



ASE 6 - Electrical Electronic Systems

Module 11
Operation of Solid State Devices

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Lesson 1- Semiconductors

Objectives

- Identify the structure of semiconductor materials.
- Identify the processes of creating semiconductor materials.
- Differentiate between “N” and “P” material.
- Identify the barrier voltage of silicon semiconductors.

NATEF Area VI-A-15 :

- Inspect and test switches, connectors, relays, solid state devices, and wires of electrical/electronic circuits; perform necessary action.

NATEF Area VI-F-3 :

- Inspect and test switches, connectors, relays, solid state devices, and wires of electrical/electronic circuits; perform necessary action.

STC Tasks:

Identify the characteristics of semiconductors.

Semiconductors

Earlier we learned that some elements, such as copper, are good conductors, while other elements are poor conductors, but good insulators. There are still other elements, however, that are neither good conductors nor good insulators. If an element falls into this group, but can be changed into a useful conductor, it is called a semiconductor. Some of the more common semi conductors available are: selenium, copper oxide, gallium arsenide, silicon and germanium. Silicon and germanium are used for semi-conductors; however, silicon is the most commonly used in automotive applications.

All semiconductors are solid-state devices. A solid-state device is one that can control current without moving parts, heated filaments, or vacuum bulbs.

Examples of semiconductors include diodes, transistors, and integrated circuits (ICs).

Advantages

Since semiconductors have no moving parts they do not wear like mechanical control devices and can switch on/off at rates up to thousands of times per second.

How and Why Semiconductors Work

A semiconductor is described as being neither a good conductor nor a good insulator. This is due to the atomic structure or more importantly, the valence or outer shell electrons. Figure 11-1 shows the atomic structure of the two semiconductors used in solid-state devices: silicon and germanium. Note that both have 4 valence electrons. Compare this to the best conductors, which have one valence electron, or to the best insulators, which have a full valence shell of eight electrons.

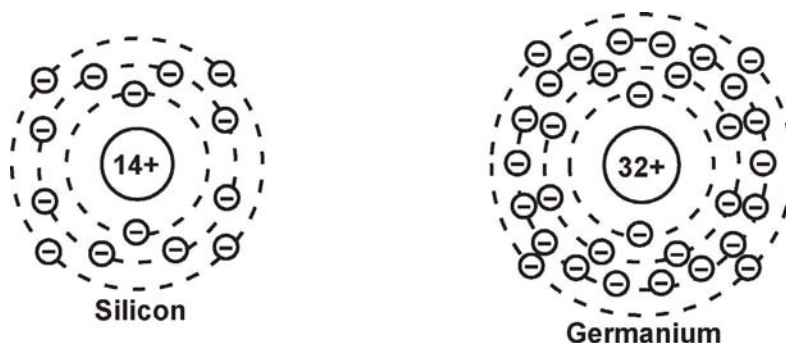


Figure 11-1

Silicon and germanium, in their pure form, are actually worse conductors than is indicated by their four valence electrons. This is due to their crystalline structure. A simplified diagram of the germanium crystal structure is shown in figure 11-2. Note that only the valence electrons are shown.

In the crystal structure, each of the four valence electrons of any one atom is shared with four neighboring atoms. Thus, each atom appears to have eight electrons in its valence shell. This fills each atom's valence shell and it becomes very difficult to free an electron for current flow.

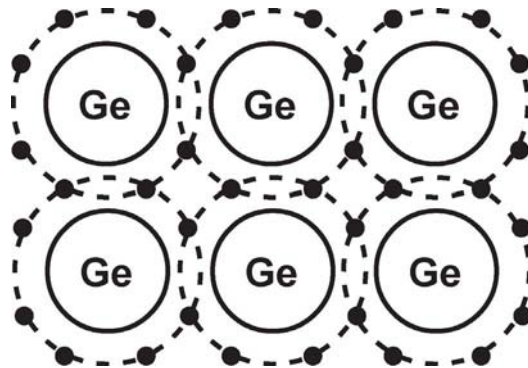


Figure 11-2

In this natural state, these elements aren't useful for conducting electricity.

However, semiconductors can be made into good conductors through doping. Doping is the addition of impurities. The impurities affect how many free electrons the semiconductor has. Depending on which impurity is added, the resulting material will have either an excess of free electrons or a shortage of free electrons.

If the added material creates an excess of free electrons, the semiconductor is negative or N-type. If it creates a shortage of free electrons, the semiconductor is positive or P-type.

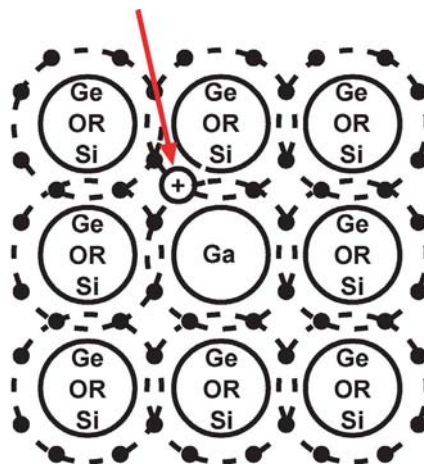


Figure 11-3A

An example of an impurity atom is arsenic, which has 5 valence electrons. When it is added to a semiconductor crystal, only 4 of its 5 valence electrons can be fitted into the crystal structure. The additional fifth electron becomes free to act as a current carrier. This is shown in the Figure 11-3B. A crystal doped in this way is known as N-Type semiconductor material, since it contains additional electrons.

Another impurity atom used to dope semiconductors is gallium. However, it has only three electrons. Therefore, when it is added to semiconductor crystal a deficiency of electrons occurs. As shown in Figure 11-3A there now exists an area or hole in the crystal structure that lacks an electron. These holes behave as positively charged particles, which are free to drift throughout the crystal. Due to the presence of the holes, the doped material is known as a P-Type semiconductor.

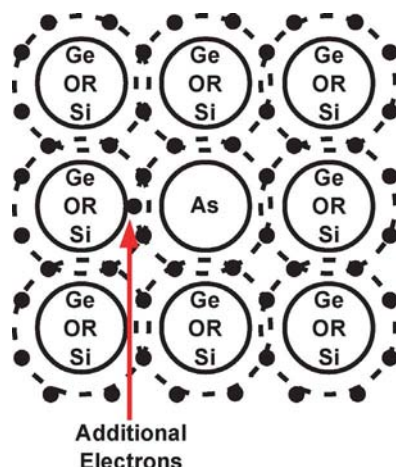


Figure 11-3B

While a hole is not actually positive, it is an area that a randomly drifting electron can “fall” into, thus completing the crystal structure. However, once an electron “falls” into a hole, another hole is created in the region from which the electron came. The movement of a hole in this way is equivalent to the movement of a positive charge equal to the charge carried by one electron.

Semiconductors are made from a sandwich of at least one slice of N-type material and at least one slice of P-type material. These slices are mounted inside a plastic or metal housing. The area where the N-type material and P-type material meet is called the PN junction.

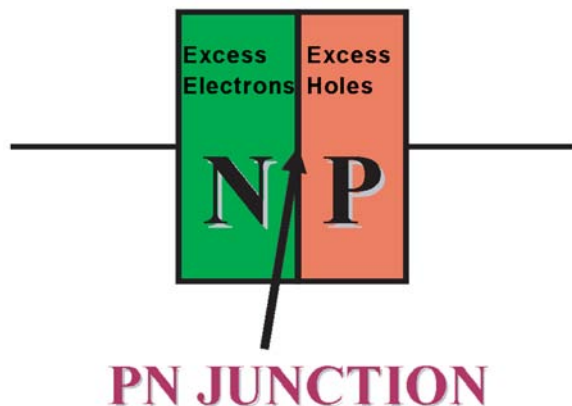


Figure 11-4,

When N and P type semiconductor materials are grown together to form a single crystal, a solid-state diode results. This is shown in Figure 11-5. As soon as the junction is formed, there will be a movement of electrons across it. Electrons near the junction will move from the N-type material into the P-type and fill the holes. As a result of this, the N-type material near the junction is depleted of electrons, while the P-type material near the junction is depleted of holes. Therefore, this area is called the depletion region.

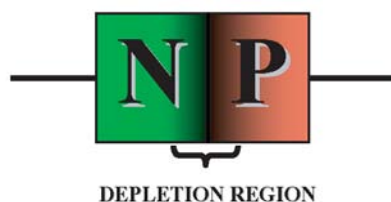


Figure 11-5

Barrier voltage

Due to the nature of this action, this junction requires a certain bias voltage to overcome the natural depletion area before current will flow through the semi-conductor. The typical barrier voltage used to bias a silicon junction requires about .5 to .7 volts.

Current Flow through Semi-Conductors

When we describe the flow of electricity through a semiconductor, we describe it a little differently than with other electrical devices. Usually, we define the movement of electricity as the movement of free electrons bumping each other from the negative terminal of the voltage source through the conductor and towards the positive terminal. When discussing semiconductors, we describe not only the flow of electrons, but also the flow of the “holes”, spaces in an electron shell to which an electron will be attracted.

