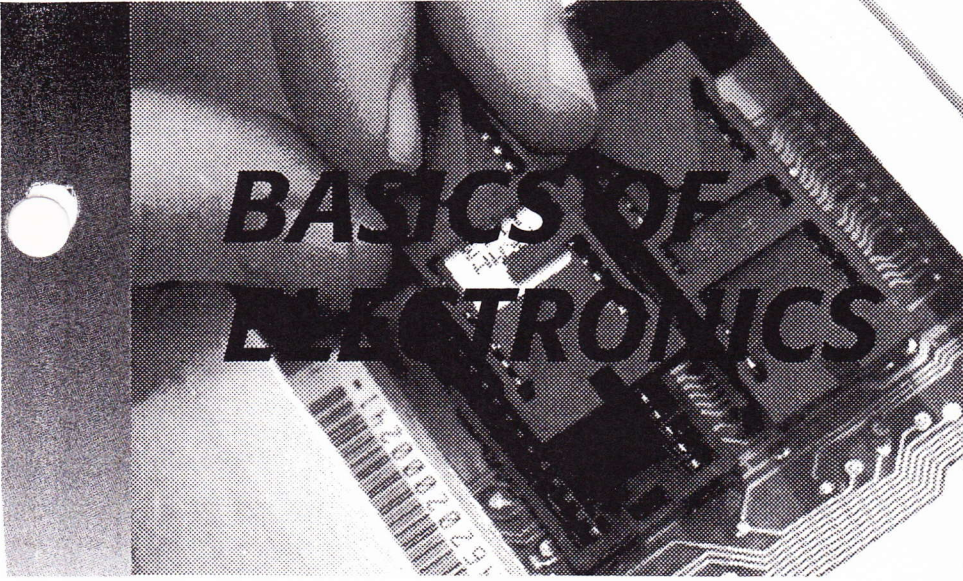


Basics of Electronics



BASICS OF ELECTRONICS

15

OBJECTIVES

◆ *Describe how semiconductors, diodes, and transistors work.* ◆ *Explain the principles of operation for common electronic circuits.* ◆ *Explain the principle of multiplexing.* ◆ *Describe the basic function of the central processing unit (CPU).* ◆ *List and describe the functions of the various sensors used by computers.* ◆ *Describe the principle of analog and digital signals.* ◆ *Explain the principle of computer communications.* ◆ *Summarize the function of a binary code.* ◆ *Name the various memory systems used in automotive microprocessors.* ◆ *List and describe the operation of output actuators.* ◆ *Identify the proper procedures to safeguard electronic systems.* ◆ *Describe the basic electronic logic circuits.* ◆ *Explain how to use an oscilloscope for diagnosing electronic systems.*

INTRODUCTION

Computerized engine controls and other features of today's cars would not be possible if it were not for electronics. For purposes of clarity, let us define **electronics** as the technology of controlling electricity. Electronics has become a special technology beyond electricity. Transistors, diodes, semiconductors, integrated circuits, and solid-state devices are all considered to be part of electronics rather than just electrical devices. Keep in mind that all the basic laws of electricity apply to all electronic controls.

Although it is not necessary to understand all of the concepts of computer operation to service the systems they control, a good knowledge will allow you to be more productive.

A **computer** is an electronic device that stores and processes data. It is also capable of operating other computers. The operation of a computer is divided into four basic functions:

1. **Input:** A voltage signal sent from an input device. The device can be a sensor or a button activated by the driver, technician, or mechanical part.
2. **Processing:** The computer uses the input information and compares it to programmed instructions. This information is processed by logic circuits in the computer.

3. **Storage:** The program instructions are stored in the computer's memory. Some of the input signals are also stored in memory for processing later.
4. **Output:** After the computer has processed the sensor input and checked its programmed instructions, it will put out control commands to various output devices. These output devices may be instrument panel displays or output actuators. The output of one computer may also be an input to another computer.

Semiconductors

A semiconductor is a material or device that can function as either a conductor or an insulator, depending on how its structure is arranged. Semiconductor materials have less resistance than an insulator but more resistance than a conductor. Some common semiconductor materials include silicon (Si) and germanium (Ge).

In semiconductor applications, materials have a crystal structure. This means that their atoms do not lose and gain electrons as the atoms in conductors do. Instead, the atoms in these semiconductor materials share outer electrons with each other. In this type of atomic structure, the electrons are tightly held and the element is stable.

Because the electrons are not free, crystals cannot conduct current. These materials are called **electri-**

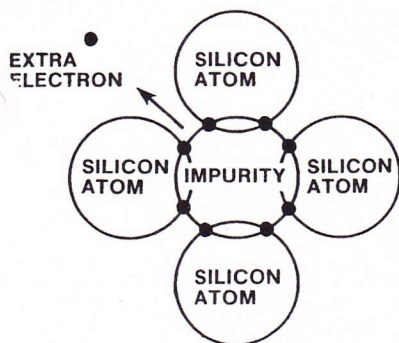


FIGURE 15-1 Atomic structure of N-type silicon semiconductor.

cally inert materials. To function as semiconductors, a small amount of trace element must be added. The addition of these traces, called **impurities**, allows the material to function as a semiconductor. The type of impurity added determines what type of semiconductor will be produced.

N-Type Semiconductors N-type semiconductors have loose, or excess, electrons. They have a negative charge. This enables them to carry current. N-type semiconductors are produced by adding an impurity with five electrons in the outer ring (called pentavalent atoms). Four of these electrons fit into the crystal structure, but the fifth is free. This excess of electrons produces the negative charge. Figure 15-1 shows an example.

P-Type Semiconductors P-type semiconductors are positively charged materials. This enables them to carry current. P-type semiconductors are produced by adding an impurity with three electrons in the outer ring (trivalent atoms). When this element is added to silicon or germanium, the three outer electrons fit into the pattern of the crystal, leaving a hole where a fourth electron would fit. This hole is actually a positively charged empty space that carries the current in the P-type semiconductor. Figure 15-2 shows an example of a P-type semiconductor.

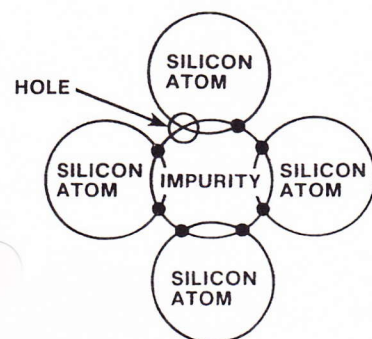


FIGURE 15-2 Atomic structure of P-type silicon semiconductor.

HOLE FLOW Understanding how semiconductors carry current without losing electrons requires understanding the concept of hole flow. The holes in a P-type semiconductor, being positively charged, attract electrons. Although the electrons cannot be freed from their atom, they can rearrange their pattern and fill a hole in a nearby atom. Whenever this happens, the electron leaves a hole. This hole in turn is filled by another electron, and the process continues. The electrons move toward the positive side of the structure, and the holes move to the negative side. This is the principle by which semiconductors carry current.

Semiconductor Uses Because semiconductors have no moving parts, they seldom wear out or need adjustment. Semiconductors, or solid-state devices, are also small, require little power to operate, are reliable, and generate very little heat. For all these reasons, semiconductors are being used in many applications.

Diodes and Transistors

Because a semiconductor can function as both a conductor and an insulator, it is very useful as a switching device. How a semiconductor functions depends on the way current flows (or tries to flow) through it. Two common semiconductor devices are diodes and transistors.

Diodes The diode is the simplest semiconductor device. Basically there are three types of diodes used in automobiles: regular diodes, LEDs, and Zener diodes.

A **diode** allows current to flow in one direction (Figure 15-3) but not in the opposite direction. Therefore, it can function as a switch, acting as either conductor or insulator, depending on the direction of current flow. Diodes turn on when the polarity of the current is correct and turn off when the flow has the wrong polarity.

One application of diodes is in the alternator, where they function as one-way valves for current flow. All charging systems, whether alternators or generators, produce alternating current. In the generator, current was rectified (changed from AC to DC) by a rotating commutator and a set of brushes. In the alternator, current is rectified by the use of diodes. The diodes are arranged so that current can leave the alternator in one direction only (as direct current).

Inside a diode are small positive and negative areas, which are separated by a thin boundary area. The boundary area is called the **PN junction**. When a diode is placed in a circuit with the positive side of the circuit connected to the positive side of the diode and the negative side of the circuit connected to the negative side of the diode, the diode is said to have **forward bias** (Figure 15-4).

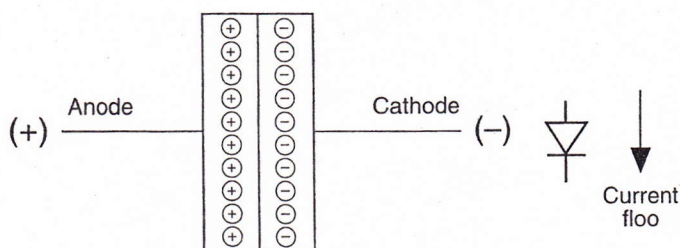


FIGURE 15-3 Diode and its schematical symbol.

Unlike electrical charges are attracted to each other and like charges repel each other. Therefore, the positive charge from the circuit's power supply is attracted to the negative side of the circuit. The voltage in the circuit is much stronger than the charges inside the diode and causes the charges inside the diode to move. The diode's P conductive material is repelled by the positive charge of the circuit and is pushed toward the N material and the N material is pushed toward the P. This causes the PN junction to become a conductor, allowing the circuit's current to flow.

When **reverse bias** is applied to the diode, the P and N areas of the diode are connected to opposite charges. Since opposites attract, the P material moves toward the negative part of the circuit whereas the N material moves toward the positive part of the circuit. This empties the PN junction and current flow stops.

Light-emitting Diodes (**LEDs**) are much the same as regular diodes (Figure 15-5). However, they emit light when they are forward biased. LEDs are very

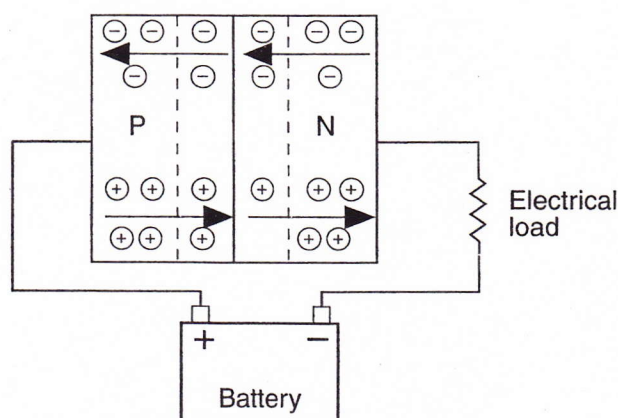


FIGURE 15-4 Forward-biased voltage allows current flow through the diode.

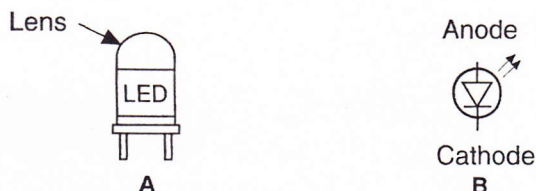


FIGURE 15-5 (A) An LED uses a lens to emit the light generated by current flow. (B) Schematical symbol for an LED.

current sensitive and can be damaged if they subjected to more than 50 mAmps. LEDs also require higher amounts of voltages to turn on than do regular diodes. Normally 1.5 to 2.5 volts are required to forward bias an LED enough to cause it to light up. LEDs also offer much less resistance to reverse bias voltages. High reverse bias voltages may cause the LED to light or cause it to burn up.

Zener diodes (Figure 15-6) are a more complex type of diode. They are used to regulate voltage in a circuit and are available in many voltage sizes, typically from 2 to 200 volts. Although Zener diodes work in the same way as a regular diode when forward biased, they are placed backwards in a circuit. When the Zener voltage is reached, the Zener diode begins to allow current flow but maintains a voltage drop across itself. This voltage drop is regulated at whatever voltage the diode is rated. A Zener diode functions just like a regular diode until a certain voltage is reached. When the voltage level reaches this point, the Zener diode allows current to flow in the reverse direction. Zener diodes are often used in electronic voltage regulators.

Transistor Another semiconductor commonly used in the automotive industry is the **transistor**. These devices are used in place of switches and relays in electronic circuits. They are used to turn an electrical circuit ON or OFF and are controlled by another electrical circuit. Perhaps the easiest way to describe the action of a transistor is to say it is a switch controlled by conditions. The conditions are the voltages present at the parts of the transistor.

A transistor is produced by joining three sections of semiconductor materials. Like the diode, it is very useful as a switching device, functioning as either a conductor or an insulator. Figure 15-7 shows two designs of transistors, which come in many different sizes and types.

A transistor resembles a diode with an extra side. It can consist of two P-type materials and one N-type material or two N-type materials and one P-type

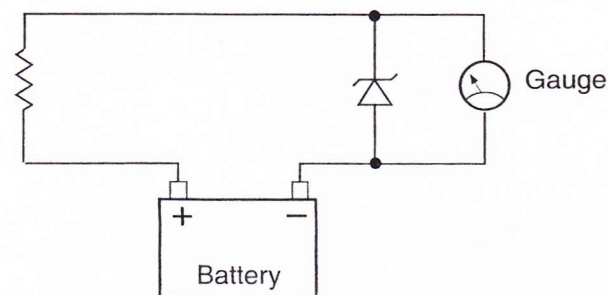


FIGURE 15-6 A simplified gauge circuit with a Zener diode used to maintain a constant supply voltage to the gauge.

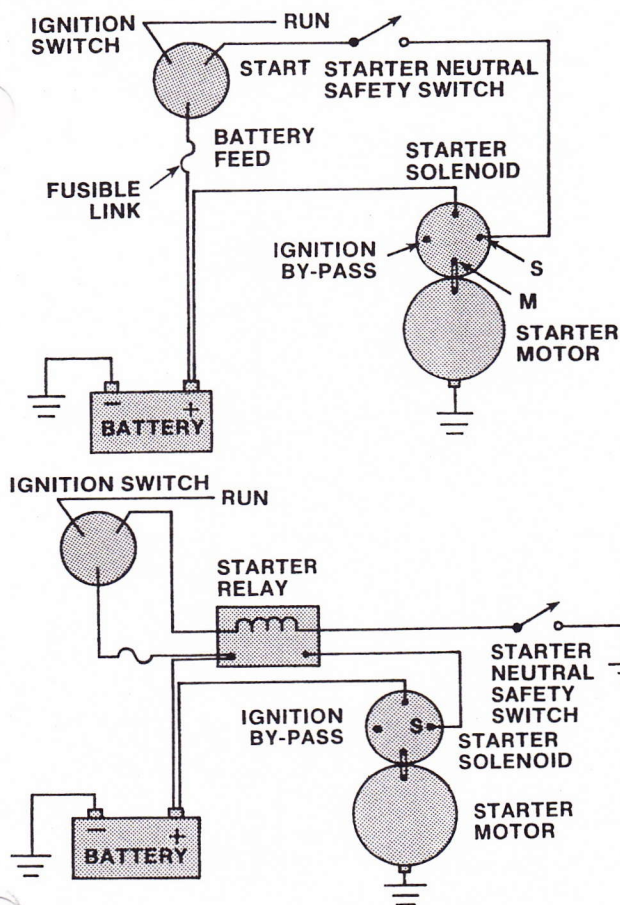


FIGURE 15-7 Typical transistors.

material. These are called **PNP** and **NPN** types. In both types, junctions occur where the materials are joined. Figure 15-8 shows a PNP junction transistor in a circuit, while Figure 15-9 shows an NPN transistor. Notice that each of the three sections has a lead connected to it. This allows any of the three sections to be connected to the circuit. The different names for the legs of the transistor are the **emitter**, **base**, and **collector**.

