

Course Objectives

Upon completion of this course, technicians should understand and be able to apply their knowledge of:

- Concepts, applications and components of automotive electronics
- Measuring and interpreting analog and digital signals, pulse-width modulation, computer inputs and outputs
- Semiconductors: standard diodes, zeners, LEDs, and transistors
- Semiconductor circuitry: rectifiers, regulators, indicators, and control devices
- Automotive computer systems: memory and memory types, communications and Class II data
- System actuators: switched and pulse-width modulated controls
- Performance testing for all inputs and outputs
- Input devices: switched, analog, and digital signals
- Test procedures

Using the Job Sheets

As you proceed through the online modules, on some pages you will find links that will open a window with a printable procedure or job sheet containing hands-on lab activities based on the NATEF standards related to the content you are studying. When you come upon a procedure or job sheet link, click on it and print the job sheet for completion in the shop. See your instructor for guidance in completing the job sheets. Some jobs sheets will require supplemental materials such as a vehicle service manual, equipment manual, or other references.

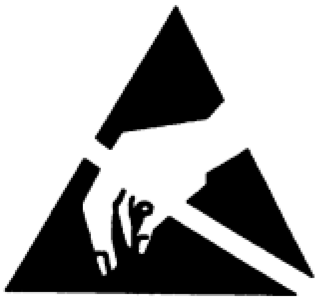
Module 1

Overview

Semiconductors are a group of devices that are, in a normal state, neither good conductors nor good insulators. From our earlier study of electrical fundamentals, we recall that good conductors have only one or two electrons in the outer shell while insulators have many more, around eight. Semiconductors, usually made of silicon or germanium, tend to have four outer shell electrons and have the unusual characteristic of becoming conductors as voltage is applied. Although there are many types of semiconductors, also called solid-state devices, we will limit our discussion to the two most common types: diodes and transistors.

Electrostatic Discharge

The electrostatic charge that can build up on your body and discharge to another object (such as a doorknob), is in excess of 50,000 volts. That "static" discharge is enough to destroy many of the semiconductor components you may come into contact with in automotive systems. In order to prevent damage to components, look for the Electrostatic Discharge (ESD) symbol shown in the box below and carefully follow the instructions on handling those devices. In addition, any electronic parts or components shipped in a dark-blue or black "anti-static" bag should be left in the bag until they are ready to be installed. Electronic components can be easily protected against accidental damage by following these few simple precautions.



Handling Sensitve Parts Notice

Notice: Electrostatic Discharge (ESD) can damage solid-state electrical components. ESD susceptible components may or may not be labeled with the ESD symbol. Handle all electrical components carefully. Use the following precautions in order to avoid ESD damage.

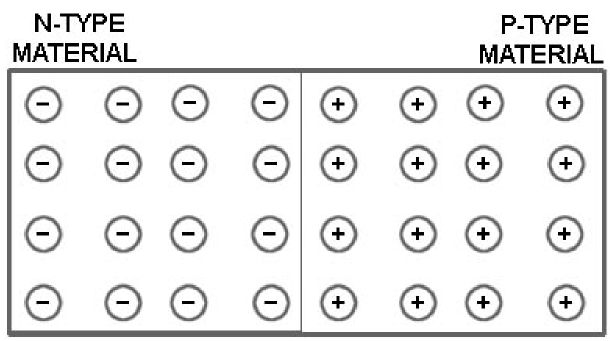
- Touch a metal ground in order to remove your body's static charge before servicing any electrical component, especially after sliding across a vehicle seat.
- Do not touch exposed terminals. Terminals may connect to circuits susceptible to ESD damage.
- Avoid the following actions unless required by the diagnotic prodecure:
  - Jumpering or grounding the components or connectors.
  - Connecting test equipment probes to components or connectors. Connect the ground lead first when connecting test probes.
- Ground the protective packing of any components before opening. Do not rest solid state components on metal workbenches, or on top of TVs, radios, or other electrical devices.

Electrostatic Discharge Notice

Semiconductor Construction

Semiconductors start out as either pure silicon or pure germanium. Other elements, such as boron or phosphorus, are then added to those substances in a process called "doping". Doping causes a change in the electrical properties of the base materials and forms two new substances we will call N-material and P-material. N-type material gets its name because it has an excess of electrons, or negatively charged particles. Likewise, P-type materials have a shortage of negatively charged electrons and are thus more positive. If we join one N material and one P material, we create a P-N junction, which is the basic building block of all semiconductors.

Semiconductors do not conduct well in their normal state; that is, they have a high resistance when no voltage is applied. Conductors, on the other hand, will exhibit a low resistance even if unpowered. However, when a voltage is properly applied across a P-N junction, the internal resistance of the device decreases and the current flow increases. The minimum voltage required to allow current to flow across the junction is called the Barrier Voltage.



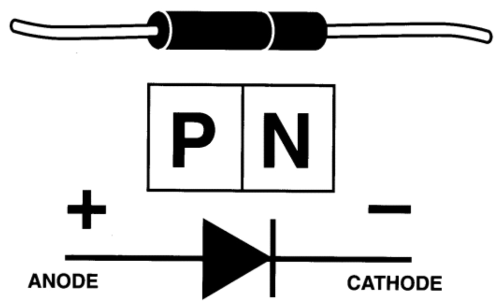
P-N Junction

The barrier voltages for different components will vary depending on the basic material used in the construction of the device and the substances used in the "doping process". For our purposes, we will use the most common barrier voltages of .5 to .7 volts for silicon-based components and .3 to .5 volts for germanium components.

Diodes

Diodes are the simplest of all semiconductors and have only one P-N junction or barrier region. That is to say, they have one N-material section connected to one P-material section. Diodes serve a number of functions in automotive circuits including rectification, voltage spike protection, and indicator lighting. Those that give off light are called Light Emitting Diodes (LEDs) and all will be covered later.

When referring to the two ends of a diode, we use the terms "Anode" for the P-material end and "Cathode" for the N-material end. A silicon diode will begin to conduct when the anode end is approximately .5 to .7 volts higher than the cathode end. In the illustration of the diode symbol shown, notice the arrow on the anode (+) end. The arrow shows the current flow direction when viewed in a conventional (plus to minus) manner. Also notice, there is a stripe on the outside of a diode. The stripe is used to signify the cathode (-) end of the device.

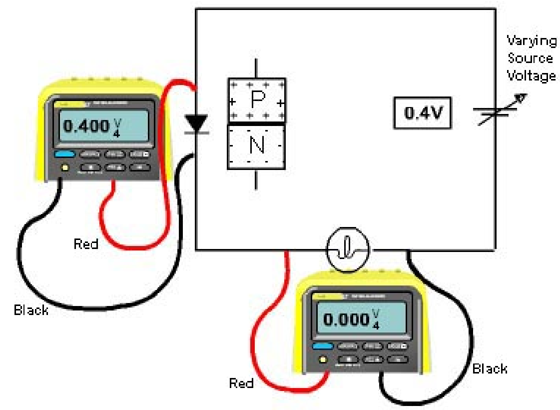


Diode with schematic symbol

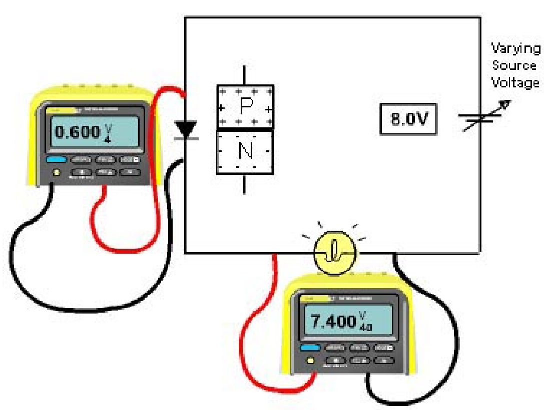
Forward Bias

Diodes can be inserted into a circuit in either a Forward Bias or Reverse Bias configuration. In a forward-biased application, the anode is connected to the more positive part of a circuit while the cathode is connected to a more negative part of the circuit. When power is applied to a silicon diode, and the barrier voltage exceeds .5 to .7 volts, current is allowed to flow through the diode and therefore through the circuit.

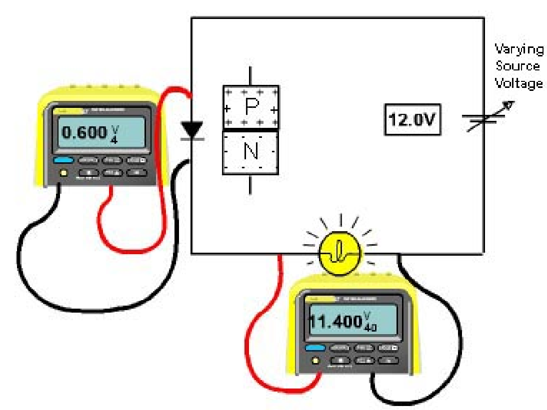
Notice in this circuit that the diode does not conduct until the applied voltage matches the rated barrier voltage of the device. The diode behaves like an open in a circuit and drops all of the applied voltage until the barrier voltage is reached. Once the applied voltage exceeds the barrier voltage, the voltage drop across the diode will remain the same regardless of additional increases in the applied voltage. Any applied voltage greater than the barrier voltage of the diode will be dropped across the load (a bulb in this case).



Below the barrier voltage, no current flows



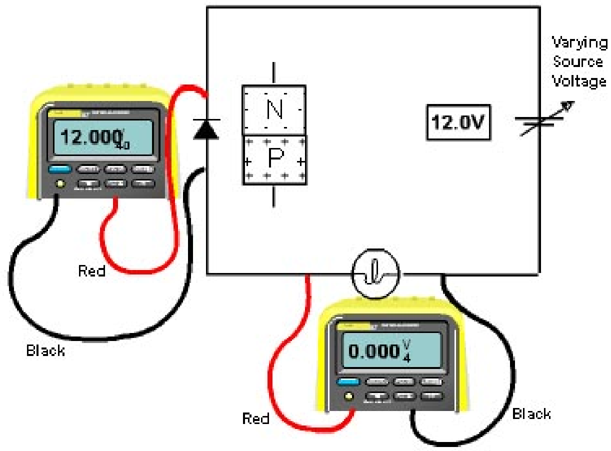
Above the barrier voltage, current flows



Additional voltage is dropped across the load

Reverse Bias

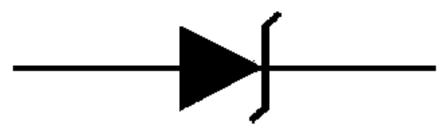
If a diode is inserted into a circuit with the N-material connected to the plus side and the P-material connected to the negative side, it is said to be reverse-biased and will not conduct. We will later see that some diodes are intentionally installed this way to control current flow and provide circuit protection when loads are turned off. There is also a limit to the amount of reverse bias voltage, called Peak Inverse Voltage or PIV, that a device can tolerate. If a voltage is applied that exceeds the PIV, the device may be destroyed and require replacement. When replacing a diode, make sure the PIV rating is sufficiently high to fulfill the current requirements. A reverse bias application is shown in this circuit.



No current flow across load

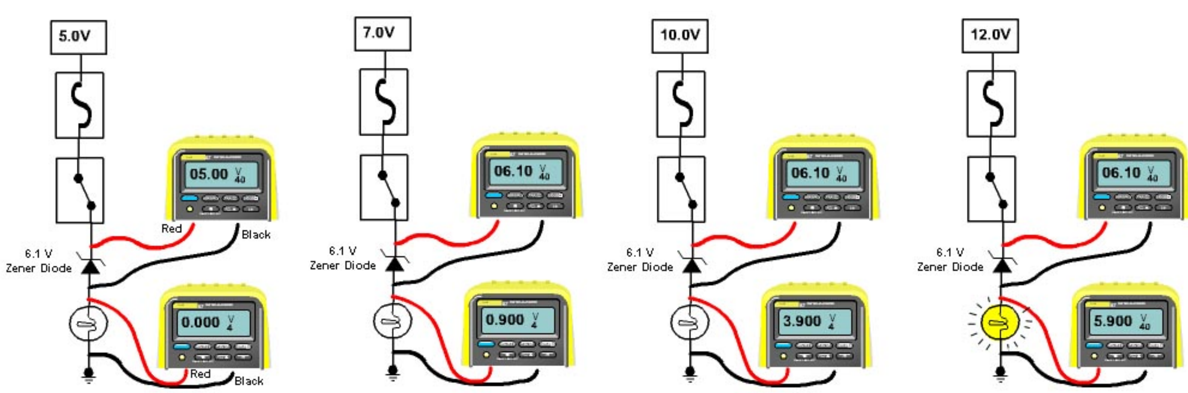
Zener Diodes

Zeners are a special type of diode that is designed to be installed in a reverse-biased configuration, and is used as voltage regulator or controller. If a Zener is inserted into a circuit in a forward-biased configuration, it will behave exactly like a standard diode. The symbol for a Zener diode is different from the standard diode symbol, as shown in this illustration.



