



# **Technicians Reference Booklet**

**Basic Electrical Theory**

**Module 601**

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# Basic Electrical Theory & Diagnosis Module

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# Basic Electrical Theory & Diagnosis Module

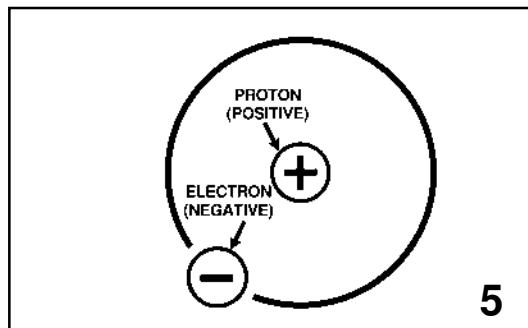
## Introduction

This Technicians Reference Booklet contains information pertaining to basic automotive electricity, and the Subaru electrical system. It reviews electron theory, current flow, circuitry, and the types and causes of electrical shorts. Electrical terms are defined, Ohm's Law is explained, and the following major components of Subaru electrical systems are discussed: the battery, circuit protectors, switches, relays, and motors. Finally, the six-step method of troubleshooting is introduced. This method presents a logical step by step process of identifying and correcting typical electrical system problems.

The text and illustrations are derived from the classroom lecture and slide presentation material and are intended to reinforce previous classroom instruction and lab participation.

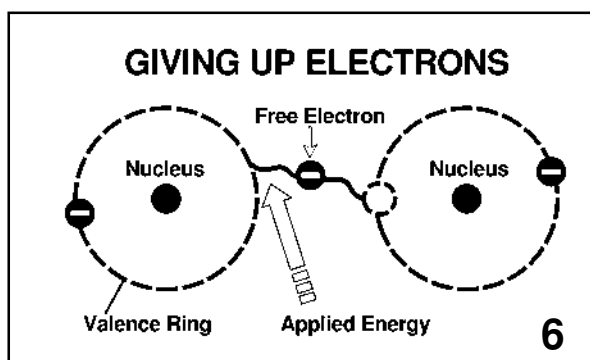
Technicians Worksheets provided by your instructor will be completed during the "hands-on" lab work segments of the Basic Electrical Theory & Diagnosis Module. Always refer to the appropriate model year Subaru Service Manual and the applicable Service Bulletins for all specifications and detailed service procedures.

## Electrical System Theory



*Electron theory*

Atoms are composed of electrons and protons. Electrons have a negative charge and whirl around a nucleus composed of protons, which have a positive charge.

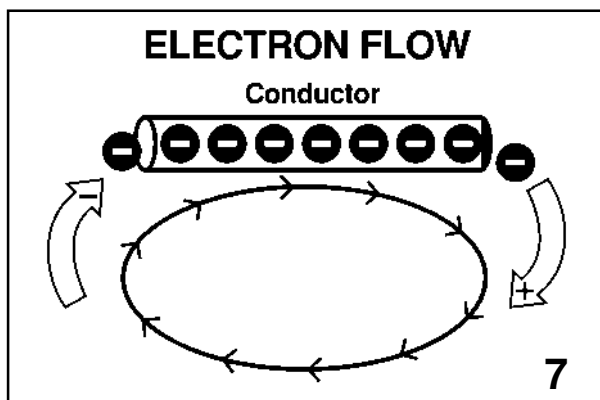


*Electron flow*

The electrons can move from the valence ring of one atom to the valence ring of another atom. This chain reaction effect type of movement of electrons constitutes electric current.

Atoms with fewer than four electrons are considered to be conductors because they give up electrons to other atoms easily.

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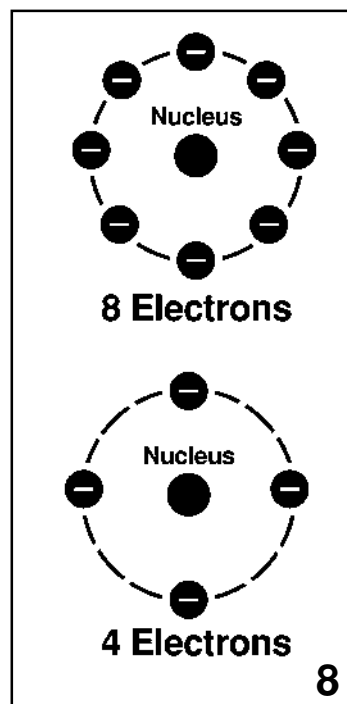


*Conductors*

All circuits must have conductors and insulators to operate properly. Electricity will always return to its source if a path (circuit) is available. Circuits provide a path for electrons to travel from a source to the load and back to the source.

Conductors such as copper, iron, and aluminum allow electrons to flow freely, or be released. There are several methods to produce electromotive force which causes electrons to be released:

- Magnetic (Alternator)
- Pressure (Knock sensor)
- Heat (Thermo-couple)
- Chemical (Storage battery)



*Insulators/Semiconductors*

Atoms with more than four electrons are insulators because they do not freely give up electrons. Examples are:

- Glass
- Rubber
- Vinyl

The best insulators have eight (8) electrons.

Atoms with exactly four electrons in the outer valence ring are called semiconductors.

Examples are:

- Carbon
- Silicon
- Germanium

A semiconductor may be a conductor or an insulator, depending on the application and circuit conditions.

**NOTE: SEMICONDUCTORS WILL BE ADDRESSED FURTHER IN THE ADVANCED ELECTRICAL THEORY & DIAGNOSIS MODULE.**

# Basic Electrical Theory & Diagnosis Module

## Electrical Terms

- Amps—Current flow of electrons or intensity: Symbol = I
- Volts—Electromotive force or pressure: Symbol = V
- Ohms—Resistance to electron movement: Symbol = R

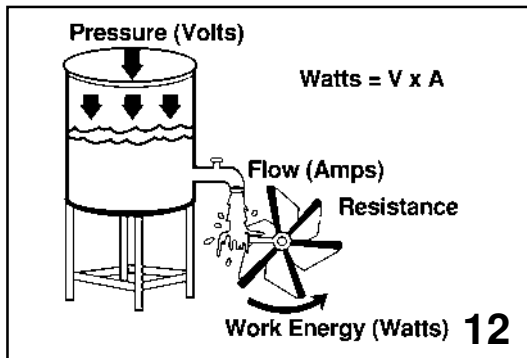
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## Watts

- Measurement of electrical power: Symbol = W
- Watts = Volts x amps:  $W = V \times I$
- Example: 1)  $12\text{ V} \times 5.01 = 60\text{ W}$   
2)  $120\text{ V} \times 0.51 = 60\text{ W}$

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It is important that you understand the definitions of the electrical terms listed above.



