therefore, all adjustment of ignition timing and dwell are accomplished electronically. The system uses the E coil and TFI-I rotor and cap to distribute the high voltage to the spark plugs. Also, the universal distributor is adjustable for resetting base timing, if required.

This distributor also has an *octane rod*. The rod provides a method of adjusting for differences in fuel octane ratings. The adjustment is accomplished by replacing the standard zero degree rod located in the distributor bowl by either a three- or six-degree retard service replacement rod.

In place of a pickup coil, the TFI-IV distributor has a *profile ignition pickup (PIP) sensor*. The PIP sensor consists of a special armature and a Hall-effect switch. The armature, made of ferrous material, attaches to the end of the distributor shaft. The armature has a certain number of windows and metal tabs or shutters, the number of which depends on the engine. For example, a four-cylinder engine has four windows and four tabs, while a V-8 engine will have eight of each. In either case, these windows and tabs rotate past the stator assembly whenever the distributor shaft turns.

The stator assembly contains a Hall-effect switch. The *Hall-effect switch* consists of a semiconductor chip on one side and a magnet on the other. The semiconductor chip has a small but constant input voltage applied to it (Fig. 6-42).

Edward Hall, in 1879, discovered the principle upon which this sensor operates. Simply speaking, Hall discovered he could generate a small voltage in

a semiconductor material by passing a small constant current through it in one direction, while at the same time, directing the magnetic field from the magnet across the chip at a right angle to the flow of current.

The force of this field produces an output voltage (called Hall voltage) across the semiconductor, as shown. If the current flow through the chip is from left to right, the voltage produced in the semiconductor will be on its upper and lower edges.

The movement of a tab or shutter between the magnet and the chip creates a shunt, or alternate path, for its magnetic field (Fig. 6-43). This changes the magnetic field strength through the semiconductor and causes the chip's output Hall voltage to vary.

When a TFI-I armature window enters the area between the magnet and the chip, the magnetic field begins to pass through the chip as indicated by the left illustration in Fig. 6-44. As the magnetic field enters the semiconductor, it produces a positive Hall voltage on the chip edges, which is used to close the primary coil circuit. The voltage increases to maximum as the window fully opens for magnetic pathway through the chip.

Notice in this illustration that the switch is off during this time. The reason for this switch designation is that the positive voltage has turned off the operation of the secondary ignition circuit.

As a tab begins to come between the semiconductor and the magnet, its magnetic lines of force are shunted back to the magnet. Since fewer lines of force are cutting the semiconductor, its voltage drops rapidly and the Hall switch turns on the secondary ignition circuit. With the switch on, the zero

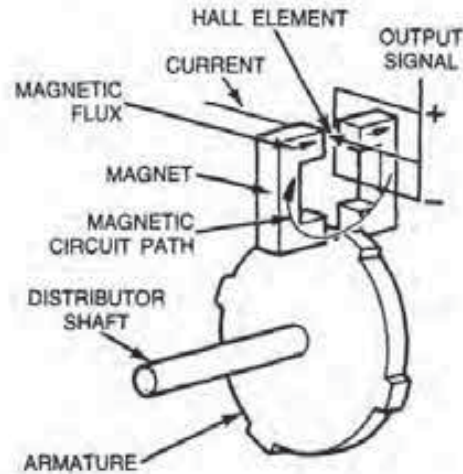


FIGURE 6-43

Effect of armature on the magnetic field. (Courtesy of Ford Motor Co.)

Hall voltage triggers the opening of the primary circuit. The voltage remains at positive zero during the period that the tab completely blocks the air gap between the chip and the magnet.

Although the Hall sensor requires a connection for input voltage to the chip, its output voltage does not depend on the speed of the rotating armature. Therefore, the sensor generates a full-strength Hall voltage even at slow cranking speeds.

Moreover, the Hall switch, as it turns off and on, produces a pulsating DC sine wave signal with sharp corners that looks similar to a square wave. The signal is known as the *PIP* signal and is an indication of both crankshaft position and speed. The PIP signal is fed to both the TFI-IV module and the ECA (Fig. 6-45).

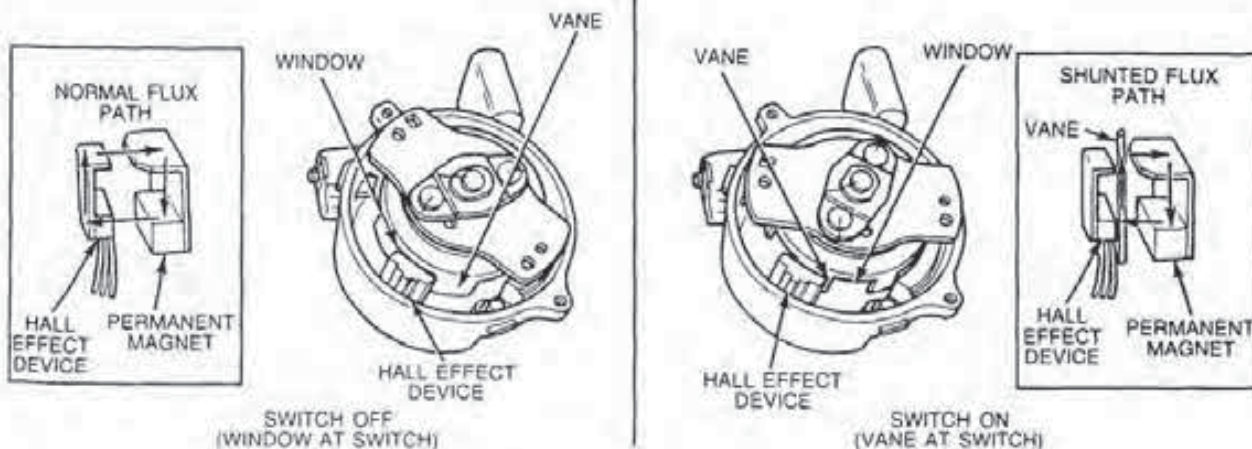


FIGURE 6-44

Hall-effect switch operation in a TFI-IV distributor. (Courtesy of Ford Motor Co.)

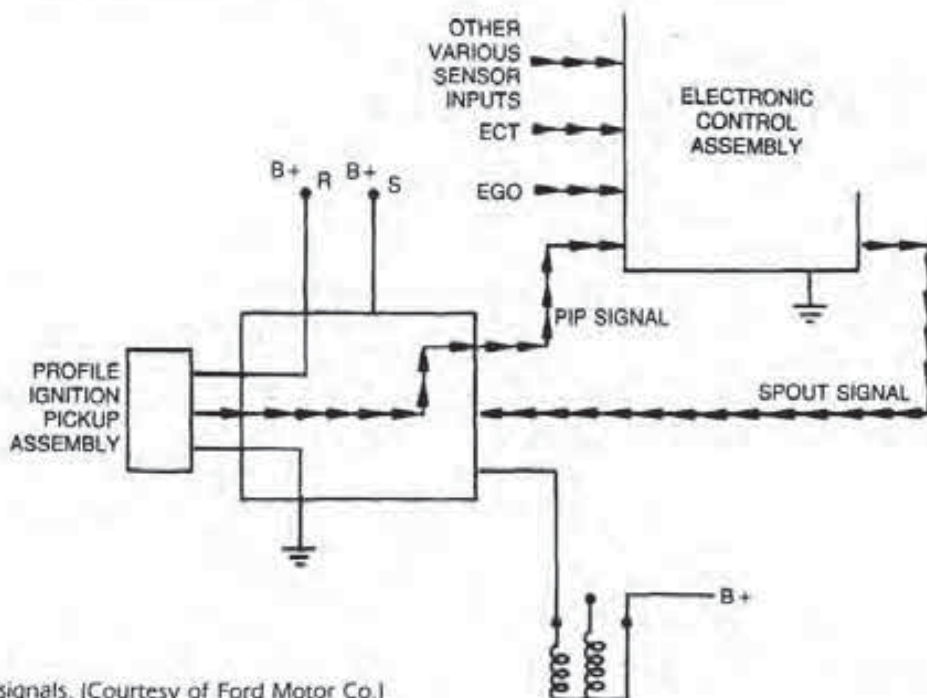


FIGURE 6-45
PIP and SPOUT signals. (Courtesy of Ford Motor Co.)

The PIP signal is just one of the many inputs processed by the ECA. The ECA, after monitoring all sensor information, produces the *spark output (SPOUT)* signal. The SPOUT signal represents engine-operating conditions electronically, and it is sent back to the TFI-IV module for comparison with the PIP signal. The TFI-IV module then uses both of these signals to close and open the primary coil circuit at the correct timing intervals for all engine speeds and loads.

If the PIP signal is not generated by the Hall sensor, the engine cannot run because there will be no ignition. If the ECA has failed, or the PIP signal of a carbureted engine does not reach it, the engine will still run because the module can produce a base timing from the PIP signal. This is not the case in a fuel-injected engine because the ECA cannot operate the injectors without a PIP signal.

TFI-IV Modifications

The 5.0-liter sequential electronic fuel injection (SEFI) system incorporates a unique trigger armature for ignition/fuel synchronization. The ECA must be able to determine which PIP signal is for the number one cylinder. To accomplish this, one tab on the armature is narrower than the others, causing a different signal (Fig. 6-46). This is referred to as the *signature PIP signal*. The signal is necessary due to the need to energize each injector in relation to the engine firing order.

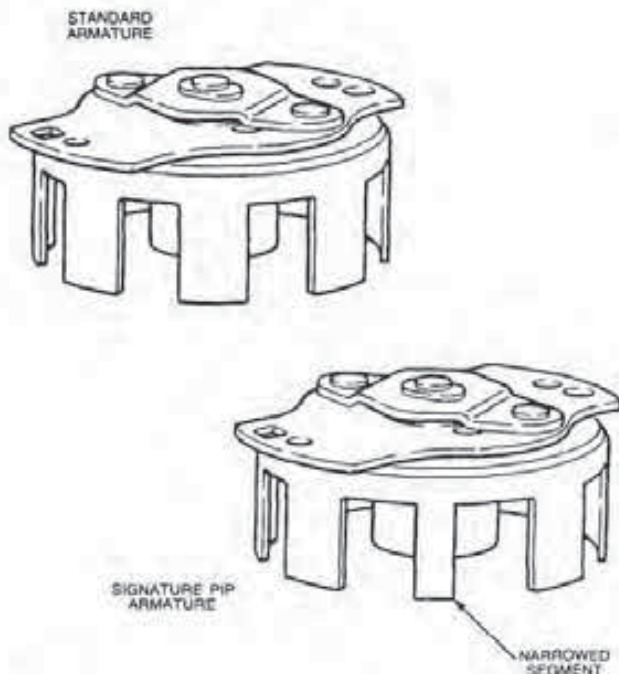


FIGURE 6-46
Signature PIP armature. (Courtesy of Ford Motor Co.)

CHAPTER REVIEW

The following two sections will assist you in determining how well you remember the material contained in this chapter. If you cannot complete a statement or question, refer back to the section marked in brackets that contains the material.

SELF-CHECK

1. Name the four negative characteristics of a contact point ignition system [6-1].
2. Why doesn't the TFI-IV distributor require any built-in advance mechanisms [6-8]?
3. What is the function of the contact points in a transistorized ignition system [6-2]?
4. TFI-I is similar to what other ignition system [6-7]?
5. What are the functional objectives of the SSI system [6-3]?
6. How does the Duraspark III system advance ignition timing [6-6]?
7. What is the main functional difference between the Duraspark I and II systems [6-4]?
8. Which Duraspark system utilizes the SSI coil [6-5]?
3. Where is the PIP sensor located [6-8]?
 - a. in the TFI-IV distributor
 - b. on the front of the engine
 - c. on the rear of the engine
 - d. in the microcomputer
4. What is the term used to describe the reduction in ignition system voltage at high speed [6-1]?
 - a. voltage decay
 - b. voltage reduction
 - c. voltage variation
 - d. potential loss
5. Which ignition system uses an E coil [6-7]?
 - a. the Duraspark II system
 - b. the SSI system
 - c. both a and b
 - d. neither a nor b
6. What part directly controls the primary current flow in the transistorized ignition system [6-2]?
 - a. switching transistor
 - b. contact points
 - c. condenser
 - d. zener diode
7. Where is the TFI-I system module located [6-7]?
 - a. on the distributor
 - b. on the left fender panel
 - c. in the microcomputer
 - d. in the coil assembly
8. What is the expected life of a contact point in a transistorized ignition system [6-2]?
 - a. 5,000 miles
 - b. 10,000 miles
 - c. 15,000 miles
 - d. over 20,000 miles

REVIEW

1. What produces the Hall voltage in the TFI-IV distributor [6-8]?
 - a. inducing a voltage in the pickup coil
 - b. passing a magnetic field through a current-carrying semiconductor chip
 - c. passing current through the pickup coil in one direction
 - d. passing current through the pickup coil in both directions
2. What is the name used to describe the difference between required and available voltage [6-1]?
 - a. coil potential
 - b. voltage reserve
 - c. current reserve
 - d. voltage potential
9. The pulse ring of a Duraspark III system is installed to create a reference timing of how many degrees [6-6]?
 - a. 20 degrees
 - b. 10 degrees
 - c. 5 degrees
 - d. 0 degrees or TDC
10. At what point does the spark plug fire [6-3]?
 - a. when the magnetic pulse generator in the distributor produces a positive zero voltage
 - b. when the magnetic pulse generator in the distributor produces a positive voltage
 - c. either a or b
 - d. neither a nor b

11. Which distributor cap uses male cable terminals?
 - a. Duraspark I
 - b. Duraspark II
 - c. both a and b
 - d. neither a nor b
12. The CP sensor is part of what system [6-6]?
 - a. SSI system
 - b. Duraspark I
 - c. Duraspark II
 - d. none of these
13. Which ignition system uses centrifugal and vacuum advance mechanisms [6-3]?
 - a. Duraspark I
 - b. SSI
 - c. Duraspark II
 - d. none of these
14. What system can use the universal ignition module [6-5]?
 - a. Duraspark II
 - b. Duraspark I
 - c. SSI
 - d. transistorized
15. The coil in which system has a special alignment lug [6-4]?
 - a. SSI
 - b. Duraspark II
 - c. transistorized
 - d. none of these
16. Dual-mode ignition modules are used on what system [6-5]?
 - a. SSI
 - b. Duraspark II
 - c. Duraspark I
 - d. transistorized

TESTING TYPICAL FORD ELECTRONIC IGNITION SYSTEMS

OBJECTIVES

After reading and studying this chapter, you will

- know the general precautions relating to testing electronic ignition systems.
- have a working knowledge in the use of test equipment on Ford electronic ignition systems.
- know where to locate Ford calibration codes.
- understand the use and importance of troubleshooting guides.
- be able to test a typical Ford solid state ignition (SSI) system.
- be able to test typical Ford Duraspark II and III systems.
- be able to test a typical Ford TFI-IV system.

Electronic ignition is one of the main operating systems of any engine. The gasoline power plant cannot function without it. Moreover, any malfunction in this system, no matter how small, affects not only engine performance but also the operation of other systems.

Most engineers consider electronic ignition the most important system for emission control and fuel economy on an engine. The number of ignition system modifications that have been made over the years, and the effects of component maladjustment or spark plug misfire on emissions and fuel economy support this view.

Therefore, if the engine is to operate properly, the electronic ignition system must work perfectly from the battery supply voltage at the ignition switch to the high voltage arc at the spark plugs. In other words, any problem that develops in either the primary or secondary circuit seriously affects performance, emission control, fuel economy, and driveability.

Over the years, Ford has produced quite a number of electronic ignition systems for various applications. Obviously, there is insufficient room in this chapter to thoroughly discuss the testing procedures for all of them. As an introduction to the process, this chapter will cover typical test procedures used on some of the systems covered in the last chapter. *Always follow the manufacturer's instructions, guides, and specifications when testing any of these system applications in order to prevent damage to the various components.*

7-1 GENERAL PRECAUTIONS, TEST EQUIPMENT, CALIBRATION CODES, AND TROUBLESHOOTING GUIDES

Before learning to test Ford systems, you must become familiar with a number of general precautions for working on electronic ignition systems, in general, and Ford systems, in particular. See the shaded box for these general precautions. Also, always observe the safety instructions covered in Chapter 5.

General Precautions

The precautions and instructions listed below will not only save you time in locating the actual cause of the problem but prevent the possible destruction of an otherwise serviceable component.

All Electronic Ignition Systems

1. The battery must be up to full charge in order to provide a test voltage. The charging system must also function correctly. If either the battery or the charging system is not operating properly, you may obtain incorrect test data, which will lead to the replacement of serviceable ignition components.

2. An alternator produces maximum or near maximum current flow if the battery does not hold a charge. When operating in this manner for long periods, the alternator can be damaged. Therefore, check the alternator for correct charging rate and its drive belt for specified tension before beginning ignition testing.

3. Always disconnect the negative (-) battery cable before changing any system components or removing and cleaning connections.

4. The correct parts must be used whenever replacing system components. Although many of the systems use devices that appear similar, many are not identical. Consequently, always check the catalog applications for the correct replacement part numbers.

5. Always adhere carefully to the manufacturer's instructions as to the use and care of test equipment. Make sure you are not using a piece of test equipment in a way not specified by its manufacturer. *Make certain that the test instruments you're using are compatible with the ignition system being tested (or spark control system, in the case of some Chryslers). If in doubt about whether to use a certain piece of equipment on a particular system, contact the equipment manufacturer or check the service manual of the vehicle.*

6. Before beginning any electrical testing, inspect all the connections throughout the system to make sure they are clean and tight before checking voltages or continuity. Corroded or loose terminals may cause incorrect readings.

7. Turn off the ignition switch before unplugging the module or wiring harness connectors.

8. Do not test an engine with a catalytic converter for more than 30 seconds at a time with a spark plug not firing. This can damage the converter.

9. Always replace spark plug cables with ones equivalent to the originals.

10. Never puncture a spark plug or coil cable for any reason.

11. If a wire is punctured during a test, repair it with tape or some nonacetic RTV compound before placing the vehicle back in service.

12. The ohmmeter is used in a number of ignition system tests to confirm continuity of a circuit. To make this form of test, the meter is connected in parallel with the circuit or component being tested.

13. To determine if there is high resistance or there are corroded connections, use a voltmeter connected in parallel with the components or circuit to perform a voltage drop test.

14. Do not disconnect the battery terminals with the ignition switch on. The resulting high voltage surges can damage electronic components.

15. Do not disconnect or connect any electrical connections with the ignition switch on unless *specifically* directed to do so. Breaking or making an electrical connection can cause a high voltage surge that may damage electronic components.

Ford Systems

16. Always follow the emission label's specifications and test procedures.

17. Disconnect the ignition wiring harness connectors before conducting a compression test.

18. The ignition modules for the different systems are not interchangeable.

19. Whenever an ignition cable is removed from a spark plug, coil, or distributor, use silicone grease to coat its boot before reconnecting the wire.

20. All color codes referred to in the tests relate to stator pickup coil or module wiring. You must trace the wires back to these components for correct identification.

21. On the 1975-1976 SSI and the Duraspark I and II systems, while they are operating, do not remove the number one or number three spark plug cable from a four-cylinder engine, a

number three or number five cable from an inline six-cylinder engine, the number one or number four cable from a V-6 engine, or the number one or number eight cable from a V-8 engine. The resulting high secondary voltage could arc to the stator pickup coil and damage it.

22. On 1979-1982 Duraspark and TFI-I systems, coat the brass rotor electrode surfaces on all sides with silicone grease to about 1/4-inch (3.17-mm) thickness. This is not necessary on the 1983 and later rotors, which have two-pronged electrodes. The grease is necessary to suppress radio noise or interference. The grease has no effect on the operation of the ignition or electronic engine control system.

Test Equipment

Various pieces of test equipment are necessary to check the various types of Ford electronic ignition systems. Having the proper test equipment available plays an important part in diagnosing and repairing the systems. Before you begin the ignition diagnostic procedures that follow, be sure you have an accurate analog volt-ohmmeter, power timing light with induction pickup, modified spark plug with the side electrode removed, 12-volt test light, several straight pins, and an ignition diagnostic test adapter (Fig. 7-1).

Larger pieces of equipment that are necessary include an engine analyzer or oscilloscope and a module tester. The scope will be used to test the operation of both the primary and secondary circuits. A unit that is especially helpful is the Allen "Smart" scope because it is capable of reading distributor pickup coil signals. The module tester electronically checks the serviceability of the ignition module either on or off the vehicle.

Figure 7-2 illustrates a spark tester. This device eliminates the use of a modified spark plug and a jumper lead while testing secondary voltage.

Lastly, you will need to prepare a number of jumper wires. Figure 7-3 shows the number of leads needed, their respective lengths, and the types of terminal ends required.

Calibration Codes

The 1981 and later emission control decals or the engine code label provide vehicle calibration and engine operating specifications (Fig. 7-4). From the de-

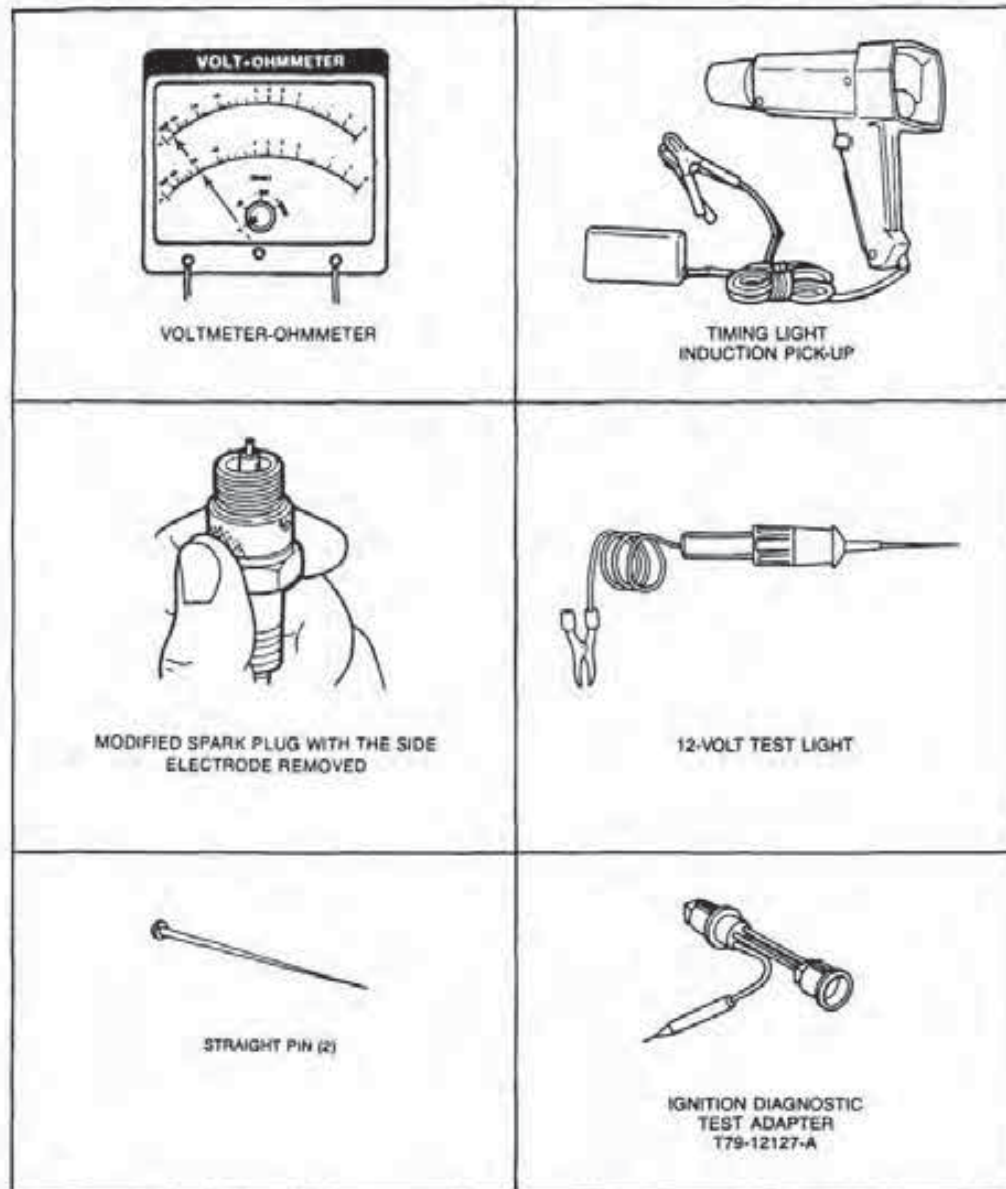


FIGURE 7-1
Diagnostic test equipment. (Courtesy of Ford Motor Co.)

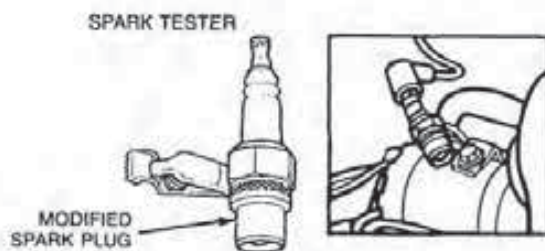


FIGURE 7-2
Spark tester. (Courtesy of Ford Motor Co.)

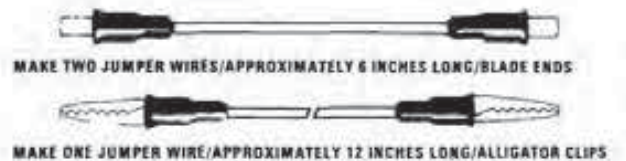



FIGURE 7-3
Preparation of jumper wires. (Courtesy of Ford Motor Co.)

ALL 1981 AND EARLY 1982 MODELS



**FORD MOTOR COMPANY
VEHICLE EMISSION CONTROL INFORMATION**

ENGINE FAMILY: 27M-830-123 2.0L/1100cc
ENGINE DISPLACEMENT: 3.3L
TRAN: 4R70
SPARK PLUG: COP 021 24A

SHIFT: 5
THROTTLE: 6
TIMING: 100°

FAST IDLE: 1500 RPM
IDLE: 700 RPM
AIR/FILTER: 1000 RPM

CHOCKS: 1000 RPM
DASHPOT: 1000 RPM

NEVER TO SERVICE PUBLIC VEHICLE. ADJUSTMENT AND TEST INSTRUCTIONS. COMPLIANCE DEMONSTRATED BELOW ADDS FT. CARBON MONITORING SYSTEM. MONITOR AUTO. TRANS. LUBRICANT. SEE SHOP MANUAL FOR DETAILED INSTRUCTIONS.

THIS VEHICLE COMPLIES WITH THE U.S. EPA AND CALIFORNIA REGULATIONS FOR 1982 MODEL YEAR NEW MOTOR VEHICLES INTRODUCED INTO U.S. SERVICE FOR SALE IN CA. JUNE 1981.

**1981-82 Code Label
Early 1982 Models**

ENGINE CODE LABEL
— ALL ENGINES EXCEPT 1.6L

Item B

C		12B	
2		10	
R		28	
S		28	

NOTE: Some calibrations are carried over from prior model years. If you cannot locate calibration number using 2 prefix, check 1, 0, 9, 8, 7 or 5 prefixes.

**1981-82 Code Label
Early 1982 Models**

ENGINE CODE LABEL
1.6L ENGINE ONLY

Item B

NA671AB	
1.6 LITER DEARBORN ENG BLD 258S145-12	
C	03G
R	00
S	(N)
800 10 2	

1. DETERMINE ENGINE DISPLACEMENT FROM EMISSION CONTROL DECAL — ENTER IN BLANK "A" OF EXAMPLE SHOWN BELOW

2. DETERMINE VEHICLE MODEL YEAR FROM EMISSION CONTROL DECAL — ENTER LAST DIGIT IN BLANK "B" SEE EXAMPLE BELOW

3. DETERMINE CALIBRATION BASE NUMBER FROM ENGINE CODE LABEL — ENTER NUMBERS AND LETTERS IN BLANK "C"

4. DETERMINE REVISION LEVEL FROM ENGINE CODE LABEL — ENTER IN BLANK "D"

(A) (B) (C) (D)

EXAMPLE: ENGINE: 3.3L (200 CID) CALIBRATION 2 - 12B - R10

FIGURE 7-4
Vehicle engine and emission decals. [Courtesy of Ford Motor Co.]

cal and label, you can obtain the vehicle calibration code, which will provide the exact information regarding the ignition system installed on the vehicle being serviced.

To determine the calibration code on 1981 and early 1982 production engines, follow Steps 1-4, as shown in the illustration and described in Items A

and B. To do this, look at the vehicle emission decal to determine Steps 1 and 2. For Steps 3 and 4, look at the engine code label for the additional information required. Then follow the instructions in Steps 1-4 that are shown in Fig. 7-4. For late 1982 and newer models, it is only necessary to examine the calibration code label, as shown in Item C, Step 1A.

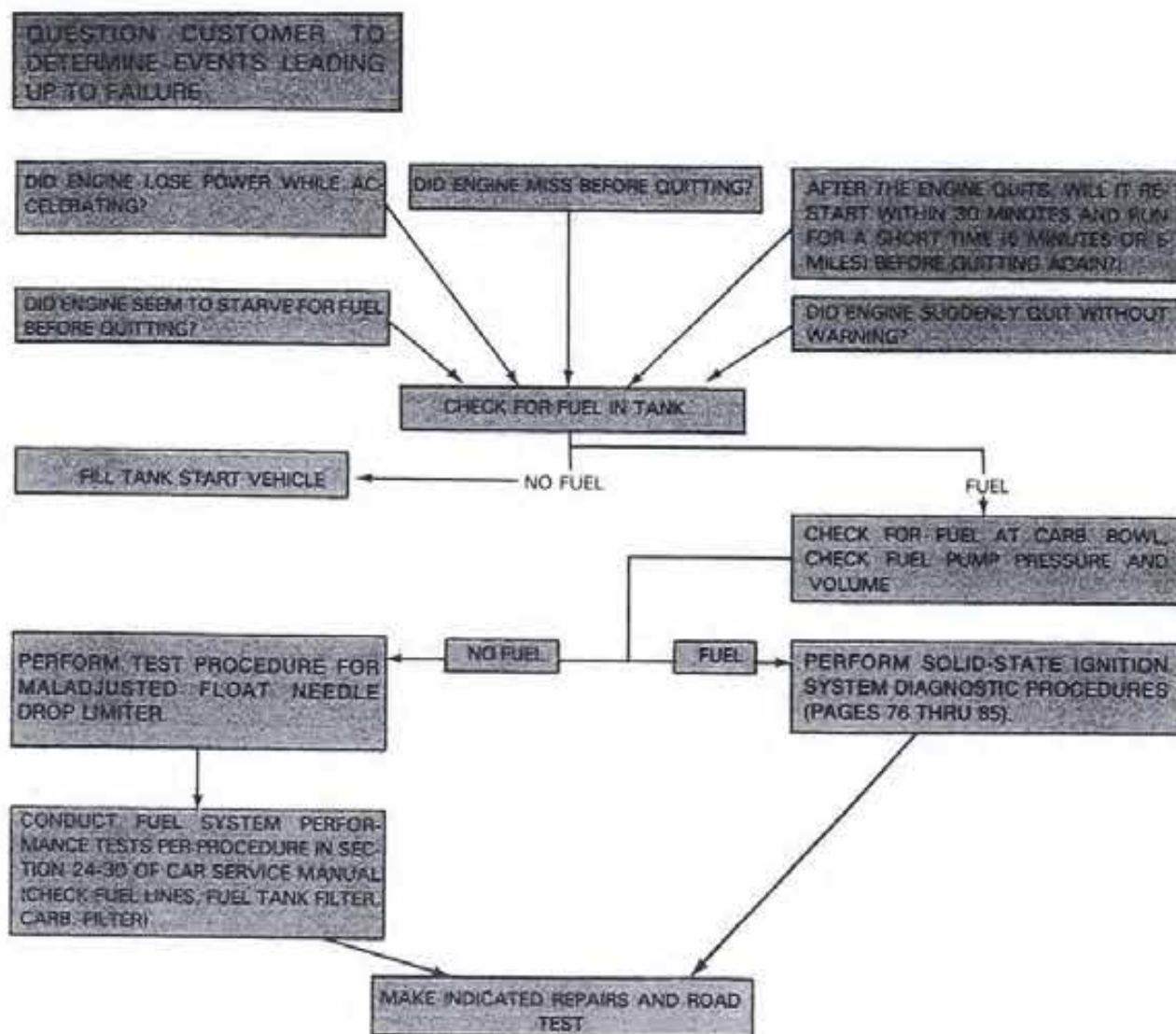


FIGURE 7-5
Typical troubleshooting guide. (Courtesy of Ford Motor Co.)

Troubleshooting Guides and Procedures

Ford and other vehicle manufacturers provide troubleshooting guides and procedures to assist the technician in locating the cause of a malfunction (Fig. 7-5). The guide shown in the illustration is for a poor but intermediate engine operating condition. First, the guide provides a number of customer questions that attempt to determine the events leading up to the problem. Next, the guide provides a number of items to check out in a given order.

It is extremely important that the technician follow the steps listed on the guide in the order shown. Also, the steps must always be performed no matter how insignificant they may appear. If these instructions are not followed, the technician will

more than likely find that the parts replaced were not faulty and the driveability problem still remains. Obviously, this leads to a dissatisfied customer and extra work for the technician.

7-2 TESTING SSI AND DURASPARK II SYSTEMS

This section presents a troubleshooting procedure for typical solid state and Duraspark II ignition systems. The test procedure is divided into three parts: (1) engine cranks over normally but will not start, (2) engine operates but its performance is poor, and (3) engine starts up but fails to continue operating.

Engine Cranks Over Normally But Will Not Start

To locate the cause of the no-start condition, follow the steps outlined below.

1. Visually check the ignition system for any of the following defects:

- a. Disconnected spark plug cables.
- b. Insulation damage, or burned, overheated, loose, broken, or corroded conditions in wiring harnesses and connectors.
- c. Oil or moisture on the top surface area of the ignition coil or on the inner surfaces of the distributor cap. If moisture is present, remove it with a clean cloth. If there is an oil film on either part, remove it with alcohol and a clean cloth.
- d. Cracked or incorrectly installed distributor cap. If the cap is cracked, replace it, or install the cap correctly.
- e. If the engine still will not start, proceed to Step 2.

2. Check the ignition coil secondary voltage that is available during cranking by doing the following:

- a. Clamp the pickup lead of a scope to the coil high tension cable, following the manufacturer's instructions.
- b. Remove the coil wire from the distributor if a scope is not available and insert a modified spark plug or spark tester into its terminal boot (Fig. 7-6). Attach a spark tester to a good ground (see Fig. 7-2).
- c. Have an assistant crank the engine over with the ignition switch. Observe the scope screen for a vertical voltage trace; the voltage value is not important. Or check for spark at the modified plug or spark tester.
- d. If a strong spark is observed, the problem may be caused by the secondary ignition delivery system, or it may be a malfunction in the fuel system.
- e. If there was no evidence of a spark either on the scope screen or at the plug, use an ohmmeter to measure the resistance of the coil wire. Replace the cable if the resistance is not to specifications. Also, inspect the

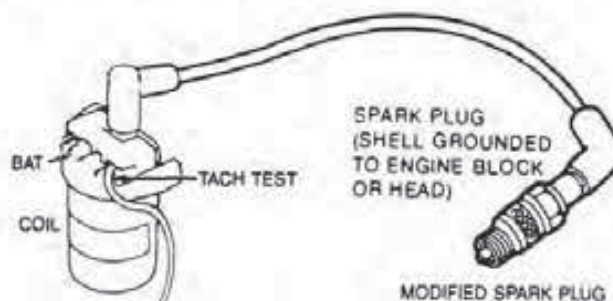


FIGURE 7-6
Secondary voltage check. (Courtesy of Ford Motor Co.)

ignition coil for damage and carbon tracking. Replace the coil as necessary.

- f. If there is still no indication of a spark, proceed to Step 3.
3. Check for spark by tapping on the distributor (Fig. 7-7). To perform this test, do the following:
 - a. Turn the ignition switch to the RUN position.
 - b. Tap on the distributor with the plastic handle of a screwdriver.
 - c. Check for the indication of a spark on the scope screen or at the modified plug. Tapping of the distributor should cause enough vibration to generate a strong enough voltage in the pickup coil to trigger a spark.
 - d. If a good spark is observed each time you tap the distributor, the RUN circuit is op-

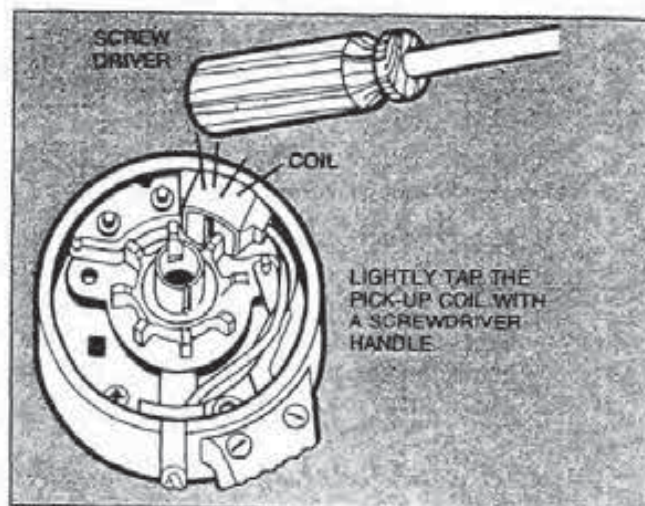


FIGURE 7-7
Testing for spark by tapping on the distributor. (Courtesy of Ford Motor Co.)

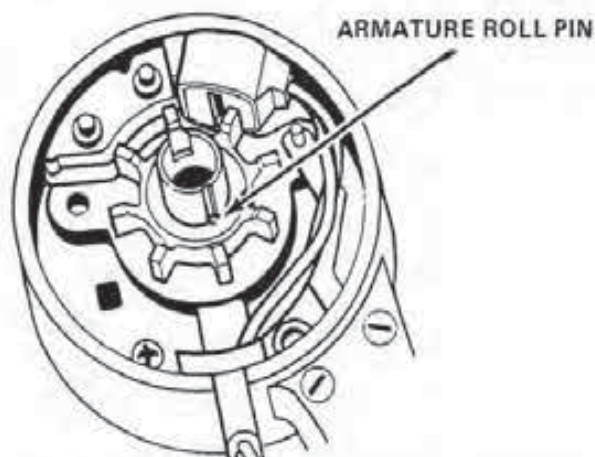


FIGURE 7-8
Checking the armature roll pin. (Courtesy of Ford Motor Co.)

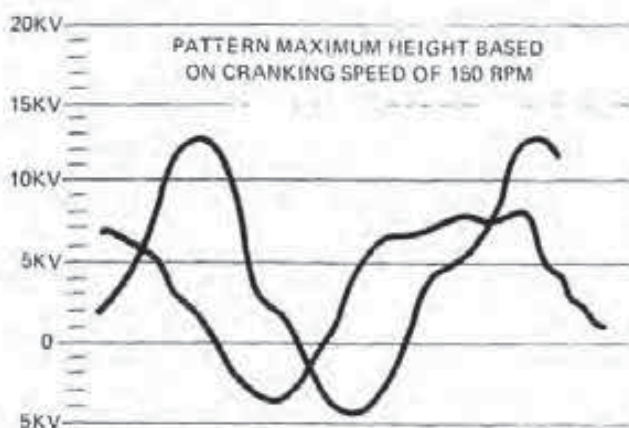


FIGURE 7-9
Testing pickup coil operation on a scope.

erating properly. In this case, proceed to Step 9.

- e. If there is no spark indication, proceed to Step 4.

4. Check for proper rotor alignment. To perform this check, follow these instructions:

- a. Remove the distributor cap.
- b. Using a remote starter switch, crank the engine over until the timing marks are lined up exactly at the correct initial timing specification. Observe the motion of the armature while its engine is turning over.
- c. If the armature does not rotate, the timing chain or gears may be broken, or the armature roll pin may be broken or not installed (Fig. 7-8).

- d. If the roll pin installation was satisfactory and there is still no indication of a spark, proceed with Step 5.

5. Test the magnetic pickup within the distributor by using an Allen "Smart" scope on self-sweep operating mode.

- a. Disconnect the pickup coil harness connector.
- b. Connect the red test probe from the scope to the orange pickup wire.
- c. Connect the black test probe to the purple pickup lead.
- d. Place the ohm scale selector switch in the X10 position.
- e. Crank the engine while observing the screen display.
- f. The pattern in Fig. 7-9 is typical if the pickup coil is good. If the pattern is okay, move to Step 7.
- g. If there is no pattern, proceed to Step 6.

6. Test the resistance within the stator pickup coil by doing the following:

- a. Separate the ignition module four-wire connector. Inspect the connector for dirt, corrosion, and damage.
- b. Using an ohmmeter, measure the pickup coil and harness resistance between the wiring harness terminals by mating with the orange and purple module wires (Fig. 7-10). Note: Wiggle the wires during the test.
- c. If the resistance is to specifications, the pickup coil is serviceable.
- d. If the resistance is not to specifications, replace the pickup coil.
- e. Attach one ohmmeter lead to the distributor base.
- f. With the other lead, alternately measure the resistance between the pickup coil wiring harness terminals by mating with the orange and purple module wires.
- g. If the resistance between the two points is greater than 70,000 ohms, the harness is satisfactory. Proceed to Step 7.
- h. If the resistance is less than 70,000 ohms, inspect the wiring harness between the

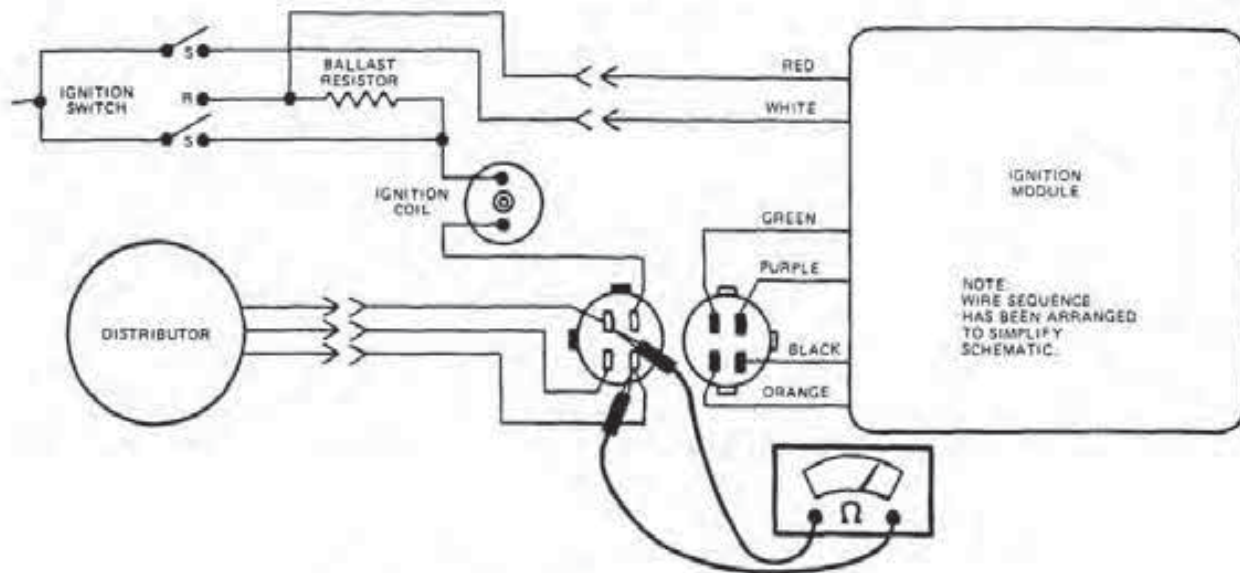


FIGURE 7-10

Checking pickup coil resistance. (Courtesy of Ford Motor Co.)

module connector and the distributor, including the distributor grommet.

- i. Reconnect the four-wire connector.

7. Test the module voltage to see if it is 90 percent of battery voltage by doing the following:

- a. Make sure the ignition switch is off.
- b. Carefully insert a small straight pin in the red module wire (Fig. 7-11).

Caution: Do not permit the straight pin to contact an electrical ground.

- c. Attach the negative (–) lead of the voltmeter to the base of the distributor.
- d. With the voltmeter positive (+) lead, measure and record battery voltage.
- e. With the voltmeter (+) lead, measure and record the voltage at the straight pin with the ignition switch in the RUN position.
- f. Turn the ignition switch to the OFF position.
- g. If the voltage is within 90 percent of that of the battery, proceed to Step 8.
- h. If the voltage is less than 90 percent of battery voltage, inspect the wiring harness between the ignition module and the switch. Repair or replace the harness as necessary. If the wiring is okay, replace the

ignition switch.

- i. Remove the straight pin, and repair the puncture in the wire insulation.
8. Check the ballast resistor for the correct amount of resistance by doing the following:

- a. Separate and inspect the ignition module two-wire connector with the red and white wires.
- b. Disconnect and inspect the ignition coil connector.
- c. Using an ohmmeter and jumper leads as necessary, measure the ballast resistance between the BATT terminal of the ignition coil connector and the wiring harness connector terminal with the red module wire (Fig. 7-12).
- d. If the resistance is not to specifications, replace the ballast resistor.
- e. If the resistance is to specifications, assemble all the connectors and proceed to Step 9.

9. Test the supply voltage to the ignition switch and the ignition module wiring harness to make sure it is within 90 percent of that supplied by the battery by doing the following:

- a. Remove the modified spark plug or spark tester, and reconnect the coil high tension cable into the distributor cap.

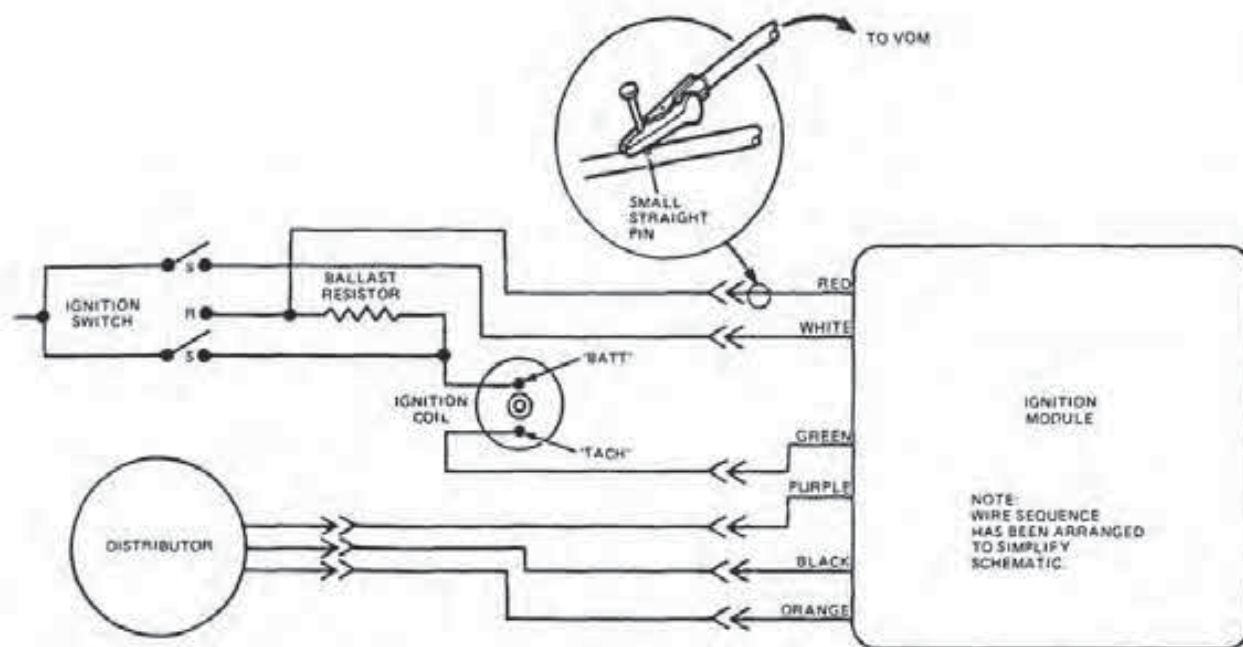


FIGURE 7-11
Testing module voltage. (Courtesy of Ford Motor Co.)

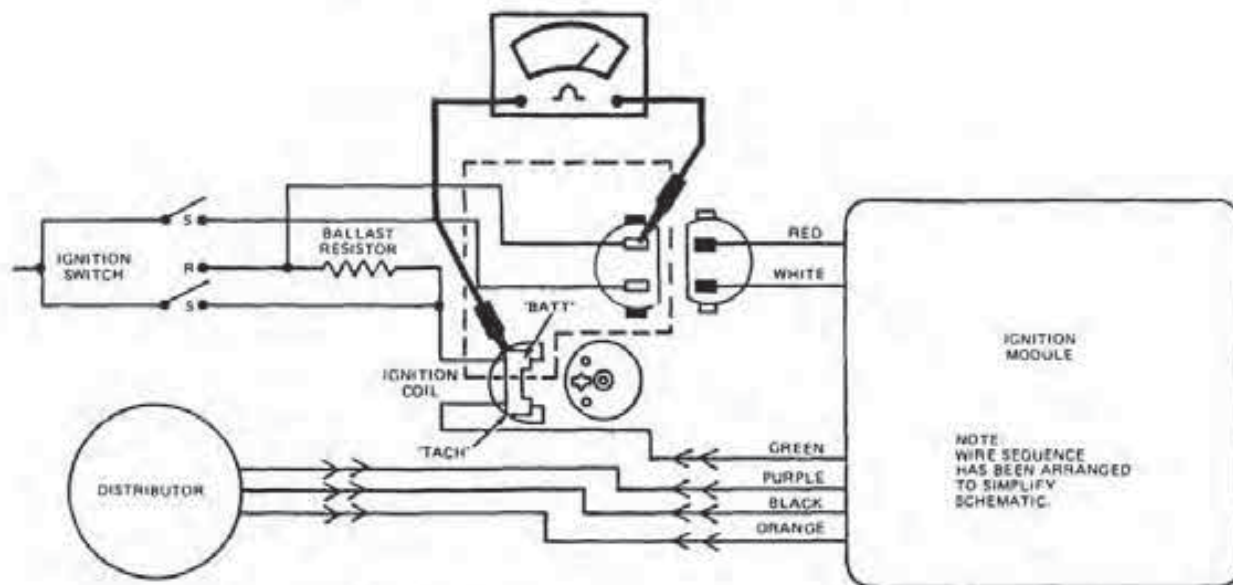


FIGURE 7-12
Ballast resistor check. (Courtesy of Ford Motor Co.)

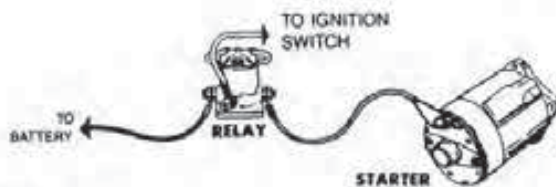


FIGURE 7-13
Starter relay terminals. (Courtesy of Ford Motor Co.)

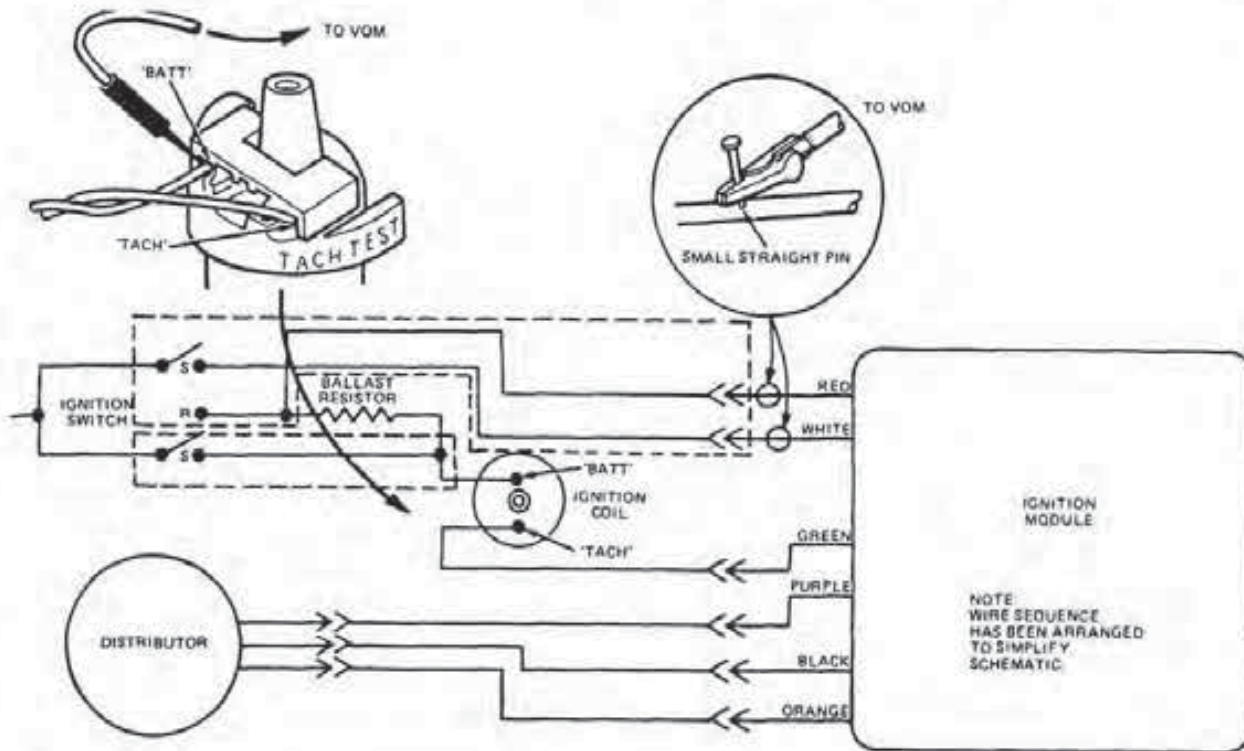


FIGURE 7-14
Checking supply voltage circuits. (Courtesy of Ford Motor Co.)

- b. If the starter relay has an I terminal, disconnect the cable leading from the relay to the starter motor.
- c. If the starter relay does not have the I terminal, disconnect the wire to its S terminal (Fig. 7-13).
- d. Carefully insert small straight pins into the red and white module wires (Fig. 7-14).

Caution: Do not allow the straight pins to contact any electrical ground.

- e. Using the voltmeter, measure and note the voltage at the battery.
- f. Following the table in Fig. 7-15, use jumper leads and a voltmeter to measure the voltage at the points shown, with the ignition switch in the position indicated. Attach the voltmeter (-) lead to the distributor base. Also, wiggle the wires in the harness while making the tests.
- g. After the test is complete, turn the ignition switch off.
- h. If the measurements are not within 90 per-

CONNECT + VOM LEAD TO WIRE/TERMINAL	CIRCUIT	IGNITION SWITCH TEST POSITION
Red	Run	Run
White	Start	Start
"BATT" Terminal Ignition Coil	Ballast Resistor Bypass	Start

FIGURE 7-15
Supply voltage measuring points. (Courtesy of Ford Motor Co.)

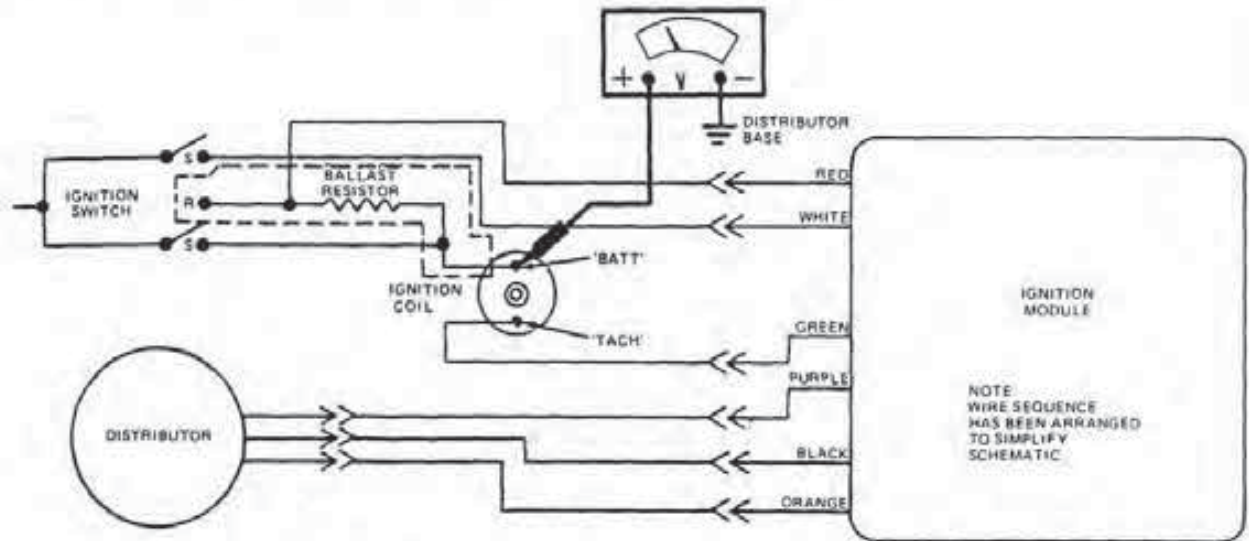


FIGURE 7-16
Testing coil supply voltage. (Courtesy of Ford Motor Co.)

cent of battery voltage, inspect the wiring harness, connectors, ignition switch, and the radio interference capacitor on the ignition coil. Repair or replace defective parts as necessary.

