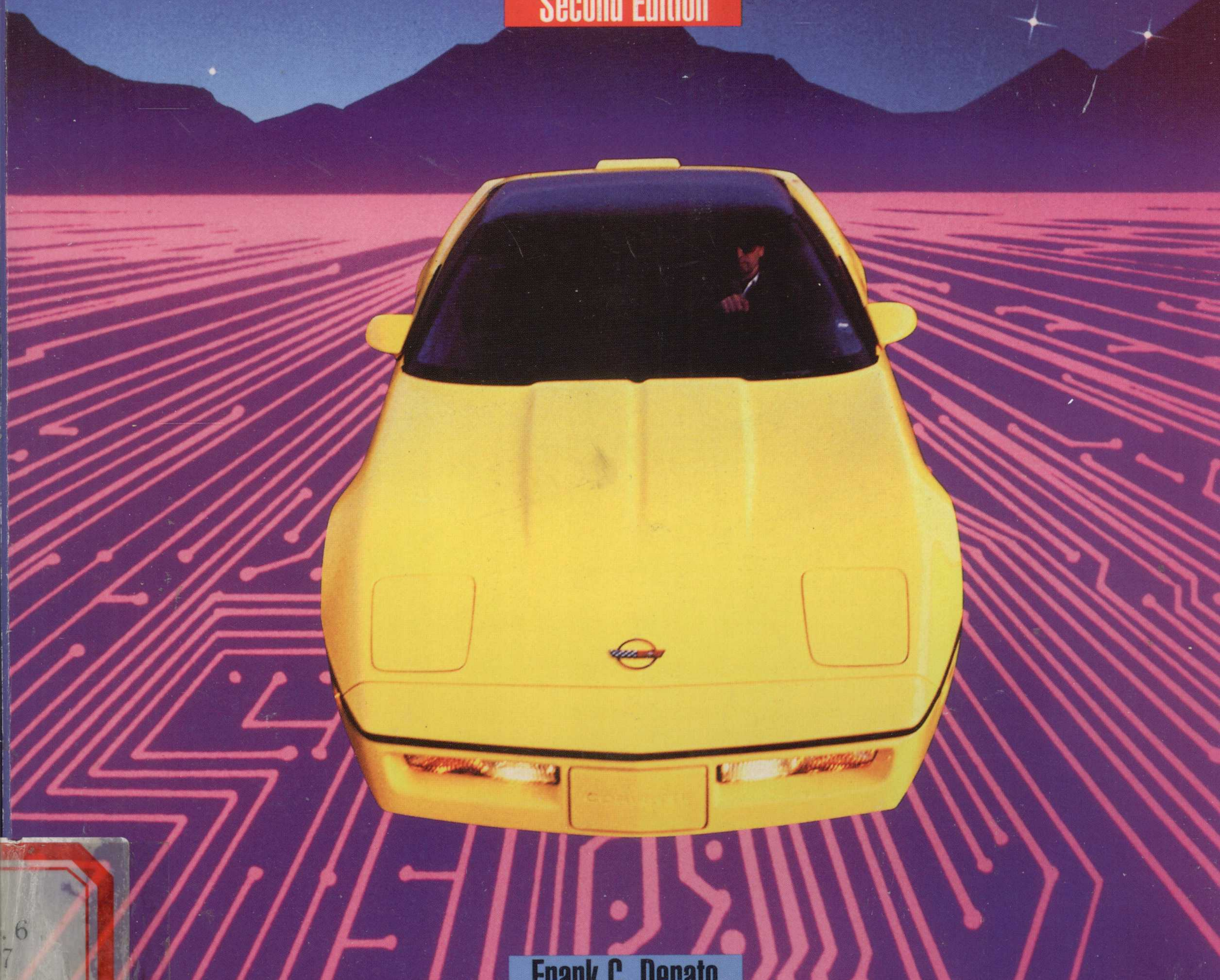
AUTOMOTIVE

ELECTRICAL AND ELECTRONIC SYSTEMS

Second Edition



Frank C. Derato

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PREFACE

Since the first edition of this book was published, many changes have taken place in automotive electrical systems. These changes are largely related to the increased use of microcomputers. At one time, it was a novelty to have a computer in an automobile. Now, it is commonplace. Microcomputers have become an integral part of electrical system design. On-board computers control such functions as ignition, fuel delivery, and vehicle emissions. Electricity and electronics are now being applied to parts of the automobile that were never before electrically operated. For example, microcomputers are used in electronically controlled power-steering systems, suspension systems, and automatic transmissions, and in antilock-brake and traction-control systems.

As the automobile becomes increasingly complex, new and more sophisticated service techniques must be learned. This two-book set, textbook and shop manual, provides information on the latest electronic systems. These books have been designed to prepare a technician for the National Institute for Automotive Service Excellence (ASE) Electrical Systems Test. The information provided is relevant to that required for the test, and the end-of-chapter questions are similar in format to questions found in the test. But the information in this edition is not limited to that required for the ASE test. The coverage has been expanded to include distributorless ignition systems, electronic fuel injection, and passive restraints.

The *textbook* presents a background of basic electricity, magnetism, semiconductors, and microcomputers. Then, the battery and the ignition, charging, and starting systems are analyzed in detail. The operation of horn, windshield wiper, lighting, signal, and power accessory circuits is covered. A detailed description of the various types of instrument panel displays is included. Finally, passive restraints, and systems such as entertainment, cellular telephone, keyless entry, antitheft, and speed control are covered.

The *shop manual* covers the service aspect of the topics covered in the textbook. Chapters on basic electrical troubleshooting and the use of diagnostic equipment are also presented.

These two books provide automotive students with the means to learn electrical systems from basic concepts to the advanced electronic systems. They also provide experienced technicians the opportunity to learn the latest troubleshooting methods. No matter how complex these systems seem, the basic principles of electricity still apply. With a thorough knowledge of the basics, and the proper test equipment, a technician can diagnose trouble in any of these systems.

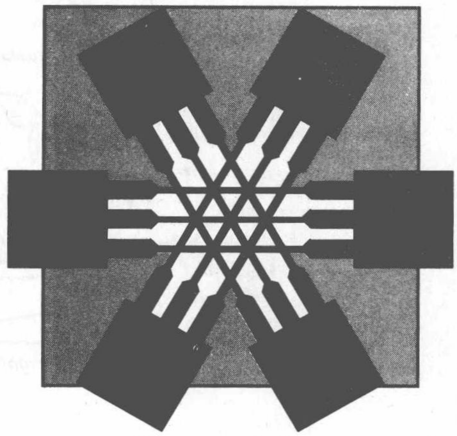
The author would like to thank the many people who helped in the preparation of this book including Freida O'Neil-Robinson, the editor, and Linda D. Jefferson, the production editor, and especially, Howard Buzzutto, Bill Campana, John Greenhalgh, Richard N. Hipp, Edward J. Karl, Ray Legenzowski, Frank Ofiero, James E. Raymond, Paul Rysz, and Peter Rysz, who provided technical assistance. The author is grateful to Les Goings, Henry Ford Community College, Michigan; Sheldon Huber, International Technical Institute, Florida; Joe Rich, Harrisburg Area Community College, Pennsylvania; and Fredrick McGuire, State Technical Institute, Tennessee, for their detailed and practical suggestions.

Frank C. Derato

CONTENTS

CHAPTER 1

ELECTRICITY AND THE AUTOMOBILE



OBJECTIVES

After you have studied this chapter, you should be able to:

1. Discuss the ways that electricity and electronics are used in automobiles.
2. Explain the functions of the major electrical components of an automobile.
3. Explain how microcomputers are used in automobiles.

The first electrical device used on an automobile was the spark plug. Jean J. Lenoir is credited with inventing the spark plug in 1860, 26 years before the first automobile. He was working on an internal combustion engine to be used as a stationary engine for industrial purposes.

In 1886, Gottlieb Daimler and Karl Benz, working independently, each built an automobile. These vehicles, both built in Germany, are considered the first successful automobiles. Both were powered by internal combustion engines, but only the engine designed by Benz used a spark plug. He used a small battery to provide electrical energy to the spark plug. (*Energy* is the ability to do work.) The engine designed by Daimler used a gas flame as the method of ignition and did not require electricity in any form. In fact, the first automobiles did not even use electricity for lighting. Acetylene gas lamps were used when automobiles were driven at night.

The early cars did not have starter motors; they were cranked by hand. But hand cranking was dangerous. Many people were injured, breaking fingers, hands, or wrists while attempting to crank an automobile. In 1912, an electric starter motor was developed by Charles F. Kettering. It was first used on the 1912 Cadillac. This was the first car to combine ignition, starting, and lighting in a complete electrical system. It represented the most advanced technology of the time.

Figure 1–1 on page 2 shows the complete electrical system of a 1920 Model T Ford. The electrical equipment on that car consisted of a battery, an ignition system, a generator, a starter motor, a horn, two headlamps, and a single taillamp. Judged by today's standards, these early systems appear primitive.