Zener diode symbol

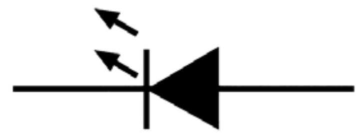
Zeners are manufactured in such a way that they have a certain “breakover voltage” or Zener point. The Zener point is the amount of reverse bias voltage that must be applied to the device to make it conduct current. Once the breakover voltage is reached, the voltage drop across the Zener will not increase even if the applied voltage is increased. For example, if a six-volt Zener is placed in a parallel circuit with a series lamp with 5 volts applied, all of the voltage will be dropped across the Zener and the bulb will not light, since the breakover voltage has not been reached. Applying seven volts to the same circuit will show a six-volt drop across the diode and one volt across the lamp. Increasing the applied voltage to 10 volts, we find the voltage across the Zener remains at its rated six volts but the lamp voltage is increased to four volts. This operating characteristic is what makes Zener diodes useful as voltage regulators in applications such as generators and power supplies.



Series circuit with 6.1V Zener diode

Light Emitting Diodes (LEDs)
Light Emitting Diodes conduct when forward-biased and block current flow when reverse-biased, just like standard diodes. The two primary differences between LEDs and standard diodes are that LEDs emit light when they begin to conduct, and the forward bias voltages for LEDs are slightly higher, about 1.5 to 2.5 volts. A resistor, usually 470 ohms, must also be used in series with an LED to limit current (typically 20-30ma) and prevent damage to the device. The symbol for an LED, shown here, is a standard diode symbol with two arrows pointing outward to signify that it gives off light. Do not confuse this symbol with one that has arrows pointing in. That is the symbol for a photodiode that conducts when exposed to light.

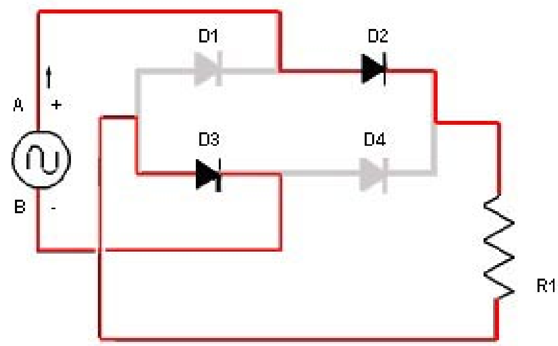
Because they turn on and off more quickly, LEDs are typically used as indicator lights, in instrument panels, and more recently as rear park/brake lights. They consume less energy to operate and create less heat than standard bulbs.



Light Emitting Diode symbol

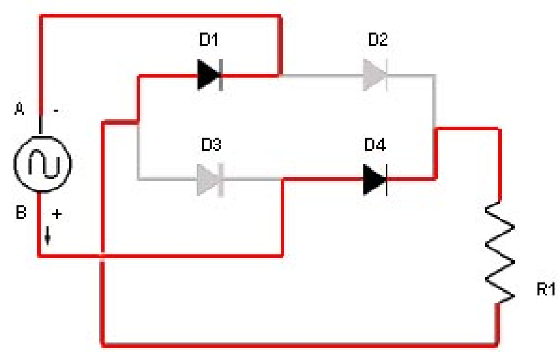
Rectifier
A Rectifier is a device used to change AC to DC. The most common use of diodes as rectifiers is in the generator. Automotive generators produce 3-phase alternating current that must be converted to direct current by a rectifier bridge before it can be used. A rectifier bridge is a network of six diodes arranged in such a way that the half-cycles of each AC phase are made to travel in the same direction rather than in opposite directions as is typically the case in alternating current. Each phase of a generator uses only four of the six diodes, and the rectification of one full cycle is described in the following section.

Rectifier Operation
During the first half-cycle of an AC wave, point A is positive and point B is negative. Beginning at point A and using conventional flow, we find that the positive pulse sees D2 as forward biased and D1 as reverse biased and passes through D2. After passing through D2 we find that D4 is also reverse biased and the current moves through R1 and around to the junction of D1 and D3. D1 will not conduct since it has positive voltage on each side, but D3 is forward biased and the circuit is completed back to point B, bypassing D4, which also has positive voltage on each side.

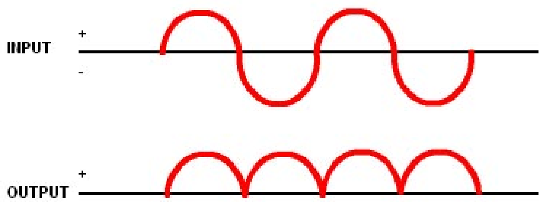


Diode Rectifier Bridge, 1st half-cycle

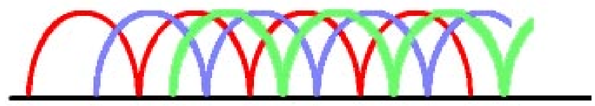
On the second half-cycle, point A is negative and point B is positive. Current will flow from point B through D4, through R1 (in the same direction as the first half-cycle), through D1 and back to point A. This application is called a Full Wave Rectifier and results in the type of output shown on the next page.
The signal in the illustration, which is labeled as input, is the basic AC produced by a single winding in a generator. The output signal is the same wave after it has been converted in a full wave rectifier. These two signals are for one phase only and are measured across the resistor R1. The actual total output of a generator will have three identical phases, each 120 degrees later than the previous one, as shown.



Diode Rectifier Bridge, 2nd half-cycle



AC to DC rectification

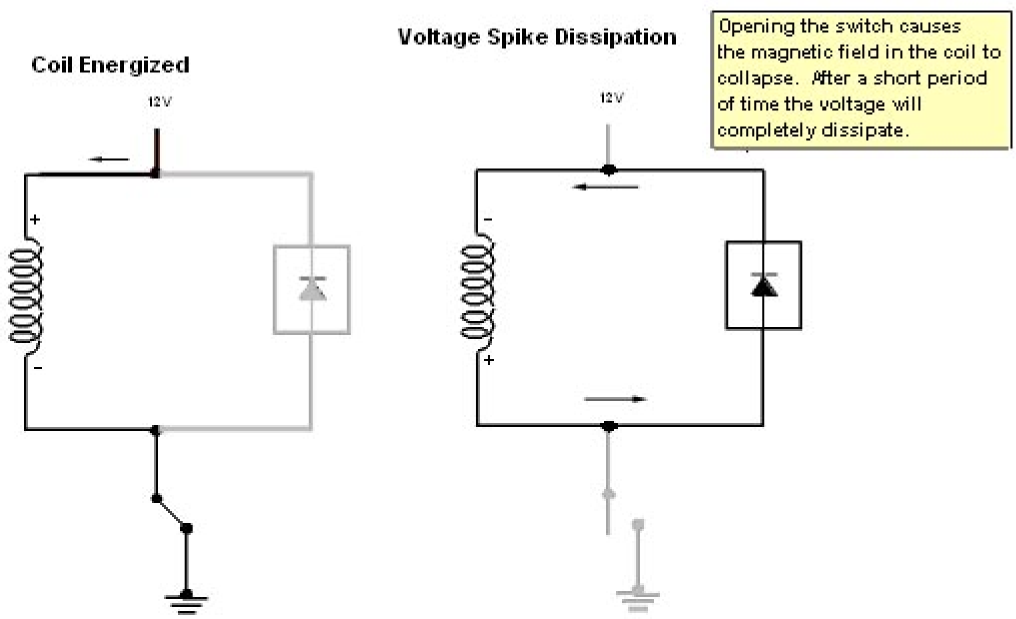


Three phase full-wave rectified generator output

Clamping Diodes

Whenever a current is passed through a device with a coil (relay, solenoid, etc.), a magnetic field is created around the coil. Turning the device off causes the magnetic field to collapse and create an electrical pulse in the opposite direction as the original current flow. This pulse is referred to as a voltage spike. Voltage spikes can be many times larger than the original voltage that was applied to the device and, if not controlled, can cause damage to circuits and other electronic components. To protect these circuits we use clamping diodes.

Clamping diodes are standard diodes placed across device coils so as to be reverse biased to current flow in normal operation. When the circuit is opened, however, the resulting spike flows in the opposite direction, which now makes the diode forward biased. The current continues to flow in a circle, dissipating the electrical energy through the coil in the form of heat.



Clamping diode to dissipate voltage spike

Diode Testing

Unlike resistors, the voltage drop across a diode does not increase with an increase in applied voltage. Diodes are rated in volts, not in ohms, and should therefore not be tested with an Ohmmeter even though this is a common practice for many technicians.

Test Procedure

Using a meter with a “Diode test” position, check the diode’s forward bias voltage (red lead on the anode and black lead on the cathode) and ensure that it is the same as the device’s rating (.5 to .7 V for standard silicon, for example). Reverse the leads, and the meter should read OL, or its absolute highest resistance value. If the diode shows a voltage reading in each direction, or OL in both directions, it is bad.

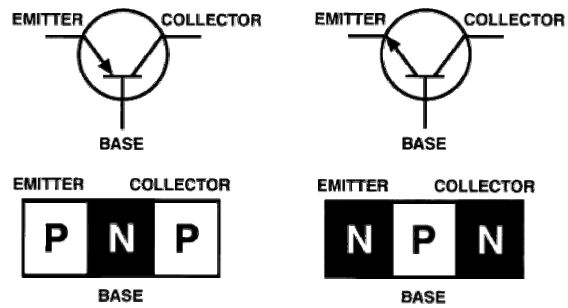
Transistors

A second type of semiconductor device found in automotive applications is the transistor. Transistors can be used as switches to turn circuits on and off, or as amplifiers to control a variable current output. In the simplest sense, a transistor can be seen as a resistor whose value decreases as the electrical input increases.

Transistors fall into one of two primary categories: Bi-polar or Field Effect Transistor (FET). Both types are designed to control output current, but bi-polars operate based on input current while FETs operate on input voltage.

Since the bi-polar transistor is most commonly used in automotive applications, we will limit our discussion to it.

Bi-polar transistors are composed of the same N-type and P-type materials used in diodes. Unlike a diode, a transistor has three layers of material and two barrier regions arranged either as an NPN type or as a PNP type.



Bipolar transistors

Transistor Construction

In this figure, the basic construction of the two bi-polar transistor types is shown along with the corresponding symbols for each. Although their construction is different, both NPN and PNP transistors have the same three parts known as the Emitter, the Base, and the Collector. To determine from the symbol which type you have, notice that the arrow points toward the base (in) on a PNP type and toward the emitter (out) on an NPN type. Therefore, the rule to keep in mind is that the arrow always points to an N material. The arrow also indicates the direction of current flow through the transistor using conventional flow theory. NPN transistors tend to be more commonly found in automotive applications than PNP transistors.

Field Effect Transistors operate differently than bi-polars and have different names for the sections. FETs have a gate (base), a source (emitter), and a drain (collector) to distinguish them from other types.