The flow of electrons is relatively easy to visualize. You can think of a flow of marbles through a channel, for instance. The flow of holes is slightly harder to visualize.

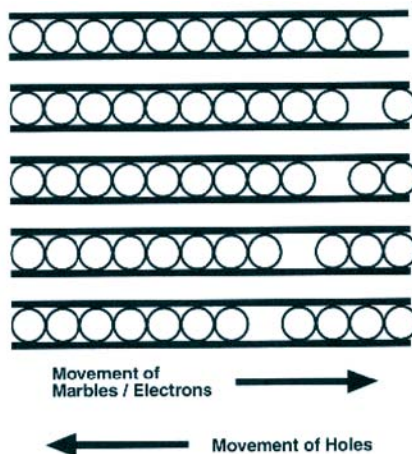


Figure 11-6

Think of the same channel, filled with marbles, as in the illustration above. On marble moves ahead, leaving a hole in its place. The next marble moves into the position vacated by the first marble; at the same time, the hole can be said to be moving from the position of that the first marble had held to the position that the second marble had held. As marbles move in one direction in the channel, holes can be said to be moving in the opposite direction.

Keep in mind that the junctions of these semi-conductors are very sensitive to excessive voltages and currents. The physical size of a semi-conductor directly affects its wattage handling capability. Currents higher than the junction is designed for will destroy the junction. A semi-conductor can also be destroyed by static electricity. A static discharge against the junction will burn a microscopic hole in it just like lightning burns holes in objects in which it passes through.

Lesson 2

Objectives:

- Identify ESD sensitive components by symbols in the service information.
- Identify ways that static discharge develops.
- Identify proper handling procedures of ESD sensitive components.

NATEF Area

- Inspect and test switches, connectors, relays, solid state devices, and wires of electrical/electronic circuits; perform necessary action.

STC Tasks:

Competencies for Electrical Stage 3 18043.03 W

A. Electrical Components

4. Identify the characteristics of electrostatic discharge
5. Select process for testing automotive solid state devices

Electrostatic Discharge (ESD)

Everyone knows what static electricity looks like. We usually notice it when it is being discharged. That annoying “zap” when you touch a door knob on a cool, dry day – or the lightning during a thunderstorm – are familiar examples (see Figure 11-7)

Electronic components can be very easily damaged by electrostatic discharge.

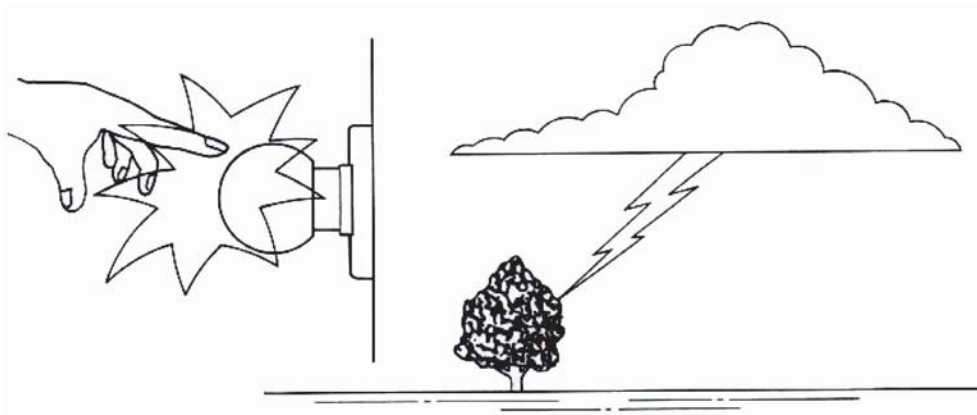


Figure 11-7

How ESD Develops

Static charges build up very easily on non-conductive, or insulator materials. These include things like glass, rubber, plastic, and fabrics, particularly synthetics (nylon and polyester). Dry skin and hair on your body also hold large static charges. The charges on the surfaces of all these materials tend to concentrate in a certain area because the material itself (being an insulator) prevents the charge from moving freely on it.

Body movement produces an electrostatic charge and can occur when you:

- Slide across the car seat
- Sit down or get up
- Walk

ESD Voltage

ESD voltages are high, so why are you not severely injured or killed by the discharge? There are several reasons. First, static electricity usually has much lower amperage than is found in many AC and DC circuits.

Although a 25,000-volt discharge sounds incredibly high, remember that voltage is simply the push behind the electrons. The static voltage itself is not what causes bodily injury. It is the current (or amperage), meaning the number of flowing electrons that causes bodily injury. And the current associated with static discharges is low.

Another reason is that our bodies provide resistance to the flow of current. That resistance is sometimes very high – usually more than 100,000 ohms when our skin is dry. (Perspiration lowers our body's resistance, as does a break in the skin).

The final factor that keeps static discharges from causing bodily injury is time. The typical static discharge lasts for only a fraction of a second; that is not long enough to cause injury. The combination of these factors – low current, some body resistance, and short time – keeps static discharges from being little more than an annoyance to use (See Figure 11-8)

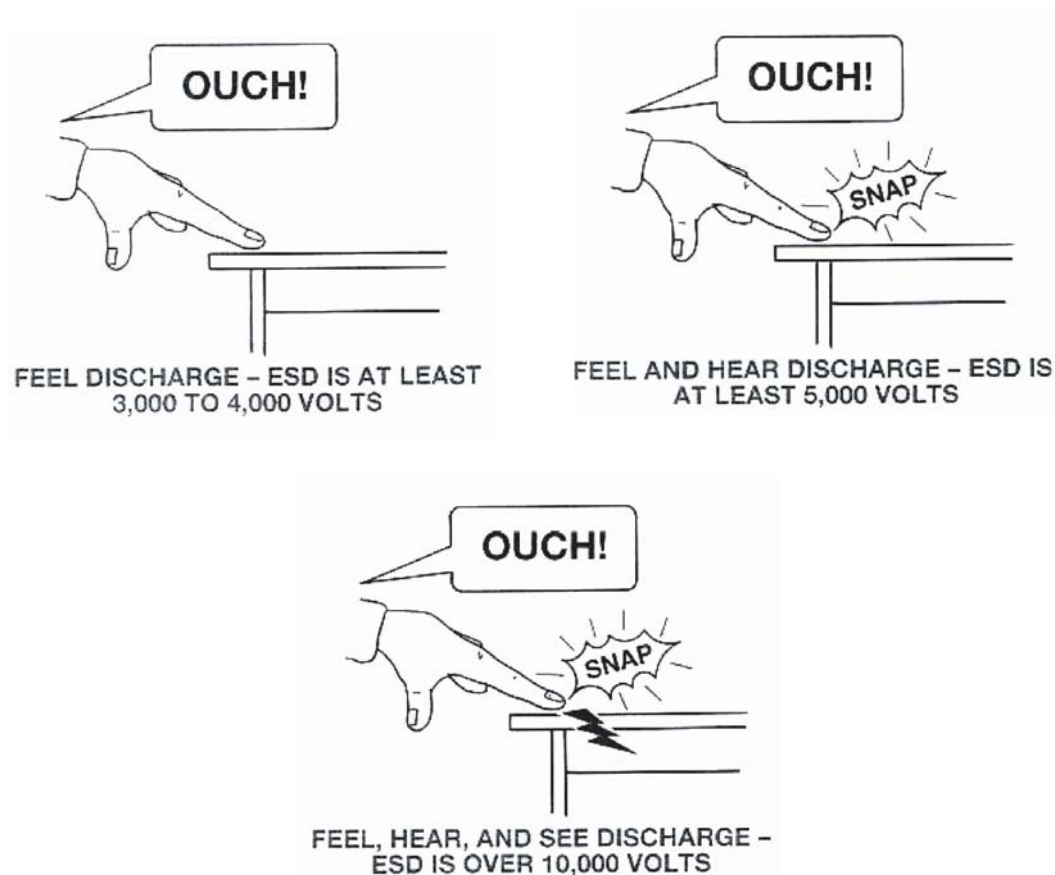


Figure 11-8

Types of ESD Damage

Though most discrete electronic components can be damaged by ESD, the most vulnerable components are highly compressed integrated circuit (IC) chips. IC's have a lot of circuitry packed into a very small amount of space. Therefore, the materials used to make an IC are very thin, and little insulation is used between its circuits. They are designed to operate on micro-amps (millionths of an amp) of current and very low voltage signals. In addition, they respond to signals that last just billionths of a second. So, even a small discharge through one of these chips can cause catastrophic damage.