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*An electrical analogy*

Think of an electrical system as a water system in which the water tank represents the power source (potential energy). The tank is similar to a battery. The water flowing from the water tank is measured in gph (gallons/hour) and represents electron flow. In a battery, chemical interaction produces this electron flow which is measured in amperes (amps).

Pressure is created by the physical weight of the water which causes the water to move. Water pressure is measured on pounds/in<sup>2</sup> (psi). Similarly, the pressure that moves the electrons, which is called electromotive force, is measured on volts (V).

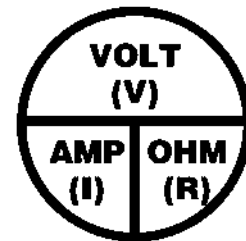
As the water strikes the water wheel, the weight of the water causes the wheel to turn. A continuous volume of water keeps the wheel turning. The weight of the wheel impedes (provides resistance to) the flow of the water. This resistance is measured as friction or drag. In an electrical system, the wire provides resistance through the covalent bonding of the electrons. This resistance is measured in ohms (R).

Work is equal to the pressure of the water times the flow of water which is equal to rotation of the wheel. An increase in the pressure or volume at the same resistance will equal an increase in the flow of water which in turn increases the speed or amount of wheel rotation. In an electrical system, the voltage (pressure - V) X amps (flow of electrons - I) will equal the watts (the wheel rotation) or work performed.

## Ohm's Law

- one volt applied to one ohm of resistance will result in one amp of current, therefore

- $I = V / R$
- $V = I \times R$
- $R = V / I$



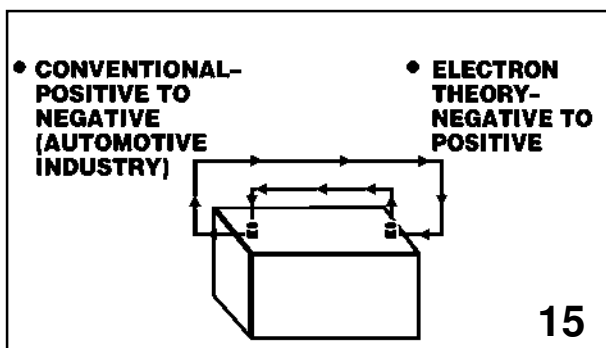
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# Basic Electrical Theory & Diagnosis Module

Using Ohm's Law, complete the following problems:

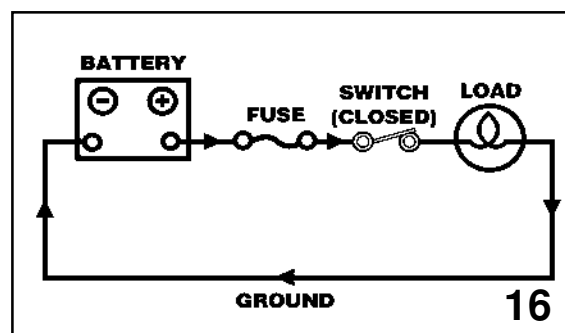
1. How many amps of current can flow through a 12-ohm resistor if 12,000 volts are available?
2. How many volts are required to move 10 amps of current through a 0.5-ohm wire?
3. What resistance value will allow the flow of 15 amps of current if 12 volts are available?



*Theory of electron flow*

The conventional theory of electron flow states that the direction of current flow is from the positive (+) terminal of the voltage source, through the external circuit, and then back to the negative (-) terminal of the voltage source. The electron theory states that the direction of current flow is from the negative (-) terminal of the voltage source, through the external circuit, and then back to the positive (+) terminal of the voltage source.

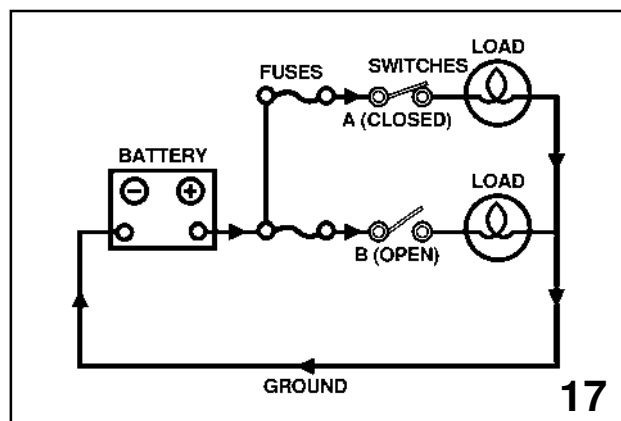
## Circuits: Electron Flow



*Basic electrical circuit*

The basic circuit shown above has a battery as the power source. The wires carry the current from the battery (positive wire to the load (bulb) and back to the source (ground wire)). A switch controls the flow of current, and a fuse protects the circuit from an overload or an unintentional ground.

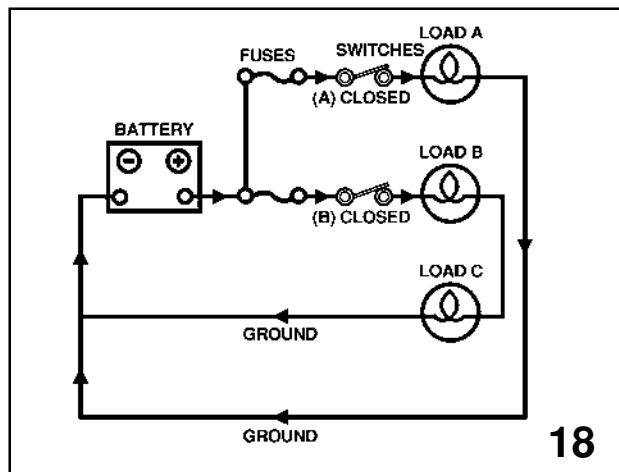
The circuit shown above is a series circuit because it provides only one path for current flow. A break or short anywhere in the circuit will stop the current flow.