The center section is called the base and is the controlling part of the circuit or where the larger controlled part of the circuit is switched ON and OFF. The path to ground for the base circuit is through the emitter leg of the transistor. A resistor is normally in the base circuit to keep current flow low. This prevents damage to the transistor. The emitter and collector make up the controlled circuit. When a transistor is drawn in electrical schematics, the arrow on the emitter points to the direction of current flow. When positive voltage is applied to the base of an NPN transistor, the emitter to collector circuit is turned on (Figure 15-10).

The base of a PNP transistor is controlled by its ground. Current flows in from the emitter through the base, then to ground. A negative voltage or

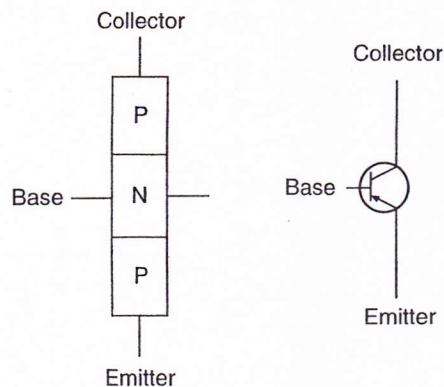


FIGURE 15-8 PNP transistor and its schematical symbol.

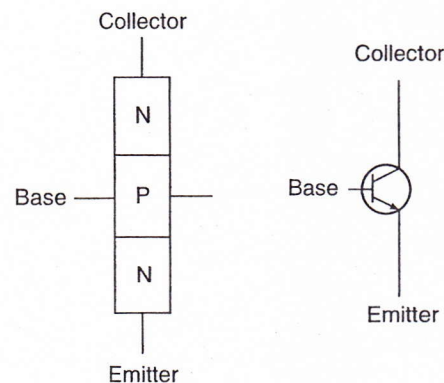


FIGURE 15-9 NPN transistor and its schematical symbol.

ground must be applied to the base to turn on a PNP transistor. When this transistor is on, the circuit from the emitter to the collector is closed.

Transistors can also serve as variable switches. By varying the voltage applied to the base, the completeness of the emitter and collector circuit will also vary. This is done simply by the presence of a variable resistor in the base circuit. This type of arrangement is typically part of a light-dimming circuit.

Semiconductor Circuits

One transistor or diode is limited in its ability to do complex tasks. However, when many semiconductors

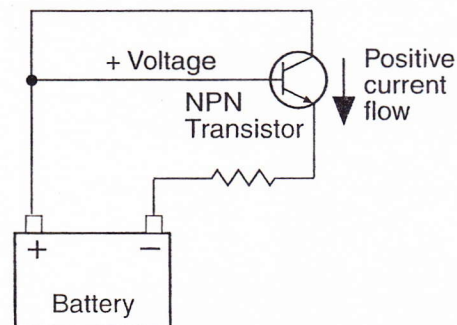


FIGURE 15-10 When positive voltage is applied to the base of an NPN transistor, current flows through the collector and the emitter.

are combined into a circuit, they can perform complex functions. An example of this is the electronic voltage regulator.

The heart of the electronic regulator is a Zener diode. As mentioned, the Zener diode has the ability to conduct in the reverse direction without damage.

The Zener diode used in regulators is doped, so it conducts in reverse once the maximum battery voltage has been achieved.

Figure 15-11 shows a typical transistorized regulator circuit in simplified form. When the voltage of the vehicle's system rises above the maximum battery

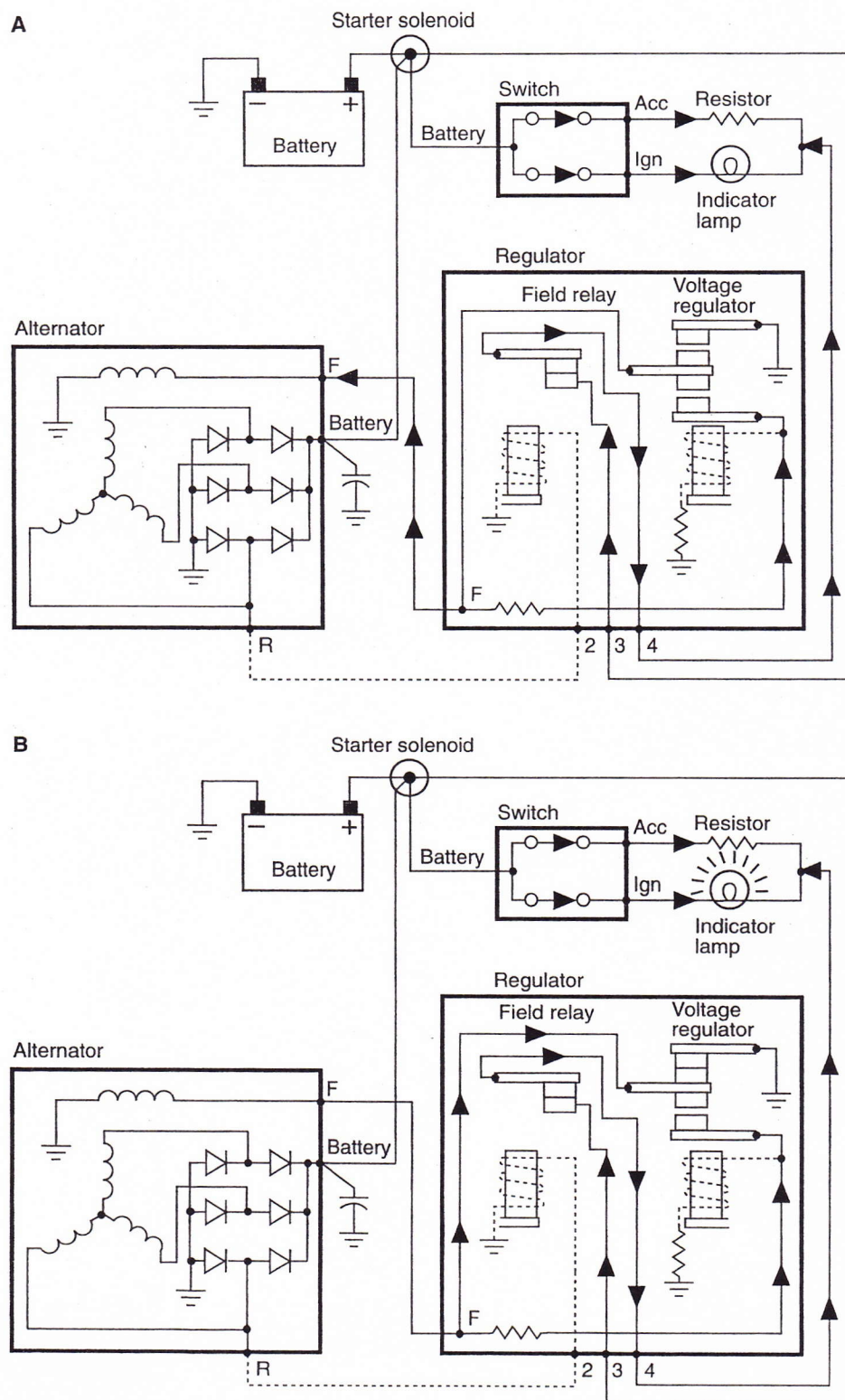


FIGURE 15-11 (A) Voltage regulator operation when battery is charging. (B) Voltage regulator operation when maximum battery voltage is exceeded.

voltage, the diode conducts and permits current to flow to the base of transistor 1. This turns the transistor on, which in turn switches off transistor 2. Transistor 2 is in control of field current for the alternator. With it off, no field current can flow, thus shutting off the alternator until the voltage level drops below specification. Transistor 2 is acting like a switch turning field current on then off as the system voltage rises and falls above and below the specified voltage. This occurs many times a second and cannot be measured with a standard voltmeter. The thermistor in the upper left of the diagram gives the temperature voltage change necessary to keep the battery charged in cold weather. An actual voltage regulator would have many additional parts, such as capacitors to protect the regulator from voltage surges. These systems can use conventional electronic components or integrated circuits.

INTEGRATED CIRCUITS

An **integrated circuit** is simply a large number of diodes, transistors, and other electronic components, such as resistors and capacitors, all mounted on a single piece of semiconductor material (Figure

15-12). These circuits are commonly called **ICs** or **chips**. These circuits are extremely small. Circuitry that used to take up entire rooms can now fit into a pocket. The principles of semiconductor operation remain the same in integrated circuits.

The size of chips is constantly becoming smaller. This means electronics is no longer confined to the simple tasks, such as rectifying alternator current. Enough transistors, diodes, and other solid-state components can be installed in a car to make logical decisions and issue commands to automobile systems, such as the ignition, fuel injection, transmission, brake, and suspension systems.

OPERATION OF MICROPROCESSORS

The microprocessor has taken over many of the tasks in cars and trucks that were formerly performed by vacuum, mechanical, or electromechanical devices. When properly programmed, they can carry out explicit instructions with blinding speed and almost flawless consistency.

A typical electronic control system is made up of sensors, actuators, and related wiring that is tied into

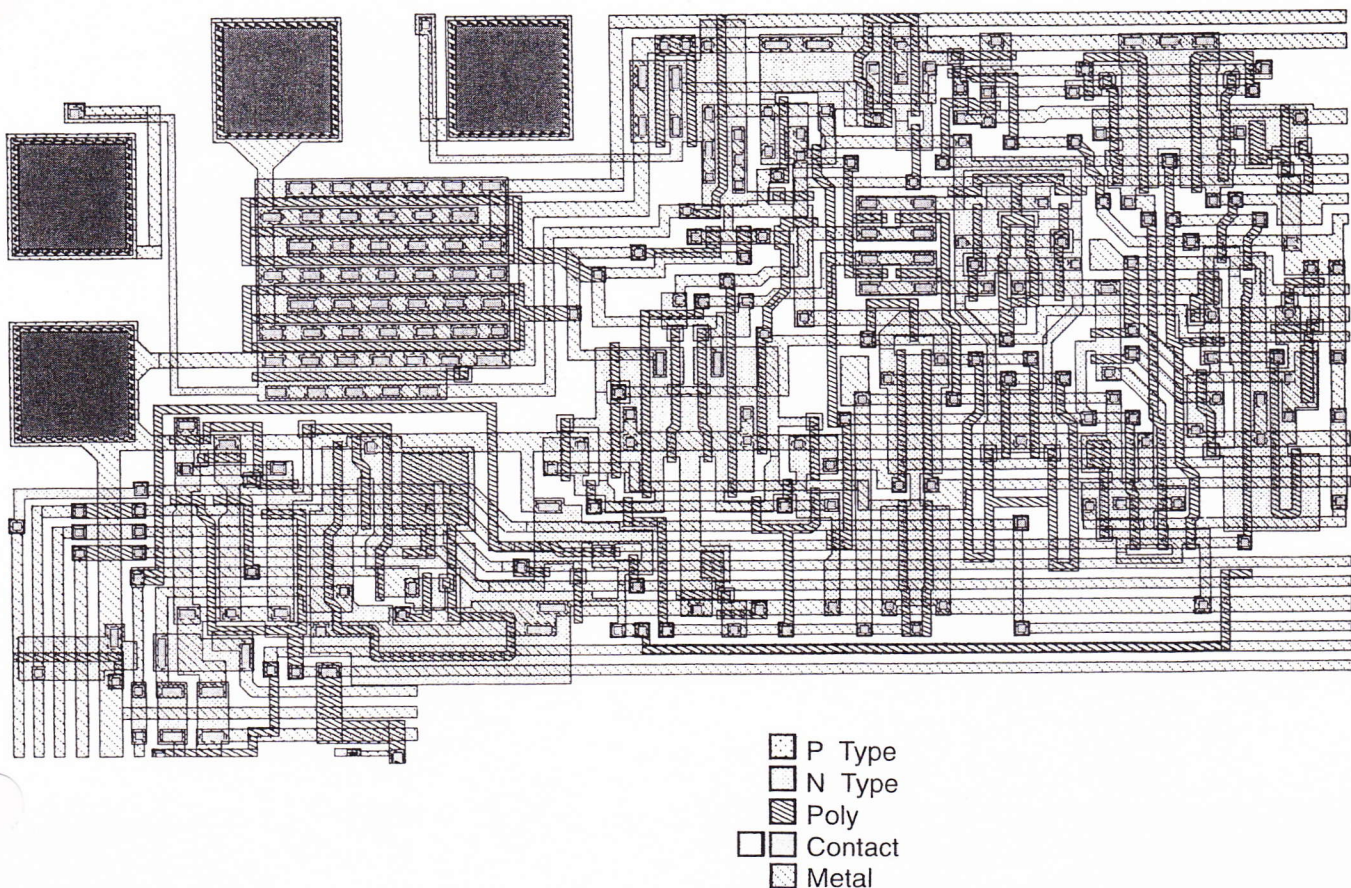


FIGURE 15-12 Enlarged illustration of an IC with thousands of transistors, diodes, resistors, and capacitors. The actual size of this chip can be less than 1/4 inch square.

a central processor called a **microprocessor** or micro-computer (a smaller version of a computer).

The central processing unit (**CPU**) is the brain of a computer. The CPU is constructed of thousands of transistors placed on a small chip. The CPU brings information into and out of the computer's memory. The input information is processed in the CPU and checked against the program in the computer's memory. The CPU also checks the memory for any other information regarding programmed parameters. The information obtained by the CPU can be altered according to the instructions of the program. The CPU may be ordered to make logic decisions on the information received. Once these decisions, or calculations, are made, the CPU sends out commands to make the required corrections or adjustments to the system being controlled (Figure 15-13).

Sensors

The CPU receives inputs that it checks with programmed values. Depending on the input, the computer will control the actuator(s) until the programmed

results are obtained. The inputs can come from other computers, the driver, the technician, or through a variety of sensors.

Driver input signals are usually provided by momentarily applying a ground through a switch. The computer receives this signal and performs the desired functions. For example, if the driver wishes to reset the trip odometer on a digital instrument panel, a reset button is depressed. This switch provides a momentary ground that the computer receives as an input and sets the trip odometer to zero.

Switches can be used as inputs for any operation that only requires a yes-no, or on-off, condition. Other inputs include those supplied by means of a sensor and those signals returned to the computer in the form of **feedback**. Feedback means that data concerning the effects of the computer's commands are fed back to the computer as an input signal.