Some of the components that can be damaged by electrostatic discharge are:

- PCM's
- Radio
- IPC's
- Modules
- Automatic day/night mirror
- Controllers
- Transceivers
- Amplifiers

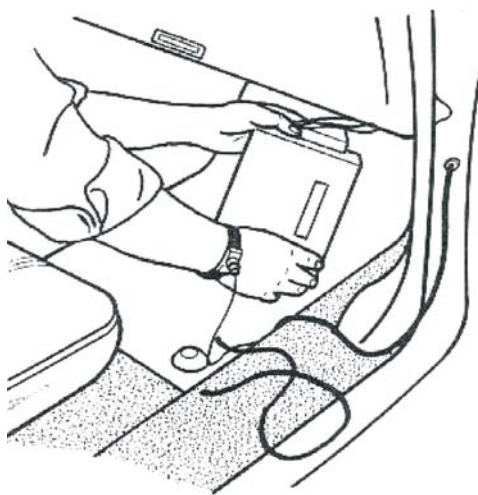


Figure 11-9

Preventing ESD Damage

Your main task is to prevent static charges from passing through electronic circuitry. To be safe, you must remove the charge from anything that might come in contact with an electronic component. This includes your own body, plastics, and the component itself. This is especially important when you are installing new electronic parts. The part itself may have gained a charge simply in packing or handling; contact between that part and a conductor will cause ESD. If a discharge occurs through the part's circuitry, it may be damaged.

What do you do to install a static-sensitive part without exposing it to the risk of ESD damage?

The safest solution is to wear a grounded wrist strap and stand on a grounded mat. You can also use a dissipative mat on which to carry and place parts. The dissipative mat works like conductive foam, except it reduces static by moving electrons at a slower controlled rate. (See Figure 11-9)

However, most shop situations are not conducive to applying the above method so the list below should be used to help you determine the easiest method for you to employ.

ESD Prevention Rules

1. Always touch a known good ground on the car before handling the part. Because static can be built up by scuffing or simple movement, this self-grounding should be repeated while handling the part and more frequently when sliding across the seat, sitting down from a standing position, or walking.
2. Do not touch exposed electric terminals, components, or connectors with your finger or any tools. Remember, the connector you are checking might be tied into a circuit that could be damaged by electrostatic discharge.
3. When using a screwdriver or similar tool to disconnect a connector, never let the tool come in contact with or come between the exposed terminals.
4. Never jumper, ground, or use test equipment probes on any components or connectors unless specified in the diagnosis. When using test equipment, always connect the ground lead first.
5. Do not open solid-state component's package until you are ready to install the part.
6. Always touch the solid-state component's package to a ground before opening. Solid state components can also be damaged if:
 - a. They are burned or dropped
 - b. They are laid on metal workbenches or on components that operate electrically, such as a radio, TV or oscilloscope.

You should be aware that some service manuals use the word "solid state" instead of the ESD symbol. Look for these indicators and take the suggested ESD precautions when you work on sensitive components.



Handling Sensitive 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 the vehicle seat.
- Do not touch exposed terminals. Terminals may connect to circuits susceptible to ESD damage.
- Do not allow tools to contact exposed terminals when servicing connectors.
- Do not remove components from their protective packing until required to do so.
- Avoid the following actions unless required by the diagnostic procedure:
 - Jumpering or grounding of 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.

Figure 11-10

It's up to you to protect ESD components. Don't depend on the service manual to point out every component that is vulnerable to ESD. Make resistance measurements only when instructed to do so by the service manual, and follow the service manual handling guidelines.

Electromagnetic Interference (EMI)

Magnetic fields are generated by, high-current components and their related conductors. Typically, the ignition and charging systems generate the highest levels. If these fields cause induced voltages in low voltage electronic circuits, a module or computer may behave erratically. This condition is called “**Electro-Magnetic Interference**”. If EMI is not suppressed, it could adversely affect the Powertrain control, Body control or Audio systems. As the Engine loads or RPM change, the magnetic fields increase in size, strength and frequency. The point at which an electronic system becomes affected varies due to its sensitivity and operating frequencies. However, the ignition, charging systems and harnesses are designed to suppress EMI from the factory.

Note: It is very important that the technician pay particular attention to OEM harness routing. Incorrect routing of harness can cause EMI related behaviors of electronic systems. A typical driveability symptom would show as occasional surging or lurching with possible flickering malfunction indicator lamps and no stored codes. This symptom could wrongly be interpreted as a transmission problem. A typical audio system fault may be noise in the speakers. Proper diagnosis, using service information procedure, is essential.

Exercise

Review questions for lesson 1 and 2

Read and answer each question carefully.

1. Doping is the process of adding impurities to pure semiconductors.
 - a. True
 - b. False

2. A semiconductor that gains free electrons through doping is _____. A semiconductor that loses free electrons through doping is _____.
 - a. N-type, P-type
 - b. P-type, N-type
 - c. Defective, operative
 - d. Phase-locked, phase-inversed

3. P-type semiconductors have an excess of _____.
 - a. Electrons
 - b. Junctions
 - c. Holes
 - d. Dielectrics

4. Doped silicon has a barrier voltage of about _____ volts.
 - a. 12
 - b. 6
 - c. 0.7
 - d. 0.1

5. All semiconductors are solid-state.
 - a. True
 - b. False

6. Which of the following statements about working with ESD-sensitive components is true?
- a. If convenient, touch a known good ground before you handle the part
 - b. Touching the component's terminals will protect the terminal against ESD
 - c. You only need to worry about the components that have an ESD symbol next to them on the schematics
 - d. ESD sensitive components should be left in their bags until you are ready to install them
7. The technician through which of the following activities can generate static electricity?
- a. Using air powered tools.
 - b. Sliding across a car seat.
 - c. Removing plastic wrap from a part.
 - d. Both B and C.
 - e. None of the above.

Lesson 3 - Diodes

Objectives:

- Identify the construction of a diode.
- Identify the conditions that forward or reverse bias a diode.
- Identify the correct symbols for regular diodes, zener diodes and LED's.
- Identify the uses and applications of diodes.
- Bench test diodes and determine their condition.
- Construct a circuit using a diode.
- Demonstrate an understanding of the operating characteristics of diodes.
- Construct a circuit properly installing a clamping diode into the circuit.
- Analyze a coils fly-back or spike voltage with and without a clamping diode.
- Test a clamping diode attached to a circuit using a DMM min/max function.
- Identify the correct installation of a diode in a circuit for de-spiking or clamping.
- Identify correct and incorrect methods of testing clamping diodes.

NATEF Area VI-A

- Inspect and test switches, connectors, relays, solid state devices, and wires of electrical/electronic circuits; perform necessary action.
- Diagnose the cause of incorrect operation of warning devices and other driver information systems; determine necessary action.

STC Tasks:

Competencies for Electrical Stage 3 18043.03 W

A. Electrical Components

1. Identify the characteristics of diodes
5. Select processes for testing automotive solid state devices

Diodes

The simplest kind of semiconductor is a diode. It's made of one layer of P-type material and one of N-type material. Diodes allow current flow in only one direction. On a schematic, the triangle in the diode symbol points in the direction current is permitted to flow using conventional current flow theory.

Diodes are used for many purposes in automotive circuits, including but not limited to illumination, rectification and voltage spike protection.

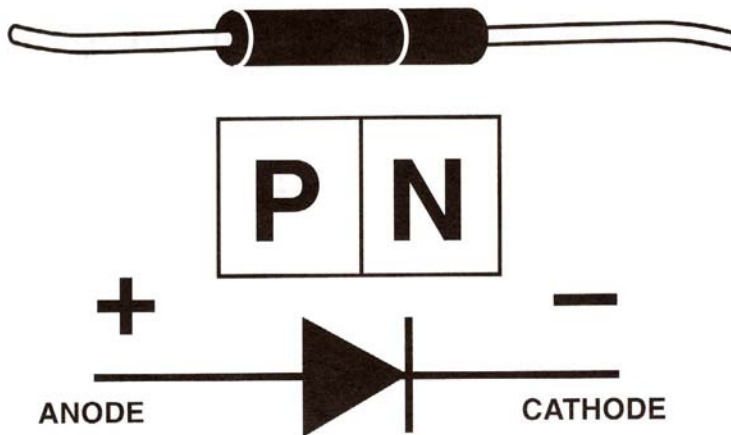


Figure 11-10

Anode | Cathode

Current flows from left to right in this illustration. We can indicate this by a positive/plus sign to the left and a negative minus sign to the right of the diode. The positive side of the diode is the anode and the negative side is the cathode.

There's an easy way to remember the names "anode" and "cathode." Associate "anode" with A+ (it's the positive side) and "cathode" with C- (the negative side). In Figure 11-10 the cathode is the end with the stripe.

Diode Bias

The term “bias” is used to refer to a diode’s ability to allow or prevent the flow of current in a circuit. A forward biased diode is connected to a circuit in such a way as to allow the flow of electricity. This is done by connecting the “N” side of the diode, (the cathode) to the negative voltage, and the “P” side (the anode) to the positive voltage. When the diode is connected in this way, both electrons and holes are being forced into the depletion zone, connecting the circuit.

When a **forward biased** diode is connected to a voltage source in this way, it acts as a switch closing a circuit. You can think of the voltage as forcing both electrons and holes into the depletion region, which allows current to flow.

A diode that is connected to voltage so that current cannot flow is **reverse biased**. This means that the negative terminal is connected to the P side of the diode, and the positive terminal is connected to the N side.

When voltage is applied to this circuit, the electrons from the negative voltage terminal combine with the electron holes in the P-type material. The electrons in the N-type material are attracted towards the positive voltage terminal. This enlarges the depletion area. Since the holes and electrons in the depletion area don’t combine, current can’t flow.