*Parallel circuit*

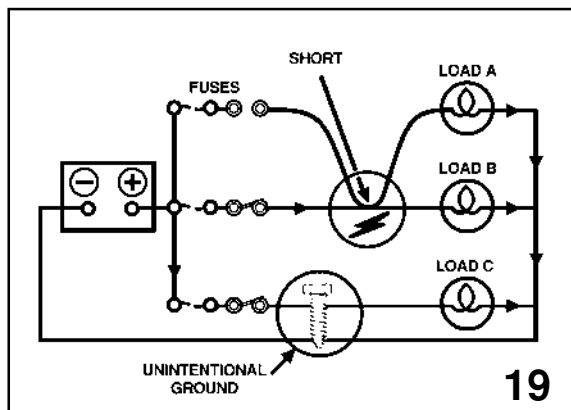
Current flows through parallel branches of the circuit only affects that branch and does not stop the flow of current to other components on the other branches of the circuit.

# Basic Electrical Theory & Diagnosis Module



*Series-parallel circuit*

This type of circuit is a combination of the series and parallel forms of circuitry and has the advantages and disadvantages of both types. If the fuse blows in the main feed line, current cannot flow to Load A, Load B, or Load C. On the other hand, a break in the Load A wire will not affect the operation of the Load B or Load C circuit. This is the most common type of circuit used in automotive electrical systems.

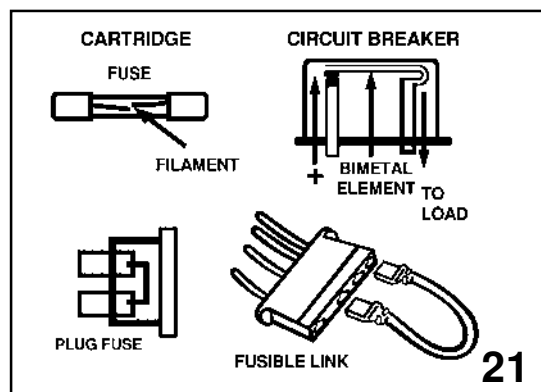


*Shorts grounds and opens*

The figure above shows two types of shorts that occur in automotive electrical systems. A short circuit can be a connection of two circuits caused by a break in the insulation of the circuits or an unintentional ground caused when a circuit comes in contact with a ground as shown above. An open is an interruption of the current flow in a circuit caused by the activation of a switching device or a break in a conductor.

## Electrical Terminology

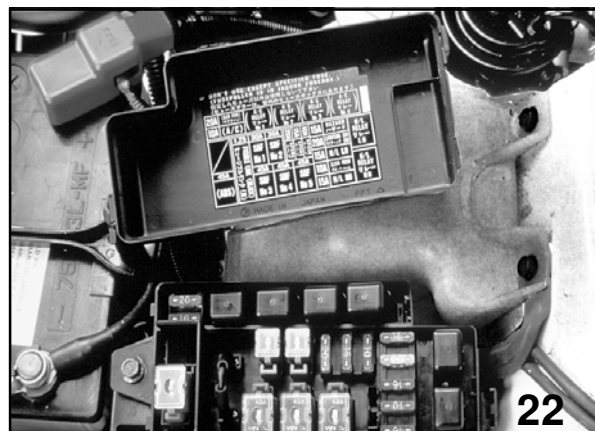
### Circuit Protectors



*Circuit Protectors*

Circuit protectors provide a vital safeguard to an electrical system.

A blown circuit protector is an indication of a problem in the circuit. Replacing the circuit protector is not usually the solution to the problem.



*Fusible link*

A fusible link is a short piece of insulated wire that is usually four gauges smaller in wire size than the circuit it protects. Subaru vehicles use up to five fusible links depending on model and year.

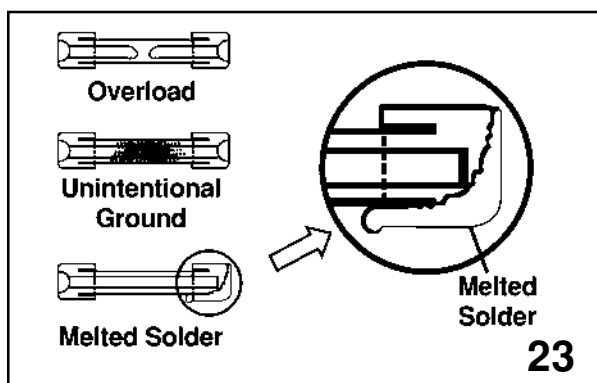
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There are two types of fuses used in Subaru vehicles:

1. Cartridge type  
These fuses have a zinc strip attached to two metal end caps. The end caps are separated by a clear glass tube.
2. Plug type  
This fuse has a zinc strip attached to two metal terminals are imbedded a plastic holder.

Some Subaru vehicles use plug type fuses as main fuses instead of fusible links. Examples are certain circuits in the Legacy and Justy vehicles.

Circuit breakers are a thermal mechanical device that opens a circuit when its amperage rating is exceeded. The advantage of a circuit breaker is that it is reusable and automatically resets.

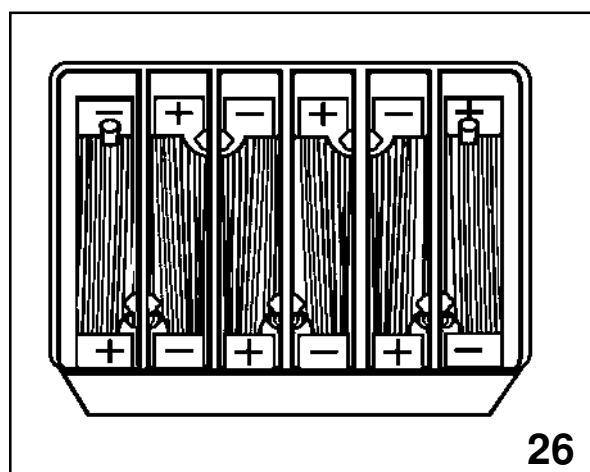


*Fuse interpretation*

When a fuse blows because of a circuit fault, it will exhibit one of three visual characteristics as described below. By examining the fuse closely, it can be determined what type of circuit fault caused the problem.