If the computer sends a command signal to actuate an output device, a feedback signal may be sent back from the actuator to inform the computer that the task was performed. The feedback signal will

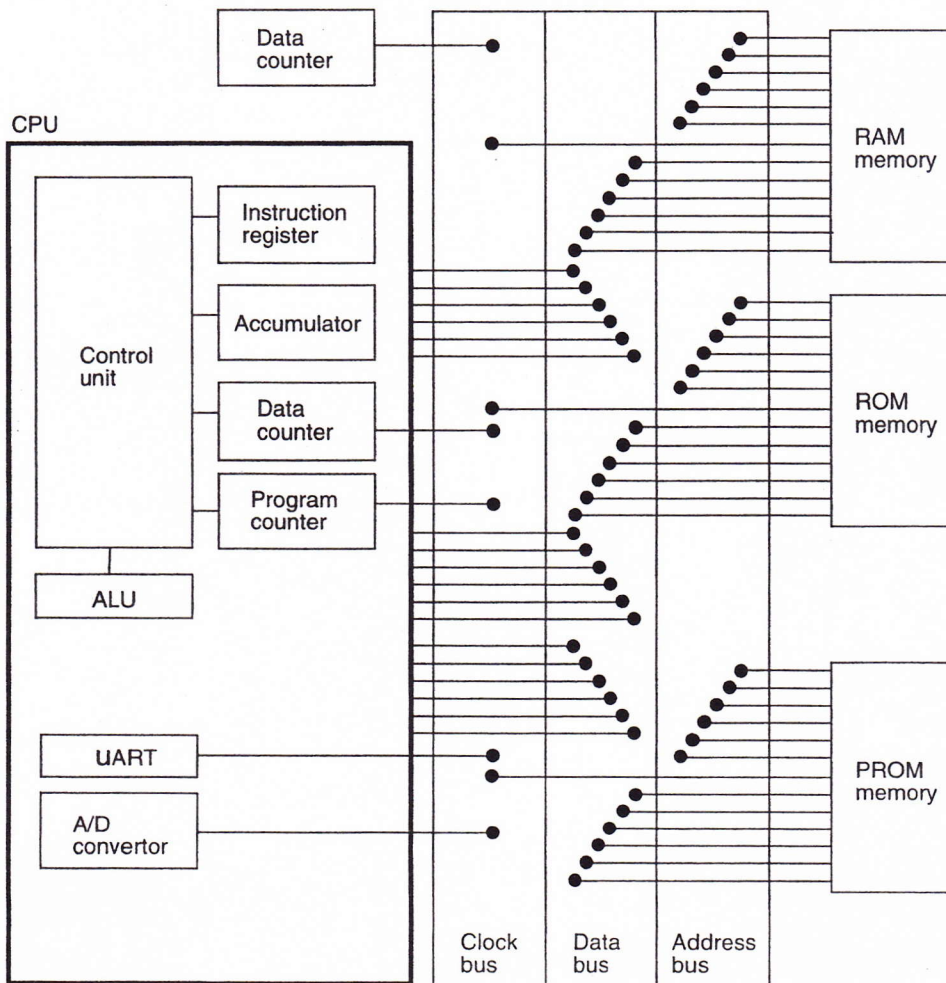


FIGURE 15-13 Main components of a computer and its CPU.

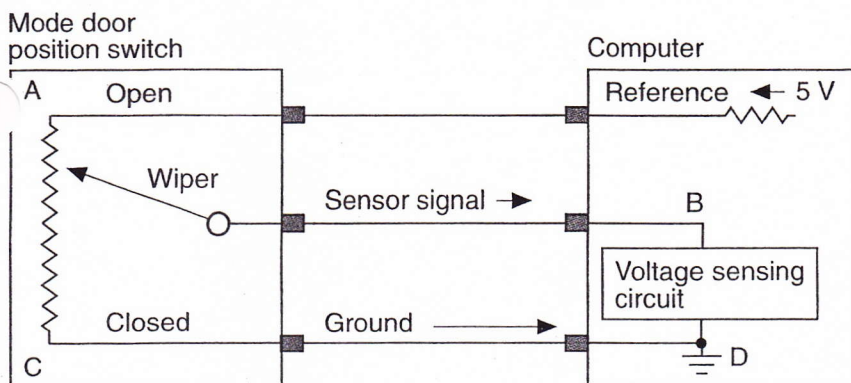


FIGURE 15-14 A potentiometer sensor circuit measures the amount of voltage drop to determine the position of the A/C mode door.

confirm both the position of the output device and the operation of the actuator. Another form of feedback is for the computer to monitor voltage as a switch, relay, or other actuator is activated. Changing positions of an actuator should result in predictable changes in the computer's voltage sensing circuit. The computer may set a diagnostic code if it does not receive the correct feedback signal.

All sensors perform the same basic function. They detect a mechanical condition (movement or position), chemical state, or temperature condition and change it into an electrical signal that can be used by the computer to make decisions. The CPU makes decisions based on information it receives from the sensors. Each sensor used in a particular system has a specific job to do (for example, monitor throttle position, vehicle speed, manifold pressure). Together these sensors provide enough information to help the computer form a complete picture of vehicle operation. Even though there are a variety of different sensor designs, they all fall under one of two operating categories: reference voltage sensors or voltage-generating sensors.

Reference voltage (V_{ref}) sensors provide input to the computer by modifying or controlling a constant, predetermined voltage signal. This signal, which can have a reference value from 5 to 9 volts, is generated and sent out to each sensor by a reference voltage regulator located inside the CPU. Because the computer knows a certain voltage value has been sent out, it can indirectly interpret things like motion, temperature, and component position, based on what comes back. For example, consider the operation of the throttle position sensor (TPS). During acceleration (from idle to wide-open throttle), the computer monitors throttle plate movement based on the changing reference voltage signal returned by the TPS. (The TPS is a type of variable resistor known as a rotary potentiometer that changes circuit resistance based on throttle shaft rotation.) As TPS resistance varies, the computer is

programmed to respond in a specific manner (for example, increase fuel delivery or alter spark timing) to each corresponding voltage change.

Most sensors presently in use are variable resistors or potentiometers (Figure 15-14). They modify a voltage to or from the computer, indicating a constantly changing status that can be calculated, compensated for, and modified. That is, most sensors simply control a voltage signal from the computer. When varying internal resistance of the sensor allows more or less voltage to ground, the computer senses a voltage change on a monitored signal line. The monitored signal line may be the output signal from the computer to the sensor (one- and two-wire sensors), or the computer may use a separate return line from the sensor to monitor voltage changes (three-wire sensors).

Another commonly used variable resistor is a thermistor. A thermistor is a solid-state variable resistor made from a semiconductor material that changes resistance in relation to temperature changes. Thermistors are used to monitor engine coolant, intake air, and ambient temperatures. By monitoring the thermistor's resistance value, the CPU is capable of observing small changes in temperature. The CPU sends a reference voltage to the thermistor, normally 5 volts, through a fixed resistor. As the current flows through the thermistor to ground, voltage is dropped by the thermistor. A voltage-sensing circuit compares the voltage sent out by the CPU to the voltage returned to the CPU and determines the voltage drop. Using its programmed values, the computer is able to translate the voltage drop into a temperature reading.

There are two basic types of thermistors: NTC and PTC. A negative temperature coefficient (NTC) thermistor reduces its resistance as temperature increases. This type is the most commonly used thermistor. A positive temperature coefficient (PTC) thermistor increases its resistance with an increase in temperature. To diagnose thermistors accurately, you must be able to identify the type by looking at a wiring diagram.

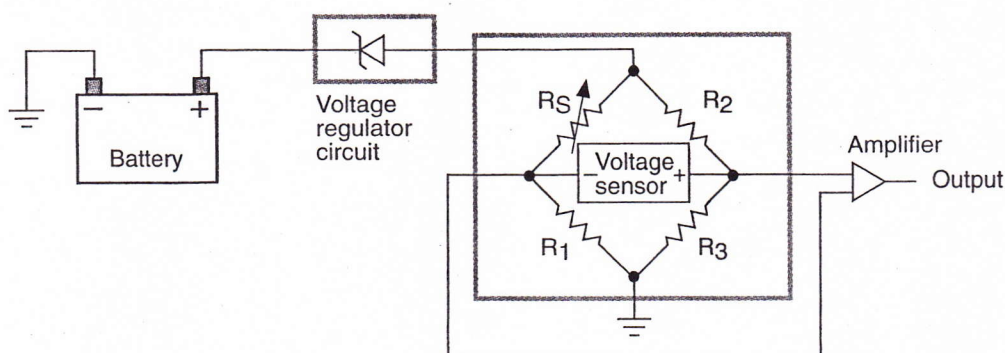


FIGURE 15-15 Wheatstone bridge.

Wheatstone bridges (Figure 15-15) are also used as variable resistance sensors. These are typically constructed of four resistors, connected in series-parallel between an input terminal and a ground terminal. Three of the resistors are kept at the same value. The fourth resistor is a sensing resistor. When all four of the resistors have the same value, the bridge is balanced and the voltage sensor will have a value of 0 volts. If the sensing resistor changes value, a change will occur in the circuit's balance. The sensing circuit will receive a voltage reading proportional to the amount of resistance change. If the Wheatstone bridge is used to measure temperature, temperature changes will be indicated as a change in voltage by the sensing circuit. Wheatstone bridges are also used to measure pressure (**piezoresistive**) and mechanical strain.

In addition to variable resistors, another commonly used reference voltage sensor is a switch. By opening and closing a circuit, switches provide the necessary voltage information to the computer so vehicles can maintain the proper performance and driveability.

While most sensors are variable resistance/reference voltage, there is another category of sensors—the **voltage-generating devices**. These sensors include components like the magnetic pulse generators, Hall-effect switches, oxygen sensors (zirconium dioxide), and knock sensors (piezoelectric), which are capable of producing their own input voltage signal. This varying voltage signal, when received by the computer, enables the computer to monitor and adjust for changes in the computerized engine control system.

Magnetic pulse generators use the principle of magnetic induction to produce a voltage signal. They are also called permanent magnet (PM) generators. These sensors are commonly used to send data to the computer about the speed of the monitored component. This data provides information about vehicle speed, shaft speed, and wheel speed. The signals from speed sensors are used for instrumentation, cruise control systems, antilock brake systems, ignition systems, speed-sensitive steering systems, and automatic ride control systems. A magnetic pulse generator is

also used to inform the computer about the position of a monitored device. This is common in engine controls where the CPU needs to know the position of the crankshaft in relation to rotational degrees.

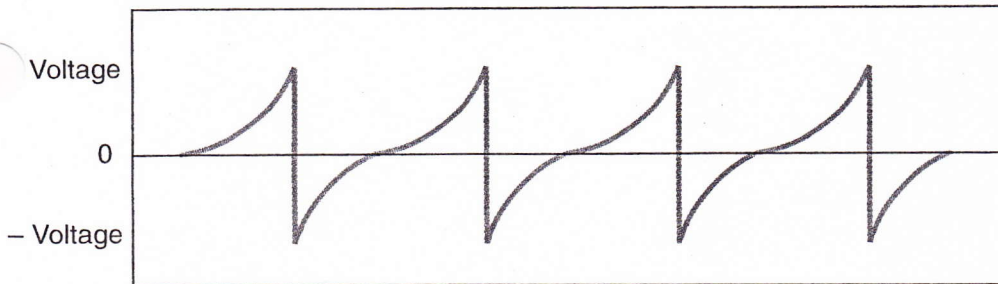
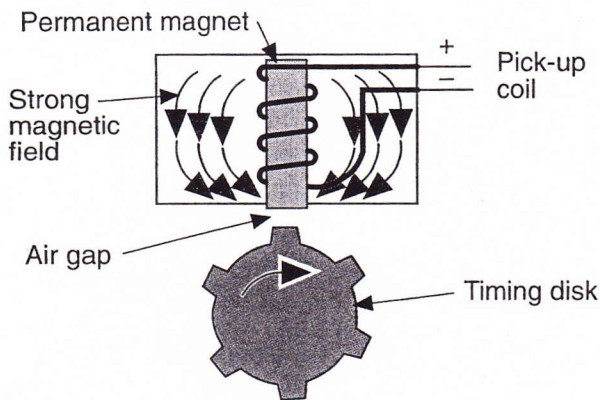
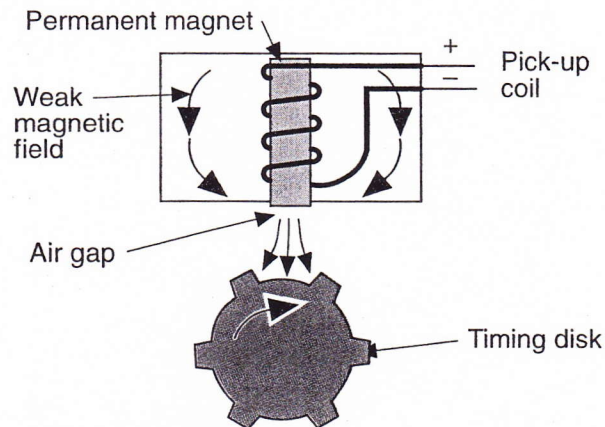
The major components of a pulse generator are a timing disc and a pick-up coil. The **timing disc** is attached to a rotating shaft or cable. The number of teeth on the timing disc is determined by the manufacturer and the application. If only the number of revolutions is required, the timing disc may have only one tooth. Whereas, if it is important to track quarter revolutions, the timing disc needs at least four teeth. The teeth will cause a voltage generation that is constant per revolution of the shaft. For example, a vehicle speed sensor may be designed to deliver 4,000 pulses per mile. The number of pulses per mile remains constant regardless of speed. The computer calculates how fast the vehicle is going based on the frequency of the signal. The timing disc is also known as an armature, reluctor, trigger wheel, pulse wheel, or timing core.

The **pick-up coil** is also known as a stator, sensor, or pole piece. It remains stationary while the timing disc rotates in front of it. The changes of magnetic lines of force generate a small voltage signal in the coil. A pick-up coil consists of a permanent magnet with fine wire wound around it.

An air gap is maintained between the timing disc and the pick-up coil. As the timing disc rotates in front of the pick-up coil, the generator sends a pulse signal (Figure 15-16). As a tooth on the timing disc aligns with the core of the pick-up coil, it repels the magnetic field. The magnetic field is forced to flow through the coil and pick-up core (Figure 15-17). When the tooth passes the core, the magnetic field is able to expand (Figure 15-18). This action is repeated every time a tooth passes the core. The moving lines of magnetic force cut across the coil windings and induce a voltage signal.

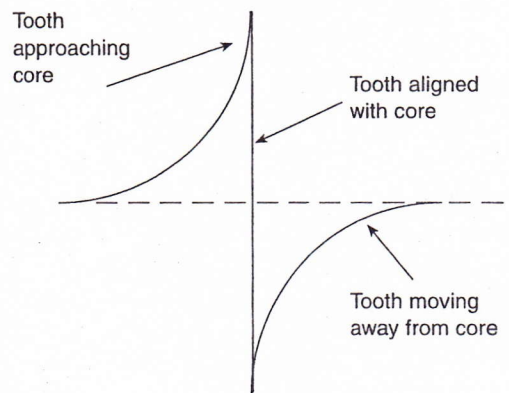
When a tooth approaches the core, a positive current is produced as the magnetic field begins to concentrate around the coil. When the tooth and

Alternating current sine wave

**FIGURE 15-16** Pulse signal sine wave.**FIGURE 15-17** A strong magnetic field is produced in the pick-up coil as the teeth align with the core.**FIGURE 15-18** The magnetic field expands and weakens as the teeth pass the core.

core align, there is no more expansion or contraction of the magnetic field and the voltage drops to zero. When the tooth passes the core, the magnetic field expands and a negative current is produced (Figure 15-19). The resulting pulse signal is sent to the CPU.