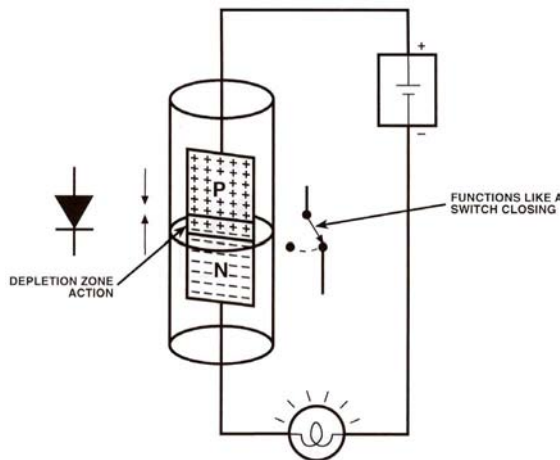


Figure 11-11A

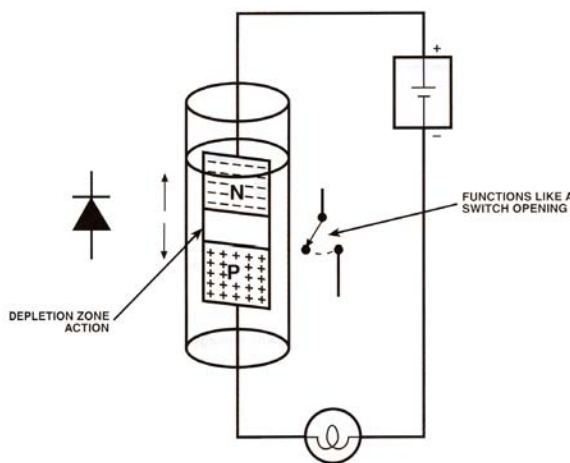


Figure 11-11B

When a diode is reverse biased, the depletion region acts like an open switch, blocking current. With the negative terminal connected to the P material, holes are attracted away from the depletion region. With the positive terminal connected to the N material, electrons are likewise attracted away from the depletion region. The result is an enlarged zone that contains neither holes nor electrons that cannot support current flow.

Diode Characteristics and Ratings

Figure 11-12 shows the “characteristic curve” for a solid-state diode. The curve shows diode current under forward and reverse bias conditions. In the forward bias condition, it shows that the forward voltage drop (V_f) is a relatively constant 600 millivolts regardless of the forward current (I_f)

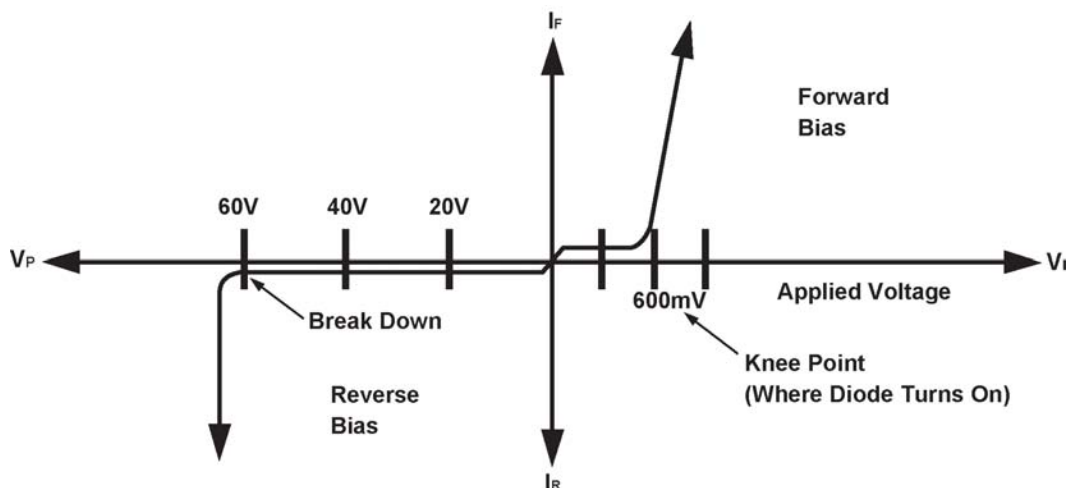


Figure 11-12

Current flow and Saturation Point

As the voltage reaches the barrier voltage (knee point) the diode is handling all the current that it is rated for. The area of the PN junction which carries current will increase in size as the current increase until the diode reaches “saturation.” At this point the diode is handling all the current that is rated for. Therefore the current subjected to a diode must not exceed the rating.

Since most diodes are rated in watts, their current handling capacity can be calculated using the barrier or forward bias voltage drop and the power formula.

The curve of Figure 11-12 also shows reverse bias characteristics. Note the small amount of reverse current (I_R). Since this current is normally a few microamperes, it can usually be ignored. However, when the reverse voltage (V_R) reaches 60 V, the reverse current drastically increases. This is due to a **breakdown** of the depletion region. The electrons are “ripped” from the valence shell and a high current results. Normally, this will damage the diode; however, some diodes are specially designed to operate in breakdown. They are called zener diodes, and will be discussed later.

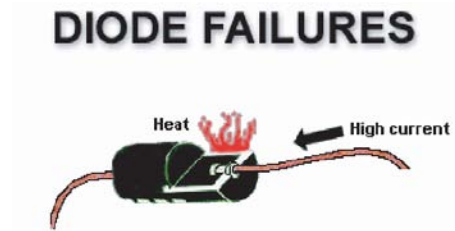


Figure 11-13

When a reverse bias voltage is connected to a diode, it may be true that a small current will flow through the diode in the reverse direction, but the reverse current is very, very small in magnitude. If the voltage across the diode is increased, a value eventually will be reached called the *maximum reverse voltage*, **avalanche**, or **peak inverse voltage** of the diode. At this voltage value, the covalent bond structure will break down and a sharp rise in reverse current will occur. If the reverse current is sufficient in magnitude and duration, the diode will be damaged from excessive heat. Diodes are selected, of course, with an adequate maximum-reverse-voltage rating so that damaging reverse currents will not normally occur during operation. The PIV or “Peak Inverse Voltage” rating denotes the maximum amount of voltage a diode can handle without breaking down.

Testing Diodes

When a diode is functioning properly in a circuit, it acts as a .5V to .7V voltage drop in one direction, and as an open in the other. Here are four possible ways in which you can test diodes depending on the application:

1. Bench test. Take the diode out of the circuit and test it with a DMM on the diode test position as the illustration shows (sometimes this is not possible).
2. If the diode is in a series circuit, it can be tested with the circuit power off, using the same procedure as above, making sure to isolate at least one end of the circuit as you would when using an ohmmeter.
3. If the diode is in a series circuit, and the circuit forward biases the diode, it can be tested with the power on. This will yield a result of +.5 - 0.7 volts, and only checks the diode in one direction so you must then figure out how to reverse bias the diode.
4. If the diode is fixed in parallel to an inductor coil, it may be tested with a test lamp, a low impedance analog meter or with fluke min/max/ms capture feature.



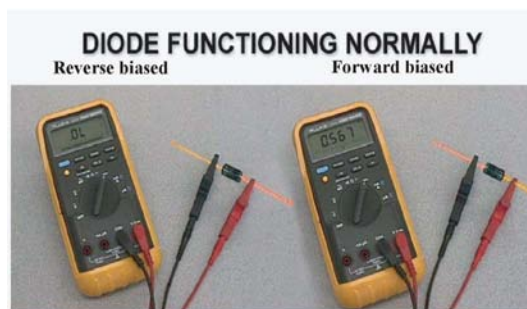
Bench Test

A quick and easy diode bench test can be made with a DMM on diodes, which are removed or isolated from the circuits.

On most digital multimeters there is a Diode Test setting. This setting gives much more information than the old way of testing diodes (using a swing need analog meter).

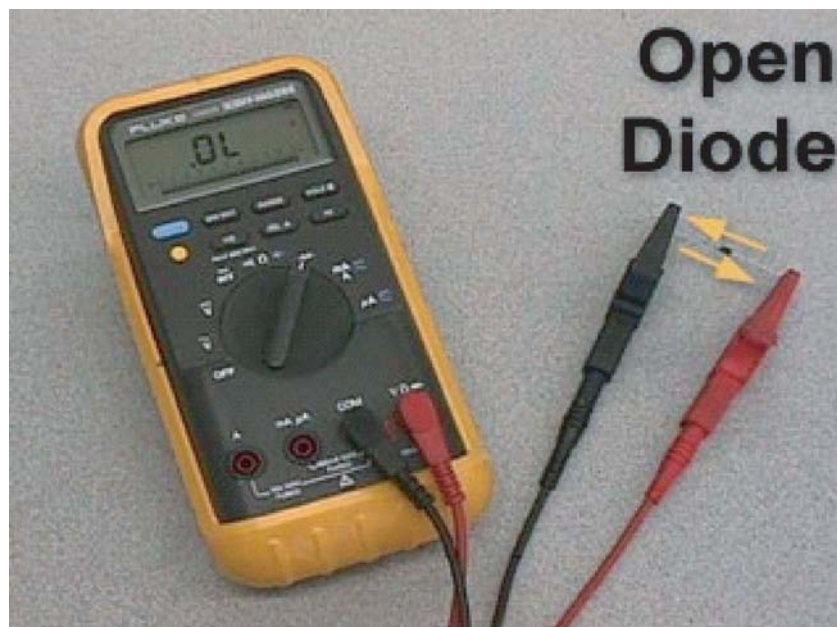
The reading that a digital multimeter gives when the red lead is hooked to the P side of the diode and the black lead is hooked to the N side is the amount of voltage required to push the P and the N materials together enough for the diode to conduct.