1. Overloaded circuit, occurs when 20 amps pass through a 15 amp fuse. The center of the fuse strip will get hot, droop then melt leaving the ends drooping down at the break point.

2. A short circuit or unintentional ground causes an extremely high current to pass through the fuse strip. The strip melts so quickly that it vaporizes. The strip particles splatter the glass tube or plastic body and the glass tube or plastic body will appear tinted (silvery/black).
3. A poor fuse connection is caused by a loose contact between the fuse cap and holder (cartridge type only). This creates a resistance, which can produce enough heat to melt the solder attaching the fuse strip to the end caps. In this case beads of solder or flux stains may be seen on the inside or on the outside of the glass tube, however the fuse strip will appear to be intact.



*Battery*

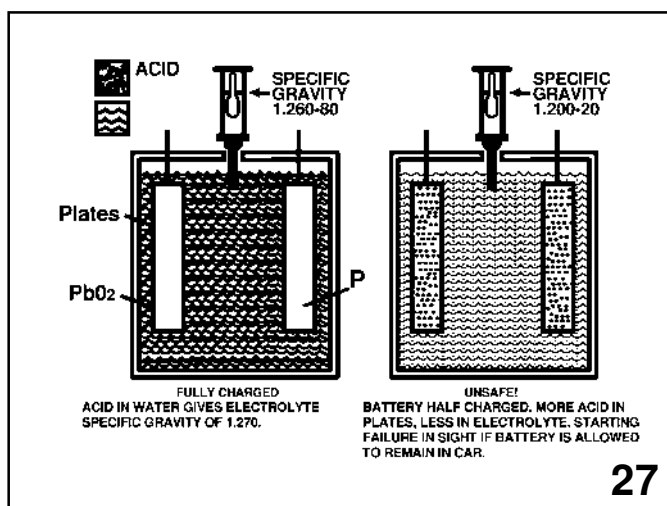
The automotive battery is an electrochemical device that stores and converts chemical energy into electrical energy. It is not a storage container for electricity. The battery provides the initial electrical energy for the ignition system and starting system. It also supplies additional current when the current demand of the system exceeds the output of the alternator.

Automotive batteries normally have six cells. Each cell produces 2.1 volts; thus a six-cell battery produces 12.6 volts. The voltage output of the battery is determined by the material used in the construction of the plates.

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Automotive battery plates are made of two dissimilar materials, for example, lead peroxide (positive plate) and sponge lead (negative plate). A thin separator of rubber or plastic is between each negative and positive plate.

The cells are then connected in series, i.e., the positive plates of one cell are connected to the negative plates of the next cell, etc. Note that additional plates in a cell do not increase the voltage capability of the cell or battery, but they do increase the length of time that the battery can produce electricity (amperage rating).



*Electrolyte specific gravity*

Electrolyte is the final ingredient required for an active battery. Without electrolyte, a battery is inactive and does not produce electricity. Electrolyte is a solution of water and purified sulfuric acid which allows the chemical reaction to occur between the plates. Generally, the percentage of sulfuric acid in a battery is 36 percent by weight and 25 percent by volume.

To determine the amount of charge of a battery, the specific gravity of the electrolyte is measured. A full charged battery theoretically should have an electrolyte specific gravity of 1.299. However, a normally charged battery will most likely indicate specific gravity readings ranging from 1.260 to 1.280 at 80° F.

Specific gravity is the ratio of the weight (or mass) of the water to the weight (or mass) of the sulfuric acid. Thus, a specific gravity of 1.000 is equal to water. Specific gravity will change with changes in temperature of the electrolyte, For each 10° above 80° F., add .004 to the electrolyte reading. For each 10° below 80° F., subtract .004 from the electrolyte reading. Or you may use an electrolyte temperature correction chart or a temperature equipped hydrometer.

**NOTE: THE SPECIFIC GRAVITY READINGS MUST NOT VARY MORE THAN 50 POINTS BETWEEN CELLS. A VARIATION OF MORE THAN 50 POINTS INDICATES CELL DETERIORATION, AND A NEED FOR BATTERY REPLACEMENT.**



*Voltmeter usage*

There are two basic types of voltmeters:

- Digital type which is best for low or fractional voltages.
- Analog type which is best for measuring rapid or large voltage changes.

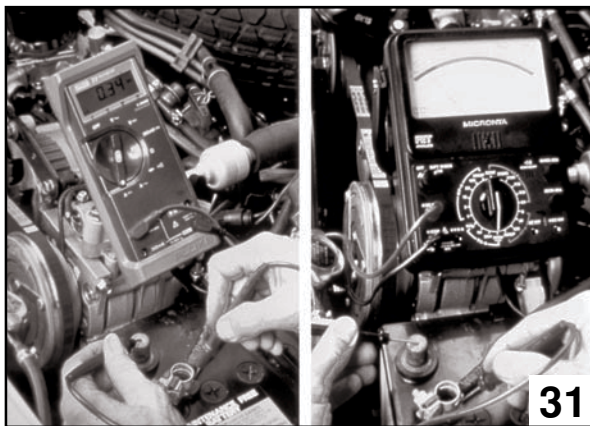
A high input resistance of usually 10 megohms (W) per volt input resistance prevents overloading of low current circuits by the voltmeter. An overloaded circuit will produce inaccurate voltmeter readings.

# Basic Electrical Theory & Diagnosis Module

**Always** connect a voltmeter in parallel, i.e., positive (+) lead to the positive (+) side of the circuit/component and the negative (-) lead to the negative (-) side of the circuit/component.

## Voltmeter Cautions

- Never connect in series
- Use the proper scale for the circuit voltage
- Always zero the meter
- Voltmeters are precision instruments, handle with care.