- i. If the measurements are within 90 percent of battery voltage, supply voltage is satisfactory. Proceed to Step 10.
 - j. Remove the straight pins and repair the punctures in the wire insulation.
 - k. Reconnect the cable or wire removed from the starter relay.
10. Test the supply voltage to the ignition coil in the RUN mode by doing the following:
- a. Connect the negative lead of the voltmeter to the base of the distributor (Fig. 7-16).
 - b. Turn the ignition switch to the RUN position.
 - c. With the voltmeter (+) lead, measure the voltage at the BATT terminal of the ignition coil.
 - d. If the voltage is between six volts and eight volts, the supply voltage is okay. Proceed to Step 11.
 - e. If the voltage is less than six volts or more than eight volts, proceed to Step 13.
11. Check the resistance in the coil's secondary windings by doing the following:
- a. Disconnect and inspect the ignition coil connector and wires.
 - b. Connect the ohmmeter leads to the BATT and high voltage terminals of the coil (Fig. 7-17). Read the total resistance on the ohmmeter.
 - c. If the resistance is not to specifications, replace the ignition coil and reinstall its wiring connector.
 - d. If the resistance is to specifications, proceed to Step 12.
12. Test the resistance in the ignition coil primary windings by doing the following:
- a. Disconnect the ignition coil wiring connector if you have not already done so.
 - b. Connect the ohmmeter leads to the coil BATT and TACH terminals (Fig. 7-18). Read the total resistance.
 - c. If the resistance is not to specifications, replace the coil, and reinstall its wiring connector.
 - d. If the resistance is to specifications, reinstall the wiring connector and proceed with Step 13.
13. Check the voltage drop across the primary circuit between the coil and the ignition module in the RUN mode by doing the following:
- a. Carefully insert a small straight pin in the module's green wire (Fig. 7-19).

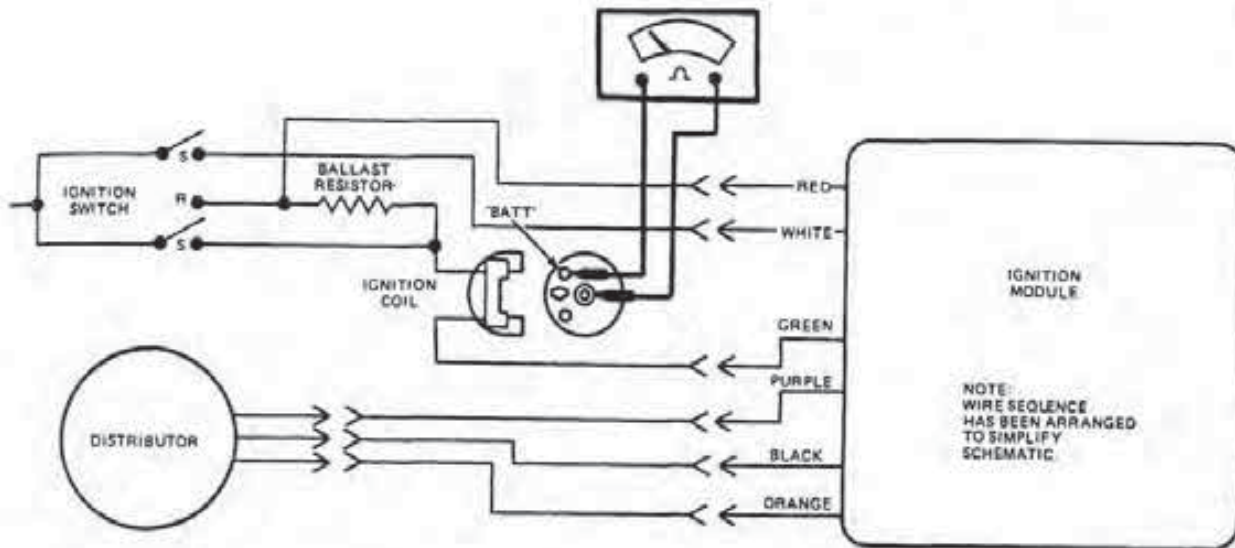


FIGURE 7-17
Checking secondary coil resistance. (Courtesy of Ford Motor Co.)

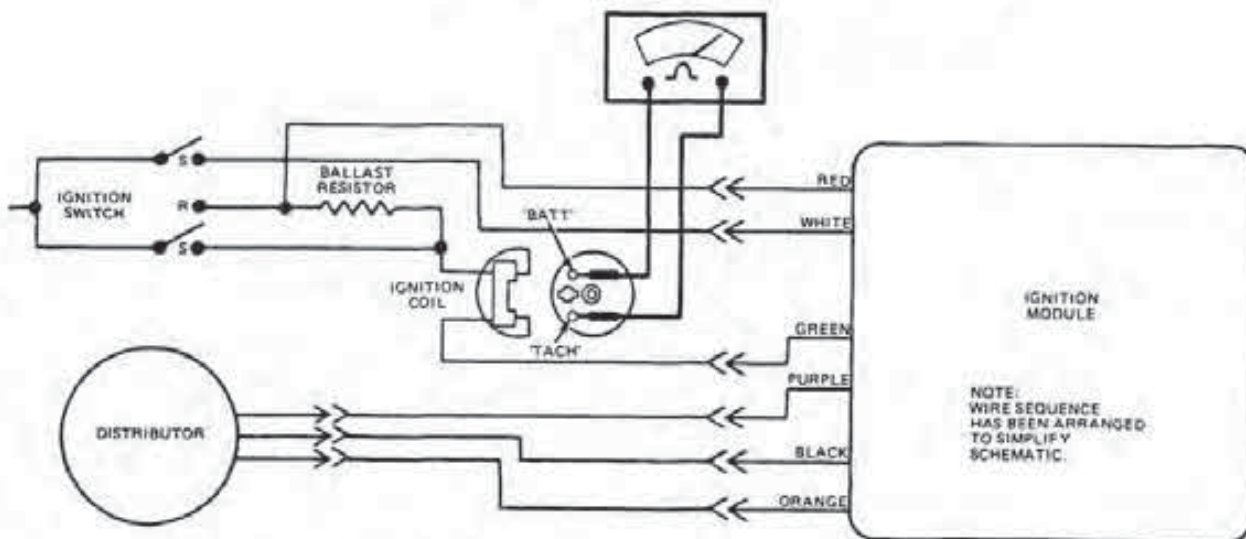


FIGURE 7-18
Testing primary coil resistance. (Courtesy of Ford Motor Co.)

Caution: Do not permit the pin to contact an electrical ground.

- b. Attach the negative lead of the voltmeter to the base of the distributor.
- c. Turn the ignition switch to the RUN position.
- d. Connect the voltmeter positive (+) lead to the pin and measure the voltage.
- e. Turn the ignition switch off.
- f. If the voltage is greater than 1.5 volts, pro-

ceed to Step 14.

- g. If the voltage is 1.5 volts or less, check the wiring harness between the ignition module and the coil.
- h. Remove the straight pin and repair the wire insulation.
14. Test the distributor ground circuit for continuity by doing the following:
 - a. Separate the distributor connector from the harness. Inspect the connector for dirt, corrosion, and damage.

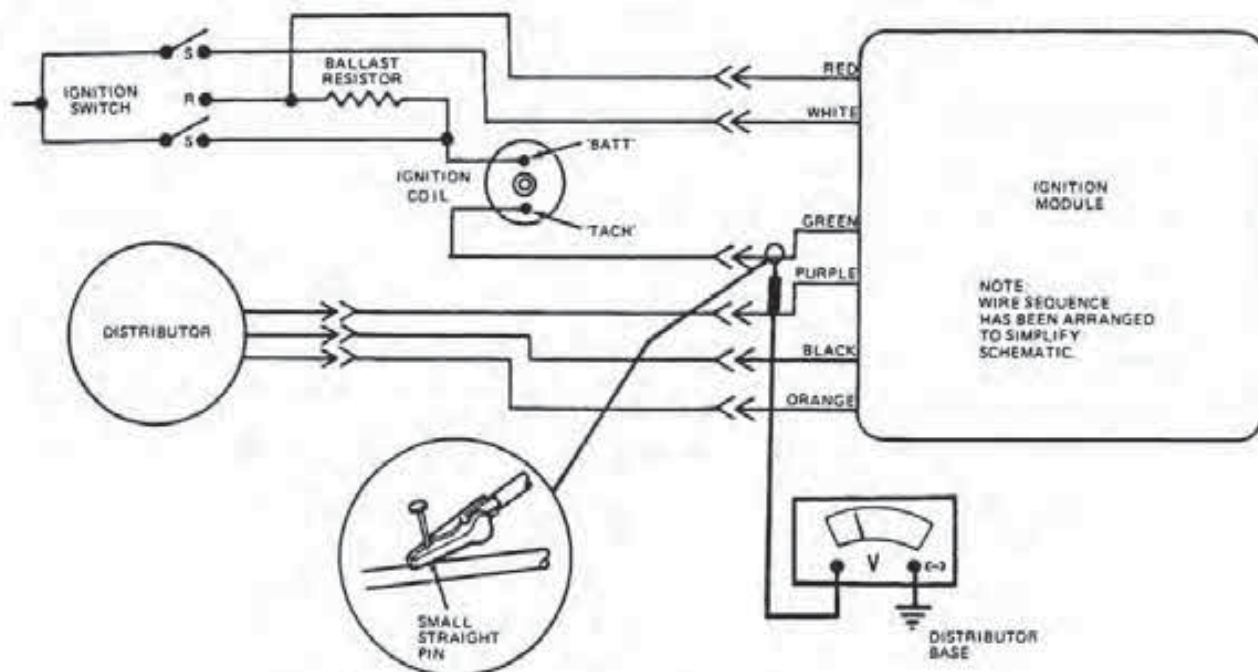


FIGURE 7-19
Primary circuit voltage drop test. (Courtesy of Ford Motor Co.)

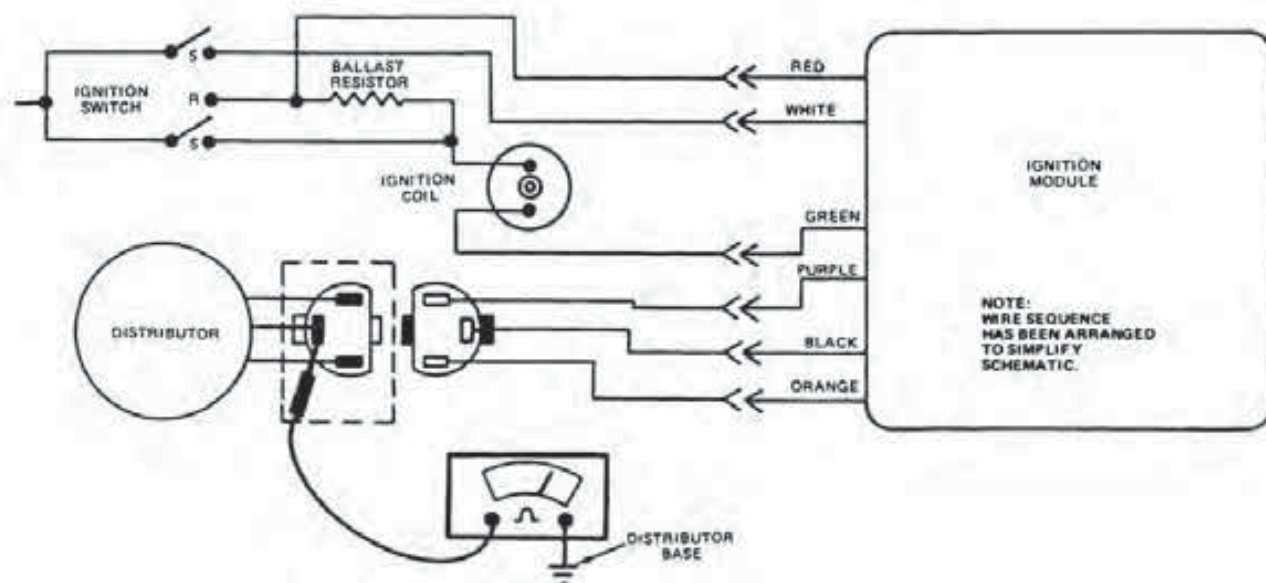


FIGURE 7-20
Distributor ground circuit continuity test. (Courtesy of Ford Motor Co.)

- b. Attach one lead of the ohmmeter to the base of the distributor (Fig. 7-20).
- c. Connect the other ohmmeter lead to the black wire in the distributor harness and read the resistance on the meter.
- d. If the reading is one ohm or less, the continuity of the distributor ground circuit is okay.
- e. If the resistance is greater than one ohm, check the ground screw in the distributor.

- f. After the test is complete, assemble the distributor harness connector.

15. If none of the preceding steps has identified the problem, do the following to test the module:

- a. Plug in a known good module at the harness connectors. Do not remove the old module at this point.
- b. Perform a secondary voltage check as outlined earlier.
- c. If the arc at the spark tester is satisfactory, the old module is defective and requires replacement.
- d. Use an Echlin 4643 computerized module tester or its equivalent, if available, to check the original module. If the module fails the test procedure, replace it.

Engine Operates But Its Performance Is Poor

Poor performance of an engine may include such items as unsatisfactorily accelerating, detonating, misfiring, or stalling. These symptoms may just be an indication that the engine requires preventive maintenance, or they may be due to a malfunction resulting from wear on or failure of a component.

In any case, finding the cause of such a malfunction can require a considerable amount of testing. The following steps include methods of testing individual components as well as the entire system as a whole.

1. Check the ignition system visually for the following problems:

- a. Disconnected spark plug cables.
- b. Loose module and coil harness connectors.
- c. Oil or moisture on the top surface of the ignition coil or on the inner surface of the distributor cap. If the coil or cap is wet, dry each with a clean shop towel. If there is an oil film, remove it with alcohol and a towel.
- d. Cracked or incorrectly installed distributor cap. Replace the defective cap or attach it properly, as necessary.
- e. Carbon tracking and burned electrodes inside of the cap and rotor. If any of these conditions are found, replace the defective component.

- f. Incorrect installation of spark plug cables into the distributor cap sockets.

2. Check all vacuum hoses by doing the following:

- a. Make sure the hoses are installed at the proper locations. Use a vehicle vacuum diagram as needed to check all hose routing.

Caution: Vacuum hoses should never be disconnected in order to improve economy or performance. This may result in engine damage.

- b. If any vacuum hose is cracked or damaged, replace it.

3. Check ignition timing. To check initial or base timing and the operation of the centrifugal advance mechanisms, do the following:

- a. Connect a power timing light or magnetic timing unit to the engine following the manufacturer's instructions.
- b. Following the instructions on the emission decal, remove and plug vacuum line(s) as necessary. *Unplug the harness connector from the barometric or vacuum sensor on Duraspark II systems.*
- c. Adjust curb idle speed to timing specifications. Make sure the engine is at normal operating temperature.
- d. Read the base timing in the readout window or visually check it with a timing light (Fig. 7-21). It should be set dead-on to the specifications.
- e. If the timing is off, loosen the distributor mount bolt. Next, turn the unit to align the marks on the damper and pointer, or until the correct amount of timing is shown in the readout window. Finally, securely tighten the distributor mount bolt.
- f. Adjust engine speed to 2,000 rpm or the speed recommended for the engine.
- g. Check the amount of advancement with the power timing light or by looking at the readout window.
- h. If the timing advanced to specifications, the centrifugal unit is functioning correctly. If the timing advanced unevenly or not to the specified amount, check and repair the centrifugal mechanism.

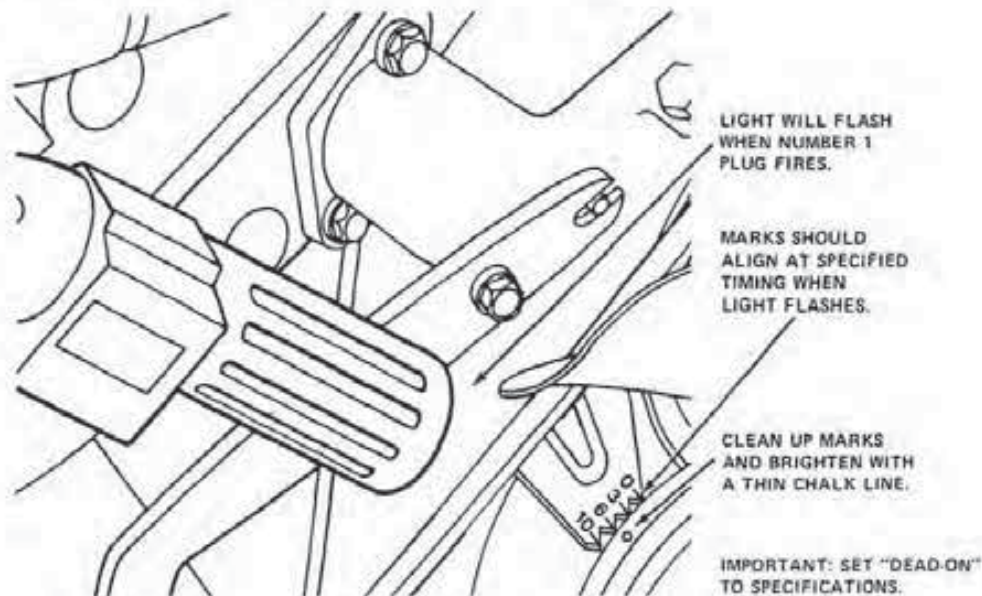


FIGURE 7-21

Checking ignition timing with a light. (Courtesy of Ford Motor Co.)

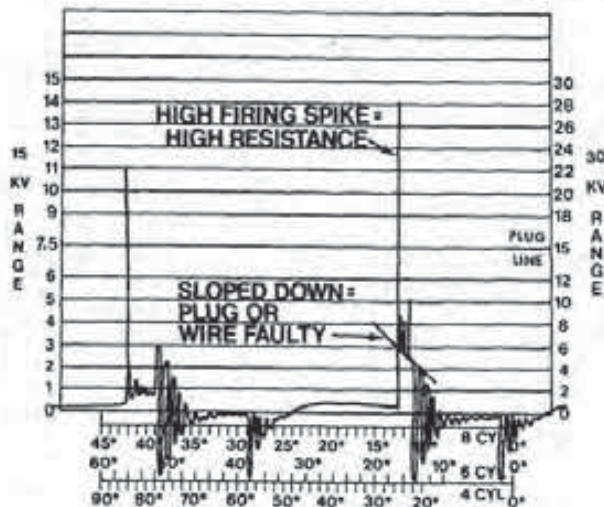


FIGURE 7-22

High resistance in a plug wire. (Courtesy of Ford Motor Co.)

4. Scope test the secondary system by doing the following:

- a. Connect the scope to the engine following manufacturer's instructions.
 - b. Adjust the idle to the speed recommended for the test or factory specifications.
 - c. Set the scope for an expanded parade pattern.
 - d. Check the pattern for high resistance in a spark plug or cable (Fig. 7-22). To determine if the problem is in the plug or cable, pull and ground the wire. If the high voltage spike drops, check and service the spark plug. If the spike remains high, check the cable and its connection at the distributor cap with an ohmmeter.
 - e. Check all the spark plug lines for evidence of high internal resistance (Fig. 7-23). If this pattern shows up at all speeds, the spark plug gap is too wide. If this condition changes with speed or load, it may be due to high compression, a lean air/fuel mixture, or a burned valve.
 - f. Inspect the pattern for signs of low firing voltage (Fig. 7-24). This may be the result of spark plugs that are shorted out, fouled, or gapped too narrow. Low compression or a grounded plug cable can also cause this
- i. Set the engine speed to 1,500 rpm to 2,000 rpm.
 - j. Connect and disconnect the hose to the vacuum advance while observing the readout window or timing marks.
 - k. The timing should advance and retard. If the timing does not change, the vacuum diaphragm may be defective or the breaker plate may be stuck. Check the diaphragm for serviceability with a vacuum pump. If the diaphragm is defective, replace it or repair the breaker plate as needed.

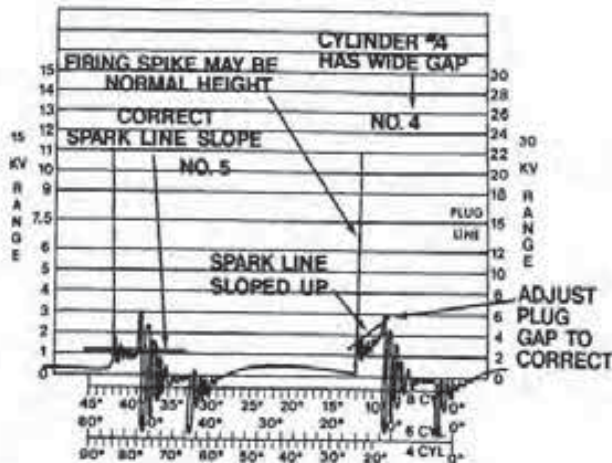


FIGURE 7-23
Plug spark line showing high internal resistance. (Courtesy of Ford Motor Co.)

- pattern. Check, service, replace, or regap the spark plug as necessary. If the spark plug is not at fault, check the cable or perform a compression test.
- g. Check all the plug firing voltages under load. To do this, operate a vehicle with an automatic transmission in gear at 1,500 rpm with the brakes applied. If any firing line reaches within two-thirds of the coil's reserve voltage, replace the spark plug (Fig. 7-25).
 - h. Check the pattern for signs of cross firing or arcing in the cap (Fig. 7-26). If the bottom of the oscillation is lost intermittently, check the cap and rotor for cracks, carbon tracks, and scratches. Replace the defective part as necessary.
 - i. If all the firing lines indicate high resistance, test the rotor air gap. To do this, remove a cable for one of the spark plugs and ground it (Fig. 7-27). If the voltage of the grounded plug is 8,000 volts or less, the air gap clearance is not excessive. If the voltage is over 8,000 volts, replace the rotor and repeat the test. If the voltage is still high, replace the distributor cap.
 - j. Set the scope display on raster and place a 250-watt heat lamp about one inch to two inches from the top surface of the module (Fig. 7-28). Apply the heat for about ten minutes, but do not permit the module tem-

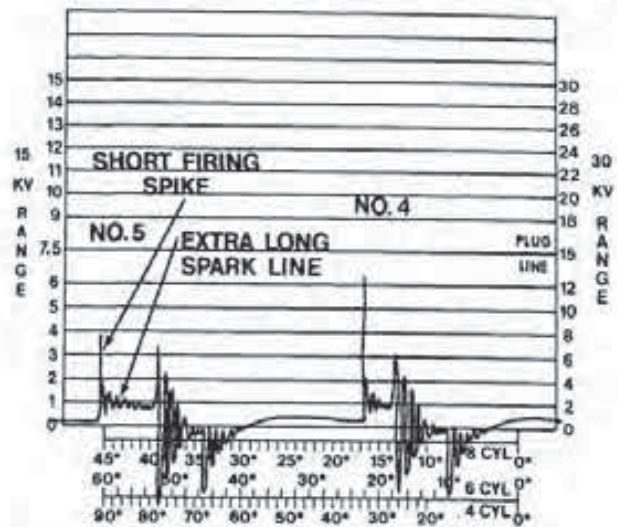


FIGURE 7-24
Low firing voltage. (Courtesy of Ford Motor Co.)

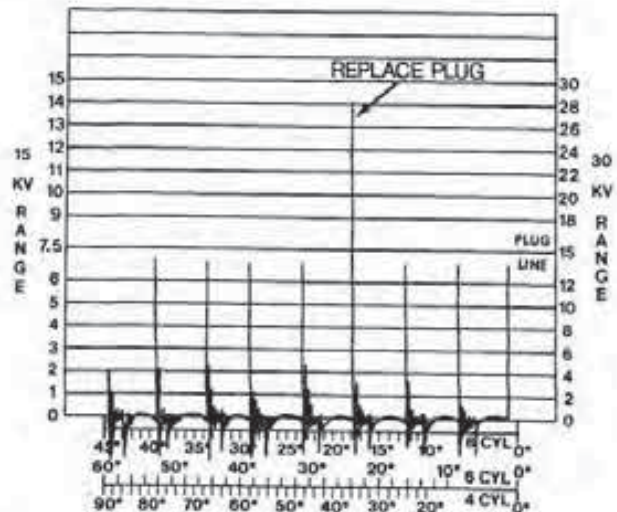


FIGURE 7-25
High firing line under load. (Courtesy of Ford Motor Co.)

perature to exceed 212°F (100°C). Check the temperature of the module by applying a few drops of water to the module housing. Repeat the process every few minutes until the water drops just begin to boil; then remove the lamp. Next, start the engine and observe the scope pattern while lightly tapping on the module.

Caution: Do not tap the module too hard; this may damage the unit. An erratic scope pattern while tapping the module indicates a defective unit.

- k. The distributor pickup coil may be tested with a heat lamp in a similar manner as the module. Remove the distributor cap and dis-

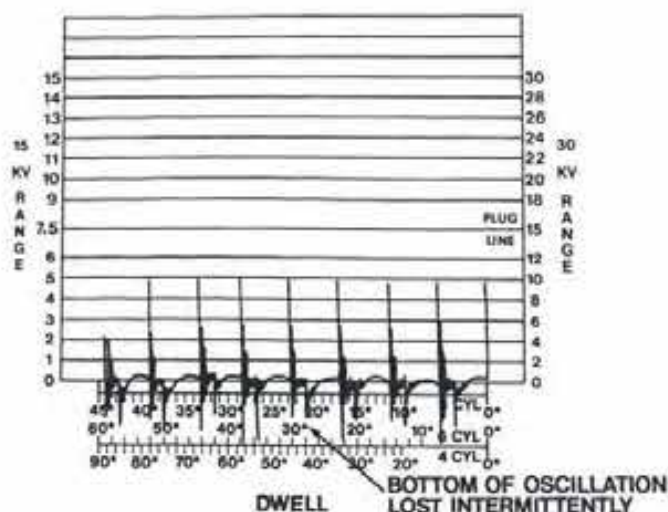


FIGURE 7-26

Cross firing or arcing in the distributor cap. (Courtesy of Ford Motor Co.)

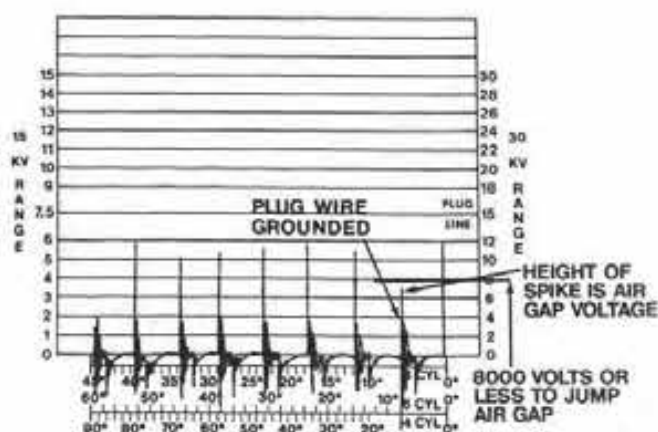


FIGURE 7-27

Rotor air gap test. (Courtesy of Ford Motor Co.)

connect the pickup coil harness connector. Connect the ohmmeter leads to the orange and purple wires. Tap the coil assembly very lightly with a screwdriver handle while watching the ohmmeter. The needle should remain steady in the specified range. Next, apply heat to the coil and watch the meter as you tap on the unit again. If the reading does not remain in the specified range, replace the coil. Connect one ohmmeter lead to the distributor base. Attach the other ohmmeter lead to first the orange and then the purple lead. Tap the coil while testing each lead and observe the ohmmeter. The

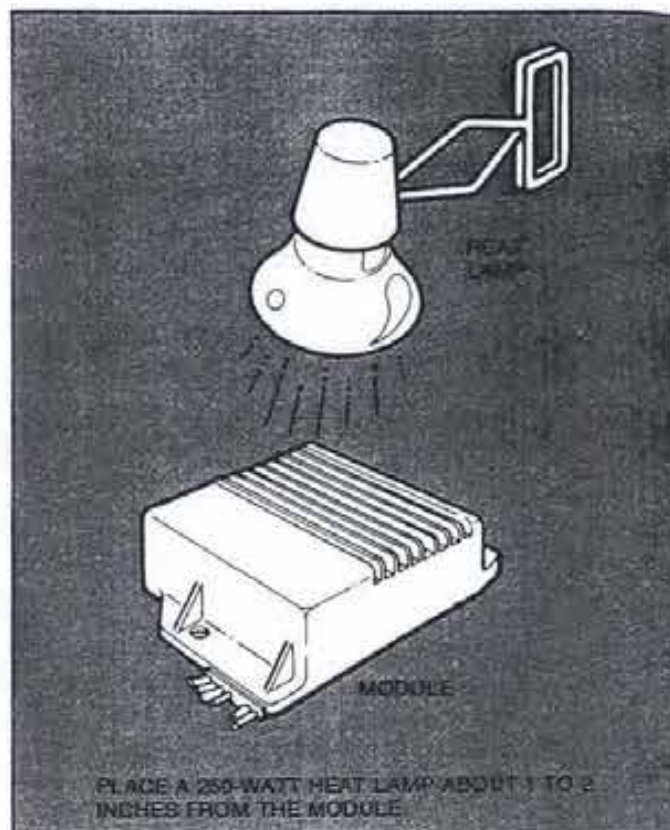


FIGURE 7-28

Heat testing a module. (Courtesy of Ford Motor Co.)

meter needle should remain steady on infinity. If the coil does not pass this ground test while heated, replace it.

1. With the engine operating, attempt to recreate the problem by wiggling the wires at the coil, module, distributor, and all ignition harness connectors. While doing so, observe the raster scope pattern. If the pattern changes during the procedure, repair or replace the defective wire or connector.

Engine Starts But Fails to Continue Operating

In this situation, the engine will start but will stop when the key is released to the RUN position. This problem is usually the result of a fault in the voltage supply to the BATT terminal of the ignition coil. In this situation, check the ballast resistor and supply voltage by completing Steps 8 and 9 listed earlier in this section.

7-3 TESTING A FORD DURASPARK III IGNITION SYSTEM

There are many similarities in design as well as testing procedures between the Duraspark III and the systems presented in Section 7-2. One of the main differences is that the Duraspark III system uses a crankshaft position (CP) sensor in place of a pickup coil in the distributor. Consequently, there will be no pickup coil test procedures in this section. In addition, the distributor has no vacuum or centrifugal advance mechanisms because Duraspark III uses an electronic timing advance.

The secondary and timing tests for poor performance are almost the same for all systems. *Before testing a Duraspark III, always check the calibration code and use the specifications and instructions found on the emissions label.*

If an engine with a Duraspark III system cannot be started and operationally checked with a scope, perform the primary tests listed below to locate the cause of the problem.

Test 1—Run Circuits

The ignition module's run circuit can be easily checked by doing the following:

1. Separate the ignition module three-wire harness connector. Inspect the connector for dirt, corrosion, and damage.
2. Install the ignition diagnostic test adapter (Fig. 7-29).
3. Remove the coil high tension wire from the distributor and install it onto a modified plug and spark tester.
4. Turn the ignition switch to the RUN position.
5. Touch the diagnostic adapter lead to the battery positive (+) terminal. A spark should occur every time the lead touches the battery terminal.
6. Turn the ignition switch off.
7. If there was a spark, go to Test 2 of this section.
8. If there is no spark, proceed to Test 4.

Test 2—Start Circuits

Test the proper operation of the coil and its high tension cable by doing the following:

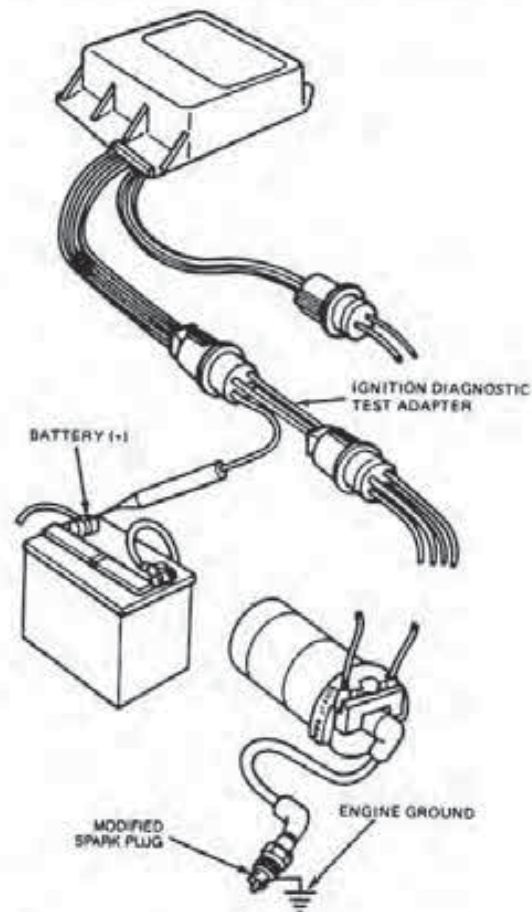


FIGURE 7-29
Testing the run circuits. (Courtesy of Ford Motor Co.)

1. Remove the diagnostic test adapter and assemble the ignition module connector.
2. While observing the spark tester, have an assistant crank the engine over with the ignition switch.
3. If sparks appear at the modified plug, inspect the distributor cap and rotor for cracks, carbon tracking, and silicone compound. Also, using the appropriate service manual, check for rotor alignment.
4. If there are no sparks at the plug, go to Step 3.
5. After completing the test, remove the spark tester and reconnect the coil wire to the distributor cap.

Test 3—Start Voltage

In this procedure, the ignition switch and the wiring harness to the module are checked to make certain

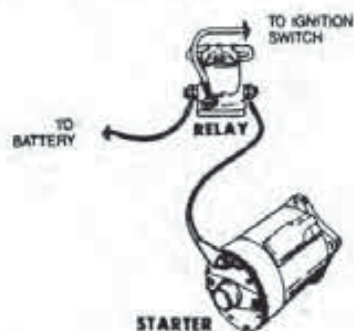


FIGURE 7-30
Terminal on the starter relay. (Courtesy of Ford Motor Co.)

the supply voltage is within 90 percent of that supplied by the battery. To perform this test, do the following:

1. If the starter relay has an I terminal, disconnect the cable between the relay and the starter motor.
2. If the starter relay does not have an I terminal, remove the wire from its S terminal (Fig. 7-30).
3. Carefully insert a small straight pin into the white module wire (Fig. 7-31). *Do not permit the pin to contact an electrical ground.*

4. Using the leads of a voltmeter, measure and note battery voltage.

5. Attach the negative (-) voltmeter lead to a good engine ground.

6. Using the table shown in Fig. 7-32 and the positive (+) voltmeter lead, measure the voltage at the straight pin with the ignition switch in the START position. Wiggle the wires in the harness during the test.

7. Turn the ignition switch off.

8. If the reading taken is less than 90 percent of battery voltage, inspect the wiring harness and connectors in the faulty circuit. If these are satisfactory, replace the ignition switch.

9. If the reading taken is at least 90 percent of battery voltage, inspect the wiring harness and connectors between the ignition and electronic engine control modules. If these are okay, proceed with Test 4.

10. Remove the straight pin and repair the wire insulation.

11. Reconnect the cable or wire removed from the starter relay.

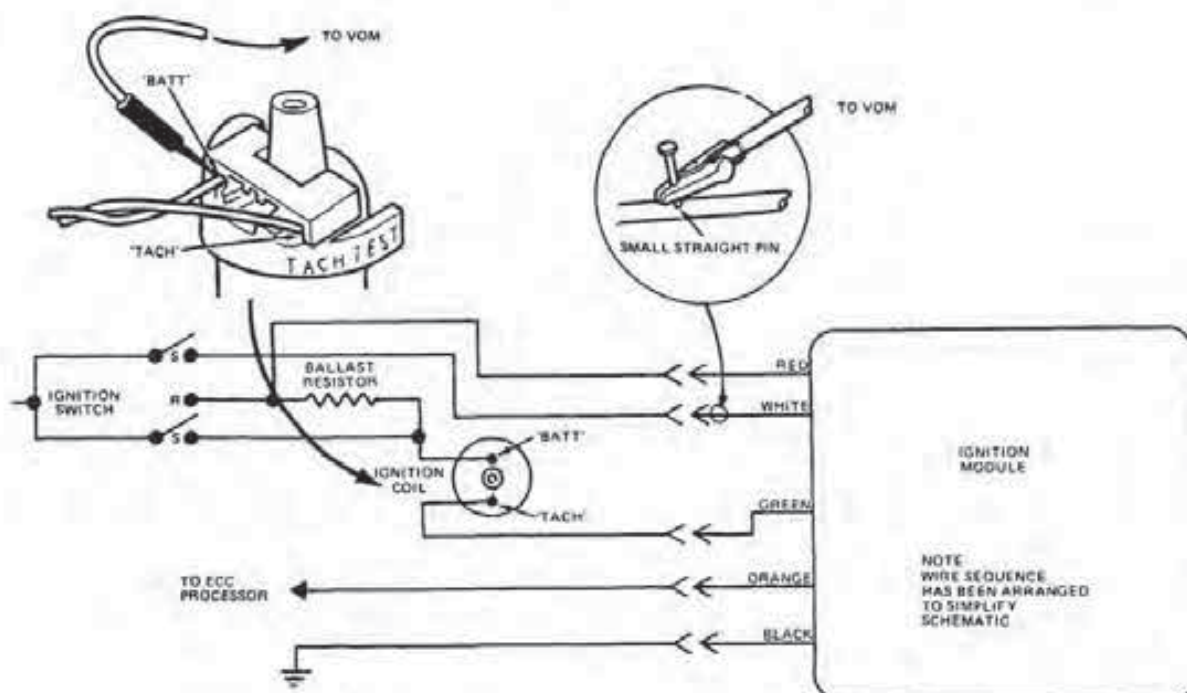


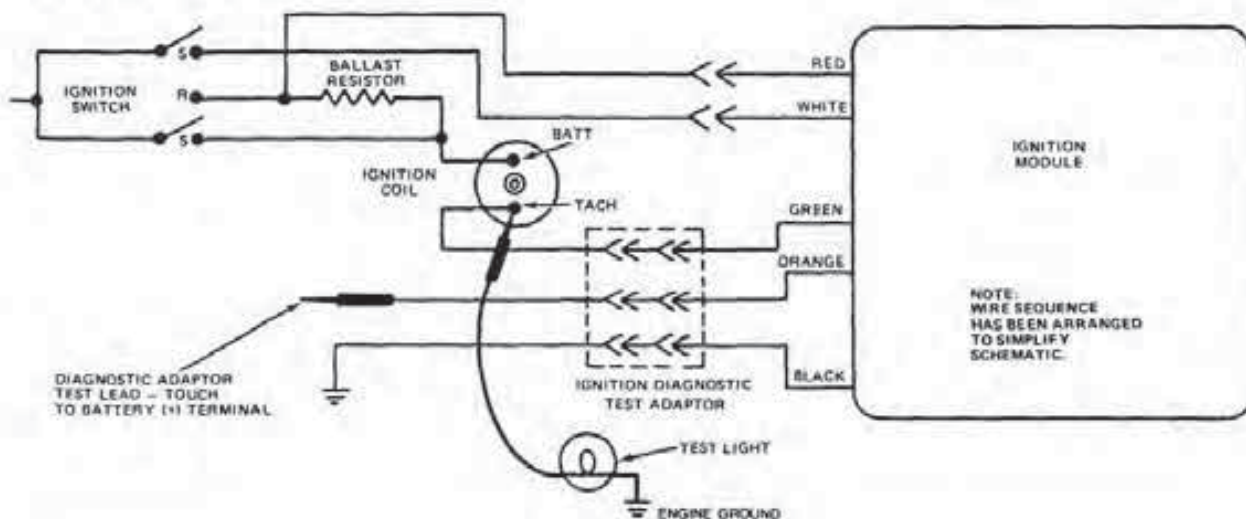
FIGURE 7-31
Checking start voltage. (Courtesy of Ford Motor Co.)

Test 4—Ignition Coil Primary Circuit Switching

Determine if the primary circuit of the ignition coil is properly switching by doing the following:

1. Attach 12-volt test light leads between the TACH terminal of the ignition coil and a good engine ground (Fig. 7-33).
2. Remove the module harness connector and install the diagnostic adapter.
3. Turn the ignition switch to the RUN position.
4. Touch the diagnostic adapter to the positive (+) battery terminal and then remove it several times. The test light should flash each time the adapter touches the battery terminal and is removed.
5. Turn the ignition switch off.
6. Remove the diagnostic adapter and test light; assemble the ignition switch module connector.
7. If the test light flashes, proceed to Test 5.
8. If the test light does not burn or is dim, go to Test 6.

FIGURE 7-33
Testing the switching of the ignition coil primary circuit.
(Courtesy of Ford Motor Co.)



CONNECT + VOM LEAD TO WIRE/TERMINAL	CIRCUIT	IGNITION SWITCH TEST POSITION
White	Start	Start
"BATT" Terminal Ignition Coil	Ballast Resistor Bypass	Start

FIGURE 7-32
Measuring points and switch positions from start voltage test. (Courtesy of Ford Motor Co.)

Test 5—Ignition Coil Secondary Resistance

To measure the resistance in the secondary coil windings, do the following:

1. Disconnect and inspect the ignition coil connector and the coil high tension cable.
2. Using the ohmmeter leads, measure secondary resistance from the BATT to the high voltage terminals (Fig. 7-34).
3. If the resistance in the secondary windings is to specifications, check the coil high tension cable. If the resistance in it is greater than specifications, replace the cable. Also, check the ignition coil for damage or carbon tracking. If the coil checks out okay, proceed to Test 6.
4. If the coil's secondary resistance is not within specifications, replace the coil.
5. After the test is complete, install the ignition coil high voltage cable.

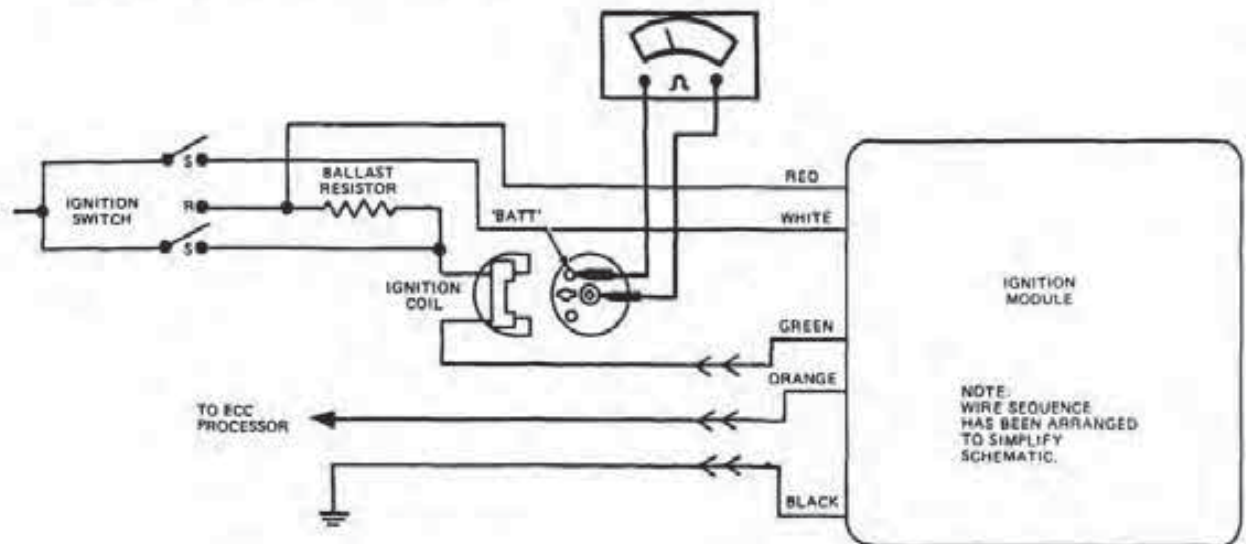


FIGURE 7-34
Measuring the resistance in the coil's secondary windings. (Courtesy of Ford Motor Co.)

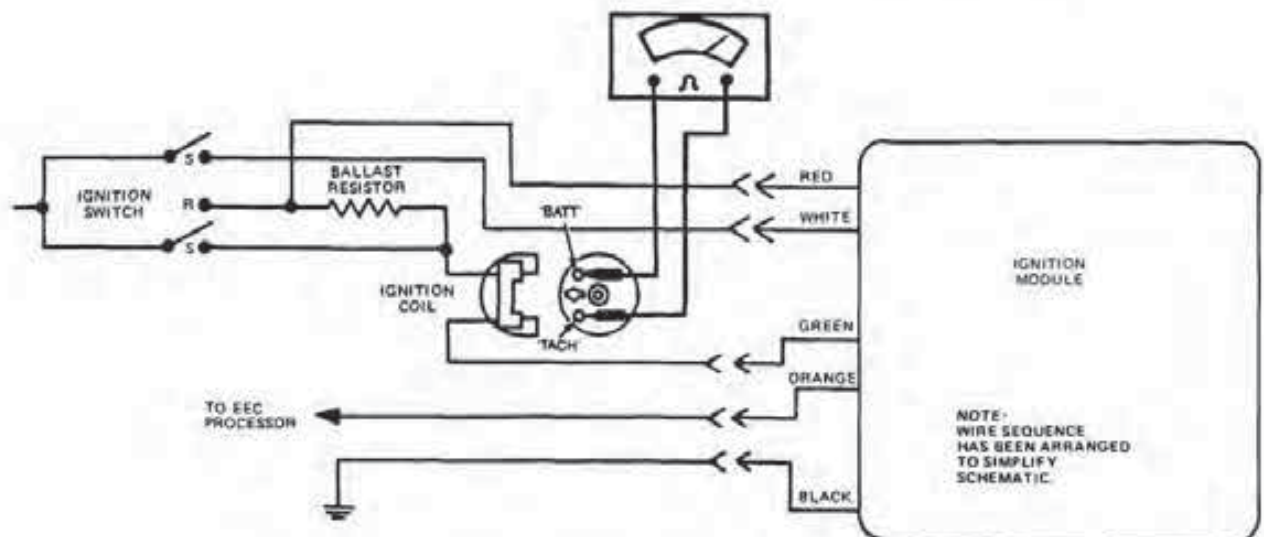


FIGURE 7-35
Measuring the resistance in the coil's primary windings. (Courtesy of Ford Motor Co.)

Test 6-Ignition Coil Primary Resistance

To measure the resistance in the primary windings of the coil, do the following:

1. Using the leads of the ohmmeter, measure the resistance from the BATT to TACH terminals of the coil (Fig. 7-35).

2. If the winding resistance is to specifications, proceed to Test 7.

3. If the resistance is less or more than specifications, replace the ignition coil.

4. After completing the test, install the ignition coil connector.

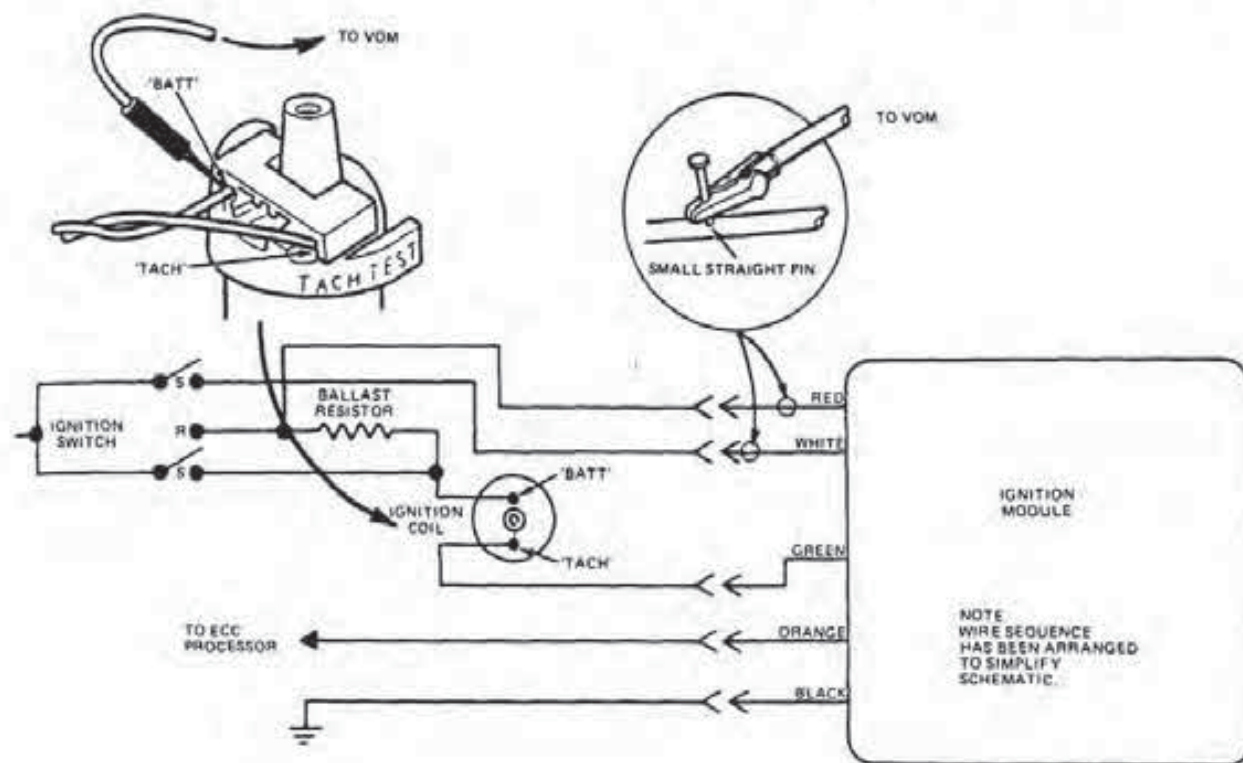


FIGURE 7-36
Checking the supply voltage circuits. (Courtesy of Ford Motor Co.)

Test 7—Run and Start Supply Voltage Circuits

The purpose of this test is to check the voltage in the run and start circuits. This procedure checks to make sure the ignition switch and wiring harness to the ignition module have a voltage supply that is within 90 percent of that provided by the battery during these two operating modes. To perform this test, do the following:

1. If the starter relay has an I terminal, disconnect the cable from between the relay and starter motor (see Fig. 7-30).
2. If the starter relay does not have the I terminal, remove the wire to its S terminal.
3. Carefully insert small straight pins into the red and white module wires (Fig. 7-36).

Caution: Do not permit the pins to contact an electrical ground.

4. With the voltmeter, measure and record battery voltage.

CONNECT + VOM LEAD TO WIRE/TERMINAL	CIRCUIT	IGNITION SWITCH TEST POSITION
Red	Run	Run
White	Start	Start
"BATT" Terminal Ignition Coil	Ballast Resistor Bypass	Start

FIGURE 7-37
Test points and switch positions for the voltage supply test. (Courtesy of Ford Motor Co.)

5. Attach the negative (–) voltmeter lead to the distributor base.
6. Using the table shown in Fig. 7-37 and the positive (+) voltmeter lead, check the voltage at the points indicated with the ignition switch in either the RUN or START position. Wiggle the wires in the harness while making the measurements.
7. Turn the ignition switch off.
8. If the voltage readings are less than 90 percent of battery voltage, inspect the wiring harness and connector(s) in the defective circuit(s). If these are okay, check the ignition switch. If the switch is satisfactory, replace the radio interference capacitor on the ignition coil.

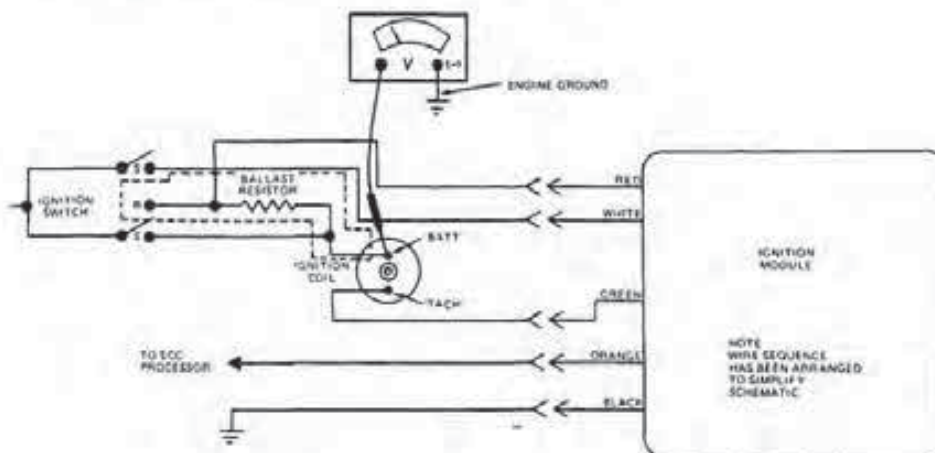


FIGURE 7-38

Testing coil supply voltage. (Courtesy of Ford Motor Co.)

9. If the readings are at least 90 percent of battery voltage, proceed to Test 8.

10. Remove the straight pins and repair the wire insulation.

11. Reconnect the cable or wire removed from the starter relay.

Test 8—Ignition Coil Supply Voltage

Check the supply voltage to the ignition coil in the RUN mode by doing the following:

1. Connect the negative (-) voltmeter lead to a good engine ground (Fig. 7-38).

2. Turn the ignition switch to the RUN position.

3. With the positive (+) voltmeter lead, measure the voltage at the BATT terminal of the ignition coil.

4. Turn the ignition switch off.

5. If the voltage reading is between six volts and eight volts, perform a continuity check of the wiring harness to the ignition module. If the harness wiring is okay, replace the ignition module. If available, use a module tester to verify that the unit is defective.

6. If the voltage reading is less than six volts or greater than eight volts, proceed with Test 9.

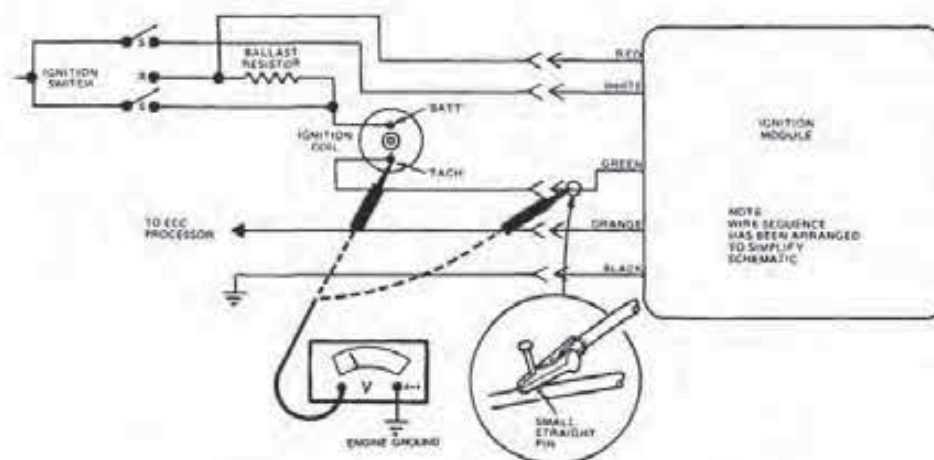


FIGURE 7-39

Checking the coil to module wire. (Courtesy of Ford Motor Co.)

Test 9—Module to Coil Wire

To test the voltage drop across the ignition module to the coil wire, do the following:

1. Carefully insert a small straight pin into the green module wire (Fig. 7-39).

Caution: Do not allow the pin to contact an electrical ground.

2. Attach the negative (-) voltmeter lead to a good engine ground.

3. Turn the ignition switch to the RUN position.

4. With the positive (+) voltmeter lead, measure and compare the voltage at the green module wire and the TACH terminal of the ignition coil.

5. Turn the ignition switch off.

6. If the voltage reading difference is greater than 0.5 volt, remove the straight pin and inspect the wiring harness between the ignition module and the coil.

7. If the voltage reading difference is 0.5 volt or less, proceed to Test 10.

Test 10—Primary Circuit Voltage Drop and Continuity

Check the RUN mode voltage drop and the continuity of the primary circuit between the ignition coil and the module by doing the following:

1. Attach the negative (-) voltmeter lead to a good engine ground (Fig. 7-40).

2. Insert a straight pin into the green module wire.

Caution: Make sure the pin does not contact an electrical ground.

