

SENSORS AND ACTUATORS

Computer controlled systems continually monitor the operating condition of today's vehicles. Through sensors, computers receive vital information about a number of conditions, allowing minor adjustments to be made far more quickly and accurately than mechanical systems. Sensors convert temperature, pressure, speed, position and other data into either digital or analog electrical signals.

A digital signal is a voltage signal that is either on or off with nothing in between. A switch is the simplest type of digital signal sensor. The signal from the switch could be 0 volts when off and 12 volts when on. Analog signals on the other hand have continuously variable voltage. A good example is the coolant temperature sensor. The coolant temperature sensor may vary the voltage signal anywhere between 0 volts and 5 volts depending on the temperature of the engine.

The digital signal is the easiest for the computer to understand because it reads the signal as either "on" or "off." The analog signal must be conditioned or converted to digital so the computer can understand it. (This will be covered later.)

While a vehicle may have many different sensors, there are three main categories: voltage-generating, resistive and switches. A voltage-generating sensor generates its own voltage signal in relation to the mechanical condition it monitors. This signal in turn relays to the computer data about the condition of the system it controls. A resistive sensor reacts to changes in mechanical conditions through changes in its resistance. The computer supplies a regulated voltage or reference voltage to the sensor and measures the voltage drop across the sensor to determine the data.

Switch sensors toggle a voltage from the computer high or low, or supply an "on" or "off" voltage signal to the computer. This type of sensor may be as simple as a switch on the brake pedal or as complex as a phototransistor speed sensor.

The computer uses the sensor data to control different systems on a vehicle through the use of actuators. An actuator is an electromechanical device such as a relay, solenoid or motor. Actuators can adjust engine idle speed, change suspension height or regulate the fuel metered into the engine.

This chapter describes several specific sensors used in automobiles, such as potentiometers, thermistors and phototransistor / LED combinations. This chapter also addresses actuators that complete the control process by carrying out the computer's instructions.

The Sensors and Actuators section is divided into the following areas:

Resistive sensors:

- potentiometers
- thermistors
- piezo resistive

Voltage generating sensors:

- piezo electric
- zirconia-dioxide
- magnetic inductance

Switch sensors:

- phototransistors and LEDs
- speed sensors
- G-sensors (Air Bag Impact Sensors)

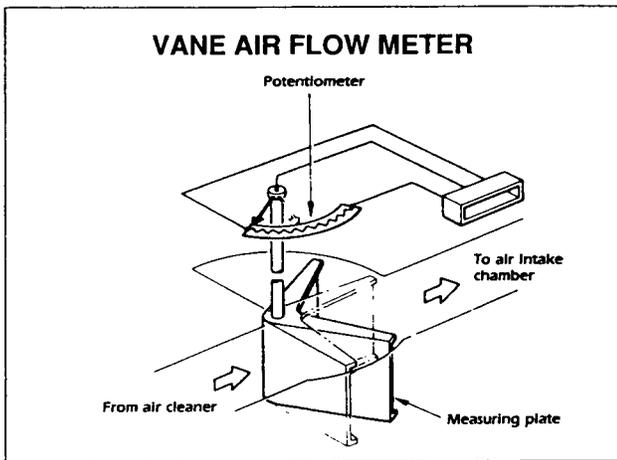
Actuators:

- stepper motors
- solenoids

RESISTIVE SENSORS

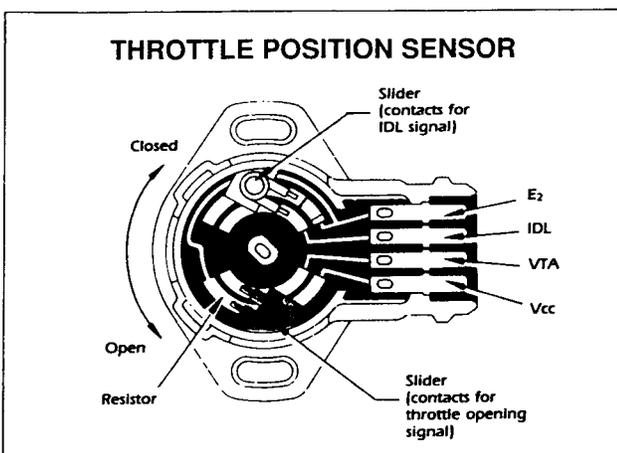
Potentiometers

A potentiometer is a variable resistor that is commonly used as a sensor. A potentiometer has three terminals: one for power input, one for a ground and one to provide a variable voltage output. A potentiometer is a mechanical device whose resistance can be varied by the position of the movable contact on a fixed resistor. The movable contact slides across the resistor to vary the resistance and as a result varies the voltage output of the potentiometer. The output becomes higher or lower depending on whether the movable contact is near the resistor's supply end or ground end.



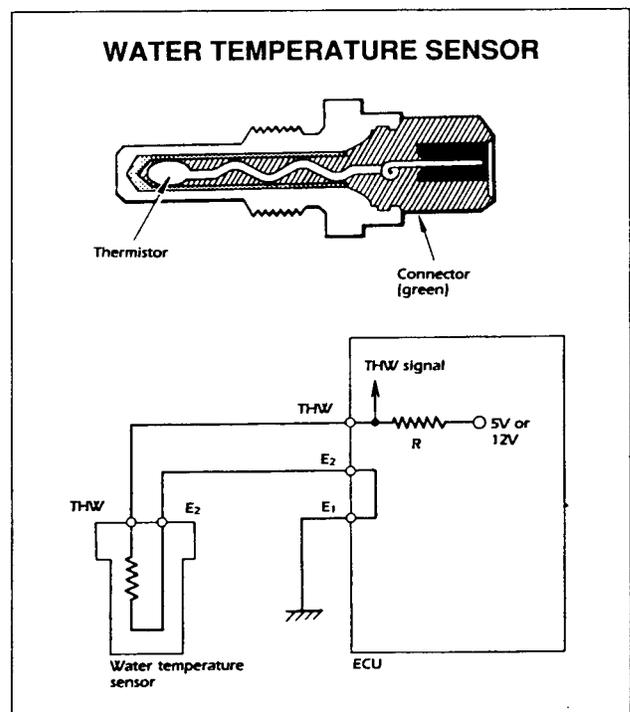
The vane type air flow meter on an EFI equipped vehicle is a common location on a Toyota for a sensor that uses a potentiometer. This sensor converts the air flow meter vane opening angle to a voltage and sends it to the Electronic Control Unit (ECU). This signal allows the ECU to determine the volume of air that is entering the engine.

Some models also use a potentiometer as the throttle position sensor. The potentiometer in this case is attached to the throttle shaft of the throttle body. As the shaft is rotated the voltage output of the potentiometer changes. The voltage output of the potentiometer supplies data to the ECU about the throttle opening angle.



Thermistors

Thermistors are variable resistors whose resistance changes in relation to temperature. Thermistors can have either a negative temperature coefficient (NTC) or a positive temperature coefficient (PTC). A thermistor with a negative temperature coefficient will decrease in resistance as the temperature is increased. On the other hand, a thermistor with a positive temperature coefficient will increase in resistance as the temperature is increased. The thermistor has two terminals, one for power and one for ground. A reference voltage is supplied to one terminal through a fixed series resistor located inside the computer. The other terminal of the thermistor is connected to ground, usually back through the computer. The computer monitors the voltage after the internal fixed resistor and compares this voltage to the reference voltage to determine the temperature of the thermistor. The relationship between the two voltages changes as the temperature of the thermistor changes.