Transistor Operation

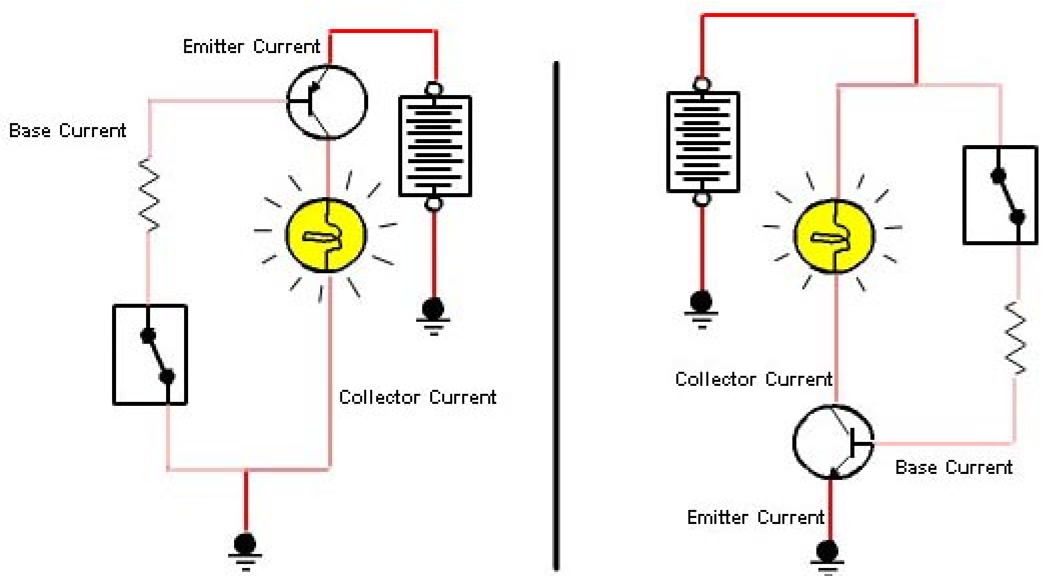
For our discussion of transistor operation, we'll use an NPN component as our example. In an NPN transistor, the emitter is an N material and the base is a P material. The Emitter-Base junction is like that in a diode, meaning that for a silicon-based transistor, if the voltage between the base and the emitter is .5 to .7 V, it will conduct and current will begin to flow. As the Emitter-Base (E-B) junction conducts, the resistance of the Emitter-Collector (E-C) begins to drop and current begins to flow through the transistor, thus turning on the circuit. Further increasing the base current reduces the Emitter-Collector resistance even more and produces an increase in the circuit current. Notice also that base current flows into the base and out the emitter while the collector current enters the collector and exits the emitter. Therefore, the emitter current is the sum of both the base current and the collector current, or:

$$I_E = I_B + I_C$$

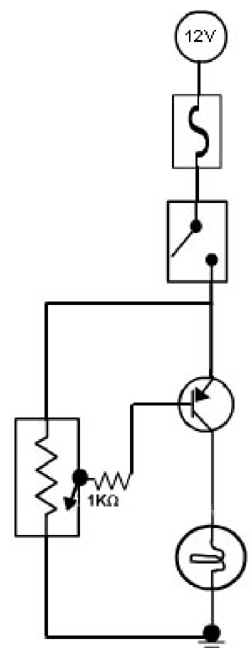
When selecting a transistor for use, make sure the current ratings are sufficient to handle the circuit requirements.

A PNP transistor will operate the same as an NPN except the base will be at least .7 V lower than the emitter rather than higher.

Applications
In a transistor being used as an amplifier, small variations to the base current will correspond as much larger outputs at the collector. If, however, base current is not varied but is toggled between high current (saturation) and off, then the transistor becomes a high-speed switch for On-Off applications. A "saturation switch" can also be compared to a relay in that it uses a small current to control a large current. However, a transistor has only three legs compared to the relay's four. Transistors also contain no moving parts.



Transistor Currents

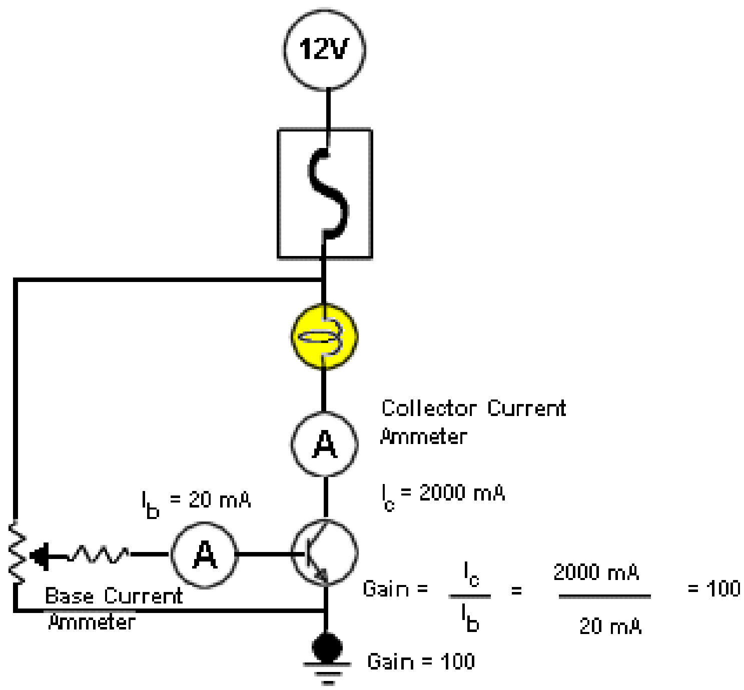


Current Limiting
Refer to the schematic at right and notice the 1KW resistor in the base circuit. This resistor serves two purposes: first, it limits the amount of current that flows through the base circuit and protects the transistor from damage, and second, it is the output controller for the Emitter-Collector circuit. As we increase or decrease the amount of base current by changing the base resistor, we control how much the transistor turns on. This will limit the Emitter-Collector current, which protects the transistor. The resistance of the lamp also serves to limit the E-C current when the transistor is operating.

Gain
Gain is a factor that affects the operation of a transistor and must be taken into account when selecting a replacement component. There are no units associated with gain such as volts or amps; it is simply the ratio of the collector current compared to the base current. For instance, if a transistor has a gain of 100, then 20 mA of base current will yield 2000 mA of collector current. Simply multiply the gain times base current to get the collector output. Gain can also be used to calculate maximum base current. If a transistor has a maximum collector current of 2500 mA and a gain of 200, then dividing the collector current by the gain gives the highest base current that can be used. In this case:

2500 mA ÷ 200 = 12.5 mA

maximum base current. Technicians should consider all these factors when doing repairs to ensure the transistor has the necessary capabilities.



Gain formula

Transistor Testing
The testing of transistors is a simple process, but just as with diodes, it is often done incorrectly. As we did before, we'll use an NPN transistor for our example to show the six possible checks.

To make the process easier, look at transistors as two diodes connected back-to-back. An NPN transistor is then just two P-N junctions, one between the Emitter-Base and one between the Base-Collector. Some of the connections will be forward-biased and some will be reverse-biased.

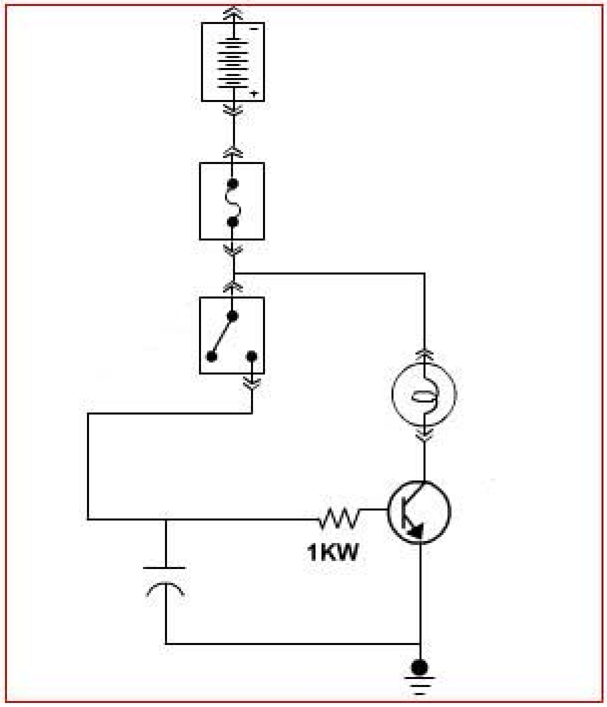
Use the diode position on a DVOM just as if you are measuring a diode and it will be easy. Do not use an ohmmeter since different meters will give different and sometimes erroneous results. The six tests on a silicon-based NPN will be as follows:

1. Red lead on the Base (P) and the Black lead on the Emitter (N); the meter should read approximately .5 -.7 volts.
2. Black lead on the Base (P) and the Red lead on the Emitter (N); the meter should read OL (no conduction).
3. Red lead on the Base (P) and the Black lead on the Collector (N); the meter should approximately .5 - .7 volts.
4. Black lead on the Base (P) and the Red lead on the Collector (N); the meter should read OL.
5. Red lead on the Emitter (N) and the Black lead on the Collector (N); the meter should read OL.
6. Black lead on the Collector (N) and the Red lead on the Emitter (N); the meter should read OL.

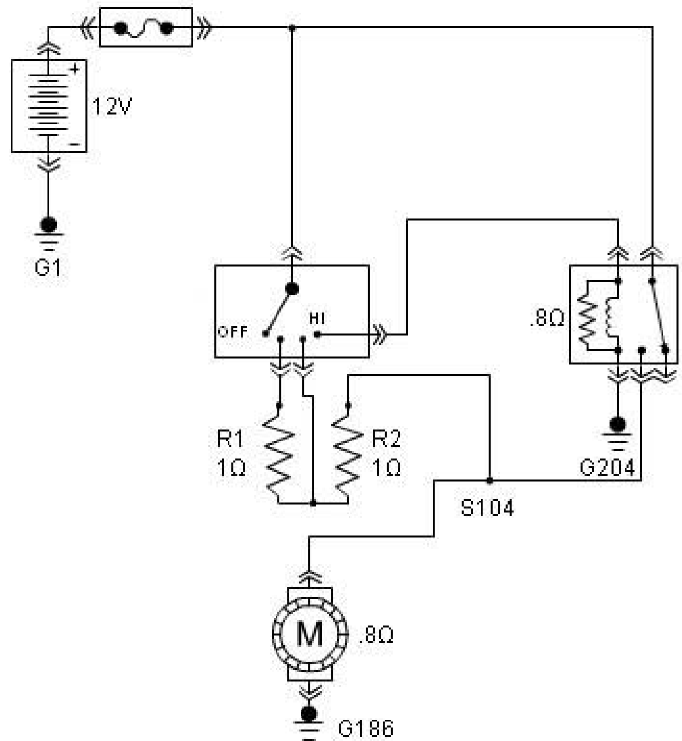
Testing for PNP transistors is similar and just as easy, if you keep track of which junctions are forward-biased and which are reverse-biased. The Emitter-Collector junctions should always read OL.

Transistor Circuit

This is a simple transistor circuit using a capacitor and a load (bulb). Study the schematic to determine the circuit's function. What might this circuit be used for in an automotive application? When the switch is closed, a voltage is applied to the base circuit that is sufficient to make the transistor conduct. A ground is then provided through the transistor to the bulb, which lights since it has full time power. The capacitor also charges when the switch is on. If the switch is turned off, the capacitor discharges through the base circuit and the transistor continues to operate the bulb until the capacitor is depleted. This particular application could be used for interior lights dimming, sometimes called "theater dimming", where the switch would indicate the opening and closing of a door.