3. Turn the ignition switch to the RUN position.

4. With the positive (+) voltmeter lead, measure the voltage at the green module wire.

5. Turn the ignition switch off.

6. If the voltage reading is greater than 1.5 volts, proceed to Test 12.

7. If the voltage reading is 1.5 volts or less, go to Test 11.

8. Remove the straight pin and repair the wire insulation.

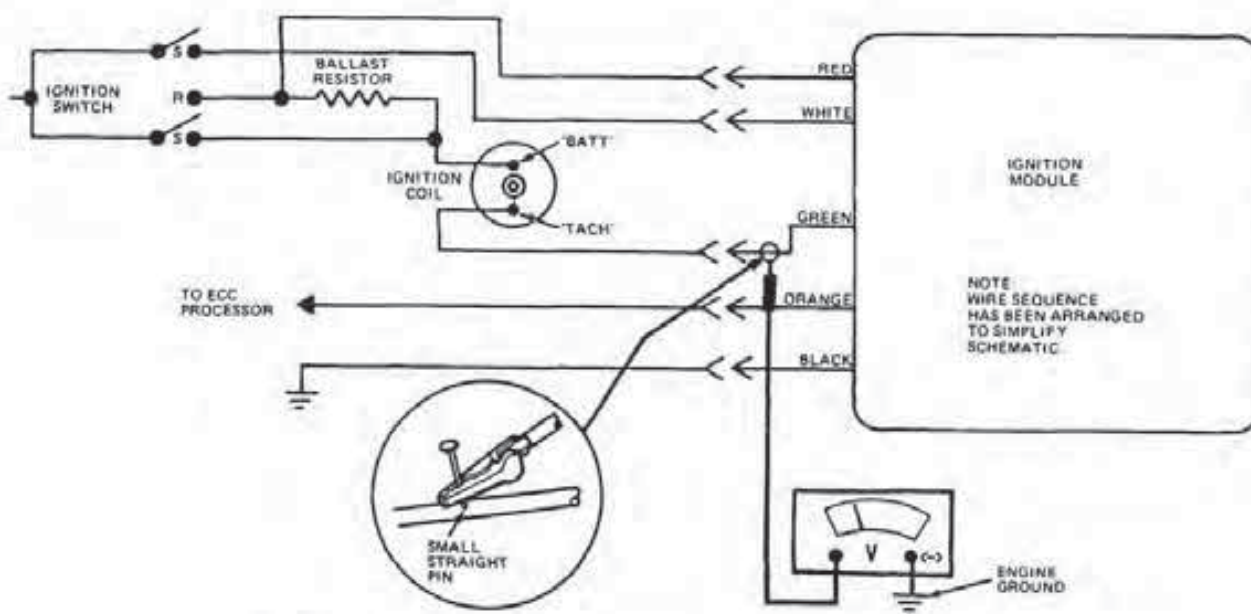


FIGURE 7-40

Testing primary circuit continuity. (Courtesy of Ford Motor Co.)

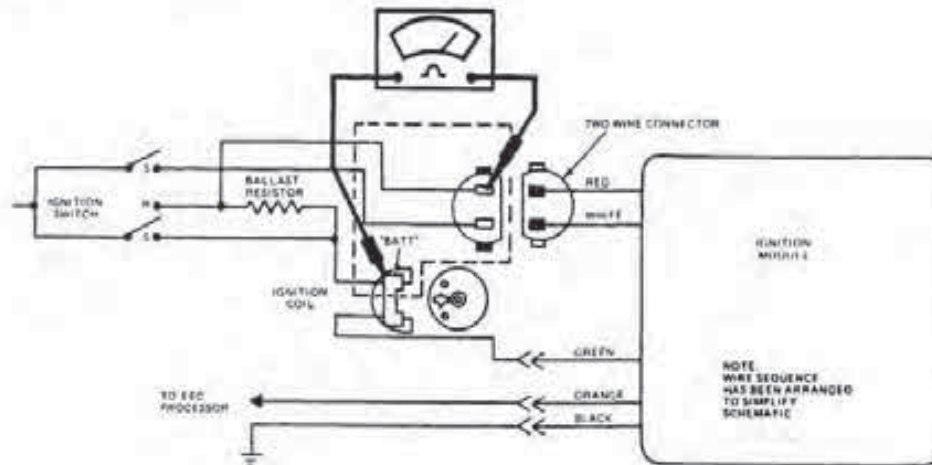


FIGURE 7-41
Checking the ballast resistor. (Courtesy of Ford Motor Co.)

Test 11—Ballast Resistor

Check the resistance within the ballast resistor by doing the following:

1. Separate and inspect the ignition module two-wire connector.
2. Remove the ignition coil connector.
3. Using the ohmmeter leads, measure the resistance between the BATT terminal of the ignition coil connector and the wiring harness connector with the red module wire (Fig. 7-41).
4. If the resistance is to specifications, the ballast resistor is satisfactory.
5. If the resistance is less or more than speci-

cations, replace the ballast resistor.

6. After the test is over, assemble all connectors in their proper locations.

Test 12—Wiring Harness Ground Circuit

Check the continuity of the wiring harness ground circuit by doing the following:

1. Separate the ignition module three-wire connector, and inspect it for dirt, corrosion, and damage.
2. Attach one ohmmeter lead to a good engine ground (Fig. 7-42).
3. Use the other ohmmeter lead to measure the

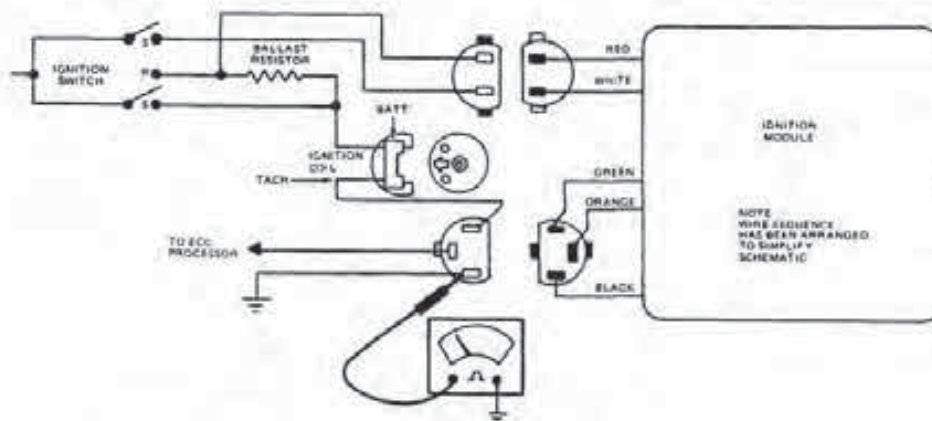


FIGURE 7-42
Testing the wiring harness ground circuit. (Courtesy of Ford Motor Co.)

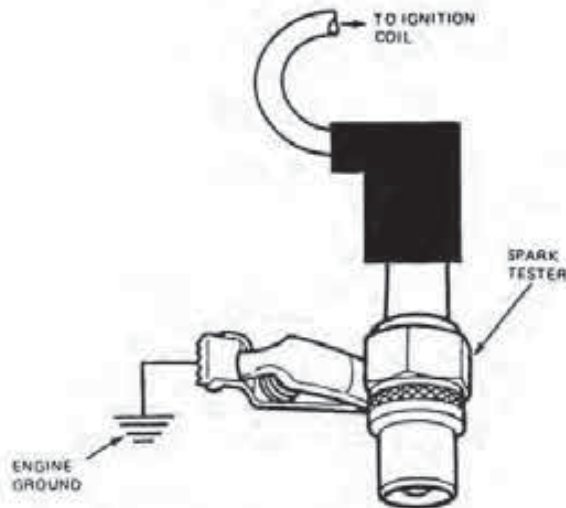


FIGURE 7-43
Checking secondary coil voltage. (Courtesy of Ford Motor Co.)

resistance in the harness terminal with the black module wire. Wiggle the wiring harness while making the measurement.

4. If the resistance is one ohm or less, the ground circuit is okay.
5. If the resistance is greater than one ohm, inspect the wiring harness and connector between the ignition module and the ground connection.
6. After the test is over, assemble the ignition module connector.

7-4 TESTING A FORD TFI-IV IGNITION

The following is a step-by-step procedure for locating the cause of a no-start condition in a Ford TFI-IV ignition system. If the engine operates but performs poorly, you should use the secondary and timing diagnostic procedures presented earlier. Just keep in mind that there are some differences between the TFI-IV and the other systems. *Always use the calibration code to verify the system type, and use the data from the emission decal and service manuals to determine specifications and service instructions.*

Test 1—Ignition Coil Secondary Voltage

To determine whether the E coil is providing sufficient secondary voltage for the spark plugs, do the following:

1. Disconnect the coil high tension cable from the distributor.
2. Attach the spark tester to a good engine ground and connect the high tension cable to the plug (Fig. 7-43).
3. While observing the spark tester, have an assistant crank the engine over using the ignition switch.
4. If there is a good spark at the tester, inspect the rotor and distributor cap for damage, carbon tracking, or cracks. Replace the rotor and cap as necessary.
5. If there is no spark at the tester, use an ohmmeter to measure the resistance in the coil wire. If the resistance value is greater than the specifications, replace the cable. Also, inspect the coil for cracks, damage, and carbon tracking, and replace it as necessary. If the cable and coil are okay, proceed to Test 2.
6. Remove the spark tester and reconnect the coil wire.

Test 2—Ignition Coil Primary Circuit Switching

To see if the primary circuit is switching on and off properly, do the following:

1. Separate the wiring harness connector from the ignition module. Inspect the connector for dirt, corrosion, and damage. Assemble the harness connector.
2. Attach one lead of a 12-volt test light to a good engine ground (Fig. 7-44).

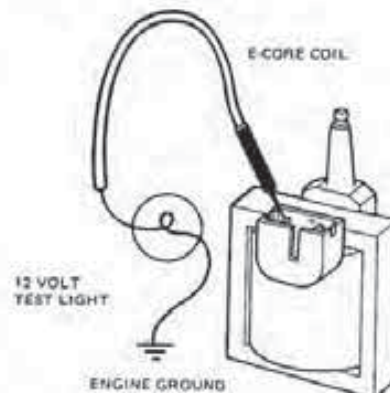


FIGURE 7-44
Testing the primary switching circuit. (Courtesy of Ford Motor Co.)

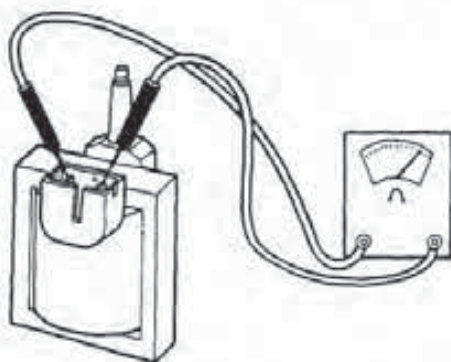


FIGURE 7-45
Checking primary coil resistance. (Courtesy of Ford Motor Co.)

3. Install the other lead on the TACH terminal of the E coil.
4. Observe the test light as an assistant cranks the engine over using the ignition switch.
5. Turn the ignition key off.
6. If the test light flashes, proceed to Test 3.
7. If the test light comes on but does not flash, go to Test 5.
8. If the test light is very dim or does not come on, proceed to Test 8.

Test 3—Ignition Coil Primary Resistance

To check the total resistance of the E coil's primary windings against specifications, do the following:

1. Disconnect the ignition coil connector. Inspect it for dirt, corrosion, and damage.
2. Using the ohmmeter leads, measure the resistance between the two primary terminals of the coil (Fig. 7-45).
3. If the resistance is to specifications, the primary windings are okay. Proceed to Test 4.
4. If the resistance is below or above specifications, replace the ignition coil.

Test 4—Ignition Coil Secondary Resistance

To check the total resistance of the E coil's secondary windings against specifications, do the following:

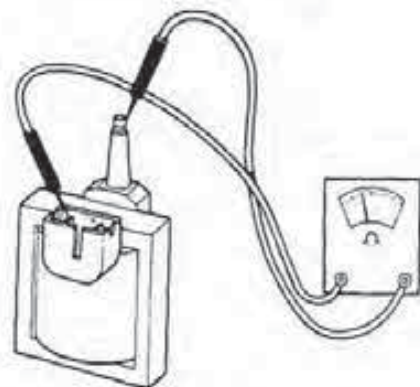


FIGURE 7-46
Testing secondary coil resistance. (Courtesy of Ford Motor Co.)

1. Remove the high tension cable from the coil.
2. Using the ohmmeter leads, measure the resistance from the positive (+) primary terminal to the high voltage secondary terminal (Fig. 7-46).
3. If the total resistance is within specifications, proceed to Test 5.
4. If the resistance is less or more than specifications, replace the coil.
5. After the test is complete, reinstall the connector and high tension cable.

Test 5—Wiring Harness

This test checks the supply voltage in the wiring harness to the module to make sure the supply voltage is within 90 percent of that provided by the battery. Follow these directions to complete the test:

1. Separate the wiring harness from the ignition module. *Note: Push on the connector tabs to separate.* Inspect the wiring harness for dirt, corrosion, and damage.
2. Disconnect the S terminal of the starter relay.
3. Attach the negative (-) lead of the voltmeter to the distributor base.
4. With the positive (+) lead, measure and record battery voltage.
5. Install a straight pin into the terminal of the connector (Fig. 7-47).

Caution: Do not allow the pin to contact an electrical ground.

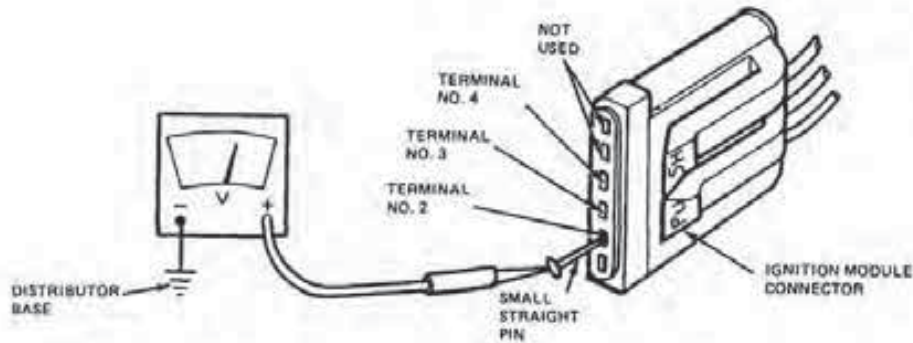


FIGURE 7-47
Checking the wiring harness for supply voltage. (Courtesy of Ford Motor Co.)

6. Following the table shown in Fig. 7-48 and the positive (+) voltmeter lead, measure the terminal voltage at the straight pin locations with the ignition switch positioned as indicated.

7. Turn the ignition switch off.

8. If the voltage readings are at least 90 percent of the one taken in Step 4, proceed to Test 6.

9. If a voltage reading is less than 90 percent of the one taken in Step 4, refer to the vehicle wiring diagrams for the appropriate circuit, and inspect its wiring harness and connectors. If they are satisfactory, replace the ignition switch.

10. Remove the straight pin from the connector.

11. Reconnect the wire to the S terminal on the starter relay.

Test 6—Ignition Coil Primary Voltage

To check the voltage at the negative terminal of the E coil against that of the battery, do the following:

CONNECTOR TERMINAL	WIRE/CIRCUIT	IGNITION SWITCH TEST POSITION
#2	TO IGNITION COIL (-) TERMINAL	RUN
#3	RUN CIRCUIT	RUN AND START
#4	START CIRCUIT	START

FIGURE 7-48
Test points and switch positions for the voltage supply checks. (Courtesy of Ford Motor Co.)

1. Attach the negative (-) lead of the voltmeter to the distributor base.

2. With the positive (+) voltmeter lead, measure and record battery voltage.

3. Turn the ignition switch to the RUN position.

4. With the positive (+) voltmeter lead, measure the voltage at the negative (-) terminal of the E coil (Fig. 7-49).

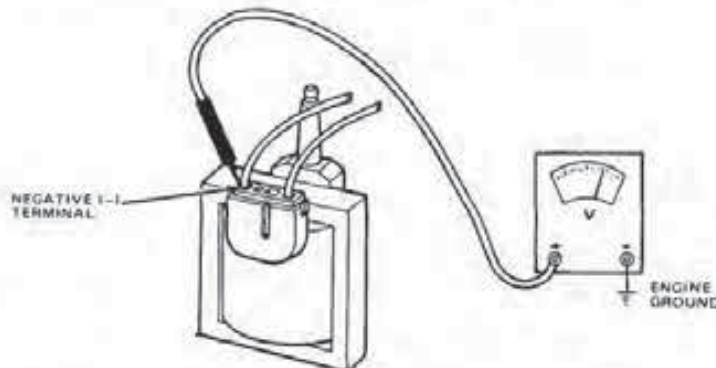


FIGURE 7-49
Checking ignition coil primary voltage. (Courtesy of Ford Motor Co.)

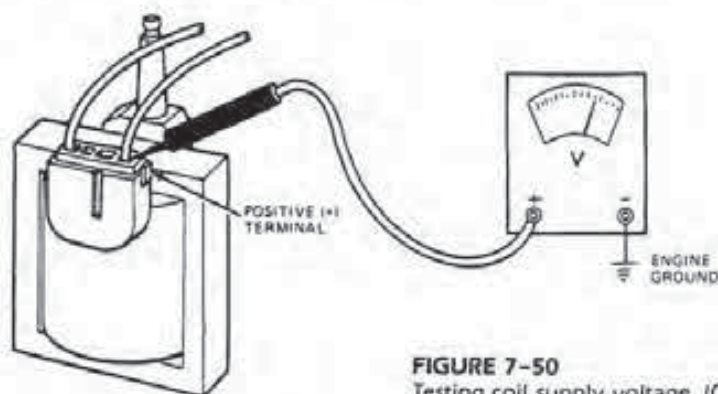


FIGURE 7-50
Testing coil supply voltage. (Courtesy of Ford Motor Co.)

5. Turn the ignition switch off.
6. If the voltage reading is 90 percent of that from the battery, the circuit is satisfactory.
7. If the voltage reading is less than 90 percent of that from the battery, inspect the wiring harness between the ignition module and the coil negative terminal, and then go to Test 7.

Test 7—Ignition Coil Supply Voltage

To test the voltage at the positive terminal of the E coil against that of the battery, do the following:

1. Attach the negative (–) voltmeter lead to the distributor base.
2. With the positive (+) voltmeter lead, measure and record battery voltage.
3. Turn the ignition switch to the RUN position.
4. With the positive (+) voltmeter lead, measure the voltage at the positive terminal of the ignition coil (Fig. 7-50).
5. Turn the ignition switch off.
6. If the reading is within 90 percent of that provided by the battery, inspect the ignition coil and connector terminals for dirt, corrosion, or damage, and proceed to Test 8.
7. If the reading is less than 90 percent of that provided by the battery, inspect and service the wiring between the ignition coil and switch. Also, check for a worn or damaged ignition switch.

Test 8—EEC-IV and TFI-IV Signal

To test the ignition module signal from the electronic control assembly, do the following:

1. Connect the coil high tension cable to a spark tester.
2. Push the tabs and separate the wiring harness connector from the ignition module. Inspect it for dirt, corrosion, and damage, and then reassemble the connector.
3. Separate the inline base timing connector.
4. While observing the spark tester, have an assistant crank the engine over with the ignition switch.
5. If there is a spark at the tester, check the ignition module signal wire for continuity. If the wire is okay, proceed to the electronic engine control diagnostic section of the service manual.
6. If there is no spark at the tester, go to Test 9.

Test 9—Distributor and TFI-IV Module

Check the operation of the PIP sensor in the distributor and the module by doing the following:

1. Remove the distributor assembly from the engine.
2. Install a new TFI-IV module onto the distributor.
3. Connect the harness to the TFI-IV module.
4. Ground the distributor with a jumper lead.
5. Rotate the distributor by hand with the ignition switch in the RUN position, and observe the spark tester.
6. If there is a spark, replace the old distributor with the new module.
7. If there is no spark, replace the distributor with the old module because the PIP sensor is defective.

CHAPTER REVIEW

The following two sections will assist you in determining how well you remember the material contained in this chapter. If you cannot complete a statement or question, refer back to the section marked in brackets that contains the material.

SELF-CHECK

1. The TFI-IV system uses what type of coil [7-4]?
 - a. two minutes
 - b. both a and b
 - c. neither a nor b
2. Before testing an ignition system, why must the battery be fully charged [7-1]?
 - a. the distributor cap
 - b. the rotor
 - c. both a and b
 - d. neither a nor b
3. What test procedure is not necessary when checking a no-start condition on an engine with a Duraspark III ignition system [7-3]?
 - a. Tape should be wrapped around the punctured area.
 - b. Nonacetic RTV compound should be spread on the area.
 - c. both a and b
 - d. neither a nor b
4. What is the first step in locating the cause of a no-start condition [7-2]?
 - a. the voltage drop in the circuit to the coil.
 - b. the voltage drop across the coil itself.
 - c. both a and b.
 - d. neither a nor b.

REVIEW

1. A Ford vehicle with a TFI-IV ignition system will not start. How do you test the ignition module [7-4]?
 - a. use an aftermarket tester
 - b. use a voltage drop test
 - c. both a and b
 - d. neither a nor b
2. Technician A states that ignition parts for Ford systems are usually not interchangeable, but Technician B says that all system parts are interchangeable [7-1]. Who is correct?
 - a. A only
 - b. B only
 - c. both a and b
 - d. neither a nor b
3. If the TFI-IV system will not pass the primary switching test, which component may be at fault [7-4]?
 - a. the secondary coil windings
 - b. the primary coil windings
 - c. both a and b
 - d. neither a nor b
4. During testing procedures, how long is it safe to operate an engine with a spark plug not firing [7-1]?
 - a. five minutes
 - b. two minutes
 - c. both a and b
 - d. neither a nor b
5. If an engine with a TFI-IV system passes the secondary voltage test but will not start, what component should be inspected [7-4]?
 - a. the distributor cap
 - b. the rotor
 - c. both a and b
 - d. neither a nor b
6. How should a wire punctured during a test procedure be repaired [7-1]?
 - a. Tape should be wrapped around the punctured area.
 - b. Nonacetic RTV compound should be spread on the area.
 - c. both a and b
 - d. neither a nor b
7. When checking a Duraspark III system, the ignition coil supply voltage test measures [7-3]
 - a. the voltage drop in the circuit to the coil.
 - b. the voltage drop across the coil itself.
 - c. both a and b.
 - d. neither a nor b.
8. How is the voltmeter connected to test voltage drop [7-1]?
 - a. in series
 - b. in parallel
 - c. both a and b
 - d. neither a nor b
9. While testing which ignition system is an ignition system test adapter needed [7-3]?
 - a. Duraspark II
 - b. Duraspark III
 - c. both a and b
 - d. neither a nor b
10. For checking secondary output voltage, the spark tester replaces what other test component(s) [7-1]?
 - a. the modified plug and jumper wire
 - b. the module tester
 - c. both a and b
 - d. neither a nor b
11. If the coil's secondary resistance gives a satisfactory measurement but the primary does not, what must be done [7-2]?
 - a. check the module harness

- b. replace the ignition switch
 - c. both a and b
 - d. neither a nor b
12. Before attempting testing or service, where can you find exact information for the ignition system installed on a given Ford vehicle [7-1]?
- a. the manuals
 - b. the calibration code
 - c. both a and b
 - d. neither a nor b
13. How can tapping on a Duraspark distributor during the test procedures cause an arc at the spark tester [7-2]?
- a. The resulting vibration induces a voltage in the pickup coil.
 - b. The resulting vibration induces a voltage in the primary windings.
 - c. both a and b
 - d. neither a nor b
14. Technician A states it is not always necessary to follow a troubleshooting guide. Technician B says the troubleshooting guide is not a reliable diagnostic tool. Who is correct [7-1]?
- a. A only
 - b. B only
 - c. both a and b
 - d. neither a nor b
15. If an engine will not start but there is an arc at the spark tester, what may be the cause of the problem [7-2]?
- a. a vacuum leak
 - b. a malfunctioning fuel system
 - c. an open spark plug wire
 - d. a malfunctioning vacuum advance

CHRYSLER ELECTRONIC IGNITION SYSTEMS

OBJECTIVES

After reading and studying this chapter, you will be able to

- identify and know the function of the components of a Chrysler electronic ignition system.
- describe the design and operation of the pickup coil assembly found in an electronic ignition system (EIS) distributor.
- explain the operation of both centrifugal and vacuum advance mechanisms.
- describe the design of a Hall-effect EIS.
- describe the design of the Mitsubishi EIS.
- describe the design and explain the operation of the lean burn system.
- describe the function and design of the electronic spark advance and electronic spark control systems.

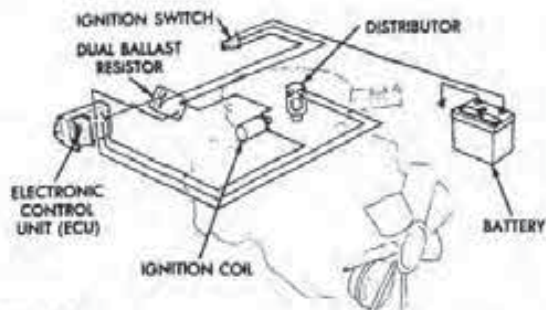


FIGURE 8-1
Chrysler electronic ignition system (EIS). [Courtesy of Chrysler Motors Corp.]

Chrysler Corporation first introduced its electronic ignition system (EIS) as a mid-year model change in 1971 passenger cars. In that year, its use was limited to automobiles with 340 CID engines that were equipped with a manual transmission (Fig. 8-1).

In January 1972, engines in light-duty conventional cab and compact trucks had EIS as an option. By June 1972, EIS was made available on 318-3 and 413-1 engines on motor home chassis.

By the end of the 1972 model year, EIS was standard equipment on all V-8 models sold in California, and was available in other states as an extra-cost option. However, since 1973, all North American-built Chrysler automobiles and trucks have the electronic ignition system, which eliminated completely the production of any contact point systems.

Chrysler developed ESI to minimize ignition system maintenance and to help prevent misfiring. Misfiring is a common complaint about the early system and usually results from owner neglect of needed maintenance, especially on the contact points. Furthermore, a misfire in one cylinder can increase undesirable exhaust emissions by as much as ten times.

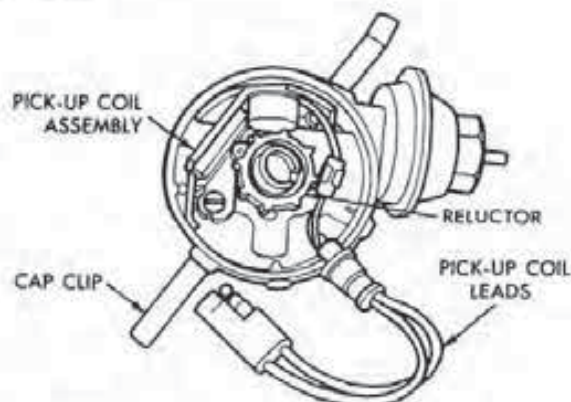


FIGURE 8-2
EIS distributor. [Courtesy of Chrysler Motors Corp.]

EIS eliminates misfires due to inadequate maintenance by eliminating the contact points from the system. The system also very accurately controls dwell and ignition timing, resulting in maximum exhaust emission control and fuel economy.

8-1 DESIGN AND OPERATION OF CHRYSLER ELECTRONIC IGNITION

Chrysler's first EIS is relatively simple in both its design and operation. Outwardly, the EIS looks just like the contact point system used previously. The only apparent outward change is the addition of a control unit and modification of the ballast resistor.

Distributor and Magnetic Pickup Design

The size of the distributor housing and the cap remain unchanged from the contact point system. However, in place of the breaker points and condenser, the EIS uses a pickup coil and a gear-like ferrous element similar to that found in the Ford SSI and Duraspark I and II systems (Fig. 8-2).

The Chrysler pickup assembly consists of a permanent magnet attached to a pole piece. The pole piece is an extension of the mounting bracket and attaches to the permanent magnet. Because of this arrangement, the pickup unit resembles a horseshoe-type magnet with the reluctor end of the pole piece acting as one of the magnetic poles.

Wound near the end of the pole piece is a coil of insulated wire. Each of the ends of this coil connects to one of the pickup coil leads. On the opposite end of the leads is a harness connector.

The spoked ferrous element in the EIS distributor is known as the reluctor. The reluctor attaches to the distributor shaft and has a tooth for each of the engine cylinders. Like the armature in the Ford system, the reluctor reduces the magnetic resistance of the field from the permanent magnet.

Pickup Coil Operation

The permanent magnet of the pickup coil assembly produces a magnetic field from the pole piece to the bracket supporting the permanent magnet. This magnetic field passes through the coil that is wound around the pole piece (Fig. 8-3). Without the influence of the reluctor teeth, the magnetic field is relatively weak because of the air gap between the pole piece and the support bracket.

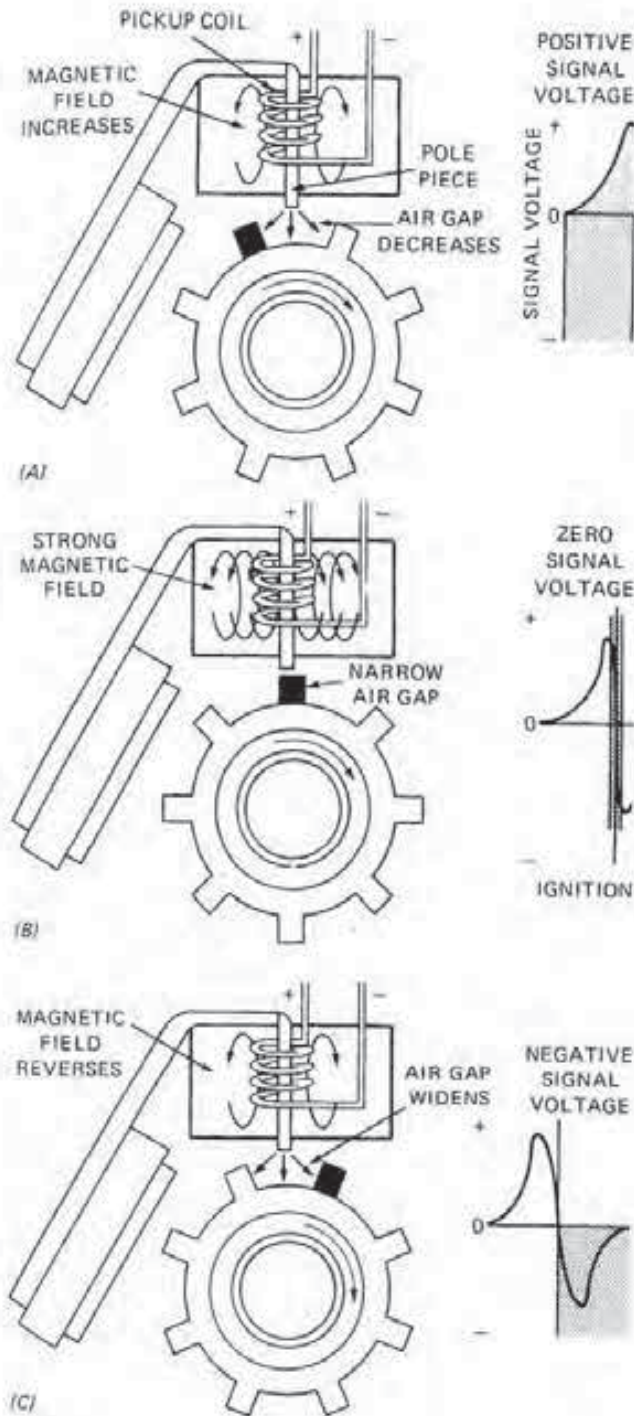


FIGURE 8-3
Operation of the pickup coil. (Courtesy of Chrysler Motors Corp.)

But as one of the reluctor teeth enters the magnetic field, the tooth provides a better path for the magnetism. This increases the magnetic field surrounding the pickup coil. Increasing the field

strength at the coil induces a positive voltage at one of its terminals (Fig. 8-3A). This voltage is proportional to the rate of change of the magnetic field.

The level of the positive voltage continues to build until the reluctor tooth approaches the pole piece. However, voltage falls to zero when the tooth is directly aligned with the pole piece (Fig. 8-3B). Even though the magnetic field strength is the strongest when a tooth is aligned with the pole piece, the rate of magnetic field density change is zero at this point. For this reason, voltage rapidly drops to zero.

As the tooth continues to move away, there is an induction of a negative voltage at the same terminal of the pickup coil (Fig. 8-3C). This is due to the collapse or reversal of the magnetic field through the pickup coil. This negative voltage is induced again by the change, in this case reduction, in field strength. Remember, no voltage is induced in the pickup coil unless the reluctor is moving. The rapid increase and decrease of the magnetic field as the rotating reluctor teeth approach and pass the pole piece is what induces first the positive and then the negative voltage into the same pickup coil terminal.

The change of the strength of the magnetic field induces an AC analog voltage signal. This signal is used by the electronic control unit (ECU) to close and open the coil's primary circuit.

Ballast Resistor

The Chrysler EIS uses a dual ballast resistor (Fig. 8-4). This resistor plays a dual role. On the one side is a 0.5-ohm resistor, which is a voltage-limiting de-

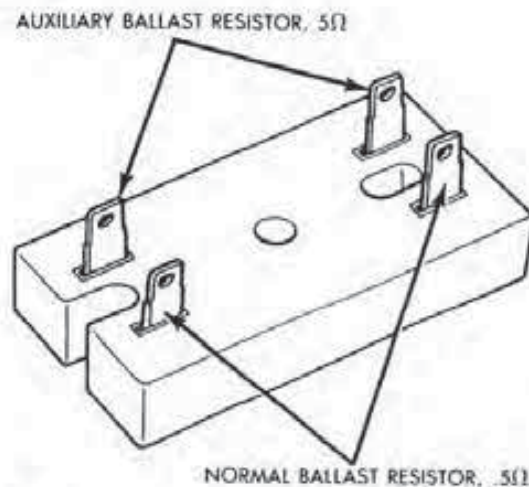


FIGURE 8-4
Dual ballast resistor. (Courtesy of Chrysler Motors Corp.)

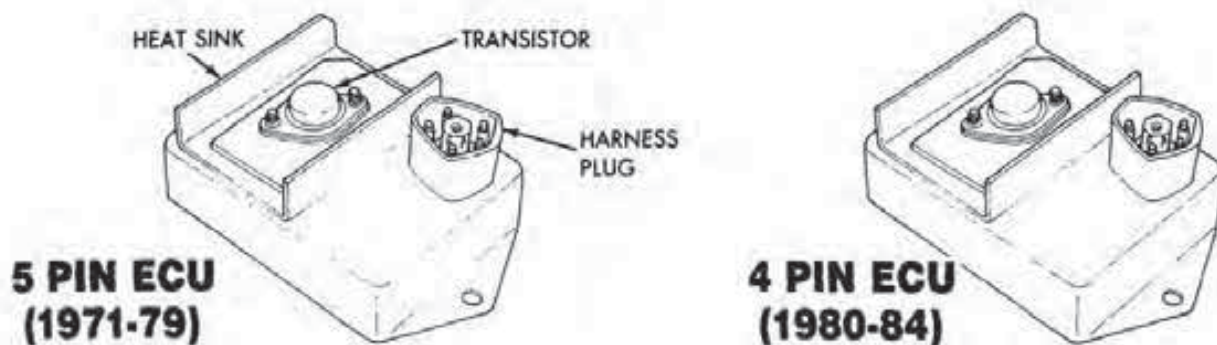


FIGURE 8-5

Electronic control unit. The 1971-1979 modules have a five-pin connector, while 1980 and later models use a four-pin connector. (Courtesy of Chrysler Motors Corp.)

vice that maintains constant primary current flow even with variations in engine speed. This protects the ignition coil against high current flow at low engine speeds. However, this resistor is bypassed during engine cranking so that full battery voltage is applied to the coil primary circuit.

On the other side of the dual unit is a 5.0-ohm resistor. This is also a voltage-limiting device to control current flow. But in this case, the resistor limits the current flow through the electronic part of the ECU.

Electronic Control Unit (ECU)

The *electronic control unit (ECU)* is the heart of the EIS (Fig. 8-5). It consists of a switching transistor and electronic circuitry. The *switching transistor* opens and closes the coil primary circuit. The function of the ECU circuitry is to determine how long the ignition coil primary circuit remains open and closed. Moreover, the closed period, when current

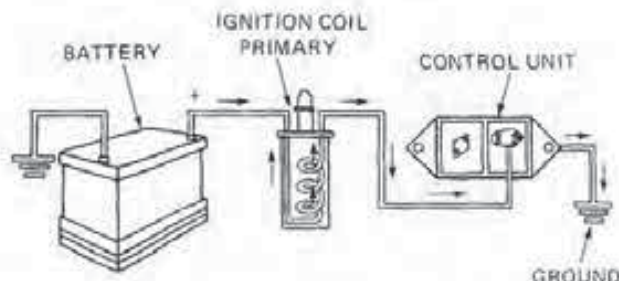
flows in the primary (i.e., the dwell period), must vary with engine speed, which is measured in crankshaft rotations. Since the control unit circuitry is sealed and has no moving parts, the desired dwell rate is established and cannot be adjusted.

The switching transistor mounts on the exterior of the ECU in a *heat sink* that is necessary for cooling. The ground circuit for the ECU is through its mounting bolts. In addition, the ECU connects into the ignition via an exterior connector.

ECU Operation

As a reluctor tooth approaches the pole piece, there is a small but positive voltage signal induced in the pickup coil. This tiny signal is fed via the harness to the ECU. The positive signal, in turn, turns on the switching transistor (Fig. 8-6). As a result, battery current flows through the primary windings of the coil and then through the ECU to ground. The switching transistor remains on as long as there is a positive pickup coil signal.

As the reluctor tooth aligns and then passes the pole piece, the pickup coil voltage signal drops first to a positive zero and then turns negative at the output terminal (Fig. 8-7). The positive zero signal turns off the switching transistor, and it remains off as long as there is a negative voltage applied to it. When the switching transistor turns off, current cannot flow through the ECU to ground. Consequently, this interrupts the flow of current through the primary coil windings.



CURRENT FLOW THROUGH CONTROL UNIT
MAINTAINS COIL PRIMARY CURRENT

FIGURE 8-6

Electronic control unit (ECU) operation with a positive pickup coil signal.

Ignition Coil Function and Design

The *ignition coil* is nothing more than an electrical transformer. This unit steps up battery voltage through magnetic induction until it is high enough

to bridge the spark plug gap during all phases of engine operation (Fig. 8-8).

To function as a transformer, the coil assembly is made up of two sets of windings that are wound around a soft, laminated iron core. Wound nearest the core are the *secondary windings*, which consist of as many as 22,000 turns of approximately #38, fine, insulated wire. One end of the windings connects to the high tension terminal, while the other attaches to the positive (+) primary terminal.

The outer windings are the *primary windings*, which consist of about 200 turns of #20 insulated wire. One end of this winding attaches to the primary positive (+) terminal and the other to the negative (-) terminal.

The windings and core are sealed into a metal housing. The housing is filled with oil to serve as a coolant and to provide additional insulation.

Coil Operation

From the battery, current flow in the primary coil enters at the (+) terminal and then flows through the larger windings. With the switching transistor on, the electronic control unit (ECU) becomes the

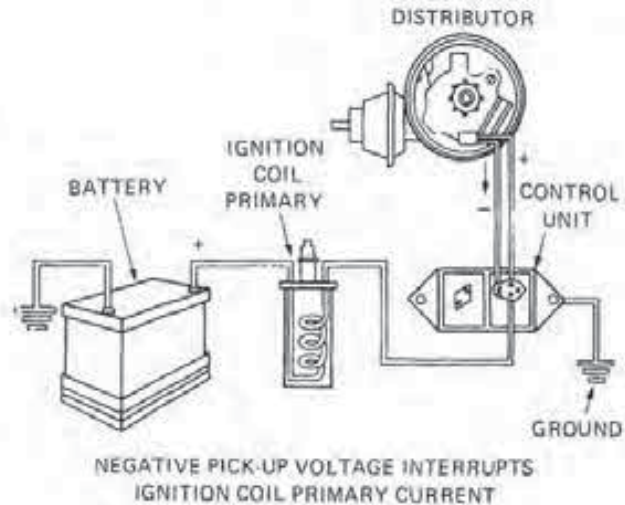


FIGURE 8-7
ECU operation with a negative pickup coil signal.

ground for the primary current flow. With current flowing through the primary windings to ground, the coil builds up a magnetic field.

As the switching transistor turns off, the primary current cannot reach ground through the ECU. When the primary circuit opens, the magnetic

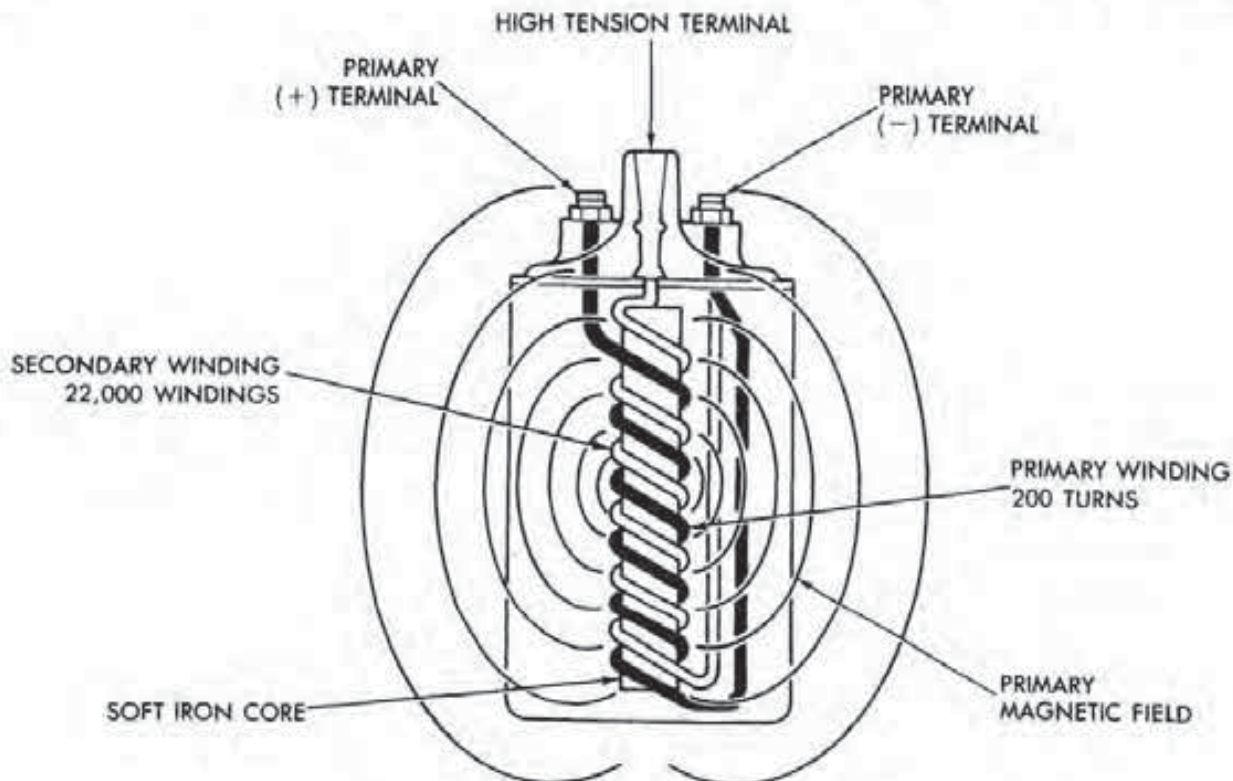


FIGURE 8-8
EIS ignition coil. (Courtesy of Chrysler Motors Corp.)

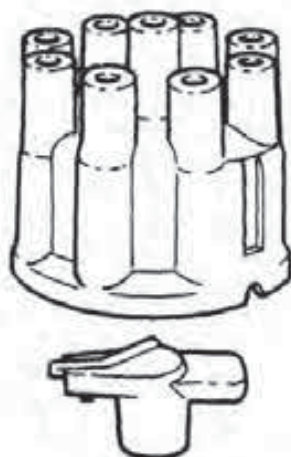


FIGURE 8-9
Rotor and distributor cap. (Courtesy of Chrysler Motors Corp.)

field collapses across both windings. This induces a high voltage in the thousands of turns of the secondary windings. The coil develops this high secondary voltage at the high tension terminal.

Due to the ratio of the primary to secondary windings, the voltage is stepped up about a hundred times. That is, if 250 volts are induced in the primary windings, the secondary voltage at the terminal can be 25,000 volts. However, the secondary current flow will be reduced below that flowing in the primary as the voltage is increased. In other words, the induced secondary voltage is extremely high, but the amount of current flow is very small, from 0.001 ampere to 0.002 ampere.

Rotor and Cap

The rotor operates in conjunction with the cap to distribute the high voltage, low amperage surges

from the ignition coil to the individual spark wires in the firing order (Fig. 8-9). The rotor has a spring-loaded blade electrode that maintains contact with the inside-center carbon terminal of the distributor cap.

When the high voltage surge enters the distributor center electrode via the coil's high tension wire, it travels through the rotor electrode. The current then arcs across the small air gap of several thousandths of an inch that is between the rotor electrode and the spark plug terminal inside the cap.

From the terminal inside the cap, current flows to the outer cap's spark plug wire sockets. The spark plug wires, or cables, are arranged in these sockets according to the firing order of the engine and in the direction of distributor shaft rotation. The number one cable is installed in the cap corresponding to the rotor position when the first cylinder is top dead center (TDC) of its compression stroke.

Secondary Ignition Cables

The spark plug wires, including the coil lead, are referred to as *high tension* or *secondary ignition cables* (Fig. 8-10). These cables carry the high voltage arc from the coil to the cap and from the cap to the spark plugs. The coil wire is of the same type of construction as the plug cables.

The cables are the resistance type for radio noise suppression. Factory-installed wires have the words "Electronic Suppression" printed on the cable jacket. The cable itself is a graphite-impregnated woven fiber with hypalon insulation to resist electrical leakage. When underhood temperatures are expected to be high due to the operation of emission control equipment, a silicone-rubber jacket is used to resist heat.

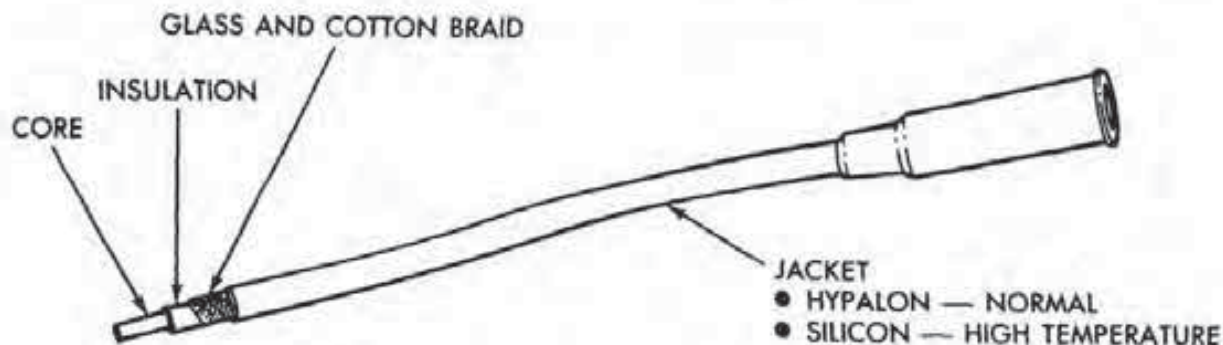


FIGURE 8-10
Secondary ignition cable. (Courtesy of Chrysler Motors Corp.)

8-2 CONVENTIONAL ADVANCE MECHANISMS

The EIS utilizes a conventional spark advance system that includes centrifugal and vacuum advance mechanisms. Both of these assemblies advance the ignition firing from the basic, or initial, timing.

Centrifugal Mechanism

The *centrifugal advance mechanism* is interconnected between the distributor shaft and the reluctor (Fig. 8-11). This mechanism is used to vary the reluctor position in relation to engine speed. To do this, the mechanism has weights that are thrown outward by centrifugal force. This movement is resisted by the action of calibrated springs.

As engine speed increases, the centrifugal force on the weights overcomes spring tension, and the weights swing outward, thereby advancing the reluctor in the direction of distributor shaft rotation. This causes the reluctor to enter the pickup coil assembly's magnetic field sooner, and thus advances the ignition timing.

Vacuum Advance Mechanism

The *vacuum advance mechanism* is necessary to alter ignition timing during part-throttle operation (Fig. 8-12). This form of advanced timing provides maximum fuel economy.

During part-throttle cruise operation, the air/fuel mixture requires more time to burn in order to obtain the best economy. The vacuum mechanism provides the extra time by simply advancing the ignition timing to start the burning process earlier in the cycle. The mechanism accomplishes this task by means of a diaphragm unit connected to the pickup plate assembly within the distributor.

Since the carburetor's ported vacuum varies with throttle valve position, the vacuum advance mechanism provides a means of sensing part-throttle conditions. As the carburetor throttle valve is opened from the idle to part-throttle position, the ported engine vacuum applies itself to the vacuum diaphragm unit. The vacuum acting on the diaphragm causes the pickup coil assembly to turn opposite to the distributor shaft rotation. This action causes the pickup coil to sense the reluctor's tooth position sooner, thus advancing the timing.

But as the throttle plate is closed from part-throttle to idle, the vacuum signal to the diaphragm

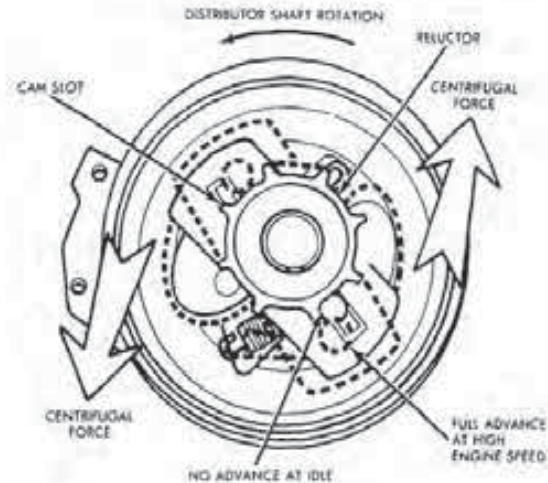


FIGURE 8-11 Centrifugal spark advance. (Courtesy of Chrysler Motors Corp.)

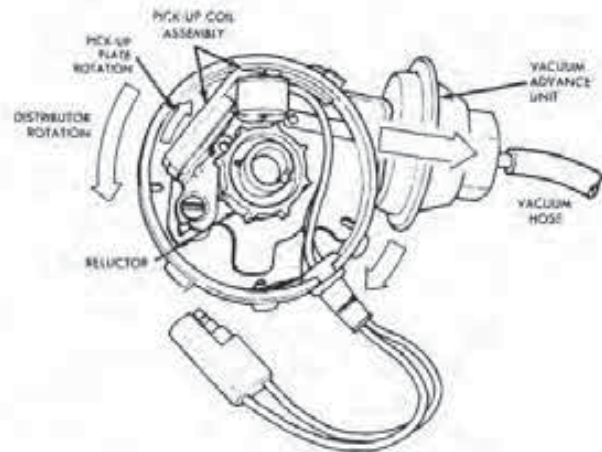


FIGURE 8-12 Vacuum spark advance. (Courtesy of Chrysler Motors Corp.)

unit is cut off. The spring within the unit acting on the diaphragm causes the pickup assembly to return to its fully retarded position.

When the engine is in a steady, part-throttle, cruising condition at about 40 mph (64 km/h) on a level road, both the vacuum and centrifugal mechanisms are advancing the spark in correct proportion to engine load and speed, respectively. If the driver accelerates to the wide-open throttle position, the ported engine vacuum drops to near zero. This causes the vacuum diaphragm spring to force the pickup assembly into the retarded position. However, the centrifugal mechanism continues to provide the needed ignition advance based on the engine speed necessary for acceleration.

8-3 HALL-EFFECT EIS

For one year, in 1980, Chrysler placed a Hall-effect EIS on its Federal Omnis and Horizons, which are both four-cylinder vehicles (Fig. 8-13). This system required no ballast resistor but used the conventional centrifugal and vacuum advance mechanisms within the distributor.

Hall-effect Pickup

In place of a coil-type pickup assembly, the system has a Hall-effect pickup that is similar in design and operation to the Ford PIP sensor. The *Hall-effect pickup* produces a DC voltage pulse as the distributor shaft rotates. This pulse is controlled by a magnetic field. The ECU uses this signal to trigger the switching transistor, which controls the primary coil's ground circuit.

The Hall-effect pickup consists of an integrated circuit (IC) and a permanent magnet, both of which mount onto the pickup plate. The permanent magnet faces the IC with an air gap between them.

The distributor rotor has downstanding shutter blades with spaces between them, one for each of the four engine cylinders. The pickup plate, located in the distributor housing, has a gate through which the shutter blades pass as the distributor shaft rotates. If a shutter is in the gate, it blocks the air gap between the permanent magnet and the IC. This changes the magnetic field strength through the IC and causes its Hall voltage to vary.

As the shutters and spaces of the rotor pass through the air gap, the Hall-effect pickup produces a pulsating DC sine wave signal with sharp corners. This signal is fed to the ECU to trigger the switching transistor.

Hall-effect ECU

As in the electronic ignition system, the electronic control unit (ECU) is the only control unit within the Hall-effect system. This special Hall-effect, five-pin ECU mounts on the firewall or fender well and operates when the ignition switch is in the START or RUN position. When turned on, the Hall-effect ECU controls the ground circuit of the primary coil windings, and thus its current flow.

When an open space between shutters is in the gate, the magnetic field can pass through the IC unit. As it does so, it generates a positive Hall voltage. This voltage turns on the switching transistor within the ECU. The ECU, in turn, completes the ground circuit for the primary windings, and current flows.

As a shutter blade enters the air gap, it causes the magnetic field to bypass the IC assembly. This causes the Hall voltage to drop to zero. The zero signal turns off the switching transistor, and the ECU breaks the primary coil's ground circuit.

The voltage signal from the Hall-effect pickup to the ECU is not changed by the speed of the distributor shaft as it is with a coil-type pickup. Therefore, the pickup generates a full-strength Hall voltage signal to the ECU, even at slow cranking speeds.

Hall-effect Distributor Cap and Wires

The Hall-effect EIS uses a redesigned cap and secondary cables (Fig. 8-14). This cap has a vent to prevent moisture build-up inside. In addition, the cap is held in place on the distributor by mounting screws, while the six- and eight-cylinder EIS caps use spring clips. Finally, the cap utilizes a notch or pin to index it, which assures proper seating in the distributor housing.

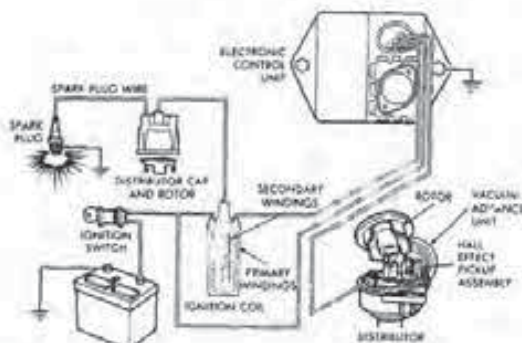


FIGURE 8-13
Hall-effect EIS. (Courtesy of Chrysler Motors Corp.)

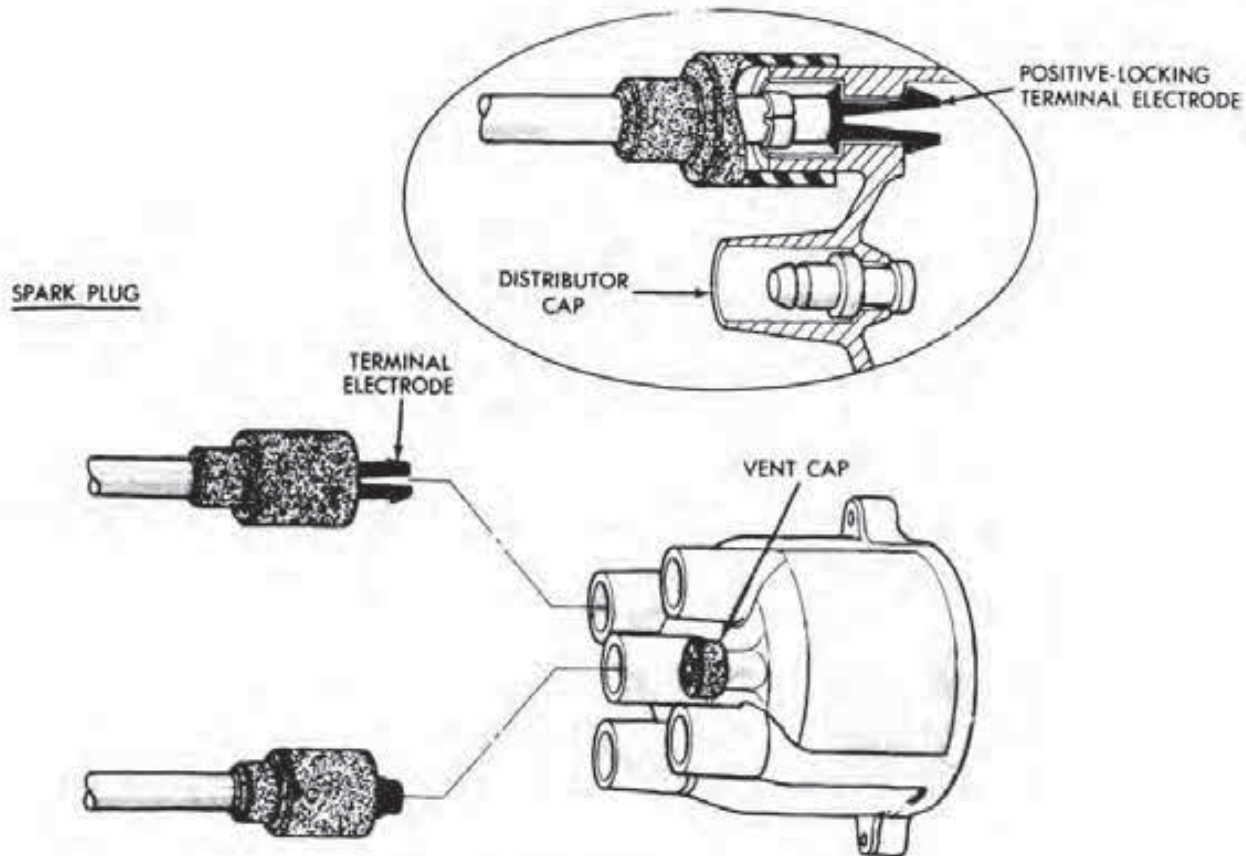


FIGURE 8-14
Hall-effect EIS distributor cap and wires. (Courtesy of Chrysler Motors Corp.)