The coolant temperature sensor and the air temperature sensor in the air flow meter are both NTC thermistors. Thermistors are also used as sending units for temperature gauges such as the coolant temperature gauge. The TCCS ECU uses data from the coolant temperature sensor and air temperature sensor to help determine the proper amount of fuel and how long to open the fuel injectors. The ECU also uses this data to determine how much the ignition timing should be advanced as well as the proper setting for the ISC to maintain the proper idle speed. When either the air temperature or the coolant temperature is low, the respective thermistor's resistance increases and the computer receives a high voltage signal at the respective sensor wire. Conversely, a high temperature at either sensor results in a low voltage signal due to the lower resistance of the thermistor.

Piezo Resistive

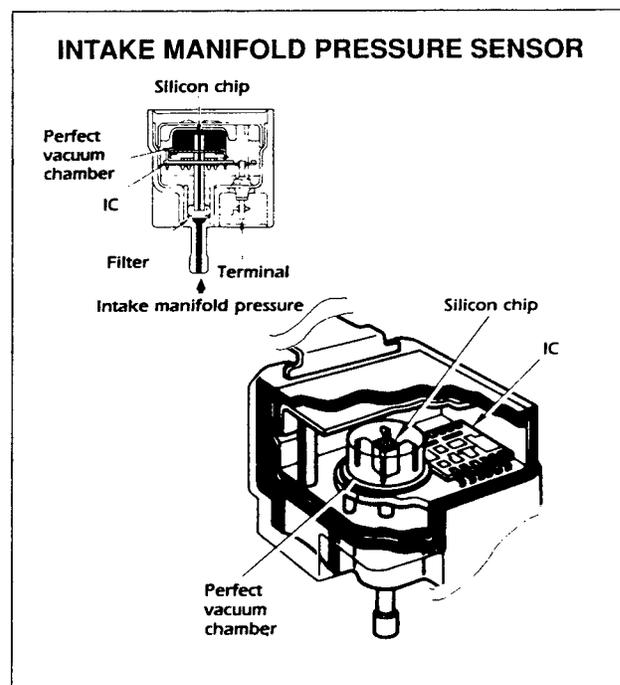
A piezo resistive sensor is a resistor circuit constructed on a thin silicon wafer. Physically flexing or distorting the wafer a small amount changes its resistance. This type of sensor is usually used as a pressure sensing device such as a manifold pressure sensor, although it may also be used to measure force or flex in an object such as the deceleration sensor located in the SRS air bag center sensor.

One of the most important piezo resistive sensors is the manifold pressure sensor which monitors the air intake volume for Electronic Fuel Injection (EFI). The signal it sends to the ECU determines the basic fuel injection duration and ignition advance angle.

Within the sensor is a silicon chip combined with a vacuum chamber. One side of the chip is exposed to the intake manifold pressure and the other side to the internal perfect vacuum in the chamber.

A change in the intake manifold pressure causes the shape of the silicon chip to change, with the resistance value of the chip fluctuating in relation to the degree of deformation. An integrated circuit converts the fluctuation to a voltage signal that is sent to the ECU, where the air-fuel ratio is regulated. The sensor has three external terminals: one for power, one for ground and one to provide the voltage signal to the computer. The voltage signal varies with the pressure in the intake manifold.

Another use for this same type of sensor is to sense turbocharger boost. On turbocharged engines, the sensor is used to measure pressures that are higher than atmospheric pressure and to supply corresponding voltage signals to the ECU. To prevent engine damage, the ECU can cut off the fuel being injected if the manifold pressure becomes too high.