The **Hall-effect switch** performs the same function as a magnetic pulse generator. It operates on the principle that if a current is allowed to flow through thin conducting material exposed to a magnetic field, another voltage is produced (Figure 15-20).

**FIGURE 15-19** Waveform produced by a magnetic pulse generator.

A Hall-effect switch contains a permanent magnet and a thin semiconductor layer made of Gallium arsenate crystal (Hall layer) and a shutter wheel (Figure 15-21). The Hall layer has a negative and a positive terminal connected to it. Two additional terminals located on either side of the Hall layer are used for the output circuit.

The permanent magnet is located directly across from the Hall layer so its lines of flux will bisect at right angles to the current flow. The permanent magnet is mounted; a small air gap is between it and the Hall layer.

A steady current is applied to the crystal of the Hall layer. This produces a signal voltage perpendicular to the direction of current flow and magnetic flux. The signal voltage produced is a result of the effect the magnetic field has on the electrons. When the magnetic field bisects the supply current flow, the electrons are deflected toward the Hall layer negative terminal (Figure 15-22, page 372). This results in a weak voltage potential being produced in Hall switch.

The shutter wheel consists of a series of alternating windows and vanes. It creates a magnetic shunt that changes the strength of the magnetic field from the permanent magnet. The shutter wheel is attached to a rotational component. As the wheel rotates, the

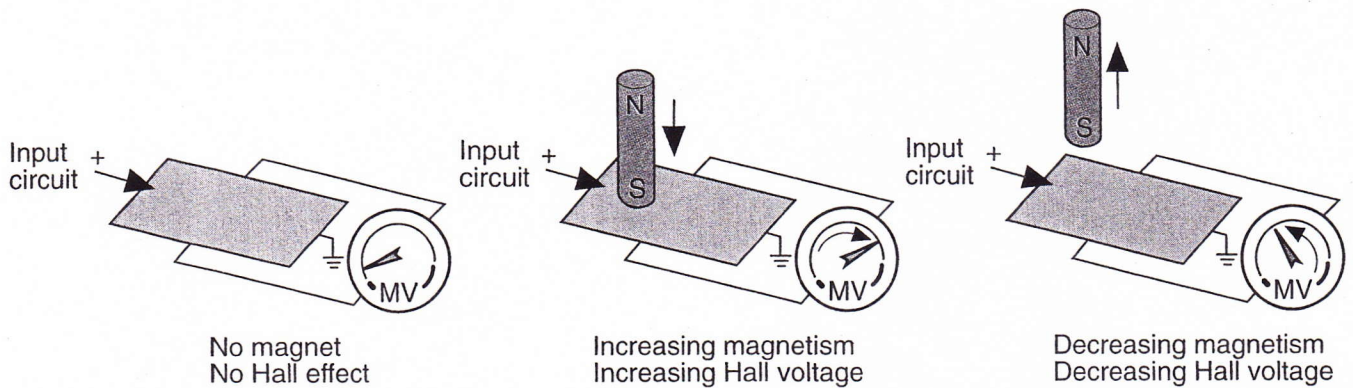


FIGURE 15-20 Hall-effect principles of voltage induction.

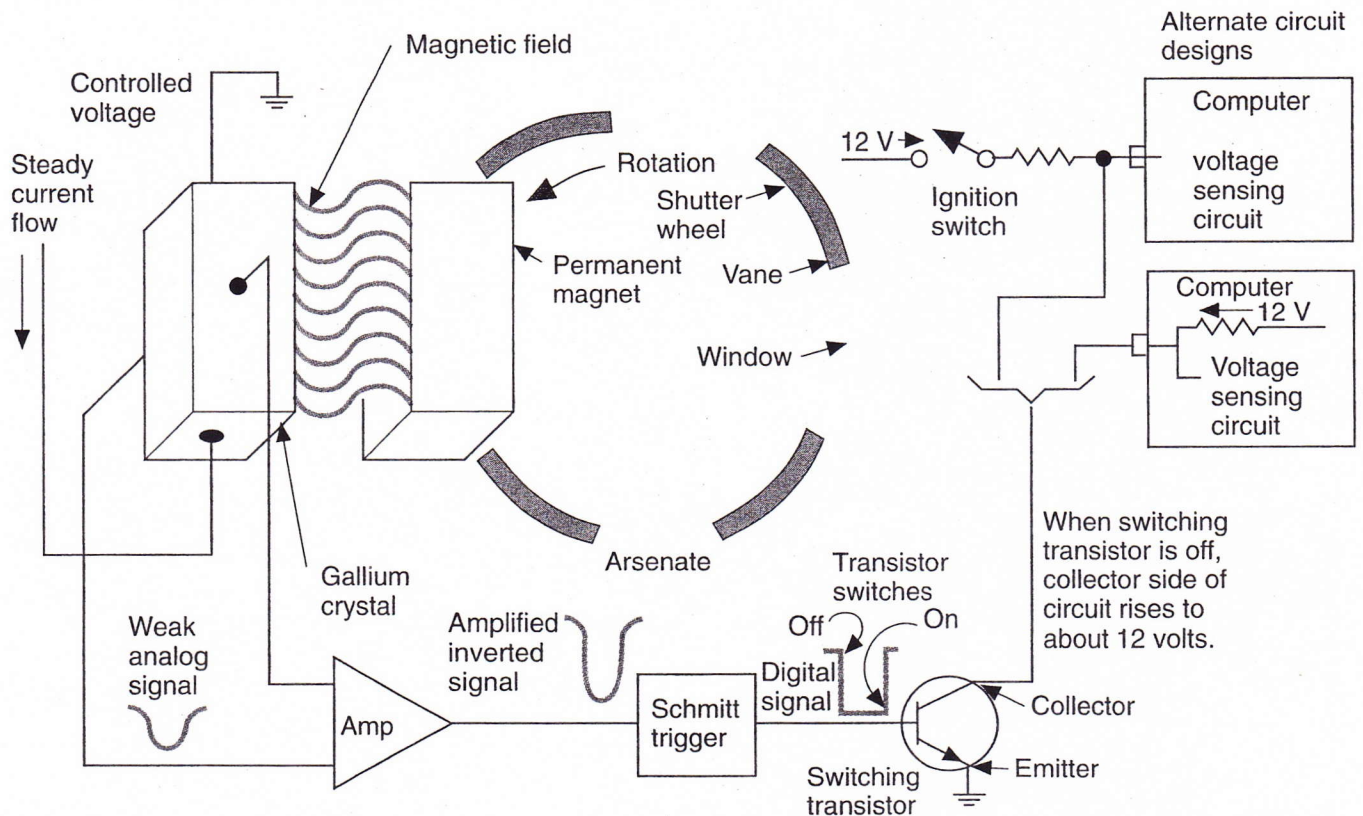


FIGURE 15-21 Typical circuit of a Hall-effect switch.

vanes pass through the air gap. When a shutter vane enters the gap, it intercepts the magnetic field and shields the Hall layer from its lines of force. The electrons in the supply current are no longer disrupted and return to a normal state. This results in low voltage potential in the signal circuit of the Hall switch.

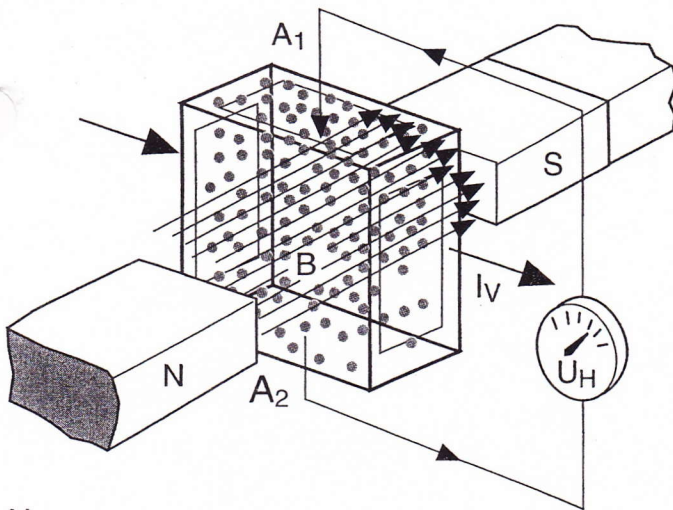
The signal voltage leaves the Hall layer as a weak analog signal. To be used by the CPU, the signal must be conditioned. It is first amplified because it is too weak to produce a desirable result. The signal is also inverted; a low input signal is converted into a high output signal. It is then sent through a **Schmitt trigger**, which is a type of A/D converter, where it is digitized and conditioned into a clean square wave signal. The signal is finally sent to a switching transistor.

The computer senses the turning on and off of the switching transistor to determine the frequency of the signals and calculates speed.

Regardless of the type of sensors used in electronic control systems, the computer is incapable of functioning properly without input signal voltage from sensors.

Communication Signals

Voltage does not flow through a conductor, current flows while voltage is the pressure that pushes the current. However, voltage can be used as a **signal**, for example, difference in voltage levels, frequency of change, or switching from positive to negative values can be used as a signal.



U_H = Hall voltage
 B = Magnetic field (flux density)
 I_v = Constant supply current
 A_1, A_2 = Hall layer

FIGURE 15-22 The magnetic field causes the electrons from the supply current to gather at the Hall layer's negative terminal. This creates a voltage potential.

A computer is capable of reading voltage signals. The programs used by the CPU are "burned" into IC chips using a series of numbers. These numbers represent various combinations of voltages that the computer can understand. The voltage signals to the computer can be either analog or digital. **Analog** means a voltage signal is infinitely variable, or can be changed, within a given range. **Digital** means a voltage signal that is one of two states—either on-off, yes-no, or high-low. Most input sensors are designed to produce a voltage signal that varies within a given range, which is an analog signal. For example, ambient temperature sensors do not change abruptly. The temperature varies in infinite steps from low to high.

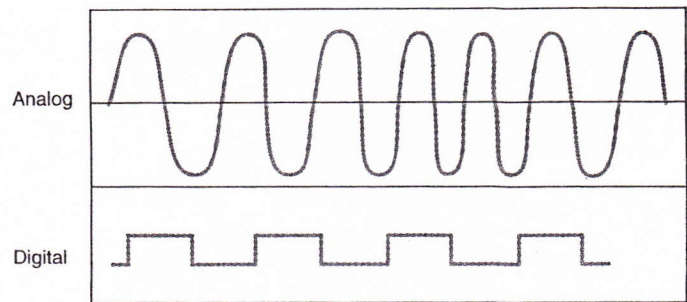


FIGURE 15-23 Analog signals can be constantly variable. Digital signals are either on-off or low-high.

The same is true for several other outputs, such as engine speed, vehicle speed, fuel flow, etc.

Compared to an analog voltage signal, digital voltage patterns are square-waved because the transition from one voltage to another is very abrupt (Figure 15-23). A digital signal is produced by an on-off or high-low voltage. In a digital signal, the voltage is represented by a series of digits, which create a **binary code**.

A computer can only read a digital binary signal. To overcome this communication problem, all analog voltage signals are converted to a digital format by a device known as an analog-to-digital converter (**A/D converter**). The A/D converter (Figure 15-24) is located in a section of the processor called the input signals. However, some sensors, such as the Hall-effect switch, produce a digital or square-wave signal that can go directly to the CPU as an input. The term **square wave** is used to describe the appearance of a digital circuit after it has been plotted on a graph. The abrupt changes in circuit condition (on and off) result in a series of horizontal and vertical lines that connect to form a square-shaped pattern.

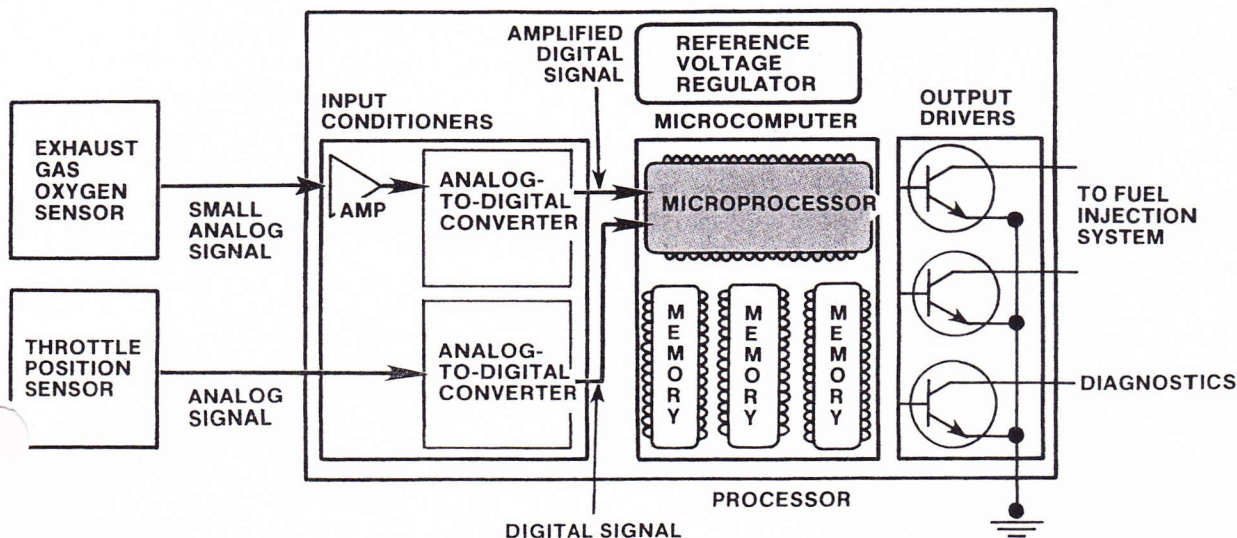


FIGURE 15-24 The A/D converter prepares input signals for the CPU.

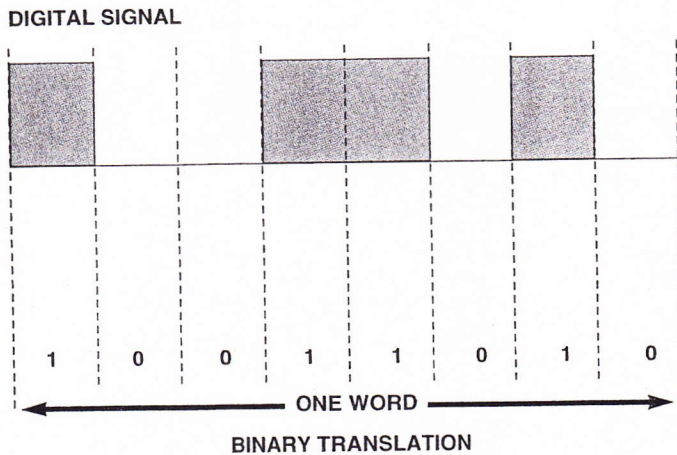


FIGURE 15-25 Each zero (0) and one (1) represents a bit of information. When eight bits are combined in specific sequence, they form a byte or word that makes up the basis of a computer's language. *Courtesy of General Motors Corporation*

The A/D converter changes a series of signals to a binary number made up of 1s and 0s. Voltage above a given value converts to 1, and zero voltage converts to 0 (Figure 15-25). Each 1 or 0 represents a **bit** of information. Eight bits equal a **byte** (sometimes referred to as a word). All communication between the CPU, the memories, and the interfaces is in binary code, with each information exchange in the form of a byte.