Exercise – Blower Motor Circuit



1. In the circuit shown here, what is the total resistance with the blower switch in LOW position?
   - .8Ω
   - 1 .8Ω
   - 2.0Ω
   - 2 .8Ω

2. What is the total resistance of above circuit with blower switch set to MED position?
   - .8Ω
   - 1 .8Ω
   - 2.0Ω
   - 2 .8Ω

3. The total resistance of circuit equals how many Ohms with blower in HI position?
   - .8Ω
   - 1 .8Ω
   - 2.0Ω
   - 2 .8Ω

4. With the blower in HI position, how many amps will this circuit draw?
   - 10 amps
   - 20 amps
   - 25 amps
   - 30 amps

5. How many amps will the blower circuit draw in LOW position?
   - 2.8 amps
   - 4.2 amps
   - 6.6 amps
   - 15 amps

6. How many amps will the blower circuit draw in MED position?
   - 2.8 amps
   - 4.2 amps
   - 6.6 amps
   - 15 amps

7. What is the minumum fuse that should be used in this circuit?
   - 5 amps
   - 10 amps
   - 15 amps
   - 30 amps

8. How much voltage is dropped at R-1 with blower switch in LOW position?
   - 0 volts
   - 4.2 volts
   - 6.3 volts
   - 12 volts

9. How much voltage is dropped at R-1 with blower switch in MED position?
   - 0 volts
   - 4.2 volts
   - 6.3 volts
   - 12 volts

10. The voltage drop at R-2 with blower switch in LOW position will equal:
    - 0 volts
    - 4.2 volts
    - 6.3 volts
    - 12 volts

11. How many volts are dropped at the blower motor with blower switch in HI position?
    - 3.3 volts
    - 6.6 volts
    - 8.7 volts
    - 12 volts

12. The total power consumed by the blower motor in HI position equals:
    - 1.8 Watts
    - 18 Watts
    - 180 Watts
    - 1800 Watts

13. A defective relay will keep the blower motor from operating in:
    - LOW speed
    - HI speed
    - MED speed
    - All speeds

14. If S-104 has high resistance, how will voltage drop at the blower motor be affected?
    - It will go down
    - It will go up
    - It will be unchange
    - None of the above

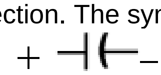
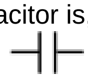
Exercise answers: 1) 2.8 Ω, 2)1.8 Ω, 3).8 Ω, 4) 30 amps, 5) 4.2 amps, 6) 6.6 amps, 7) 30 amps, 8) 4.2 volts, 9) 0 volts, 10) 4.2 volts, 11) 12 volts, 12) 180 watts, 13) HI speed, 14) It will go down.

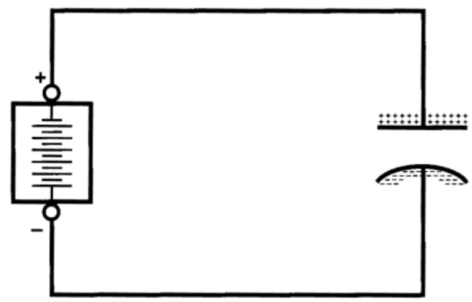
Capacitors

Capacitors are devices that store electrical charges and behave like temporary batteries. Technicians may have seen them used as filters on alternators or radios to reduce noise, or even in older point-style distributors as condensers. By controlling how quickly they charge and discharge, we can also use them as timers.

Capacitors store electrical charges and act like temporary batteries

Capacitors basically consist of two metallic plates separated by an insulator called a "dielectric." Dielectrics can be something as simple as a piece of paper. A simple capacitor can be made by placing a sheet of paper between two equal sized sheets of aluminum foil. Wrap all three sheets around a paper towel roll (don't let the aluminum sheets touch) and attach a connector wire to each piece of aluminum foil. That is the basic construction of a capacitor.

There are two types of capacitors, electrolytic and non-electrolytic. Electrolytic capacitors have both a positive and negative end while non-electrolytics can be inserted in either direction. The symbol for an electrolytic capacitor is,  and for a non-electrolytic .
Since the plates in a capacitor do not touch, it acts like an open in a circuit and will not pass DC current.



Electrical Charges on capacitor plates

Units

Capacitors are rated in terms of their storage capacity, called Farads, as well as their working voltage. The Farad (F) is a measure of the number of electrons a capacitor can store and is very large. Most applications will be rated in microfarads (μF) or nanofarads (nF). A microfarad is one-millionth of a farad and a nanofarad is one-billionth of a farad. When selecting a capacitor for a given application, make sure the working voltage rating is higher than the source voltage to prevent damage.

Capacitors are rated in microfarads (mf) or nanofarads (nf) and working volts DC (wvdc).

Capacitors in Parallel

If two or more capacitors are placed in parallel in a circuit (figure 3-16), the total capacitance is determined by adding the individual capacitor values as shown by the equation:

$$C_T = C1 + C2$$

Therefore, two 1000 μF capacitors in parallel have a total of 2000 μF capacitance. Keep in mind that combining capacitors does not increase the working voltage. Any number of capacitors in parallel will have the same working voltage as the capacitor with the lowest working voltage rating.

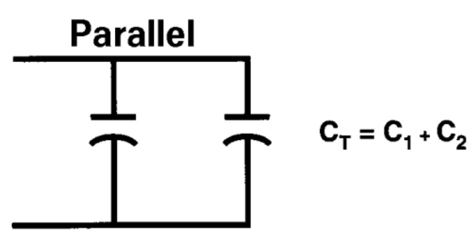
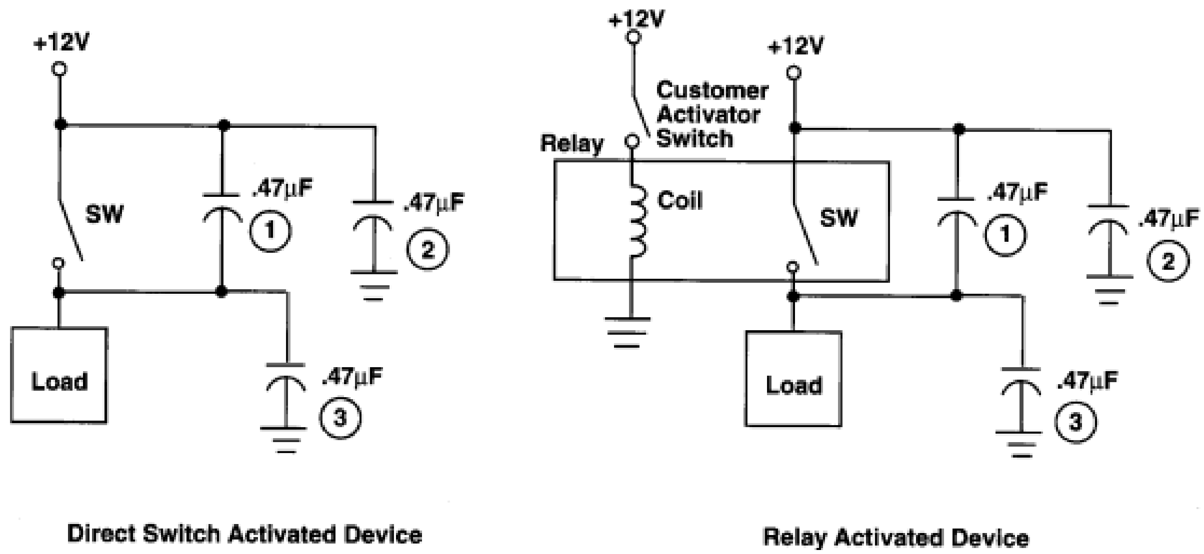


Figure 3-16 Capacitors in parallel

Note: It is always a good idea to discharge any capacitor, by touching the leads together, before connecting it to a circuit or meter.

Applying Capacitors for Noise

If a noise or pop occurs in the audio system when a switch or contact is deactivated, capacitors can be used to filter out the noise. Referring to the diagram below, the first .47µF capacitor will be placed across the switch/contact (1) to absorb any surge current at deactivation. If the pop is gone, you're finished. If not, place a second capacitor (leaving the first) from the positive side of the switch/contact to ground (2) and test again. This capacitor will filter out noise on the power side. If a problem still exists, insert the third capacitor between the switch and load to ground (3). This capacitor will filter out noise on the load side of the switch.



Adding capacitors to eliminate popping noises

Module 2

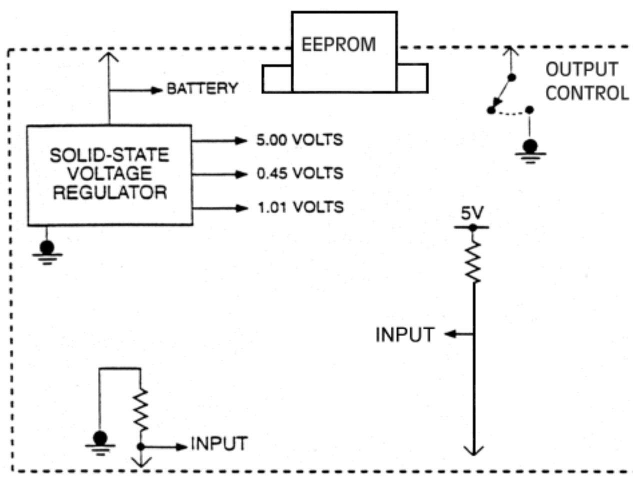
Computers
In recent years, automotive computers have shown up in areas from engine control to air conditioning, and everywhere in between. They control engine performance and emissions, operate the Anti-lock brakes, shift the transmission, adjust the suspension, and in some vehicles, control the radio. Ironically, these electronic wonders are often credited with capabilities they don't have, and blamed for problems they didn't cause. A simple understanding of what automotive computers do, and how they work, will greatly assist in helping the technician diagnose and repair microprocessor based systems.

First of all, computers do not think. They are just machines (with some very small parts) that take information from sensors, apply that information to an internal microprocessor program, and then tell some device to turn on or off. Computers also have memories for storing diagnostic codes, power supplies for sensors, and communications capabilities for sharing information with other computers.

Computer Features

Automotive computers, as shown in this example, tend to have the same general features even though they control different systems. From this illustration we can see the following:

- Memory – shown here as an EEPROM, they have both long-term and short-term memories.
- Voltage Regulators – the regulators take the 12 V input voltage and convert it to other lower voltages. Those voltages can then be used to power input sensors (5V) or to operate the internal electronics.
- Inputs – this illustration shows both types of inputs used by automotive computers: voltage inputs and grounding inputs. If a sensor has an external power feed it will connect to a grounding input. Likewise, a sensor with an external ground will be applied to on internal voltage. Note that both types of inputs use internal resistors to limit the current and protect the electronics. Both types of inputs will be covered in more detail in the next module.
- Output Control – these are the output drivers that operate the actuators by turning them on and off. Most actuators are controlled by applying or removing ground, however, some outputs control the applied voltage as is the case with fuel pump relays.



Typical Computer

Computer Memory
Automotive computers have four basic forms of memory:

- Random-Access Memory (RAM)
- Read-Only Memory (ROM)
- Programmable Read-Only Memory (PROM)
- Electrically Erasable Programmable Read-Only Memory (EEPROM)

Random Access is the only "volatile" form of memory, which means that it will clear if the power is removed. RAM has two functions in an automotive application:

1. It stores information from the sensors while it calculates the actions it needs to take and,

2. It stores the diagnostic codes while the vehicle is operating and allows them to be read with a scan tool.

When an ignition key is turned off, all of the information in RAM must be transferred to a different kind of memory to prevent its loss when power is removed.

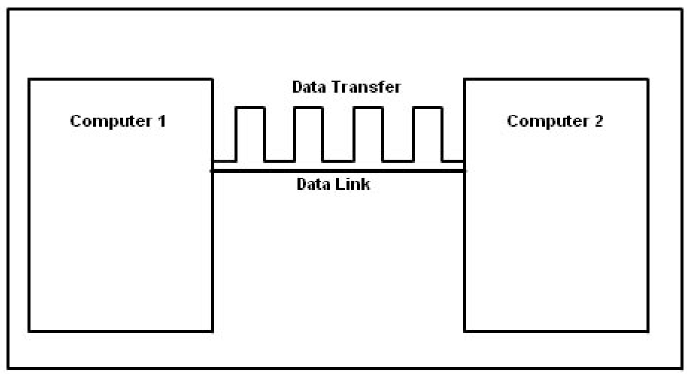
Read-Only Memory is programmed at the factory and usually contains the basic operating instructions for the computer to function. ROM information cannot be changed once the programming is done, and it does not require any action on the part of the technician.

Programmable Read-Only Memory is a form of ROM that can be reprogrammed, with the proper equipment, at the factory. PROMs carry the calibration information for vehicle engine/transmission operation and can be replaced by the technician. The PROM is often referred to as the computer "chip." When a vehicle is turned off, current information in RAM is transferred to PROM memory.

Electrically Erasable Programmable Read-Only Memory is the newest form of computer memory and can be recalibrated by a technician with a scan tool. Some technicians may have already done EEPROM updates or flash calibrations" to correct a driveability condition, or in response to a Technical Service Bulletin.