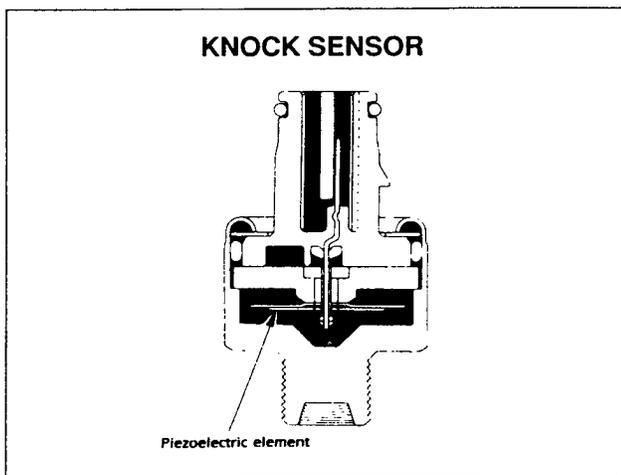


VOLTAGE GENERATING SENSORS

Piezo Electric

Piezo electricity is generated by pressure on certain crystals, such as quartz, which will develop a potential difference, or voltage, on the crystal face. When the crystal flexes or vibrates, an AC voltage is produced.

Knock sensors, which are becoming more common, take advantage of this phenomenon by sending the ECU a signal that engine knock is occurring. The ECU in turn retards the ignition timing to stop the knocking. Knock sensors contain a piezo electric element which, when deformed by cylinder block vibration caused by knocking, generates a voltage.



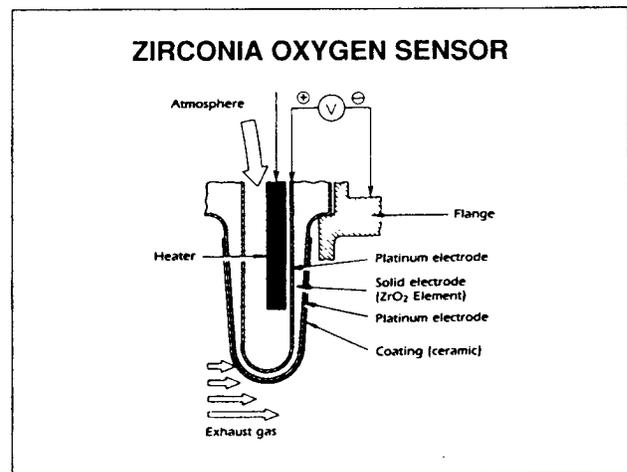
There are two styles of knock sensors used. The mass type produces a voltage output over wide range, but the signal is greatest at a vibration of approximately 7 kHz. The other style is the resonance type which only produces a significant voltage signal when exposed to a vibration of approximately 7 kHz. Since the voltage output from either knock sensor varies continually, the system is highly susceptible to electromagnetic and radio interference. The computer can be

fooled by these stray electrical signals if they get mixed with the knock sensor signal. For this reason the signal wire running from the sensor to the ECU is a special ground-shielded type. The shield surrounds the signal wire and is connected to ground so any electrical interference is taken to ground. If this shield is damaged or not grounded, the electrical interference can reach the ECU and cause it to retard the timing unnecessarily.

Oxygen Sensors

The oxygen sensor, located in the exhaust manifold, senses whether the air-fuel ratio is rich or lean, and sends signals to the ECU which in turn makes minor corrections to the amount of fuel being metered. This is necessary for the three-way catalytic converter to function properly.

There are two kinds of oxygen sensors: zirconia and titania. The zirconia oxygen sensor is constructed in a bulb configuration from zirconia dioxide. A thin platinum plate is attached to both the inside and outside of the bulb. The inner area is exposed to the atmosphere and the outside is exposed to the exhaust. When the sensor is heated to approximately 600°F, electrically