*Ammeter usage*

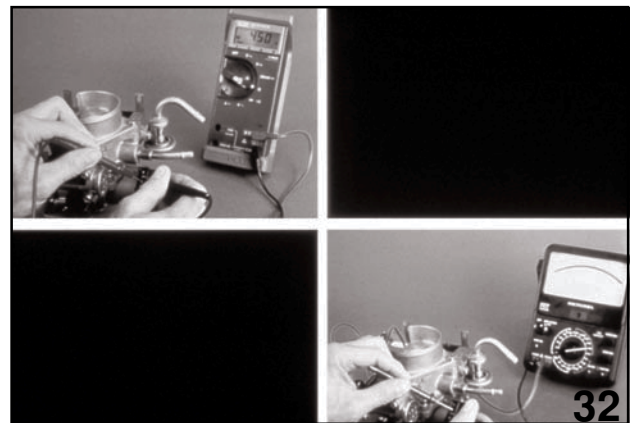
There are two types of ammeters:

- Digital type which is best for low or fractional current readings.
- Analog type which is best for varying current readings.

Always use an ammeter with a low input resistance. There is not a standard input resistance specification available, however higher quality meters offer this feature. Proper connection will protect your ammeter from damage. **Always** connect in series with a circuit. Connect the leads to either end of an opened/separated part of the circuit; the positive (+) lead connector toward the positive (+) side of the circuit/component and the negative (-) lead connector toward the negative (-) side of the circuit/component.

## Ammeter Cautions

- **Never connect in parallel with power source** (Will cause immediate meter damage)
- Use a meter with a high enough capacity for the potential current in the circuit being measured
- Use a higher scale first and work down
- Handle the meter carefully
- Always zero the meter



*Ohmmeter usage*

There are three types of ohmmeters:

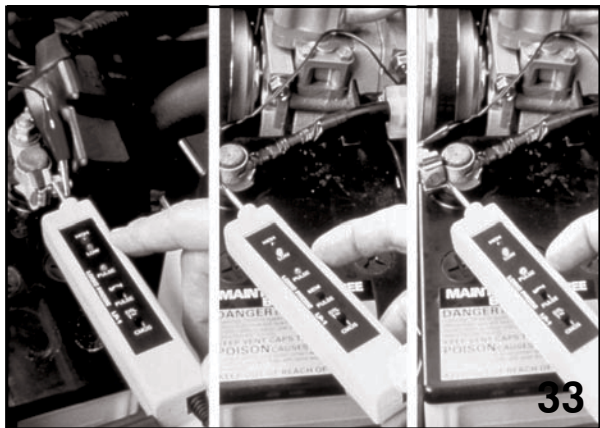
- Digital types are best for reading low and fractional resistance values. Some digital meters are also self-ranging.
- Analog types are difficult to read fractional resistance values. The analog type is not the preferred meter for measuring resistance.
- The field effect transistor type (F.E.T.).  
A very low voltage is provided at the tips which prevents damage to computer circuits. This feature can be found on either analog or digital type meters, and is used in conjunction with the diode testing scale for checking diodes.



# Basic Electrical Theory & Diagnosis Module

## Ohmmeter Cautions

- **Never connect to a powered circuit/component**
- Use proper scale
- Handle meter carefully
- Always zero the meter



*Digital logic probe (DLP)*

The digital logic probe can be used to quickly test the power supply or ground circuit. It is used in lieu of the test light which can damage computerized circuitry. It is best to have a DLP with a pulse/memory feature, which is used to check for pulsing signals or intermittent opens. Also, it is best to have an input overload protection to a minimum of 250 volts at the probe.

Connect the positive (+) lead to the B+ power source and the negative (-) lead to any viable ground. (A cigarette lighter adaptor can be used for working inside of the vehicle.) Touch the center probe to any power source or ground in the electrical system.

The DLP is used to determine high or low voltage in a circuit.

- Above 10 volts the "HIGH" LED illuminates.
- Below 4 volts the "LOW" LED illuminates.
- Between 4.1 and 9.9 volts, neither LED illuminates, but the "PULSE" LED flashes: "ON" and "OFF" once. This indicates the voltage availability in this range.

- The "PULSE" LED will flash "ON" and "OFF" to indicate any change in voltage, i.e., the crank angle sensor, cam angle sensor, speed sensor, ignitor, or any circuit where varying voltage is present.

The pulse memory is used to detect an intermittent open or short in the circuit. Connect the probe to the circuit. Then wiggle the connections, wires, etc., the "MEM" LED illuminates when an intermittent or poor connection is disturbed.

## DLP Cautions

- Do not use on high voltage sources, i.e., ignition secondary.
- Only use on automotive 12 volt power sources.

# Basic Electrical Theory & Diagnosis Module

## Battery Testing Procedures

The first step is to check the operation of the electrical components. Then complete the following checks:

1. Check the battery for damage
2. Check the positive and negative leads for corrosion and proper installation.
3. Check that the electrolyte is at the full level indicator(s). Check the color of the electrolyte.
  - Clear means there is no damage.
  - Red means there is positive plate deterioration.
  - Gray means there is negative plate deterioration.
4. Check the specific gravity, it must be a minimum of 1.230 to test the battery. There should be no more than a maximum of a 50 point differential between the cells.
5. On sealed maintenance free batteries, check the open circuit voltage and compare its value with the manufacturer's specifications.
6. If the specific gravity is below 1.230 or the open circuit voltage is below the recommended value, charge the battery and recheck the specific gravity/open circuit voltage.

### **Weak Battery Diagnosis**

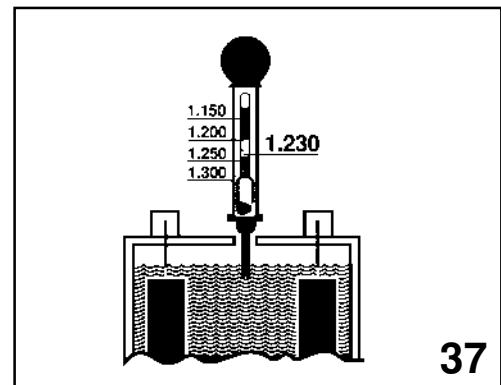
- Check for damage
- Check positive and negative leads for damage
- Check electrolyte level and specific gravity
- Check alternator belt tightness
- Check connection and wires of charging system for damage

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*Battery performance test*

A battery performance test is required when the engine cranks slowly or does not start. If the battery specific gravity is greater than 1.230, conduct a battery performance test. If the specific gravity is less than 1.230, charge the battery in accordance with the manufacturer's recommended procedures. Then proceed with a battery performance test.