A second test should be done on diodes to be sure they are turned OFF when the polarity is reversed. Simply reverse the meter leads on the diode. With the red lead on the N side of the diode and the black lead on the P side, the meter should indicate an open circuit.





A **shorted diode** will pass current both directions resulting in both readings showing a voltage. You will not get an OL reading one direction.



An **open diode** will not pass current either direction resulting in both readings showing OL on the meter.

Forward Bias Characteristics of Diodes

(review of current and volt drop)

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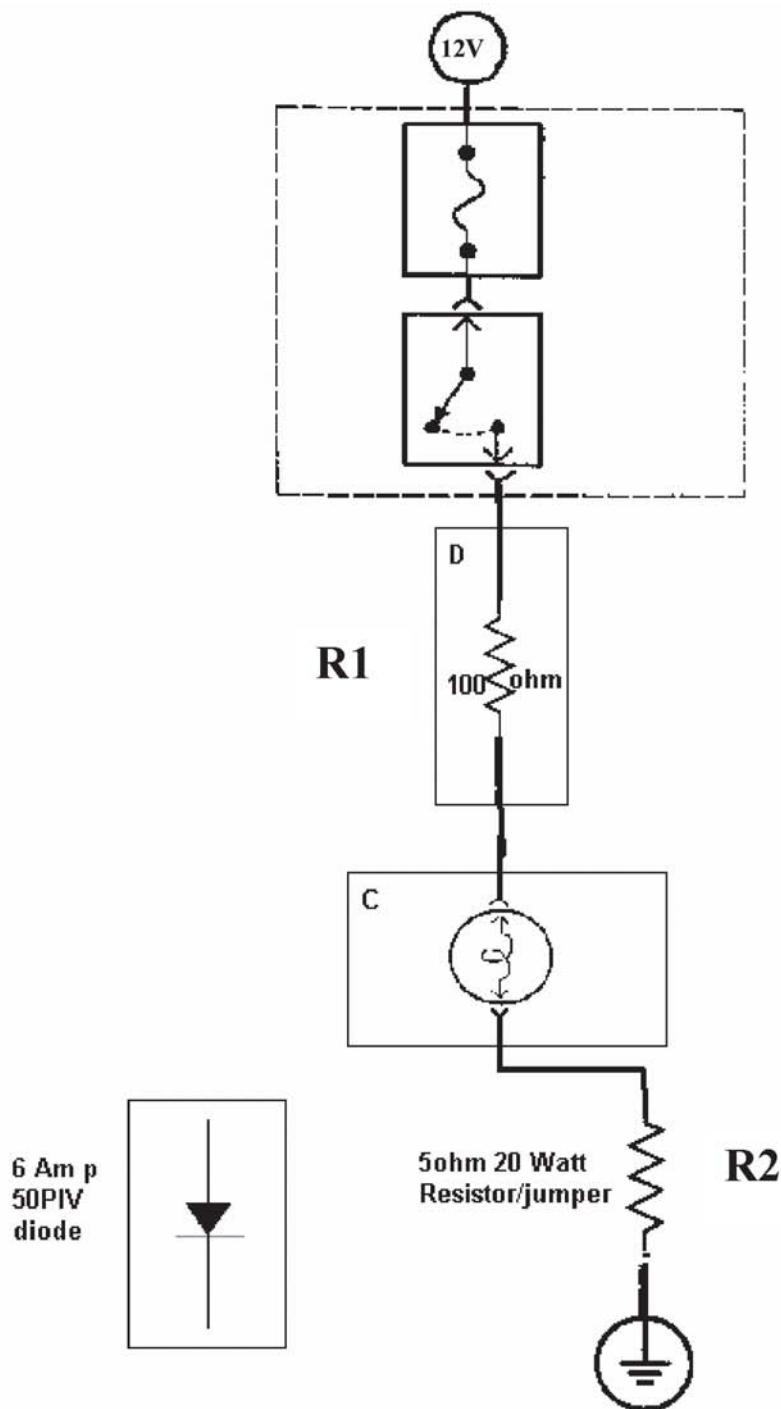


Figure 11-14

Forward Bias Characteristics of Diodes

(Current and diode volt drop)

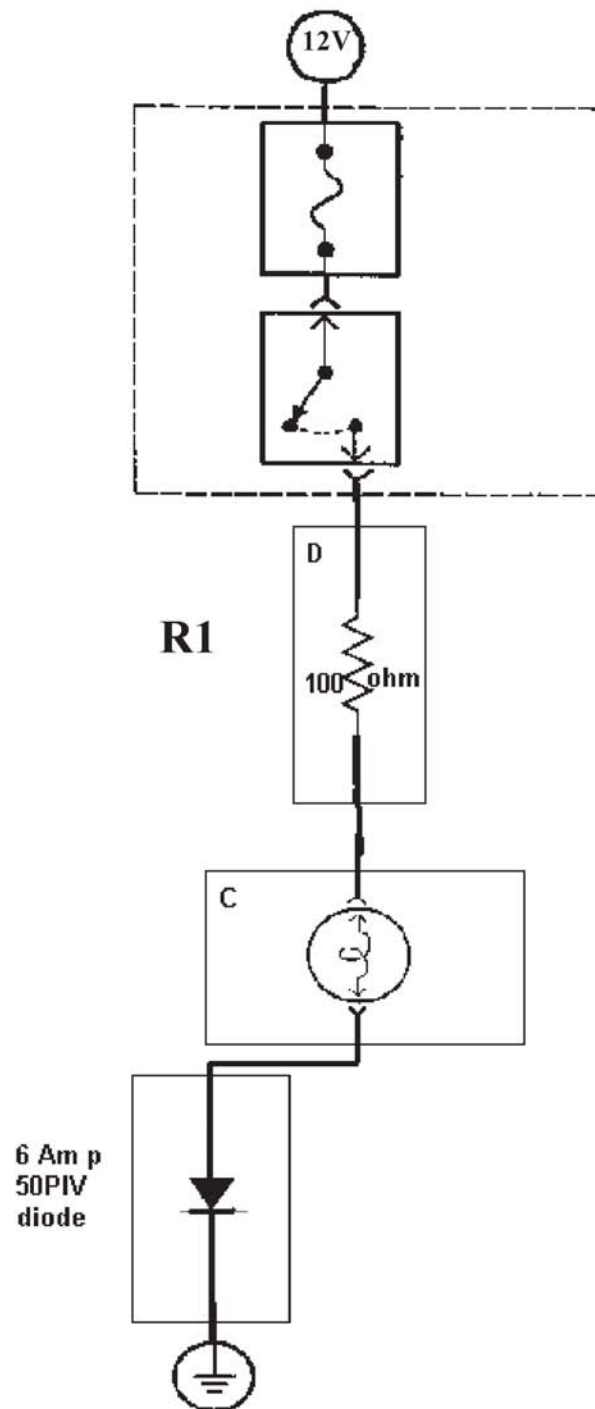


Figure 11-15, Experiment 11-1

Experiment 11-1 – Understanding the Forward Bias Characteristics of Diodes

Goal: To help the student understand the characteristic forward bias voltage drop caused by diodes.

1. Place the components shown on the diagram in Figure 11-14 in the same configuration on the electrical trainer. Make a series circuit as shown so that current flows through the circuit breaker 1st, then R1, then a small bulb and last, through R2 to ground.
2. Turn on the circuit, measure and record the volt drop across R2 to ground. _____
3. Now bypass R1 (remove it from the circuit). Current should flow through the fuse, switch, the bulb and R2. What happened to the lamp intensity? _____
4. Measure and record the volt drop across R2 again. _____
5. Did the volt drop change? Why? _____
6. Now rewire the circuit with the breaker, R1, the small bulb and diode in series as shown in Figure 11-15. **Do not use R2.**
7. Measure and record the volt drop across the diode. _____
8. Switch the wiring to bypass R1 again as done in the first exercise.
9. Did the lamp intensity change? _____
10. Measure and record the volt drop across the diode. _____
11. Did the volt drop change as it did through the resistor on the first exercise? Why?

12. What would happen if there were no current limiting resistance in the diode circuit?

Diode Uses

Rectification

- Change AC current to DC current.

Clamping Protection

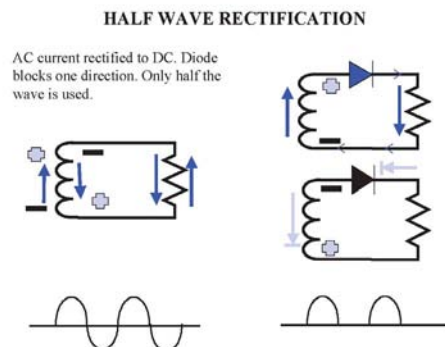
- Keep voltage spikes from damaging sensitive solid-state circuits.
- Maintain circuit voltage within specific range.