The secondary cables are the same as in the EIS design, except where each attaches into the cap. The spark plug cables have unique positive-locking terminal electrodes, which provide secure engagement at all times. The locking electrodes also form the internal cap terminals. On the other hand, the coil's high tension wire has a female connection that presses onto a male terminal in the center of the cap.

8-4 MITSUBISHI EIS

Chrysler introduced the Mitsubishi EIS system for use on its 1.4-, 2.0-, and 2.6-liter, four-cylinder engines (Fig. 8-15). The Mitsubishi system uses a distributor with a coil pickup and reluctor. The pickup produces the AC signal used by the ignitor (i.e., the ECU) to close and open the coil primary circuit. The distributor also contains conventional centrifugal and vacuum advance mechanisms.

The ignitor serves the same function as the ECU on other Chrysler systems. The 1979 and 1980 models used an ignitor that mounted on the side of

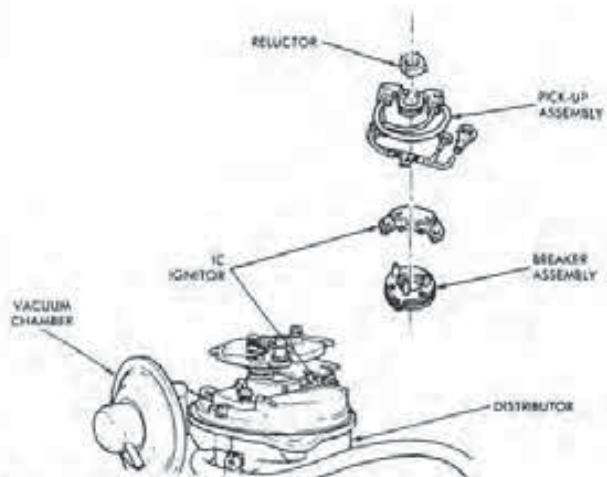


FIGURE 8-15
Mitsubishi EIS distributor. (Courtesy of Chrysler Motors Corp.)

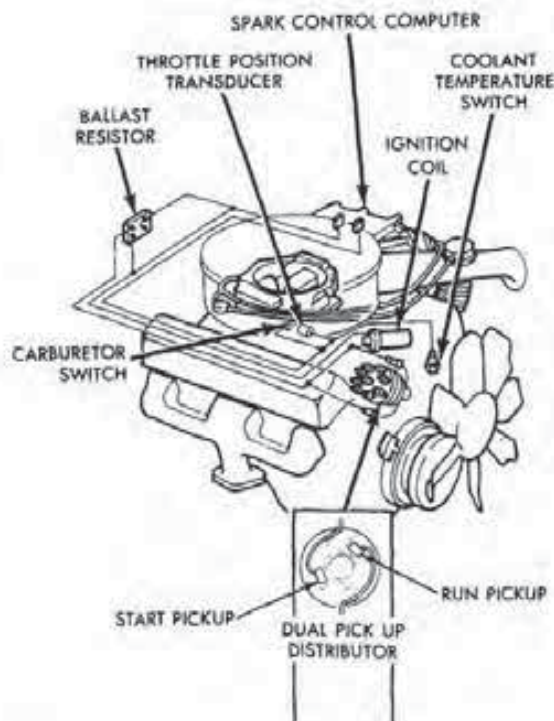


FIGURE 8-16
Electronic lean burn system. (Courtesy of Chrysler Motors Corp.)

the distributor. After 1981, all 2.6-liter engines (except those with electronic fuel injection) use an ignitor mounted inside the distributor (see Fig. 8-15). To aid in properly cooling the ignitor, silicone grease is used between its lower side and the distributor housing.

The engines with electronic fuel injection have an externally mounted ignitor. This unit links the ignition system to a computer-controlled, fuel injection system.

8-5 CHRYSLER ELECTRONIC LEAN BURN SYSTEM

Chrysler introduced the electronic lean burn (ELB) system in 1976 and used it through 1978 (Fig. 8-16). The purpose of the *electronic lean burn* system is to electronically provide the correct spark advance curves to ignite the lean air/fuel mixture. This lean mixture is necessary to lower harmful exhaust emissions and to increase fuel economy.

A lean mixture requires a tighter control on spark timing because it burns slower. This is due to the reduced density of a lean mixture; that is, there is a greater distance between the fuel particles.

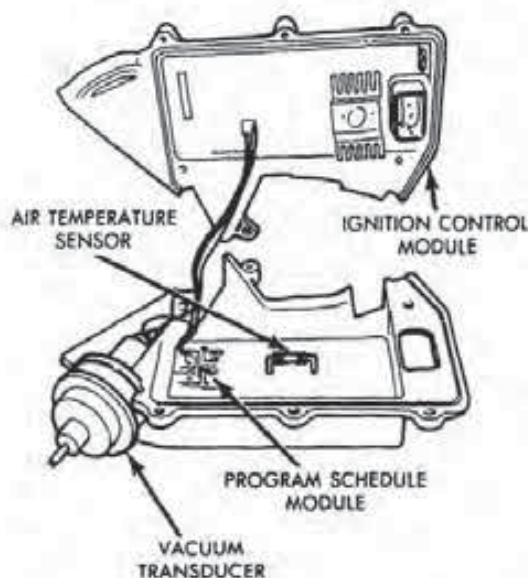


FIGURE 8-17
Spark control computer. (Courtesy of Chrysler Motors Corp.)

The ELB system was the first electronic spark control used in the automotive industry. This device permits a more precise control of ignition spark timing than the conventional centrifugal and vacuum advance mechanisms can provide. By accurately controlling the spark timing, ELB reduces emission, improves engine performance, and increases fuel economy.

The ELB was first used in 1976 on the 400 CID engine. In 1977, Chrysler also installed it on vehicles with 360, 400, and 440 CID engines. Lastly, the ELB was installed on 1977 vehicles with 318 CID engines.

Spark Control Computer

The ELB system consists of a ballast resistor, computer, and seven sensors. The *spark control computer* mounts on the air cleaner housing (Fig. 8-17). This unit controls the operation of the primary coil circuit and provides a variable amount of advance curves. In the case of the 1976 ELB system, the computer supplements the centrifugal advance mechanism.

The analog computer controls the spark advance based on input from the seven sensors. To do this, the computer is made up of two electronic printed circuit boards, the program schedule module, and the ignition control module. In later computers, the two circuit boards are combined into a single unit.

Based on input from the seven sensors, the program schedule module determines the exact ignition timing required and then signals this information to the ignition control module. The ignition control module, after receiving the signal from the schedule module, interrupts the current flow in the primary windings. This results in the induction of high secondary voltage at the coil's high tension terminal at the precise moment it is needed for efficient spark timing.

The spark control computer assembly fastens into the system by means of a multi-pin connector. The female connectors slide and lock into receptacles beneath the spark control computer housing. Although the socket pins are not physically numbered, they have numerals assigned to them for identification purposes.

Vacuum Transducer

The ELB system uses two types of transducers, a vacuum and a throttle position. A *transducer* converts mechanical motion into an electrical signal through *reactance*, which is the amount of resistance in an alternating current circuit caused by self-inductance.

The *vacuum transducer* mounts onto the microcomputer (Fig. 8-18). This device provides a voltage signal to the microcomputer that reflects the engine's manifold vacuum. To accomplish this function, the transducer has a moveable metallic core that connects to a vacuum diaphragm. With this design, the metallic core moves back and forth with changes in engine vacuum inside a coil. The higher the manifold vacuum, the farther the diaphragm and core move toward the vacuum fitting. A low vacuum causes the core to move in the opposite direction.

The coil receives an AC reference voltage signal from the microcomputer. It then monitors the amount of voltage drop that occurs across the terminals as the diaphragm moves the core into or out of the coil. With a high vacuum, the voltage drop and

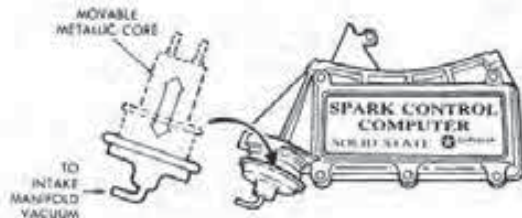


FIGURE 8-18
Vacuum transducer. (Courtesy of Chrysler Motors Corp.)

reactance are lower, and the transducer signal is high. A low vacuum places the core more inside the coil to provide the opposite conditions—that is, a higher voltage drop and a higher reactance, plus a lower transducer signal. In any case, the microcomputer uses the signal to calculate the timing based on vacuum.

Throttle Position Transducer

The *throttle position transducer* has the same function as the vacuum unit but its core is activated by a piece of carburetor linkage. The transducer itself provides an electrical voltage signal to the computer. This signal relates to the throttle valve position within the carburetor.

The throttle transducer consists of a wire-wound resistor coil and a moveable metallic core (Fig. 8-19). The coil is inside a housing with a threaded section on one end. This is used not only to secure the housing to a bracket but also to adjust the transducer.

The metallic core attaches by the steel wire to the throttle valve lever. With this arrangement, as the throttle valve opens, the core is pulled outward from the transducer housing. Consequently, when the throttle valve opens and closes, the transducer varies its voltage signal to the computer. Using this signal, the computer can provide additional spark advance when the throttle valve begins to open until it reaches the wide-open position.

Carburetor Switch

The *carburetor switch* is part of the idle stop solenoid assembly that mounts to the base of the carburetor (Fig. 8-20). This switch informs the spark control computer when the throttle valve is in the closed position. The switch performs this task by grounding the vacuum transducer electrical circuit. This action cancels any spark advancement when the engine is idling.

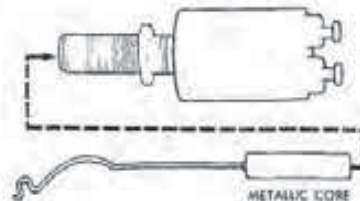


FIGURE 8-19
Throttle position transducer. (Courtesy of Chrysler Motors Corp.)

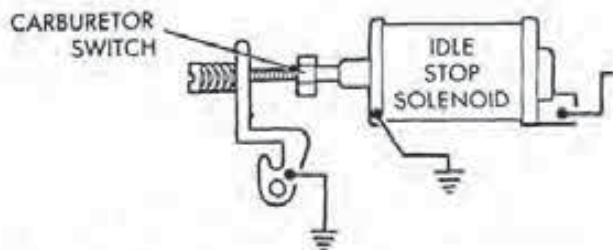


FIGURE 8-20
Carburetor switch. (Courtesy of Chrysler Motors Corp.)



FIGURE 8-21
Coolant temperature switch. (Courtesy of Chrysler Motors Corp.)

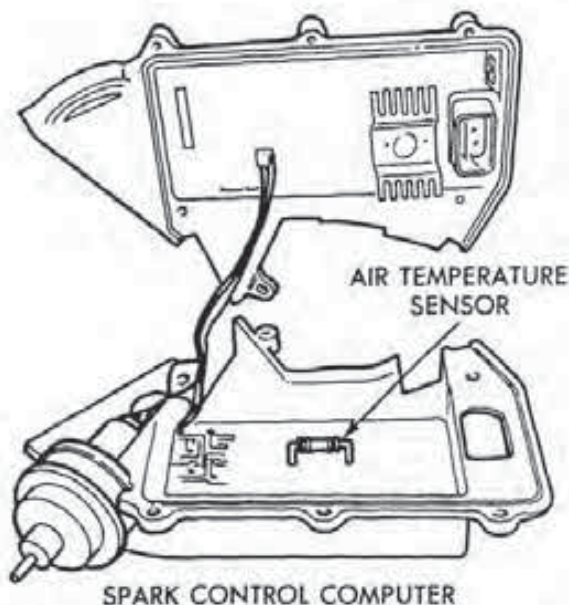


FIGURE 8-22
Air temperature sensor. (Courtesy of Chrysler Motors Corp.)

Coolant Temperature Sensor

The *coolant temperature sensor* supplies a ground circuit to the spark control computer (Fig. 8-21). It does so whenever the engine coolant temperature is below 150°F (65°C). The coolant switch is wired into the vacuum transducer electrical circuit inside the computer. When the coolant temperature is less than 150°F (65°C), regardless of the level of the intake manifold vacuum, the switch grounds out the transducer electrical circuit. As a result, there can be no additional spark advancement due to vacuum transducer action.

Air Temperature Sensor

The 1976 electronic lean burn (ELB) system has an *air temperature sensor* inside the spark control computer (Fig. 8-22). This sensor, also referred to as an ambient air sensor, develops a DC analog signal for the computer that is based on air temperature.

The sensor itself is a *thermistor*. A thermistor is made of a semiconductor material whose resistance changes inversely with temperature. Therefore, as the air temperature increases, the sensor's resistance decreases. This causes the sensor's output signal to increase.

The air temperature sensor operates in conjunction with the throttle transducer to control spark advance. The air temperature sensor controls the maximum allowable spark advance. If the air temperature sensor is hot, a smaller amount of advancement is allowed. On the other hand, if the sensor is cold, the computer will permit additional spark advancement.

Start-Pickup Coil Sensor

The ELB system uses two pickup coils within the distributor, the start and the run. The *start-pickup coil* controls the spark timing during engine starting (Fig. 8-23). The air gap between the start coil's metal core and its reluctor is less than that of the run-pickup coil. This small gap causes the start-pickup coil to produce a stronger signal as the reluctor turns slowly during engine starting. Moreover, during engine cranking, the spark timing is determined by the position of the start-pickup coil.

Run-Pickup Coil Sensor

The *run-pickup coil* produces a signal during all phases of engine operation. The run-pickup coil takes over when the computer senses increases in en-

gine speed and immediately overrides the start-pickup signal.

1977 ELB Modifications

There were two modifications to the 1977 ELB system. First, the air temperature sensor was taken out of the spark control computer. Second, the distributor no longer contained a centrifugal advance mechanism. With this last change, the spark control computer provided all spark timing advances based on engine speed and vacuum, as long as the carburetor switch was open.

1978 ELB Modifications

There were a number of alterations to the ELB system of 1978 models. For example, a single ignition resistor replaced the dual type, and the spark control computer contained only a single printed circuit board (Fig. 8-24). In addition, the sensor source for the vacuum transducer was now a ported vacuum instead of a manifold vacuum.

Finally, the throttle position transducer has a 30-degree timing offset before beginning to advance the spark. By not allowing any spark advance from the throttle transducer until the throttle valve was opened more than 30 degrees helped to eliminate part-throttle spark knock.

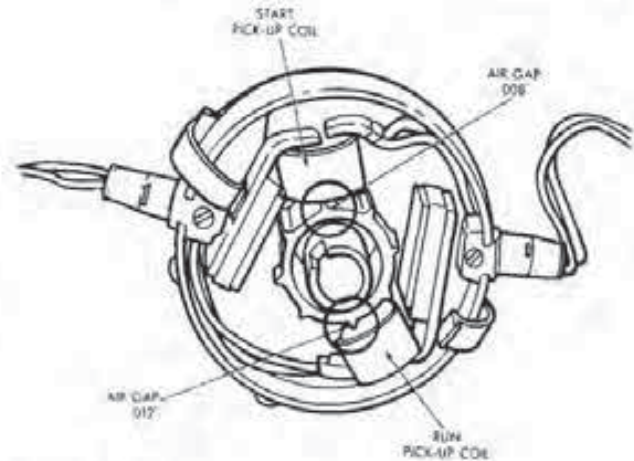
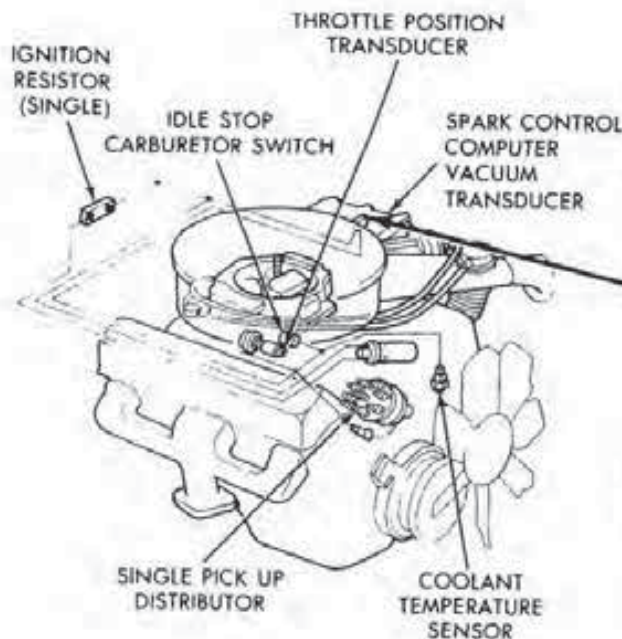


FIGURE 8-23

Start and run pickup coils. (Courtesy of Chrysler Motors Corp.)

8-6 ELECTRONIC LEAN BURN SYSTEM OPERATION

There are eight modes of operation in an ELB system: (1) initial start-up advance, (2) cold engine operation, (3) air temperature sensor advance, (4) vacuum transducer operation with a warm engine, (5) spark advance count-up, (6) spark advance count-down, (7) wide-open throttle advancement, and (8) limp-in operation.

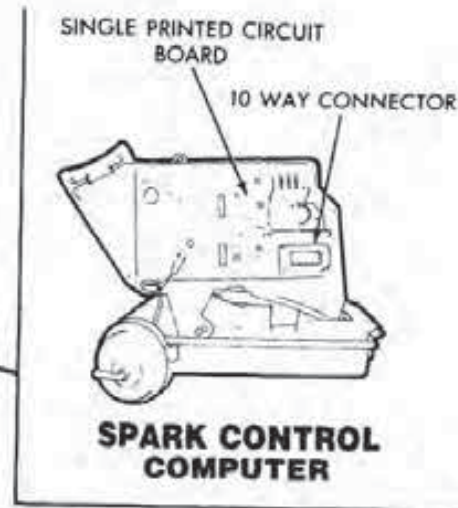


FIGURE 8-24

The 1978 electronic lean burn (ELB) system. (Courtesy of Chrysler Motors Corp.)

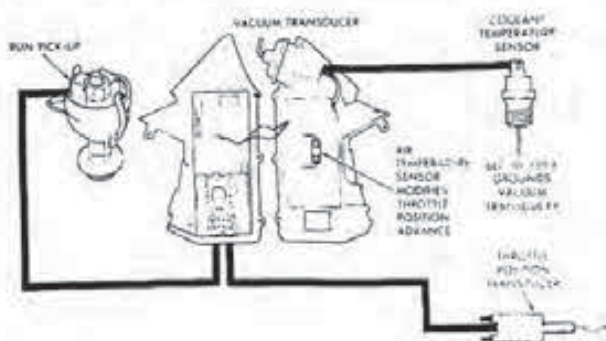


FIGURE 8-25
ELB system operation. (Courtesy of Chrysler Motors Corp.)

Initial Start-Up Advance

Once the engine starts, the computer switches over to the run-pickup coil within the distributor. The computer then provides additional spark advance for about one-and-a-half minutes (Fig. 8-25). This action during warm-up stabilizes engine operation and reduces the chances of cold engine stalling. After this period of time, the computer begins to slowly cancel out the additional spark timing and returns the engine to its basic timing.

Cold Engine Operation

As long as engine temperature is below 150°F (65°C), the coolant switch remains closed, which grounds out the vacuum transducer signal to the computer. Although the vacuum transducer signal is being grounded at this time, the throttle position transducer's signal to the computer is providing spark advancement. At part-throttle, for instance, the transducer signals the computer to provide about 5 degrees of spark advancement. While at wide-open throttle, the transducer signals the computer to provide 10 degrees to 12 degrees of advancement.

Air Temperature Sensor Advance

If the air temperature sensor monitors less than 75°F (23.8°C), the computer will only advance the spark about 10 degrees at wide-open throttle. When the air temperature reaches 105°F (40°C), the sensor signals the computer to provide only about half the advancement called for by the throttle position transducer. Lastly, at air temperatures of 140°F (60°C), there will be no spark advance resulting from throttle transducer action, regardless of throttle position.

Vacuum Transducer Operation with a Warm Engine

Once the engine reaches 150°F (65°C), the coolant temperature switch no longer grounds out the vacuum transducer signal to the computer. As a result, the computer can perform advance functions from the vacuum transducer signal once the throttle is opened and off idle.

Spark Advance Count-Up

For every minute the vacuum transducer receives 16 inches of vacuum or more with both the carburetor and coolant switches open, the spark control computer begins to advance the spark timing about 5 degrees (Fig. 8-26). This computer action is known as *count-up*. Under these conditions and after three minutes of operation, the spark timing will advance about 15 degrees. After seven to nine minutes, the timing will build up to the maximum of about 35 degrees, depending on the computer's program. However, as the vacuum applied to the transducer varies, the timing advance provided by the computer also changes.

Spark Advance Countdown

When the throttle closes, the carburetor switch contacts the curb-idle screw, which grounds out the vacuum transducer circuit. This cancels the advance provided through the vacuum transducer signal, and the engine returns to basic timing.

The amount of advancement previously built up is stored electronically within the computer. For every minute that the throttle remains closed, the memory of the built-up timing begins to count down about 10 degrees. After about three-and-a-half minutes of closed throttle operation, all the memory of spark advancement that is stored in the computer from the vacuum transducer signal is wiped out.

If the throttle opens once again, the vacuum transducer circuit is no longer grounded out. If the vacuum to the transducer is over 16 inches, the computer will begin to count up and store spark advance data.

Wide-Open Throttle Operation

At wide-open throttle, the resulting low vacuum on the transducer causes the computer to cancel out the spark advance. This returns the engine to its base

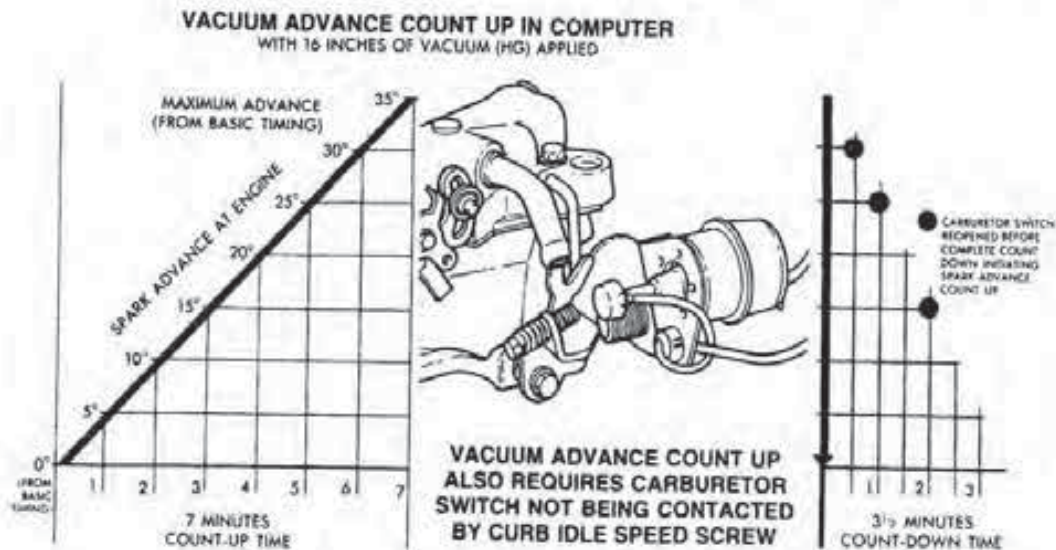


FIGURE 8-26
Spark advance count-up and countdown. (Courtesy of Chrysler Motors Corp.)

timing. However, in this case, the spark advance stored in computer memory remains intact until 16 inches or more vacuum returns to the transducer.

Limp-In Mode Operation

If there is a malfunction in the start-pickup coil or the ignition control module of the computer, the engine will not start or run. However, with a battery voltage below nine volts, or a malfunction of the vacuum transducer, run-pickup coil, or computer, the engine may run but will go into what is called the *limp-in mode*. In this situation, the system operates at the basic timing with resulting poor performance and fuel economy.

Four-Cylinder ELB System with Hall-effect Distributor

Beginning in 1978, the front-wheel drive Horizon and Omni models used an ELB system with a Hall-effect distributor (Fig. 8-27). The spark control computer in this system does not mount on the air cleaner. Instead, its location is on the left-front fender side shield within the engine compartment, but it operates the system in much the same manner as the ELB system discussed earlier (Fig. 8-28).

The system utilizes five sensors: (1) a vacuum transducer, (2) a coolant switch, (3) a throttle position switch, (4) a carburetor switch, and (5) the Hall-effect sensor. A single ballast resistor with a resistance of 0.5 ohm is used to reduce voltage and current flow in the primary circuit. However, the resistor is bypassed during starting.

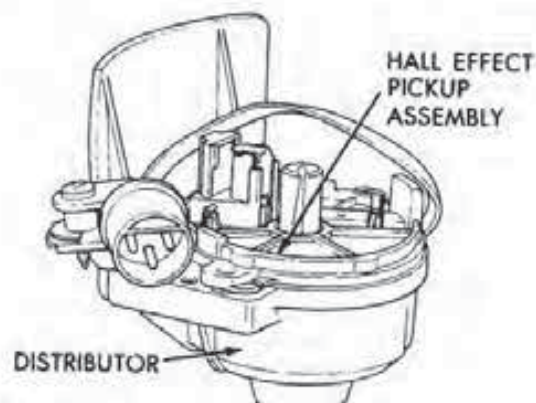


FIGURE 8-27
Hall-effect distributor. (Courtesy of Chrysler Motors Corp.)

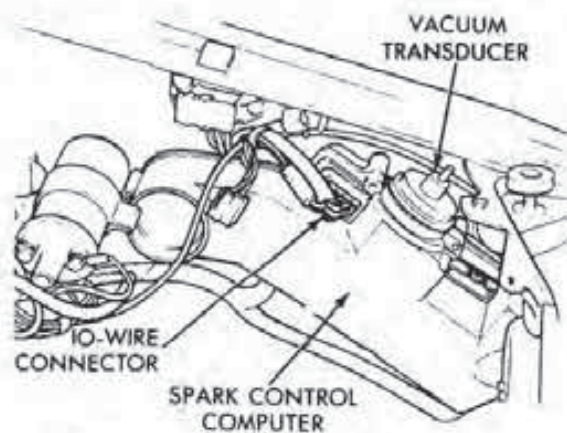


FIGURE 8-28
Location of the spark control computer. (Courtesy of Chrysler Motors Corp.)

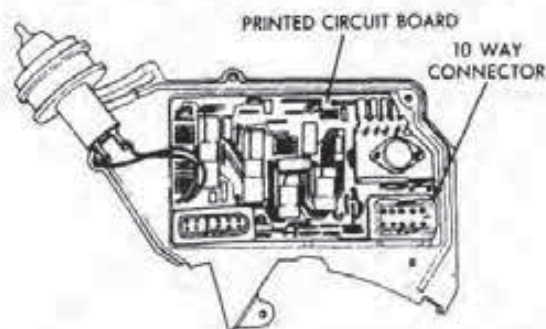


FIGURE 8-29
Digital electronic spark advance (ESA) computer. (Courtesy of Chrysler Motors Corp.)

8-7 ELECTRONIC SPARK CONTROL SYSTEM

For 1979 models, Chrysler introduced the *electronic spark control (ESC)* system that replaced ELB. The reason for this was the change from a lean air/fuel ratio of 18:1 to a richer 15:1 at cruise.

Six- and eight-cylinder engines equipped with ESC use magnetic pickup distributors. Four-cylinder models have Hall-effect distributors (see Fig. 8-27).

The ESC system is slightly different in some respects than ELB. For instance, ESC does not use a start-pickup coil sensor in magnetic impulse distributors. The throttle position transducer is eliminated in four-cylinder applications; on six- and eight-cylinder models, it has a 20-degree humped curve. The curve eliminates most of the advancement at wide-open throttle in order to reduce detonation or spark knock.

8-8 ELECTRONIC SPARK ADVANCE SYSTEM

In 1980, Chrysler introduced the *electronic spark advance (ESA)* system. This system is used in conjunction with a feedback carburetor, an oxygen sensor, and a combustion computer for closed loop fuel control. The ESA system uses a digital instead of an analog computer to improve performance and flexibility in programming (Fig. 8-29). The unit still mounts on the air cleaner except on four-cylinder engines and has a ten-way connector. Also, the system does not use a ballast resistor.

Distributor Types

As in the electronic spark control system, the electronic spark advance (ESA) system may use either a magnetic pickup or Hall-effect distributor. Six- and eight-cylinder engines use the former, while the four-cylinder models use the latter.

Computer Changes

The ESA computer is also different in several other ways from the electronic lean burn system. First, the ESA computer no longer provides the start-up advance mode for the first minute and a half. Second, due to the speed of this digital unit, the spark advance count-up and countdown are eliminated. The computer acts immediately to change spark timing according to sensor inputs.

Sensor Changes

The ESA does not use a throttle position transducer. The amount of spark advance is determined by the engine speed input signals from the run-pickup coil and vacuum transducer.

On California 318 and Federal 360 engines with 4V carburetors, the systems use a dual pickup coil distributor. This provides these configurations with better idle quality. But California six-cylinder engines use a single pickup distributor.

1981 ESA Modifications

The ESA system underwent several changes for the 1981 model year. For example, all engines used the dual pickup distributor except for electronic fuel injection (EFI) vehicles, which used a Hall-effect pickup.

A thermistor-type coolant sensor replaced the coolant temperature switch on some applications. This sensor is not a switch because its resistance changes with alterations in coolant temperature.

In four-cylinder applications, the computer provides a cold spark advance whenever the engine vacuum decreases and the engine is cold. This is the opposite reaction from normal operation, which is characterized by a decrease in spark advance with drops in the vacuum to the transducer. The cold spark advance helps improve cold driveability but is cancelled out when the engine reaches normal operating temperature.

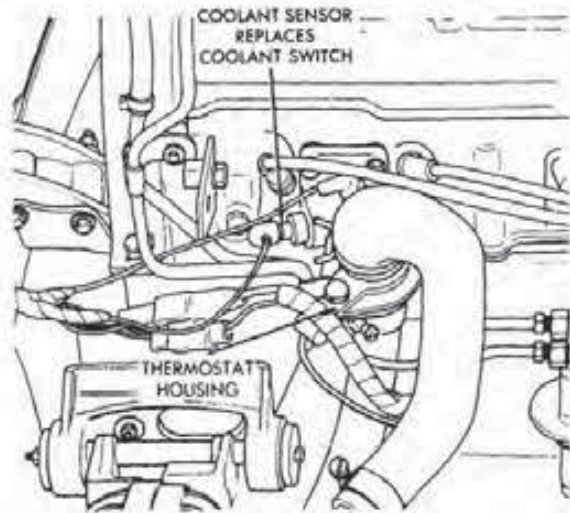


FIGURE 8-30
Coolant sensor. (Courtesy of Chrysler Motors Corp.)

1982 ESA Modifications

There were two modifications to the 1982 ESA system for four-cylinder engines. First, a coolant switch was used on all applications. Second, the distributor cap had a vent added to it.

1984 ESA Modification

There was one modification to the 1984 ESA system used on all four-cylinder models. The coolant switch was replaced by a thermistor-type coolant sensor (Fig. 8-30). The sensor controls the amount of timing advance during cold engine operation.

8-9 EFI SPARK CONTROL SYSTEM

In 1984 Chrysler began to use a redesigned electronic spark control system (ESC) on its fuel-injected, 2.2-liter engines. The 2.2-liter system uses logic and power modules to control both the ignition and fuel injection systems.

Logic Module

The *logic module* contains a digital computer that processes the input signals from the various engine sensors. In turn, the logic module controls the ignition primary and fuel injection drive circuits from

the power module (Fig. 8-31). The logic module also provides the memory for on-board diagnostics and initiates the limp-in mode. This module also supplies five volts to the manifold absolute pressure (MAP) sensor, and to the throttle position, coolant temperature, and charge temperature sensors.

The ignition portion of the system uses a Hall-effect distributor, MAP, and coolant temperature sensors for input signals to the logic module. The logic module monitors these signals to determine the proper spark advance, and supplies differing spark advancement schedules for cold and warm engine operating conditions. Other sensor inputs such as vehicle speed, oxygen, and throttle position are used to control the fuel and other system operations.

The logic module is a separate unit from the power module. The logic module is inside the vehicle and behind the right-front kick pad.

Power Module

The *power module* is located in the left-front fender well behind the battery and has several functions. First, the power module supplies the ground for the ignition coil and fuel injection circuits, as directed by the logic module. Second, the power module supplies eight volts to the logic module and the Hall-effect pickup within the distributor.

Sensor Inputs

The *MAP sensor* is inside the vehicle and mounted above the logic module (see Fig. 8-31). In this system, the MAP sensor performs the same function as a vacuum transducer.

A hose connects the intake manifold vacuum to this sensor. The MAP sensor measures *manifold pressure*, which is a comparison of atmospheric pressure to the intake manifold vacuum. A low manifold vacuum indicates high manifold pressure, and a high vacuum means low pressure.

The logic module supplies five volts to the MAP sensor. As the vacuum is applied to the sensor diaphragm, the MAP output voltage changes in proportion to the vacuum signal's strength. For example, the approximate voltage output at zero vacuum (atmospheric pressure) is 4.9 volts. On the other hand, at maximum engine vacuum, the sensor output voltage may be as low as 0.3 volt.

The *coolant temperature sensor* is in the ther-

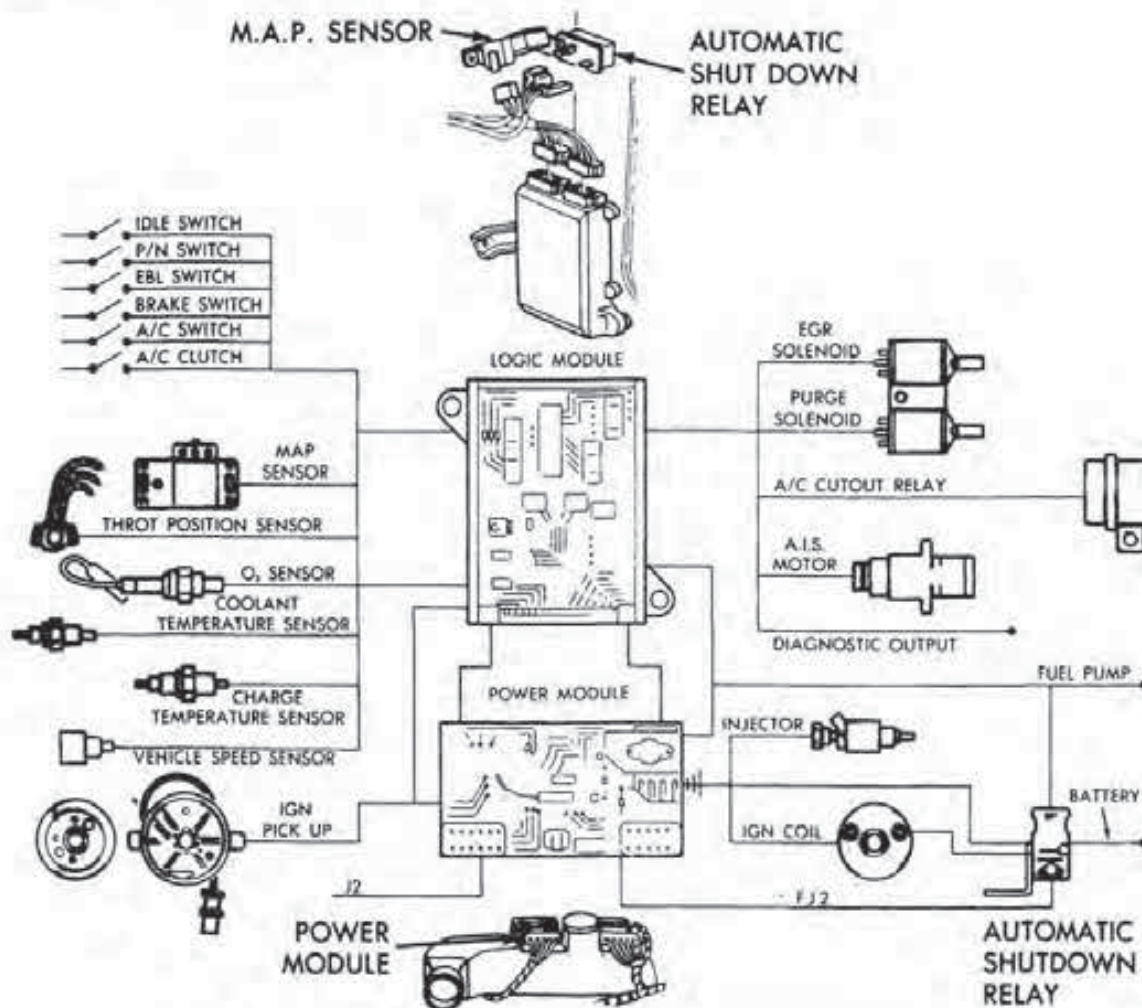


FIGURE 8-31

Electronically fuel-injected, electronic spark control system. (Courtesy of Chrysler Motors Corp.)

mostat housing. It monitors the engine coolant temperature. The sensor is a thermistor, so as the coolant's temperature increases, the resistance of the unit decreases. However, when the coolant temperature is low, the sensor resistance is higher. This causes a voltage drop across the sensor.

The five volts applied to the sensor by the logic module are therefore dropped by the sensor resistance to a lower value and then returned to the module. These sensor input signals are used to provide a cold engine spark advance in order to improve engine operation. As the engine warms up, the sensor input signal causes the computer to modify the spark advance.

The Hall-effect distributor provides a DC pulse signal to both the logic and power modules. The logic module uses the pulse signal to determine both engine rpm and piston position within the cylinder.

The distributor pulse signal also determines the spark advance reference for the engine speed spark advance schedule. The logic module can then modify the spark advance as determined by the pulse signal and MAP sensor inputs.

The power module uses the distributor pulses to ground the *automatic shutdown relay* (see Fig. 8-31). Grounding of this relay allows it to supply battery voltage to the fuel pump, logic module, ignition coil (+) terminal, and the injector and ignition coil switching circuits within the power module.

The power module must receive the first distributor pulses for a minimum of one-half second at higher than 60 rpm. If it does not, the power module will shut down the fuel and ignition systems.

The automatic shutdown relay is inside the vehicle above the logic module. In 1985 models, the relay is built into the power module.

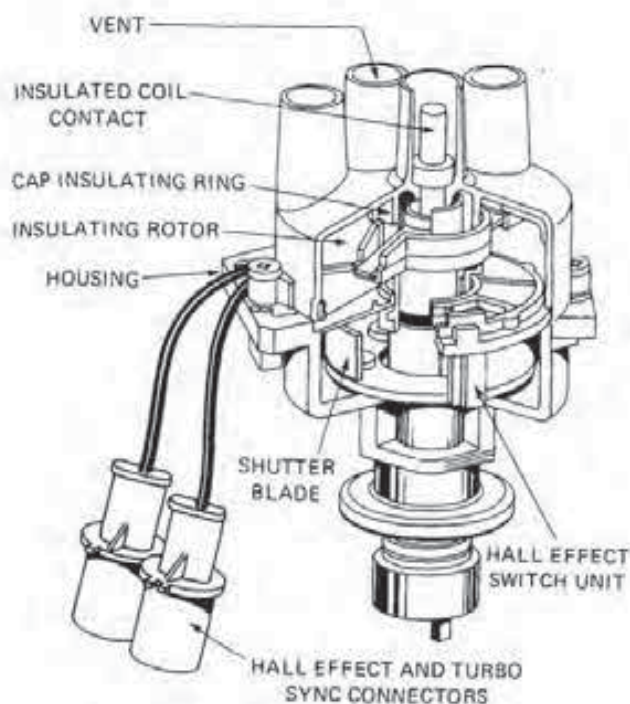


FIGURE 8-32
Labyrinth distributor.

1986 Distributor Modification

In 1986, the four-cylinder, 2.2-liter engine uses a *labyrinth distributor* (Fig. 8-32). This distributor has three concentric rings in the cap that are designed to reduce cross firing and tracking. The distributor is also shorter than previous models.

Detonation Suppression Systems

Chrysler has utilized a *detonation suppression* spark control system since 1980. Figures 8-33 and 8-34 show examples of system applications on both V-8 and four-cylinder engines.

The system employs a *detonation sensor* mounted in the intake manifold. When the sensor detects knock frequencies, it sends a low voltage signal to the ESA computer. The computer then retards the timing up to a maximum of 11 degrees. The actual amount the timing is retarded will be in proportion to the frequency strength of the detonation condition. When detonation no longer exists, the computer will advance the timing to its original value before the problem existed.

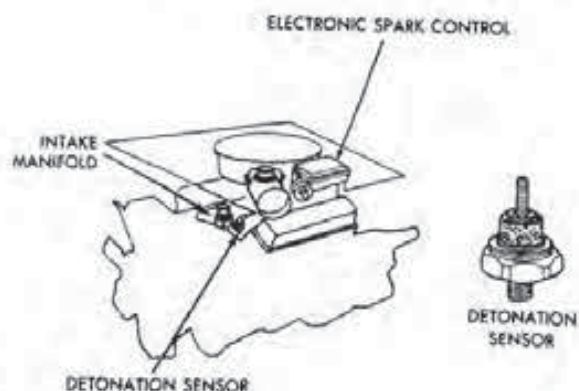


FIGURE 8-33
V-8 detonation suppression system. (Courtesy of Chrysler Motors Corp.)

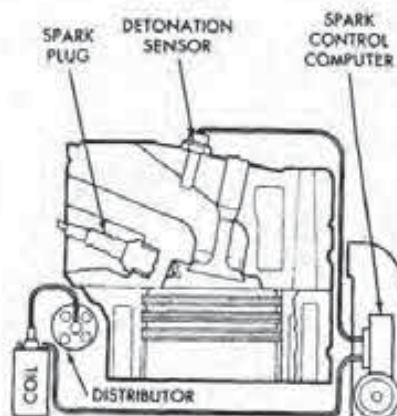


FIGURE 8-34
Four-cylinder detonation suppression system. (Courtesy of Chrysler Motors Corp.)

Some spark control computers have time delays built in to prevent cold engine noise from affecting the ignition timing. In addition, abnormal engine noises caused by worn or damaged parts can create a false input signal into the detonation sensor that will retard the spark timing.

CHAPTER REVIEW

The following two sections will assist you in determining how well you remember the material contained in this chapter. If you cannot complete a statement or question, refer back to the section marked in brackets that contains the material.

SELF-CHECK

1. Electronic fuel injection engines use what type of distributor [8-9]?
2. When Chrysler introduced electronic ignition systems (EIS), what were the two outward changes to the ignition system [8-1]?
3. Which type of ignition system is used with a feedback carburetor [8-8]?
4. Electronic ignition systems use what method to control spark timing [8-2]?
5. Why did the electronic spark control system replace electronic lean burn [8-7]?
6. The Hall-effect distributor produces what type of signal [8-3]?
7. How many operating modes does the electronic lean burn system have [8-6]?
8. The Mitsubishi electronic ignition system uses what type of distributor pickup [8-4]?
9. Why was the electronic lean burn system necessary [8-5]?
3. What unit replaces the vacuum transducer in the electronic fuel-injected, electronic spark control system [8-9]?
- a. MAP sensor
- b. coolant sensor
- c. charge sensor
- d. distributor sensor
4. The five-ohm resistance in a dual ballast resistor protects which component in the EIS [8-1]?
- a. coil
- b. ignition switch
- c. module harness
- d. none of these
5. Which system computer does not provide a spark timing count-up and countdown [8-8]?
- a. electronic lean burn
- b. electronic spark advance
- c. either a or b
- d. neither a nor b
6. How many shutters will a Hall-effect rotor have [8-3]?
- a. one for each cylinder
- b. four for a four-cylinder engine
- c. both a and b
- d. neither a nor b
7. Which ignition system does not use a start-pickup coil [8-7]?
- a. electronic lean burn
- b. electronic spark control
- c. both a and b
- d. neither a nor b
8. When does the vacuum advance mechanism provide a spark timing advancement [8-2]?
- a. during part-throttle operation
- b. at wide-open throttle operation
- c. at closed throttle operation
- d. any time the engine is operating
9. Below 150°F, which electronic lean burn transducer circuit is grounded out [8-6]?
- a. the vacuum transducer circuit
- b. the throttle position transducer circuit
- c. both a and b
- d. neither a nor b
10. Which mechanism advances the timing in relation to engine speed [8-2]?
- a. vacuum
- b. centrifugal

REVIEW

1. A detonation sensor reacts to [8-9]
- a. coolant temperature changes.
- b. knock frequencies.
- c. changes in engine speed.
- d. changes in engine vacuum.
2. In the Chrysler EIS, the pickup coil is wound around what component [8-1]?
- a. magnet
- b. pole piece
- c. centrifugal advance
- d. condenser

- c. both a and b
 - d. neither a nor b
11. Which electronic lean burn transducer senses engine load changes [8-5]?
a. vacuum transducer
b. throttle position transducer
c. both a and b
d. neither a nor b
12. When does the Hall-effect pickup produce a (+) signal [8-3]?
a. when the space between shutters is in the air gap
b. when a shutter is in the air gap
c. both a and b
d. neither a nor b
13. The electronic lean burn computer has how many circuit boards [8-5]?
a. one
b. two
- c. both a and b
d. neither a nor b
14. What is the name given the Mitsubishi electronic control unit [8-4]?
a. module
b. spark controller
c. both a and b
d. neither a nor b
15. The electronic lean burn system uses what type of computer [8-8]?
a. analog
b. digital
c. both a and b
d. neither a nor b

TESTING TYPICAL CHRYSLER ELECTRONIC IGNITION SYSTEMS

OBJECTIVES

After reading and studying this chapter, you will be able to

- explain the precautions to be followed when testing Chrysler systems.
- describe how to test both the primary and secondary portions of a Chrysler electronic ignition system (EIS).
- explain the procedures for testing a Chrysler Hall-effect EIS.
- describe how to test a Chrysler electronic lean burn (ELB) system.
- describe how to test a Chrysler electronic fuel injected (EFI), electronic spark control system.

Since 1971, Chrysler Corporation has developed and used a number of electronic ignition and spark control systems for various applications. It would be impossible to discuss the testing procedures for all of them. To provide an introduction to the process, this chapter provides samplings of procedures used on the various systems covered in the last chapter. *Always follow the manufacturer's instructions, guides, and specifications when testing any system application in order to prevent damage to its many components.*

The following sections provide step-by-step electrical test procedures on system components. These steps are necessary to locate the cause of a no-start condition or poor performance, or are called for when a computer signals an ignition fault code.

9-1 GENERAL PRECAUTIONS AND TEST EQUIPMENT

Before learning to test Chrysler systems, you must review the general precautions for working on electronic ignition systems, in general, which are listed in the box below. In the box below are general precautions for working on Chrysler systems. Also, always observe the safety instructions outlined in Chapter 5.

General Precautions

The precautions and instructions listed below and on page 244 will not only save you time in locating the actual cause of a problem but prevent the possible destruction or replacement of an otherwise serviceable part.

Chrysler Systems

1. Always follow the emission label's specifications and test procedures over those found in a service manual.
2. Disconnect the ignition wiring harness connectors before conducting a compression test.
3. Make sure the ignition control module or computer is grounded properly before reconnecting the battery.
4. Do not file the teeth of the reluctor. They are designed to have sharp corners.
5. *Do not touch the transistor mounted on the ignition module with the engine running. The high voltage present in the transistor can cause a severe electrical shock.*
6. In the Hall-effect distributors, make sure the correct rotor is installed. It should have either a R x H, EIS, or A stamping.

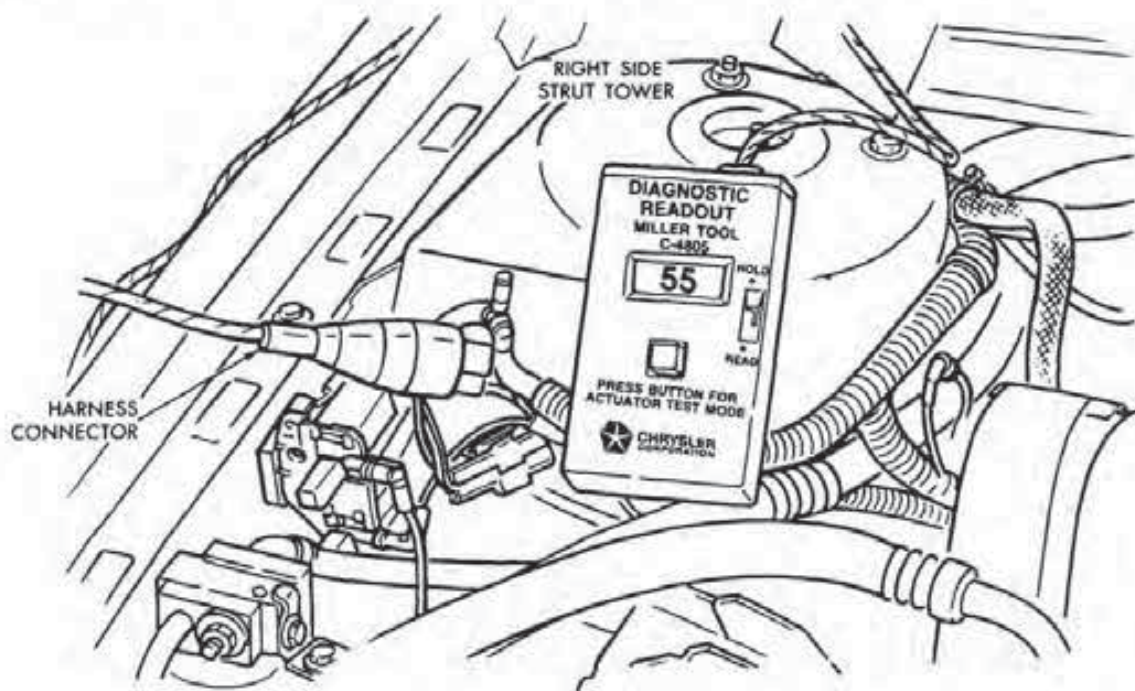


FIGURE 9-1
Diagnostic readout box. (Courtesy of Chrysler Motors Corp.)

7. A Hall-effect rotor must be seated and grounded properly on the distributor shaft.

8. Do not remove the multipurpose grease from the wiring connectors in the ignition system or pin junctions of the computer assembly. The grease is necessary in order to prevent moisture from corroding the terminals and to prevent electrical leakage between the pins.

9. There are no serviceable parts inside a computer or ignition module. If a unit is defective, it must be replaced as an assembly.

Test Equipment

Various pieces of test equipment are necessary to check the many types of Chrysler electronic ignition systems. Before you begin the ignition procedures that follow, be sure you have an accurate analog volt-ohmmeter, a power timing light with induction pickup, a spark tester, jumper leads, a nonmagnetic feeler gauge, and a vacuum pump tester.

Larger pieces of equipment necessary are an oscilloscope, module tester, and diagnostic readout box. The scope will be used to check the operation of both the primary and secondary circuits. A unit that is especially helpful is the Allen "Smart" scope because it is capable of reading distributor pickup coil signals. The module tester electronically checks the serviceability of the ignition module either on or off the vehicle.

The *diagnostic readout box* is used on the electronic fuel-injected (EFI), electronic spark control systems (Fig. 9-1). This box is not only used to read out the computer-stored fault codes but also to initiate an ignition system test sequence.

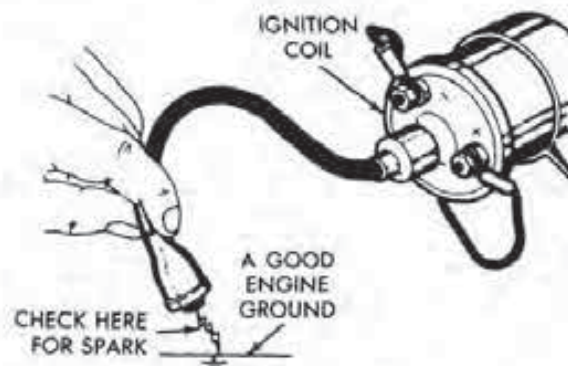


FIGURE 9-2
Coil output check. [Courtesy of Chrysler Motors Corp.]

9-2 TESTING A CHRYSLER ELECTRONIC IGNITION SYSTEM

If an engine with an electronic ignition system (EIS) will not start, troubleshoot the system for the cause of the problem by following the steps listed below.

Step 1—Coil Output Check

To determine if the coil is producing enough secondary voltage to bridge the spark plug gap, do the following:

1. Remove the coil's high tension wire and connect it to a spark tester, or disconnect the high tension wire and hold its end about 1/4 inch (6.35 mm) from a good ground (Fig. 9-2).

2. Have an assistant crank the engine over by means of the ignition switch. Observe the spark tester or wire end. If a crisp, bluish-white spark occurs, the coil is okay. In this case, check the cap and rotor for cracks, carbon tracking, and burned electrodes. Also, inspect the spring rotor terminal for lack of tension (Fig. 9-3).

3. If there is no spark or it is very weak, check the coil for cracks and arcing at the coil tower. If the coil is not cracked but arcing is present, use a towel to wipe the top of the coil off and check again. If arcing is still present, or the coil is cracked, replace it. Also, check the coil's high tension cable with an ohmmeter. If the wire is open or has excessive resistance, replace it. If the wire is satisfactory, proceed to Step 2.

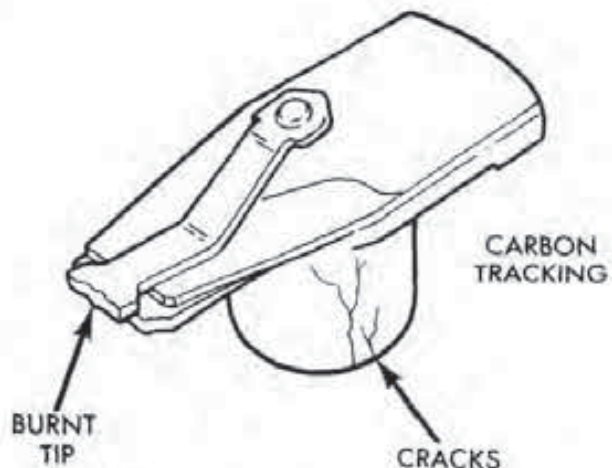


FIGURE 9-3
Rotor inspection. [Courtesy of Chrysler Motors Corp.]

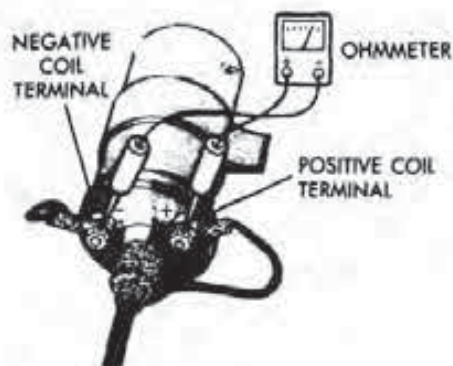


FIGURE 9-4
Primary resistance test. (Courtesy of Chrysler Motors Corp.)

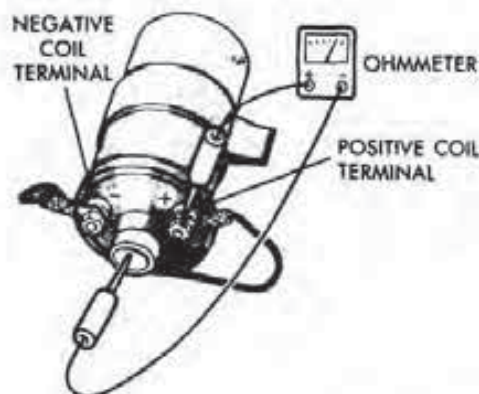


FIGURE 9-5
Secondary resistance test. (Courtesy of Chrysler Motors Corp.)

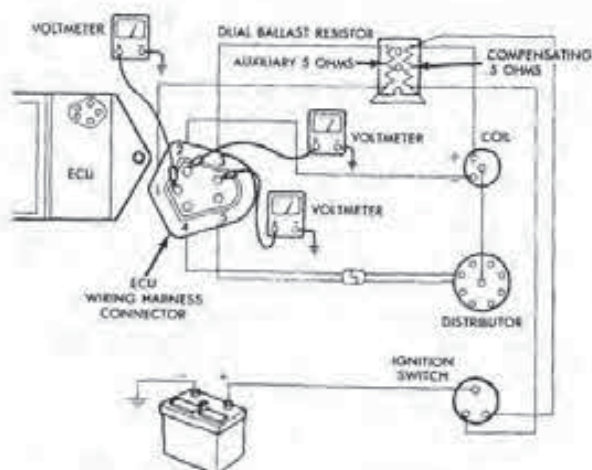


FIGURE 9-6
ECU harness voltage checks. (Courtesy of Chrysler Motors Corp.)