**NOTE: WHEN CONDUCTING A BATTERY PERFORMANCE TEST ALWAYS FOLLOW THE EQUIPMENT MANUFACTURER'S RECOMMENDED PROCEDURES. APPLY A LOAD EQUAL TO 1/2 THE COLD CRANKING AMP RATING OF THE BATTERY FOR 15 SECONDS. OBSERVE THE BATTERY VOLTAGE WHILE THE LOAD IS BEING APPLIED AND COMPARE IT WITH THE MANUFACTURERS' SPECIFICATIONS.**

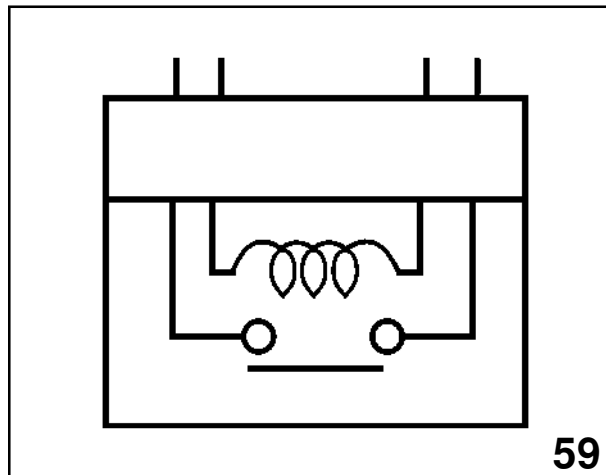
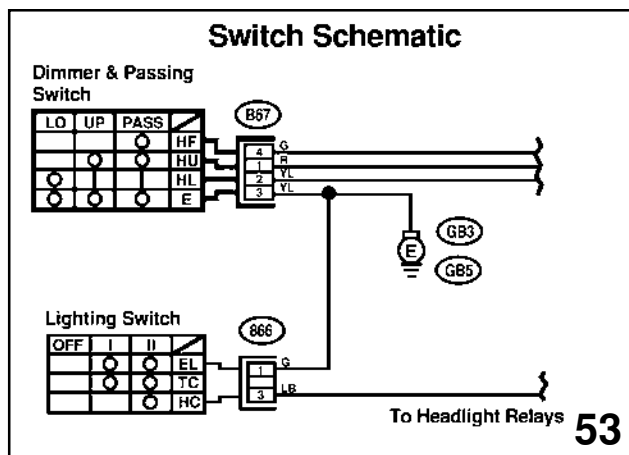
# Basic Electrical Theory & Diagnosis Module

## Switches, Relays and Motors

### System Components

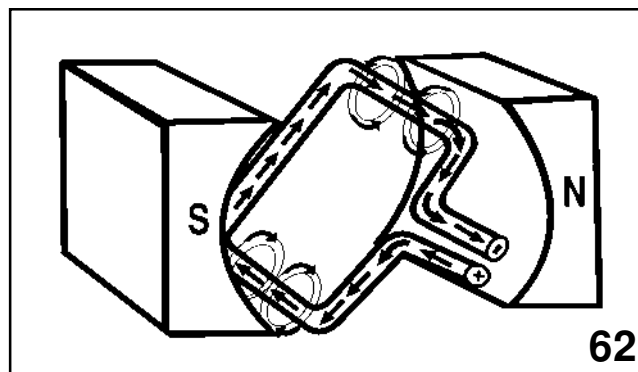
A switch is a device used to open, close, or redirect the flow of current in an electrical circuit. Switches are available in various shapes, sizes, and capabilities to meet circuit control requirements. A single-position switch, such as a stop light switch, controls the stop light by closing/opening the circuit to allow/stop the flow of current to the stop light.

A multiple-position switch, such as a lighting switch, controls the flow of current to several components. Finally, a switch may work in conjunction with other switches, such as the four courtesy light switches in a four-door vehicle.



*Relays*

A relay is an electromagnetic switching device that uses low current to open or close a high-current switching device. There are two basic types of relays used on Subaru vehicles: normally open (NO) and normally closed (NC). A third type of relay is used in special automotive applications. This relay transfers current flow from one circuit to another.

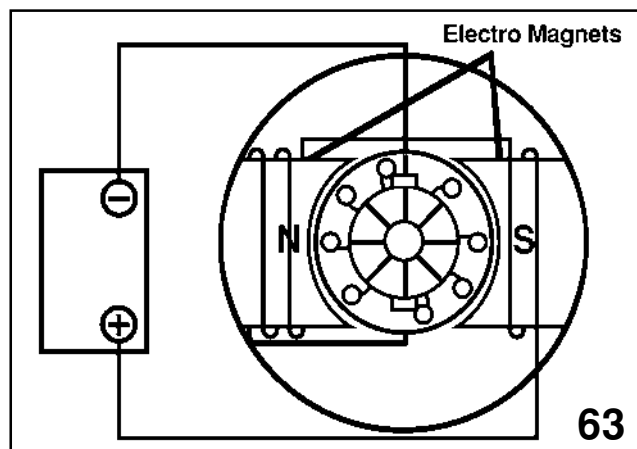


*Motors*

A motor is an electromagnetic device that converts electrical energy into mechanical energy. Motor operation is accomplished by placing a loop-shaped conductor in a magnetic field and then passing current through the conductor. The flow of the current through the conductor loop causes an unbalanced field condition, which causes the loop to rotate to a position where the field is once again in balance. Then the loop will stop rotating.