Circuit Control

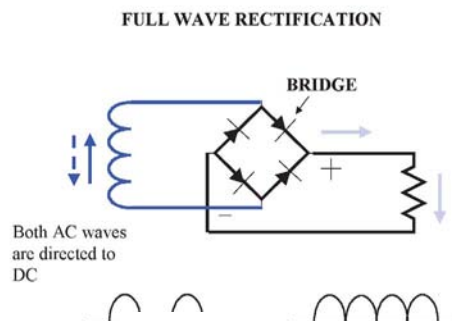
- Direct current in specific directions between circuits.
- Prevent back feeds between parallel circuits.

Rectification Methods

Half wave Rectification. Here's how it works: A diode (allows current to flow one direction only) placed in the AC circuit as shown on the figure: Stops reverse current Flow and Allows only half the current pulses to be used.



Full Wave Rectification: 4 diodes are placed to form a bridge. Both sides of the AC circuit are connected to the bridge. A new DC circuit is created. Both AC current pulses are used.



Rectifier / Generator

The most common use of a rectifier in today's automotive systems is in the alternator. From here on, we will refer to them using the same term as applied to the Delcotron, which is generator. The Delcotron generator produces alternating current (AC). Because automotive electrical systems use direct current (DC), The generator must somehow convert the AC to DC. The DC is then provided at the generator's output terminal.

These generators use a Diode Rectifier Bridge to change AC current to DC current. When six diodes are mounted inside two heat sinks, the assembly is called a rectifier bridge. This type of assembly is widely used in generators where the six diodes act to rectify, or change, the AC voltages in the stator to a DC voltage at the generator output terminal. The heat sinks are located in cooling air to dissipate the heat generated in the six diodes.

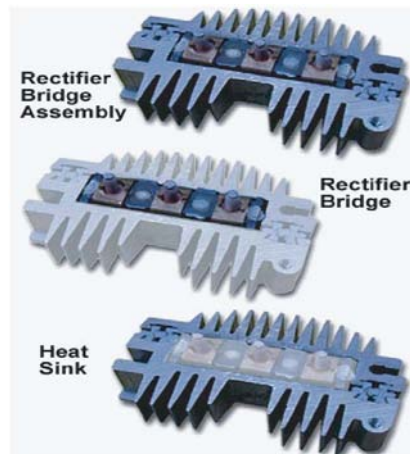


Figure 11-17

Worksheet

The diagrams show the generator during its operation through three phases. In each diagram, trace how current flows through the diode bridge assembly.

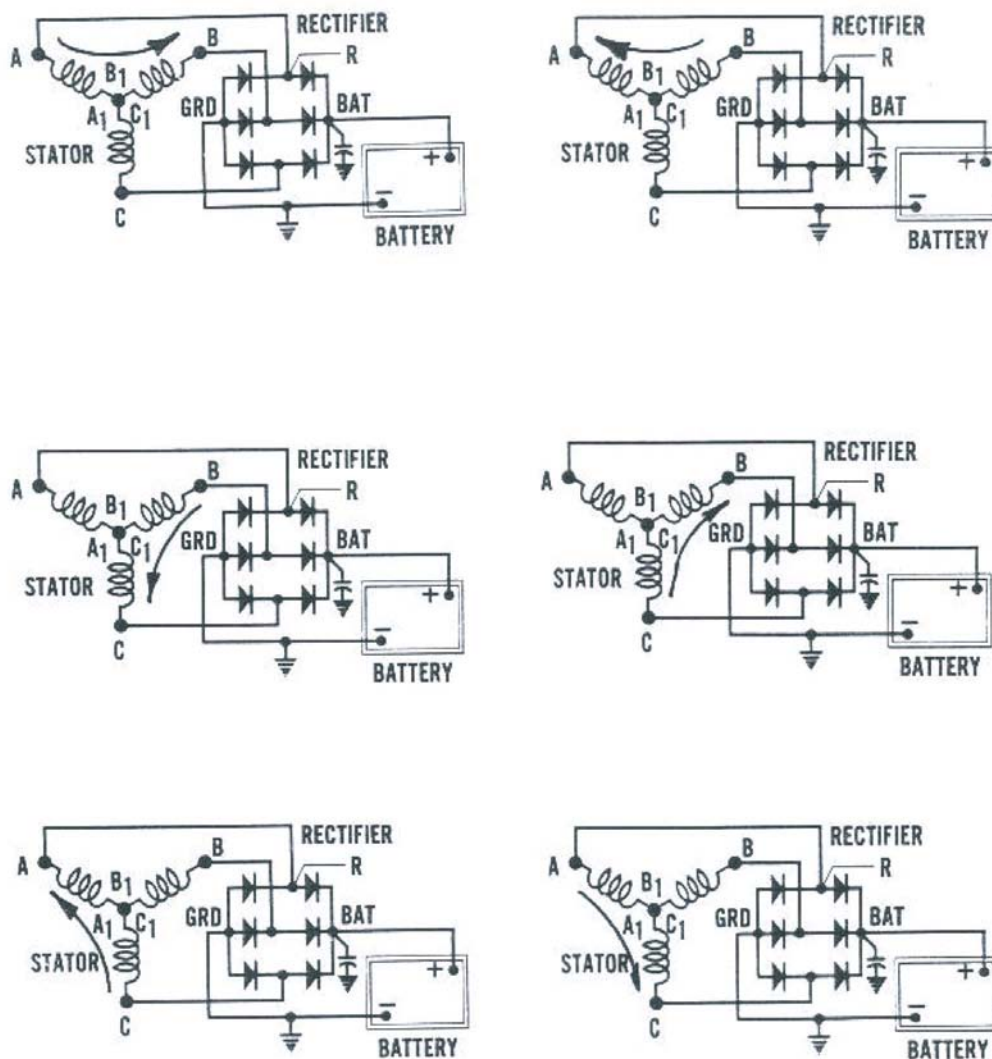


Figure 11-18

Induced Voltage and “Clamping” or “De-Spiking”

Electromagnetic devices like solenoids and relays have a unique characteristic that can cause sparks if not controlled. The coil in such a device sets up a magnetic field as current flows through it. When the circuit is abruptly opened and the supply voltage is removed, the collapsing magnetic field actually generates its own voltage potential. The voltage potential produces an induced current that flows through the circuit. Electrons begin to pile up against the open in the circuit. If enough voltage is produced, the electrons will jump the open contacts and cause a spark that can damage circuit components.

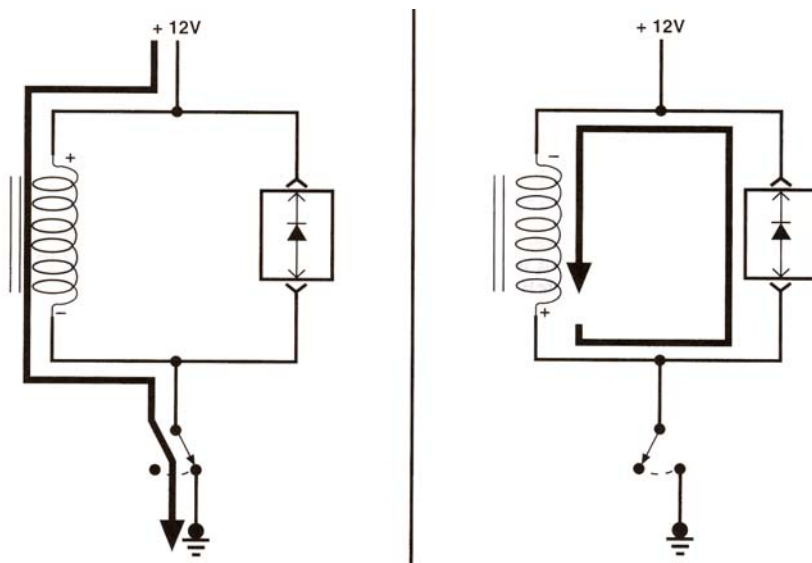


Figure 11-19

To protect against sparks or surges, clamping diodes are added in parallel with the coil. While voltage is applied to the circuit, the diode is reverse biased and doesn't conduct electricity. When voltage is removed and the induced current is flowing, the diode is forward biased and does conduct. The current flows in a circular path through the diode and coil until it dissipates. Resistors are also used for surge protection and their use is common in some relays, connected in parallel to the coils. A resistor may not clamp the spike as low as a diode but they are much more durable. All magnetic devices generally require clamping protection. If the clamping device is not soldered to the coil, it will either be in the wiring harness or in the controlling device. For example, today's shift and TCC solenoids are clamped internally in the PCM's.

Induced current can cause problems other than sparks. The computers in today's vehicles read circuit voltages and make decisions based on them. The computers make the wrong decision if electromagnetic devices cause abnormal voltages.

For instance, if a PCM is spiked it many times will cause the PCM to momentarily shut down and start over, a condition called “PCM reset”. A spike can also destroy a driver in a module or computer.