The electrical systems used in the early cars were just that—*electrical systems.* The term *electronics* does not apply to any of the equipment on those cars. An electrical system has components such as wires, switches, motors, and lamps, and these components perform relatively simple functions. The word *electronics* implies the use of transistors. (Before transistors were developed, vacuum tubes were used.) An electronic system can perform complex functions. Examples of electronic systems are radios and computers. The first use of electronics in automobiles was the car radio. Radios became widely used in cars in the 1930s.

For many years, the electrical systems of cars remained relatively simple. Even as late as the 1960s, a diagram of the electrical system of an automobile could be printed on a single page the size of this book. But since then, the automobile electrical system has gone through many changes and has become increasingly complex. The modern automo-

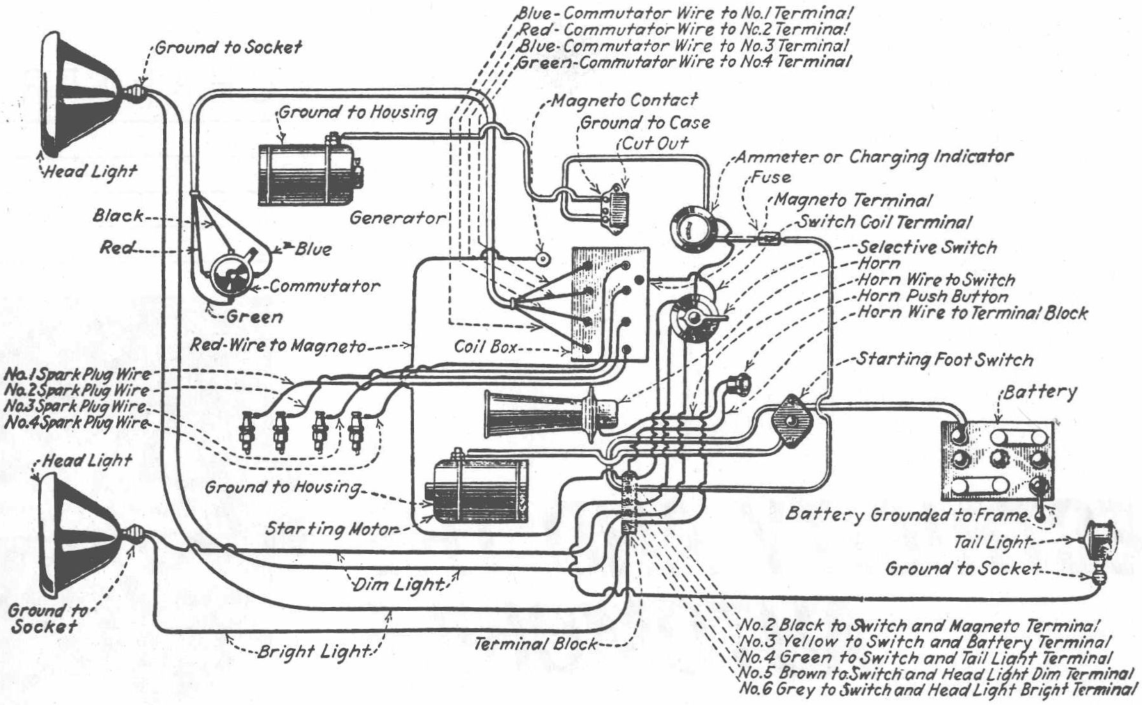


Fig. 1–1. Wiring diagram for a 1920 Motel T Ford.

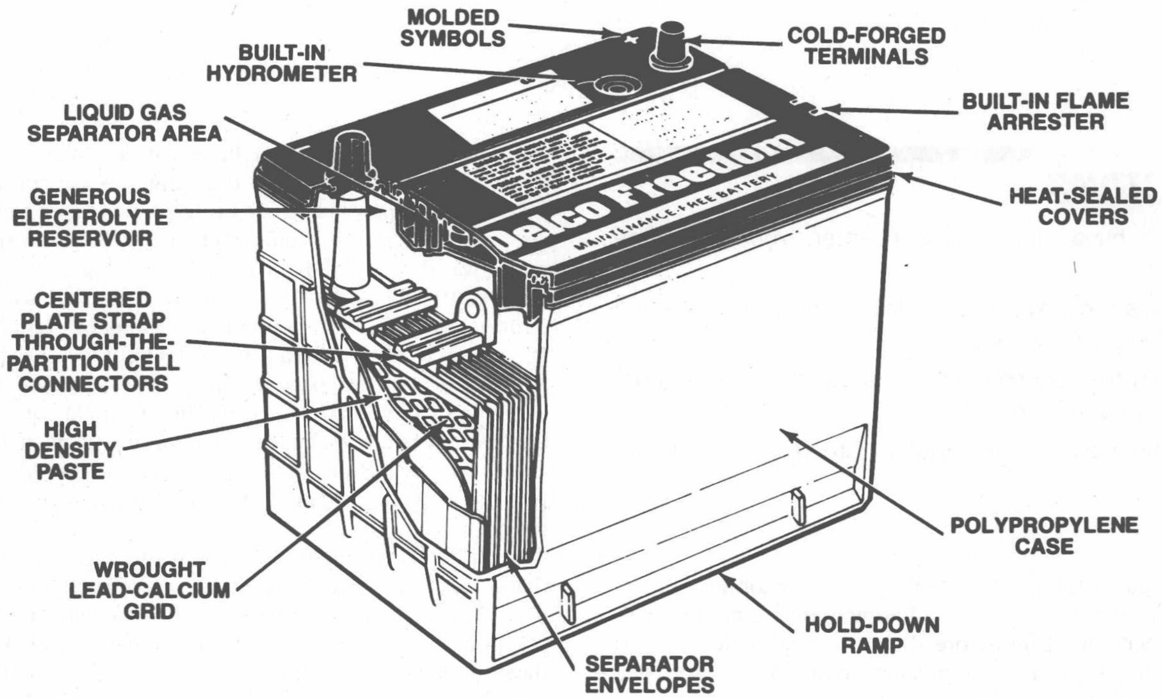


Fig. 1–2. An automotive battery. *(General Motors Corporation)*

bile uses electricity and electronics in all phases of vehicle operation. Now, instead of a single-page diagram, some cars have a manual of 50 to 60 fold-out pages to show the entire electrical system. Today's automobile uses the latest in electronic technology—from the microprocessors in computerized engine control systems to the electronic displays on instrument panels. This chapter shows some of the ways that electricity is used in automobiles.

THE BATTERY

A *battery* is a device that converts chemical energy into electrical energy (Fig. 1–2). The battery supplies electric current to the starter motor and to the ignition system while the engine is being cranked. While the engine is running, the battery stabilizes the voltage in the charging system. In addition, if there is a greater demand for current than the charging system can supply, the battery will provide the additional current. On vehicles with microcomputers, some of the computer circuits must remain operational even if the vehicle is not being used. The battery supplies the energy to do this. Batteries are described in Chapter 8.

THE CHARGING SYSTEM

The charging system includes the battery, the alternator, and the regulator (Fig. 1–3). When the engine is started, the battery supplies the energy to operate the starter motor. However, the battery cannot supply energy indefinitely. If the energy is not replaced, the battery will run down and stop functioning.

The purpose of the charging system is to replace the energy removed from the battery. This is called *charging the battery*. The alternator is used for this purpose. An *alternator* is a device that converts mechanical energy into electrical energy. The alternator is belt-driven from the engine crankshaft.

The *regulator* controls how much the alternator charges the battery by adjusting the charging rate of the alternator to the needs of the battery. At one time, regulators were electromechanical devices (Chap. 3) and were separately mounted in the engine compartment. Now, regulators use electronic components and are made small enough to be built into the alternator (Fig. 1–4). On some vehicles, the regulator is part of the engine-control computer. Charging systems are covered in Chapter 12.

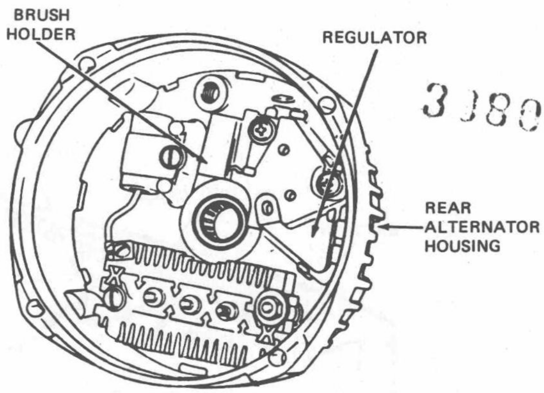


Fig. 1–4. Rear housing of an alternator, showing the location of the electronic regulator. *(Chevrolet Motor Division of General Motors Corporation)*

THE STARTING SYSTEM

An engine cannot be started if the pistons are not moving. This is because the pistons must be moving on their intake strokes for air and fuel to enter the cylinders. If the pistons were standing still, no fuel would enter the cylinders and combustion could not take place.