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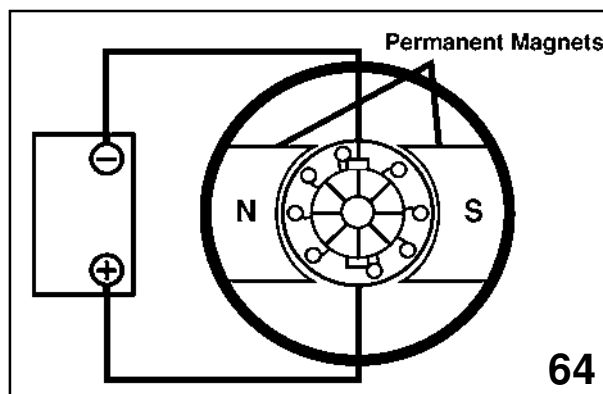


*Motor operation*

To obtain continuous rotation, a motor must contain numerous conductor loops, and the direction of the current must be reversed at the halfway point of rotation for each of the loops. This is accomplished through a split ring called a commutator. The rotating loops and commutator make up the armature of the motor.

Rotation of the motor creates a generating action called back voltage or counter electromotive force.

This force limits the current draw of the motor (armature) so that the motor only draws the amount of current to perform the job required. If the force required to perform the job exceeds the current capacity of the armature, the armature will stop rotating, the current will overheat the wires in the armature, and the motor will be damaged.

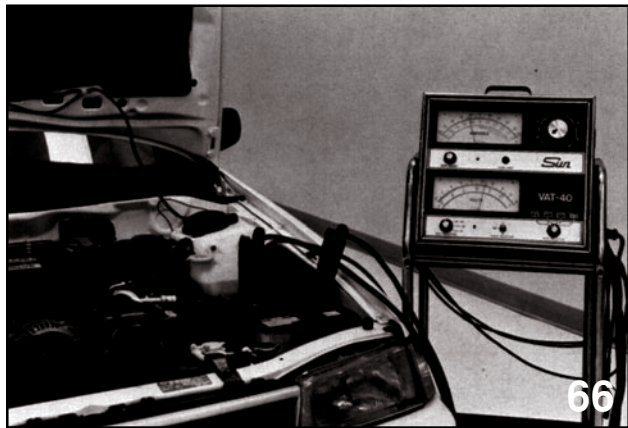


*Permanent magnet motor operation*

Permanent magnet motors do not use field coil construction. Because the field magnetism is constantly available from highly efficient permanent magnets, the current is sent directly to the brushes. The operating principle is similar to a field coil type motor. The advantage of this motor design is a significant reduction in the size and weight of the motor with no loss of operating capacity.

# Basic Electrical Theory & Diagnosis Module

## Starting and Charging Systems Tests



*Starting system test*

A performance test is required if any of the following conditions are present:

1. Difficult starting is experienced.
2. Cranking speed is slow.
3. Consecutive starting of the engine results in a slower cranking speed.
4. The starter does not engage.
5. All other components of the starting system have been eliminated as the possible fault.

Cautions and preliminary steps to conducting a performance test:

1. A performance test should only be made with a serviceable battery.
2. Turn off all lights and accessories and close all doors.
3. Adjust test equipment according to the operator's instructions.
4. Prevent the engine from starting during the cranking test.
  - Ground the negative coil primary wire or the tach terminal on gasoline engines with an externally mounted ignition coil, or disconnect the distributor primary connector. On distributorless ignition vehicles, disconnect the crank angle sensor.

- On gasoline engines with an integral mounted ignition coil, disconnect the ignition switch lead from the ignition system assembly. Do not allow the lead to touch a ground.
5. Conduct the performance test according to the directions contained in the operator's instructions.

**NOTE: REFER TO SEC. 6-1 OF APPROPRIATE MY SUBARU SERVICE MANUAL FOR SPECIFICATIONS.**

6. Restore the engine and component connections to the normal starting condition.



*Alternator performance tests*

An alternator performance test is required if any of the following conditions are present:

1. The battery is dead (discharged), but holds a charge when charged. Also, the battery performance test indicates a good battery.
2. The vehicle voltmeter indicates a discharging condition or the charge warning light is illuminated during normal vehicle operation.
3. The system is overcharging.
4. All other components of the charging system have been eliminated as the fault.

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Conduct the alternator performance test in accordance with the operator's instructions for the test equipment you are using. Conduct an alternator charging test, a voltage regulator test, and a diode stator test. Compare the results of the tests to the specifications listed in the appropriate MY Subaru Service Manual and repair and or replace components as required. Then retest the system.



*Charging system requirements test*

Conduct a charging system requirements test in accordance with the operator's instructions for the test equipment you are using. Be sure to connect the D-Check connectors so that the fuel pump and other fuel system components operate.

Note the total accessory load reading and compare the reading to the total alternator output reading obtained in the alternator performance test. The total alternator output reading should exceed the total accessory load reading by at least 5 amps.

If the readings are below specifications, conduct a voltage drop test between the alternator and the battery, (between the alternator B+ terminal and the battery positive terminal).

# Basic Electrical Theory & Diagnosis Module

## Troubleshooting

### *Slides 71 through 78*

#### **The Six Step Troubleshooting Method**

1. Verify the problem.
2. Determine related symptoms.
3. Isolate the problem.
4. Identify the cause.
5. Repair and/or replace.
6. Verify operation.

This method of troubleshooting will save time and effort in the diagnosis and analysis of electrical problems. It provides a logical approach to solving the problem—not just treating the symptoms. The steps are defined as follows:

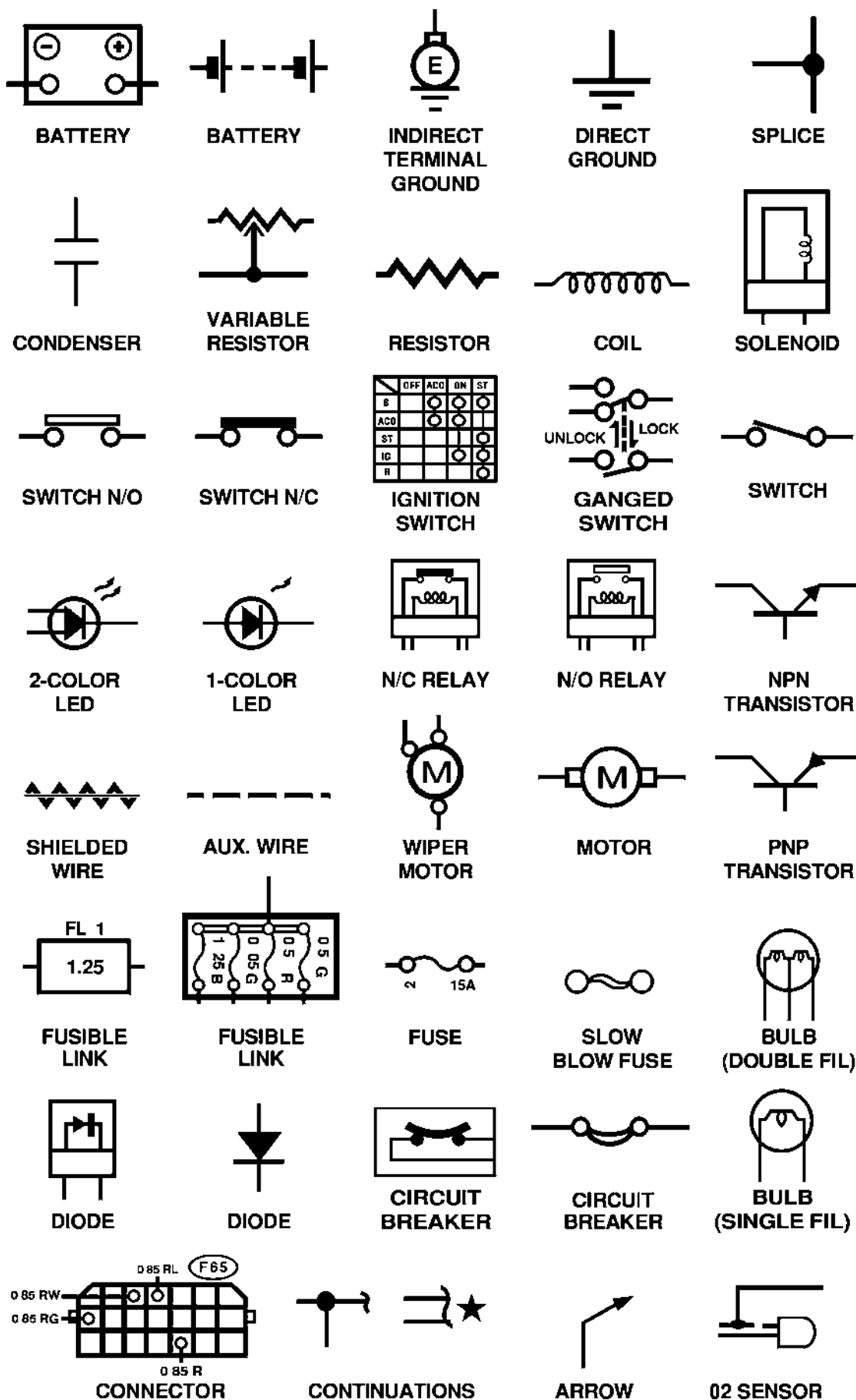
1. Verify the problem (operational check). Identify the symptoms of the problem. Are components inoperable or malfunctioning? When, how often, and where does the problem occur?
2. Determine related symptoms (operational check). Identify other symptoms that exist. Are other circuits and components affected? Do the related symptoms always occur with the primary symptom?
3. Isolate the problem. Use the split half technique\*, the wiring diagram, and the wiring harness diagram to locate a short in a grounded circuit.

\*The split-half technique is used as follows:

- Obtain the proper wiring diagrams.
- Divide the circuit in half at an accessible connector.
- Check half of the circuit.
- Repeat the process if the first half of the circuit is good, check the second half of the circuit, etc.,
- The problem always exists between a positive and a negative result.

4. Identify the cause of the problem. Is the circuit grounded, shorted, feeding through another circuit, or is a component defective?
5. Repair and/or replace defective wiring and components as required.
6. Verify operation. Check the circuit to verify that the problem has been solved. Ensure that all circuit components operate properly under standard operating conditions according to technical specifications. Also check related circuits for proper operation.

# Basic Electrical Theory & Diagnosis Module



# Basic Electrical Theory & Diagnosis Module

## Electrical Terms Glossary

### Resistance

*Property of an electrical circuit that tends to prevent or reduce the flow of current.*

### Dynamic resistance

*Effect of a resistor or resistance in a circuit.*

### Voltage Drop

*The difference in voltage between one point in a circuit and another, or the difference in measured voltage from one side of a component to the other side.*

### Resistor

*Device that permits a predetermined current to flow at a given voltage. Examples are a SPFI ballast resistor and a 4EAT dropping resistor.*

### Rheostat

*See variable resistor.*

### Variable Resistor/Rheostat

*A device that adjusts the amount of resistance required. An example is a sliding contact resistor. The position of the contact determines the amount of resistance. The fuel sending units of a vehicle equipped with an analog dash use a variable resistor.*

### Potentiometer

*A resistive element with a sliding wiper contact that is used in applications in which a division of resistance is required (such as a three-terminal adjustable resistive divider). Example: The throttle sensor on SPFI and MPFI fuel systems.*

### Splice

*Joining of two or more conductors at a single point.*

### Terminal

*Device attached to the end of a wire or cable to make an electrical connection.*

### Ground/Chassis ground

*Negative side of a complete circuit. In automotive applications the negative side of the battery or any wire connected to the engine, frame, or body sheet metal.*

### Relay

*Electromagnetic switching device using low current to open or close a high-current device.*

### Solenoid

*An electromagnetic device consisting of a tubular coil of wire containing a core that moves when the coil is energized. Movement of the core can open/close a circuit. A solenoid converts electrical energy to mechanical energy.*

### Filament

*A fine high resistance wire or thread which glows and produces light when current is forced through it.*

### Diode

*Solid-state device that permits current to flow in one direction only; performs like a one-way check valve.*

### Transistor

*Solid-state semiconductor that is a combination current amplifier and switch (similar to a solenoid in the starter circuit or a relay in function). It uses low control current to channel high current.*

### Capacitor (Condenser)

*Device used to store an electrical charge.*

Notes:

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