To get an idea of how binary coding works, let us see how signals from the coolant temperature sensor (CTS) are processed by the CPU. The CTS is a type of thermistor (negative coefficient to be exact) that controls a reference signal based on temperature changes. Upon receiving the CTS's analog signals, the input conditioner immediately groups each signal value into predetermined voltage range and assigns a numeric value to each range. In our example, use the following ranges and numeric values: 0 to 2 volts = 1, 2 to 4 volts = 2, and 4 to 5 volts = 3 (assuming a V_{ref} of 5 volts). If you are wondering where these ranges and numeric values come from, they are written into the computer's memory by a human programmer at the time of the computer's development.

When the CTS is hot, its resistance is low and the modified voltage signal it sends back falls into the high range (4 to 5 volts). Upon entering the A/D converter, the voltage value is assigned a numeric value of 3 (based on the ranges previously cited) and is ready for further translation into a binary code format. Binary numbers are represented by the numbers 0 and 1. Any number and word can be translated into a combination of binary 1s and 0s.

Without going into the finer points of binary numbering, the number 3 in binary is expressed as

TABLE 15-1 BINARY NUMBER CODE

Decimal Number	Binary Number Code 8421	Binary to Decimal Conversion
0	0000	$= 0 + 0 = 0$
1	0001	$= 0 + 1 = 1$
2	0010	$= 2 + 0 = 2$
3	0011	$= 2 + 1 = 3$
4	0100	$= 4 + 0 = 4$
5	0101	$= 4 + 1 = 5$
6	0110	$= 4 + 2 = 6$
7	0111	$= 4 + 2 + 1 = 7$
8	1000	$= 8 + 0 = 8$

11. To the thousands of tiny transistors and diodes that act as the on-off switches inside digitally oriented microprocessors, 11 instructs the computer to turn on or apply voltage to a specific circuit for a predetermined length of time (based on its program). Table 15-1 illustrates how binary numbers can be converted into decimal or base ten numbers. Note how the right-hand binary number equals one and the left number equals eight.

In addition to A/D conversion, some voltage signals require amplification before they can be relayed to the CPU. To perform this task, an input conditioner known as an **amplifier** is used to strengthen weak voltage signals (Figure 15-26).

After input has been generated, conditioned, and passed along to the computer, it is ready to be processed for the purposes of performing work and displaying information. The computer contains a crystal oscillator or **clock** that delivers a constant time pulse. The clock is a crystal that electrically vibrates when subjected to current at certain voltage levels. As a result, the chip produces very regular series of voltage pulses. The clock maintains an orderly flow of information through the computer circuits by transmitting one bit of binary code for each pulse. In this manner, the computer is capable of distinguishing between the binary codes such as 101 and 1001. For the CPU to make the most informed decisions regarding system operation, sensor input is sent through different logic gates constructed within the CPU.

Logic Gates

Logic gates are the thousands of field-effect transistors (FET) incorporated into the computer's circuitry. The FETs use the incoming voltage patterns to determine the pattern of pulses leaving the gate. These circuits are called logic gates because they act as gates

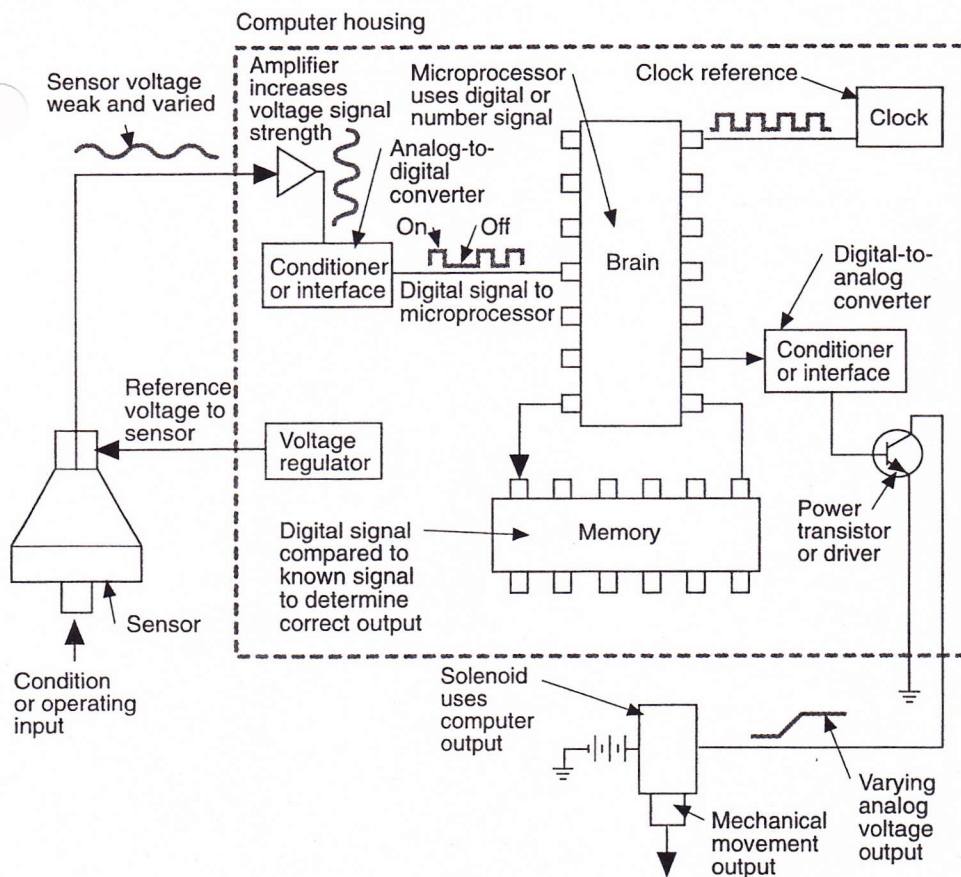


FIGURE 15-26 Here is an example of how digital voltage signals relay information. After receiving the digital signal and converting it to a binary format, the information is then displayed in a numerical form that is easily understood by the CPU. *Courtesy of General Motors Corporation*

to output voltage signals depending on different combinations of input signals. The following are the most common logic gates and their operation. The symbols in the figures represent functions and not electronic construction.

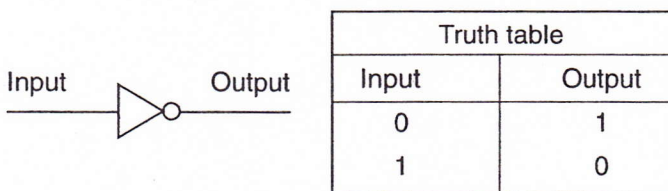


FIGURE 15-27 NOT gate symbol and truth table. The NOT gate inverts the input signal.

- 1. NOT gate:** A NOT gate simply reverses binary 1s and 0s and vice versa (Figure 15-27). A high input results in a low output, and a low input results in a high output.
- 2. AND gate:** The AND gate will have at least two inputs and one output. The operation of the AND gate is similar to two switches in series with a load (Figure 15-28). The only way the light will turn on is if switches A and B are closed. The output of the gate will be high only if both inputs are high. Before current can be present at the output of the gate, current must be present at the base of both transistors (Figure 15-29).

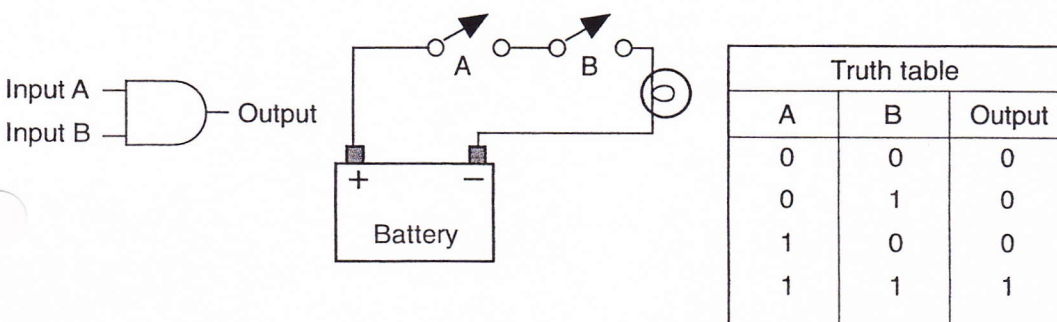


FIGURE 15-28 AND gate symbol and truth table. The AND gate operates similarly to switches in series.

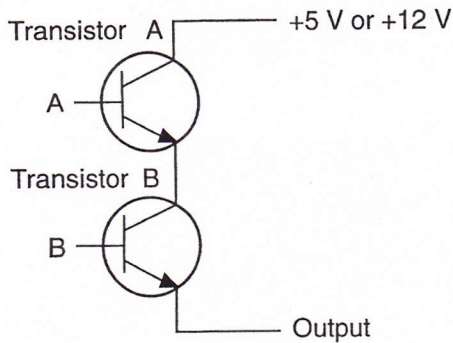


FIGURE 15-29 AND gate circuit.

3. **OR gate:** The OR gate operates similarly to two switches that are wired in parallel to a light (Figure 15-30). If switch A or B is closed, the light will turn on. A high signal to either input will result in a high output.
4. **NAND and NOR gates:** A NOT gate placed behind an OR or AND gate inverts the output signal (Figure 15-31).

5. **Exclusive-OR (XOR) gate:** A combination of gates that will produce a high output signal only if the inputs are different (Figure 15-32).

These different gates are combined to perform the processing function. The following are some of the most common combinations.

1. **Decoder circuits:** A combination of AND gates used to provide a certain output based on a given combination of inputs (Figure 15-33). When the correct bit pattern is received by the decoder, it will produce the high-voltage signal to activate the relay coil.
2. **Multiplexer (MUX):** The basic computer is not capable of looking at all of the inputs at the same time. A multiplexer is used to examine one of many inputs depending on a programmed priority rating (Figure 15-34).
3. **Demultiplexer (DEMUX):** Operates similar to the MUX except that it controls the order of the

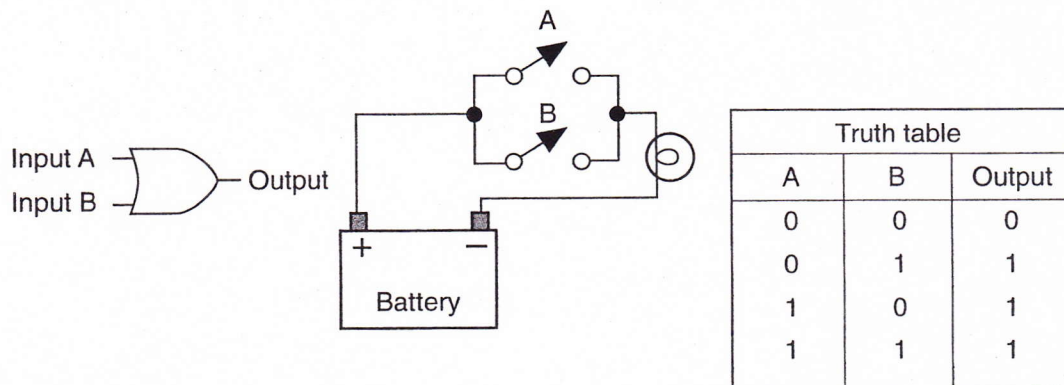
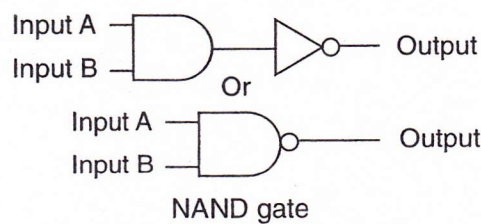
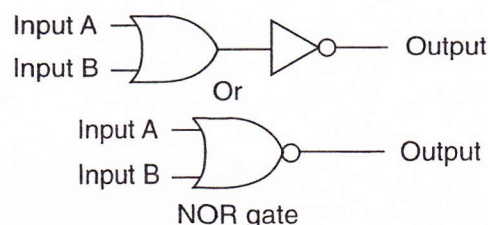


FIGURE 15-30 OR gate symbol and truth table. The OR gate is similar to parallel switches.



Truth table		
A	B	Output
0	0	1
0	1	1
1	0	1
1	1	0



Truth table		
A	B	Output
0	0	1
0	1	0
1	0	0
1	1	0

FIGURE 15-31 Symbols and truth tables for NAND and NOR gates. The small circle represents an inverted output on any logic gate symbol.

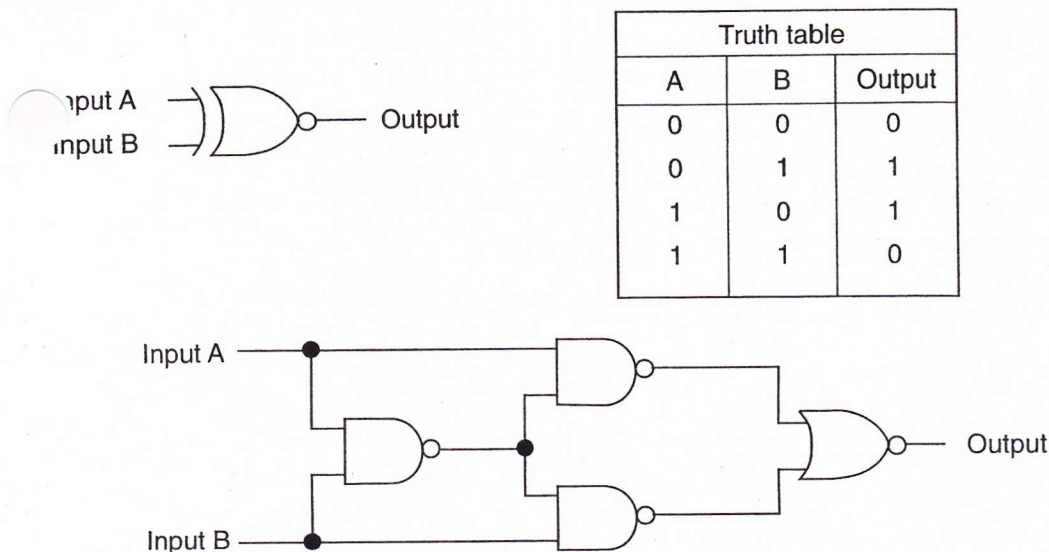


FIGURE 15-32 XOR gate symbol and truth table. An XOR gate is a combination of NAND and NOR gates.