Hand cranking was not difficult on the old one- and two-cylinder engines. But as engines became larger, hand cranking became more difficult. The starter motor replaced the hand crank. The *starter motor* is an electric motor that

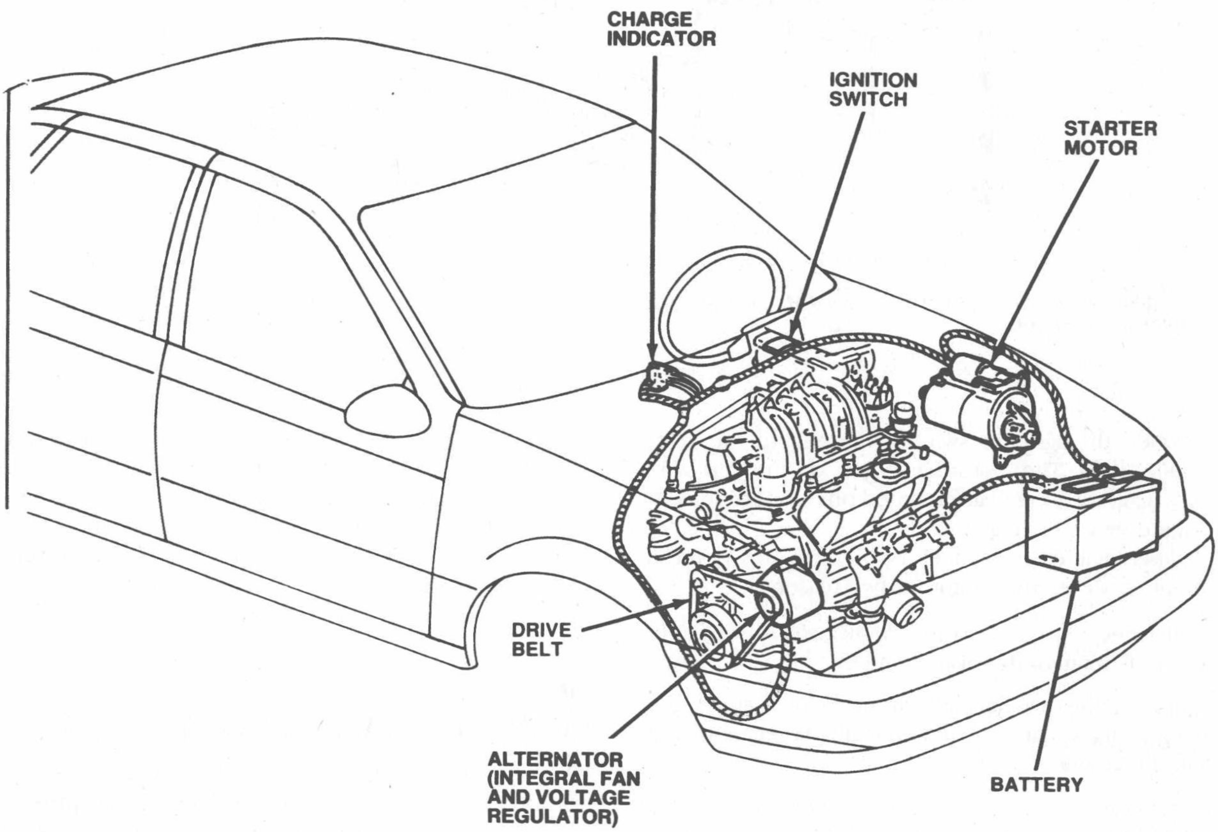


Fig. 1–3. Components of a charging system. *(Ford Motor Company)*

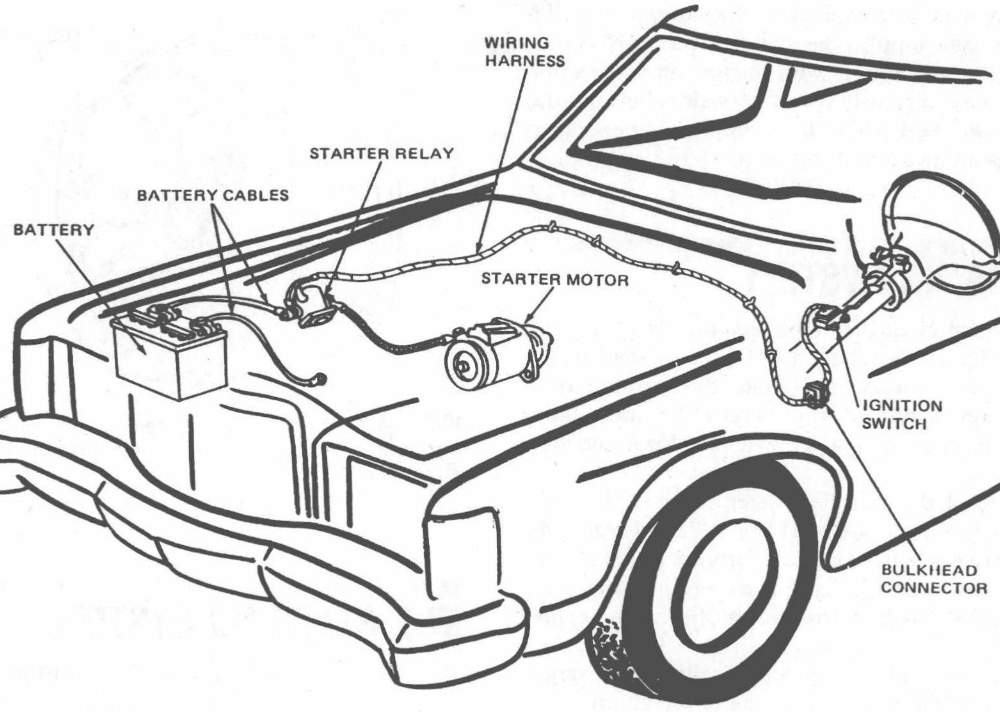


Fig. 1-5. Components of a starting system. *(Ford Motor Company)*

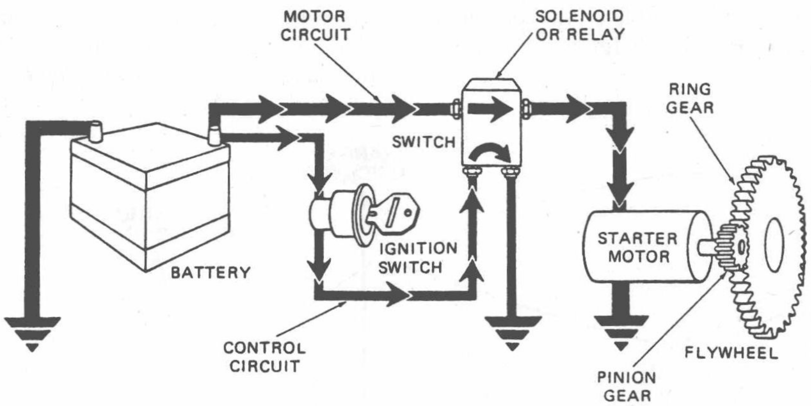


Fig. 1-6. Diagram of a starting system. *(Chevrolet Motor Division of General Motors Corporation)*

operates when the ignition switch is turned to the START position (Fig. 1-5). The motor has a gear on the end of its shaft that engages a large gear mounted on the outside edge of the engine flywheel (Fig. 1-6).

The large-diameter flywheel is used as the point of engagement for the starter motor for two reasons:

- The flywheel is bolted to the crankshaft, so when the flywheel is rotated, the pistons move.
- Because of the mechanical advantage of a small gear driving a large gear, a relatively small starter motor can crank the engine.

Other components used in starting systems are relays and solenoids (Chap. 3). They are used to direct electric energy from the battery to the starter motor when the ignition switch is turned to the START position. In addition, solenoids engage the starter-motor gear into the flywheel gear. Once the engine starts, the starter-motor gear automatically disengages from the flywheel. If the starter motor remained engaged after the engine started, the starter motor would be driven at an excessive speed and would be damaged. Starting systems are described in Chapter 10.

THE LIGHTING SYSTEM

Automotive lighting can be separated into exterior and interior lighting. Exterior lighting includes headlamps, parking lamps, stoplamps, turn-signal lamps, backup lamps, fog lamps, and side-marker lamps (Fig. 1-7). The purpose of exterior lighting is to illuminate the road and to provide warning to other drivers. Most exterior lighting is regulated by state and federal law. These laws regulate the size and number of lamps and the lighting pattern produced by the headlamps.

Interior lighting includes instrument-panel lamps, map lamps, dome lamps, and courtesy lamps. Interior lighting is used for safety and convenience. Vehicle lighting is covered in Chapter 14.