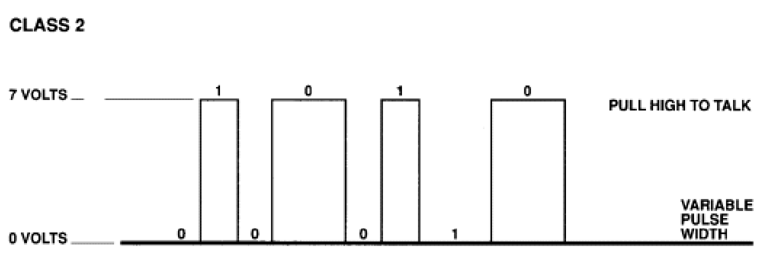
Serial Communication

In addition to controlling the vehicle's functions, automotive computers also need to communicate with each other. They do this by sharing "serial data" on a single wire that connects the computers. Serial data is groups of ones and zeroes (electrical ons and offs) transmitted between computers in a language they can decipher. It is also the information, including diagnostic codes, read by a scan tool.



Serial Data Link

Before 1996, manufacturers used different forms of communication and not all systems were compatible. Beginning in 1996, a new standard was adopted as part of the OBD II emissions implementation. The new standard is called Class 2 and uses a 7 volt line toggled on and off to make ones and zeroes. The newest data transmission protocol to be used is called Class C, or CAN, for Controller Area Network, and it will be much faster than Class 2.

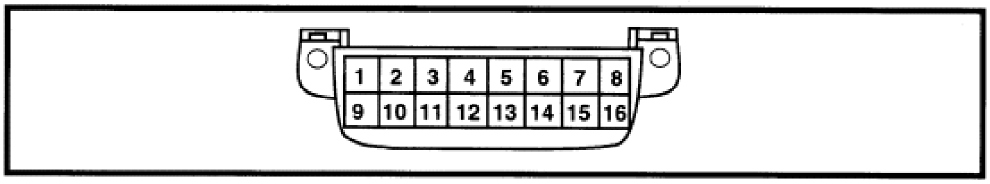


Class II Data Format

Modern automotive computers must be able to communicate with each other; otherwise, they will begin limited operation or stop working all together. Some systems, such as air conditioning, may require several computers to function, and the failure of one can cause the entire system to fail. If any or all of the computers will not communicate with each other, or with a scan tool, then one of four problems is usually the cause. They are:

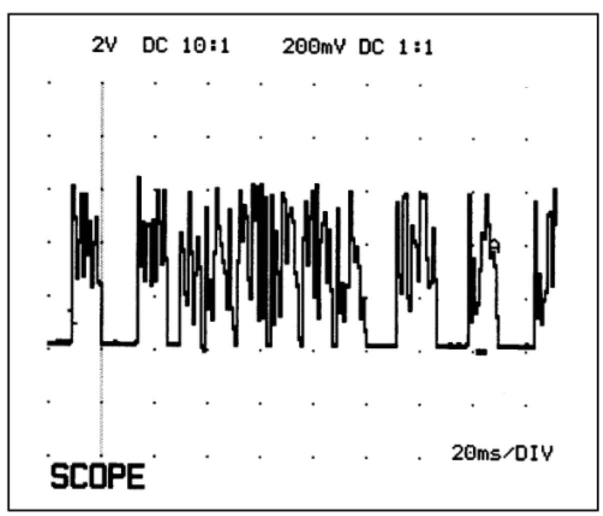
1. Loss of voltage to a computer
2. Loss of ground to a computer
3. Data line has grounded or is open
4. A computer has failed internally

The 16 pin Data Link Connector (DLC) is shown here with a list of typical pin identifications.

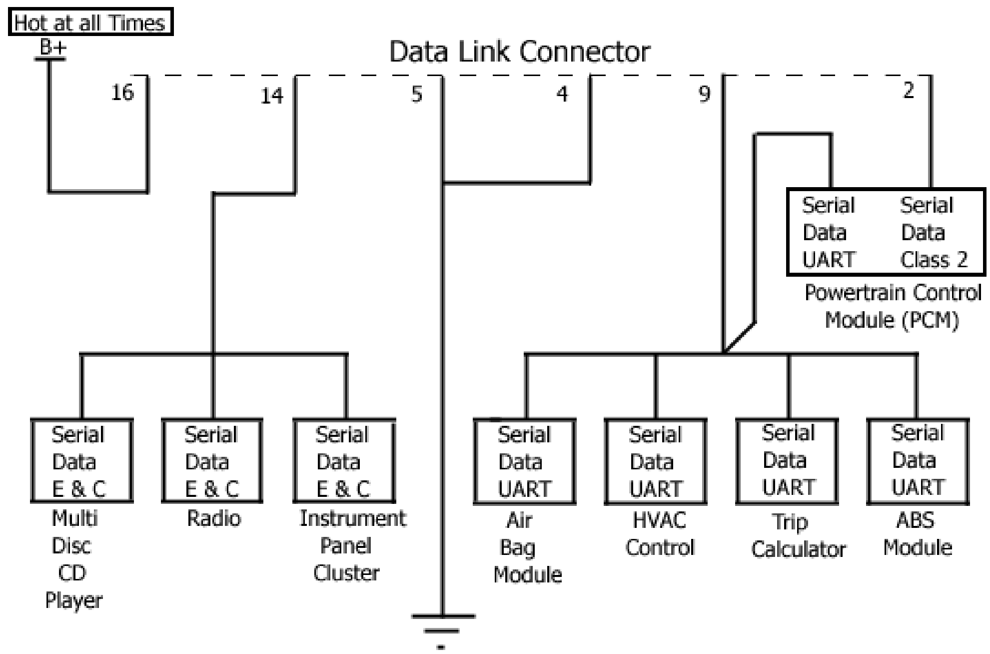


1. Secondary UART 8192 Baud Serial Data (CKT 800), Secondary Class B (CKT 710) or 160 Baud Serial Data (1995 only) (CKT 461)
2. J1850 Bus + L Line on 2-Wire Systems, or Single Wire (Class 2) (CKT 1807)
3. Ride Control Diagnostic Enable (CKT 1826)
4. Chassis/Body Ground Pin (CKT 150)
5. Signal Ground Pin (CKT 451)
6. PCM/VCM Diagnostic Enable (CKT 448)
7. K Line for International Standards Organization (ISO) Application
8. Keyless Entry Enable (CKT 1455) or Theft Diagnostic Enable (CKT 477)
9. Primary UART (CKT 1061)
10. J1850 Bus-Line for J1850-2 Wire Applications
11. Electronic Variable Orifice (EVO) Steering (CKT 1294) or Magnetic Steering Variable Assist (MSVA)
12. ABS Diagnostic (CKT 799) or CCM Diagnostic Enable (CKT 555)
13. SIR Diagnostic Enable (CKT 326)
14. E&C Bus (CKT 835)
15. L Line for International Standards Organization (ISO) Application
16. Battery Power from Vehicle Unswitched (4 AMP MAX.)

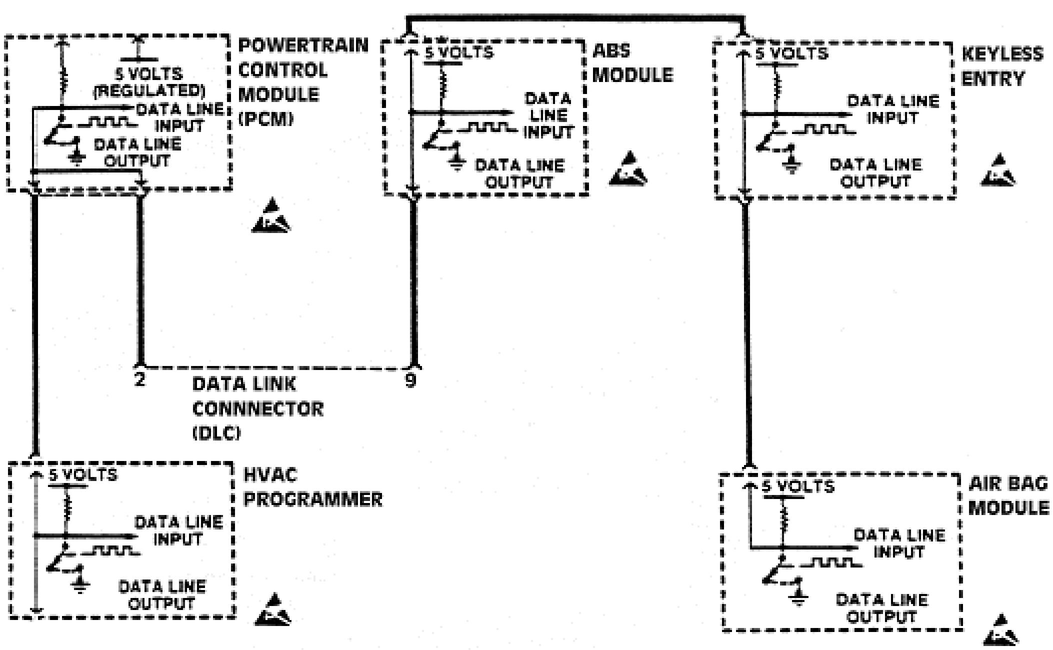
If a serial data failure is suspected, a simple voltage test on the data line will validate its operation. Check the DC voltage on the Data Link Connector between pins 2 and 5, with the vehicle operating. The DVOM should measure approximately .2 V to .7 V. A reading of 7 V indicates a short to power and a reading of 0 V is a short to ground.



A typical Class II data waveform as it appears on an oscilloscope



This schematic is an example of serial data/communication lines on late model vehicles.



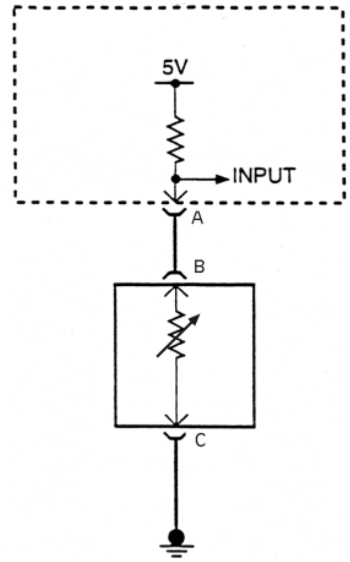
Computer data line inputs and outputs

Computer Output Testing

If an input sensor or an output actuator is inoperative and the computer is suspected, perform a preliminary voltage test on the computer before replacement.

In this example, a voltage measurement of zero at point A (to ground) may be a computer failure or it may be a shorted sensor or wire. To determine which, remove the wire from the computer at point A and insert a 5000Ω resistor between point A and ground. If the voltage at point A is still zero, the computer is bad. If there is now a voltage at point A, the sensor or wire is the problem.

To check a computer output suspected of failure, remove the connecting wire from the computer and insert a ½ A (500 mA) bulb between the output and 12 volt power. Activate the output (usually with a scan tool) and check for operation of the bulb. If the bulb lights, the actuator is the problem, if not, the computer has failed. **Caution:** Be very careful performing this test with a test light! Many test lights draw far more than ½ A and will damage the computer!



Typical Input Sensor

Fault Protection

In addition to protecting against Data Line problems, modern automotive computers monitor current and voltage on input and output wires. If a failure (wire or component) causes the amperage or voltage in a particular circuit to be too high, the computer will disable the line to prevent internal damage. Some applications will also disconnect for voltage/current failures that are too low; for instance, if an injector is disconnected.