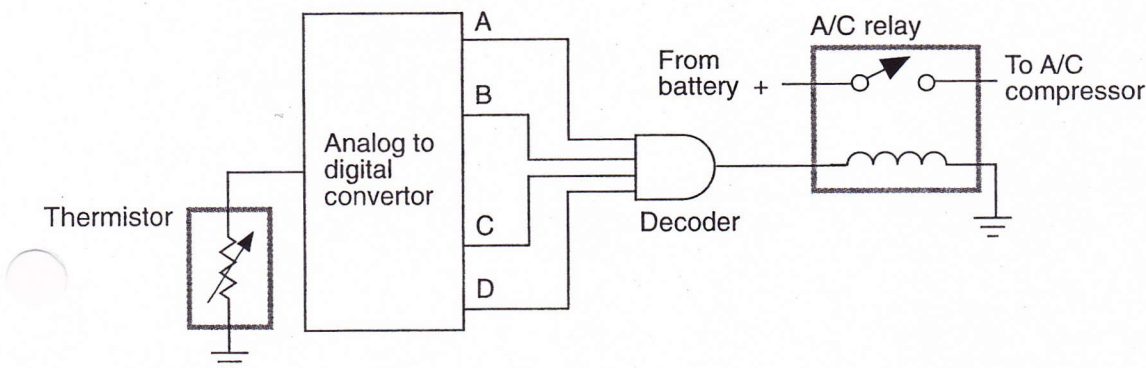


FIGURE 15-33 Simplified temperature sensing circuit that will turn on the A/C compressor when the inside temperature reaches a predetermined level.

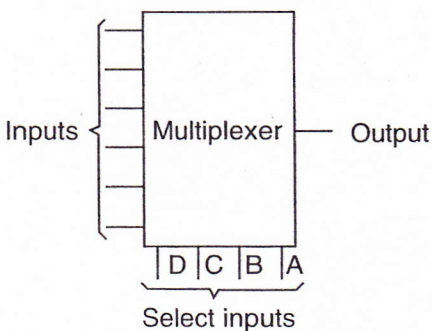


FIGURE 15-34 Selection at inputs DCBA will determine which data input will be processed.

- outputs (Figure 15-35). The process that the MUX and DEMUX operate on is called **sequential sampling**. This means the computer will deal with all the sensors and actuators one at a time.
4. **RS and clocked RS flip-flop circuits:** Logic circuits that remember previous inputs and do not change their outputs until they receive new input

signals. Figure 15-36 shows a basic RS flip-flop circuit. The clocked flip-flop circuit has an inverted clock signal as an input so circuit operations occur in the proper order (Figure 15-37). Flip-flop circuits are called **sequential logic circuits** because the output is determined by the sequence of inputs. A given input affects the output produced by the next input.

5. **Registers:** Used in the computer to temporarily store information. A register is a combination of flip-flops that transfers bits from one to another every time a clock pulse occurs (Figure 15-38, page 378).
6. **Accumulators:** Registers designed to store the results of logic operations that can become inputs to other computers or modules.

Logic gates process input information to command output devices. The order of this logic or the instructions to the computer are held in the computer's memory.

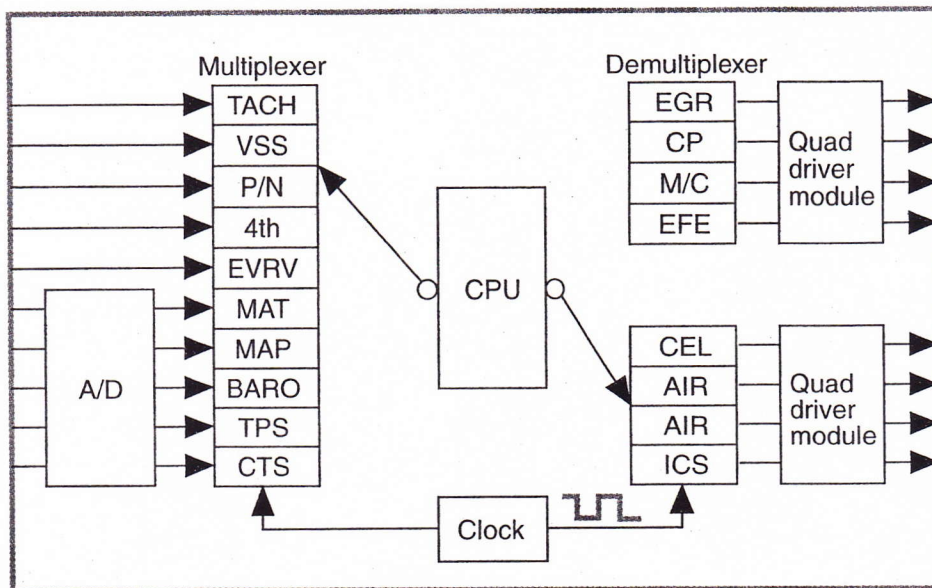


FIGURE 15-35 Block diagram representation of the MUX and DEMUX circuit.

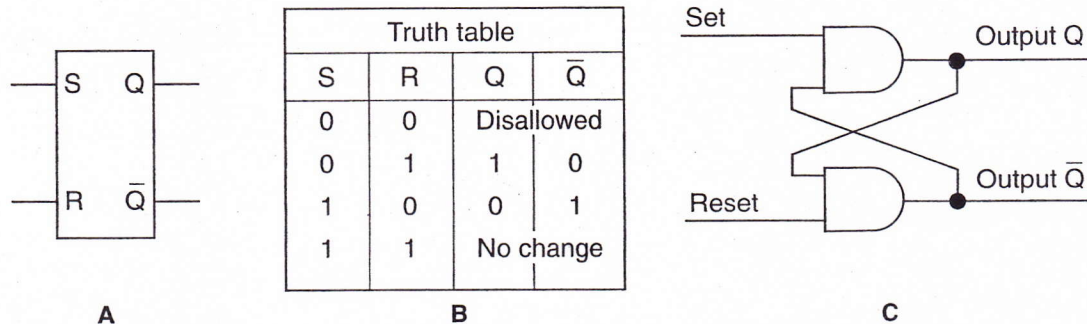


FIGURE 15-36 (A) RS flip-flop symbol. (B) Truth tables. (C) Logic diagram.

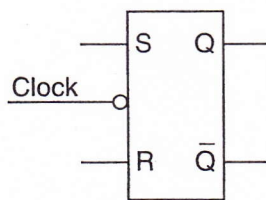


FIGURE 15-37 Clocked RS flip-flop symbol.

Memories

A computer's memory holds the programs and other data, such as vehicle calibrations, which the microprocessor refers to in performing calculations. To the CPU, the program is a set of instructions or procedures that it must follow. Included in the program is information that tells the microprocessor when to retrieve input (based on temperature, time, etc.), how to process the input, and what to do with it once it has been processed.

The microprocessor works with memory in two ways: it can read information from memory or change information in memory by writing in or storing new

information (Figure 15-39). To write information in memory, each memory location is assigned a number (written in binary code also) called an address. These addresses are sequentially numbered, starting with zero, and are used by the microprocessor to retrieve data and write new information into memory. During processing, the CPU often receives more data than it can immediately handle. In these instances, some information has to be temporarily stored or written into memory until the microprocessor needs it.

When ready, the microprocessor accesses the appropriate memory location (address) and is sent a copy of what is stored. By sending a copy, the memory retains the original information for future use.

There are basically three types of memory used in automotive CPUs today (Figure 15-40, page 379). They are read only memory, programmable read only memory, and random access memory.

READ ONLY MEMORY (ROM) Permanent information is stored in read only memory (ROM). Information in ROM cannot be erased, even if the system is turned off or the CPU is disconnected from

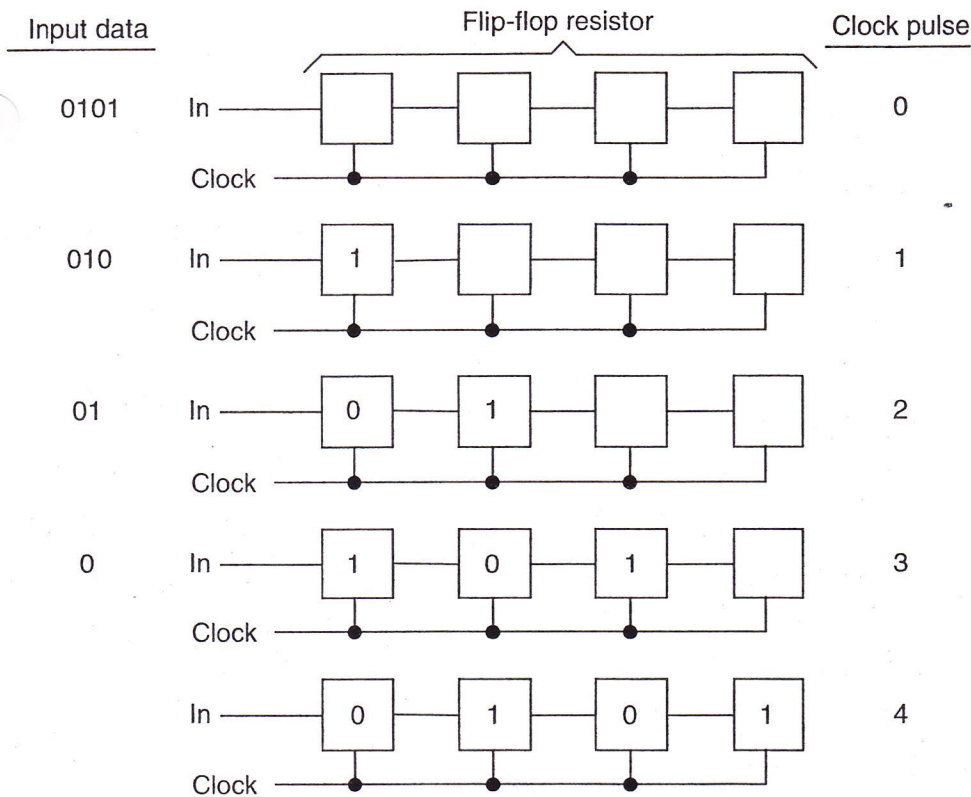


FIGURE 15-38 It takes four clock pulses to load four bits into the register.

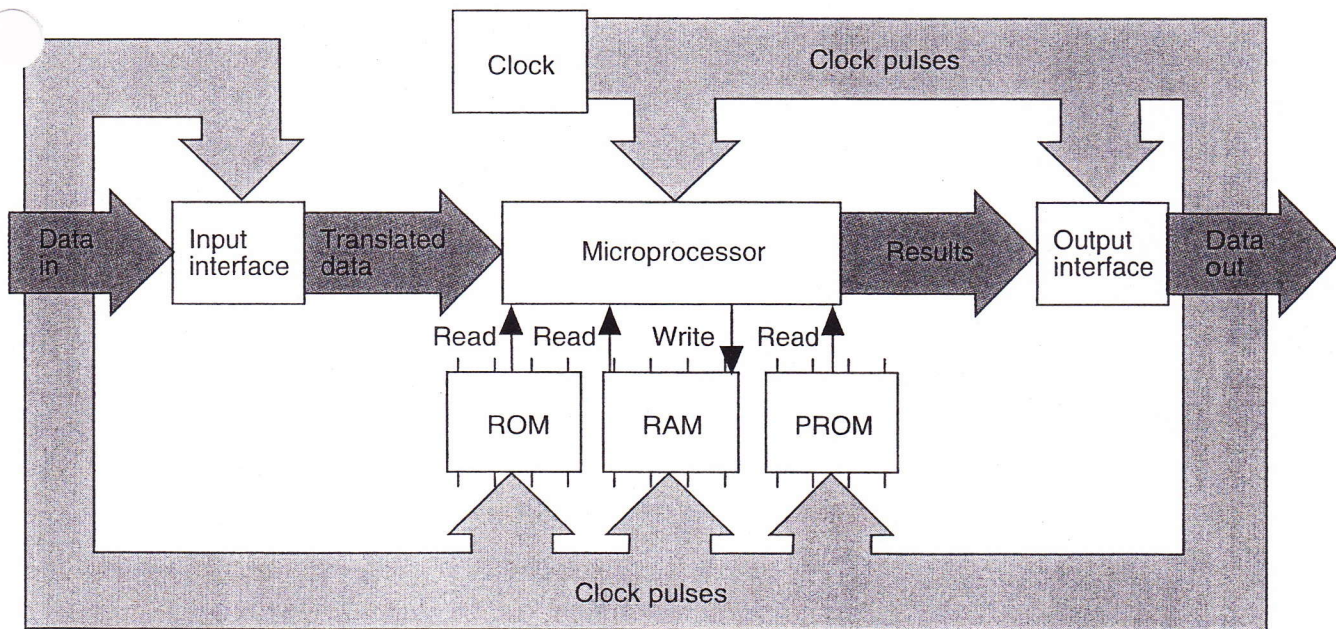


FIGURE 15-39 Interaction of the microprocessor and its support systems and memory banks. *Courtesy of General Motors Corporation*

the battery. As the name implies, information can only be read from ROM.

When making decisions, the microprocessor is constantly referring to the stored information and the input from sensors. By comparing information from these sources, the CPU makes informed decisions.

PROGRAMMABLE READ ONLY MEMORY (PROM) The **PROM** differs from the ROM in that it plugs into the computer and is more easily removed and reprogrammed or replaced with one containing a revised program. It contains program information specific to different vehicle model calibrations.