INSTRUMENTS AND WARNING DEVICES

Gauges and warning devices provide information to the driver on the operating conditions of the vehicle (Fig. 1-8). This information includes fuel level, oil pressure, engine-coolant temperature, and the condition of the brake system. As the use of electronics increases in automobiles, more information is provided to the driver. For example, some vehicles have electronic circuits that warn the driver if the fuel drops below a certain level or if a headlamp or taillamp has burned out.

Information is also presented to the driver in the form of electronic displays (Fig. 1-9). Displays use numbers, words, or symbols to represent operating conditions in the vehicle. Gauges, warning devices, and displays are covered in Chapter 16.

MICROCOMPUTERS

A *microcomputer* is a miniature computer (Fig. 1-10 on the next page). When used in an automobile, a microcomputer receives information from various sensors, processes that information, and then controls some part of the vehicle operation. Most late-model vehicles have microcomputers. In fact, some cars are built with as many as seven or more microcomputers to control various vehicle functions. Microcomputers are described in Chapter 6.

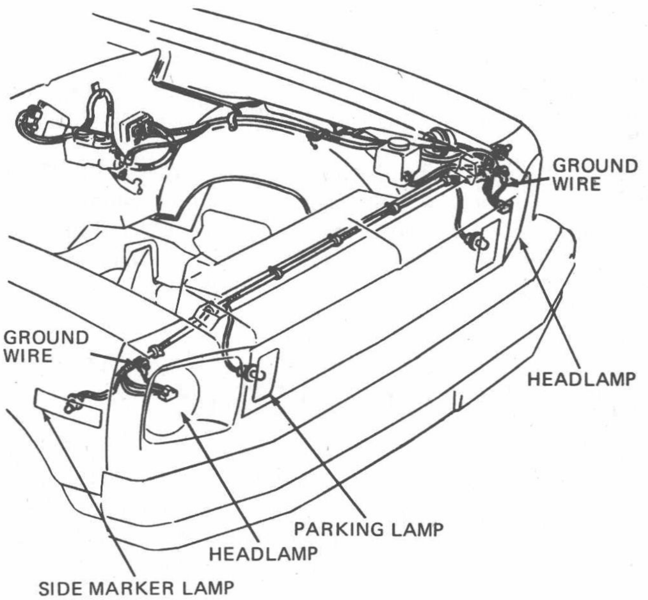


Fig. 1-7. Exterior front lighting. *(Chevrolet Motor Division of General Motors Corporation)*

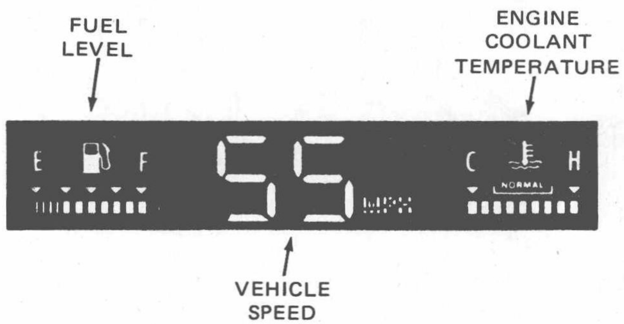


Fig. 1-9. Electronic display. *(Ford Motor Company)*

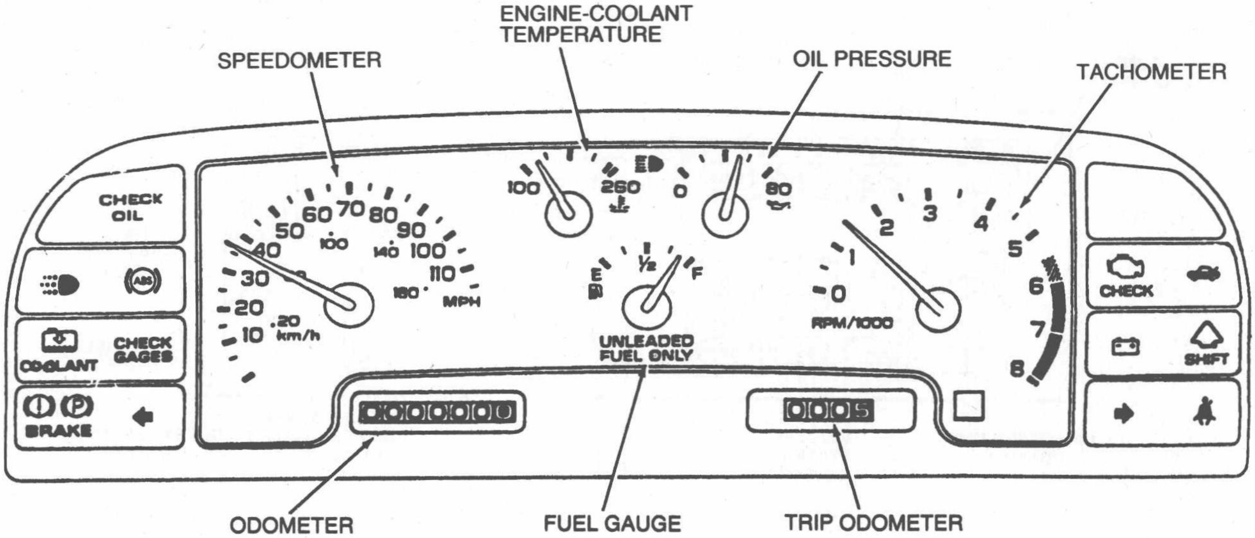


Fig. 1-8. Automobile instrument panel. *(Chevrolet Motor Division of General Motors Corporation)*

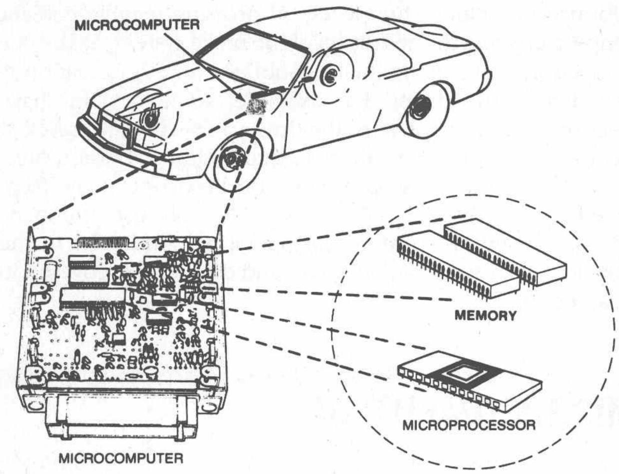


Fig. 1-10. A microcomputer, showing the location of the microprocessor and memory chips. *(Ford Motor Company)*

CONVENIENCE SYSTEMS

Power windows, power seats, electric door locks, speed control, and antitheft alarm systems are part of the convenience systems of automobiles. Although some of these systems have been used on cars for many years, they are constantly being upgraded. On some cars, for example, power seats are electronically operated. A microcomputer "remembers" the seat position selected by the driver. Then, if the seat is moved, operating a switch automatically returns the seat to the selected position.

This feature is particularly useful if a car is driven by two drivers. Each driver stores his or her seat position in the microcomputer memory. Then, when one of the drivers enters the car and presses a button on the seat control, the microcomputer operates the seat-positioning motors, and the seat moves to the desired position. Convenience systems are covered in Chapter 18.

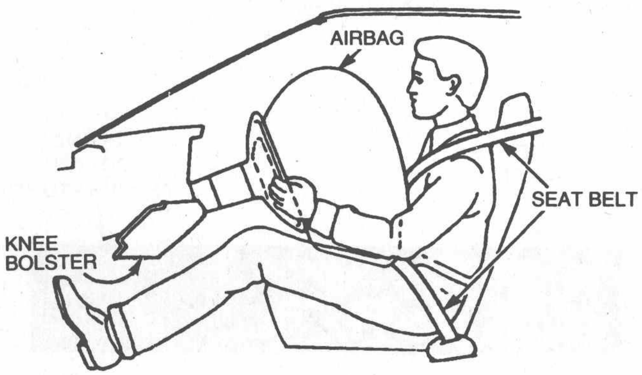


Fig. 1-11. Restraint devices. *(Chevrolet Motor Division of General Motors Corporation)*

SAFETY

Many components used on cars are safety-related. These components include windshield wipers and washers, horns, window defrosters, motorized shoulder belts, and air bags (Fig. 1-11). These components are covered in Chapter 15 and Chapter 17.