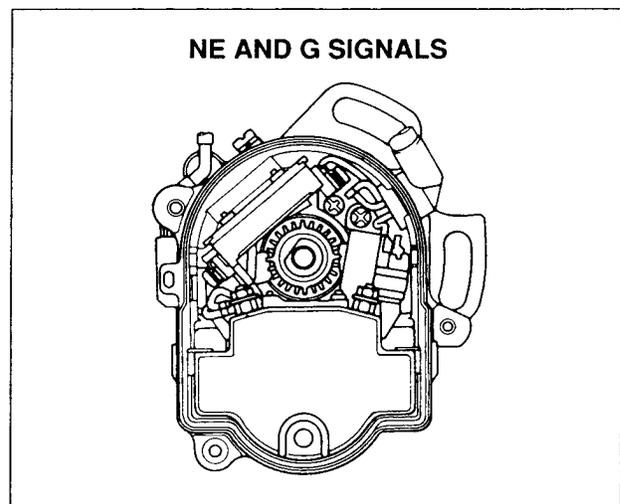
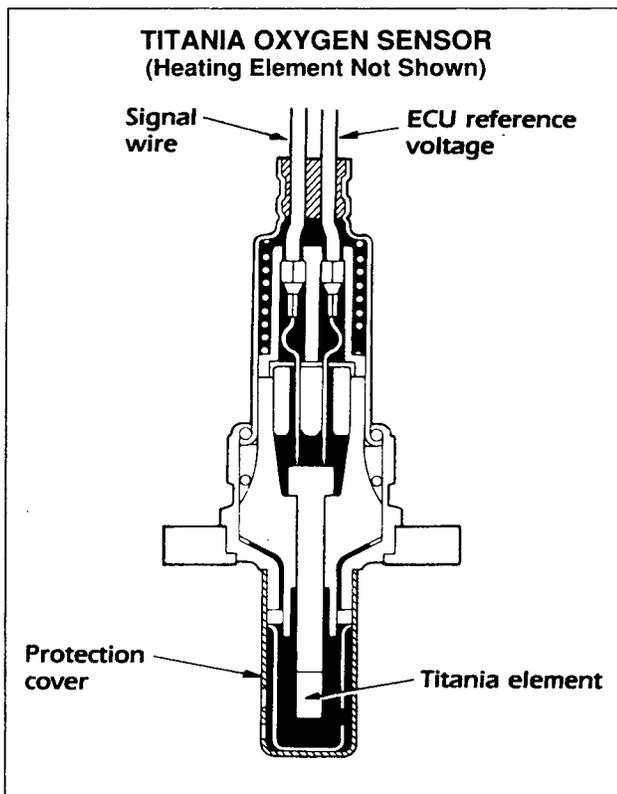
charged oxygen ions form on the platinum plates. The amount of oxygen to which each plate is exposed determines how many ions form on the plates. When there is a difference in the number of ions on the plates, a difference in potential or voltage occurs between the two plates. The less oxygen there is in the exhaust, the greater the voltage produced. When the air-fuel mixture is lean, the voltage created is low. Conversely, when the mixture is rich, the voltage is high.

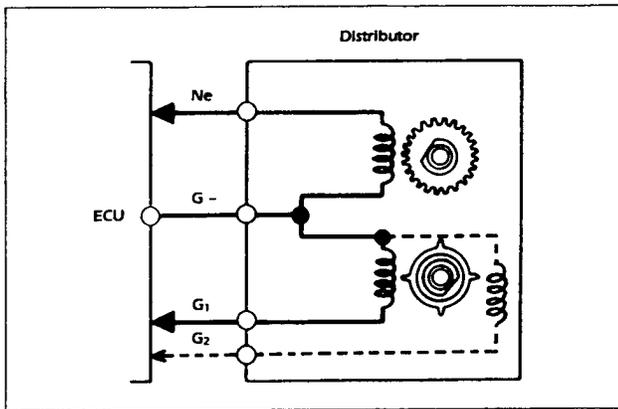
The titania oxygen sensor does not produce a voltage. Instead, it undergoes a change in resistance in relation to the oxygen content in the exhaust. This type of oxygen sensor is referred to as a thick film sensor. It consists of a piece of titania with two wires connected to it located at the end of an insulator. The sensor is not exposed to the atmosphere only to the exhaust. Because the operating temperature must remain constant, the sensor has an electric heater. After the

sensor is at operating temperature, the amount of oxygen to which the titania is exposed will change the physical resistance of the sensor. The ECU supplies a reference voltage to the sensor and monitors the voltage at the signal wire, similar to a thermistor.