Step 2—Primary Resistance

To check the resistance of the primary windings against specifications, do the following:

1. Remove the wires from the primary (+) and (-) terminals.
2. Connect the leads of the ohmmeter to the terminals, as shown in Fig. 9-4, and read the resistance.
3. If the reading is to specifications, proceed to Step 3.
4. If the reading is not to specifications, replace the coil, and reconnect its primary wires.

Step 3—Secondary Resistance

To measure the resistance in the secondary coil windings, do the following:

1. Remove the high tension cable from the coil and both primary wires if it has not already been removed.
2. With the leads of the ohmmeter, measure the resistance between the high tension tower and the (+) primary terminal (Fig. 9-5).
3. If the reading is to specifications, reconnect the primary wires and high tension cable and proceed to Step 4.
4. If the reading was not to specifications, replace the coil.

Step 4—Voltage Tests at ECU Harness Connector

This test checks the voltage at harness connector locations against that of the battery. When performing the cavity tests, flex the wires at the connector.

1. With the voltmeter leads, measure, and record battery voltage.
2. With the ignition switch off, remove the wiring connector at the electronic control unit (ECU) (Fig. 9-6).
3. Turn the ignition switch on.
4. With the voltmeter leads, check the feed voltage between Cavity 1 and ground. The voltage should be within one volt of the battery reading. If

it is not, check the wiring harnesses and connectors from the ECU to the ignition switch. Also, test the ignition switch for an opening or high resistance. Repair or replace any defective component.

5. Check the voltage with the meter between Cavity 2 and ground. The reading should be within one volt of battery voltage. If it is not, check the ignition resistor, coil, connecting wires, and connectors.

6. With the meter leads, check the voltage at Cavity 3. The reading should be within one volt of battery voltage. If it is not, check the auxiliary side (five ohms) of the ballast resistor, wiring, and connectors between the resistor itself and the connector. If Cavities 1, 2, and 3 were okay, proceed to Step 5 or 6.

7. After finishing the test, turn the ignition switch off.

Step 5—Pickup Resistance Check

To measure the resistance within the pickup coil and for a grounded circuit, do the following:

1. With the leads of an ohmmeter, check the pickup resistance between Cavities 4 and 5 (Fig. 9-7). The resistance should be to specifications.

2. If the resistance is incorrect, disconnect the pickup coil connector at the distributor. Then, recheck the pickup coil resistance at the connector with the ohmmeter. If the resistance is still not to specifications, replace the pickup assembly. However, if the coil resistance is satisfactory, replace the harness between the pickup and the ECU connectors.

3. With the ohmmeter leads, check the resistance between Cavity 5 and ground, and then Cavity 4 and ground (see Fig. 9-7). The meter should read infinite resistance. If, on the other hand, continuity is indicated, replace the pickup assembly.

4. If the pickup coil checked out okay, go to Step 7.

5. Plug in the pickup coil connector.

Step 6—Testing Coil Operation

This test can be used as an alternative to Step 5 if you have an Allen "Smart" scope or its equivalent. It will check the pickup coil operation with the en-

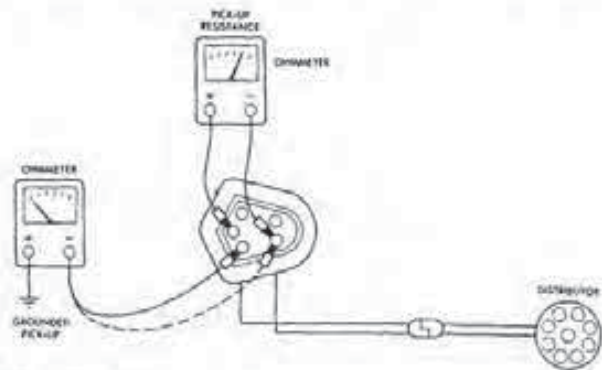


FIGURE 9-7
Pickup resistance and ground checks. (Courtesy of Chrysler Motors Corp.)

gine cranking over. To perform this test, do the following:

1. Disconnect the pickup coil harness connector.

2. Connect the red test probe to the male terminal of the pickup connector.

3. Attach the black test probe to the female terminal of the pickup connector.

4. Operate the scope in the self-sweep operating mode.

5. Place the ohm scale selector switch in the X10 position. The scope is now a 2.5 voltmeter using the left grid scale.

6. Crank the engine over using the ignition switch, while observing the scope screen.

7. If there is no scope pattern, replace the pickup coil.

8. If there is an AC sweep pattern, as shown in Fig. 9-8, the pickup coil is okay. Proceed to Step 7.

Step 7—Pickup Air Gap Check and Adjustment

To determine if the reluctor-to-pole-piece air gap is to specifications, do the following:

1. Remove the distributor cap.

2. Position a reluctor tooth exactly centered on the pole piece.

3. Measure the reluctor-to-pole-piece air gap with a nonmagnetic feeler gauge (Fig. 9-9).

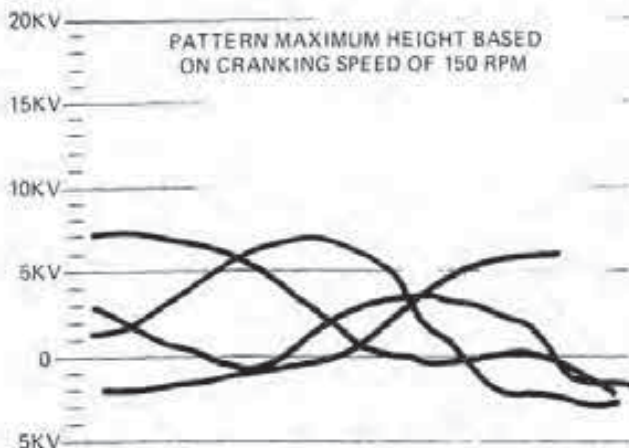


FIGURE 9-8
Testing pickup coil operation with a scope.

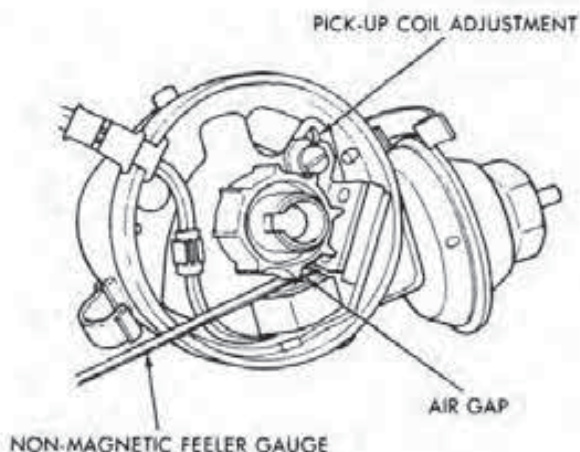


FIGURE 9-9
Checking pickup coil air gap. (Courtesy of Chrysler Motors Corp.)

4. If the air gap is to specifications, proceed to Step 8.

5. If the air gap is not to specifications, adjust it by loosening the pickup coil assembly holddown screw (Fig. 9-10) and inserting the correct thickness feeler gauge between the reluctor tooth and pole piece. Move the pole piece and coil assembly until it just contacts the gauge. Then, tighten the holddown screw. There should now be no clearance present between the feeler gauge and the reluctor tooth and pole piece. If there is, readjust the pickup assembly.

6. Rotate the reluctor and make a clearance check on several other teeth. If the clearance changes, either the reluctor tooth or the distributor shaft bushing is worn. Replace worn or defective parts.

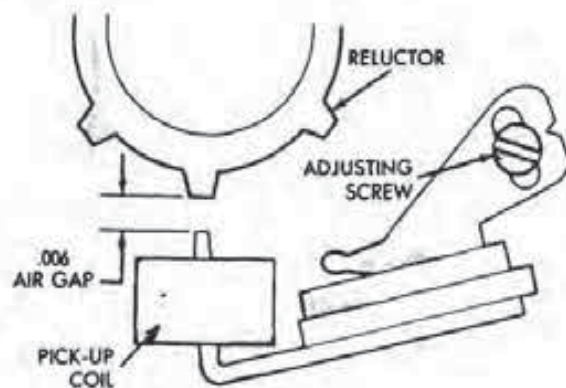


FIGURE 9-10
Adjusting pickup coil air gap. (Courtesy of Chrysler Motors Corp.)

7. If the pickup coil air gap is satisfactory, go to Step 8.

8. Reinstall the distributor cap.

Step 8—ECU Ground Check

To check the ECU grounding circuit, do the following:

1. With the ohmmeter leads, check the continuity between Pin 5 of the ECU and ground (Fig. 9-11).

2. If the meter indicates no continuity, remove the ECU attaching bolts and clean the module mounting surfaces.

3. Reinstall the bolts and recheck for continuity with the ohmmeter.

4. If continuity is still not present, replace the ECU. If you have a module tester, check the unit before replacing it to verify the problem.

5. Plug in the ECU connector.

Primary and Secondary Circuit Scope Tests

Primary and secondary scope analysis is the best way to quickly determine the cause of poor performance caused by a problem in the primary or secondary circuit. Figure 9-12 shows a comparison between the ideal primary pattern for a standard ignition system and the electronic ignition system (EIS).

Note in the illustration that the EIS primary pattern has fewer and smaller oscillations in the fir-

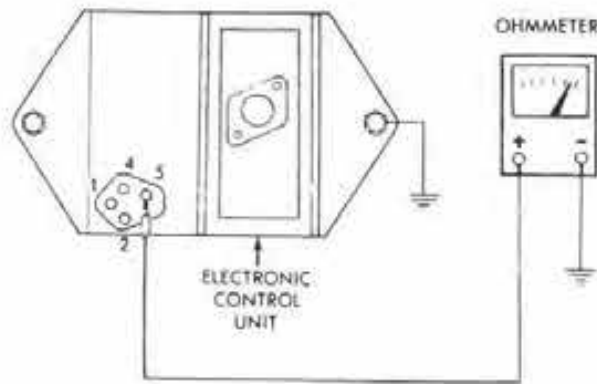


FIGURE 9-11
Checking the ECU ground. (Courtesy of Chrysler Motors Corp.)

ing section as compared to the standard system. Moreover, the EIS has no intermediate section. Therefore, as soon as the spark extinguishes, the power transistor in the ECU turns on again due to a positive pickup coil signal. This allows current to flow in the primary windings. Finally, at the end of the dwell section that is fixed and does not change, the transistor turns off the primary current flow as the ECU receives a positive zero signal from the pickup coil.

If there is any deviation from this primary EIS pattern, you can use any or all of the primary circuit tests just outlined to locate the cause of the problem.

Figure 9-13 shows a comparison of a standard to an EIS secondary pattern. Note also in the secondary the absence of the intermediate section. Once the spark extinguishes, the transistor turns on. The oscillations present when the transistor turns on represent the remaining voltage in the secondary windings that are dissipating as the current begins to flow in the primary circuit.

If there is any deviation from the transistor on and off signal, the cause can be found using the primary circuit tests outlined earlier in this section. Causes of malfunctions in the firing and spark lines can be diagnosed in the same way as outlined in Chapter 7, Section 7-2, Step 4.

9-3 TESTING A HALL-EFFECT EIS

If an engine with a Hall-effect EIS will not start, complete the secondary voltage test outlined under Section 9-1, Step 1. If the system fails this test, proceed with the primary voltage and continuity checks listed below.

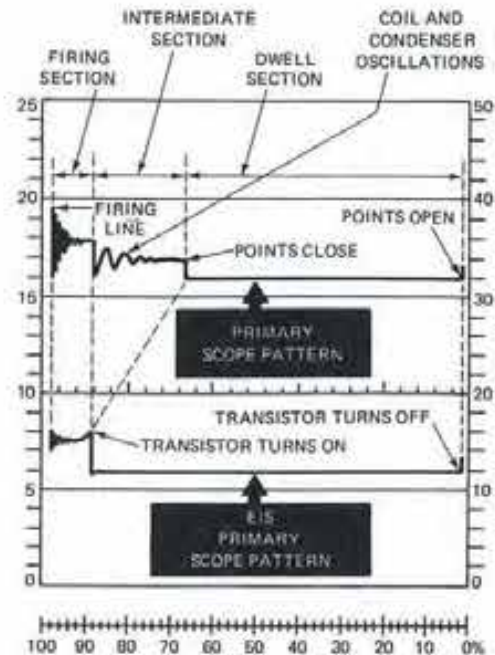


FIGURE 9-12
Primary EIS scope pattern. (Courtesy of Chrysler Motors Corp.)

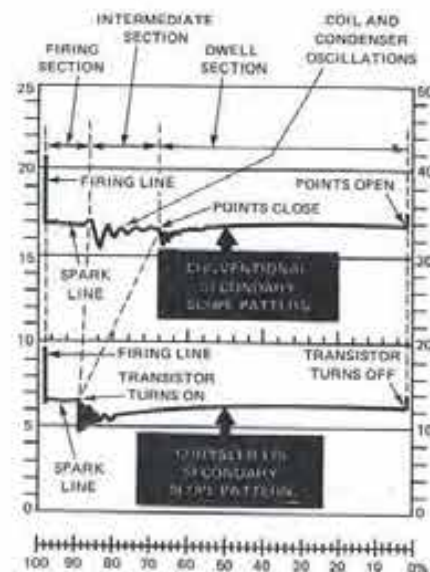


FIGURE 9-13
Secondary EIS scope pattern. (Courtesy of Chrysler Motors Corp.)

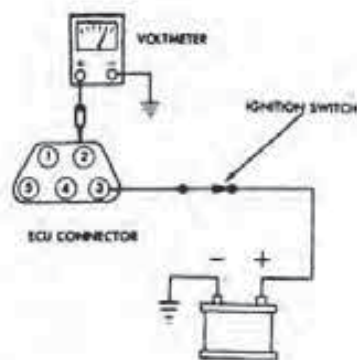


FIGURE 9-14
Checking Cavity 2 voltage. (Courtesy of Chrysler Motors Corp.)

Step 1—Cavity 2 Voltage Check

To test the voltage at Cavity 2 of the ECU connector harness against that of the battery, flex the wires at the connector and do the following:

1. With the voltmeter leads, measure and record battery voltage.
2. With the ignition switch off, remove the wiring connector at the ECU.
3. With the voltmeter leads, check the voltage between Cavity 2 and ground. The voltage should be within one volt of the battery reading (Fig. 9-14).
4. If the voltage is not correct, check the ignition feed circuit for an open, loose connection or excessive resistance.
5. If the voltage reading is satisfactory, proceed to Step 2.

Step 2—Cavity 5 Voltage Test

To check the voltage at Cavity 5 of the ECU connector harness against that of the battery, do the following:

1. With the voltmeter leads, measure the voltage between the ECU connector Cavity 5 and ground (Fig. 9-15). The reading should be within one volt of battery voltage.
2. If the voltage is incorrect, check the wire from the connector to the (-) side of the coil and the resistance of the primary coil. Repair or replace any defective parts.
3. If the voltage reading is okay, proceed to Step 3.

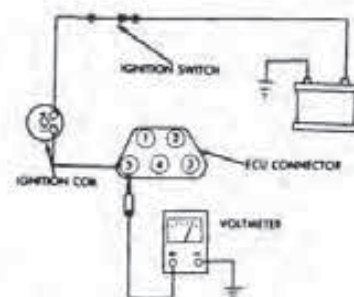


FIGURE 9-15
Testing Cavity 5 voltage. (Courtesy of Chrysler Motors Corp.)

Step 3—Distributor Connector Cavity 1 Voltage Test

To test the voltage of the distributor connector at Cavity 1 against that of the battery, do the following:

1. Turn off the ignition switch and assemble the harness connector to the ECU.
2. At the distributor, disconnect the wiring connector.
3. Turn the ignition switch on.
4. With the voltmeter leads, measure the voltage between the distributor harness Cavity 1 and ground (Fig. 9-16). The measurement should be within one volt of battery voltage.
5. If the voltage is not correct, use an ohmmeter to check the wiring harness for continuity between Cavity 1 of both the ECU and distributor connectors. If the harness has no continuity, repair or replace it. If the harness has continuity, replace the ECU. Before replacing the ECU, check it for serviceability with a module tester.
6. If the reading at Cavity 1 was okay, proceed to Step 4.

Step 4—Distributor Connector Cavity 2 Continuity Check

To check the continuity of the circuit between Cavity 2 and ground, do the following:

1. With the ignition switch off, use the ohmmeter leads to check for continuity between the distributor connector Cavity 2 and ground (Fig. 9-17).
2. If there is no continuity, proceed to Step 5.

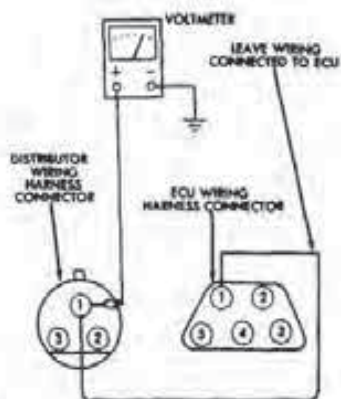


FIGURE 9-16
Checking distributor connector Cavity 1 voltage. (Courtesy of Chrysler Motors Corp.)

3. If the meter indicates continuity, check the wiring harness between the connectors for ECU Pin 4 and the distributor Pin 2 for an open circuit. Repair or replace the harness as necessary.

Step 5—ECU Continuity Check

To make sure there is continuity between ECU Pin 4 and ground, do the following :

1. With the leads of an ohmmeter, check for continuity between the ECU Pin 4 and ground (Fig. 9-18).

2. If there is no continuity, remove the ECU to make sure its mounting surfaces are clean. Recheck for continuity. If the test is again unsatisfactory, replace the ECU. However, check the ECU on a module tester before condemning the unit.

3. If the continuity was okay, proceed to Step 6.

Step 6—Hall-effect Pickup Test

To check the serviceability of the Hall-effect pickup within the distributor, do the following:

1. Reassemble the ECU connector but leave the distributor harness connectors separated.

2. Turn the ignition switch on.

3. Connect the coil's high tension wire to a spark tester.

4. While observing the spark tester, momentarily connect together with a jumper lead Cavities 2 and 3 in the distributor wiring harness connector (Fig. 9-19).

5. If a spark is produced, proceed to Step 7.

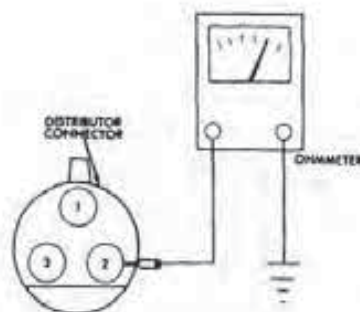


FIGURE 9-17
Testing distributor connector Cavity 2 voltage. (Courtesy of Chrysler Motors Corp.)

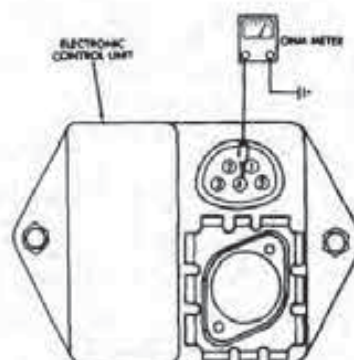


FIGURE 9-18
ECU ground test. (Courtesy of Chrysler Motors Corp.)

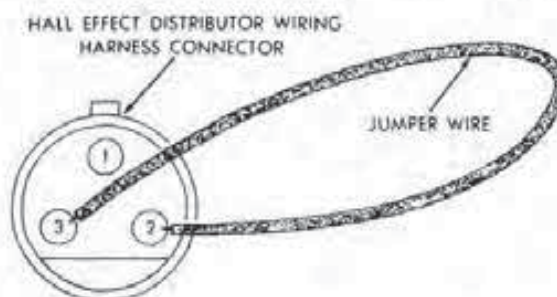


FIGURE 9-19
Shorting the distributor connector. (Courtesy of Chrysler Motors Corp.)

Step 7—Shutter Continuity Check

To test the continuity between the rotor shutters and ground, do the following:

1. Connect the leads of an ohmmeter between a shutter and a ground (Fig. 9-20). The meter should show continuity.

2. If there is continuity, replace the Hall-effect pickup.

3. If there is no continuity, push down on the rotor to seat it; perform the test again. If there is still no continuity, remove the rotor, scrape the in-

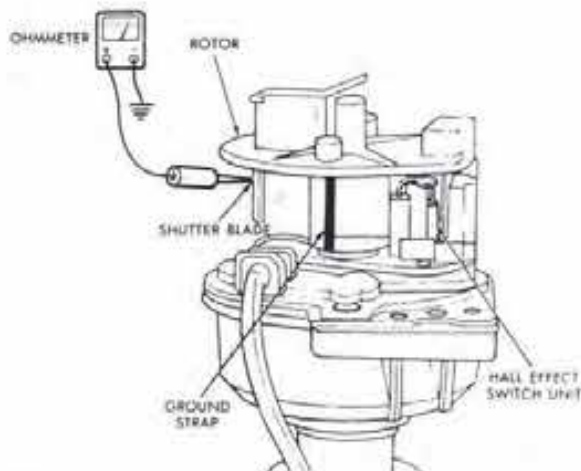


FIGURE 9-20
Shutter continuity check. [Courtesy of Chrysler Motors Corp.]

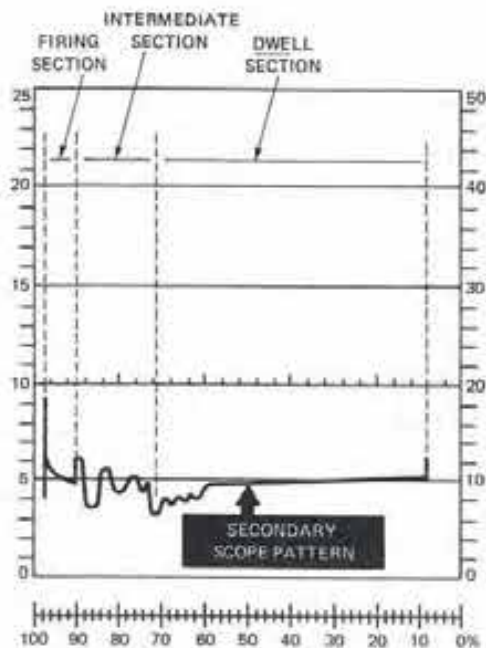


FIGURE 9-21
Hall-effect secondary pattern. [Courtesy of Chrysler Motors Corp.]

side of the shutter ground strap, and clean the spring contact grounding area of the shaft.

4. Repeat the continuity test. If there is still no continuity, replace the rotor.

Secondary Circuit Scope Tests

Scope testing the secondary pattern is the best way to quickly reveal the cause of most poor performance complaints. Figure 9-21 illustrates the secondary

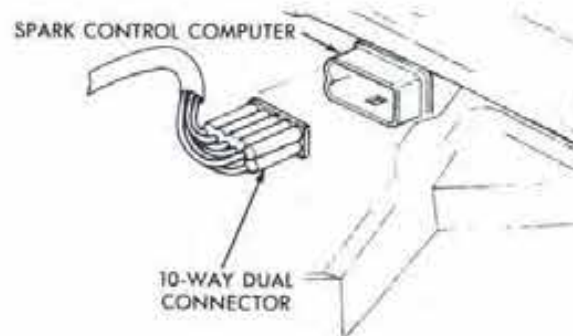


FIGURE 9-22
Separating the computer connector. [Courtesy of Chrysler Motors Corp.]

pattern for the Hall-effect EIS. Although the dwell in this system is also fixed, it does have an intermediate section.

If there is any deviation from the pattern shown in Fig. 9-21 within the intermediate and dwell sections, the cause can be found by performing the coil resistance checks or the primary circuit tests outlined in this section. Causes of malfunctions in the firing and spark lines can be diagnosed in the same way as outlined in Chapter 7, Section 7-2, Step 4.

9-4 TESTING AN ELECTRONIC LEAN BURN SYSTEM

If an engine with an electronic lean burn (ELB) system will not start, troubleshoot the system for the cause of the problem by following the steps listed below.

Step 1—Coil Output Check

To determine if the coil is producing enough secondary voltage to bridge the spark plug gap, do the following:

1. Remove the coil's high tension wire and connect it to a spark tester.
2. Have an assistant crank the engine over using the ignition switch.
3. Observe the spark tester. If a good spark is produced, check the resistance in the coil wire and rotor, cap, and coil, as outlined in Section 9-2, Step 1.
4. If there is no spark or it is weak, turn off the ignition switch and separate the dual connector from the bottom of the spark control computer (Fig. 9-22).

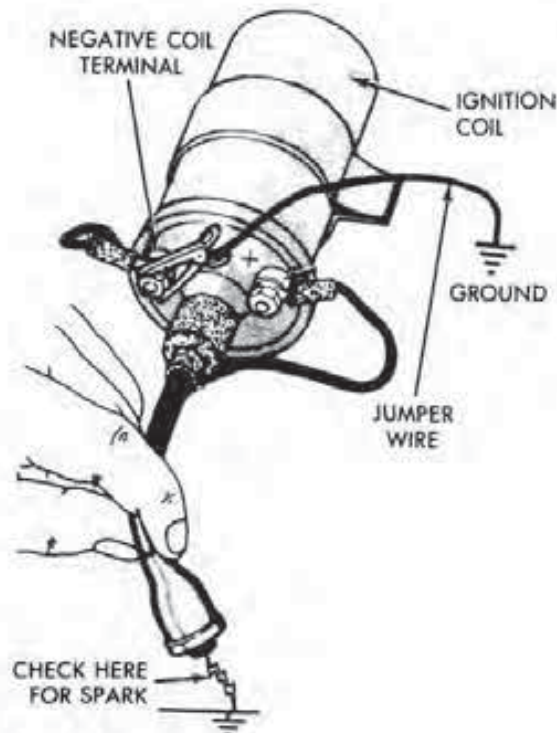


FIGURE 9-23
Performing a coil output check while grounding the negative coil terminal. (Courtesy of Chrysler Motors Corp.)

5. Turn the ignition switch on.
6. Intermittently short the primary coil (-) terminal to ground using a jumper lead (Fig. 9-23).
7. If a good spark now appears at the spark tester or when holding the coil wire 1/4 inch (6.35 mm) from ground, replace the spark control computer.
8. If there is no spark, perform the coil primary and secondary resistance tests as outlined in Section 9-2, Steps 2 and 3.
9. If the coil resistance is satisfactory, proceed to Step 2.

Step 2—Start Failure Voltage Test

To check the voltage at the carburetor switch, do the following:

1. Turn the ignition switch off.
2. Place a piece of cardboard or thick paper between the carburetor switch contact and the idle adjustment screw (Fig. 9-24).
3. Turn the ignition key on.

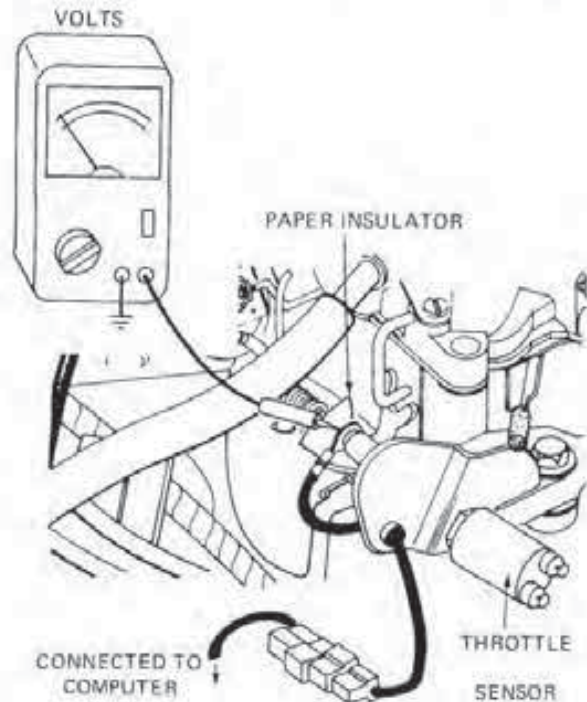


FIGURE 9-24
Checking the voltage at the carburetor switch.

4. Connect one voltmeter lead to a good ground and the other to the carburetor switch contact and check the reading.
5. If the reading obtained is between five volts and ten volts, go to Steps 4 and 6.
6. If the reading is less than five volts, proceed with Steps 3, 5, and 6, in that order.
7. If the reading is over ten volts, go to Step 6.

Step 3—Connector 2 Voltage Test

To check the level of voltage at the computer harness connector Terminal 2, do the following:

1. Turn off the ignition switch.
2. Unplug the ten-pin connector from the computer.
3. With the leads of a voltmeter, measure and record battery voltage.
4. Connect the positive (+) lead of the voltmeter to Terminal 2 of the connector (Fig. 9-25). Attach the negative (-) lead to a good engine ground.
5. Turn the ignition switch to the RUN position and read the voltage on the meter.

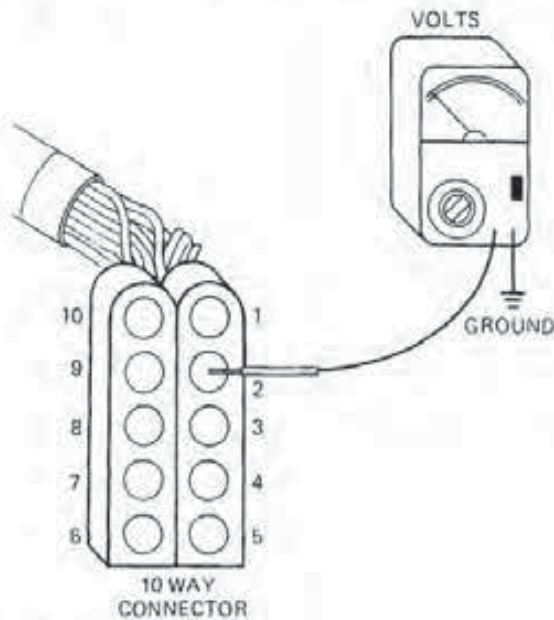


FIGURE 9-25
Testing the voltage at Terminal 2.

6. Turn the ignition switch off.

7. If the voltage is within one volt of that of the battery, go to Step 4.

8. If the reading is not within one volt of total battery voltage, check the wiring and connectors between Terminal 2 and the ignition switch. Repair or replace defective parts.

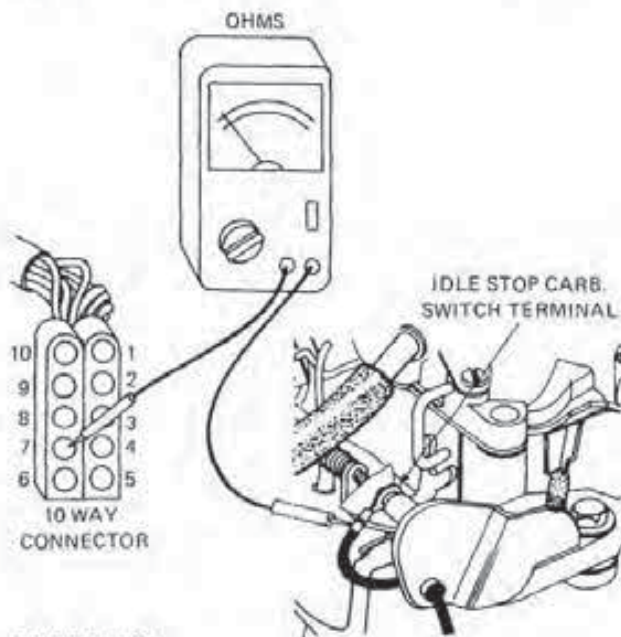


FIGURE 9-27
Testing Terminal 7 for continuity.

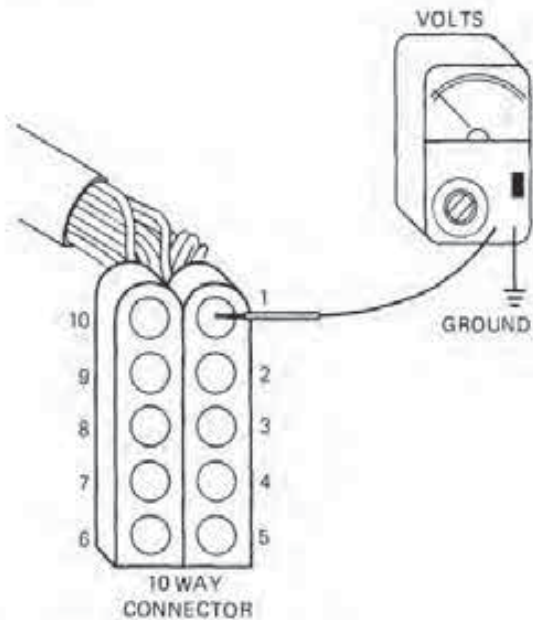


FIGURE 9-26
Checking the voltage at Terminal 1.

Step 4—Connector 1 Voltage Test

To measure the amount of voltage at Terminal 1 of the computer harness connector, do the following:

1. Attach the positive (+) voltmeter lead to the wiring connector Terminal 1.
2. Connect the negative (−) voltmeter lead to a good engine ground (Fig. 9-26).
3. Turn the ignition switch to the RUN position and read the voltage on the meter.
4. Turn the ignition switch off.
5. If the reading is within one volt of the total battery voltage, proceed to Step 5.
6. If the voltage is not within one volt of that of the battery, check the wiring and connector from Terminal 1 to the ignition switch. Repair or replace defective components.

Step 5—Terminal 7 Continuity Test

To check the continuity between Terminal 7 and the carburetor switch terminal, do the following:

1. Attach one ohmmeter lead to Terminal 7 inside the connector.
2. Connect the other ohmmeter lead to the terminal of the carburetor switch (Fig. 9-27).

3. Note the reading on the ohmmeter. If there is continuity, proceed to Step 6.

4. If there is no continuity, check the wire between the carburetor switch and Terminal 7 for openings, breaks, or shorts. Repair or replace the wire as necessary.

Step 6—Computer Ground Continuity Test

To check the continuity between Terminal 10 and ground, do the following:

1. Connect one ohmmeter lead to Terminal 10 inside the connector.

2. Attach the other ohmmeter lead to a good engine ground (Fig. 9-28).

3. Note the reading on the ohmmeter. If there is continuity, go to Step 7.

4. If there is no continuity, check the wires from Terminal 10 for any shorts, breaks, or poor connections. Make repairs or replacements as necessary. If the wires are satisfactory, replace the spark control computer.

Step 7—Ballast Resistor Test

To check the resistance within the ballast resistor against specifications, do the following:

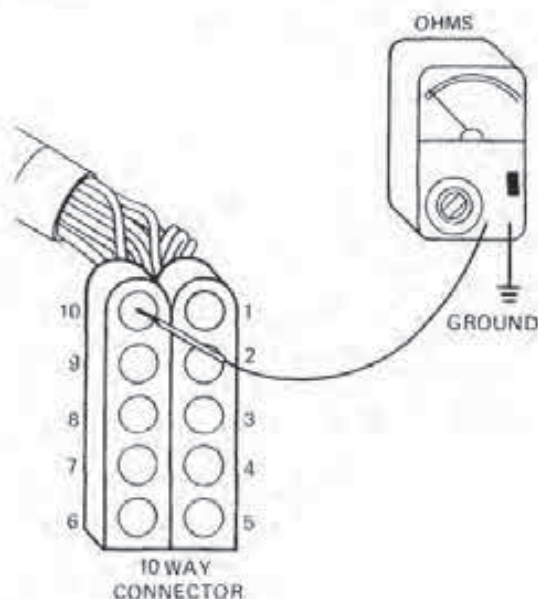


FIGURE 9-28
Computer ground continuity test.

1. Disconnect the wires attached to the ballast resistor.

2. Touch the ohmmeter leads to the resistor terminals and note the reading (Fig. 9-29).

3. If the resistance is to specifications, go to Step 8.

4. If the resistance is not to specifications, replace the ballast resistor.

Step 8—Pickup Coil Resistance Tests

To test the resistance in both the start- and run-pickup coils and to test for continuity of connector Terminals 3, 5, and 9, do the following:

1. Unplug both pickup coil connectors.

2. Touch one ohmmeter lead to each terminal of a pickup coil connector; read and note the resistance of the coil (Fig. 9-30). Wiggle the connector wires during the test.

3. Repeat the process on the other connector.

4. If the resistance is not to specifications, replace the affected pickup coil.

5. If both coil resistances are to specifications, plug in both the connectors.

6. Touch the ohmmeter leads to Terminals 5 and 9 inside the computer connector and check the resistance (Fig. 9-31). Note the reading.

7. Touch the ohmmeter leads to Terminal 3 and 9 inside the computer connector and check the resistance; note the reading.

8. If the readings are the same as those taken in 2 and 3 above, the wiring harness and connectors are satisfactory.

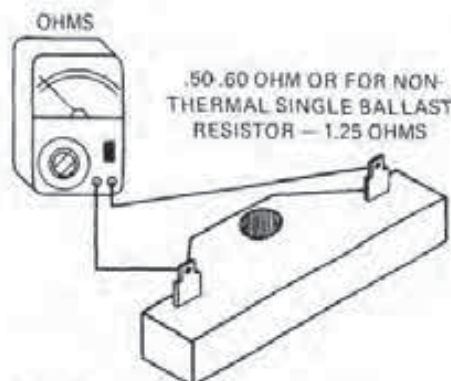


FIGURE 9-29
Ballast resistor check.

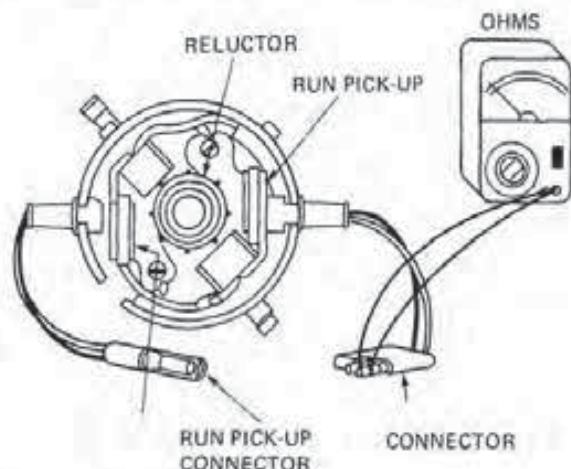


FIGURE 9-30
Pickup coil resistance tests.

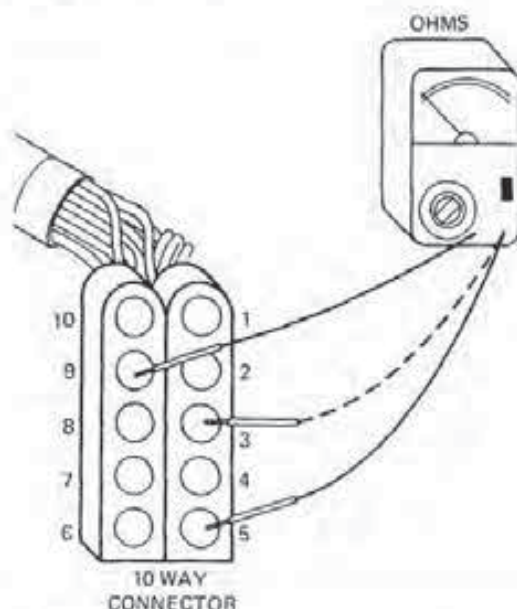


FIGURE 9-31
Checking pickup coil resistance through Terminals 3, 5, and 9.

9. If one or both readings are not the same as those taken in 2 and 3 above, inspect and repair the wiring from the computer to the distributor connector(s).

Secondary Scope Tests

Secondary scope tests check the engine for causes of poor engine performance. To perform these checks, follow the steps and the pattern used in Section 9-3, Secondary Circuit Scope Tests.

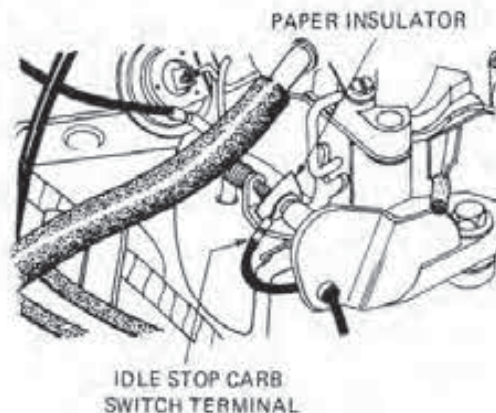


FIGURE 9-32
Insulating the carburetor switch. (Courtesy of Chrysler Motors Corp.)

Spark Advance Schedule Check

This test confirms that the spark advance system is functioning properly. If the system does not perform as it should, poor performance and fuel economy will result. To complete this test, do the following:

1. Following the manufacturer's instructions, attach a power timing light or magnetic timing unit to the engine.
2. Start the engine and allow it to reach normal operating temperature.
3. Check the basic timing and reset as necessary.
4. Place a piece of thin insulation, paper, or cardboard between the carburetor switch and the curb idle adjustment screw (Fig. 9-32).
5. Note the timing. The timing should advance above the base amount. If it does not, check the resistance in the throttle position sensor and its adjustment as outlined later in this section. If both are okay, the spark control computer is defective and requires replacement.
6. Apply 16 inches of vacuum to the transducer (Fig. 9-33) for the specified period with the carburetor switch insulated.
7. Note the timing. It should begin to count up toward the maximum spark advance.
8. Compare the spark advance against the specifications. If the advance is not to specifications, replace the spark control computer.
9. Remove the insulator from the carburetor

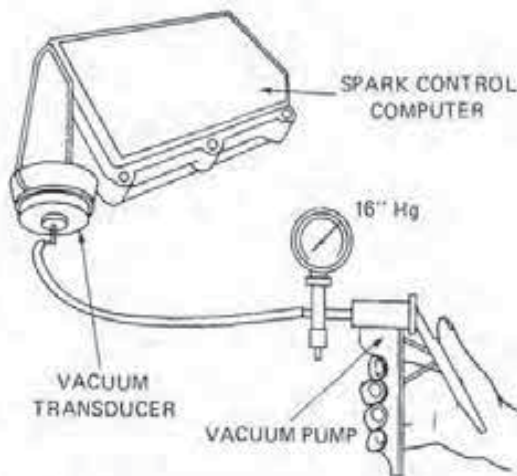


FIGURE 9-33
Applying vacuum to the transducer. (Courtesy of Chrysler Motors Corp.)

switch and note the timing. It should begin to count down toward base setting.

10. With the 16 inches of vacuum still applied to the transducer, open the throttle off idle. The timing should cease its countdown and return to the value stored in computer memory. If the timing does not respond in this manner, the spark control computer is defective and requires replacement. However, you should check the serviceability of both the throttle switch and transducer along with the coolant sensor before condemning the computer. These procedures are covered in upcoming testing sequences.

Spark Timing Advance Test

To check the timing response against input signals from the throttle position sensor, do the following:

1. Following the manufacturer's instructions, connect a timing light or magnetic timing unit to the engine.
2. Have an assistant apply the service brakes and start the engine.
3. Check the start timing against specifications. This should be between four degrees and nine degrees.
4. Observe the timing as your assistant quickly snaps the throttle open, lets it close, and then places the automatic transmission into drive. The timing will advance and should then decrease to initial timing in about one minute.

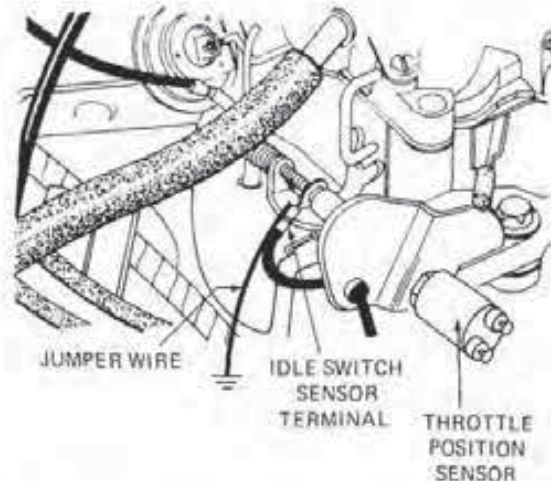


FIGURE 9-34
Grounding the carburetor switch terminal.

5. If the timing advance did not increase after the engine was placed in drive or did not decrease to base timing in one minute, check the adjustment of the throttle position sensor.

Throttle Position Sensor Adjustment

The adjustment of the throttle position sensor is important so that the sensor can relay throttle position information to the computer. To check and make the adjustment, do the following:

1. Make sure the temperature inside the engine compartment is less than 135°F (57.2°C).
2. Start the engine and let it operate at least 90 seconds, and then connect a jumper wire from the carburetor switch contact to a good ground (Fig. 9-34).
3. Unplug the throttle position sensor connector.
4. Check the timing immediately and note the initial reading.
5. Adjust the base timing according to the specifications. Then, plug in the connector to the throttle position sensor. Note the timing again.
6. If the timing is now higher than base specifications, loosen the throttle position sensor locknut. Next, rotate the sensor clockwise until the correct timing is achieved, and then rotate another half turn. Tighten the locknut.
7. If the timing is at or lower than specifica-

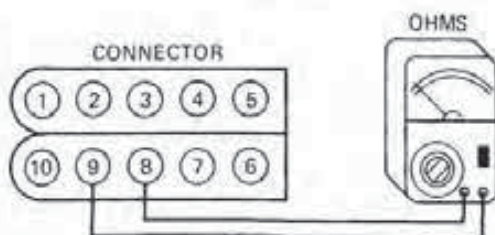


FIGURE 9-35
Testing resistance at Terminals 8 and 9.

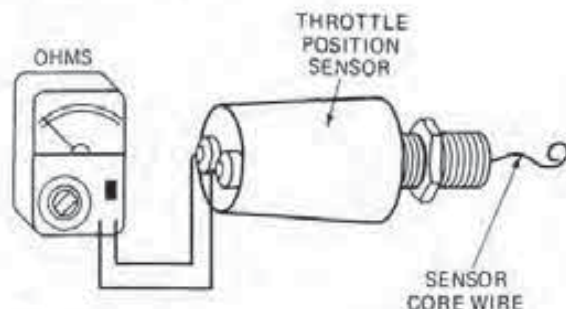


FIGURE 9-36
Checking resistance at the throttle position sensor terminals.

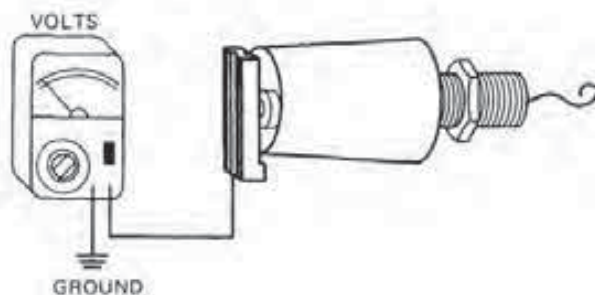


FIGURE 9-37
Testing throttle position sensor operation with a voltmeter.

tions, loosen the locknut. Rotate the sensor counter-clockwise until the correct timing is reached, and then rotate another half turn. Tighten the locknut, shut the engine off, and remove the jumper wire.

8. If rotating the throttle position sensor has no effect on the timing, use the next procedure to test the sensor's serviceability.

Throttle Position Sensor Resistance Test

To check the serviceability of the throttle position sensor, measure the amount of its internal resistance by doing the following:

1. Remove the ten-pin connector from the spark control computer.

2. Touch the ohmmeter leads to Terminals 8 and 9 inside the connector (Fig. 9-35). Note the resistance.

3. If the resistance is not to specifications, remove the connector at the throttle position sensor. With the ohmmeter, test the resistance at the throttle position sensor terminals (Fig. 9-36). If the reading is now within specifications, repair or replace the wiring harness between the computer and the sensor.

4. If the resistance is still not within specifications, replace the throttle position sensor.

5. If the resistance was satisfactory, check the operation of the throttle position sensor with a voltmeter.

Throttle Position Sensor Operation

To check the serviceability of the throttle position sensor, determine its operating voltage at the terminals by doing the following:

1. Make sure all wiring harness connectors are correctly attached.

2. Turn the ignition switch to the RUN position, but do not start the engine.

3. Attach the negative (-) terminal of the voltmeter to ground.

4. Connect the positive (+) terminal of the voltmeter to one terminal of the throttle position sensor (Fig. 9-37). Do not disconnect the sensor from its wiring harness.

5. Watch the voltage readings as you open the throttle lever fully and then close it.

6. There should be a two-volt change at the terminal when the throttle opens and closes. If the voltage does not change, run the same test on the other sensor terminal. If the voltage change still does not occur, replace the throttle position sensor.

Coolant Temperature Sensor Resistance Test

To accurately measure the resistance of the coolant sensor, it must be tested with the engine both cold and hot. To make this check, do the following:

1. Disconnect the wiring from the sensor.

2. Connect one ohmmeter lead to a good ground (Fig. 9-38).

3. Touch the other ohmmeter lead to the terminal of the sensor that normally attaches to the black wire. Note the resistance against the cold sensor specifications.

4. Start and run the engine until it reaches normal operating temperature.

5. Again touch the ohmmeter lead to the terminal on the sensor that connects to the black wire. Note the resistance against the hot sensor specifications.

6. If the readings do not match the cold and hot specifications, replace the sensor.

7. If the sensor is serviceable and the spark advance is still not functioning according to specifications, replace the computer.

9-5 TESTING AN EFI SPARK CONTROL SYSTEM

The testing sequence presented below is for an engine no-start condition. The main difference between this test and the one previously provided is that it requires the use of a diagnostic readout box. As mentioned earlier, the readout box is used to show stored computer fault codes for problem diagnoses. However, its use in the sequence presented here will be limited to just initiating an ignition system test sequence and diagnosing its fault codes. Further use of this tool for fault code diagnosis of fuel and emission control systems is covered in a later chapter.

Step 1—Initial Setup and Test Sequence

If the engine will not start, install the readout box and run the ignition test sequence by doing the following:

1. Connect the readout box to the diagnostic connector located in the engine compartment near the right-side strut tower (Fig. 9-39).
2. Remove the cable from any spark plug and connect it to a spark tester.
3. While observing the tester, have an assistant crank the engine over.
4. If there is no spark, remove the coil's high

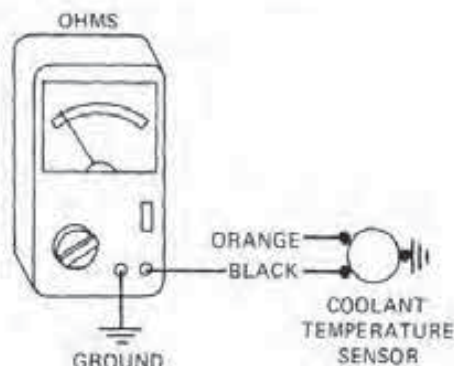


FIGURE 9-38
Testing the resistance of a coolant temperature sensor.

tension wire from the distributor and connect it to the spark tester.

5. While observing the spark tester, press in the actuator test mode (ATM) button until Test Code 01 appears on the readout window.

6. Release the button. Three arcs should be produced at the spark tester. If these arcs do not appear, remove the coil's high tension cable and check its resistance with an ohmmeter.

7. If the cable resistance is satisfactory, position the READ/HOLD switch on the readout box in the READ position.

8. Turn the ignition switch on-off, on-off, and on within five seconds. Read and record all fault codes.

9. If the readout window displays the codes 88, 12, 55, go to Step 2.

10. If the readout window shows codes 88, 43, 55, proceed to Step 6.

11. Turn the ignition switch off.

Step 2—Checking the Voltage to the Ignition Coil Positive Terminal

To check the voltage from the power module to the coil (+) terminal, do the following:

1. Attach one voltmeter lead to ground.
2. Connect the other voltmeter lead to the primary (+) terminal (Fig. 9-40). Turn the ignition switch on.
3. Push in the ATM button until Test Code 01 appears in the readout window. Release the button.

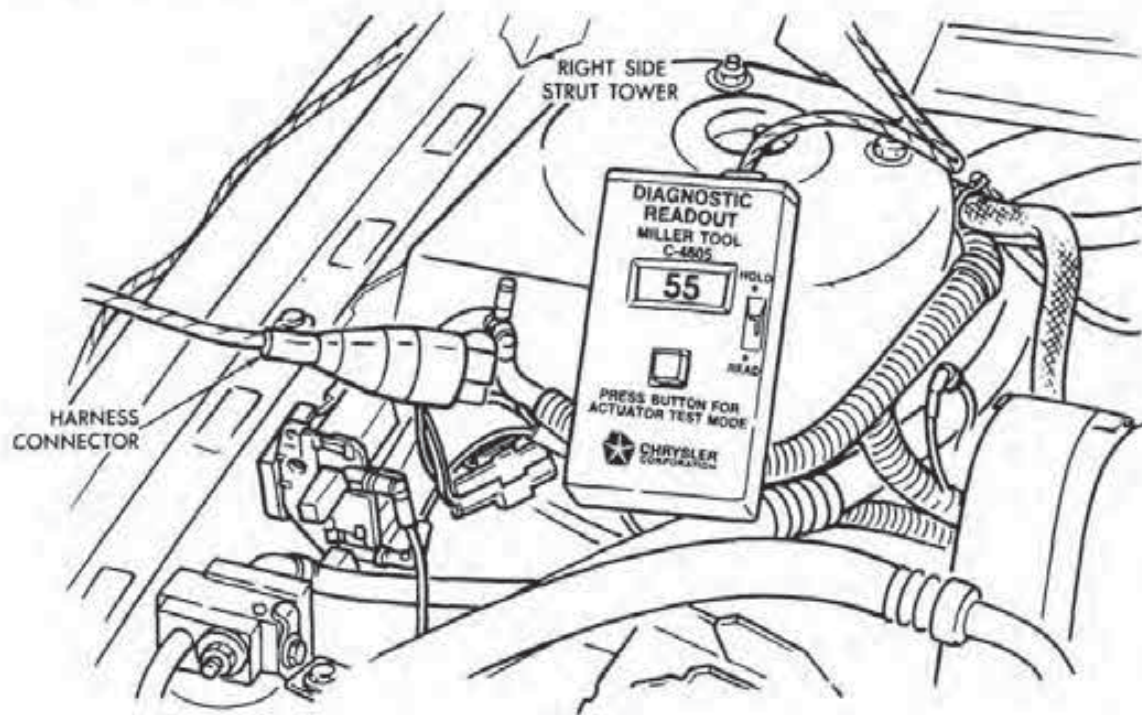


FIGURE 9-39
Installing the readout box. (Courtesy of Chrysler Motors Corp.)

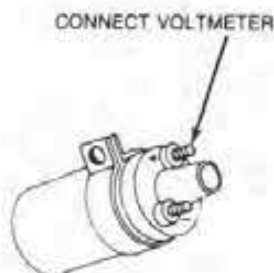


FIGURE 9-40
Testing the voltage to the coil (+) terminal. (Courtesy of Chrysler Motors Corp.)

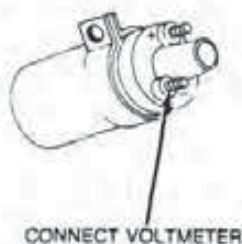


FIGURE 9-41
Checking the voltage to the coil (-) terminal. (Courtesy of Chrysler Motors Corp.)

The logic module will turn the ignition circuit on and off at two-second intervals for five minutes as long as the ignition switch is on.

4. Note the voltmeter reading. If the pulsating reading is within one volt of battery voltage, proceed to Step 3.

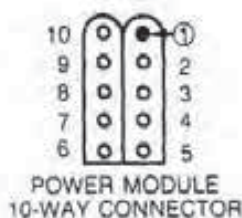
5. If the meter reads zero volts, check the wire to the power module for an open circuit. Repair or replace the wire as necessary.

6. Turn the ignition switch off.

Step 3—Testing the Voltage at the Coil Negative Terminal

To test the voltage at the coil (-) terminal against specifications, do the following:

1. Attach one voltmeter lead to ground.
2. Connect the other voltmeter lead to the (-) coil terminal (Fig. 9-41).
3. Turn the ignition switch on.
4. Push in the ATM button until Code 01 appears in the readout window; release the button.

**FIGURE 9-42**

Testing the coil (-) wire for continuity. [Courtesy of Chrysler Motors Corp.]

5. Read the pulsating voltage on the meter; it should be one volt to three volts.
6. If the voltage is okay, replace the coil.
7. If the reading is within one volt of battery voltage, proceed to Step 4.
8. If the reading is from zero volts to one volt, go to Step 5.
9. Turn off the ignition switch.

Step 4—Checking the Ignition Coil Wire for an Opening

To check the continuity of the (-) coil wire to the power module, do the following:

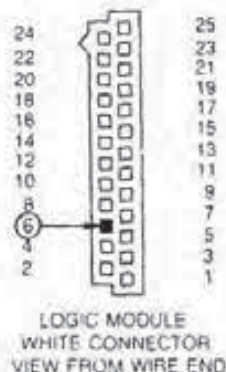
1. Unplug the ten-way connector from the power module.
2. Connect one ohmmeter lead to the (-) coil terminal.
3. Touch the other ohmmeter lead to Cavity 1 of the ten-way connector (Fig. 9-42). Note the reading on the ohmmeter.
4. If the meter shows continuity, replace the power module.

Caution: Before replacing the power module, make sure the terminals in Cavity 1 are not so spread apart they cannot touch the power module pins.

5. If the meter indicates no continuity, repair the Cavity 1 wire for an open circuit.

Step 5—Testing the Ignition Coil Control Wire for a Short

To determine if there is a short to ground in the (-) coil wire to the power module, do the following:

**FIGURE 9-43**

Checking the logic module spark control circuit. [Courtesy of Chrysler Motors Corp.]