ENTERTAINMENT SYSTEMS

AM and FM radios, stereo tape players, and compact disc (CD) players are part of the entertainment systems of many automobiles (Fig. 1-12). In addition, premium sound systems with separate amplifiers and high-quality speakers are available on many cars. Electronic tone controls called *graph-*

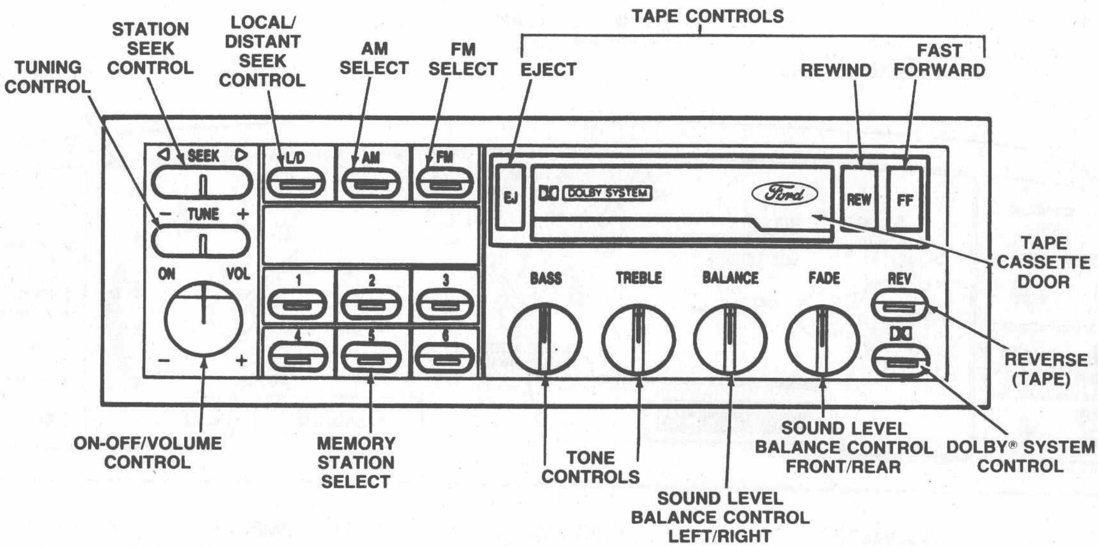


Fig. 1-12. AM-FM radio and tape player combination. *(Ford Motor Company)*

ic equalizers are used in some systems to allow the listener to precisely adjust the quality of the sound to that desired. Entertainment systems are covered in Chapter 18.

CELLULAR TELEPHONES

Many vehicles are equipped with cellular telephones. These allow the driver to place or receive telephone calls in the vehicle. A cellular telephone is a transceiver. That is, it is a radio transmitter and receiver that sends and receives radio signals. Outgoing signals are sent to a location with an antenna mounted on a tower or a high building (Fig. 1-13). From there, the signals are routed over telephone lines or sent to another mobile telephone. Incoming signals are sent from the antenna back to the cellular telephone. Cellular telephones are covered in Chapter 18.

ELECTRONIC INFORMATION SYSTEMS

Many cars have some type of electronic information system such as a travel information system or electronic message center (Fig. 1-14). These systems are microcomputer-controlled and display information in the form of words or numbers. A travel information system provides the driver with information relating to time, distance, and fuel usage. On some systems, for example, the driver can select readouts of average or instantaneous fuel economy, average speed, time of arrival at a given destination, or distance to fuel tank empty.

Some systems combine a travel information system with an electronic instrument panel, and are called *message centers* by some manufacturers. In addition to travel information, these systems display information such as oil pressure and

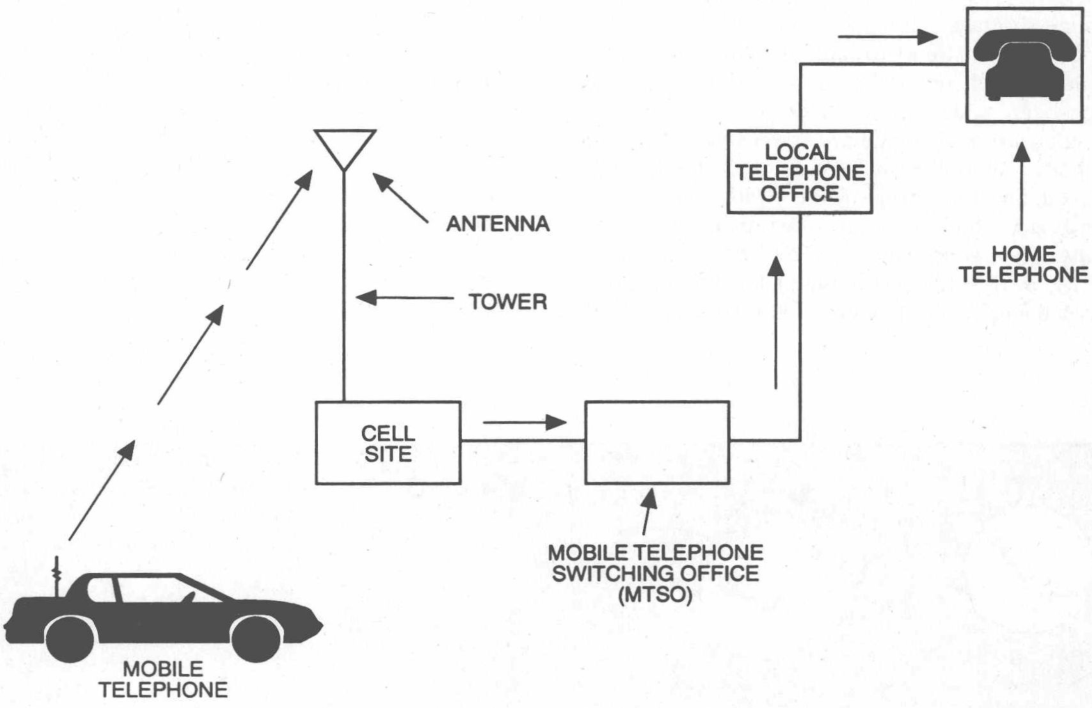


Fig. 1-13. A cellular telephone network.

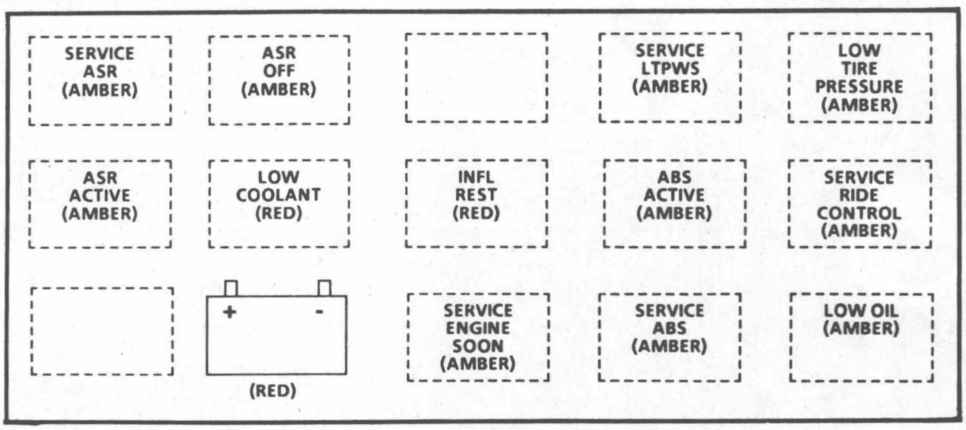


Fig. 1-14. Driver information center. *(Chevrolet Motor Division of General Motors Corporation)*

engine coolant temperature, and advise the driver if there is a problem such as a burned-out headlamp or low brake-fluid level.

ENGINE CONTROL SYSTEMS

For many years, the trend in automobiles was toward larger, faster cars, with bigger, more powerful engines. Little thought was given to fuel economy because gasoline was plentiful and inexpensive. Even less thought was given to the effect of the automobile on the environment. But by the 1950s, air pollution in some cities had become a serious threat to health. Scientific research showed that certain chemicals produced by automobiles were causing air pollution and subsequent health problems. This research led to federal air-pollution standards for automobiles and to the pollution-control devices used on automobiles today.

In the early 1970s, much of the world was affected by a severe gasoline shortage. This drastically raised the price of gasoline and started a trend toward fuel-efficient vehicles. Since that time, much research has been done, and many changes have been made in automobiles.

The results, although they have taken years to achieve, have been good. Air pollution from automobiles has been greatly reduced, and fuel economy has nearly doubled. The Federal standard for fuel economy is expressed in terms of *Corporate average fuel economy (CAFE).* The CAFE number represents the average fuel economy of all the car models produced by a manufacturer in a given year. For example, the CAFE standard for 1993 was 27.5 miles per gallon, a figure that was considered nearly impossible in the 1960s.

These achievements have been brought about largely through the development of microcomputers and their use in electronic engine-control systems (Fig. 1–15). In an electronic engine-control system, sensors provide a microcomputer with information on engine operation. The sensors measure such things as coolant temperature, air temperature, engine speed, and barometric pressure. On the basis of the information provided by the sensors, the microcomputer makes decisions and sends signals to control devices. In this way, the ignition timing, air-fuel mixture, and emission controls are constantly maintained at their best adjustment.