Magnetic Inductance

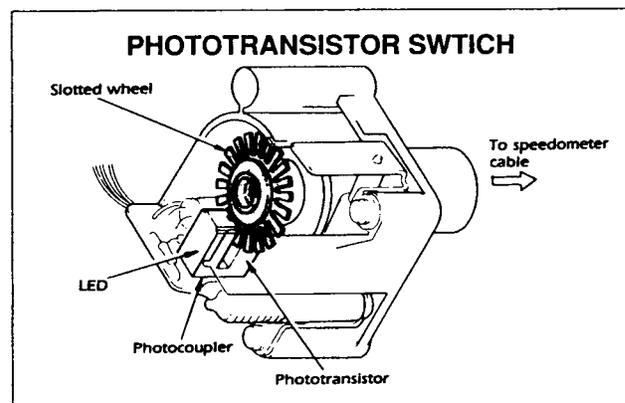
Magnetic inductance sensors consist of a coil of wire around an iron core plus a permanent magnet. The magnet can be either stationary or movable. If the magnet is the moving member, as it passes the coil the magnetic lines of force cut through the coil and a voltage is produced. Since the north and south poles of the magnet alternate as they pass the coil, the voltage polarity also alternates. As the speed of the magnet rotating past the coil is increased a larger voltage is produced and the frequency of the voltage polarity changes is increased. This same type of sensor can also work if the magnet is stationary and attached to the core of the coil. When a toothed reluctor, or rotor (made from a magnetic material) is rotated past the coil and magnet, the magnetic lines of force move and cut through the coil. The lines of force cutting through the coil will produce the same type of voltage output as when the magnet was moving.





the beam of light. The beam of light is interrupted 20 times per revolution. The ECU supplies a reference voltage to the collector of the phototransistor and the emitter is connected to ground. Each time the light hits the phototransistor, it turns it on just like a toggle switch. Each time the phototransistor is turned on, the wire from the ECU is connected to ground and the voltage is pulled down to 0 volts. The ECU can count these pulses and calculate vehicle speed.

This type of sensor is commonly used as a wheel speed sensor on ABS equipped vehicles. This sensor is also used in the distributor to determine RPM and crankshaft position. Since the voltage output of this sensor is varying continually and is low at low speeds, the computer must be able to sense the small voltage. If electrical interference is allowed to combine with the signal voltage, the computer could be fooled. To prevent stray electrical interference, the signal wire usually has a ground shield formed around it like the knock sensor.



This type of sensor is also used as a G Sensor or deceleration sensor on the Celica All Trac and Trucks equipped with ABS. This sensor has two LEDs aimed at two phototransistors that are separated by a slotted plate on a fulcrum. When the vehicle is decelerated, the plate pivots on the fulcrum and the slots in the plate line up with one or the other or both of the LEDs and phototransistors—depending on the rate of deceleration. These signals are sent to the computer so it can determine the deceleration rate for ABS to operate properly.