Inputs

Automotive computers always need to know the most current operating conditions of a vehicle to determine what changes should be made. This operating information is fed to the computers from a series of inputs called sensors. Sensor signals come in a variety of types but all generally fall into one of three broad categories:

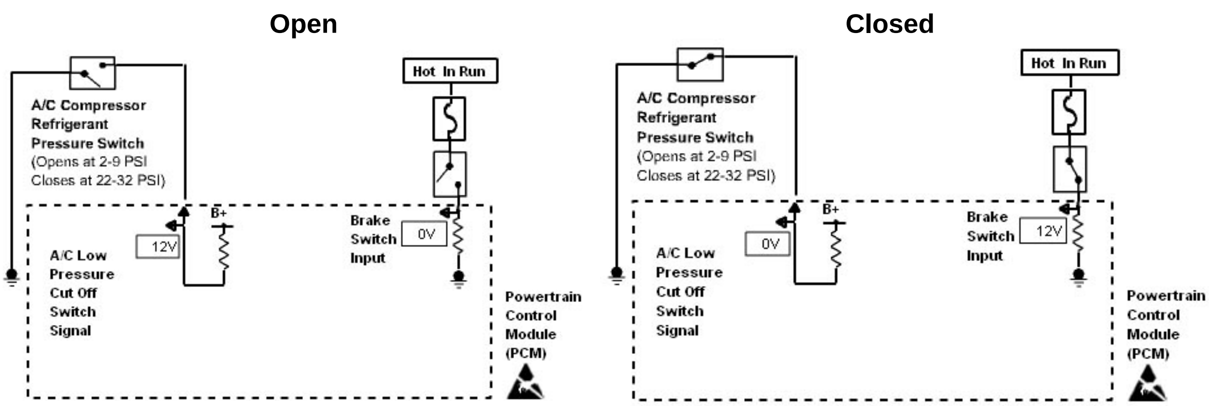
- Switches
- Digital Signals
- Analog, or Variable Signals

Switches

Switches are the simplest type of sensors and provide the computer with information that a device is on or off, open or closed, high or low, etc. In the closed position, a switch may send a voltage (usually 12 V) to the computer or it may provide a ground. For example, a brake switch may send a 12 V signal when pressed and a 0 V signal when released. A computer could then use that information to disengage a Torque Converter Clutch or engage the Anti-Lock Brake system.
Some examples of switches include:

- Door Jamb
- Oil Level
- Transmission Ranges
- Torque Converter Clutch
- Oil Pressure
- Park/Headlights
- Closed Throttle
- A/C Pressure
- Transmission Pressure
- Blower Speeds

Notice in this illustration that the A/C compressor switch is externally attached to ground while the TCC brake switch is fused to the Battery (B+). When each switch is closed, the A/C compressor signal feeds into the computer, through a limiting resistor, to B+ and the TCC switch connects through a limiting resistor to an internal computer ground. In this way, if a technician knows a particular switch is connected to ground, then the signal from the computer, with the switch disconnected, should be B+ and vice-versa. Also note that the actual input the computer uses is read across the internal resistor rather than the switch itself. As shown here, the voltage across the internal resistors for both of these switches, varies with the operation of the switches.



Typical Input Switches

Switch Input Testing

If a switch input is not functioning and the switch itself is found to be operating properly, then a suspected computer failure can be tested as follows:

For externally grounded switches-

1. Remove the switch connecting wire from the computer
2. Connect a voltmeter between ground and the input terminal of the computer
3. Check that the voltmeter reads 12 V. If not, then the computer is bad.

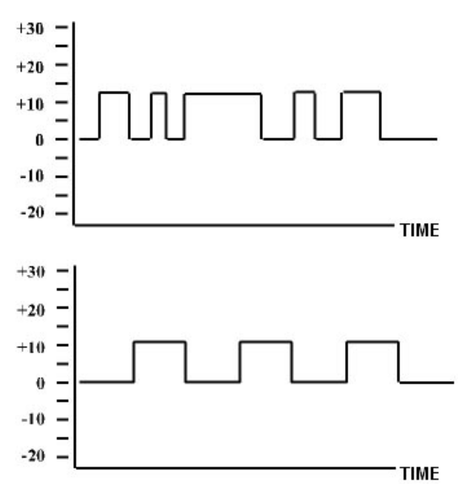
For externally powered switches-

1. Remove the switch connecting wire from the computer.
2. Connect a voltmeter between Battery power and the input terminal of the computer
3. Check that the voltmeter reads 12 V. If not, then the computer is bad.

Digital Signals

Digital inputs are similar to switch signals in that they only have two states, on or off. What makes digital signals different, however, is that they cycle many times each second to form a square wave. Digital inputs may have a constant duty cycle (each on-off cycle time is the same), or the on-off times may vary to signal a change in vehicle operation. This figure shows digital signals with both varying and constant duty cycles.

Examples of digital input signals include Hall-Effect type Crankshaft Position Sensors or Mass Airflow Sensors.



Digital Signals

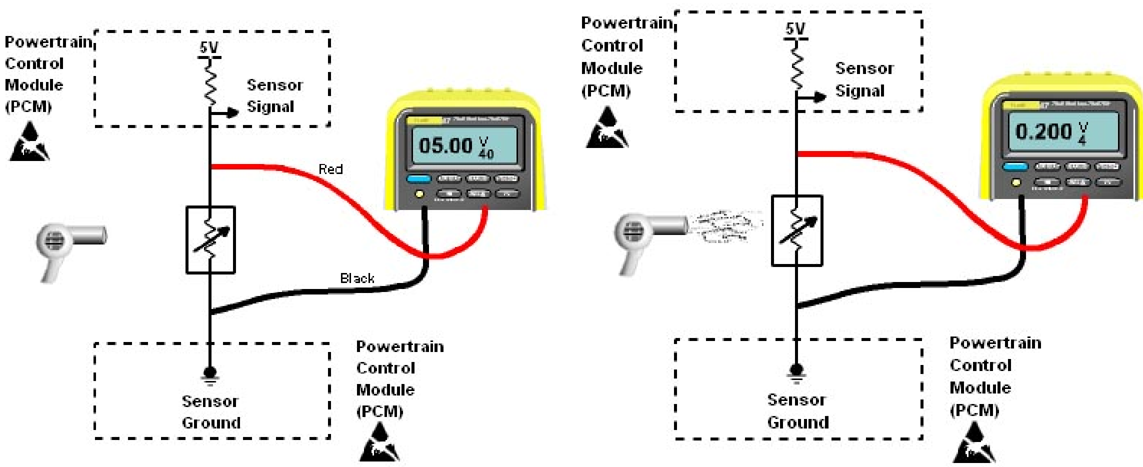
Variable or Analog Signals

Unlike Digital signals, Analog signals vary throughout a voltage range rather than just provide on or off states. Typical voltages range from 0-1 V, 0-5 V, and 0-12 V. Analog sensors will fall into one of two categories: Variable Resistance or Variable Voltage.
Variable resistor sensors will be one of four types:

- Thermistors (for temperatures)
- Rheostats (for levels)
- Potentiometers (for position)
- Pressure Transducers

Thermistors

A thermistor is a heat-activated variable resistor that receives a 5V source, through a current limiting resistor, from the Powertrain Control Module (PCM). As a thermistor's temperature increases, its resistance and voltage drop decrease. This in turn causes the voltage drop across the internal resistor, located inside the computer, to increase. The internal voltage drop then becomes the signal input. In addition to a 5V source, thermistors also receive their ground source from the PCM.



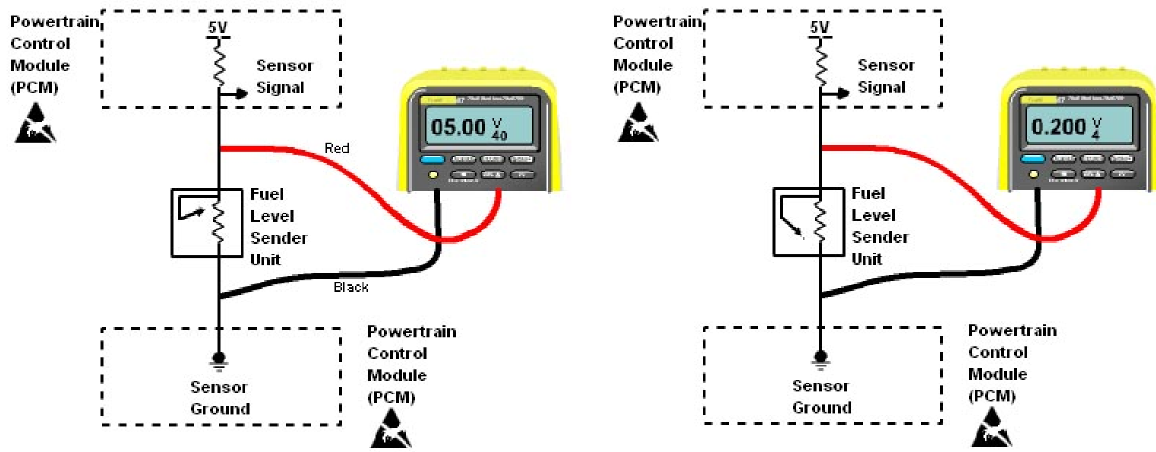
The thermistor's resistance and voltage drop decrease with heat.

Some examples of typical thermistors include:

- Engine Coolant Temperature sensor
- Intake Air Temperature sensor
- Transmission Fluid Temperature sensor
- Outside Air Temperature sensor
- Heat Duct Temperature sensor
- Ambient Air Temperature sensor
- A/C Duct temperature sensor

Rheostats

Rheostat sensors are similar to thermistors in that they are both variable resistors. The difference is that rheostats operate mechanically rather than by temperature. A Fuel Level sensor is a good example of a rheostat. As the amount of fuel in the tank decreases, the resistance and voltage drop of the sensor changes, which varies the voltage drop across the internal resistor where the input is measured. Be aware that some Fuel Level sensors will have a higher resistance with low fuel and some will have a lower resistance with low fuel. Refer to the appropriate service manual.



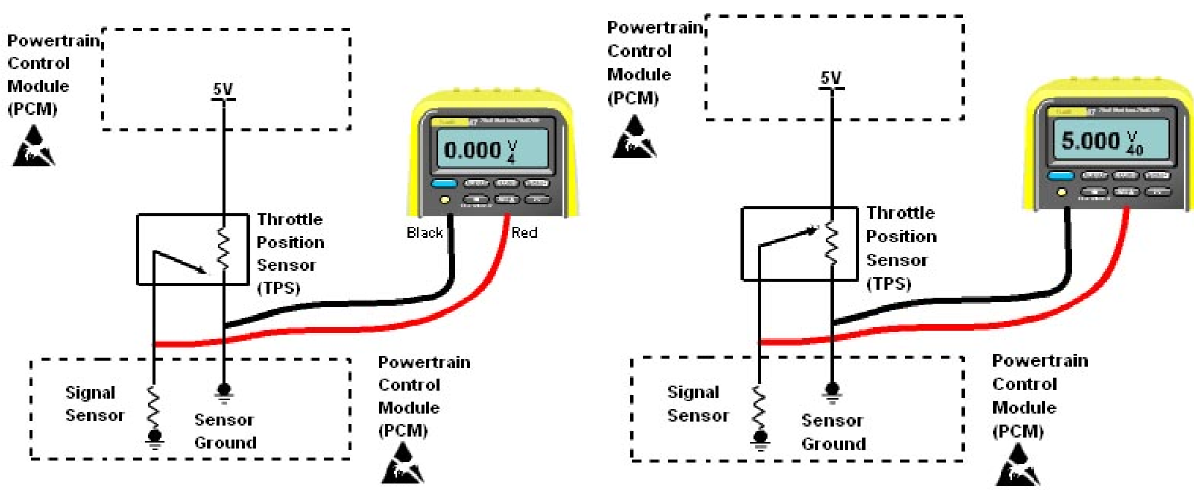
The rheostat mechanically varies the resistance and voltage drop.

Potentiometers

Potentiometers are three wire position sensors that have 5 V, ground, and input signals all tied into a computer. Like rheostats, pots are also mechanically variable, as opposed to changing by temperature, pressure, or light. However, rather than altering the voltage drop across an internal resistor, as variable resistor sensors do, potentiometers actually send a voltage signal directly to the computer. These sensor inputs supply information on the position of throttle valves, EGR pintles, etc. The sensor signal voltage is applied to the computer through a current limiting resistor to ground. Notice also that potentiometers do not use limiting resistors in the 5 volt supply line.