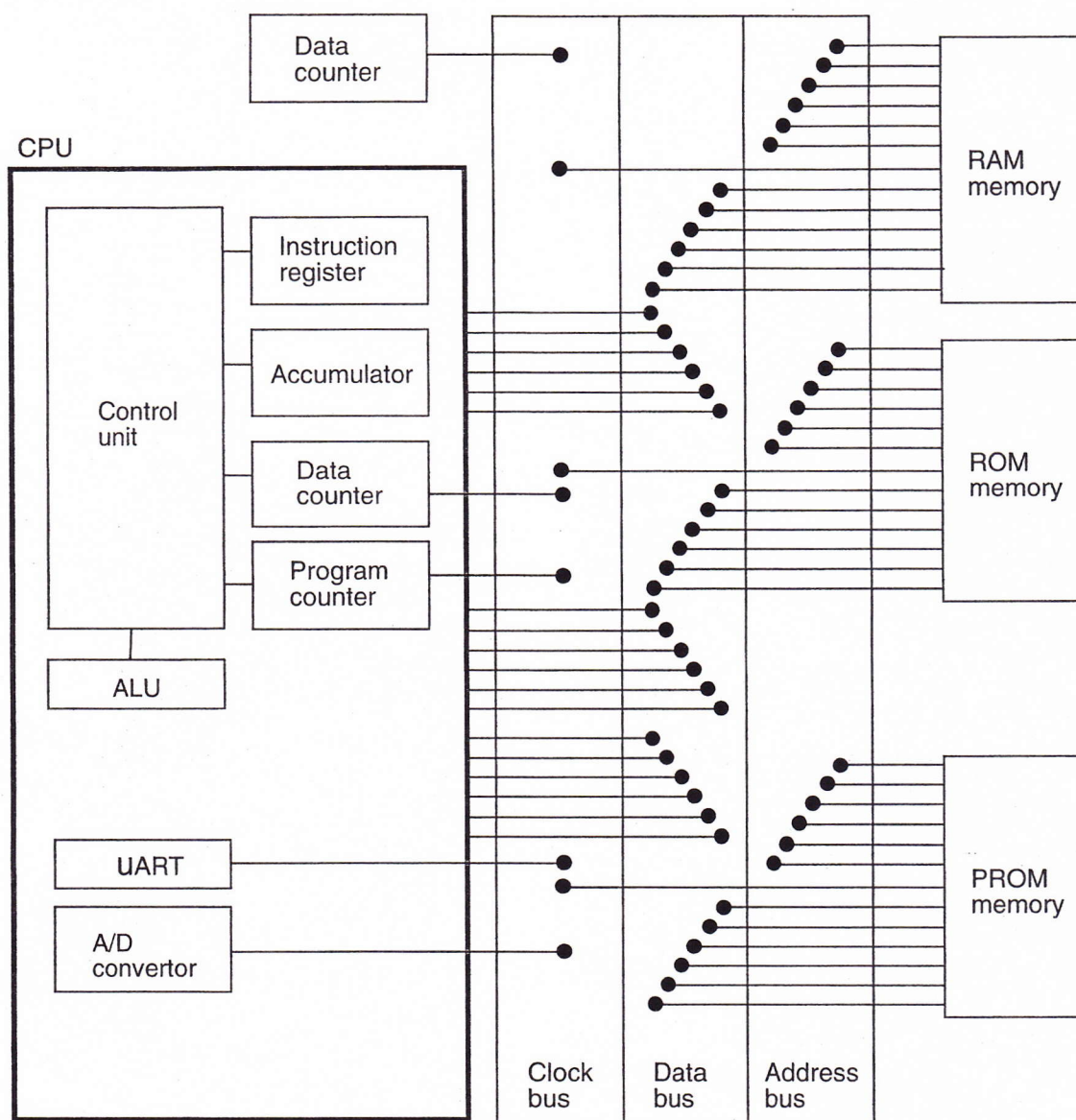


FIGURE 15-40 The three memories within a computer. *Courtesy of General Motors Corporation*

Erasable PROM (**EPROM**) is similar to PROM except that its contents can be erased to allow new data to be installed. A piece of Mylar tape covers a window. If the tape is removed, the memory circuit is exposed to ultraviolet light that erases its memory.

Electrically erasable PROM (**EEPROM**) allows changing the information electrically one bit at a time. Some manufacturers use this type of memory to store information concerning mileage, vehicle identification number, and options.

RANDOM ACCESS MEMORY (RAM) The RAM is used during computer operation to store temporary information. The CPU can write, read, and erase information from RAM in any order, which is why it is called random. One characteristic of RAM is that when the ignition key is turned off and the engine is

stopped, information in RAM is erased. RAM is used to store information from the sensors, the results of calculations, and other data that are subject to constant change.

There are currently two other versions of RAM in use: volatile and nonvolatile. A volatile RAM, usually called keep alive memory (**KAM**) has most of the features of RAM. Information can be written into KAM and can be read and erased from KAM. Unlike RAM, information in KAM is not erased when the ignition key is turned off and the engine is stopped. However, if battery power to the processor is disconnected, information in KAM is erased.

A nonvolatile RAM (**NVRAM**) does not lose its stored information if its power source is disconnected. Vehicles with digital display odometers usually store mileage information in nonvolatile RAM.

Actuators

Once the computer's programming instructs that a correction or adjustment must be made in the controlled system, an output signal is sent to control devices called **actuators**. These actuators, which are solenoids, switches, relays, or motors, physically act on or carry out the command sent by the computer.

Actually, actuators are electromechanical devices that convert an electrical current into mechanical action. This mechanical action can then be used to open and close valves, control vacuum to other components, or open and close switches. When the CPU receives an input signal indicating a change in one or more of the operating conditions, the CPU determines the best strategy for handling the conditions. The CPU then controls a set of actuators to achieve a desired effect or strategy goal. For the computer to control an actuator, it must rely on a component called an **output driver**.

The output driver usually applies the ground circuit of the actuator. The ground can be applied steadily if the actuator must be activated for a selected amount of time, or the ground can be pulsed to activate the actuator in pulses.

Output drivers operate by the digital commands issued by the CPU. Basically, the output driver is nothing more than an electronic on-off switch used to control a specific actuator.

To illustrate this relationship, let us suppose the computer wants to turn on the engine's cooling fan. Once it makes a decision, it sends a signal to the output driver that controls the cooling fan relay (actuator). In supplying the relay's ground, the output driver completes the power circuit between the battery and cooling fan motor and the fan operates. When the fan has run long enough, the computer signals the output driver to open the relay's control circuit (by removing its ground), thus opening the power circuit to the fan.

For actuators that cannot be controlled by a digital signal, the CPU must turn its digitally coded instructions back into an analog signal. This conversion is completed by the A/D converter.

Displays can be controlled directly by the CPU. They do not require digital-to-analog conversion or output drivers because they contain circuitry that decodes the microprocessor's digital signal. The decoded information is then used to indicate such things as vehicle speed, engine rpm, fuel level, or scan tool values. Common types of electronic readout devices used as displays include light-emitting diodes (LED), liquid crystal display (**LCD**), and vacuum fluorescent display (**VFD**).

Some systems require the actuator to either be turned on and off very rapidly or for a set amount of cycles per second. It is duty cycled if it is turned on and off a set amount of cycles per second. **Duty cycle** is the percentage of on-time to total cycle time. Most duty cycled actuators cycle ten times per second. To complete a cycle, it must go from off to on to off again. If the cycle rate is ten times per second, one actuator cycle is completed in 1/10th of a second. If the actuator is turned on for 30 percent of each tenth of a second and off for 70 percent, it is referred to as a 30 percent duty cycle (Figure 15-41).

If the actuator is cycled on and off very rapidly, the pulse width can be varied to provide the desired results. **Pulse width** is the length of time in milliseconds that an actuator is energized. For example, the computer program will select an illumination level of a digital instrument panel based on the intensity of the ambient light in the vehicle. The illumination level is achieved through pulse width modulation of the lights. If the lights need to be bright, the pulse width is increased, which increases the length of on-time. As light intensity needs to be reduced, the pulse width is decreased (Figure 15-42).

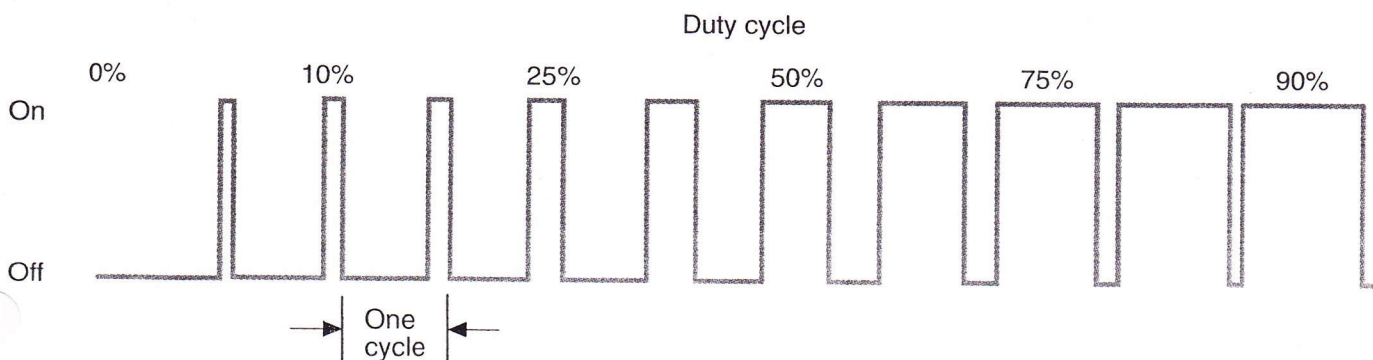


FIGURE 15-41 Duty cycle is the percentage of on-time per cycle. Duty cycle can be changed; however, total cycle time remains constant.

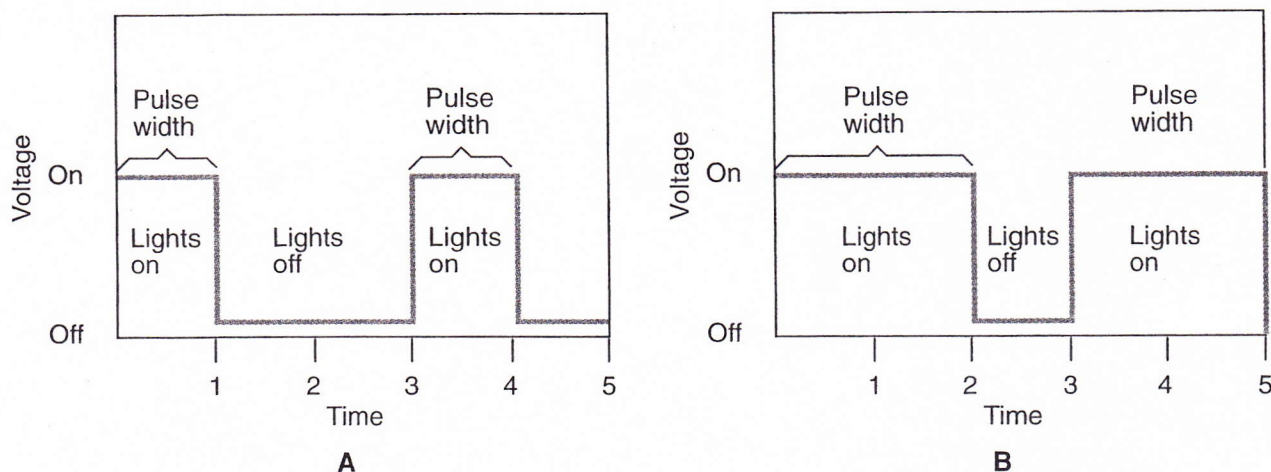


FIGURE 15-42 Pulse width is the duration of on-time: (A) pulse width modulation to achieve dimmer dash lights, (B) pulse width modulation to achieve brighter dash illumination.

Power Supply

The CPU also contains a power supply that provides the various voltages required by the microprocessor and internal clock that provides the clock pulse, which in turn controls the rate at which sensor readings and output changes are made. Also contained are protection circuits that safeguard the microprocessor from interference caused by other systems in the vehicle and diagnostic circuits that monitor all inputs and outputs and signal a warning light if any values go outside the specified parameters. This warning light is called the malfunction indicator lamp (MIL).

Complete specific information concerning the use of computers (microprocessors) in various automotive electronic systems is presented in later chapters.

MULTIPLEXING

To eliminate the necessity of adding wires and the subsequent weight to vehicles as more and more electronics are added, manufacturers are using **multiplexing**. A multiplex wiring system uses bus data links that connect different computers or control modules together. Each module can transmit and receive digital codes over the bus data links. This allows the module to share the same information with other modules. The signal sent from a sensor can go to any of the modules and can be used by any other module. This eliminates the need to have separate wires from each sensor to each of the modules, thereby eliminating many wires.

An IC or chip is used to prevent the digital codes from overlapping by allowing only one code to be transmitted at a time. Each digital signal is preceded by an identification code that establishes its priority. If two modules attempt to send a message at the

same time, the signal with the higher priority code is transmitted first.

PROTECTING ELECTRONIC SYSTEMS

The last thing a technician wants to do when a vehicle comes into the shop for repair is create problems. This is especially true when it comes to electronic components. It is a must to be aware of the proper ways to protect automotive electrical systems and electronic components during storage and repair.

The computer operates on a very low voltage, and there needs to be a word said on static electricity, which can generate up to 25,000 volts. Simply touching the computer case is not likely to damage the computer, but it is always a good idea to be careful. Never touch the electrical contacts on any other electrical part. Before touching a computer, whether removing or replacing it, always touch a good ground with your finger. This safely discharges any static electricity. Some technicians even attach a metal wire or chain around their wrist and connect the other end to a good ground. When parts inside a computer are being replaced, such as a PROM module, this is a good idea.

Avoid touching bare metal contacts. Oils from the skin can cause corrosion and poor contacts.

The sensor wires that connect to the computer should never be rerouted. Induction of voltage can occur and the resulting problems may be impossible to find. When replacing wiring, always check the service manual and follow the routing instructions.

Accidentally touching a metal slip lead or test probe between metal terminals can cause a short circuit. Expensive computer modules or sensors can be

destroyed instantly, without warning, by incorrect testing procedures.

If the code indicates a problem with the oxygen sensor, extra caution is required. The oxygen sensor wire carries a very low voltage and must be isolated from other wires. If it is not, nearby wires could add more induced voltage. This gives false data to the computer and can result in a driveability problem. Some car makers use a foam sleeve around the oxygen sensor wire for this purpose. Do not allow grease, lubricants, or cleaning solvents of any kind to touch the sensor end or the electrical connector plug. Apply the manufacturer's special anti-seize compound to the threads before installing the sensor.

Avoid jump-starting whenever possible. The discharged battery can explode, or you can create voltage spikes that could damage electronic components. This is true of both the car you are trying to start and the car providing the jump. However, if you must jump-start a car, observe these safety precautions. Connect positive terminal to positive terminal on the batteries, connect the negative terminal of the good battery to a ground other than the ground terminal of the bad battery. If you use another car for the jump, make sure the two vehicles are not touching each other. Make sure every electrical device in the car, including the dome light, is turned off before connecting the batteries. Only after the hookups are properly made should you turn the key in the dead car to get it started. Once the dead car is running, remove all jumper connections before turning on any electrical devices.

Computer diagnostic tests can be performed using a scan tool. Connect the tool to the diagnostic connector. Follow the sequence given in the service manual or the scanning tool's instruction manual. The trouble codes are displayed on the scan tool readout.

Remove any computer module that could be affected by welding, hammering, grinding, sanding, or metal straightening. Be sure to protect the removed computer equipment by wrapping it in a plastic bag to shield it from moisture and dust.

Many test procedures require that electrical power or ground be supplied to the circuit being tested. Avoid grounding powered circuits with metal tools. Avoid touching live electrical leads to grounded metal parts of the automobile. Personal injury from sparks may result, or the unit being tested may be damaged or destroyed.

Be careful not to damage connectors and terminals when removing electronic components. Some may require special tools to remove them.

When procedures call for connecting test leads, or wires, to electrical connections, use extreme care and follow the manufacturer's instructions. Identify the correct test terminals before attempting to connect test leads.

The charging system, including the battery, must remain in good operating condition. If the electrical system falls below 12 volts, the computer may not work properly. However, low voltage does not damage the computer. If there are more than 15 volts, the computer may become damaged and must be replaced.

When checking a computerized ignition system, use a high-impedance digital meter. The computer may be damaged by using an analog (needle-type) meter. Do not connect the meter directly to the computer. Use part of the circuit. Do not connect jumper wires across a sensor unless the service manual tells you to do so. This could damage the computer.