Testing Clamping Diodes

If the diode can be isolated, follow the diode test procedures in the J39200 operating manual (unless directed otherwise by the service manual).

A clamping diode should be tested when any of the conditions exist:

- Radio pops or PCM resets (SES light flashes, engine bucks, SES lamp flashes without codes) etc, when a device turns off
- An output driver is not turning on (it's destroyed), and the circuit has a clamping diode in the wiring or is hard wired to the load coil.

Methods to test a clamping diode

1. Test lamp Method

If the diode is hard wired into a solenoid or relay coil and you can disconnect the solenoid from the vehicles electrical circuit:

- Use a 12V test light and jumper wire apply power and ground to the solenoid using the test light on one side and the jumper for the other. Observe the lamp brightness
- Reverse the current flow through the solenoid or winding and observe the lamp brightness
- The lamp should be brighter in one direction. If not, the diode is not working properly.

2. Min/Max Method

- A Fluke 87 can be set to min/max/1ms capture rate and connected to the control side of the circuit. The voltage spike can be captured as the circuit is turned from on to off. If the spike is over 30 volts the diode is not functioning properly.

3. Analog ohmmeter method.

- If you have an analog ohmmeter, you can use the same method as the test light and watch for a difference in the ohm's reading. In one direction the ohmmeter should indicate the proper resistance of the coil when the diode is not conducting. The opposite direction will forward bias the diode causing the ohmmeter to read lower than the other reading.

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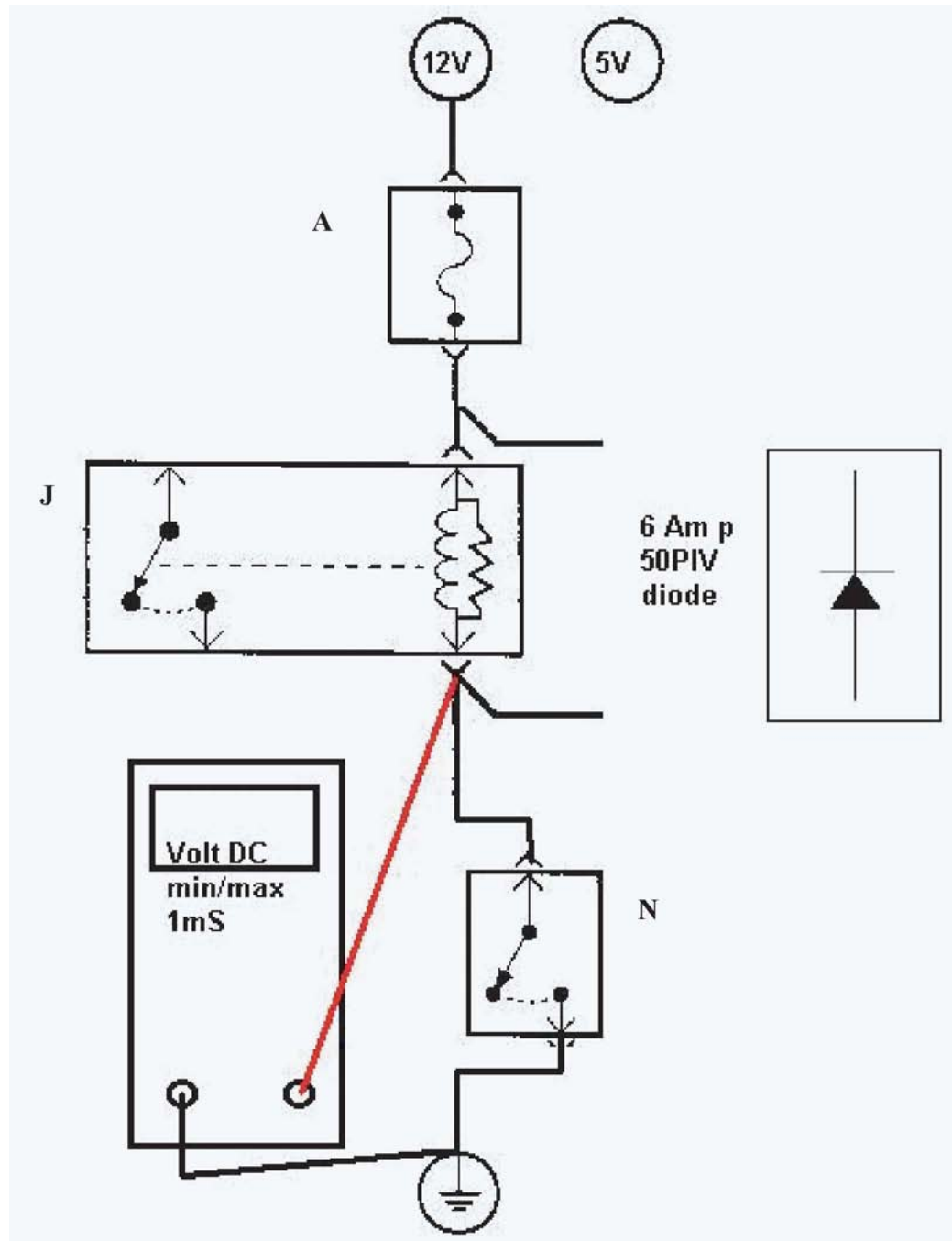



Figure 11-20

Experiment 11-2 – Clamping Diodes Min/Max Testing

Goal: To help the student understand the effects of a clamping diode on an inductor. Also to show the student the Min/Max method, using the J39200 DVOM to check for proper clamping.

- I. Wire a circuit as shown in figure 11-20 using the components illustrated. Do not wire the diode to the relay at this time. Connect a digital voltmeter to the circuit as shown.
 - A. Energize and de-energize the relay with the switch making sure that the relay clicks and the voltage changes as the switch is turned on.
 - B. Turn the switch off. Enter the min/max, 1mS record mode, on the Fluke 87 using the following steps.
 1. First select the 400 DC volt range by pressing the range button.
 2. Press the min/max button until a beep is heard. 100 mS record should show at the top of the display.
 3. Press the  button, the meter should beep again and display “1mS record max” at the top of the display.
 4. Momentarily tapping the min/max button should alternate the display from max to min and average readings.
 - C. Record the readings, they should both be at or near source voltage.
max_____ min_____
 - D. Turn on the relay (close the switch) and hold the button down while recording the voltages. **Do not open the switch yet.**
Record max_____ min_____
 - E. Turn off the relay (open the switch) and record the new readings
Record max_____ min_____
How much spike voltage did the relay coil create? _____
 - F. Try this experiment. Compare the voltage spike measured to the min/max 100 mS capture rate and to a lab scope measurement of the same spike.
Record max 100 mS_____ Oscop_____

Explain why these three measurements are different.

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G. Install a diode across the relay coil with the cathode to positive so it blocks current when the relay is on. Exit min/max by holding down the min/max button until it beeps and the min/max indicators disappear. Re-enter min/max as in steps 1-4 and select the 1mS record again.

H. Turn the relay on and hold it on. (**Do not release the switch**)

Record max_____ min_____

I. Turn the relay off. (**Release the switch**)

Record max_____ min_____

How much voltage did the diode clamp the spike the spike down to?

J. Try this again using a 100 ohm resistor as a clamping device. How much voltage spike is there with the resistor in place?