1. Disconnect the wire from the (-) side of the coil.
2. Connect one voltmeter lead to ground.
3. Attach the other voltmeter lead to the (-) coil terminal.
4. Turn the ignition switch on.
5. Push in the ATM button until Code 01 appears on the readout window. Release the button.
6. Read the voltage on the meter. It should be pulsating and within one volt of total battery voltage.
7. If the voltage is satisfactory, check the ignition coil to the power module's Cavity 1 circuit for a short to ground. If the wire is not shorted, replace the power module.
8. If the voltage is not okay, replace the ignition coil.
9. Turn the ignition switch off.

Step 6—Checking the Spark Control Circuit

To test the spark control circuitry of the logic module, do the following:

1. Disconnect the coil's high tension cable from the distributor and attach it to a spark tester.
2. Unplug the white connector from the logic module, and connect one end of a jumper lead to Cavity 6 (Fig. 9-43).
3. Turn the ignition switch on.

4. Push in the ATM button until Code 01 appears on the readout window. Release the button.

5. While observing the spark tester, touch the other end of the jumper lead to a good engine ground. Make and break this connection several times. There should be an arc at the spark tester as you make and break the connection.

6. If the spark is satisfactory, replace the logic module.

Caution: Before replacing the logic module, make sure the terminal in Cavity 6 is not crushed so that it cannot contact the logic module pin.

7. If there was no spark, proceed to Step 7.

8. Turn the ignition switch off.

9. Reconnect the coil's high tension wire to the distributor.

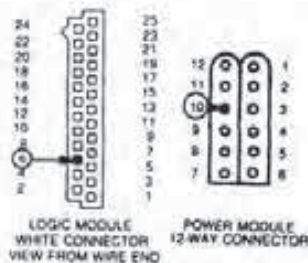


FIGURE 9-44

Testing the spark control wire for continuity. (Courtesy of Chrysler Motors Corp.)

Step 7—Testing the Spark Control Wire

To check the continuity of the spark control wire, do the following:

1. Remove the jumper wire from Cavity 6 of the white logic module connector.

2. Unplug the power module 12-way connector.

3. Attach one ohmmeter lead to Cavity 6 of the white logic module connector (Fig. 9-44).

4. Touch the other ohmmeter lead to Cavity 10 of the 12-way connector.

5. Check the ohmmeter reading; it should show continuity.

6. If there is continuity, replace the power module.

Caution: Before replacing the power module, make sure the terminals in Cavity 10 are not so spread apart they cannot touch the power module pin.

7. If there is no continuity, repair the wire from Cavity 10 of the 12-way connector to Cavity 6 of the logic module connector.

8. Plug in both the logic and power module connectors.

CHAPTER REVIEW

The following two sections will assist you in determining how well you remember the material contained in this chapter. If you cannot complete the statement or questions, refer back to the section marked in brackets that covers the material.

SELF-CHECK

1. Explain the two functions of the diagnostic readout box with regard to ignition system testing [9-5].
2. For what reasons must you always follow the general precautions for working on ignition systems before testing a malfunctioning ignition system [9-1]?

3. Describe how to quickly determine if the spark control computer is the cause of no secondary voltage output [9-4].
4. Describe the color of the spark produced during a secondary voltage output check [9-2].
5. Explain how to perform a secondary voltage test on an electronic ignition system (EIS) and a Hall-effect EIS [9-3].

REVIEW

1. A vehicle with an electronic fuel injected, electronic spark control system will not start, and testing indicates there is no power to the coil.

- What can be the cause of the problem [9-5]?
 a. defective logic module
 b. defective power module
 c. defective starter relay
 d. defective starter relay harness
2. If the timing specifications are different on the emission label and in a service manual, which should you use [9-1]?
 Technician A says the service manual.
 Technician B replies the emission label.
 Who is correct?
 a. A only
 b. B only
 c. both a and b
 d. neither a nor b
3. The ATM button on the diagnostic readout box has what function(s) [9-5]?
 Technician A states it initiates a test sequence.
 Technician B says it initiates the fault codes.
 Who is correct?
 a. A only
 b. B only
 c. both a and b
 d. neither a nor b
4. The first step in troubleshooting a malfunctioning ignition system is to [9-1]:
 Technician A replies to check for loose or corroded connections.
 Technician B states to check the battery state of charge.
 Who is correct?
 a. A only
 b. B only
 c. both a and b
 d. neither a nor b
5. To use the readout box on the electronic fuel injected, electronic spark control system, plug its connector into the matching diagnostic connector located [9-5]
 a. on the right-side of the passenger compartment.
 b. on the right-side of the engine compartment near the strut tower.
 c. both a and b.
 d. neither a nor b.
6. An electronic lean burn (ELB) coolant sensor is checked by attaching the ohmmeter leads to what connection points [9-4]?
 Technician A replies the orange and black wire terminals.
 Technician B states the orange terminal and ground.
 Who is correct?
 a. A only
 b. B only
 c. both a and b
 d. neither a nor b
7. What must be done before measuring primary and secondary coil winding resistance [9-2]?
 a. Both primary wires must be removed.
 b. The coil's high tension wire must be removed.
 c. both a and b
 d. neither a nor b
8. To check the serviceability of an ELB throttle position sensor, use a [9-4]
 a. voltmeter.
 b. ohmmeter.
 c. diagnostic readout box.
 d. both a and b.
9. When performing the electronic ignition system, electronic control unit (ECU) harness cavity checks, all readings must be within how much of battery voltage [9-2]?
 Technician A replies two volts.
 Technician B says six volts.
 Who is correct?
 a. A only
 b. B only
 c. both a and b
 d. neither a nor b
10. The ELB resistor requires how many resistance tests [9-4]?
 Technician A states one.
 Technician B says two.
 Who is correct?
 a. A only
 b. B only
 c. both a and b
 d. neither a nor b
11. The scope pattern for the pickup coil-type EIS system is missing what kind of section [9-2]?
 a. firing
 b. intermediate
 c. dwell
 d. spark
12. To perform a shutter ground check, use a (an) [9-3]
 a. ohmmeter.
 b. voltmeter.
 c. scope.
 d. ammeter.

13. The Hall-effect ECU has lost its ground. Where should you look for the cause of the problem [9-3]?
Technician A says at its mounting.
Technician B states inside the distributor.
Who is correct?
a. A only
b. B only
c. both a and b
d. neither a nor b
14. Reluctor teeth should have what kind of corners [9-1]?
a. round
b. square
c. pointed
d. sharp
15. If an engine will not start, which test do you perform first [9-3]?
a. pickup coil resistance
b. secondary voltage test
c. shutter ground test
d. ECU ground test

Chapter 10

GENERAL MOTORS ELECTRONIC IGNITION SYSTEMS

OBJECTIVES

After reading and studying this chapter, you will be able to

- explain the basic design of a high energy ignition (HEI) system.
- describe the operation of a distributor pulse generator.
- explain the function and design of an electronic spark timing (EST) system.
- describe the operation of an EST system.
- explain the function and design of an electronic spark control (ESC) system.
- describe the operation of an ESC system.
- explain the basic design of the distributorless ignition system (DIS).
- describe the operation of the DIS.

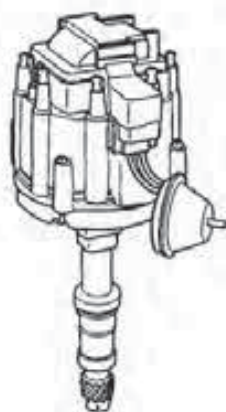


FIGURE 10-1
HEI distributor. (Courtesy of General Motors Corp.)

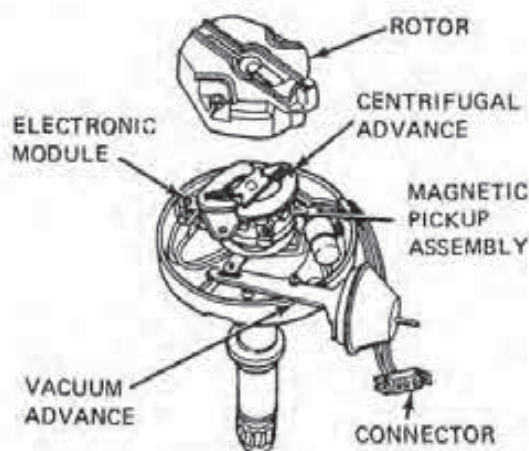


FIGURE 10-2
Lower housing components. (Courtesy of General Motors Corp.)

Before 1974, General Motors used three different types of electronic ignition systems as optional equipment. All of these systems (magnetic impulse ignition, capacitor discharge ignition, and unit ignition) improved engine performance and reduced the amount of system preventive maintenance. These systems are magnetically triggered, thereby eliminating contact points.

In early 1974, General Motors introduced the high energy ignition (HEI) system as optional equipment. By 1975, this system became standard equipment on all automobiles.

The HEI system provides a number of benefits over both the conventional contact point and early electronic systems. First, HEI requires no scheduled maintenance, so it meets the emission regulations dictating 50,000 miles of operation without a reduction in spark energy. Second, the system has up to 40 percent more voltage output and an 85 percent

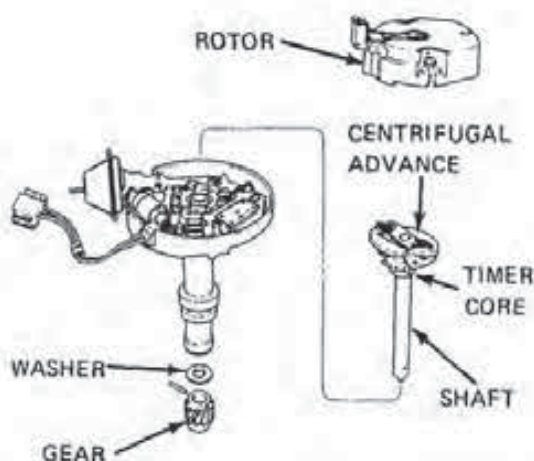


FIGURE 10-3
Distributor shaft assembly. (Courtesy of General Motors Corp.)

higher energy level than a contact point system. As a result, HEI produces up to 35,000 volts to ignite the lean air/fuel mixture of emission-controlled engines, even under the most adverse conditions. Finally, the higher voltage increases the useful life of spark plugs, especially when unleaded fuel is used.

10-1 DESIGN AND OPERATION OF THE HEI SYSTEM

The high energy ignition (HEI) system includes basically the same components as any conventional contact point system, including the battery, coil, ignition switch, and distributor. However, the physical arrangement and design of many of these parts have changed. For instance, this system does not require a resistance wire from the ignition switch to the coil, and there is only one wire from the distributor to the ignition switch. By and large, the major design change in the system is the distributor itself.

Distributor Design

In the HEI system, the ignition coil can be included within the distributor assembly rather than as a separate component (Fig. 10-1). The distributor is also larger to make room, in some models, for the coil and to prevent high-voltage arc over. Moreover, an integral pulse generator (magnetic pickup assembly) and control module more efficiently take the place of the conventional contact points.

Like a conventional distributor, the HEI unit contains two major assemblies, the lower housing

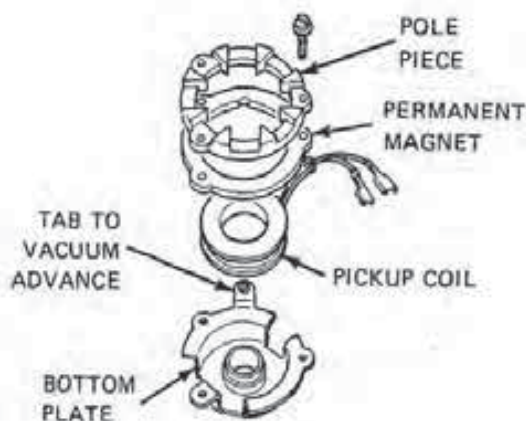


FIGURE 10-4
Design of the pulse generator. (Courtesy of General Motors Corp.)

and distributor cap. The lower housing assembly consists of the rotor, distributor shaft, magnetic pickup assembly, electronic module, centrifugal advance mechanism, vacuum advance unit, connector, and lower housing (Fig. 10-2). The rotor mounts by two screws to the centrifugal advance mechanism on top of the distributor drive shaft. In a similar manner as the rotor in a conventional system, this unit supplies secondary voltage from the coil to the distributor cap electrodes.

Figure 10-3 illustrates the components of the distributor shaft assembly. These include the shaft, gear, timer core, centrifugal advance assembly, and rotor.

The *timer core* is located on the distributor shaft where the breaker cam of a conventional system would normally be. In this location, the core rotates inside the magnetic pickup assembly. Also, the timer core incorporates the same number of teeth as the pole piece. These teeth provide a path for the magnetic field from the permanent magnet within the pulse generator.

Magnetic Pickup and Pole Piece

The *magnetic pickup and pole piece (the pulse generator)* produce a timed electrical pulse that is used by the switching transistor in the module to close and open the primary coil circuit. The assembly consists of a bottom plate, pickup coil, permanent magnet, and pole piece (Fig. 10-4). The bottom plate fits over a bushing that is installed in the distributor housing.

The *pickup coil* rests in a formed pocket within the bottom plate. The transistor triggering signal is induced in this unit by the changing magnetic field

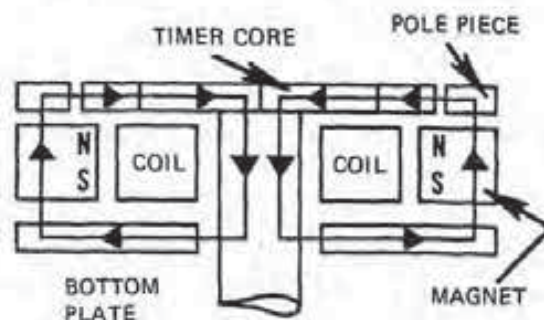


FIGURE 10-5
Magnetic circuit within the pickup coil assembly. (Courtesy of General Motors Corp.)

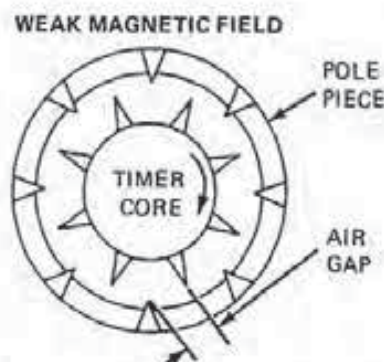


FIGURE 10-6
When the core and pole piece teeth are not in alignment, the magnetic field is weak. (Courtesy of General Motors Corp.)

from the permanent magnet. The coil itself consists of a number of turns of fine, insulated wire, the ends of which attach to external harness connectors.

The pickup coil is sandwiched between a permanent magnet and the pole piece. The pole piece has a number of internal teeth, one for each cylinder of the engine. This assembly is then held in place by three screws that thread into the bottom plate.

Pulse Generator Operation

To understand how the pickup coil produces a pulse signal to the module, let's first examine the basic magnetic circuit and then see the influence on the field from the timer core (Fig. 10-5). In the pickup assembly, the permanent magnet provides a magnetic field that flows from the attached pole piece teeth, through the timer core teeth, and back to the permanent magnet. This field can pass through the pickup coil.

If the timer core and pole piece teeth are not aligned, the magnetic field strength is weak (Fig. 10-6). This is due to the enlarged area between the

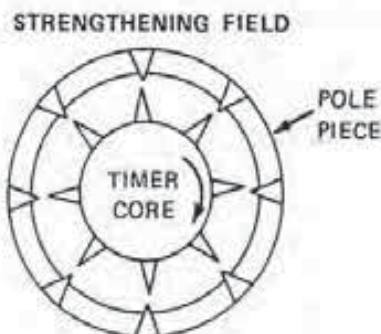


FIGURE 10-7
The magnetic field strength increases as the teeth move into alignment. (Courtesy of General Motors Corp.)

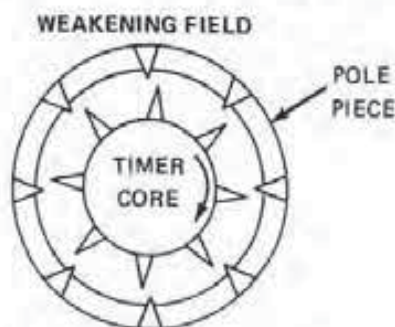


FIGURE 10-8
The magnetic field collapses as the teeth separate. (Courtesy of General Motors Corp.)

timer core and pole piece teeth, which produces a poor path for the magnetic lines of force.

When the timer core teeth approach alignment with those on the pole piece, the air gap becomes smaller (Fig. 10-7). As a result, the magnetic field becomes stronger. The increased field passes through the pickup coil and induces a positive voltage in the pickup coil in proportion to its strength. The positive signal is directed to the module to close the primary coil circuit.

The field strength continues to induce the positive voltage in the pickup coil until the teeth of the pole piece and timer core are in alignment. At this point, the magnetic field no longer is changing and the pickup coil voltage drops to positive zero. This positive zero signal is sent to the module and opens the primary coil circuit.

As soon as the timer core teeth pass those on the timer core, the air gap starts to increase (Fig. 10-8). As a result, the magnetic field collapses through the pickup coil. This action induces a voltage in the pickup coil that is negative in polarity.

The timer core, which turns with the distributor shaft, and the pole piece have the same number of teeth as the engine has cylinders. In the discus-

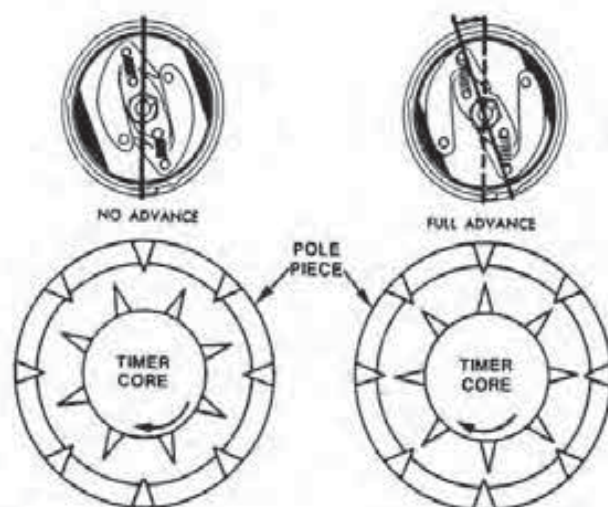


FIGURE 10-9
Centrifugal advance. (Courtesy of General Motors Corp.)

sion so far, the distributor used is for a V-8 engine. Therefore, the timer core teeth align with those of the pole piece eight times for each rotation of the distributor shaft. As a result, the pickup coil produces eight timed AC voltage pulses to the module.

Centrifugal Advance

As mentioned, the HEI distributor has a *centrifugal advance mechanism* that operates above the timer core. This mechanism operates in much the same way as on the conventional contact point distributor.

In operation, the centrifugal advance weights move against spring tension as engine speed increases. The motion of the weights turns the timer core so that it rotates in the direction of the distributor shaft (Fig. 10-9). Consequently, the teeth of both the timer core and pole piece align sooner, signaling the module to advance the opening of the coil primary circuit. This, of course, has the effect of firing the air/fuel charge earlier in the engine cycle.

Vacuum Advance

The *vacuum advance assembly* bolts onto the outside of the lower distributor housing (see Fig. 10-3). This unit uses engine vacuum to move a spring-loaded diaphragm, which connects by a rod to a tab on the bottom plate of the pickup assembly (see Fig. 10-4). The pickup assembly mounts over the main bearing on the distributor housing, so it is able to rotate.

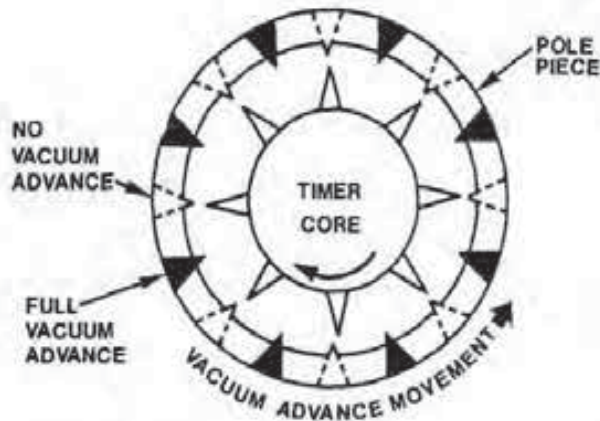


FIGURE 10-10
Vacuum advance. (Courtesy of General Motors Corp.)

Whenever a vacuum signal applies itself to the diaphragm, it, in turn, moves against spring pressure, pulling on the connecting rod. This movement causes the pickup assembly with its integral pole piece to rotate in an opposite direction from the distributor shaft and timer core (Fig. 10-10). As a result, the pole piece and timer core teeth align sooner, signaling the module to shut off primary coil current flow. This has the effect of firing the air/fuel charge earlier in the engine cycle.

Electronic Module

The *electronic module* has four terminals and bolts inside the lower distributor housing next to the magnetic pickup assembly (see Figs. 10-2 and 10-11). The module is responsible for actually closing and opening the primary coil circuit in response to signals from the pickup coil assembly. The module contains a microminiature electronic circuit with components so small that they cannot be seen even with a magnifying glass.

The module has no serviceable components and requires replacement when defective. When replacement is necessary, a special compound is required on the base of the module for proper heat transfer.

Module Signal

As mentioned, the pickup coil produces an AC signal to the module. The HEI electronic module is like any other microprocessor; that is, it will not function with alternating current. Therefore, the module contains a signal converter that changes the AC voltage to direct current (DC) that has a square wave (Fig. 10-12). The square wave DC signals are fed to the

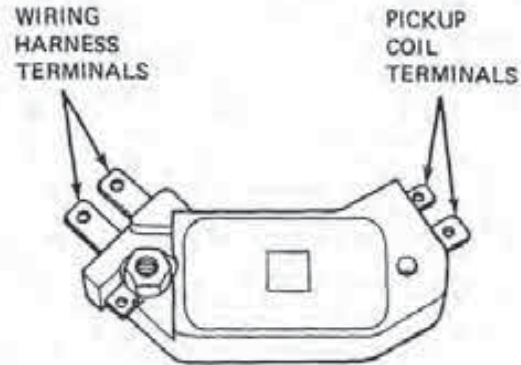


FIGURE 10-11
Electronic module. (Courtesy of General Motors Corp.)

base circuit of the switching transistor to turn it and the ignition coil primary circuit either on or off.

Module Current-Limiting Circuit

In earlier systems, the transistor operated at a value less than its maximum capacity for protection from transient voltage and current extremes found in automobile circuitry. These extremes are usually of short duration but have great magnitude. Electro-mechanical devices such as switches, motors, and contacts can withstand these conditions without permanent damage.

However, transistors, if subjected to exposure to voltage and current above their maximum capability, will fail in a few milliseconds. The earlier systems had enough resistance so that the extremes mentioned above will always be within the capabilities of the electronic devices used to avoid failures. But this is the reason why there was no available secondary voltage gain in these systems.

To safely raise secondary voltage without damaging electronic components, the HEI module has a current-limiting circuit. Rather than using an external resistance wire, as mentioned earlier, the circuit itself limits primary current to 5.5 amperes. This allows the switching transistors to operate at their maximum value.

Dwell Control Circuit

For any ignition coil to produce its maximum secondary voltage, the primary current flow must reach its highest design value before the circuit is broken. In the contact point system, the length of time primary current flows is under the control of the breaker cam within the distributor. When the cam allows the points to close, primary current can flow.

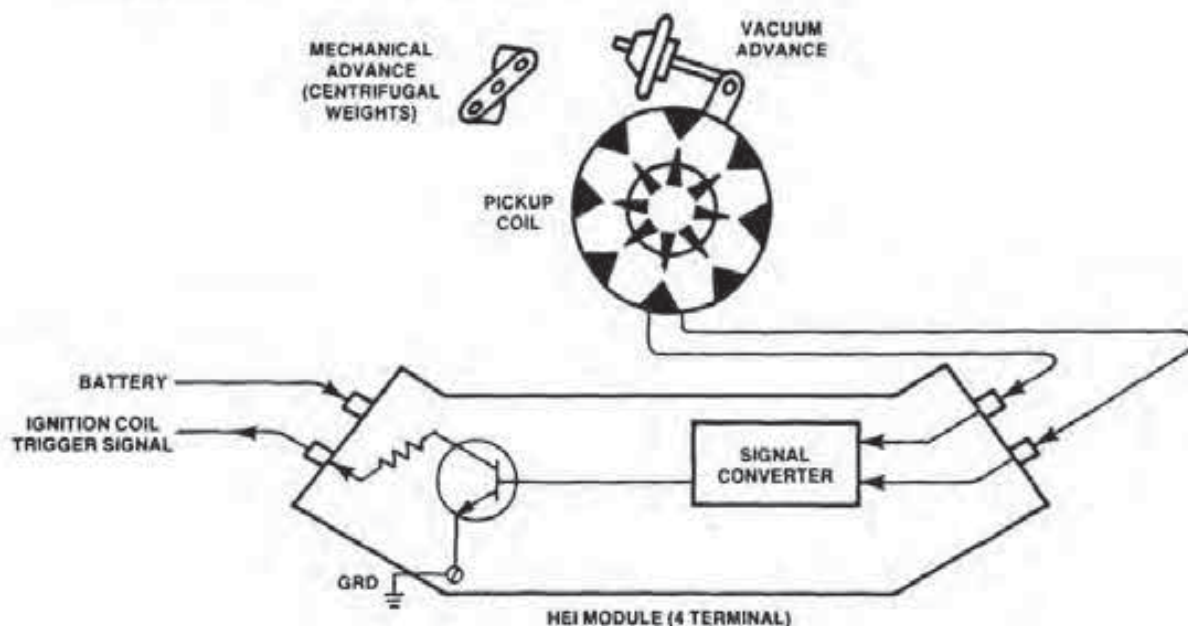


FIGURE 10-12
HEI schematic. [Courtesy of General Motors Corp.]

The period the points are closed is called *dwell* and is measured in the number of degrees of distributor shaft rotation. Most V-8 engines have a dwell of about 30 degrees before the points open to break the primary current flow. This dwell period remains unchanged regardless of engine speed. However, as engine speed increases, the period of time the points are closed decreases. This causes the secondary available voltage to decrease due to the reduction in magnetic field saturation time of the primary coil.

When the contact points close, the primary current does not instantaneously reach a value of 4.0 amperes due to self-induction of counter voltage in the windings. Thus, it takes several milliseconds for this value to be reached (Fig. 10-13).

At 1,000 engine rpm, the distributor shaft turns once every 0.12 second. During this time, the points are closed for 0.010 second (10 milliseconds) for every cylinder of the V-8 engine. As shown in the illustration, this is sufficient time for the primary current flow to build up to its maximum of just over 4.0 amperes.

However, as the engine speed goes up, the current flow time decreases. For instance, when engine speed increases to 2,000 rpm, the point-closed time for each saturation period is reduced to 5.0 milliseconds. This period only allows the primary current to build to 3.8 amperes. At 3,000 rpm, the saturation time drops to 3.3 milliseconds and the current flow to 3.2 amperes. As a result, the secondary available voltage begins to decay with reductions in time be-

cause there is insufficient current flow to cause complete magnetic saturation.

The HEI has two features that allow it to provide higher available voltage levels at high engine speeds. First, by lowering the resistance in the primary coil circuit, the time period necessary for the current to reach a maximum value is reduced (see Fig. 10-13). As shown in Fig. 10-13, it takes 10 milliseconds for the current to reach a maximum value in a coil that has a resistance of 2.6 ohms. But the HEI primary windings have a resistance of 0.5 ohm. This permits full current flow to be achieved in about 3.4 milliseconds.

Because it does take less time to reach maximum primary circuit current flow, magnetic saturation is obtainable at much higher engine speeds. But since the current flow is much higher in the HEI system, heat generation must be controlled to protect the module. This is done through the use of a dwell control circuit within the module.

The *dwell control circuit* electronically senses the primary current flow to see if it reached its maximum during the last dwell period. If maximum current flow did occur, the circuit provides no current reduction, and the dwell period remains the same.

If current flow becomes too high, such as at low engine speeds, the dwell period is shortened by turning on the primary current flow later. Since the turning off of the circuit is always at the same time, the dwell period has to be shorter.

If, on the other hand, maximum current does

not flow, as can occur at higher engine rpm, the primary circuit is turned on sooner. This results in a greater dwell period. Consequently, the HEI system is able to put out 35,000 volts to speeds above 3,000 rpm, while a conventional contact point system reaches its maximum available voltage at about 1,000 rpm and then begins to decay.

Finally, by using this dwell control to reduce the time current is flowing, system temperature is lower. This increases the reliability of the HEI system, in general, and the life of the module, in particular.

Ignition Coil

The design and construction of the coil also affect the system's operation. The HEI coil has a low primary resistance and a size and shape so that it may be mounted in the distributor cap (Fig. 10-14). Resistance is decreased by reducing the length of wire used in the primary windings. By reducing the length of the wire used, low resistance is possible with a reasonable wire diameter.

In the oil-filled ignition coil used with the conventional system, the primary winding is wrapped around the secondary, which in turn is wound around the iron core (see Fig. 10-14). The HEI coil has the secondary winding wound around the primary and both are then wrapped over the iron core.

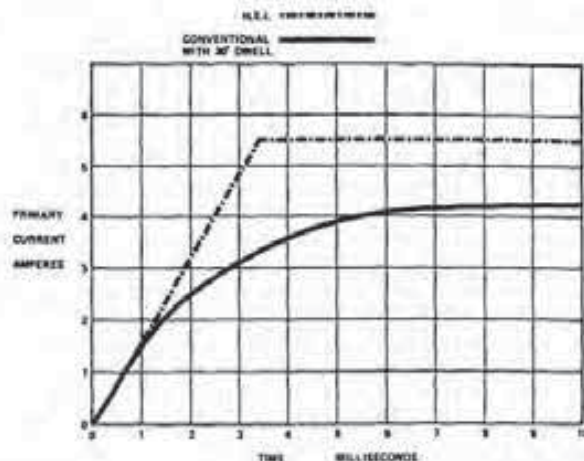


FIGURE 10-13 Primary current flow versus time. (Courtesy of General Motors Corp.)

Moreover, the HEI coil is not oil-filled. Instead, its windings are covered with an epoxy compound for protection against moisture and arc over within the coil.

Another influence of less resistance in the HEI coil primary is the reduction of the inductance values of that coil. The *inductance (self-induction)* of a coil is its ability to induce a counter voltage while carrying an increasing or decreasing primary current. The counter voltage works against flow by trying to keep the current flow value in the wire from

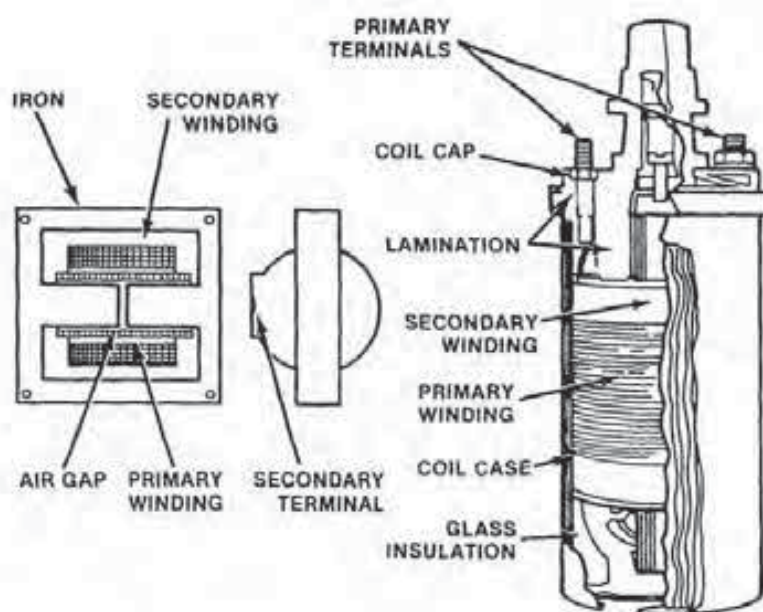


FIGURE 10-14 Conventional and HEI coil construction. (Courtesy of General Motors Corp.)

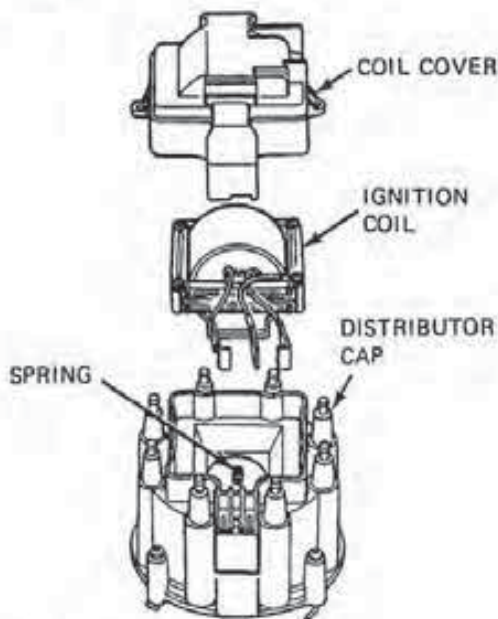


FIGURE 10-15
Distributor cap assembly. [Courtesy of General Motors Corp.]

changing. This slows up the saturation time and therefore limits the maximum secondary output of the coil.

Thus, by reducing primary inductance, secondary induced voltage is higher. This increases the spark duration over that found in a conventional system.

The HEI system was developed for use as an integrated unit that combines the distributor, magnetic pickup, ignition coil, and electronic module. This was done for two reasons. First, these parts are well protected from physical and environmental abuses. Second, the compact package reduces the number of electrical connections.

However, there are some HEI models that use a remotely mounted coil. This coil has the same construction as the integral type with the exception of a mounting bracket and a terminal for the high tension cable. This configuration is used on most in-line engines where additional distributor-to-hood clearance is necessary.

Distributor Cap

The distributor cap assembly of the integral model consists of the cap, coil, and coil cover (Fig. 10-15). The cap itself has the connection posts for the ignition and spark plug wires along with the connector for the lower housing assembly.

The coil rests on a seal in the cap. A spring,

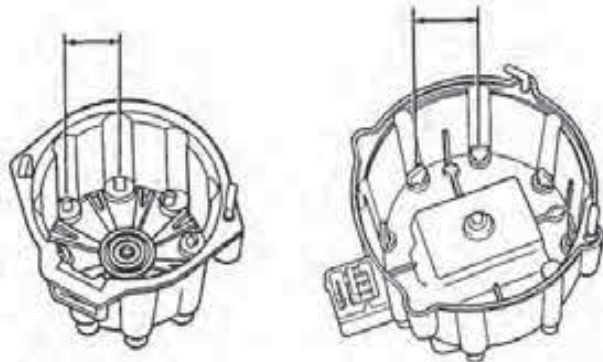


FIGURE 10-16
HEI plug electrode spacing. [Courtesy of General Motors Corp.]

which passes through a hole in the seal, connects the high voltage coil secondary to the rotor contact in the cap. The cover protects the ignition coil from the effects of moisture and dust.

The HEI distributor cap is larger than the conventional unit (Fig. 10-16). This is due to the wide spacing that must exist between the electrode inserts to prevent high-voltage arc over between adjacent terminals and to ground via the distributor housing.

The higher voltage output of the HEI system requires that new insulation material be used for the cap and rotor to prevent carbon tracking and voltage arc over. The material used is a thermoplastic, injection-molded, glass-reinforced polyester that provides the dielectric and insulation properties needed.

The HEI distributor cap also uses new high voltage terminals. They are similar in appearance to spark plug terminals. These units provide easier attachment and better sealing for the plug wire connections. In addition, latches are used to ensure proper connection of the plug wires to the cap. The latches prevent any loosening or movement, which might reduce the moisture protection at the wire attaching point.

Spark Plug Wires

The spark plug wire used with HEI systems is *television radio suppression (TVRS)* wire with a carbon-impregnated cord conductor. The outer jacket is eight millimeters in diameter and is made of silicone rubber. This jacket material will withstand very high temperatures and is an excellent insulator for the higher voltages.

However, silicone is soft and very pliable; therefore, it is more susceptible to scuffing and cut-

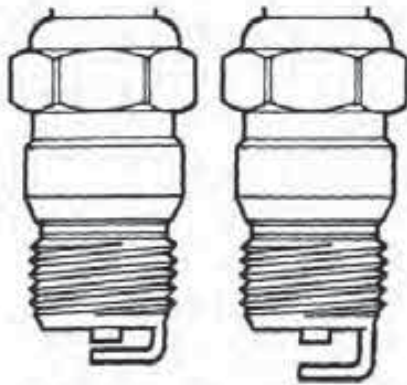


FIGURE 10-17
Conventional and wide gap spark plugs. (Courtesy of General Motors Corp.)

ting. For this reason, it is extremely important that the plug wires be handled with care. In addition, the cables must be routed so that they do not cross each other or are not in contact with other parts of the engine that might cause rubbing.

Spark Plugs

The HEI system is designed to use specially designed wide gap spark plugs (Fig. 10-17). These plugs have a longer side electrode. This design allows the proper configuration of the electrode at a 0.060-inch or 0.080-inch gap. Attempting to set a wide gap plug to 0.035 inch or a conventional plug to 0.060 inch could reduce spark plug efficiency and shorten its life.

HEI Models

There are two basic HEI distributor models used. The first has an ignition coil mounted within the distributor cap. This model is found on all V-8 and V-6 engines. The V-6 distributor differs in several ways from the V-8. For example, the V-6 distributor cap assembly has two less secondary wire terminals, and the six electrode inserts are unevenly spaced and have extended contacts on the inside of the assembly. These features are necessary to meet the requirements of the V-6's unique firing sequence, which is alternately at 45 degrees and 75 degrees.

Also necessary inside the distributor are a different timer core and pole piece (Fig. 10-18). The V-6 distributor has three evenly spaced teeth on the timer core and six alternately spaced teeth at 45 degrees and 75 degrees on the pole piece. (Remember the V-8 has a pole piece and timer core with the same number of teeth that are equally spaced.)

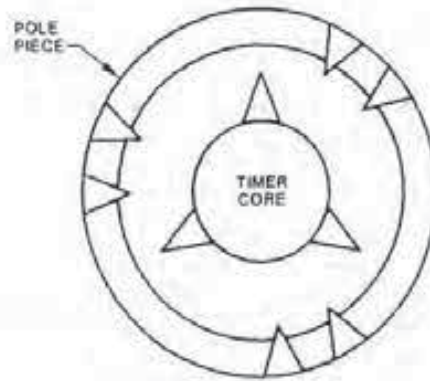


FIGURE 10-18
V-6 timer core and pole piece. (Courtesy of General Motors Corp.)

The second type of HEI distributor uses a remotely mounted coil that is similar in appearance to the one used with the integral coil (Fig. 10-19). Since the ignition coil is outside the distributor cap assembly, these units are slightly shorter than in the V-6 and V-8 models. Also, the external models require a few more wires to connect the coil to the distributor.

Inside these distributors, the number of teeth on the pole piece and timer core reflect the number of engine cylinders the unit is operating on. Therefore, a four-cylinder engine has four teeth on the pole piece and timer core, and a six-cylinder engine has six on each. In either case, the teeth are evenly spaced around the timer core and pole piece.

10-2 ELECTRONIC SPARK TIMING SYSTEM

Electronic spark timing (EST) systems have existed in different forms since 1977. EST is a microprocessor-controlled ignition system that electronically provides precise spark timing based on a number of engine operating conditions. The electronic spark timing, computer command control (CCC) version of the system is shown in Fig. 10-20. It consists of an HEI distributor and module, a number of sensors, and an EST electronic control module (ECM).

EST, HEI Distributor

The high energy ignition (HEI) distributor used with electronic spark timing (EST) resembles the integral unit described in the last section. However, the electronic spark timing HEI distributor does not

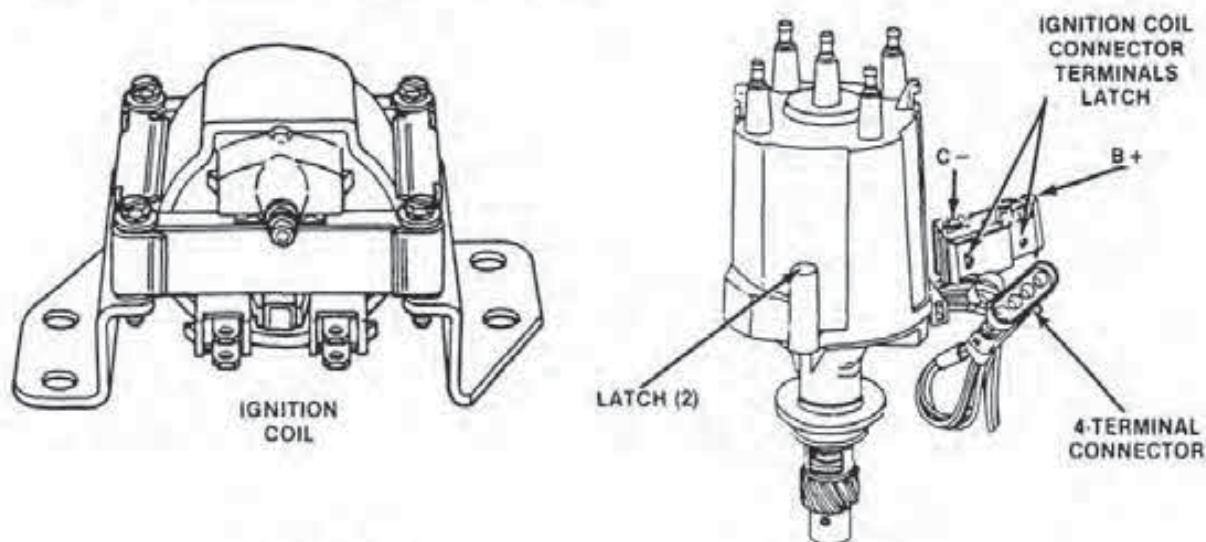


FIGURE 10-19
Remote coil and HEI distributor. (Courtesy of General Motors Corp.)

have vacuum or centrifugal advance mechanisms built in because the electronic control module now handles this function.

EST, HEI Electronic Ignition Module

The electronic spark timing HEI electronic ignition module performs the same function as its HEI counterpart discussed in the last section. The main difference between the two units is that the electronic spark timing HEI module has seven instead of four terminals.

Also notice in Fig. 10-20 what appears to be a relay with a double set of contact points in the HEI

module. Actually, there is no electromechanical relay; instead, solid state circuitry is used for the switching function. The relay is only shown to make it easier to visualize how the EST system operates.

Coolant Temperature Sensor

The *coolant temperature sensor* sends an electrical signal to the electronic control module (ECM) relating to engine temperature (Fig. 10-21). Along with other functions, the coolant sensor signal will be used by the ECM to vary the amount of spark advance according to engine operating temperature.

The coolant temperature sensor is a thermis-

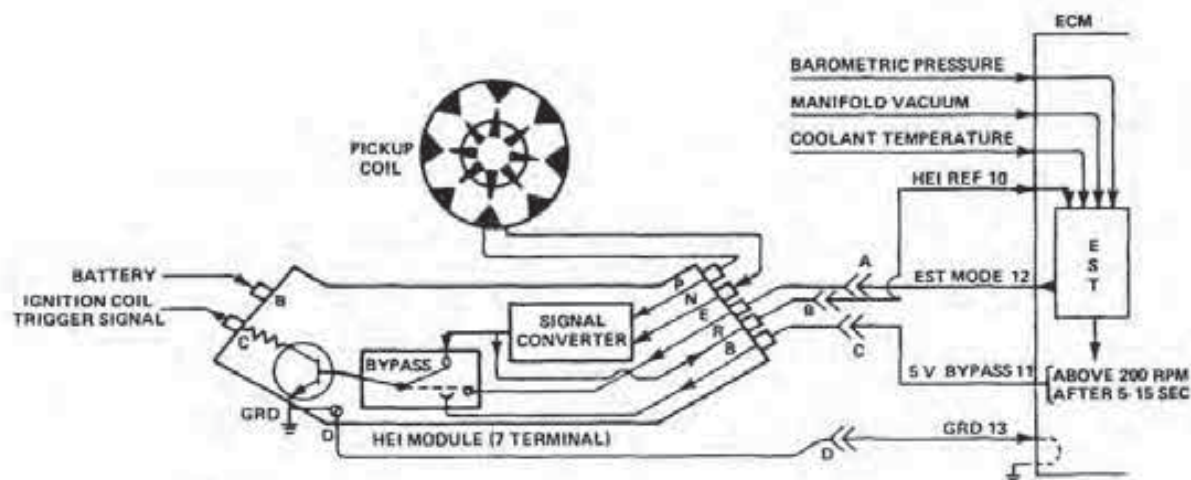


FIGURE 10-20
Electronic spark timing, computer command control schematic. (Courtesy of General Motors Corp.)

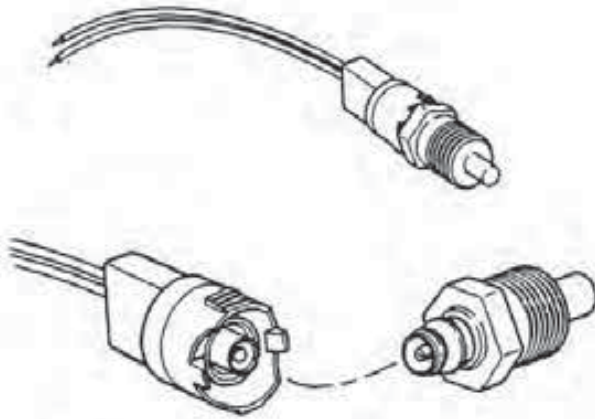


FIGURE 10-21
Coolant temperature sensor. (Courtesy of General Motors Corp.)

tor-type sensor that lowers its electrical resistance when coolant temperature increases. Likewise, the sensor's resistance raises as engine temperature decreases. As a result, the electrical output signal from the sensor varies with temperature.

Manifold Vacuum and Barometric Pressure Sensors

The barometric pressure and manifold vacuum sensors used in the electronic spark timing, computer command control system are the flexible resistor type (Fig. 10-22). That is, when the resistor is flexed, its resistance changes. As this occurs, the output signal varies from the sensor to the ECM. Pressure sensors are divided into two groups: absolute pressure and differential pressure sensors.

The *barometric (BARO)* sensor is the *absolute* type, which compares one pressure to a reference pressure or vacuum. The BARO compares both ambient and barometric pressures. The sensor then feeds a signal to the ECM based on ambient pressure changes due to altitude or weather. The signal voltage decreases with altitude but is not altered by the throttle opening.

Vacuum Sensor

The *vacuum sensor* is the *differential pressure* type in that the unit compares manifold pressure to atmospheric. The vacuum sensor is made like the absolute type with one exception. In the vacuum sensor, there is a pyrex tube located in the reference cavity that connects by a hose to the intake manifold. This design forms both vacuum and atmospheric refer-

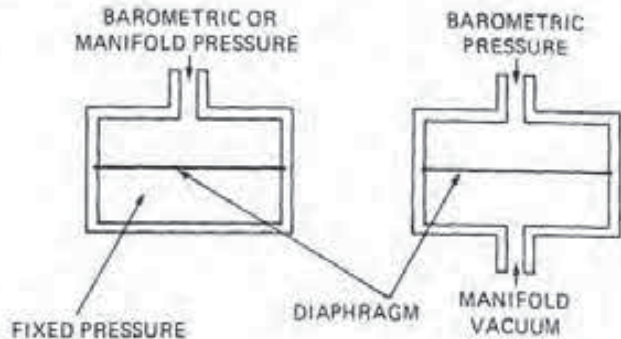


FIGURE 10-22
Pressure sensor design. (Courtesy of General Motors Corp.)

ence cavities for differential sensor applications.

As manifold pressure is applied to one side of the diaphragm, the diaphragm deflects due to the effect of atmospheric pressures. This causes the diffused resistors to change their values proportional to the difference in pressure between the two cavities. With this design, the sensor's output voltage increases as manifold pressure decreases, which is an indication of increased vacuum.

The voltage output signal of the sensor is five volts at closed throttle. But as the engine operates under varying load conditions, the signal to the ECM changes with manifold pressure. In this way, the ECM can determine the best timing advance under given engine load conditions.

Electronic Control Module

The *electronic control module (ECM)* is a reliable solid state computer that contains the electronic spark timing (EST) circuitry. The ECM monitors and controls the functions of the computer command control system, including electronic spark timing. The ECM is located in one of several places in the passenger compartment.

EST Operation During Engine Cranking

During engine cranking, the HEI relay (solid state switch) is in the de-energized position (Fig. 10-23). The HEI relay connects the pickup coil to the base of the transistor. When the pickup coil applies a positive voltage to the transistor base, the unit turns on; with a zero voltage, the transistor turns off.

With the transistor turned on, current flows

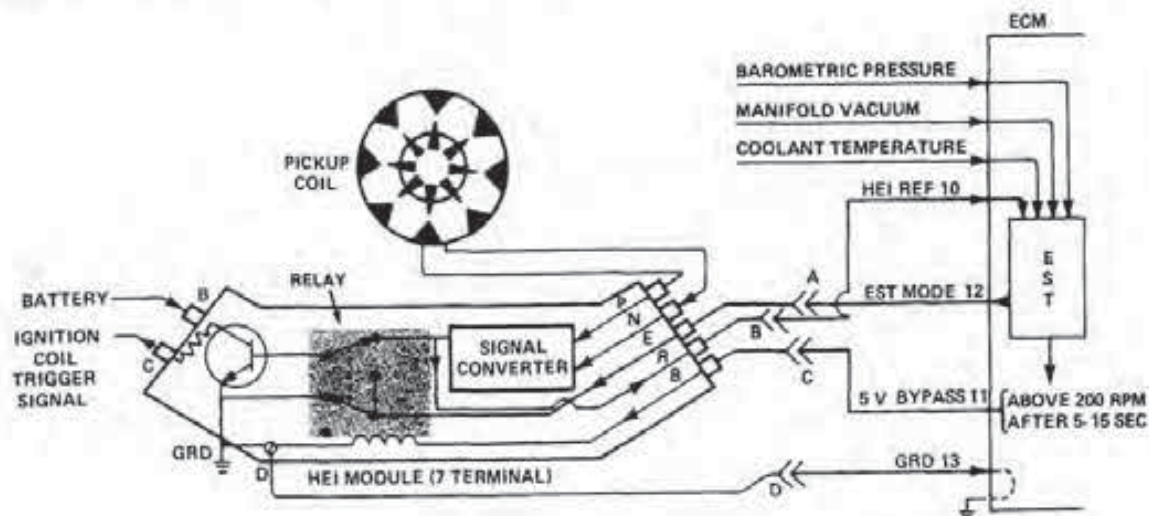


FIGURE 10-23
EST operation during engine cranking. (Courtesy of General Motors Corp.)

through the primary windings of the ignition coil. But when the transistor turns off, the primary current flow stops, and a spark occurs at the spark plug. This is called *module mode*. During this time, there is a small amount of timing advance that is built into the HEI module through a special circuit.

While the engine is cranking, the pickup coil delivers AC voltage to the signal converter in the HEI module. The converter changes the AC pickup coil signal to a DC square wave, so it can also be used by the ECM. This signal passes through HEI module Terminal R and on to the ECM as HEI reference voltage.

The ECM is capable of varying the time at

which it directs an electronic spark timing (EST) signal back to the HEI module via its Terminal E. However, during the module mode, the second set of contacts grounds the EST line.

EST Operation with the Engine Running

When the engine speed reaches a predetermined rpm (for our purposes, 200), the ECM considers it running. The ECM then applies a five-volt signal to the bypass Terminal B of the HEI module. The bypass voltage energizes the module relay (solid state switch). This action ungrounds the EST line and connects it to the base of the transistor, which also

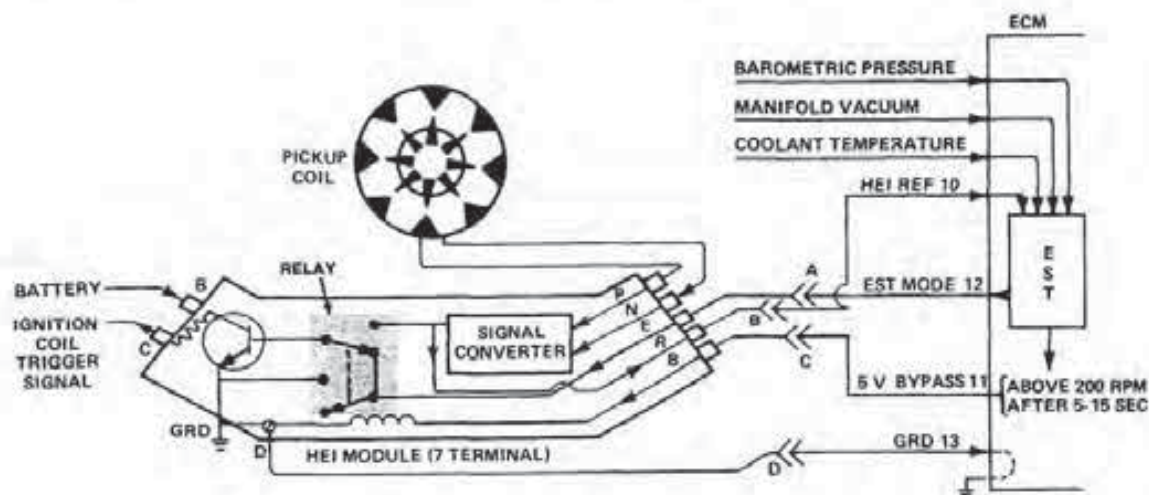


FIGURE 10-24
EST operation with the engine running. (Courtesy of General Motors Corp.)

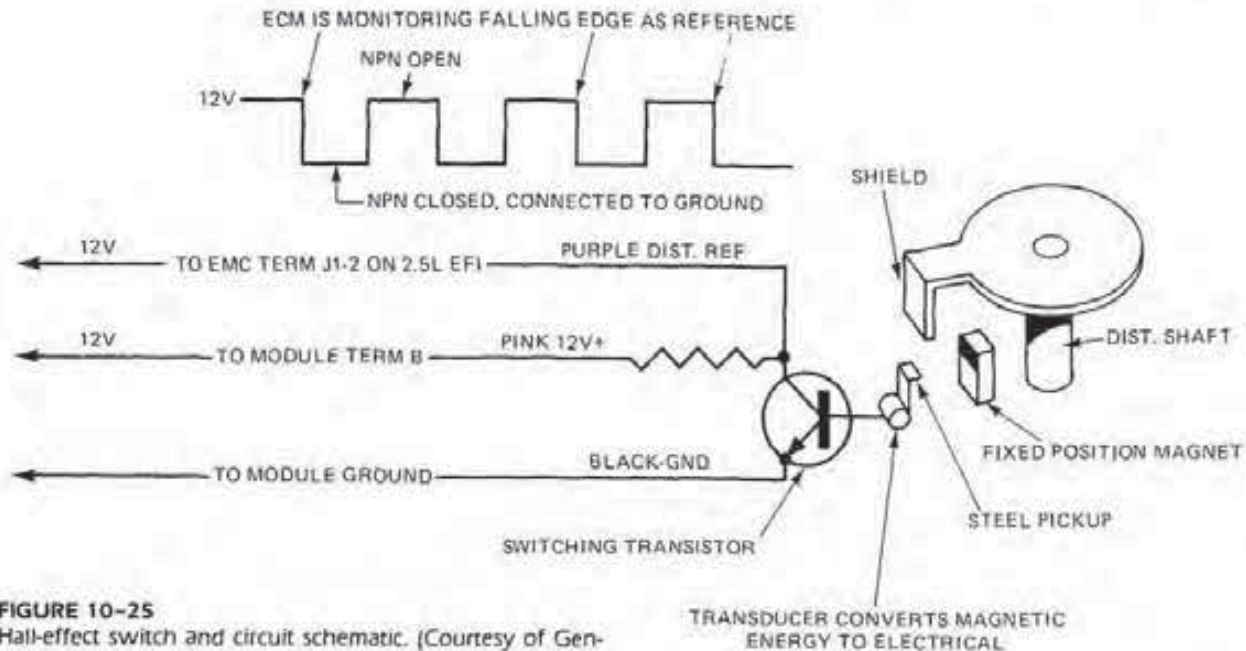


FIGURE 10-25
Hall-effect switch and circuit schematic. (Courtesy of General Motors Corp.)

bypasses the HEI module timing control (Fig. 10-24).

The operation of the HEI system is now under the control of the EST signal from the ECM. This is known as the *EST mode* of operation. The ECM can vary the time it directs the EST signal to the transistor and, by doing so, can tailor the timing to best suit the needs of the engines under all operating conditions.

Hall-effect Switch

The 1982 3.8-liter (229 cubic inch) odd firing engine and some 2.5-liter electronic fuel injected systems use a Hall-effect switch (Fig. 10-25). When used, the switch takes the place of the reference voltage from the HEI module Terminal R. The Hall-effect switch is added to the ignition primary circuit to permit the use of electronic spark timing (EST). It is necessary on the odd firing 3.8-liter V-6 due to the cylinder-to-cylinder difference in top dead center points. The switch itself informs the ECM which cylinder is to be fired next.

The Hall-effect switch mounts in the distributor above the normal pickup coil and HEI module (Fig. 10-26). The switch contains a small magnet that sits close to the Hall-effect electronic circuit. The HEI rotor attached to the distributor shaft has the same number of steel vanes, or shields, as there are engine cylinders. These vanes pass in a narrow space between the magnet and the electronic circuit or transducer. As the rotor turns, it alternately cuts

off and then passes the magnetic field from the magnet to the electronic circuit. This induces the DC square wave signal into the transducer (as seen in Fig. 10-25).