ON-BOARD DIAGNOSTICS

Most cars with computer controls have some form of diagnostic capability. That means that the computer is capable of diagnosing trouble in the system that it controls. If trouble occurs, the computer stores a coded number, called a *service code* or *trouble code,* in its memory. To diagnose trouble in the vehicle, the service technician must retrieve the service code from the computer memory. The service code does not usually indicate which component is bad. Instead, it directs the technician to a particular system or part of the vehicle that should be tested.

Service codes are retrieved by connecting a diagnostic tester (sometimes called a *scan tool*) to a diagnostic connector on the vehicle (Fig. 1–16). On some cars, the service

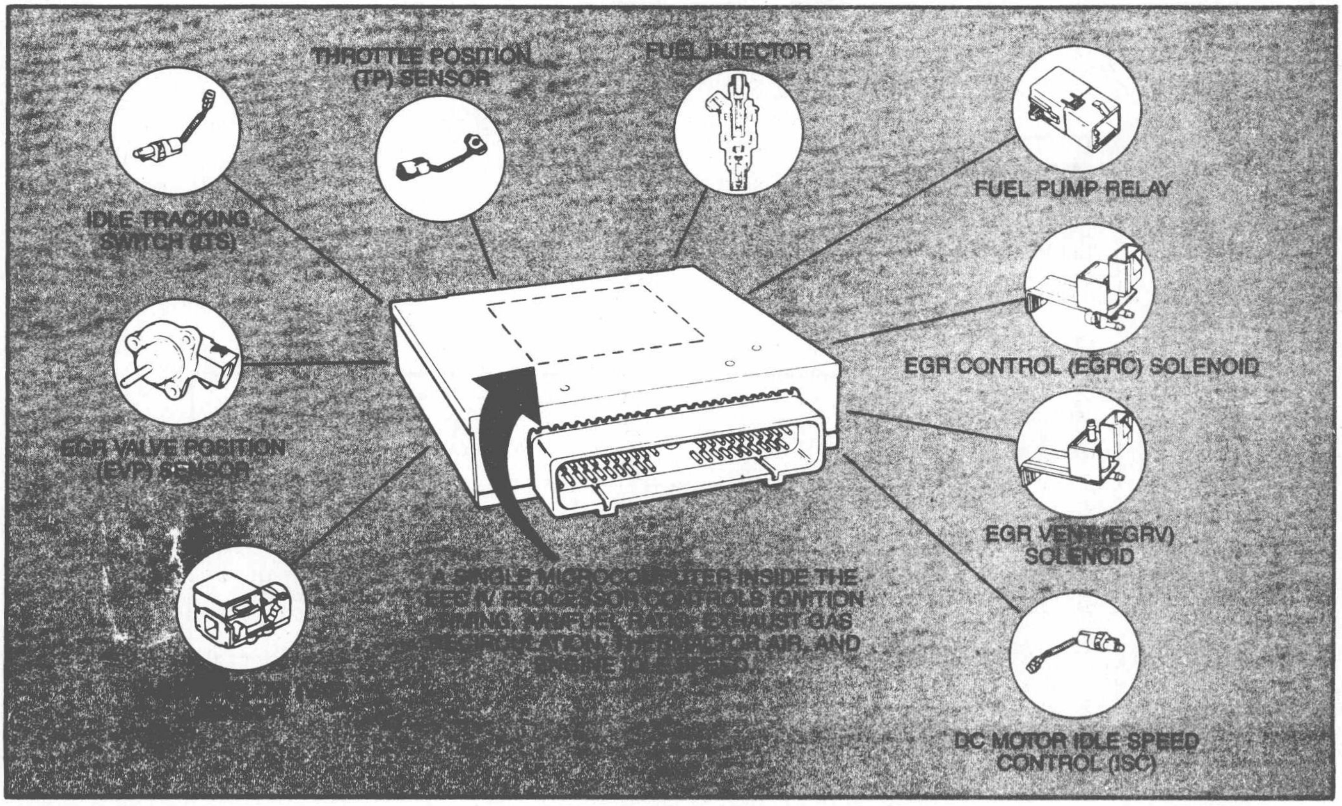


Fig. 1–15. A microcomputer used in an engine control system. *(Ford Motor Company)*

Fig. 1-16. Checking for diagnostic codes with a diagnostic tester. *(OTC Tool and Equipment Division of SPX Corporation)*

codes may also be retrieved by grounding a connector terminal or by operating certain combinations of switches on the instrument panel.

Many on-board diagnostic systems have the ability to "remember" intermittent problems. "Intermittent" means that the problem is not always there, but occurs every now and then. For example, if a customer complains that the engine stalled several times the day before, but is now operating properly, this would normally be a difficult problem to diagnose. But with on-board diagnostics, even though the engine seems to be operating properly, a service code may be stored in the computer memory. This enables the technician to diagnose a problem even though the problem no longer seems to exist.

THE IGNITION SYSTEM

The ignition system provides the energy needed to generate the spark at the engine spark plugs. This spark ignites the air-fuel mixture in the cylinders to produce the power to run the engine. Up until the 1970s, cars used a set of rapidly operating switch contacts in the ignition system, called *points,* to control current flow in an ignition coil (Fig. 1-17). Each time the points opened (the switch contacts separated), the current flow through the coil abruptly stopped. This caused the coil to generate the high voltage pulse (approximately 20,000 volts) needed to fire a spark plug. A distributor routed or distributed the high voltage to the proper spark plugs at the proper times.

In the 1970s, electronic ignition systems were introduced. In these systems, a magnetic pick-up coil replaced the points and a transistor controlled the current flow in the ignition coil (Fig. 1-18 on the next page). The advantages were more reliable operation and higher available spark-plug voltages (up to 45,000 volts in some systems).

Now, many cars do not have a distributor. Instead, several ignition coils are used, and these are electronically selected to fire the proper spark plugs at the proper times. These systems are called *distributorless ignition systems (DIS).* Figure 1-19 (on the next page)shows a four-cylinder Ford engine that has two spark plugs per cylinder and uses a distributorless ignition system. The ignition coils are mounted together in groups called *coil packs.* Two coil packs are used with this engine, and each pack contains two ignition coils. These systems eliminate the problems associated with distributors and distributor caps, and as a result, are more reliable than systems with distributors. Ignition systems are covered in Chapter 9.

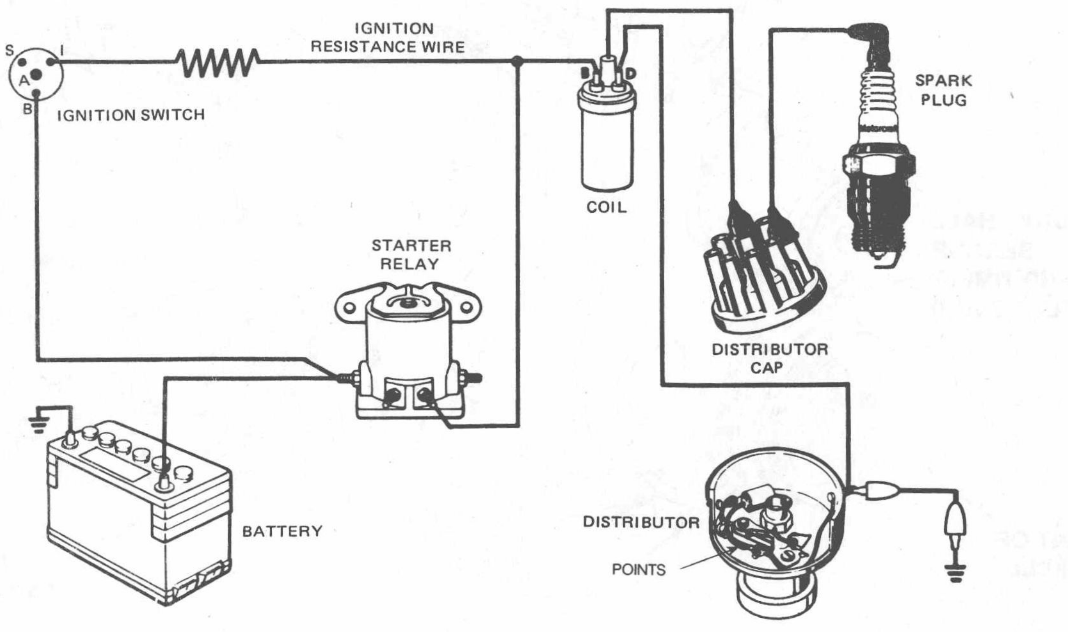


Fig. 1-17. Components of a breaker-point ignition system. *(Ford Motor Company)*

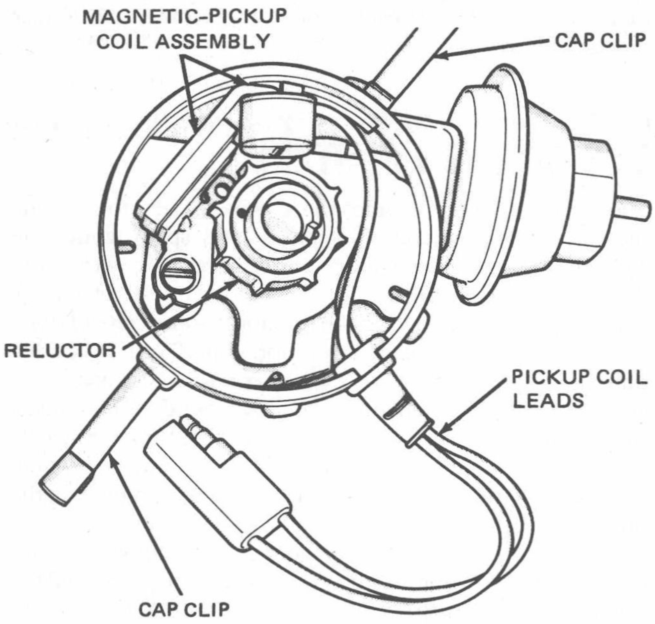


Fig. 1-18. Electronic ignition distributor. *(Chrysler Corporation)*

ANTILOCK BRAKE SYSTEMS (ABS)