Some common examples of potentiometers include:

- Throttle Position Sensor
- EGR Position Sensor
- Accelerator Pedal Position Sensor
- Air Door Motor Feedback Sensor (HVAC)

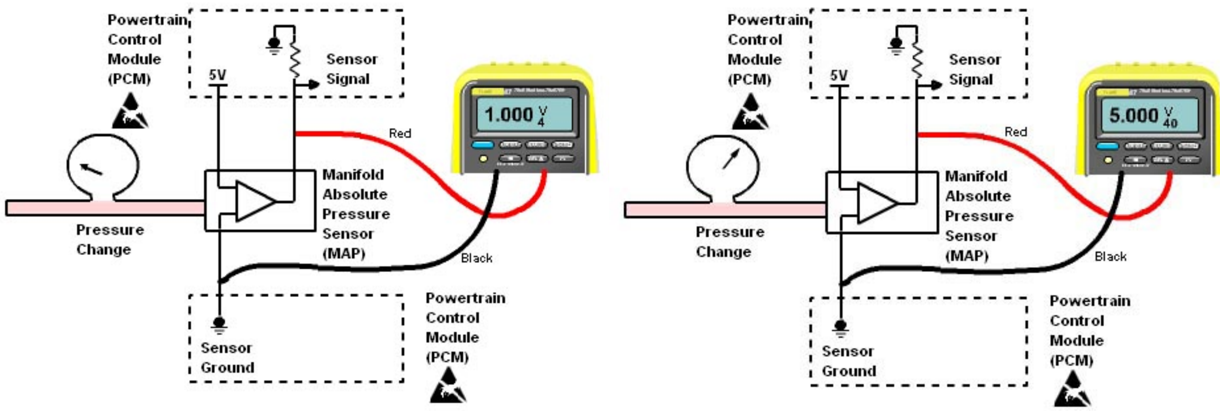


The potentiometer sends a variable voltage signal to the computer.

Pressure Transducers

Pressure Transducer sensors have the same computer connections as potentiometers. The difference is that pressure sensors operate based on a change in pressure rather than a change in position. Diagnosis and testing of pressure sensors will be basically the same as for any input potentiometer. Common types of pressure sensors include Manifold Absolute Pressure (MAP) for measuring engine load, Fuel Tank

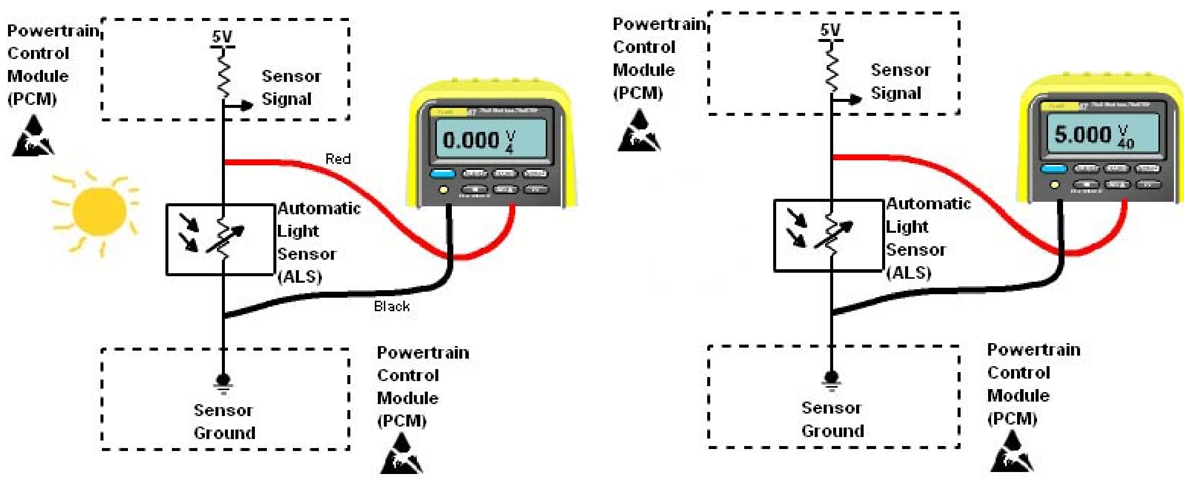
Pressure (FTP) for checking fuel tank vapor pressure as part of emissions testing, and the A/C pressure sensor for measuring air conditioning high side pressure.



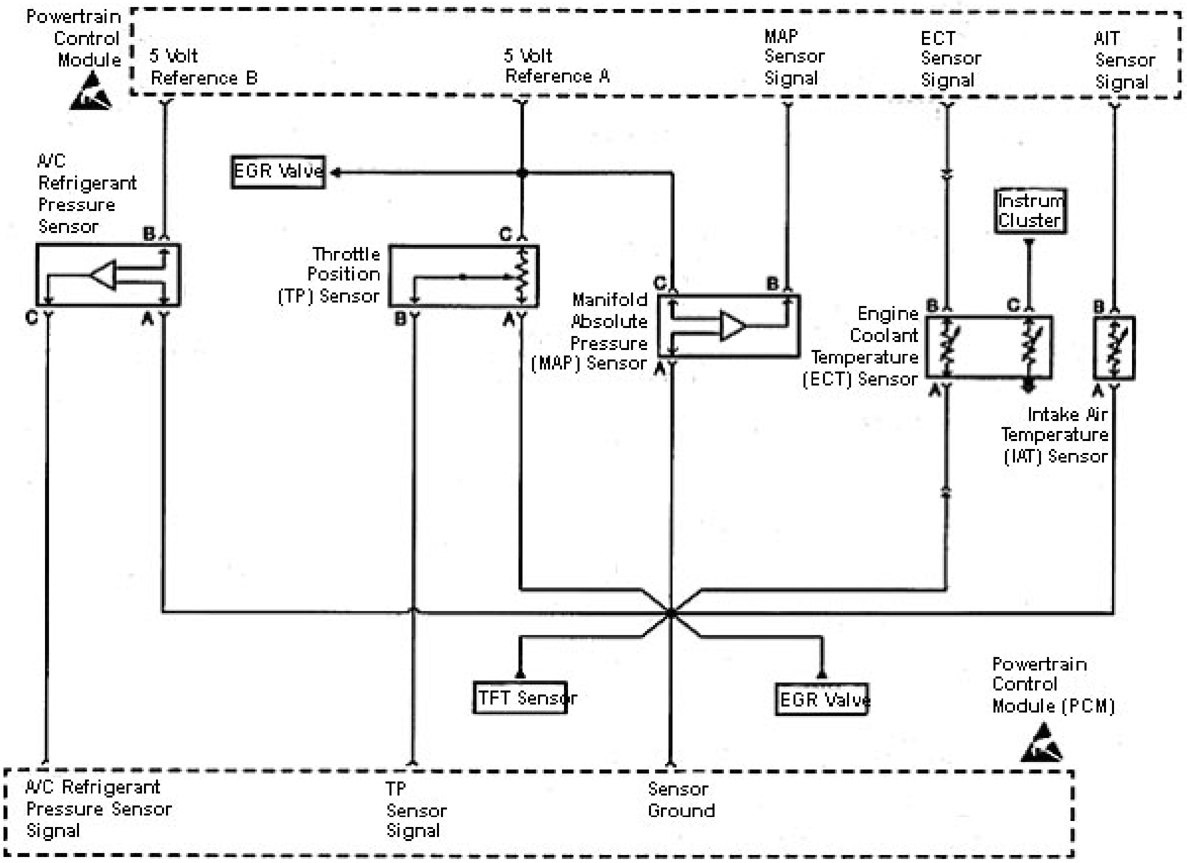
Pressure transducers operate based on a change in pressure rather than a change in position.

Photoresistors

One last type of variable resistor we need to mention is the photoresistor. Photoresistors are wired to computer modules in the same way as thermistors or rheostats. The difference is the photoresistor changes its resistance based on how much light strikes its surface rather than on temperature or position. As the amount of light changes, the voltage drop across the photoresistor changes, and causes the voltage across the internal resistor to change, which determines the input voltage. Photoresistors are used to turn on Automatic Headlights at dusk, control interior lighting operation, and determine heat load for automatic Air Conditioning systems.



The photoresistor changes its resistance based on how much light strikes its surface.



Typical Input Sensor Schematic

Voltage Generators

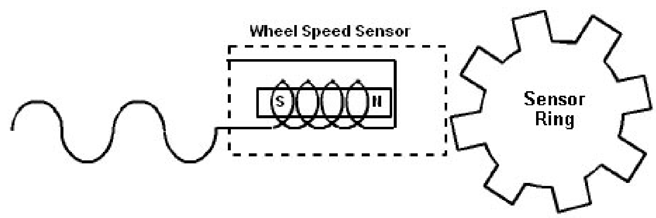
In addition to variable resistor sensors, there are a number of input sensors that actually produce their own voltage, known as Voltage Generators. Voltage generators can be electromagnetic, chemical, or Photovoltaic.

Electro-Magnetic Sensors

Electro-Magnetic sensors are made of a coil of wire wound around a permanent magnet, and use a metal sensor ring that turns very close to the sensor. As the sensor ring begins to rotate, the magnetic field is disrupted and an AC voltage is produced. The frequency of this sensor output is then translated into a rotational speed value the computer can use.

Some examples of Electro-Magnetic sensors include:

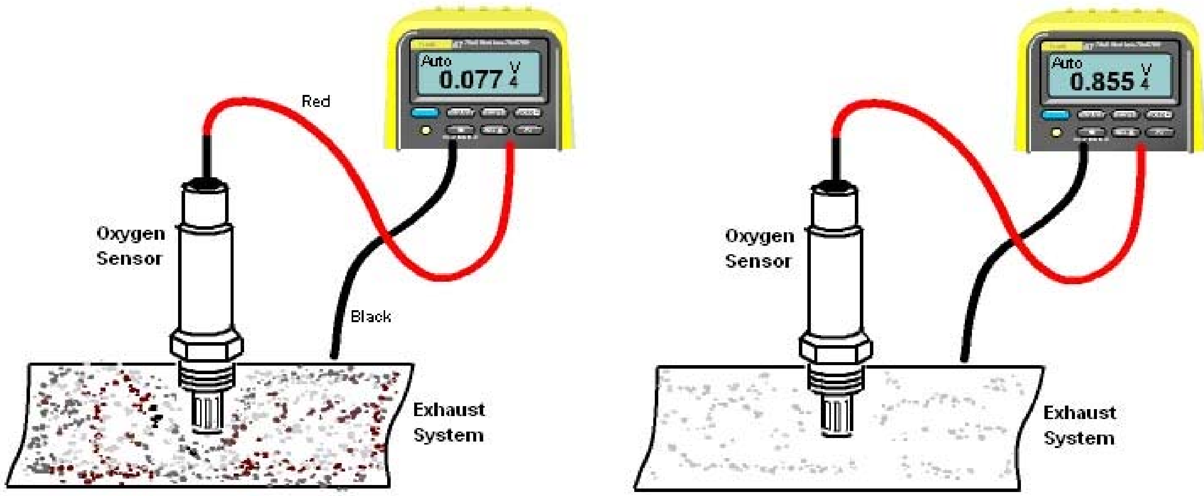
- Anti-Lock Wheel Speed Sensors (WSS)
- Crankshaft Position Sensors (CKP)
- Distributor Pick-Up
- Camshaft Sensors (CMP)
- Vehicle Speed Sensors (VSS)
- Input Speed Sensors (ISS)
- Output Speed Sensors (OSS)



Electro-Magnetic Sensor

Chemical Voltage Generator

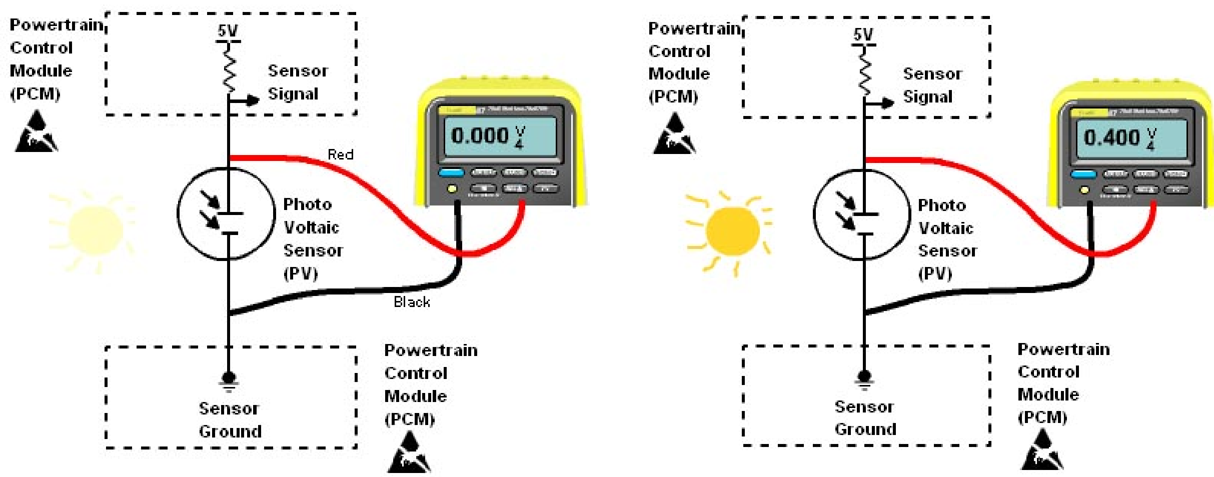
The most commonly used chemical voltage generator is the Oxygen Sensor (O2). This sensor produces an output from 0 Volts to approximately 1 Volt when the oxygen in the exhaust stream reacts with the platinum coating on the inside of the sensor and is compared to atmospheric oxygen. The O2 sensor signal is evaluated inside the PCM based both on voltage output and its transition rate from high voltage to low voltage.