HEI Pickup Coil Pulses

The HEI pickup coil's electrical pulses will switch off the primary ignition coil (1) to fire the spark plugs during engine cranking, (2) to fire the spark plugs with the engine operating at less than 400 rpm, (3) to fire the spark plugs when the diagnostic connector terminals A and B are connected for checking base timing, and (4) to fire the spark plugs when the five-volt bypass line is lower than three volts.

Hall-effect Switch Signals

The electrical signals from the Hall-effect switch will (1) cause fuel injection on engines so equipped under the above four conditions, (2) fire the spark plugs above 400 rpm, (3) provide more accurate timing signals, (4) send a reference pulse to the computer to indicate crankshaft degrees and speed, and (5) control fuel injection under all other operating conditions.

Hall-effect Distributor Operation

Figure 10-27 is a schematic of the EST system that uses the Hall-effect switch within the distributor.

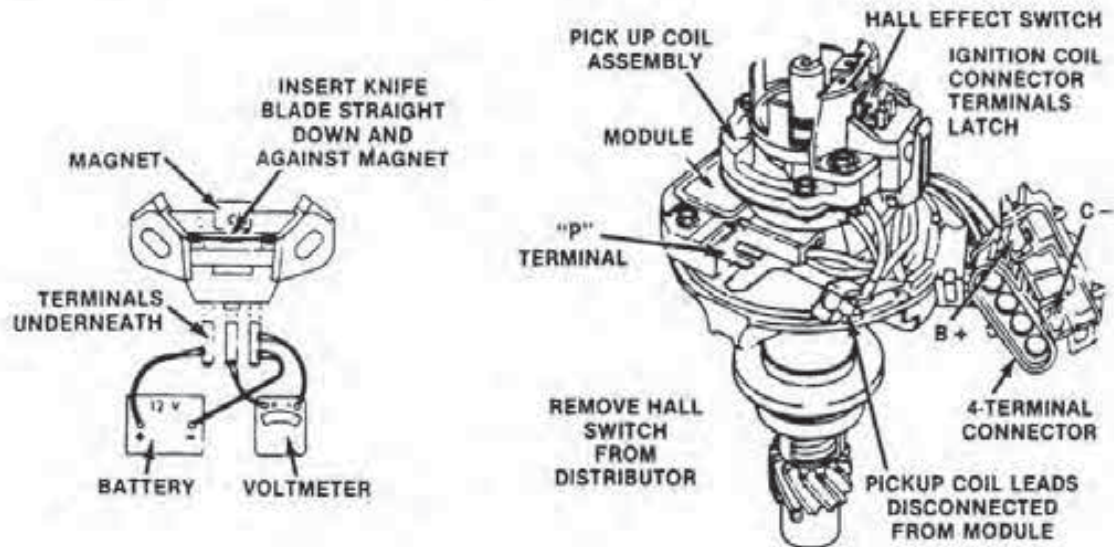


FIGURE 10-26
Hall-effect switch installation in the distributor. (Courtesy of General Motors Corp.)

The operation of this system is the same as for the one described earlier except for the action of the Hall-effect switch and its circuit. In this system, the HEI module supplies 12 volts through a resistor to the collector of the Hall-effect circuit transistor. The reference line to the ECM also connects to the collector. The emitter of the transistor connects to ground.

The base of the collector is controlled by the Hall-effect switch. When magnetism is allowed to reach the transducer of the switch, its induced volt-

age turns the transistor on. With it on, the reference voltage to the ECM is under one volt, which is the normal drop across the transistor.

When the magnetic field to the Hall-effect transducer is cut off by a vane, the transistor turns off. At this point ECM reference voltage becomes 12 volts. With the ignition key on, a voltage is present at the transducer output that will be dependent on the position of the vane of the distributor rotor. However, with the engine running, the output reference voltage will be about one-half that of the battery or six volts.

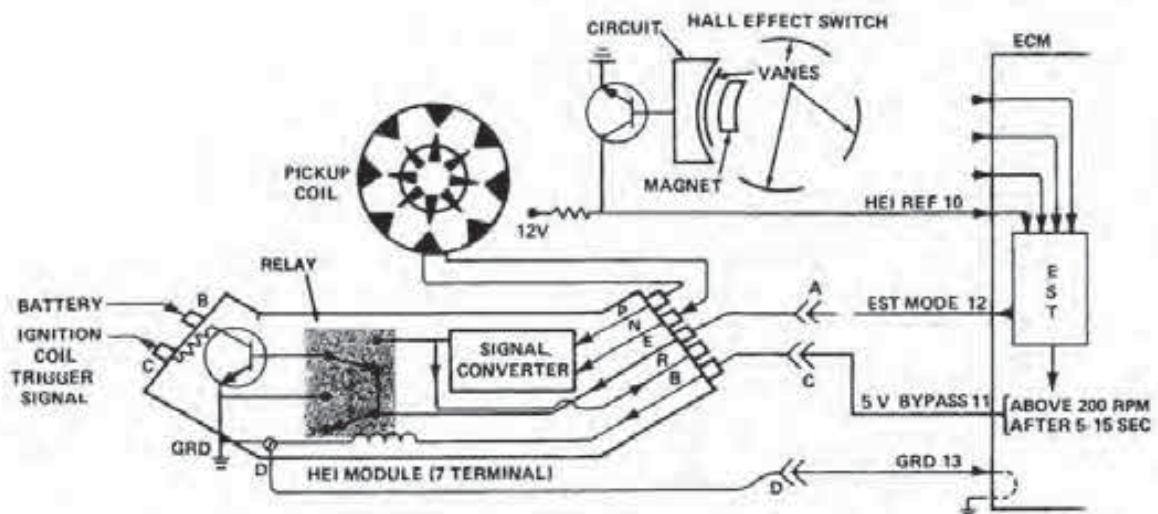


FIGURE 10-27
Hall-effect distributor and EST system operation. (Courtesy of General Motors Corp.)

10-3 ELECTRONIC SPARK CONTROL SYSTEM

The *electronic spark control (ESC)* system is used along with electronic spark timing (EST) on turbocharged engines. A *turbocharged engine* uses its exhaust gas flow to drive a small turbine. The turbine is a rotary air pump that, in turn, supplies air to the carburetor. The air is forced into the carburetor at a pressure above atmospheric, which results in more air/fuel mixture being admitted into the cylinders. This action raises the engine's volumetric efficiency and therefore its power.

However, since air is forced into the carburetor under a pressure higher than atmospheric, overall cylinder pressures are higher. This higher pressure can cause detonation in the turbocharged engine.

The ESC system is designed to prevent excessive detonation; a small amount of knock is normal on engines equipped with this system. To control detonation, the system incorporates a sensor and an electronic spark control ECM (controller) (Fig. 10-28). However, the electronic spark timing HEI module within the distributor remains unchanged.

Detonation Sensor

The *detonation sensor* mounts on the intake manifold. The sensor detects the vibrations caused by detonation. When detonation occurs, the sensor sends a signal to the ESC controller.

ESC Controller Action

The *ESC controller* evaluates the sensor signal and then directs an electronic spark timing ESC signal to the distributor to retard the timing. In case of detonation, the electronic spark timing ESC signal would be retarded by the controller about four degrees each second until the detonation sensor stopped detecting engine vibrations. After the detonation has stopped, the timing signal is returned to normal at a slower rate than it was retarded.

10-4 DISTRIBUTORLESS IGNITION SYSTEM

The *distributorless ignition system (DIS)*, as its name implies is designed to do away with the me-

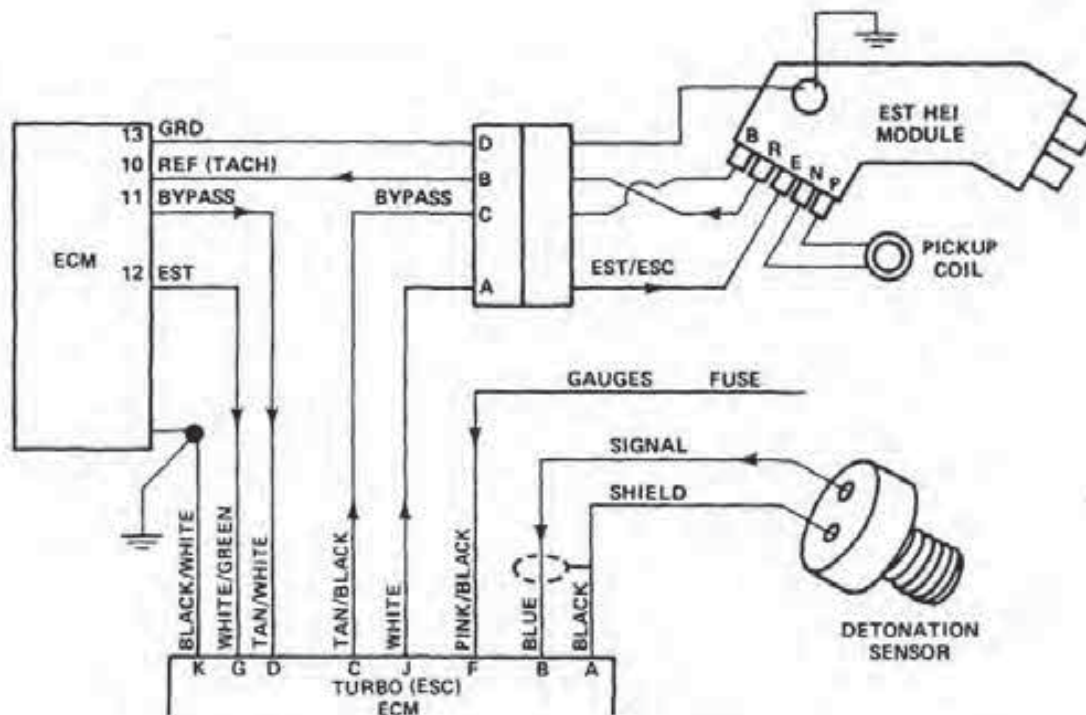


FIGURE 10-28
Electronic spark timing, electronic spark control schematic.
(Courtesy of General Motors Corp.)

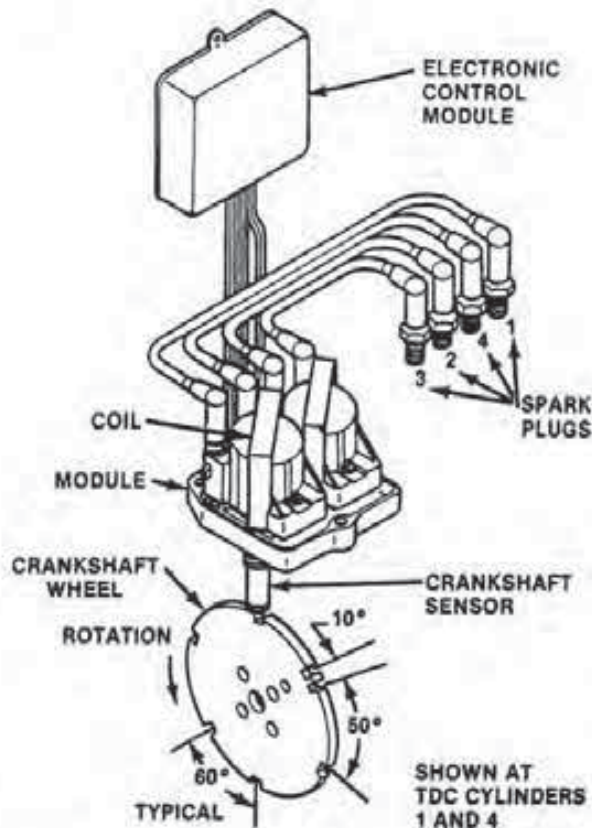


FIGURE 10-29
Typical distributorless ignition system components. (Courtesy of General Motors Corp.)

chanical distributor system (HEI) for controlling secondary ignition voltage. So far, this system is used on 2.0-, 2.5-, 2.8-, 3.0-, and 3.8-liter General Motors engines.

System Names

Different names are given the DIS system relative to the actual car division that uses it. The names in current use include

- distributorless ignition system (DIS),
- computer controlled coil ignition (C3),
- direct ignition system (DIS), and
- integrated direct ignition (IDI).

Advantages of the DIS System

The DIS offers a number of advantages over HEI. Distributorless ignition systems eliminate the possibility of tampering or misadjustment. They use even

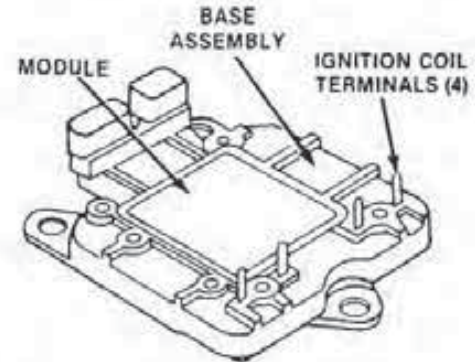


FIGURE 10-30
The base assembly forms the framework of the system. (Courtesy of General Motors Corp.)

more sophisticated electronics. Mechanical timing adjustments are eliminated. There are fewer moving components. Distributorless ignition systems also can be remotely and more compactly mounted.

System Components

In order to function, all systems have three components in common. There are the ignition module, coils, and a crankshaft sensor (see Fig. 10-29). However, the 3.8-liter engine also requires a camshaft sensor and interrupter.

Base Assembly and Ignition Module

The ignition module of the DIS is housed in the *base assembly*, which provides the basic support framework for the entire system (Fig. 10-30). The base not only securely supports the module and coils but also provides the means of mounting the DIS system to the engine.

The *ignition module* has two basic functions. First, it controls the current flow in the primary winding circuit of the coils by means of transistors. Second, the DIS module controls spark timing under 400 engine rpm.

Ignition Coils

The *ignition coils* mount above the module and base assembly (Fig. 10-31). The DIS coils are the inductive type and operate in much the same manner as those used in the HEI design.

DIS uses one coil for every two cylinders. Each coil has two secondary towers to simultaneously supply high voltage to two spark plugs. The coil cylinder pairings by engine type are

- four-cylinder—first and fourth, and second and third;
- six-cylinder—first and fourth, second and fifth, and third and sixth.

The V-6 Buick engine DIS can use either a Type I or II coil application (Fig. 10-32). This is due to the different design of the module and coil pack assemblies. *Verification of the coil application is important because diagnostic procedures are different for each.*

The type I application is used only with the 3.0-liter and 3.8-liter engines. Type I can be identified by the three coil terminals located on each side of the coil. Also, this arrangement offers the three-in-one coil pack design. The Type II application has all six coil terminals on one side. Moreover, each coil pack assembly is separate.

Magnetic Crankshaft Sensor

There are two styles of crankshaft sensors used: the magnetic type and the Hall-effect. The type used in the DIS is determined by engine application.

The *crankshaft sensor* shown in Fig. 10-33 is a magnetic switch. It is used to provide the ignition module and the ECM with engine rpm and crankshaft information in much the same manner as the HEI pickup coil.

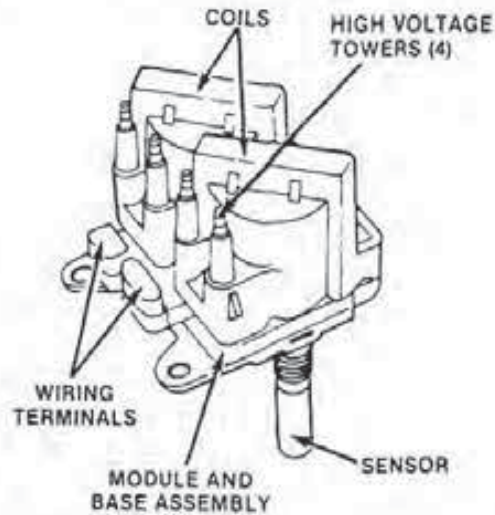


FIGURE 10-31 Ignition coil installation. (Courtesy of General Motors Corp.)

This sensor is made up of a permanent magnet with a coil of wire wrapped around it. The sensor is positioned 0.050 inch, plus or minus 0.020 inch, from the slotted portion of the crankshaft, known as the reluctor. On the 2.0-, 2.5-, and 2.8-liter engines, the reluctor has seven slots, six of which are equally spaced 60 degrees apart. The seventh is set ten degrees *after top dead center (ATDC)* from the sixth slot position. However, this is not the sixth piston position. The seventh slot is used to generate a sync pulse (see Fig. 10-29).

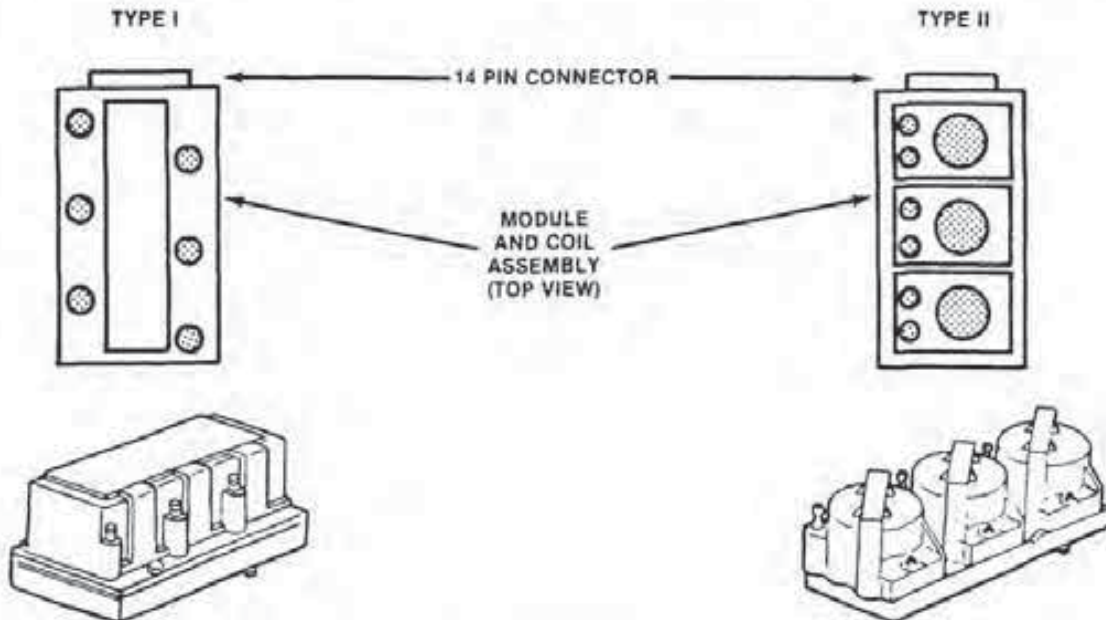


FIGURE 10-32 Type I and II coil identification. (Courtesy of General Motors Corp.)

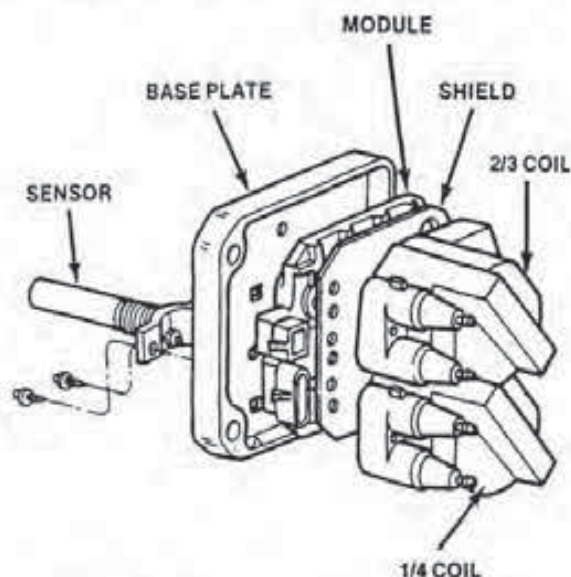


FIGURE 10-33
Sensor, base plate, module, and coils for a 2.5-liter engine. (Courtesy of General Motors Corp.)

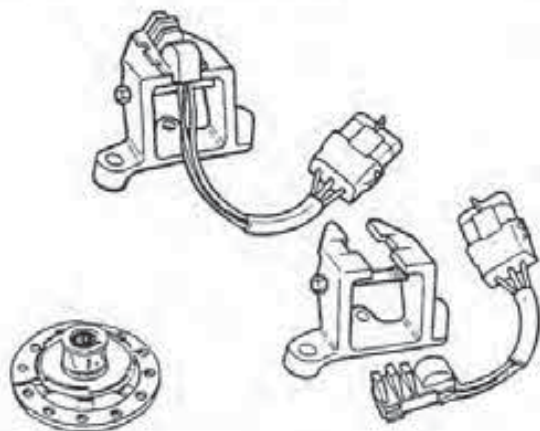


FIGURE 10-34
Hall-effect crankshaft sensor. (Courtesy of General Motors Corp.)

As the reluctor rotates as part of the crankshaft, the slots change the magnetic field of the sensor as they pass by its tip. The magnetic field therefore increases and then quickly decreases each time a slot passes the sensor. This creates an induced voltage pulse in the coil of wire in the sensor.

The voltage amplitude varies directly with engine speed. For instance, the range is from about +0.5 volt to -0.5 volt on every slow cranking speeds. At higher speeds, the range is from approximately +1.5 volts to -1.2 volts.

The gap between the sensor tip and the crankshaft reluctor has an effect on sensor output. For ex-

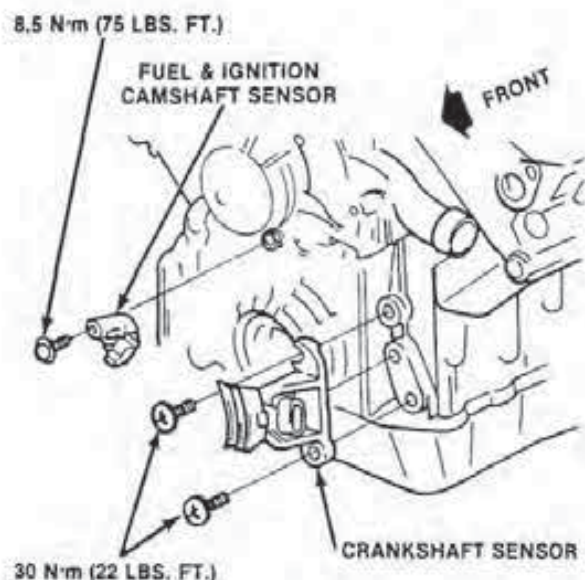


FIGURE 10-35
V-6 cam and crankshaft sensors for a 3.8-liter engine. (Courtesy of General Motors Corp.)

ample, an air gap smaller than 0.030 inch creates larger than normal voltages. A gap larger than 0.070 inch causes smaller than normal voltages.

The smaller gap can result in high speed problems due to the voltage output exceeding the module's input handling ability. The larger gap, on the other hand, could cause starting problems because the sensor output is not enough to trigger the ignition module. The induced voltages must rise above a certain positive value and then move toward positive zero volts on a negative transition. The module triggers off the primary coil current flow at the positive zero crossing of the AC waveform.

Hall-effect Crankshaft Sensor

The 3.8-liter V-6 engine uses a Hall-effect crankshaft sensor (Fig. 10-34). This sensor provides only the crankshaft rpm signal to the ignition module. The sensor mounts on the front of the engine timing cover just behind the harmonic balancer.

A magnet and *interrupter ring* attach to the backside of the balancer. The interrupter has three window slots positioned 120 degrees apart. The sensor mounts in a pedestal-type holder. When properly adjusted, the sensor has an equal distance of 0.025 inch clearance on side of the interrupter ring.

The 3.0-liter engine uses a combination crankshaft sensor that is similar in appearance and location to the 3.8-liter application. However, the 3.0-liter sensor provides information on both the crank-

shaft rpm and the first cylinder's *top dead center (TDC)* position. To do this, the balancer has a second interrupter ring that has only one window slot.

Camshaft Position Sensor

Along with an external, remotely mounted crankshaft sensor, the 3.8-liter, V-6 engine has a Hall-effect camshaft sensor (Fig. 10-35). This sensor is timed to the camshaft in much the same way as the HEI distributor.

The *camshaft sensor* provides the ECM with information on the first cylinder's TDC position. This signal is used to synchronize the firing of the ignition coil in relation to the crankshaft, pistons, and intake and exhaust valves. This synchronization enables the ignition module and the ECM to control the amount of spark advance and to time the opening of the sequential fuel injectors.

The camshaft sensor is located on the timing cover behind the water pump, near the camshaft sprocket (see Figs. 10-35 and 10-36). The sprocket has a magnet mounted on it that activates the Hall-effect switch in the sensor.

As the camshaft sprocket turns, its magnet creates a signal in the Hall-effect switch that activates the sensor circuit transistor (Fig. 10-37). When this occurs, the transistor grounds the signal line to the DIS module, pulling the crank sensor's applied line voltage down to a low value. This is interpreted as the *cam signal (synchronization pulse)*.

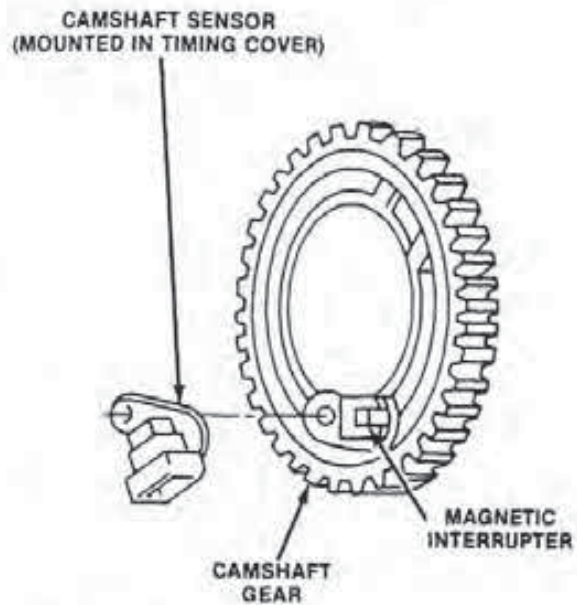


FIGURE 10-36
Design of the camshaft sensor. [Courtesy of General Motors Corp.]

Due to the manner in which the crank sensor operates, its signal is always a series of either high or low DC voltage square wave signals. However, as the camshaft sprocket rotates, its magnet turns off the transistor once, resulting in one signal each revolution of the sprocket.

The cam signal is created as the first and fourth pistons reach about 25 degrees after top dead

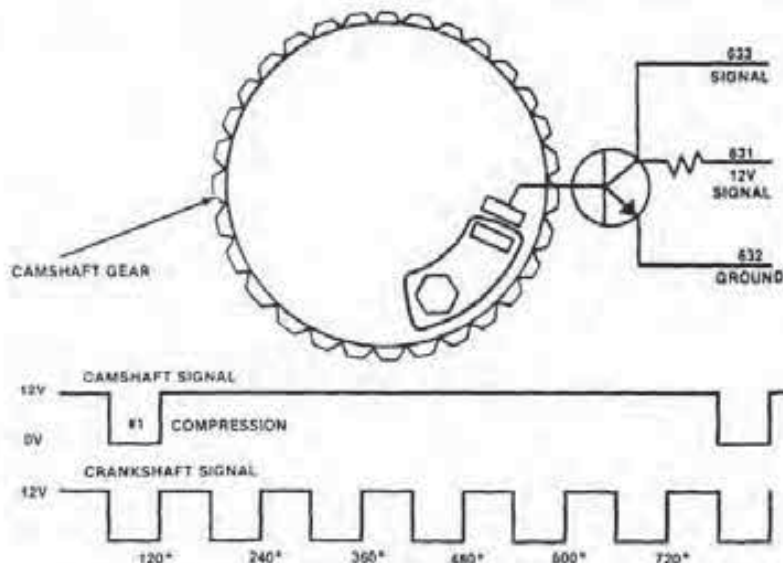


FIGURE 10-37
Camshaft circuit operation. [Courtesy of General Motors Corp.]

'87 "DIS" 2.0L & 2.5L IGNITION AND INJECTION TIMING RELATIVE TO PISTON POSITION

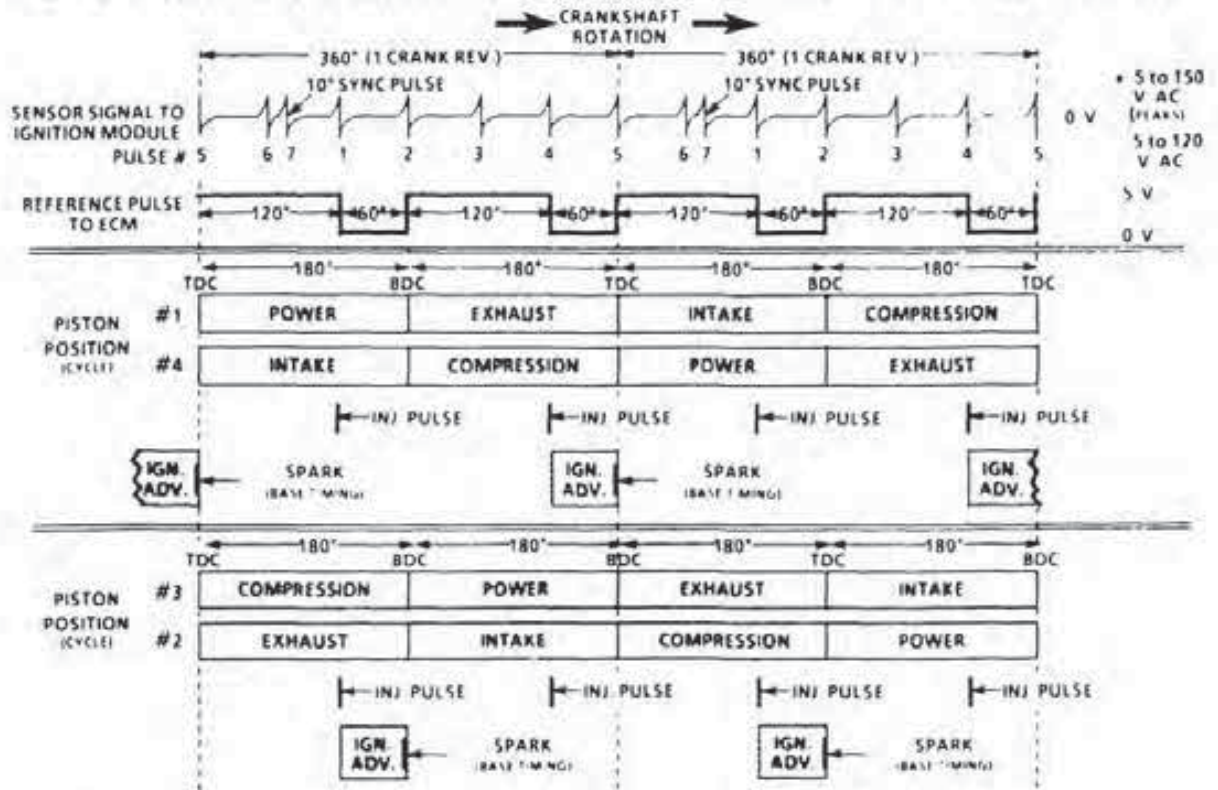


FIGURE 10-38
Ignition and injector timing in 2.0- and 2.5-liter engines.
(Courtesy of General Motors Corp.)

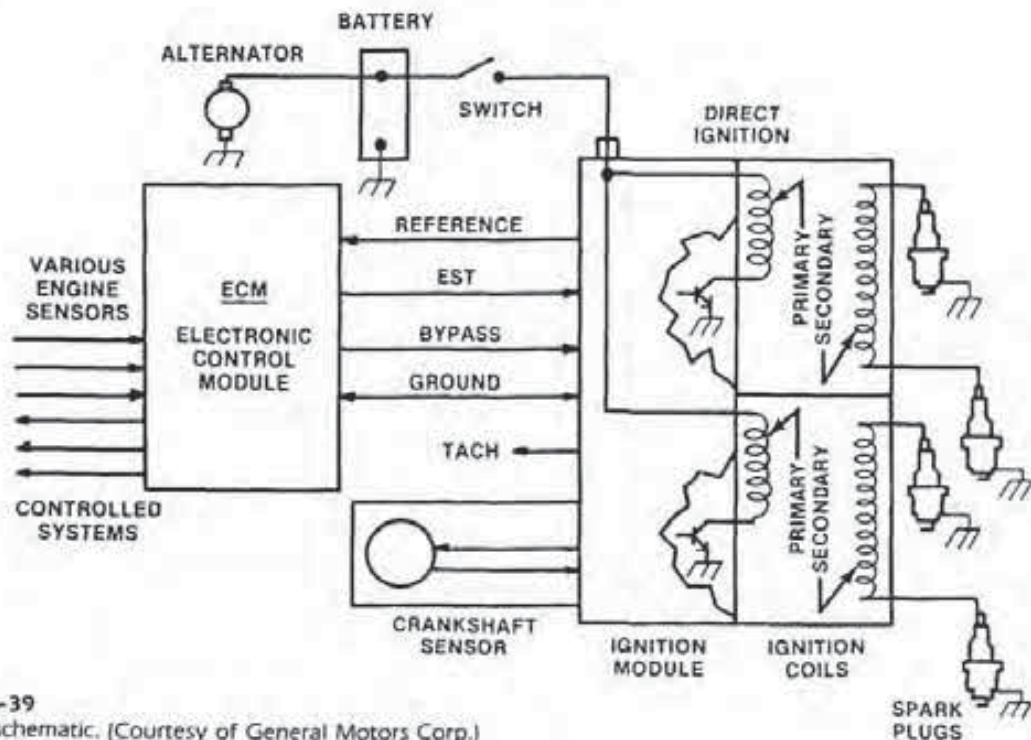


FIGURE 10-39
DIS wiring schematic. (Courtesy of General Motors Corp.)

center (ATDC). It is then used by the DIS module to begin the ignition coil firing sequence starting with the Number 3-6 coil. The firing sequence begins with this coil because the sixth piston is now at the correct position in the compression stroke for its spark plug to be fired. The plug for the third cylinder also fires but its piston is on the exhaust stroke.

DIS System Operation

DIS uses a *waste spark* method of spark distribution. Each cylinder is paired with another, such as the first and fourth and the second and third. The spark occurs in the cylinder with its piston coming up on the compression stroke, and in the paired one with its piston moving up on the exhaust stroke (Fig. 10-38).

The cylinder piston that is on the exhaust stroke requires very little of the available coil energy to fire its spark plug. Therefore, all the remaining energy is used as necessary by the cylinder on the compression stroke. The same process is repeated when the cylinders reverse roles.

The center electrodes of two spark plugs are connected to the ends of each coil's secondary winding (Fig. 10-39). An ignition module transistor controls the current flow through each coil primary winding.

The transistors control the 8.5 amperes to 10 amperes of primary current flow by being switched

on and off. A positive voltage at the base of the transistor turns the collector-emitter circuit on and allows primary current to flow. The direction of the current flow is from the ignition switch, through the module and primary winding, to the collector-emitter of the transistor, and to ground.

The current flow in the primary windings creates a magnetic line field. As current flow stops, the magnetic field collapses and induces a voltage in the secondary winding. This action produces the necessary high voltage to fire both plugs in series.

The time lag between both plug firings is about one to two milliseconds. The plug for the cylinder at the end of its exhaust stroke fires first because the atmospheric pressure between its electrodes only requires 2,000 volts to 3,000 volts to form the arc. This leaves ample available voltage to fire the other plug in the cylinder at the end of its compression stroke.

When the engine is operating at normal speeds, the bypass signal from the ECM to the module will effectively connect the base of the transistor to the EST terminal. The EST signal is determined not only by the reference signal to the ECM but also as a result of signals coming from the other engine sensors, which are at the same time directing voltage pulses to the ECM. Under these conditions, the ECM, via the EST signal, is controlling the ignition timing and is constantly tuning the engine for control of exhaust emissions and good fuel economy and performance.

CHAPTER REVIEW

The following two sections will assist you in determining how well you remember the material contained in this chapter. If you cannot complete a statement or question, refer back to the section marked in brackets that contains the material.

SELF-CHECK

1. What determines the name given to a particular distributorless ignition system (DIS) [10-4]?
2. What are the benefits provided by a high energy ignition (HEI) system [10-1]?
3. Electronic spark control (ESC) is found on what type of engine configuration [10-3]?

4. In HEI ignition, what are the purposes of the current and dwell control systems [10-1]?
5. What design changes did electronic spark timing (EST) make to the basic HEI system [10-2]?

REVIEW

1. Each end of a DIS ignition secondary coil connects to a [10-4]
 - a. primary winding terminal.
 - b. transistor terminal.
 - c. spark plug wire.
 - d. none of these.
2. Where is the ignition coil located on the HEI

- system [10-1]?
 a. inside the distributor
 b. outside the distributor
 c. both a and b
 d. neither a nor b
3. Which system uses waste spark distribution [10-4]?
 a. HEI, EST
 b. HEI, ESC
 c. HEI
 d. none of these
4. When does the HEI pickup coil produce a positive zero voltage [10-1]?
 a. as the pole piece and timer core teeth align
 b. as the pole piece and timer core teeth move apart
 c. as power is sent to the module
 d. as power is cut off to the module
5. Which DIS-equipped engine uses a Hall-effect cam and crankshaft sensor [10-4]?
 a. 3.8-liter
 b. 2.0-liter
 c. 2.5-liter
 d. 3.0-liter
6. The vacuum advance moves what component with the HEI distributor [10-1]?
 a. timer core
 b. pickup coil assembly
 c. ignition coil
 d. rotor
7. In a DIS system, what component controls engine timing under 400 engine rpm [10-4]?
 a. ECM
 b. ignition module
 c. pickup coil
 d. Hall-effect switch
8. The HEI switching transistor's base circuit receives what type of signal [10-1]?
 a. AC signal
 b. DC signal
 c. either a or b
 d. neither a nor b
9. Which system has no mechanical timing adjustments [10-4]?
 a. DIS
 b. HEI
 c. HEI, EST
 d. both a and b
10. Which system's ignition module has a solid state switch connected to the transistor base circuit [10-2]?
 a. HEI, EST
 b. DIS
 c. DIS, EST
 d. ECM
11. If detonation occurs in an engine with ESC, how is its timing affected [10-3]?
 a. It retards four degrees for every second of detonation.
 b. It begins to return to normal as the detonation stops.
 c. both a and b
 d. neither a nor b
12. The EST computer command control system requires how many engine sensors [10-2]?
 a. one
 b. two
 c. three
 d. four
13. The detonation sensor is located where [10-3]?
 a. cylinder head
 b. intake manifold
 c. water jacket
 d. ECM
14. In the EST system, what controls the operation of the switching transistor during engine cranking [10-2]?
 a. EST signal
 b. bypass signal
 c. coolant sensor signal
 d. pickup coil signal

TESTING TYPICAL GENERAL MOTORS ELECTRONIC IGNITION SYSTEMS

OBJECTIVES

After reading and studying this chapter, you will be able to

- explain the general precautions relating to testing General Motors electronic ignition systems.
- demonstrate the use of test equipment used on General Motors electronic ignition systems.
- describe how to test the high energy ignition (HEI) system.
- explain how to check the HEI electronic spark transfer system.
- describe the test procedures for the HEI electronic spark control system.
- explain how to check the distributorless ignition system (DIS) for a no-start condition.

Since its introduction in 1974 the basic high energy ignition (HEI) system has undergone a number of design changes, most of which have dealt with the introduction of various forms of electronic spark control systems. These spark control systems vary for different model years and vehicle configurations. Moreover, in recent years, General Motors started using the distributorless ignition system (DIS) along with electronic spark control.

Due to the variations in these systems, it would be impossible to discuss the service techniques on them all within the space available in this chapter. For this reason, this chapter provides samplings of procedures used on the various systems to provide you with an introduction to the process. *Always follow the manufacturer's instructions guides, and specifications when testing any system application in order to prevent damage to its many components.*

In the upcoming sections, you will find step-by-step electrical test procedures on system components. These steps are needed to locate the cause of either a no-start condition or poor performance.

11-1 GENERAL PRECAUTIONS AND TEST EQUIPMENT

Before learning to test General Motors ignition systems, you must review the general precautions for working on electronic ignition systems, in general, which are listed in the box below. In the box below are general precautions for working on General Motors systems. Also, always observe the safety instructions outlined in Chapter 5.

General Precautions

The precautions and instructions listed below and on pages 200-201 will not only save you time in locating the actual cause of a problem but prevent the possible destruction or replacement of an otherwise serviceable part.

General Motors Systems

1. Disconnect the distributor harness connectors before conducting a compression test.
2. Do not operationally test the secondary voltage of the HEI system by removing a plug wire. This can destroy the ignition module.
3. Never ground the tachometer terminal on the HEI distributor cap or coil.
4. To remove spark plug cables, twist the boot one-half turn and pull on it. *Do not pull on*

the wire itself. A light coat of silicone grease inside the spark plug wire boot will seal the connection and aid with future removal.

5. Apply the special heat-dispersing compound to the base of the ignition module during its replacement. Without this compound, the heat build-up will cause module failure. The various manufacturers of this compound and the part numbers are NAPA Echlin TPL45, Delco D1920, Dow Corning Compound 5, GM 1974984, General Electric G642, and Dow Corning 341.

6. For integral HEI coils, lubricate the rubber washer seal between the coil and distributor cap with silicone grease. If this is not done, moisture and dust may contaminate the distributor cap causing misfiring and burn through.

7. A burned through rotor is usually the result of high secondary resistance. In this case, check all spark plug wires and connections. Also, inspect the carbon brush inside the distributor cap for correct installation and excessive resistance.

8. If the complaint is excessive engine detonation, check the coolant level of the vehicle, and fill as necessary.

9. If the engine detonates or has poor performance, make sure the ignition timing is set to the specifications on the emission label. Reconnect the vacuum advance on early HEI systems after completing the check.

10. On electronic spark control (ESC) systems, inspect the detonation sensor for its physical condition and proper installation. Make certain the detonation sensor wire is not routed next to the distributor or any spark plug wires.

11. Check catalog applications for ignition coil and pickup coil combinations on given electronic spark transfer (EST) and ESC configurations. For instance, ignition coils with red and yellow leads must be matched to pickup coils with yellow connectors. Ignition coils with red and white wires must be mated to a pickup coil with a clear, black, or blue connector.

12. Always check on ohmmeter's calibration before using it to test circuit resistance or continuity.

13. Beginning with the 1980 computer command control (C3) system, *use a high input impedance digital volt-ohmmeter (DVOM) to check component or circuit resistance or voltage.*

Test Equipment

Before you begin the ignition test procedures that follow, be sure you have an accurate analog voltmeter (a high impedance DVOM for C-3 and later systems), a power timing light with induction pickup, a spark tester, jumper leads, a tachometer, a vacuum pump, and a test light.

Larger pieces of equipment that are necessary include an oscilloscope and module tester. The scope will be used to check the operation of the pickup coil and secondary ignition circuits. A unit that is especially helpful is the Allen "Smart" scope because it is capable of reading pickup coil signals. The module tester electronically checks the serviceability of the distributor ignition module.

11-2 TESTING A TYPICAL HEI SYSTEM

If an engine equipped with an integral HEI system will not start, remove a plug cable and connect it to a well-grounded spark tester. Turn the engine over with the ignition switch, and check for a spark at the tester. If there is no spark, troubleshoot the ignition system to locate the cause of the problem by following these steps.

Step 1—Coil Voltage Test in the Run Position

To determine if the coil is receiving sufficient voltage with the ignition switch in the RUN position, do the following:

1. With the ignition switch off, disconnect the battery wire from the distributor cap terminal (Fig. 11-1).
2. With the leads of the voltmeter, measure and record the voltage of the battery.
3. Attach the negative (-) lead of the voltmeter to a good ground.
4. Connect the positive (+) voltmeter lead to the connector of the distributor battery lead.
5. Turn the ignition switch to the RUN position and note the reading on the voltmeter.
6. The reading at the connector should be within one volt of that of the battery. If the reading is satisfactory, go to Step 2.
7. If the reading is lower than specified, there is high resistance in the circuit. Check the ignition switch, battery cables, neutral safety switch, clutch engage switch, main harness connector, and the wiring

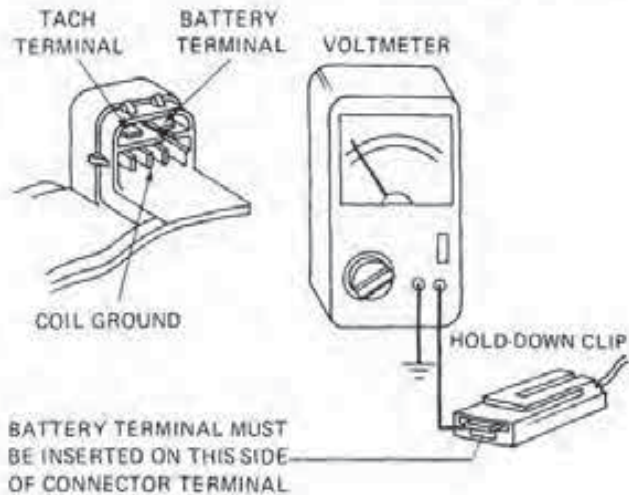


FIGURE 11-1
Testing the coil's run voltage.

between these components. Repair or replace defective parts.

8. Turn the ignition switch off.

Step 2—Coil Voltage Test in the Start Position

To test the voltage to the coil with the ignition switch in the START position, do the following:

1. Attach the (-) voltmeter lead to a good ground.
2. Connect the (+) voltmeter lead to the connector on the battery wire (see Fig. 11-1).
3. Have an assistant crank the engine over with the ignition switch.
4. Note the voltmeter reading. It should be within one volt of that of the battery. If it is, proceed to Step 3.
5. If the voltage drop is more than one volt, there is excessive resistance in the circuit. In this case, check the ignition switch, battery cables, neutral safety switch, clutch engage switch, main harness connector, and the wiring between these components. Make repairs or replacements as necessary.
6. Shut the ignition switch off, and plug in the battery connector at the distributor.

Step 3—Testing the Pickup Coil for Shorts

To check the pickup coil within the pole piece assembly for a short to ground, do the following:

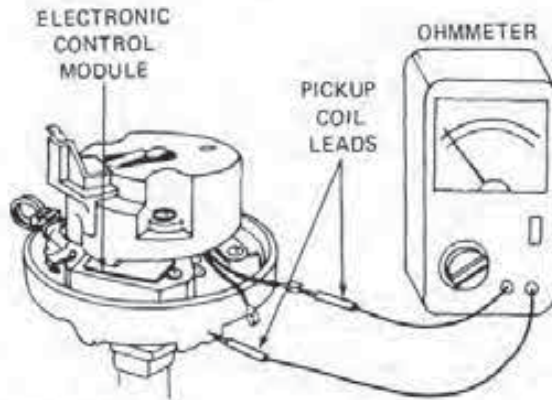


FIGURE 11-2
Checking the pickup coil for shorts.

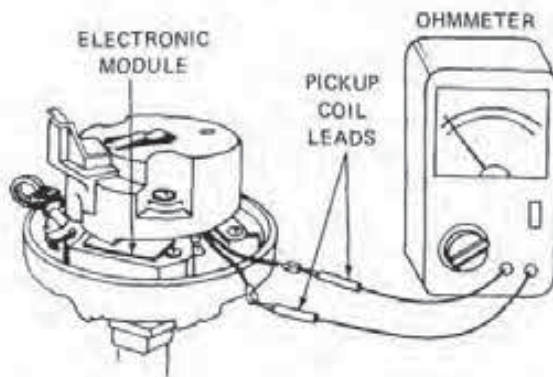


FIGURE 11-3
Testing pickup coil resistance.

1. Remove the distributor cap.
2. With the ignition switch off, disconnect the pickup coil leads from the ignition module (Fig. 11-2).
3. Connect one ohmmeter lead to a good ground on the distributor.
4. Touch the other lead to either of the pickup coil leads.
5. Note the ohmmeter reading. If it indicates infinity, go to Step 4.
6. If the ohmmeter shows continuity, the coil is shorted and requires replacement.

Step 4—Checking Pickup Coil Resistance

This process tests the resistance of the pickup coil within the distributor pole piece assembly. Use a

vacuum pump to operate the vacuum advance and wiggle the wires during the test. Also, check the pickup resistance with the engine both hot and cold. To perform this test, do the following:

1. Set the ohmmeter to the $R \times 100$ range.
2. With the ignition switch off, attach one ohmmeter lead to each of the pickup coil leads (Fig. 11-3).
3. Note the reading on the meter. If the resistance reading is steady and to specifications, proceed to Step 5.
4. If the reading fluctuates or is not to specifications, replace the pickup coil.
5. Plug the pickup coil leads into the module.

Step 5—Testing the Capacitor for Shorts

To check the capacitor within the distributor for a short circuit, do the following:

1. With the ignition switch off, remove the wire from the capacitor.
2. Set the ohmmeter to the $R \times 100$ range.
3. Attach one ohmmeter lead to a good ground on the distributor.
4. Touch the other ohmmeter lead to the capacitor terminal (Fig. 11-4).
5. Note the ohmmeter reading closely. The meter needle should move a small amount and then settle on infinity. If it does, proceed to Step 6.
6. If the meter shows any constant reading other than infinity, the capacitor is shorted and requires replacement.
7. Plug in the capacitor lead.

Step 6—Checking Primary Coil Resistance

To test the resistance of the primary windings of the ignition coil within the cap assembly, do the following:

1. With the ignition switch off, remove the BATTERY and TACH leads from the cap terminals.
2. Set the ohmmeter to the $R \times 1$ scale.
3. Connect one ohmmeter lead to the TACH

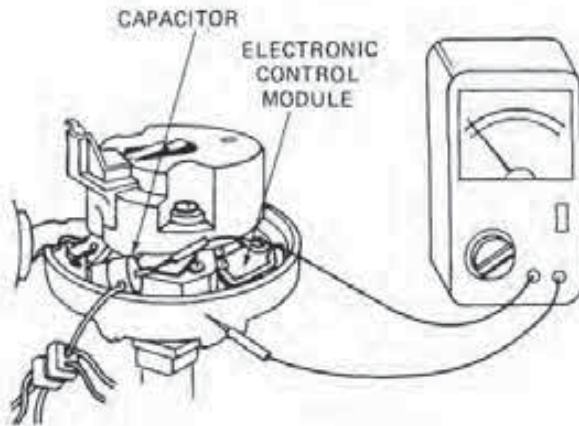


FIGURE 11-4
Checking the capacitor for shorts.

cap terminal and the other to the BATTERY terminal (Fig. 11-5).

4. Note the ohmmeter reading. If it is not to specifications, replace the coil assembly.

5. Remove the ohmmeter lead from the BATTERY terminal and attach it to the distributor GROUND terminal (see Fig. 11-5).

6. Note the ohmmeter reading. If the meter shows anything other than infinity, replace the coil.

7. If the meter shows infinity, go to Step 7.

Step 7—Testing Secondary Coil Resistance

To check the resistance of the secondary windings of the ignition coil against specifications, do the following:

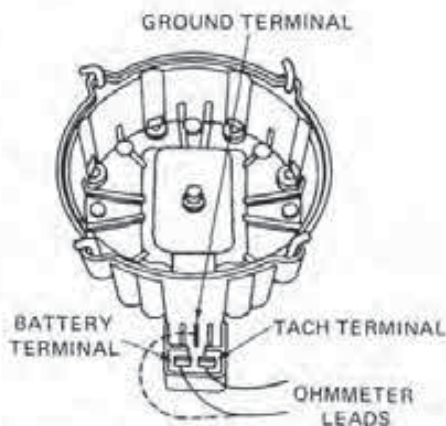


FIGURE 11-5
Testing primary coil resistance.

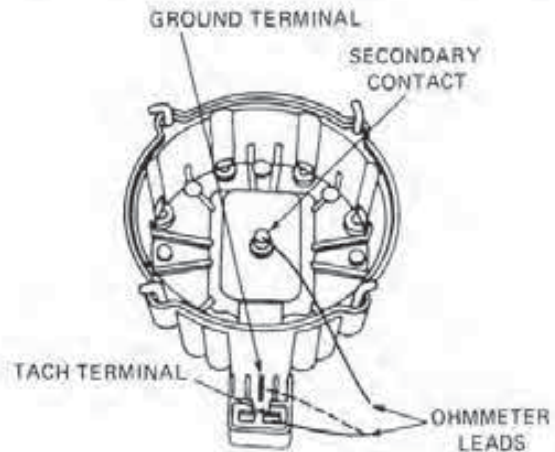


FIGURE 11-6
Checking secondary coil resistance.

1. Set the ohmmeter to an $R \times 1000$ scale.
2. Connect one ohmmeter lead to the carbon brush (Fig. 11-6).
3. Touch the second ohmmeter lead first to the TACH and then to the GROUND terminal. Note the ohmmeter reading as you check each terminal.
4. If either or both of the readings is not to specifications, replace the coil assembly.
5. If the readings are within specifications, proceed to Step 8.

Step 8—Checking the Ignition Module

To test the serviceability of the distributor ignition module, do the following:

1. With the ignition switch off, disconnect all the leads from the ignition module and remove the module from the distributor.
2. Test the unit on a module tester. If the unit is found defective, replace it.
3. If a tester is not available, substitute the old unit with a serviceable module. If the engine now operates, replace the module.
4. Reinstall the distributor cap and plug in its ignition leads.

Testing the Pickup Coil with a Scope

This test can be used as an alternative to Steps 3 and 4 if you have an Allen "Smart" scope or its equivalent. The test itself checks the pickup coil op-

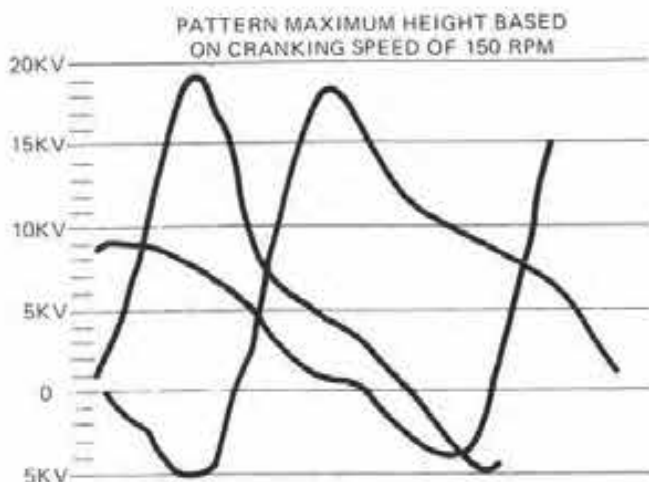
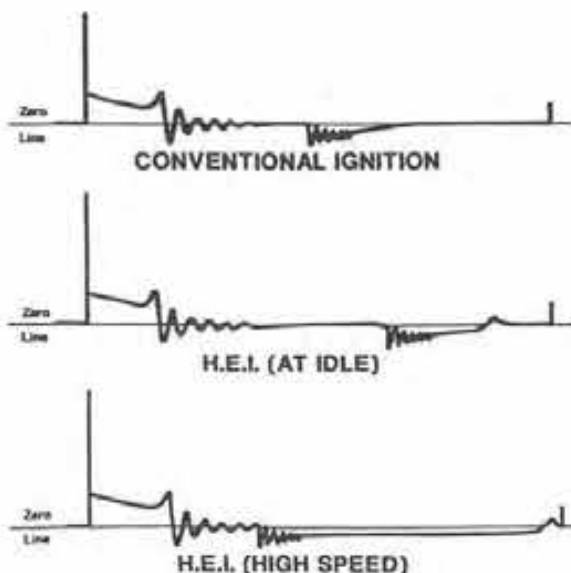


FIGURE 11-7
Testing pickup coil operation with a scope.

eration with the engine cranking over. To perform this test do the following:

1. Remove the distributor cap.
2. With the ignition switch off, remove the pickup coil leads from the module.
3. Connect the red test probe to the white pickup coil lead.
4. Attach the black test probe to the green pickup coil wire.
5. Set the scope for self-sweep operating mode.
6. Place the ohm scale selector on the $\times 10$ position. The scope is now a 2.5 voltmeter using the left grid scale.



7. Crank the engine over using the ignition switch, while observing the scope screen.

8. If there is no scope pattern, replace the pickup coil

9. If there is an AC sweep pattern, as shown in Fig. 11-7, the pickup coil is satisfactory.

HEI Secondary Circuit Scope Tests

Secondary scope analysis is the best way to quickly determine the cause of poor engine performance due to a problem in the HEI system. The oscilloscope can check required voltage, required voltage under load, available voltage, and secondary circuit insulation and condition.

Figure 11-8 shows a comparison of a basic HEI secondary pattern to one for a conventional contact point system. Notice that the firing and the oscillations within the intermediate section of both the HEI and conventional systems appear about the same. However, the HEI firing lines will be higher for two reasons. First, the spark plug gaps for HEI-equipped vehicles have a wider gap. This will increase the required voltage and therefore the height of the firing line.

Second, the HEI system uses a much larger rotor gap than a conventional system. This will also increase the height of the firing line. This also means that a shorted plug or secondary wire will not have as short a firing line with HEI as it would with a conventional system. This is due to the greater voltage needed to bridge the rotor air gap.