TESTING ELECTRONIC CIRCUITS AND SYSTEMS

Most electronic circuits can be checked in the same way as other electrical circuits. However, only high-impedance meters should be used. Multimeters and oscilloscopes are the most commonly used diagnostic tools for these circuits.

A multimeter may have AC selection modes for voltage and amperage. These modes are used to measure voltages and amperages that change polarity or levels very quickly. Most meters display the average voltage or current in an AC circuit. Some meters display **RMS** (root-mean-square) readings. These readings are very close to being average readings; however, there may be slight differences as this scale compensates for extreme fluctuations in voltage and current flow.

RMS refers to the effective or useful value of an AC signal. To determine the RMS value, peak voltage readings are multiplied by the RMS constant (0.707). The effective value of AC is the amount of current or voltage that produces the same heating effect as an equal amount of DC current or voltage. The effective RMS value is calculated by squaring the instantaneous values of all the points on the sine wave, taking the average of these values and extracting the square root. Therefore, the effective value is the root of the mean (average) square of the values along the sine wave. The resulting answer from this mathematical formula is the root-mean-square (Figure 15-43).

Multimeters can also be used to check individual components, such as a diode. To test a diode, an

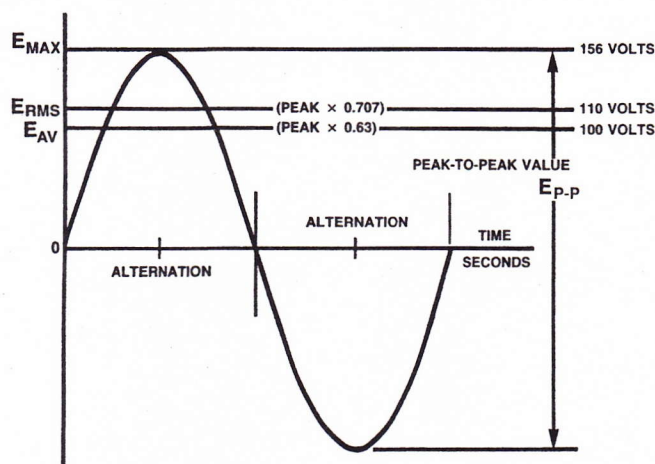


FIGURE 15-43 AC voltage: RMS. *Courtesy of Hydraulic Division of General Motors Corporation*

ohmmeter is normally used. There should be continuity in one direction only. By connecting the meter leads across the diode, the meter should show low or high resistance. When the leads across the diode are reversed, an opposite reading should be observed. If zero ohms of resistance is measured across the diode, the diode is shorted. If high or infinite resistance is measured across the diode, in both directions, the diode is open.

Some multimeters have a diode test mode that can be selected to check continuity through a diode. When using this function, remember that a good diode allows current flow in one direction only.

An oscilloscope is a valuable tool for understanding and diagnosing electronic circuits. The **scope** is primarily used to measure voltages. Scopes are relatively easy to use. Most have two leads which are connected to the circuit in the same way as a voltmeter.

The screen on the scope displays voltage over time; therefore, any change in voltage will be displayed. Changing the voltage scale on the scope changes how many volts or millivolts each horizontal line is worth. The vertical lines on the scope represent periods of time. The time control sets how long a time period each line represents. Normally these time periods are in parts of a second, such as **milliseconds** (1/1,000th of a second).

These time periods show the frequency of a voltage signal. **Frequency** is a term that describes how often a signal performs a complete cycle. A **cycle** is simply a description of the changes that a signal goes through without repeating itself. Frequency is measured in **Hertz**. Hertz is a measurement of cycles per second. To determine the frequency of something,

divide the length of time it takes to complete one cycle into 1.

Many scopes can display two signals at the same time. These are known as dual-trace scopes. They are used to compare the signals of two components or circuits.

Whenever using a scope on a circuit, always follow the meter's instruction manual for hookup and proper settings. Most service manuals have illustrations of the patterns that are expected from the different electronic components. If the patterns do not match those in the service manual, a problem is indicated. The problem may be in the component or in the circuit. Further testing is required to locate the exact cause of the problem.



SHOP TALK

It is very helpful to know if the component being tested with a scope is digital or analog based. With this knowledge, it is easier to recognize an incorrect pattern. Digital patterns should show a clear on-off signal, whereas analog signals should show steady voltage changes as conditions change. ■



CASE STUDY

A customer came in with her vehicle. Her complaint was basically that the car had poor performance, especially during acceleration. The technician road tested the car and found the customer's complaint was valid. He also noticed the engine's idle was not as smooth as it should be.

The car had electronic engine controls, but the technician did not have the proper scan tool to test the system. However, he did understand the system and knew the primary purposes of each of the components. He began to test the system with his multimeter and portable scope.

Going through the basics, he tested the primary inputs. One of these was the TPS. He knew this sensor was a potentiometer and the resistance and voltage output from the sensor should change with a change in throttle position. He connected his scope to the TPS and moved the throttle. When the analog signal on the scope did not change smoothly with a change in the throttle, he knew what the basic problem with the car was—a bad TPS.

KEY TERMS

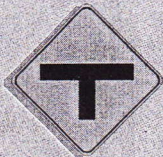
Accumulator	Microprocessor
Actuators	Millisecond
A/D converter	Multiplexer (MUX)
Amplifier	Multiplexing
Analog	NAND gate
AND gate	NOR gate
Base	NOT gate
Binary code	NPN
Bit byte	NTC
Chip	NVRAM
Clock	OR gate
Collector	Output
Computer	Output driver
CPU	Pick-up coil
Cycle	Piezoresistive
Decoder circuit	PN junction
Demultiplexer (DEMUX)	PNP
Digital	Processing
Diode	PROM
Duty cycle	PTC
EEPROM	Pulse width
Electrically inert	RAM
Electronics	Register
Emitter	Reverse bias
EPROM	RMS
Exclusive-OR (XOR) gate	ROM
Feedback	RS flip-flop
FET	Schmitt trigger
Forward bias	Scope
Frequency	Sequential logic circuits
Hall-effect switch	Sequential sampling
Hertz	Signal
IC	Square wave
Impurities	Storage
Input	Timing disc
Integrated circuit	Transistor
KAM	VFD
LCD	Voltage-generating devices
LED	Vref
Logic gate	Wheatstone bridge
Magnetic pulse generator	Zener diode

SUMMARY

- ◆ A computer is an electronic device that stores and processes data.
- ◆ A semiconductor is a material or device that can function as either a conductor or an insulator.
- ◆ Some common semiconductor materials include silicon (Si) and germanium (Ge).
- ◆ N-type semiconductors have loose, or excess, electrons. They have a negative charge.
- ◆ P-type semiconductors are positively charged materials.
- ◆ A diode allows current to flow in one direction.
- ◆ When a diode is placed in a circuit with the positive side of the circuit connected to the positive side of the diode and the negative side of the circuit connected to the negative side of the diode, the diode is said to have forward bias.
- ◆ Light-emitting diodes (LEDs) are much the same as regular diodes. They emit light when they are forward biased.
- ◆ Zener diodes are used to regulate voltage in a circuit.
- ◆ Transistors are used in place of switches and relays in electronic circuits.
- ◆ A transistor resembles a diode with an extra side. It can consist of two P-type materials and one N-type material or two N-type materials and one P-type material. These are called PNP and NPN types.
- ◆ The different names for the legs of the transistor are the emitter, base, and collector.
- ◆ A very small current applied to the base of the transistor controls a much larger current flowing through the entire transistor.
- ◆ An integrated circuit is simply a large number of diodes, transistors, and other electronic components, such as resistors and capacitors, all mounted on a single piece of semiconductor material.
- ◆ Computers are electronic decision-making centers. Input devices called sensors feed information to the computer. The computer processes this information and sends signals to controlling devices.
- ◆ A typical electronic control system is made of sensors, actuators, CPU, and related wiring.
- ◆ Most input sensors are variable resistance/reference types, switches, and thermistors.
- ◆ The central processing unit (CPU) is the brain of a computer. It brings information into and out of the computer's memory. The input information is processed in the CPU and checked against the program in the computer's memory.
- ◆ Feedback means that data concerning the effects of the computer's commands are fed back to the computer as an input signal.
- ◆ All sensors perform the same basic function. They detect a mechanical condition (movement or position), chemical state, or temperature condition and change it into an electrical signal that can be used by the computer to make decisions.
- ◆ Reference voltage (Vref) sensors provide input to the computer by modifying or controlling a constant, predetermined voltage signal.

- ◆ Most sensors presently in use are variable resistors or potentiometers. They modify a voltage to or from the computer, indicating a constantly changing status that can be calculated, compensated for, and modified.
 - ◆ A thermistor is a solid-state variable resistor made from a semiconductor material that changes resistance in relation to temperature changes.
 - ◆ There are two basic types of thermistors: NTC and PTC. A negative temperature coefficient (NTC) thermistor reduces its resistance as temperature increases. This type is the most commonly used thermistor. A positive temperature coefficient (PTC) thermistor increases its resistance with an increase in temperature.
 - ◆ A Wheatstone bridge is also used as a variable resistance sensor. These are typically constructed of four resistors, connected in series-parallel between an input terminal and a ground terminal. Three of the resistors are kept at the same value. The fourth resistor is a sensing resistor.
 - ◆ Voltage-generating sensors include components like the magnetic pulse generators, Hall-effect switches, oxygen sensors (zirconium dioxide), and knock sensors (piezoelectric), which are capable of producing their own input voltage signal.
 - ◆ Magnetic pulse generators use the principle of magnetic induction to produce a voltage signal. These sensors are commonly used to send data to the computer about the speed of the monitored component.
 - ◆ The major components of a pulse generator are a timing disc and a pick-up coil.
 - ◆ The Hall-effect switch performs the same function as a magnetic pulse generator. It operates on the principle that if a current is allowed to flow through thin conducting material exposed to a magnetic field, another voltage is produced.
 - ◆ A Hall-effect switch contains a permanent magnet, a thin semiconductor layer made of Gallium arsenate crystal (Hall layer), and a shutter wheel.
 - ◆ Outputs or actuators are electromechanical devices that convert current into mechanical action.
 - ◆ A computer is capable of reading voltage signals. The programs used by the CPU are "burned" into IC chips using a series of numbers. These numbers represent various combinations of voltages that the computer can understand. The voltage signals to the computer can be either analog or digital. Analog means a voltage signal is infinitely variable, or can be changed, within a given range. Digital means a voltage signal that is one of two states either on-off, yes-no, or high-low.
 - ◆ A computer can only read a digital binary signal.
- To overcome this communication problem, all analog voltage signals are converted to a digital format by a device known as an analog-to-digital converter (A/D converter).
- ◆ Logic gates are the thousands of field effect transistors (FET) incorporated into the computer's circuitry. The FETs use the incoming voltage patterns to determine the pattern of pulses leaving the gate. These circuits are called logic gates because they act as gates to output voltage signals depending on different combinations of input signals.
 - ◆ The most common logic gates are NOT gates, AND gates, OR gates, NAND and NOR gates, and XOR gates.
 - ◆ A computer's memory holds the programs and other data, such as vehicle calibrations, which the microprocessor refers to in performing calculations.
 - ◆ The microprocessor works with memory in two ways: it can read information from memory or change information in memory by writing in or storing new information.
 - ◆ There are basically three types of memory used in automotive CPUs today: read only memory, programmable read only memory, and random access memory.
 - ◆ Permanent information is stored in read only memory (ROM).
 - ◆ The PROM differs from the ROM in that it plugs into the computer and is more easily removed and reprogrammed or replaced with one containing a revised program. It contains program information specific to different vehicle model calibrations.
 - ◆ The RAM is used during computer operation to store temporary information. The CPU can write, read, and erase information from RAM in any order, which is why it is called random.
 - ◆ Once the computer's programming instructs that a correction or adjustment must be made in the controlled system, an output signal is sent to control devices called actuators. These actuators, which are solenoids, switchers, relays, or motors, physically act or carry out the command sent by the computer.
 - ◆ For the computer to control an actuator, it must rely on a component called an output driver. These drivers usually apply the ground circuit of the actuator.
 - ◆ Some systems require the actuator to either be turned on and off very rapidly or for a set amount of cycles per second. It is duty cycled if it is turned on and off a set amount of cycles per second. Duty cycle is the percentage of on-time to total cycle time.

- ◆ If the actuator is cycled on and off very rapidly, the pulse width can be varied to provide the desired results. Pulse width is the length of time in milliseconds an actuator is energized.
- ◆ A multiplex wiring system uses bus data links that connect different computers or control modules together. Each module can transmit and receive digital codes over the bus data links. This allows the module to share the same information with other modules.
- ◆ Most electronic circuits can be checked in the same way as other electrical circuits. However, only high-impedance meters should be used. Multimeters and oscilloscopes are the most commonly used diagnostic tools for these circuits.
- ◆ A multimeter may have AC selection modes for voltage and amperage. These modes are used to measure voltages and amperages that change polarity or levels very quickly. Most meters display the average voltage or current in an AC circuit. Some meters display root-mean-square (RMS) readings. These readings are very close to being average readings; however, there may be slight differences as this scale compensates for extreme fluctuations in voltage and current flow.
- ◆ The screen on an oscilloscope displays voltage over time; therefore, any change in voltage will be displayed.
- ◆ Frequency is a term that describes how often a signal performs a complete cycle. A cycle is simply a description of the changes a signal goes through without repeating itself. Frequency is measured in Hertz. Hertz is a measurement of cycles per second. To determine the frequency of something, divide the length of time it takes to complete one cycle into 1.



TECH MANUAL

The following procedures are included in Chapter 15 of the *Tech Manual* that accompanies this book:

1. Check continuity across electronic components and circuits with an ohmmeter.
2. Inspect and repair or replace wires and connectors.



REVIEW QUESTIONS

1. The three main types of memory in a computer are called ____, ____, and ____.
2. A device that stores and processes data is a ____.
3. ____ signals show any change in voltage.
4. Digital signals are typically called ____ patterns.
5. ____ means that data concerning the effects of the computer's commands are fed back to the computer as an input signal.
6. The type of memory that contains specific information about the vehicle and can be removed and reprogrammed or replaced is called ____.
7. What are the major components of an electronic control system?
8. A ____ is the simplest type of semiconductor.
9. What is meant by the term *pulse width*?
10. What is the major difference between ROM and RAM memory in a microprocessor?
11. Most semiconductors are made of which of the following materials?
 - a. gallium
 - b. silicone
 - c. copper
 - d. all of the above
12. Technician A says when positive voltage is present at the base of an NPN transistor, the transistor is turned on. Technician B says when an NPN transistor is turned on, current flows through the collector and emitter of the transistor. Who is correct?
 - a. Technician A
 - b. Technician B
 - c. Both A and B
 - d. Neither A nor B
13. Which of the following is *not* a type of information stored in ROM?
 - a. strategy
 - b. look-up tables
 - c. sensor input
 - d. none of the above
14. Technician A uses an ohmmeter to test diodes. Technician B uses a low-impedance voltmeter to measure the effective value of the AC voltage present in a circuit. Who is correct?
 - a. Technician A
 - b. Technician B
 - c. Both A and B
 - d. Neither A nor B