SWITCH TYPE SENSORS

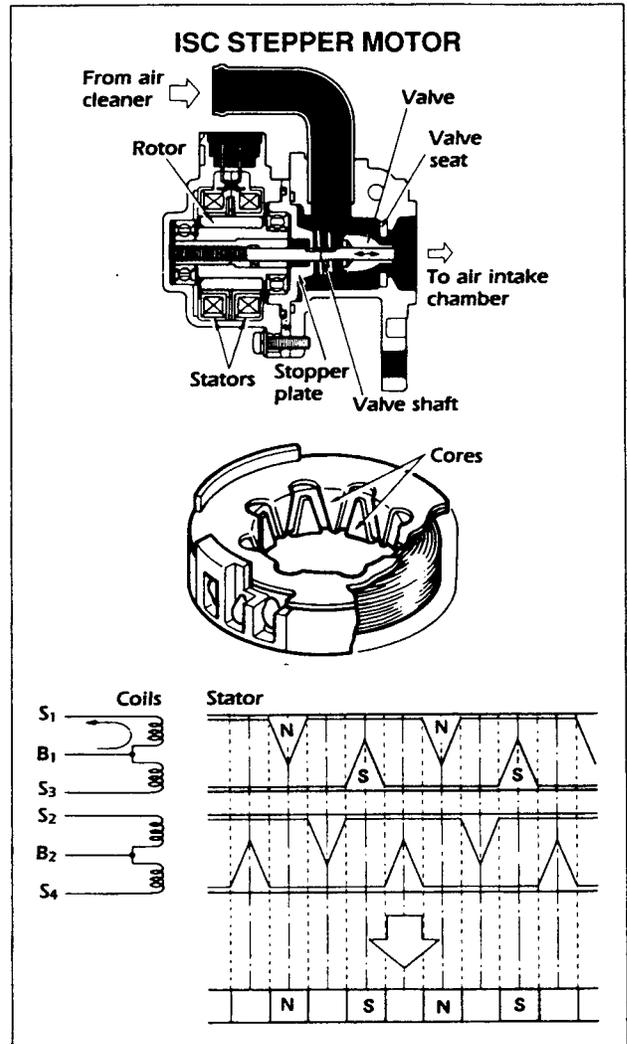
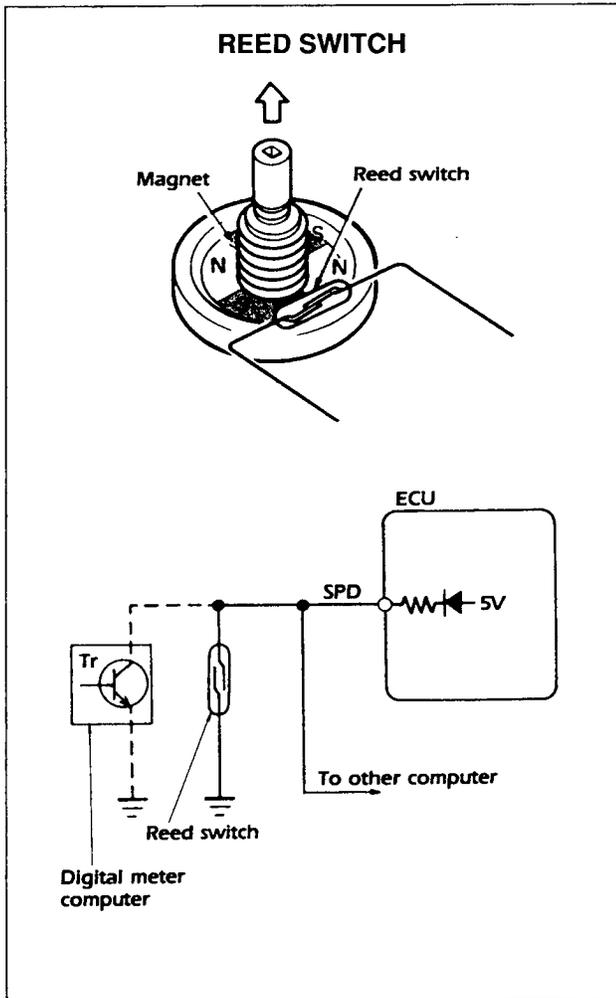
Phototransistor and LED

As discussed in the previous chapter, a phototransistor is a transistor that is activated or turned on by light. When combined with a LED and a rotating slotted wheel in a vehicle speed sensor, a phototransistor can supply vehicle speed data to a computer.