An *antilock brake system (ABS)* is a computer-controlled brake system that helps prevent wheel lockup during braking (Fig. 1-20). When a wheel locks, it stops rotating and the tire skids or slides over the road surface. This results in a greater stopping distance and the loss of directional control of the vehicle. Therefore, to stop a car in the shortest possible distance and in as straight a line as possible, the wheels must be prevented from locking. To do this, the driver must "pump" the brake pedal when the car is about to skid. Pumping the brake pedal means alternately depressing and releasing the pedal. This helps prevent skidding, because if a wheel begins to lock, releasing the pedal allows the wheel to roll again.

In a computer-controlled brake system, the driver applies and holds the brake pedal. Then, if a wheel begins to lock, a microcomputer pumps the brakes. It does this much more rapidly than the driver could, and it applies and releases the brakes at precisely the right time.

In some antilock systems, there is a sensor located at each wheel. The sensors sense the speed of rotation of the wheels and send this information to the microcomputer. If a

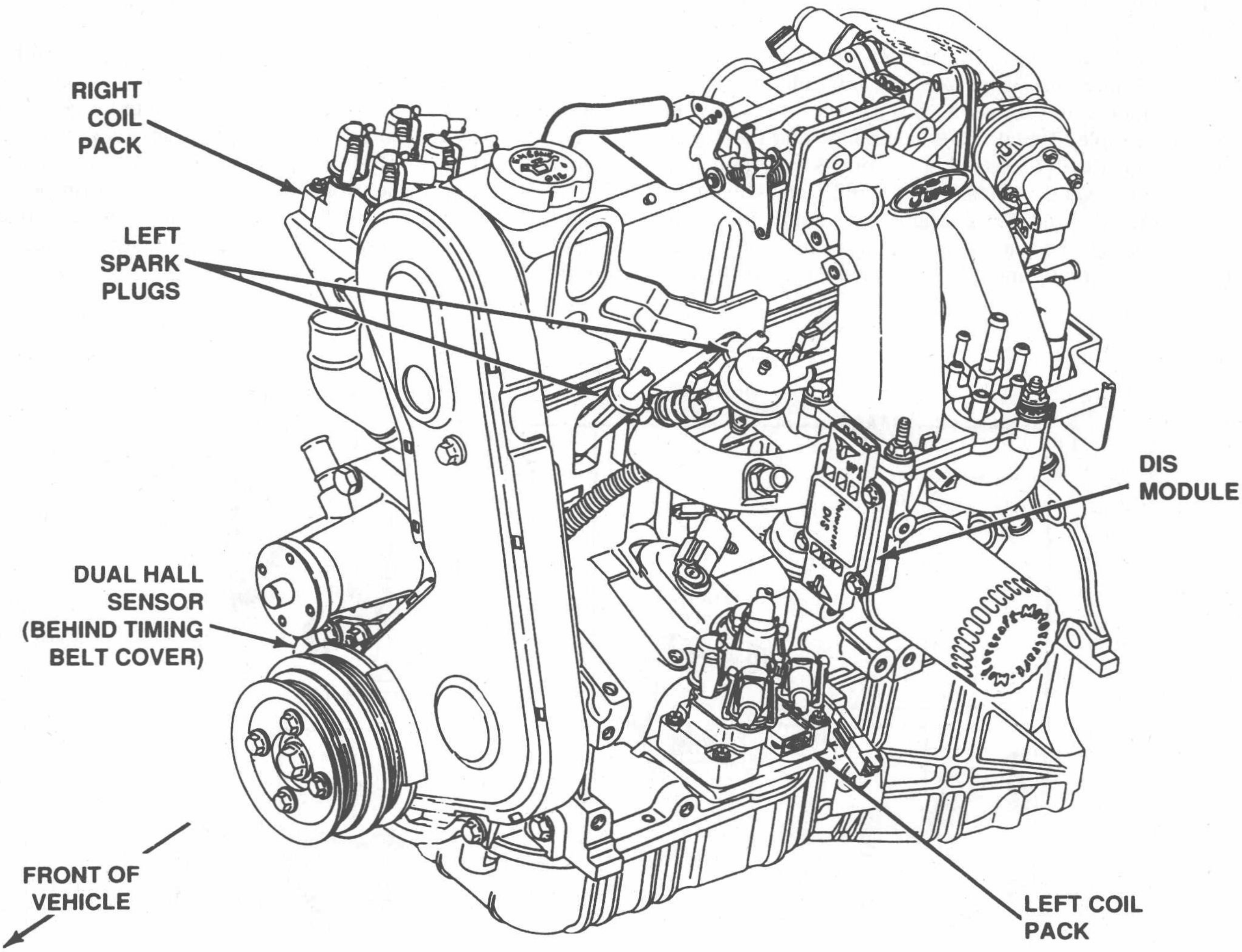


Fig. 1-19. Components of a distributorless ignition system. *(Ford Motor Company)*

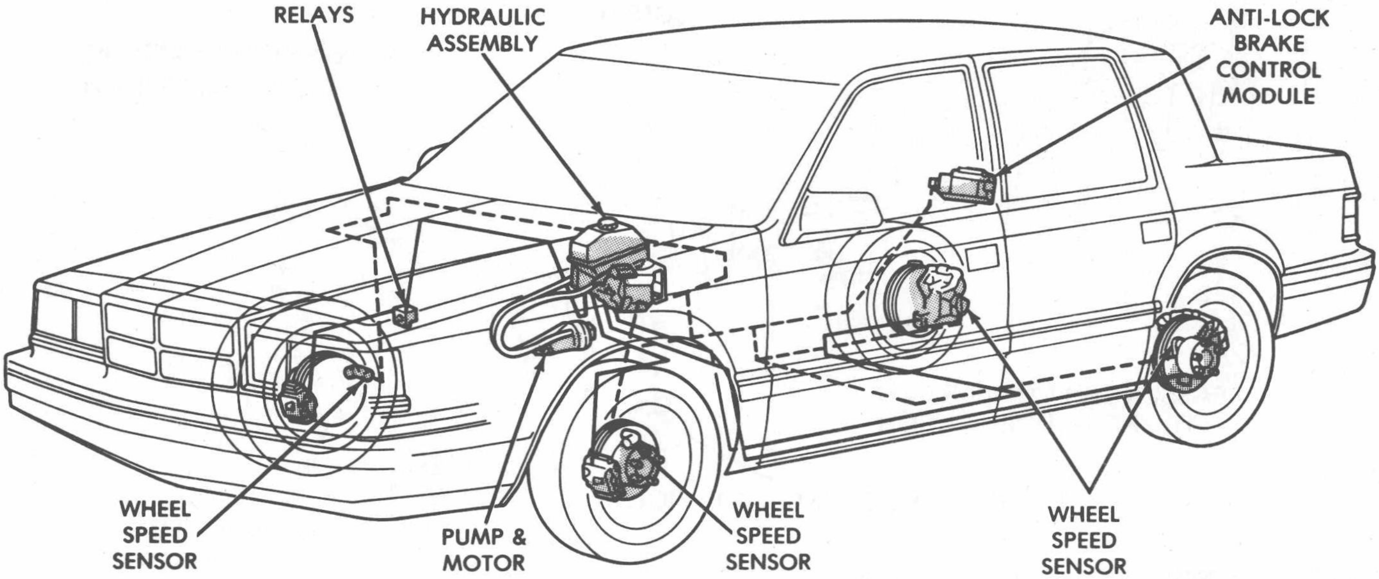


Fig. 1-20. Antilock brake system. *(Chrysler Corporation)*

wheel begins to lock during braking, the speed of rotation of that wheel drops rapidly. The microcomputer reacts to this rapid drop in wheel speed by removing the braking force from that wheel. When the wheel begins to roll again and its speed increases, the microcomputer restores the braking force to the wheel. If the wheel again begins to lock, the microcomputer will again remove the braking force. In some antilock systems the microcomputer can apply and release the brakes at each wheel as rapidly as 15 times per second.