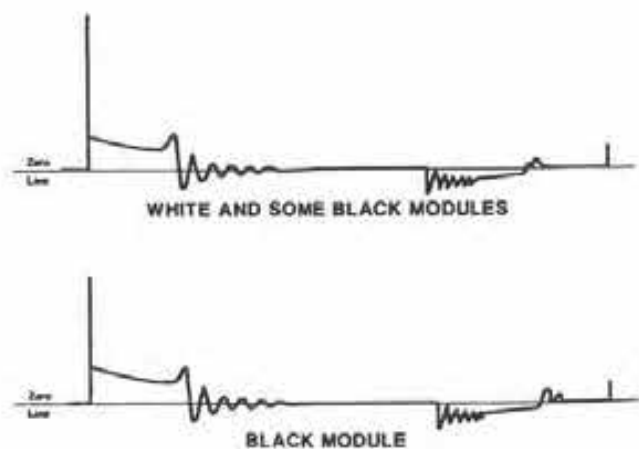


FIGURE 11-8
HEI and conventional secondary scope patterns. (Courtesy of General Motors Corp.)

There are a number of differences in what is actually occurring within the dwell section of the HEI pattern. For example, as the dwell period begins at the end of the intermediate section, the timer core teeth approach alignment with those of the pole piece. This signals the module to close the primary coil circuit. As current begins to flow, the series of oscillations, indicating the beginning of the dwell period, reflect the small voltage induction in the secondary windings.

In addition, note the voltage ripple near the end of the dwell line. The ripple, or oscillation, indicates that primary current has reached its maximum value before dropping slightly. The slight reduction in primary current flow occurs just as the timer core and pole piece teeth align, which signals the module to open the primary circuit.

Lastly, notice the difference in the length of the dwell periods between the two patterns. In the HEI system, dwell is electronically controlled and varies with engine speed.

If there is any deviation from what is shown in the HEI dwell and intermediate sections, the cause can be found using the steps outlined earlier in this section. Causes of malfunctions in the firing and spark lines can be diagnosed in the same way as outlined in Chapter 7, Section 7-2, Step 4.

11-3 TESTING A TYPICAL HEI, EST SYSTEM

There are quite a number of similarities between testing the basic HEI system and the combination HEI and electronic spark transfer system (EST). The reason for this is that the later system uses the HEI distributor but without the vacuum and centrifugal advance mechanisms. Their function is taken over by the ECM.

If an engine with an integral HEI distributor and an EST system will not start, locate the cause of the problem by following the steps below.

Step 1—Preliminary Tests

To determine if the no-start condition is due to a failure of the ignition system, do the following:

1. Carefully remove a spark plug cable.
2. Install the cable terminal over a spark tester, and connect to ground.
3. Have an assistant turn the engine over.

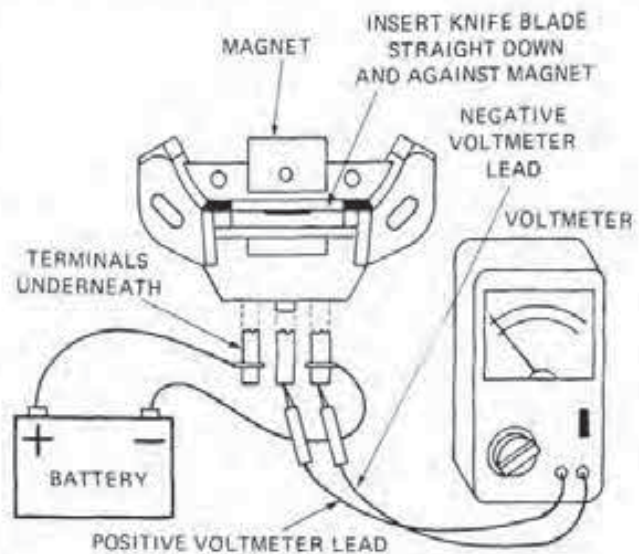


FIGURE 11-9
Testing the Hall effect switch.

4. Observe the tester for signs of a spark. If there is no spark, complete Steps 1 through 7 as outlined in Section 11-2.

5. If the system passes Steps 1 through 7, go to Step 2 below.

6. If there is a spark at the tester, proceed to Step 4.

7. Remove the tester and reconnect the cable to the spark plug.

Step 2—Checking the Hall-effect Switch

To test the serviceability of the Hall-effect switch, do the following:

1. With the ignition switch off, disconnect the three-wire connector from the Hall-effect switch.

2. Using jumper leads, connect a 12-volt battery to the Hall-effect switch terminals, as shown in Fig. 11-9.

3. Attach the leads of a voltmeter to the switch as indicated in Fig. 11-9. Make sure the positive and negative jumper and voltmeter leads are connected properly.

4. Insert a steel knife blade down between the switch and the magnet.

5. Note the reading on the voltmeter. It should read within 0.5 volt of that of the test battery.

6. Remove the knife and check the meter read-

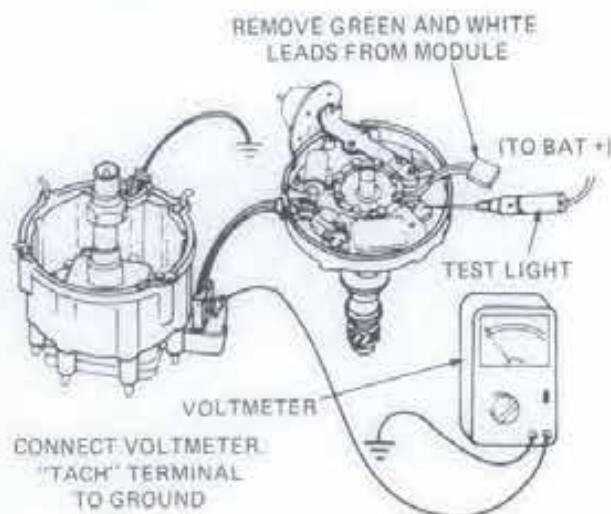


FIGURE 11-10
Ignition module test.

ing. It should now read less than 0.5 volt.

7. If either or both voltage readings are incorrect, replace the Hall-effect switch.

8. If the readings are satisfactory, proceed to Step 3.

9. Remove the test battery and voltmeter leads. Then plug in the Hall-effect switch harness connector.

Step 3—Ignition Module Test

To check the serviceability of the module while it is still inside the distributor, do the following:

1. With the ignition switch off, invert the spark tester as shown in Fig. 11-10 and install it into the coil terminal. Ground the tester with a jumper lead.

2. Remove the pickup coil leads from the module.

3. Connect the (-) lead of the voltmeter to a good engine ground.

4. Attach the (+) lead to the TACH terminal of the distributor cap. Do not unplug the control module wires from the distributor cap.

5. Turn the ignition switch to the RUN position.

6. Attach one lead of a 12-volt test light to the (+) battery terminal.

7. While observing the voltmeter, momentar-

ily touch the tip of the test light probe to the ignition module's Terminal P.

8. A voltage drop should occur when the test probe touches the terminal. If a voltage drop does not occur, inspect and repair the module ground screw.

9. Retest for a voltage drop. If it still does not occur, replace the control module.

10. Turn the ignition switch off and remove the test light and voltmeter.

11. Plug in the pickup coil leads to the module.

12. If the voltage drop is okay, and there is still no spark at the tester during cranking, proceed to Step 4.

Step 4—EST System Test

To check EST signal input to the module from the ECM, do the following:

1. With the ignition switch off, unplug the four-terminal EST connector at the distributor.

2. Crank the engine over with the ignition switch and check for an arc at the coil-mounted spark tester.

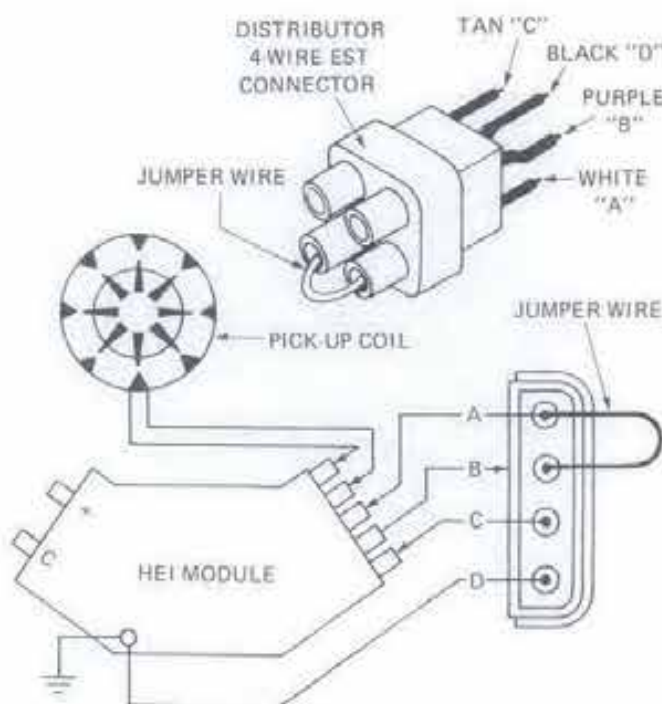


FIGURE 11-11
Test the EST system input to the distributor.

3. If a spark now occurs, attach a jumper wire between Terminals A and B on the distributor side of the EST connector (Fig. 11-11).

4. Remove the spark tester and reinstall the distributor cap.

5. Start the engine.

6. Ground the assembly line communications link (ALCL) test terminal under the dash. *Make certain you insert the jumper leads in the correct terminals for the year of the vehicle* (Fig. 11-12).

7. Connect a test light from the positive (+) terminal to Terminal C on the distributor side of the EST connector.

8. If the engine stops, again check all connections at the ignition module. Look for an open wire to Terminal E of the ignition module. If the wires and connections are okay, test the module and replace it if it is defective.

9. If the engine continues to operate, leave the test light connected but remove the jumper wire between Terminals A and B of the EST connector.

10. Now, if the engine continues to operate, check for an open wire or ground to the ignition module Terminal B, a short circuit between module Terminals R and E, or a faulty module.

11. If the engine stops when the jumper wire is removed, check for an incorrect ignition module, an open wire from the EST connector Terminal A to the ECM Terminal 12, an open wire or ground from the EST connector Terminals C to ECM Terminal 11, or poor connector contact at ECM Terminals 11 and 12. Repair or replace defective parts as necessary.

12. Remove the ground from the ALCL test terminal.

13. Plug in the EST connector to the distributor.

EST Performance Test

To check the performance of the EST system with a timing light, do the following:

1. With the engine shut off, connect a timing light by following the manufacturer's instructions.

2. Block all the vehicle wheels to prevent front or rear movement, and apply the parking brake.

3. Start the engine and place the transmission in park for automatic transmission vehicles or neutral for those with manual transmissions.

4. Start the engine. Check and note the amount of spark advance with the timing light.

5. Ground the ALCL test terminal.

6. Recheck the timing. If the engine timing changes from procedure 4, the EST system is operating properly.

7. If the timing does not change on vehicles equipped with automatic transmissions, shift the transmission into drive and observe the timing with the ALCL test terminal again grounded. If the engine timing now changes, the EST system is properly functioning. If the timing does not change, continue with the test sequence.

8. Shift the automatic transmission into park or the manual into neutral and then shut off the engine.

9. Carefully insert a pin through the wire to Terminal B of the MAP or VAC sensor (Fig. 11-13). *Make sure the pin does not contact an electrical ground.*

10. Connect the (-) terminal of the voltmeter to a good engine ground.

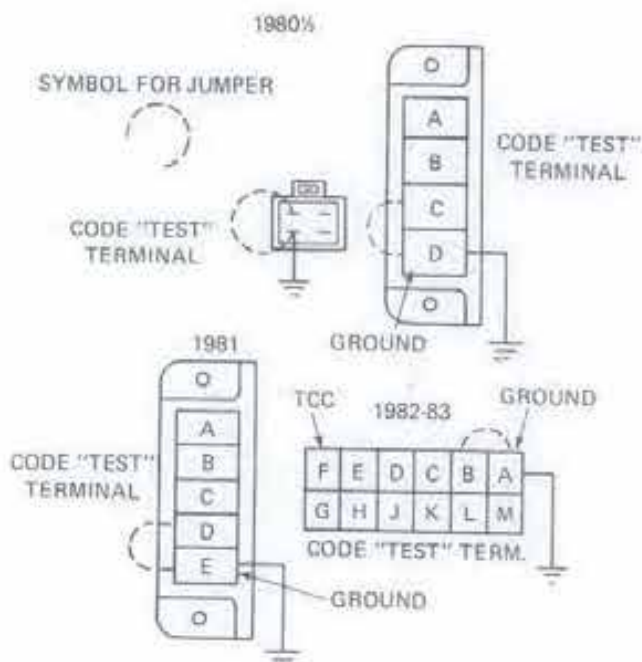


FIGURE 11-12
ALCL test terminals by vehicle model year.

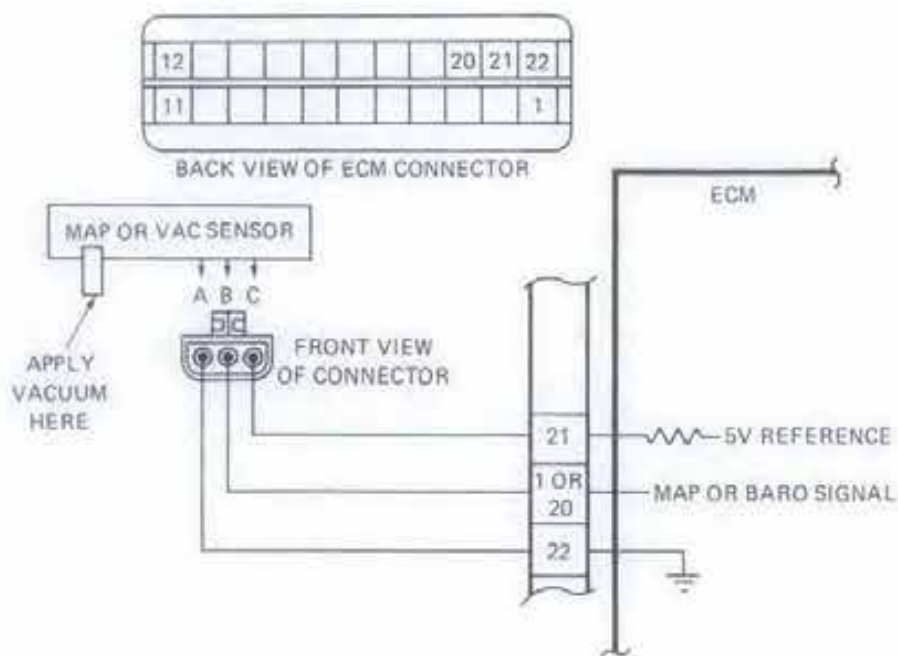


FIGURE 11-13
Checking MAP and VAC sensor voltage.

11. Attach the positive (+) voltmeter lead to the straight pin.

12. Start the engine.

13. Alternately remove and install the vacuum hose in the sensor while checking its output voltage on the meter. If voltage does not change, a problem exists in the MAP or VAC sensor or its circuit.

14. If the voltage changes, disconnect the park/neutral switch and complete procedures 4 through 6 again. If the timing now changes, replace or adjust the park/neutral switch.

15. If the timing still does not change, inspect for a grounded wire from the ECM Terminal H to the park/neutral switch.

11-4 TESTING A TYPICAL HEI, ESC SYSTEM

If an engine equipped with an HEI electronic spark control (ESC) system fails to start, remove a plug cable and attach it to a spark tester. Then, crank the engine over with the ignition switch. If there is no arc at the spark tester, use the troubleshooting steps outlined below to locate the cause of the problem.

Step 1—Start Failure Test

To check the supply voltage at the ESC controller against specifications, do the following:

1. With the ignition switch off, remove the ten-pin connector from the ESC controller.

2. Touch the (-) voltmeter lead to Terminal K of the connector (Fig. 11-14).

3. Touch the (+) voltmeter lead to the Terminal F of the connector.

4. Turn the ignition switch on and note the voltage reading. The reading should be seven volts or higher.

5. If the reading is under seven volts, check for a damaged wire between pin F and the ignition switch. Repair and replace damaged parts as necessary.

6. If the voltage is to specifications, proceed to Step 2.

Step 2—Checking the Distributor Harness

To test the wiring from the distributor to the ESC controller for continuity, do the following:

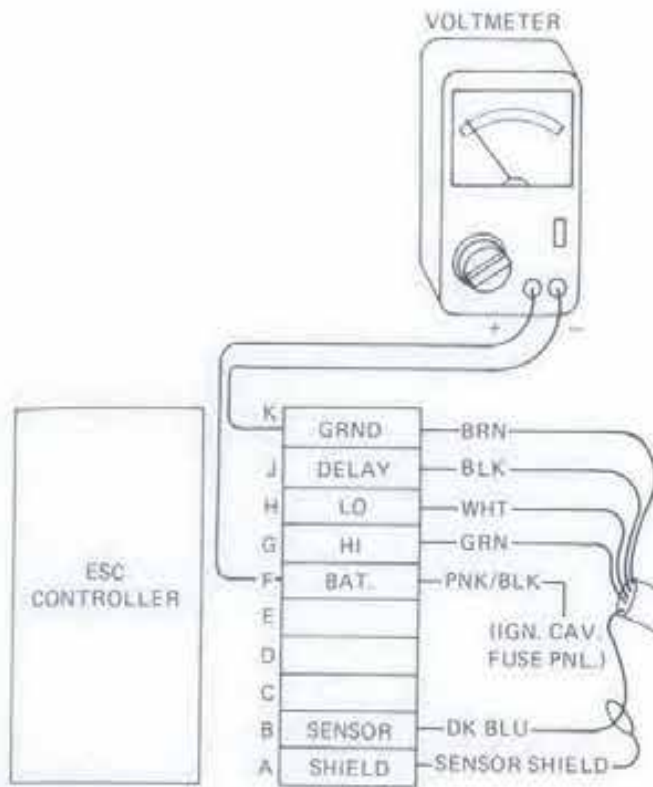


FIGURE 11-14
Testing the supply voltage at the ESC connector.

1. With the ignition switch off, remove the four-pin connector from the distributor.
2. Set the ohmmeter to the $R \times 1$ scale.
3. Touch one ohmmeter lead to Pin K of the ESC connector and the other to Terminal D of the distributor connector (Fig. 11-15). Note and record the ohmmeter reading.
4. Touch one ohmmeter lead to Pin J of the ESC connector and the other to Terminal A of the distributor connector. Note and record the reading.
5. Touch one ohmmeter lead to Pin H of the ESC connector and the other to Terminal B of the distributor connector. Note and record the reading.
6. Touch one ohmmeter lead to Pin G of the ESC connector and the other to Terminal C of the distributor connector. Note and record the reading.
7. All of the readings should indicate continuity. If any do not, repair or replace the wiring harness between the distributor and the ESC controller.
8. Plug in the ESC harness connector at the controller.
9. If all the wires showed continuity, go to Step 3.

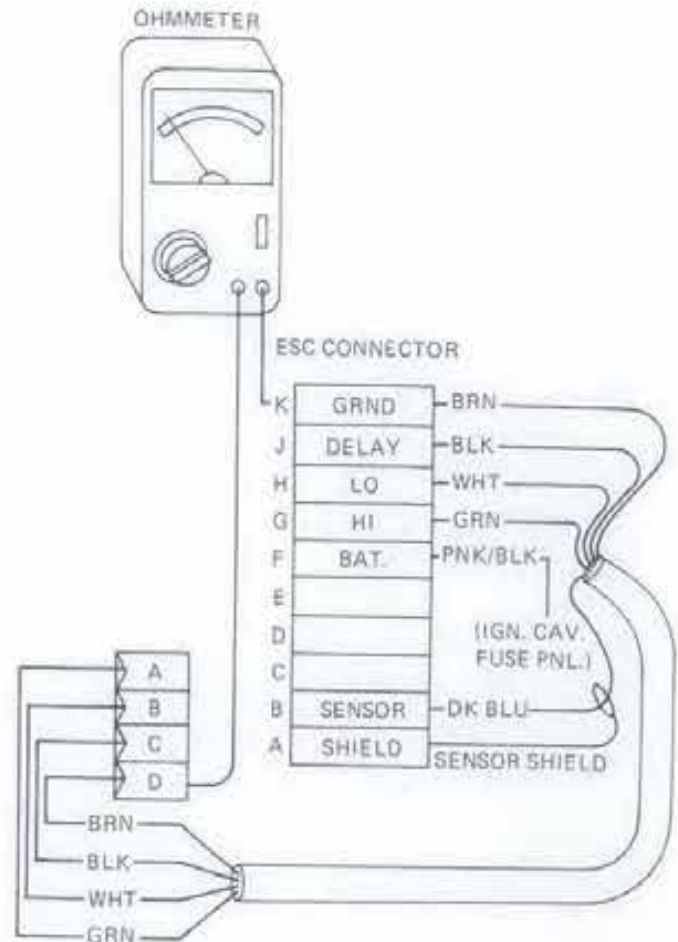


FIGURE 11-15
Checking the distributor-to-controller harness for continuity.

Step 3—Testing Coil Run Voltage

To test the voltage at the coil with the ignition switch in the RUN position, do the following:

1. With the ignition switch off, connect Terminals A and C of the distributor harness connector with a jumper wire (Fig. 11-16).
2. Disconnect the battery wire from the HEI distributor.
3. Attach the (–) voltmeter lead to a good engine ground.
4. Connect the (+) voltmeter lead to the connector on the battery wire.
5. Turn the ignition switch to the RUN position, and note the reading on the voltmeter.
6. If the reading is within one volt of battery voltage, proceed to Step 4.

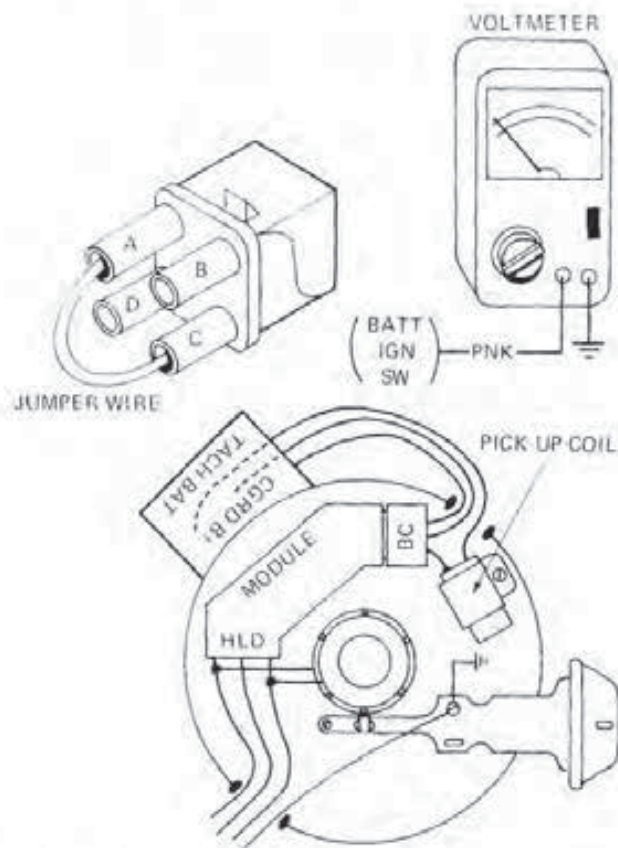


FIGURE 11-16
Testing for run voltage at the distributor harness connector.

7. If the reading is not within one volt, there is high resistance in the circuit. In this case, check the ignition switch, battery cables, neutral safety switch, main harness connectors, and the wiring between these components. Repair or replace defective parts as necessary.

Step 4—Checking Coil Start Voltage

To check the voltage at the coil with the ignition switch in the START position, do the following:

1. With the ignition switch off, connect Terminals A and C of the four-pin connector with a jumper wire (see Fig. 11-16).
2. Attach the (–) voltmeter lead to a good engine ground.
3. Connect the (+) voltmeter lead to the disconnected distributor battery wire.
4. Turn the ignition switch to the START position and note the reading on the voltmeter.

5. If the reading is within one volt of battery voltage, proceed to Step 5.

6. If the reading is not within one volt of that of the battery, there is high resistance in the circuit. In this situation, check the ignition switch, battery cables, neutral safety switch, main harness connector, and wiring between these components. Repair or replace any defective parts.

7. Turn the ignition switch off and plug in both the distributor battery and four-pin connectors.

Step 5—Pickup Coil Short and Resistance Tests

To determine if the pickup coil within the distributor has the correct resistance or is shorted out, follow Steps 3 and 4 as outlined under Section 11-2. If the pickup coil passes these tests, proceed to Step 6.

Step 6—Checking the Ignition Module

To test the serviceability of the module while it is still inside the distributor, do the following:

1. With the ignition switch off, invert the spark tester, as shown in Fig. 11-17, and install it into the coil terminal. Next, ground the tester with a jumper lead.
2. Disconnect the four-pin connector from the distributor.
3. Install a jumper wire between Terminals A and C of the four-pin connector.
4. Disconnect the pickup coil leads from the control module. Do not unplug the module wires from the distributor cap.
5. Attach the (–) voltmeter lead to a good engine ground.
6. Connect the (+) voltmeter lead to the TACH terminal of the distributor cap.
7. Turn the ignition switch to the RUN position.
8. Attach the lead of a test light to the (+) battery terminal.
9. Watch the voltmeter carefully as you touch the test light probe momentarily to the ignition module Terminal D.
10. If a voltage drop occurs, go to Step 7.

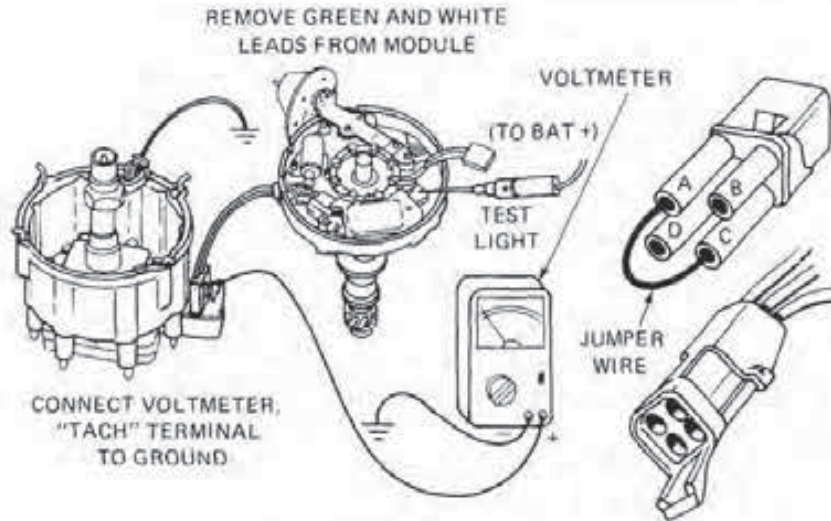


FIGURE 11-17
Checking the ignition module.

11. If there is no voltage drop, inspect and repair the module ground screw.

12. Perform the test again. If there is still no voltage drop, replace the ignition module.

13. Turn the ignition switch off.

Step 7—Testing the ESC Controller

To test the serviceability of the ESC controller, do the following:

1. Check to make sure the jumper wire is still in place between Terminals A and C of the four-way distributor connector (see Fig. 11-17).

2. Attempt to start the engine.

3. If the engine now starts, only operate it at idle. The fact the engine now runs indicates the ESC controller is defective and requires replacement.

4. Before replacing the controller, also perform Step 8.

5. Plug in the four-pin connector at the distributor.

Step 8—Checking Voltage at the ESC Controller

To check the voltage at the ESC controller with the ignition switch in the RUN position, do the following:

1. Make sure that all the vehicle accessories are turned off.

2. Start the engine.

3. With a voltmeter, test and record battery voltage.

4. With the ESC controller connector in place, connect the (–) lead of the voltmeter lead to Terminal K (Fig. 11-18).

5. Touch the (+) voltmeter lead to Terminal F.

6. Note the voltmeter reading. It should be within one volt of that noted in Procedure 3.

7. If the voltage is not to specifications, check the ignition switch wiring from the switch to the controller, and check the charging circuit. Repair or replace any defective parts.

ESC Operational Check

To check the operation of the ESC system, do the following:

1. Operate the engine until it reaches normal running temperature.

2. Shut off all vehicle accessories.

3. Following manufacturer's instructions, install a tachometer on the engine.

4. Set the carburetor fast idle cam on its high

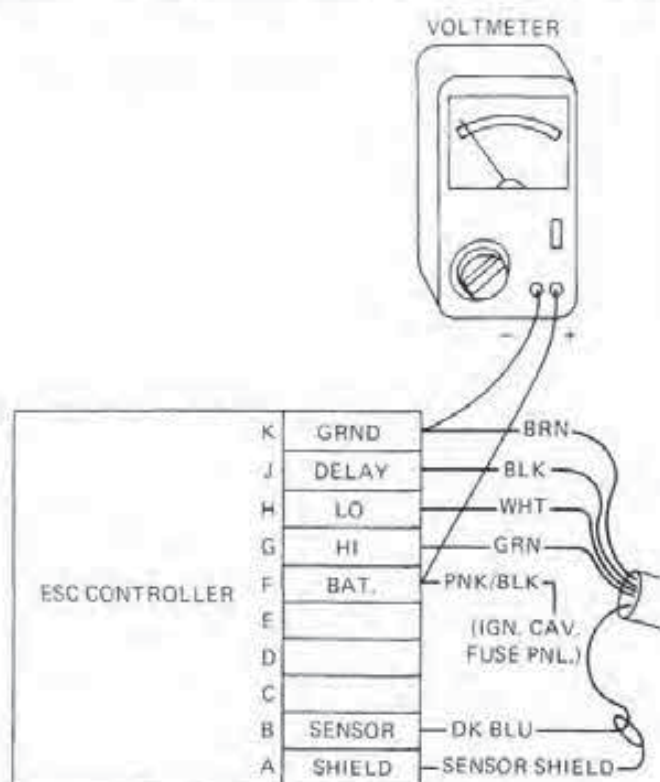


FIGURE 11-18
Testing EST controller run voltage.

step. At this point, engine speed must be above 1,800 rpm. Note and record the rpm.

5. Using a long socket extension or wrench, tap on the front area of the intake manifold near the detonation sensor (Fig. 11-19).

6. Note the engine speed on the tachometer. It should drop 200 rpm or more and return to its original speed within 20 seconds after the tapping stops.

7. If the engine speed does not drop or return as mentioned, test the detonation sensor and ESC system further.

8. Shut off the engine.

Testing the Resistance of the Detonation Sensor

To test the internal resistance of the detonation sensor against specifications, do the following:

1. Run the engine until it reaches its normal operating temperature.

2. Shut the engine off and remove the detonation sensor lead connector.

3. Set the ohmmeter to the $R \times 100$ scale.

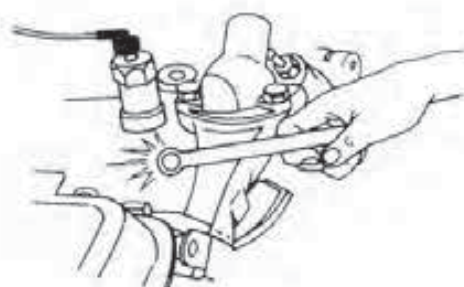


FIGURE 11-19
Tapping on the manifold to check ESC operation.

4. Attach the (-) lead of the ohmmeter to a good engine ground.

5. Touch the (+) voltmeter lead to the center conductor on the detonation sensor (Fig. 11-20).

6. Note the resistance reading on the ohmmeter. If the reading is not to specifications, replace the sensor.

7. If the reading is to specifications, proceed with the sensor wiring continuity check.

Checking Detonation Sensor Wiring Continuity

To check the continuity of the wire between the sensor and the controller, do the following:

1. With the ignition switch off, remove the ten-pin connector at the ESC controller.

2. Install a jumper wire between Terminals A and B of the ESC connector (Fig. 11-21).

3. Disassemble the detonation wiring connector.

4. Set the ohmmeter for the $R \times 1$ scale.

5. Attach the (+) ohmmeter lead to the terminal on the controller side of the harness, indexing with the wire to the center sensor conductor.

6. Touch the (-) ohmmeter lead to the drain wire terminal at the connector.

7. Note the resistance on the ohmmeter. There should be continuity between the sensor wires. If continuity does not exist, repair or replace the wiring harness between the ESC controller and the detonation sensor.

8. If the detonation sensor and its wiring are found okay and the system still does not function, replace the ESC controller.

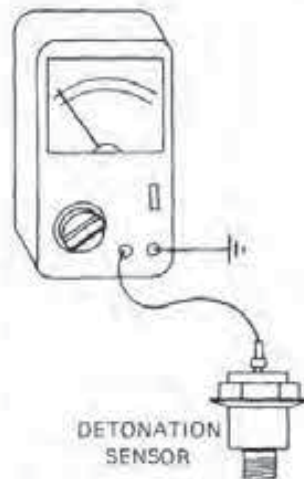


FIGURE 11-20
Checking detonation sensor resistance.

11-5 TESTING A TYPICAL DIS SYSTEM

The procedure outlined below is for locating the cause of a no-start condition on a 3.0-liter engine with a combination crankshaft sensor. The same process on other General Motors engines is somewhat different. *Always follow the service manual when testing the other systems, or damage to system components can result.*

During the following process, you will need to use a DVOM with a 10-megohm or higher input impedance and an unpowered test light. In addition, one step requires the use of a Weather-Pac terminal removal J-28742/BT8234-A and four special jumper leads with male and female terminals (Fig. 11-22). The General Motors part numbers for the terminals are 12014836 and 12014837.

Step 1—Initial Tests

If the engine cranks over but will not start, follow these steps to determine if the ignition system is at fault and, if so, the cause of the problem.

1. One at a time, connect the spark tester to the first, third, and fifth plug wires.
2. Crank the engine over and check for a spark at the tester. Repeat the process on the other two cylinders.
3. If there is no spark at the tester on any cylinder, inspect the system wiring connectors and the ECM and fuel pump fuses. If no problem exists in these areas, proceed to Step 2.

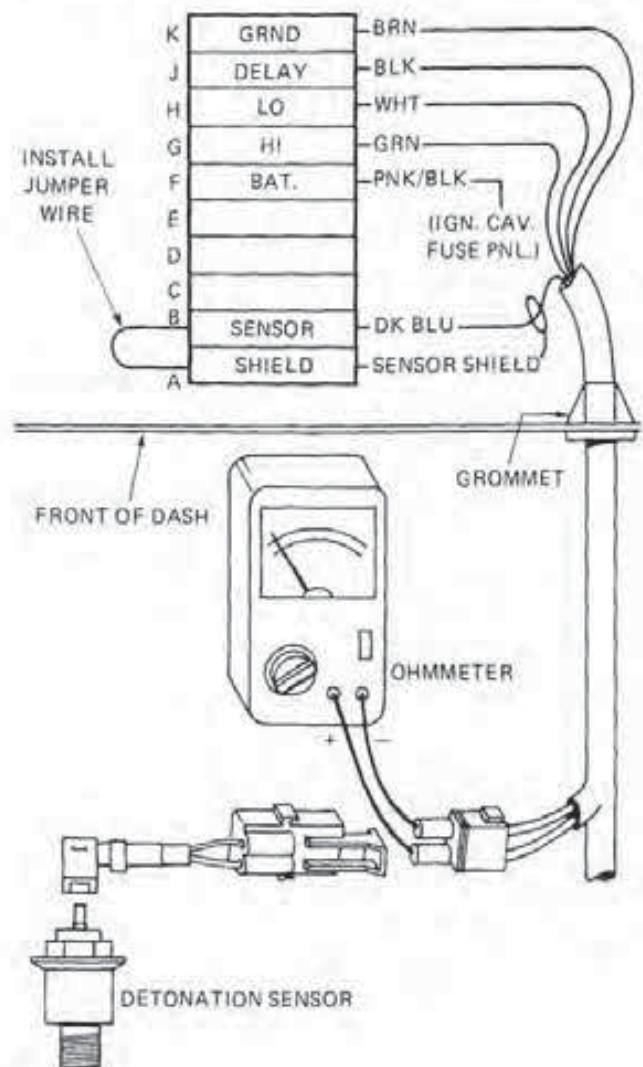


FIGURE 11-21
Testing the detonation sensor wiring for continuity.

Step 2—Checking ECM Reference Voltage

To test the reference voltage at the ECM harness connector, do the following:

1. With the ignition switch off, disconnect the ECM A-B connector.
2. Attach the (-) voltmeter lead to a good ground.
3. Touch the (+) voltmeter lead to Terminal B-5 of the ECM harness connector (Fig. 11-23).
4. Observe the voltmeter while cranking the engine over. The reading should be between one volt and seven volts and varying.

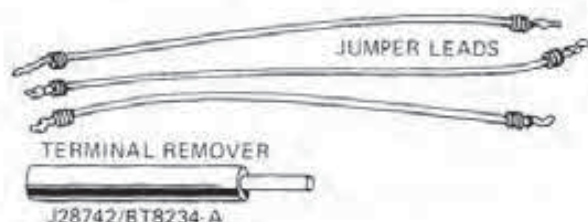


FIGURE 11-22
Weather-Pac terminal remover and jumper leads.

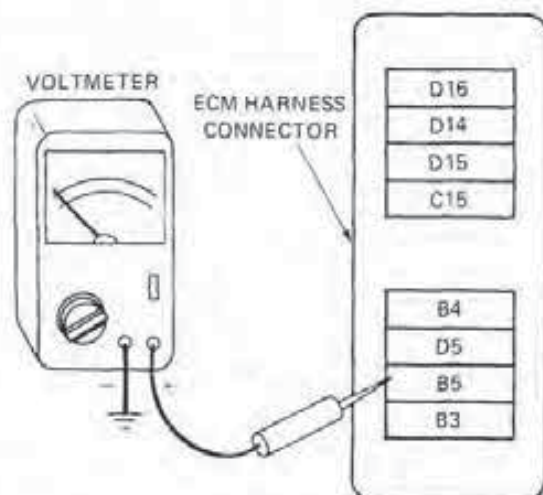


FIGURE 11-23
Checking ECM reference voltage.

5. If the reading is not to specifications, proceed to Step 5.
6. If the reading is okay, go to Step 3.
7. Reinstall the ECM A-B connector.

Step 3—Testing Voltage at the Coil

To check the supply voltage to the coil, do the following:

1. With the ignition switch off, remove the coil assembly screws and tilt back the assembly.
2. Connect the wire end of the test light to a good engine ground.
3. Turn the ignition switch on.
4. Touch the test light probe to the common blue coil feed wire (Fig. 11-24).
5. If the light burns, check the coil connections. If they are okay, replace the ignition module.

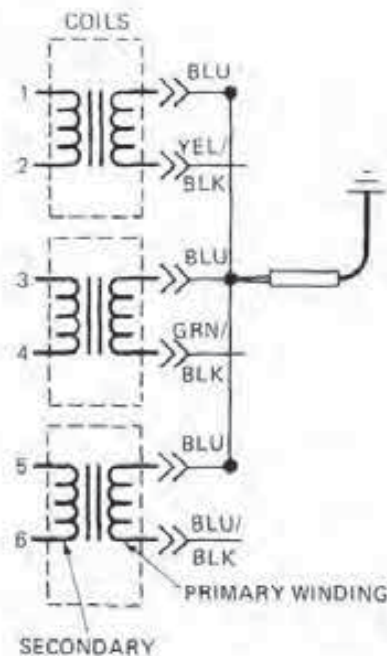


FIGURE 11-24
Testing coil supply voltage.

6. If the light does not burn, proceed to Step 4.
7. Turn the ignition switch off.

Step 4—Checking the ECM Input Voltage to the Ignition Module

To test the ECM supply voltage to the ignition module, do the following:

1. With the ignition off, disconnect the 14-pin connector at the C3 ignition module.
2. Connect the wire end of the test light to a good engine ground.
3. Turn the ignition switch on.
4. Touch the test light probe to Terminal M of the harness connector (Fig. 11-25).
5. If the light does not burn, check the 25-ampere ECM fuse. If it is okay, repair the opening in the feed wire to Terminal M.
6. If the light burns, inspect Terminal M. If it is found satisfactory, replace the ignition module.
7. Turn the ignition switch off.
8. Plug in the 14-pin connector at the module.

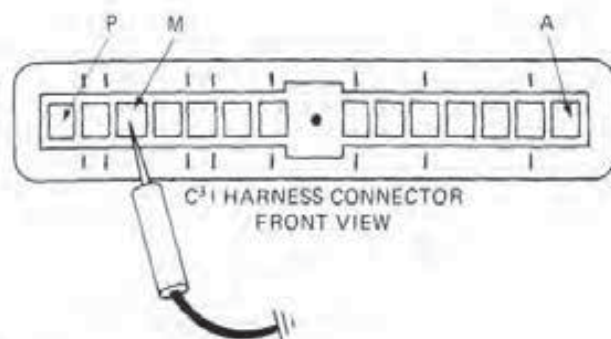


FIGURE 11-25
Checking module supply voltage.

Step 5—Testing Sensor SYNC Signal Voltage

To check the SYNC input signal at the ignition module, do the following:

1. Attach the (–) voltmeter lead to a good engine ground.
2. Connect the (+) voltmeter lead to Terminal K at the module (Fig. 11-26).
3. While observing the voltmeter reading, crank the engine over.
4. If the reading is one volt to nine volts, proceed to Step 9.
5. If the reading is not to specifications, go to Step 6.
6. Turn the ignition switch off.

Step 6—Checking Sensor Input Voltage

To test the sensor input voltage at its connector, do the following:

1. With the ignition switch off, unplug the crankshaft combination sensor's four-pin connector.
2. Connect the (–) voltmeter lead to a good engine ground.
3. Turn the ignition key on.
4. Touch the (+) voltmeter lead to Terminal A of the four-pin connector and observe the meter reading (Fig. 11-27). *Do not use a test light to check for voltage at Terminal A.*
5. Turn the ignition switch off.

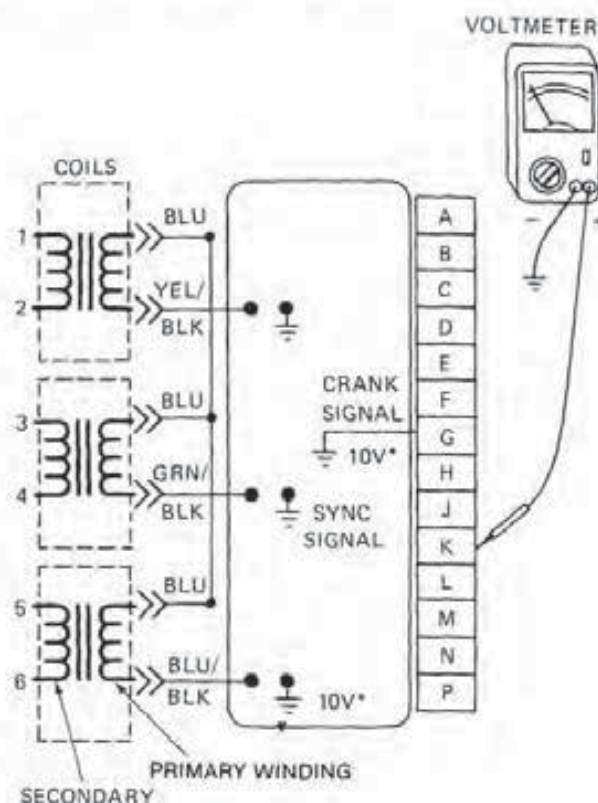


FIGURE 11-26
Testing the sensor SYNC voltage signal.

6. If the reading is between 5 and 11 volts, proceed to Step 8.
7. If the reading is not to specifications, check for an opening in the wire or Terminal H. If the wire and terminal are okay, go to Step 7.

Step 7—Testing ECM Sensor Supply Voltage to the Module

To check the sensor supply voltage from the ECM to the ignition module, do the following:

1. With the ignition switch off, unplug the 14-pin connector at the module.
2. Connect the wire end of a test light to a good engine ground.
3. Turn the ignition switch on.
4. Touch the probe of the test light to Terminal P of the harness connector (Fig. 11-28).
5. If the light does not burn, check the ten-ampere ECM fuse for serviceability. If it is okay, re-

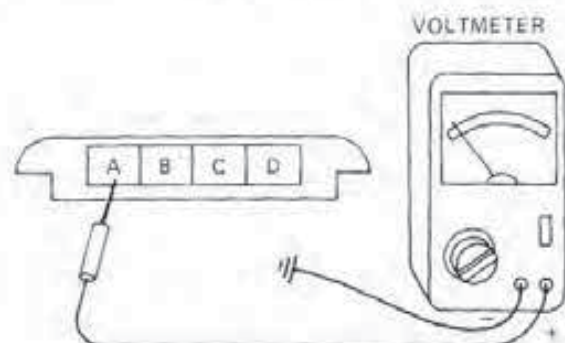


FIGURE 11-27
Checking sensor input voltage.

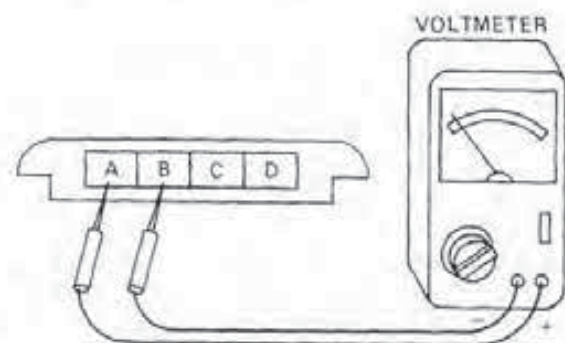


FIGURE 11-28
Testing ECM sensor supply voltage.

pair the open ignition wire to Terminal P.

6. If the light burns, check the connection at module Terminal P. If it is serviceable, replace the ignition module.

7. Turn the ignition switch off.

8. Plug in the 14-pin connector to the module.

Step 8—Checking Sensor Voltage Supply Circuit

To check the sensor supply circuit for continuity, do the following:

1. Connect the (-) lead of a voltmeter to Terminal B of the four-pin sensor connector.

2. Turn the ignition switch on.

3. Touch the (+) voltmeter lead to Terminal A of the four-pin connector (Fig. 11-29).

4. Read the voltage on the meter. If the reading is between five volts and 11 volts, go to Step 9.

5. Turn the ignition switch off.

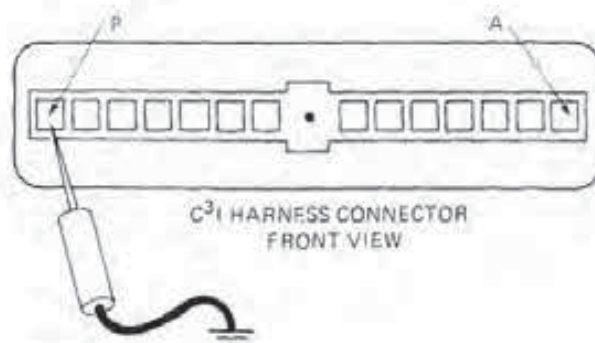


FIGURE 11-29
Checking the sensor supply voltage circuit.

6. If the reading is not to specifications, check for an opening in the wire and Terminal B of the harness. If both are satisfactory, check the connection at module Terminal B. If it is okay, replace the module.

Step 9—Testing Sensor Operation

To check the serviceability of the crankshaft combination sensor, do the following:

1. With the ignition switch off, use the Weather-Pac removal tool to take out the sensor and harness connector terminals.

2. Plug in the four special jumper leads into

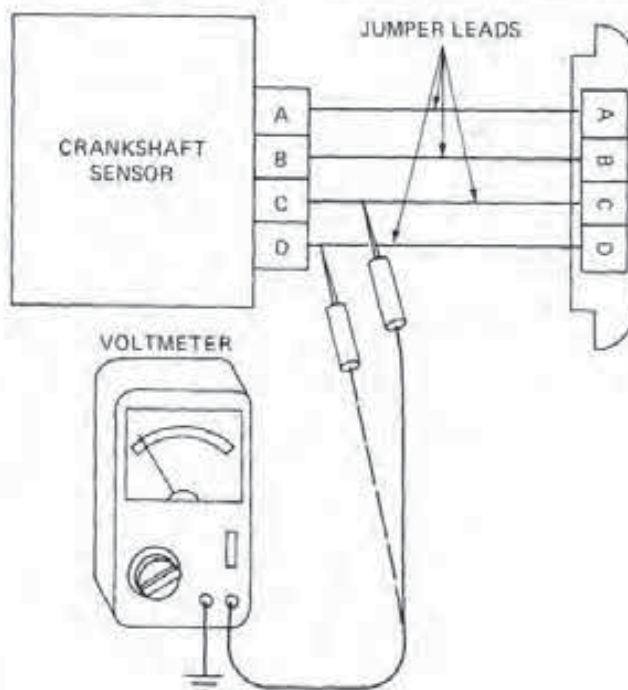


FIGURE 11-30
Testing sensor operation.

harness connector sockets A, B, C, and D. Next, plug the opposite end of each wire into its corresponding socket within the sensor connector.

3. Attach the (-) lead of the voltmeter to a good engine ground.

4. While cranking the engine, touch the (+) terminal of the voltmeter to the jumper lead attached to Terminal C of the sensor (Fig. 11-30).

5. Read the voltage on the meter. It should read a varying 0.7 volt to 9.0 volt.

6. While cranking the engine, touch the (+) terminal of the voltmeter to the jumper lead attached to Terminal D of the sensor.

7. Read the voltage on the meter. It should read a varying 1.0 volt to 9.0 volt.

8. If either or both the readings are not to specifications, replace the sensor.

9. If both the readings are within specifications and the engine will still not start, replace the ignition module.

CHAPTER REVIEW

The following two sections will assist you in determining how well you remember the material contained in this chapter. If you cannot complete the statement or question, refer back to the section marked in brackets that covers the material.

SELF-CHECK

1. What special service items are necessary to test the DIS system [11-5]?
2. Why must you coat the base of the ignition module with a special compound during its installation [11-1]?
3. What equipment is used to operationally check the ESC system [11-4]?
4. What replaces the centrifugal and vacuum advance functions in the HEI, EST system [11-3]?
5. What are the two methods available to check the pickup coil for serviceability [11-2]?

REVIEW

1. In the troubleshooting sequence for a DIS no-start condition, when is it important *not* to use a test light [11-5]?
 - a. when testing sensor input voltage
 - b. when testing SYNC signal voltage
 - c. both a and b
 - d. neither a nor b

2. If an engine will not start, how do you test its HEI system for secondary voltage output [11-1]?

Technician A replies through the use of a spark tester.

Technician B says by removing a spark plug wire.

Who is correct?

- a. A only
- b. B only
- c. both a and b
- d. neither a nor b

3. If a 3.0-liter engine cranks over but will not start, how many crankshaft sensor tests should you make [11-5]?

- a. one
- b. two
- c. three
- d. four

4. Why lubricate the distributor coil-to-cap seal with silicone grease during installation [11-1]?

Technician A states to prevent moisture contamination.

Technician B says to prevent dust contamination.

Who is correct?

- a. A only
- b. B only
- c. both a and b
- d. neither a nor b

5. If there is no power to a DIS ignition circuit, how many fuses should you check for serviceability [11-5]?

- a. three

- b. one
 - c. both a and b
 - d. neither a nor b
6. The HEI rotor is found to be burned through. What is the usual cause [11-1]?
Technician A says a lack of silicone grease on the coil seal.
Technician B states the lack of the special compound on the base of the module.
Who is correct?
- a. A only
 - b. B only
 - c. both a and b
 - d. neither a nor b
7. Coil input RUN and START voltages are checked where in the HEI, ESC system [11-4]?
- a. at the distributor harness connector
 - b. at the distributor battery connector
 - c. both a and b
 - d. neither a nor b
8. In regard to the HEI secondary scope pattern, what portion changes with engine speed [11-2]?
- a. firing
 - b. dwell
 - c. spark line
 - d. intermediate oscillations
9. Test voltages for the ESC system must be within how many volts of battery voltage [11-4]?
- a. one volt
 - b. five volts
 - c. both a and b
 - d. neither a nor b
10. For what reason will you find the HEI firing lines higher than those in a conventional system [11-2]?
Technician A replies it is due to wider spark plug gaps.
Technician B says it is due to a wider rotor air gap.
Who is correct?
- a. A only
 - b. B only
 - c. both a and b
 - d. neither a nor b
11. The speed of an ESC equipped engine should drop _____ or more while tapping on the intake manifold [11-4]?
- a. 50 rpm
 - b. 100 rpm
 - c. 150 rpm
 - d. 200 rpm
12. What equipment is necessary to test HEI pickup coil resistance [11-2]?
- a. ohmmeter
 - b. voltmeter
 - c. vacuum pump
 - d. both a and c
13. In the EST system, what should the timing do with the ALCL test terminal grounded [11-3]?
Technician A says it should not change.
Technician B states it will change.
Who is correct?
- a. A only
 - b. B only
 - c. both a and b
 - d. neither a nor b
14. What equipment is necessary to test a Hall-effect switch [11-3]?
- a. a 12-volt battery and a voltmeter
 - b. a 12-volt battery and an ohmmeter
 - c. both a and b
 - d. neither a nor b
15. When testing the HEI, EST ignition module, where is the spark tester installed [11-3]?
Technician A states in the coil terminal.
Technician B replies on a spark plug cable.
Who is correct?
- a. A only
 - b. B only
 - c. both a and b
 - d. neither a nor b

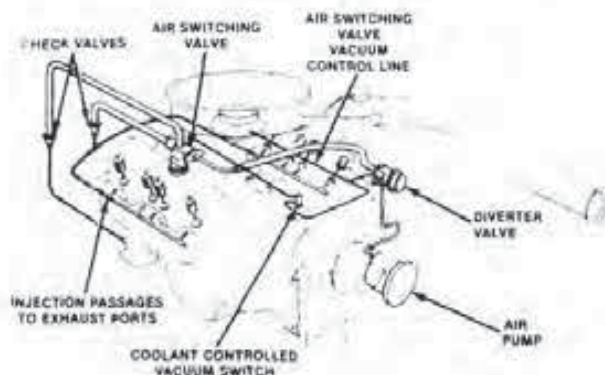
Chapter 12

COMPUTERIZED AIR INJECTION SYSTEMS

OBJECTIVES

After reading and studying this chapter, you will be able to

- explain the functions of the air injection system.
- describe the purpose and design of air injection system components.
- relate the design features and function of a typical Ford air injection system.
- describe the function and design of the components in a typical Chrysler air injection system.
- relate the design features and purpose of a typical General Motors air injection system.

**FIGURE 12-1**

Typical air injection system (Courtesy of Chrysler Motors Corp.)

Since the passage of the first California and federal emission control standards, manufacturers have extensively used various types of air injection systems (Fig. 12-1). There are several reasons for the popularity of air injection. First, the system is an external add-on unit that adapts to and functions well on most gasoline engines. Second, although the air pump does use up a small amount of engine power to drive it, and the system components take up space in the engine compartment, air injection does not affect the driveability of a vehicle like other emissions control equipment has in the past.

In the automobile industry, this system can have several different names, depending on the vehicle manufacturer. Some of the most common system names given include American Motors Air Guard, Chrysler Air Injection, Ford Thermactor, and General Motors Air Injection Reactor (AIR).

12-1 FUNCTION OF THE AIR INJECTION SYSTEM

Regardless of its name, the purpose of the system is the same no matter which vehicle it is on. However, there are functional and design differences between the systems used on early vehicles and those found on later designs with dual-bed catalytic converters.

System Function Before Dual-Bed Converters

The function of a basic air injection system is to introduce fresh air, with its oxygen content, into the hot exhaust of an operating engine. This action causes further burning, or oxidation, of the hydrocarbons (HC) and carbon monoxide (CO) remaining

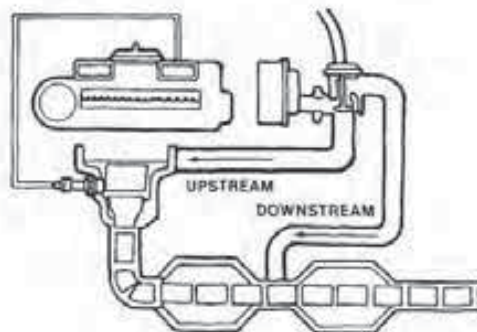
in the exhaust gases. During the process, the injected oxygen combines with the hydrocarbons to produce water (H_2O), usually in a vapor form, and with the carbon monoxide to form carbon dioxide (CO_2). As a result, the system is very effective in lowering both HC and CO emissions from any type of gasoline engine.

In some engine configurations, the air injection system directs the air into the exhaust manifold. In others, the system forces the air into the exhaust ports of the cylinder head. In either case, the end result is the same. Finally, on vehicles with single-bed catalytic converters, air flow from the system also provides the necessary oxygen content for this unit to continue oxidizing HC and CO emissions. The catalytic converter can then further reduce the levels of HC and CO from a vehicle.

System Function with a Dual-Bed Converter

When used with a dual-bed catalytic converter, the basic function of the air injection system remains the same. That is, the system forces a quantity of fresh air into the exhaust system. The main difference between the early and later designs is that when air injection is used with a dual-bed converter, the system can direct the air flow into different locations.

During cold engine operation, for example, the injection system supplies air to the upstream location (Fig. 12-2). This provides additional oxygen to begin further burning of the HC and CO compounds (that are normally higher at lower engine temperatures) either within the head or exhaust manifold. In reality, the head or exhaust manifold is the only warm area in which the oxidation could take place when the engine is cold, except for the combustion chambers.

**FIGURE 12-2**

Air injection system used with a dual-bed converter. (Courtesy of Chrysler Motors Corp.)