In this type of sensor the LED is aimed at the phototransistor. When the slotted wheel is rotated by the speedometer cable, it breaks

Reed Switches

The reed switch is commonly used as a speed sensor or position sensor. It consists of a set of contacts that open when adjacent to a magnet. In the speed sensor application, the magnet is attached to the speedometer cable and rotates with the cable. Each time one of the poles of the magnet passes the switch the contacts open and then close. A voltage is supplied to one contact on the switch and the other contact is connected to ground. Each time the points close, the voltage is pulled down to 0 volts, just like the phototransistor speed sensor.



ACTUATORS

Stepper Motor

Essentially, stepper motors are digital actuators; in other words, they are either on or off. They move in fixed increments in both directions, and can have over 120 steps of motion.

Stepper motors are commonly used to enable the ECU to control idle speed. In most fuel injection systems, the stepper motor controls an idle air bypass built into the throttle body.

In an idle speed control valve (ISCV), (located in the air intake chamber) a stepper motor is built into the ISCV where it rotates a valve shaft either in or out. This in turn increases or decreases the clearance between the valve and the valve seat, thereby regulating the amount of air allowed to pass through. The ISCV stepper motor allows 125 possible valve opening positions.

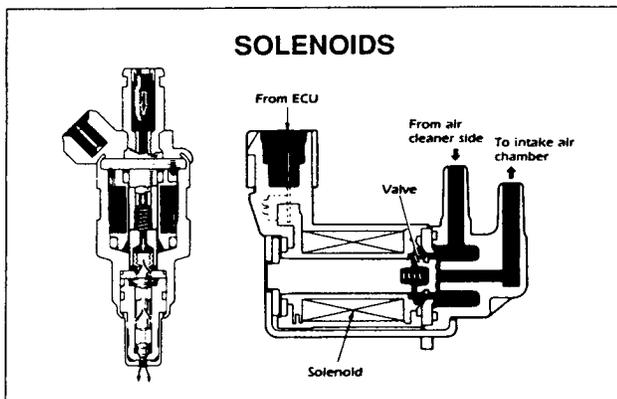
Solenoids

Like stepper motors, solenoids are digital actuators. One terminal is attached to battery voltage while the other is attached to the computer which opens and closes the ground circuit as needed. When energized, the solenoid may extend a plunger or armature to control functions such as vacuum flow to various emission-related systems or fuel injection. Most actuators are solenoids.

Solenoids are controlled two ways: pulse width or duty cycle. Pulse width control is used when the frequency is not consistent. An example of pulse width is a fuel injector which is turned on for a determined length of time and then shut off. Duty cycle control is used when the frequency does remain constant. A duty cycle solenoid in ABS is designed to be on and off for a specific time according to a selected ratio-on for 20% of the time and off the other 80%.

Idle speed control valves can be constructed with a solenoid instead of a stepper motor. In this case, the function is the same: the ECU sends a signal to the ISCV to control the intake air.

Solenoid valves are also used in ECT transmissions. Shifting is controlled by the solenoid as it opens or closes a hydraulic passage to control oil flow to the shift valves.



ASSIGNMENT

NAME: _____

1. Describe the term “Digital Signal” and provide an example.
2. List three types of “Resistive sensors” and provide an example of each.
3. List three “types of Voltage generating sensors” and provide an example of each.
4. List three types of “Switch sensors” and provide an example of each.
5. List two types of “Actuators” and provide an example of each.
6. Describe the operation of both types of “thermistors” and draw an example of the electrical circuit.
7. Explain the operation of a “Piezo Resistive” sensor.
8. Explain how a “Piezo Resistive” sensor differs from a “Piezo Electric” sensor.
9. Describe the operation and construction of the two basic types of Oxygen Sensors.
10. Outline the construction and common uses of a “Magnetic Inductance” sensor.
11. Outline the construction and common uses of a “Phototransistor” switch.
12. Explain the operation of a “Reed” switch and how they are used.
13. Describe the basic operation of a “stepper motor” and how they are used.
14. Explain two ways in which solenoids can be controlled.