Low oxygen content (rich) produces a low voltage signal; high oxygen content produces a higher voltage signal.

Photovoltaic Sensor

The photovoltaic sensor is similar to the photoresistor only in the sense that it is affected by light. While the photoresistor changes its resistive value, the photovoltaic sensor actually produces an output voltage that can be used by a computer to determine the intensity of sunlight. Photovoltaic sensors are commonly referred to as Sun Load Sensors and are primarily used with A/C systems to determine heat load. Photovoltaic sensors can also be used to turn on headlights at dark, operate an auto-dimming rear view mirror, or operate interior light functions. A photovoltaic sensor can be tested by exposing it to varying amounts of light and measuring the voltage output.



The photovoltaic sensor produces an output voltage based on the amount of light.

Outputs

In modern automotive applications, computers control many (and sometimes most) of a vehicle's functions. The commands that come from the computers are called outputs. Outputs are the voltage and current signals that operate the actuators, which directly control the vehicles operation.
Some typical examples of actuators include:

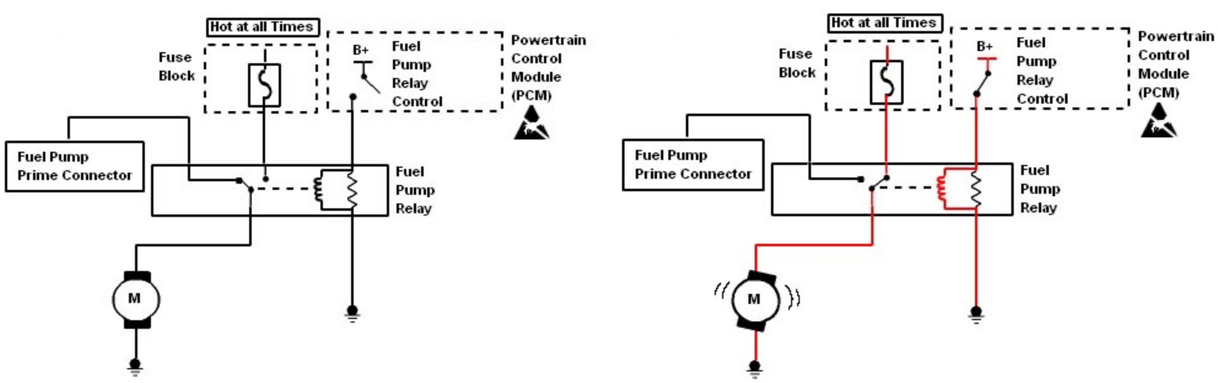
- Relays
- Solenoids
- Ignition coils
- Motors
- Valves
- Lamps

All of the actuators in automotive applications fall into one of two possible control categories, switched or variable. Switched applications, of which there are two, are either on or off (e.g. relays). However, the two types of variable applications change continuously throughout their operating range.
These four categories break down as shown here:

- Switched Voltage (on/off)
- Switched Ground (on/off)
- Constant Frequency Pulse Width Modulated (variable)
- Variable Frequency Pulse Width Modulated (variable)

Switched Voltage

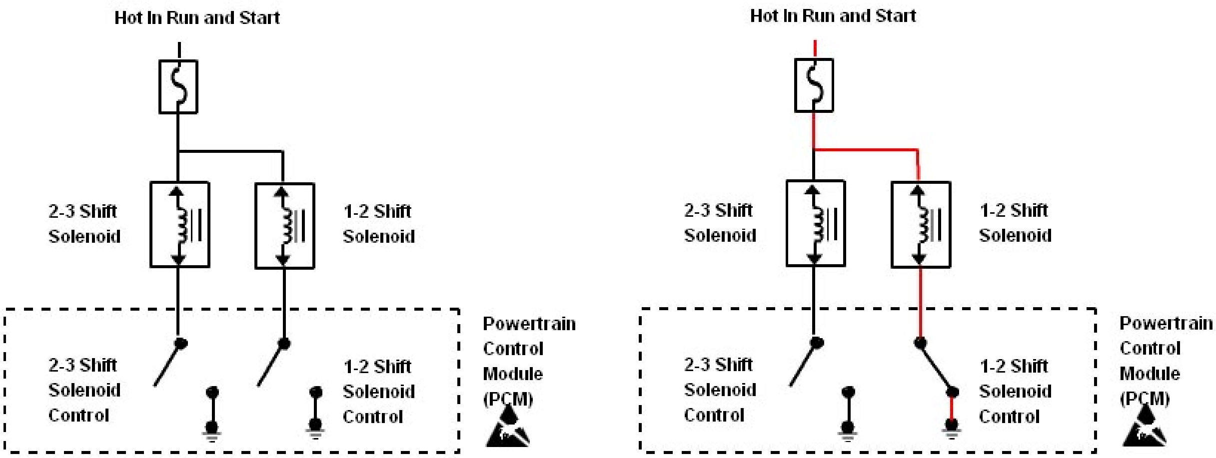
A switched voltage control is either on or off and is computer activated by applying or removing a voltage source. Refer to the fuel pump circuit below. In this typical fuel pump circuit, the relay coil has a fixed ground and the PCM supplies the 12 Volt power to energize the coil, engage the contacts, and supply power to the pump. Some applications of relays, solenoids, lamps, valves, and motors are switched voltage activated.



Switched Voltage Control

Switched Ground

Like switched voltage applications, switched ground devices are also either on or off. In the following illustration, the transmission shift valves have a constant 12 Volts on one end and are controlled by ground signals from the PCM on the other. In automotive applications, switched ground control is much more common than switched voltage applications due to a reduced possibility of arcing. Relays, solenoids, lamps, valves, and motors can all be ground switch controlled.

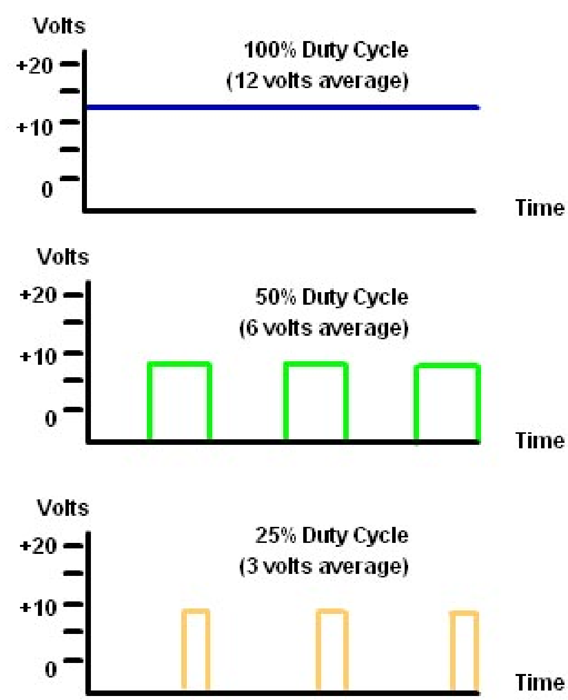


Switched ground control: 1-2 Shift Solenoid is switched on at right

Pulse Width Modulation

Pulse Width Modulation (PWM) is a control method in which a computer produces a variable or partial operation of a device by supplying a constantly cycling ground signal to the device. As seen in this illustration, the average voltage applied to a device is dependent on the Duty Cycle of a PWM signal. Duty Cycle is the amount of time a signal is turned on as compared to the total amount of operating time. For example, if a signal has a 100% duty cycle, its average voltage will be 12 volts and the actuator will operate at full capacity. Changing the output to a 50% duty cycle (on half the time, off half the time) drops the average voltage to 6 volts, and the speed or intensity of operation decreases.

Even though PWM signals are digital, the output can be measured with a DVOM using the average voltage readings.



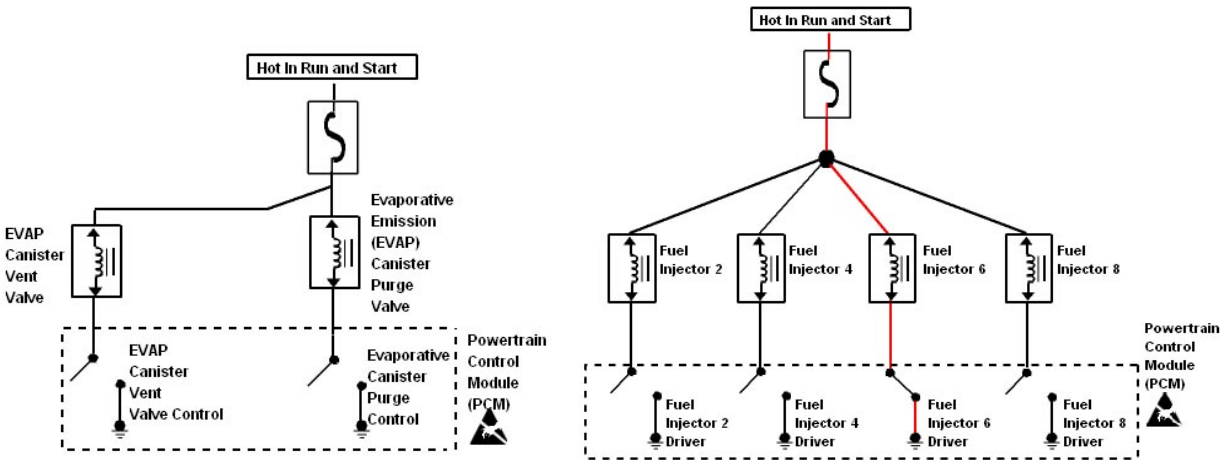
PWM Duty Cycles

Constant Frequency Pulse Width Modulation

The first type of Pulse Width Modulated signal is the Constant Frequency output. Constant frequency signals, as the name implies, turn an actuator on and off the same number of times each second. The computer then varies the duty cycle to alter the open/close time. For example, the evaporative purge valve in the next illustration will be cycled at 35 Hertz (HZ), or 35 times each second. If the duty cycle during that time is 50%, the average voltage will be 6 Volts and the valve will open approximately half way. At this setting, it will flow at one-half of its vapor capacity for emissions control. Changing the duty cycle to 25% (about 3 volts average) reduces vapor flow to one-fourth of capacity but the on/off rate remains at 35 times per second. The same concept applies if the duty cycle increases to 75%. Similar to the evaporative valves, transmission pressure control valves control line pressure, and EGR valves control recirculation gas using constant frequency PWM signals.

Variable Frequency Pulse Width Modulation

Some output actuators must change operating frequency in response to changing engine or transmission speed. As a result, these types of actuators cannot use constant frequency computer outputs. Refer to the fuel injector circuit below. Although injectors are still controlled by a cycling ground, their demands change with engine speed and their on/off times are sequenced to coincide with Crankshaft Position Sensor inputs. That means they must change both how often they open and how long they stay open. Even though injectors may have a large demand at slower engine speeds, or lower demand at higher speeds, their average voltages can still be measured with a DVOM. Simply put, as the requirement for fuel increases, the average voltage will increase. Ignition Module and Idle Control Motor outputs are additional examples of computer signals with both varying frequency and duty cycle.



Constant Frequency Pulse Width Modulation, left; Variable Frequency Pulse Width Modulation, right. The number 6 fuel injector is energized.