Traction Control Systems

Some cars equipped with antilock brakes also have traction control. *Traction* is the adhesive friction, or gripping action, of a rolling tire on a road surface. A car has traction when all four tires are rolling, not slipping, on the road surface. Traction control helps prevent the driving wheels from slipping and spinning during acceleration or when cornering. If the wheels slip and spin excessively during acceleration or cornering, the driver may lose control of the vehicle. Traction control also helps prevent wheel slip on wet or icy roads.

A traction control system uses many of the same components as the antilock brake system, such as the wheel-speed sensors, the microcomputer, and the brake components. During braking, these components prevent the speed of rotation of the wheels from decreasing too quickly. During acceleration or cornering, these components do the opposite: they prevent the speed of rotation of the wheels from increasing too quickly. The operation of a typical traction control system is as follows.

If one of the driving wheels slips and begins to spin excessively during acceleration, the wheel-speed sensor at that wheel sends the information to the microcomputer. The microcomputer then signals the antilock brake components to apply the brakes briefly at the slipping wheel. If the wheel starts to regain traction, the microcomputer removes the braking force from the wheel. But if the wheel continues to spin, the computer continues to apply the brakes.

However, applying the brakes while the vehicle is accelerating is a strain on the engine, the transmission, and the brakes. Therefore, when the brakes have been applied for a specified number of seconds (three seconds is typical), the microcomputer shuts off the fuel to one of the engine cylinders. This reduces the torque produced by the engine and relieves some of the strain on the engine and drive-line components. If excessive wheel spin is still detected, the microcomputer will shut off the fuel to another cylinder, and so on, until a maximum number (of cylinders) are disabled. On a V-8 engine, for example, as many as four cylinders may be disabled.

Once the car regains traction, the fuel is again turned on to the cylinders, one at a time, until all the cylinders are functioning normally.

HEATING, VENTILATING, AND AIR-CONDITIONING SYSTEMS

Heating, ventilating, and air-conditioning make up the "comfort system" of an automobile. The heater keeps the occupants of the vehicle warm in cold weather. The ventilating system provides a flow of fresh outside air to the passenger compartment. The air conditioner keeps the occupants of the vehicle cool in hot weather.

Much of the comfort system is electrically operated. Switches on the control panel control electric current flow to the blower motor and to the air-conditioning compressor.

Some cars have automatic temperature-control systems (Fig. 1-21 on the next page). With these systems, the driver selects a temperature. Then, a microcomputer operates the blower motor and either the heater or the air conditioner to bring the temperature to that selected by the driver.

ELECTRONIC SUSPENSION SYSTEMS

Electronic suspension systems, also called *ride control,* are used on some cars (Fig. 1-22). These systems keep the car

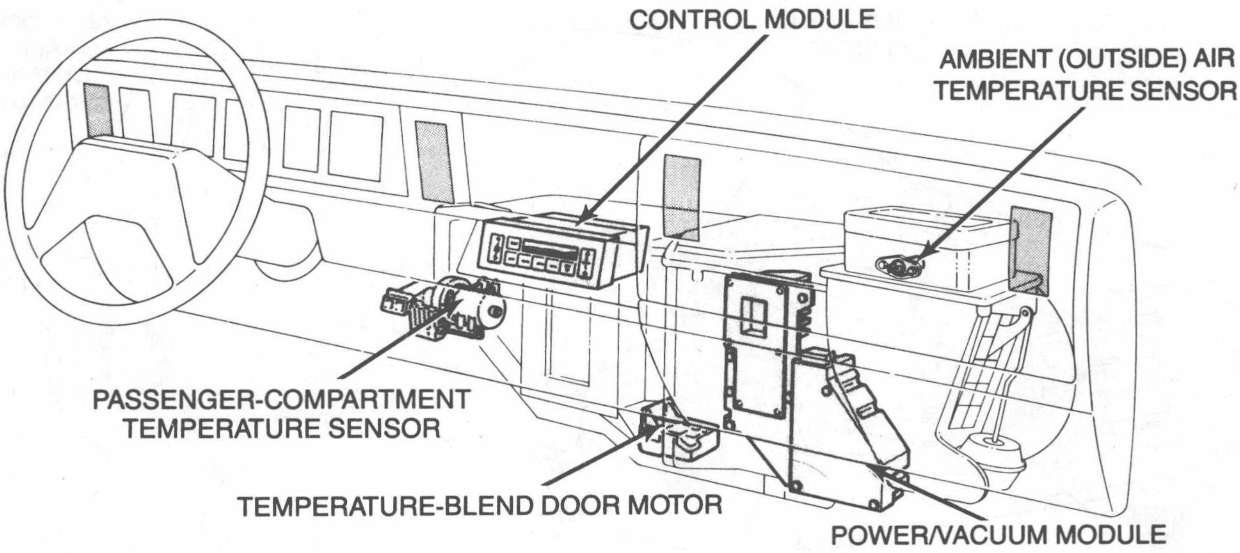


Fig. 1-21. The components of a Chrysler automatic temperature control system. *(Chrysler Corporation)*

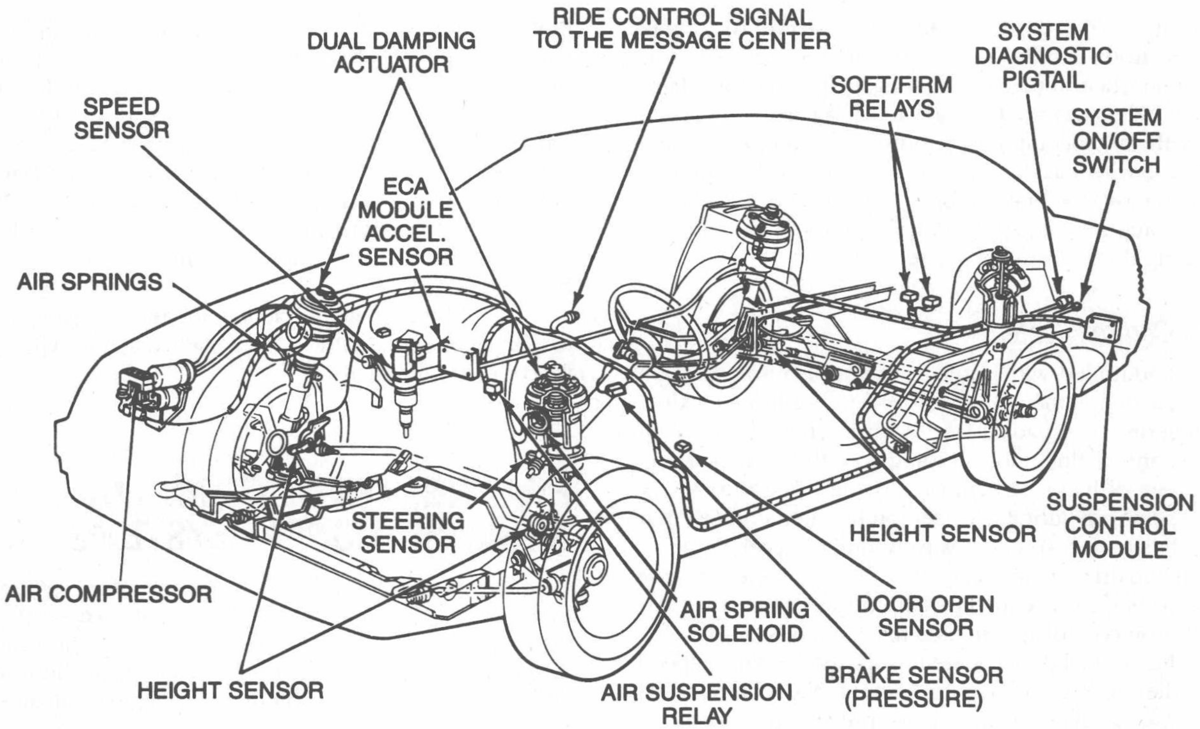


Fig. 1-22. Electronic air suspension system. *(Ford Motor Company)*

level under varying conditions of vehicle load. In addition, they adjust the shock absorbers from firm to soft, depending on the road conditions. On most systems, the driver can switch between FIRM or AUTOMATIC. In the FIRM position, a microcomputer controls actuators that adjust the shock absorbers to firm operation. In AUTOMATIC, the microcomputer controls the actuators to provide soft shock absorber action during normal operation and firm shock absorber action during hard acceleration, braking, or cornering. This provides good handling under severe driving conditions.

ELECTRONICALLY CONTROLLED POWER-STEERING SYSTEMS

Power steering makes it easier to steer an automobile at low speeds and makes parking easier. But at high speeds, power steering can result in a lack of road feel. For this reason, some cars have an electronically controlled power-steering system (Fig. 1-23). In this type of system, a microcomputer controls the amount of power assist.