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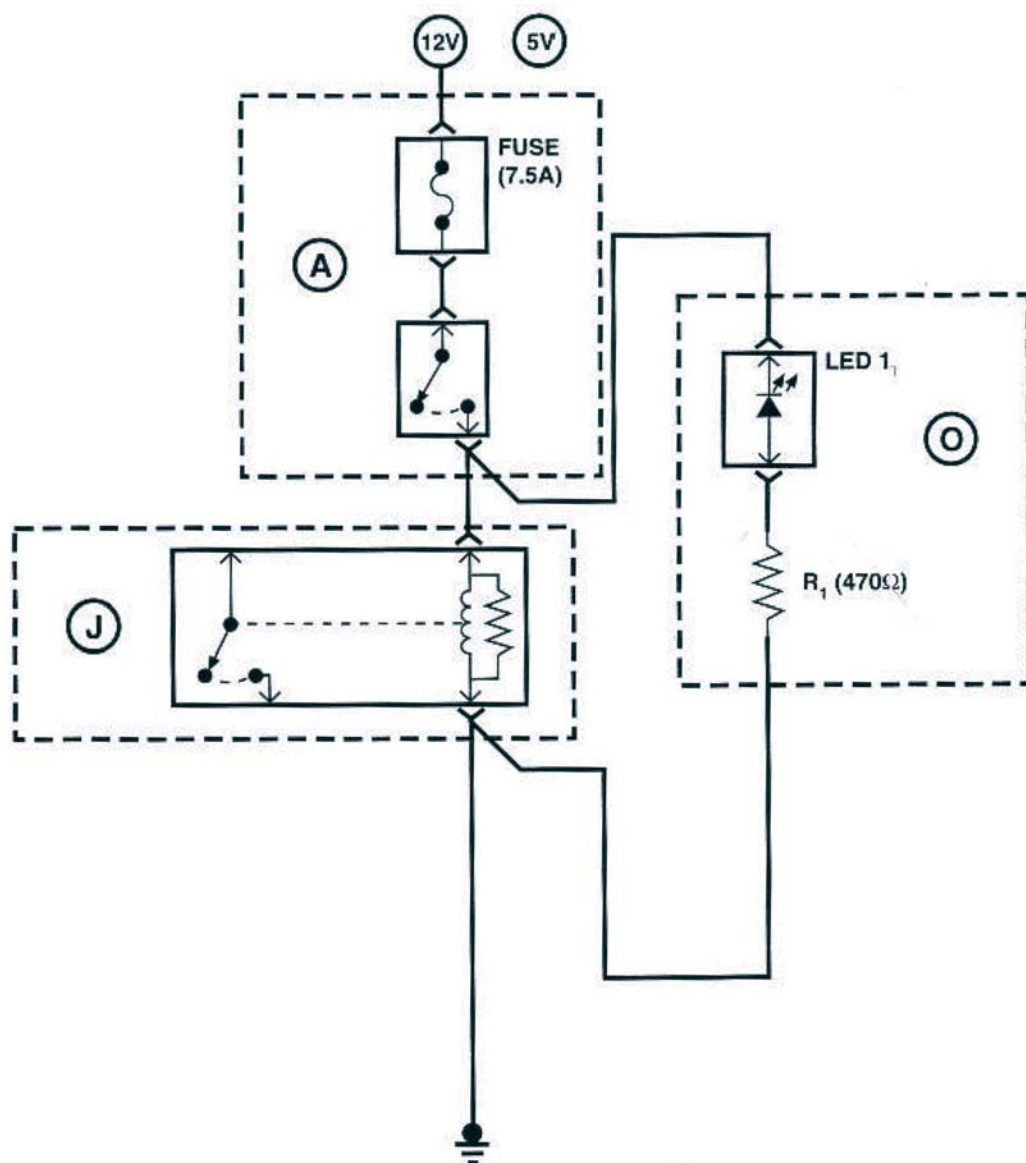


Figure 11-21

How to Operate the Fluke DVM's Peak/Mm/Max Function

1. Range the meter to the expected range.
2. Press the Mm/Max button once to enter the Mm/Max mode.
3. Press the Peak button once to enter Peak/Mm/Max.
4. Once the meter has taken readings, pressing Mm/Max once will display the minimum reading; pressing Mini Max again will display the maximum reading.

Experiment 11-3

Experiment Objective: See the result of a volt spike with the use of an LED to prevent voltage spikes

Assemble the circuit shown in Figure 11-21. The LED is in the circuit only to give you visible evidence of current flow. Observe the LED as you close the circuit to energize the relay coil (you should hear the relay contacts click). Again, observe the LED as you open the switch to de-energize the relay.

The LED lights when you _____ (open or close) the switch.

When you have completed this phase of the experiment, disconnect the LED and the resistor so that the relay is in the circuit by itself. Now as you de-energize the relay, measure the voltage spike created in the circuit by the collapsing magnetic field of the relay coil.

Set your meter for DC volts and use the PEAK MIN / MAX function.

Voltage spike reading: _____ volts.

What characteristics of a diode allow it to work well in a circuit to dissipate voltage spikes?

Zener Diodes & Voltage Regulation

A Zener diode is a special kind of diode that's heavily doped during manufacture. This results in a high number of free electrons and electron holes. These additional current carriers permit reverse current flow when a certain reverse bias voltage — the avalanche point or Zener point — is reached. In forward bias, the Zener diode acts like a regular diode.

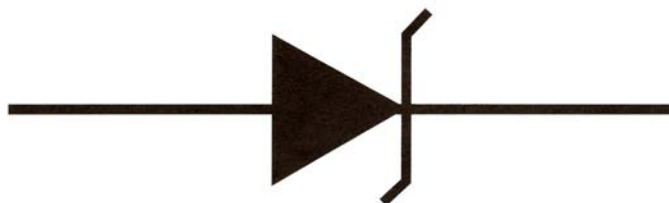


Figure 11-22, Zener Diode Schematic Symbol

Figure 11-22 shows the characteristic curve of a typical zener diode. Notice that just after breakdown, in this case at 12 V, the voltage (V_R) is constant for any value of reverse current (I_R). This is called the zener region, and once the diode is biased into this region, its voltage drop is constant. While all diodes have this characteristic, zener diodes are specially designed to dissipate the heat generated when operated in breakdown.

Zener diodes are rated according to the voltage at which they will 'turn on', or begin to flow reverse biased current. Zeners of the same rating can still be made to turn on at different points by the addition of resistors, as you will see later.

One common Zener diode won't conduct current in the reverse direction if the reverse bias voltage is below six volts. But, if the reverse bias voltage reaches or exceeds six volts, the diode will conduct reverse current. This Zener diode is often used in voltage control circuits.

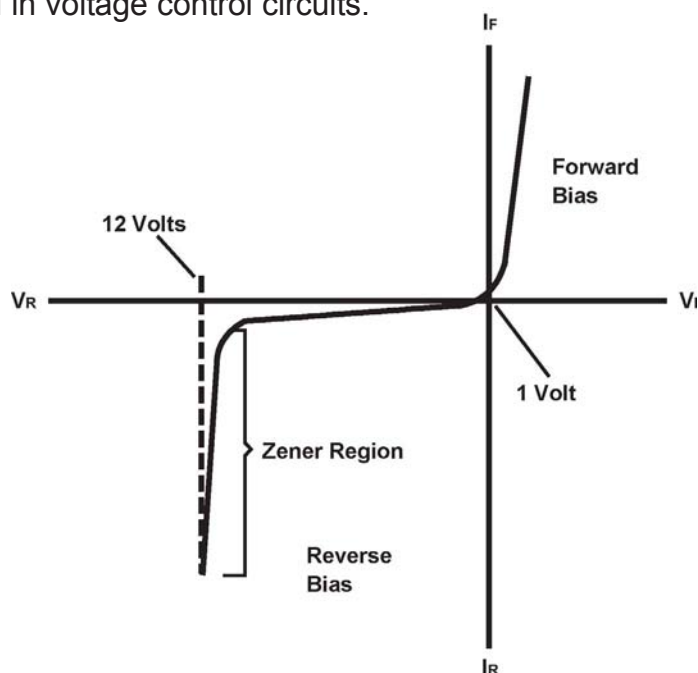


Figure 11-23

Circuit Control

Zener diodes are the voltage regulators of the diode family. Zener diodes are available in many voltage sizes, depending on the voltage level to be regulated. The range is from 2 to 200 volts

Zener diodes are placed in a circuit in reverse bias as seen in Figure 11-24. When the “Zener” voltage is reached, the Zener diode begins to conduct but maintains the voltage drop across itself. This voltage drop is “regulated” at whatever the Zener diode is rated for. Zener diodes (sometimes called “avalanche” diodes) act like a regular diode when forward biased.

As generator output increases, the charging voltage is impressed across R2 and R3. The Zener diode senses voltage across R3. When system voltage reaches a set value (13.8 to 14.4 volts), it will conduct. As the diode conducts, it opens a path for current to flow to transistor TR2.

Under the set voltage value, the Zener acts like an open circuit to the current trying to reach the transistor. Therefore, Zener diodes can be used as a solid state circuit control that is voltage sensitive.

Figure 11-25 illustrates the use of avalanche diodes in the negative rectifier bridge of a C.S. type generator. These diodes act as a safety zener diode in CS series generators and are rated to turn on at 28 volts.

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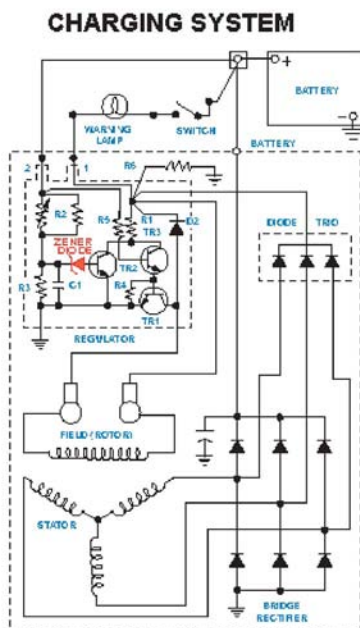


Figure 11-24

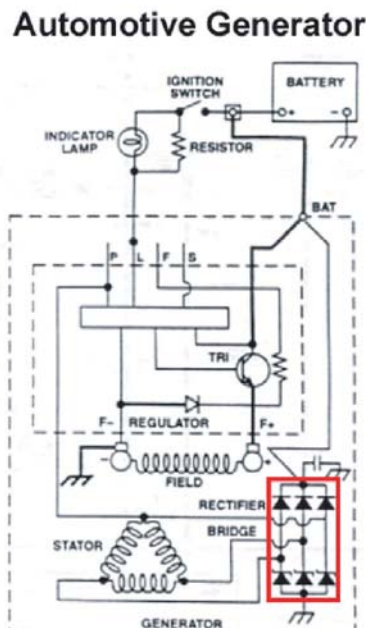


Figure 11-25

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Module 11 - Operation of Solid State Devices

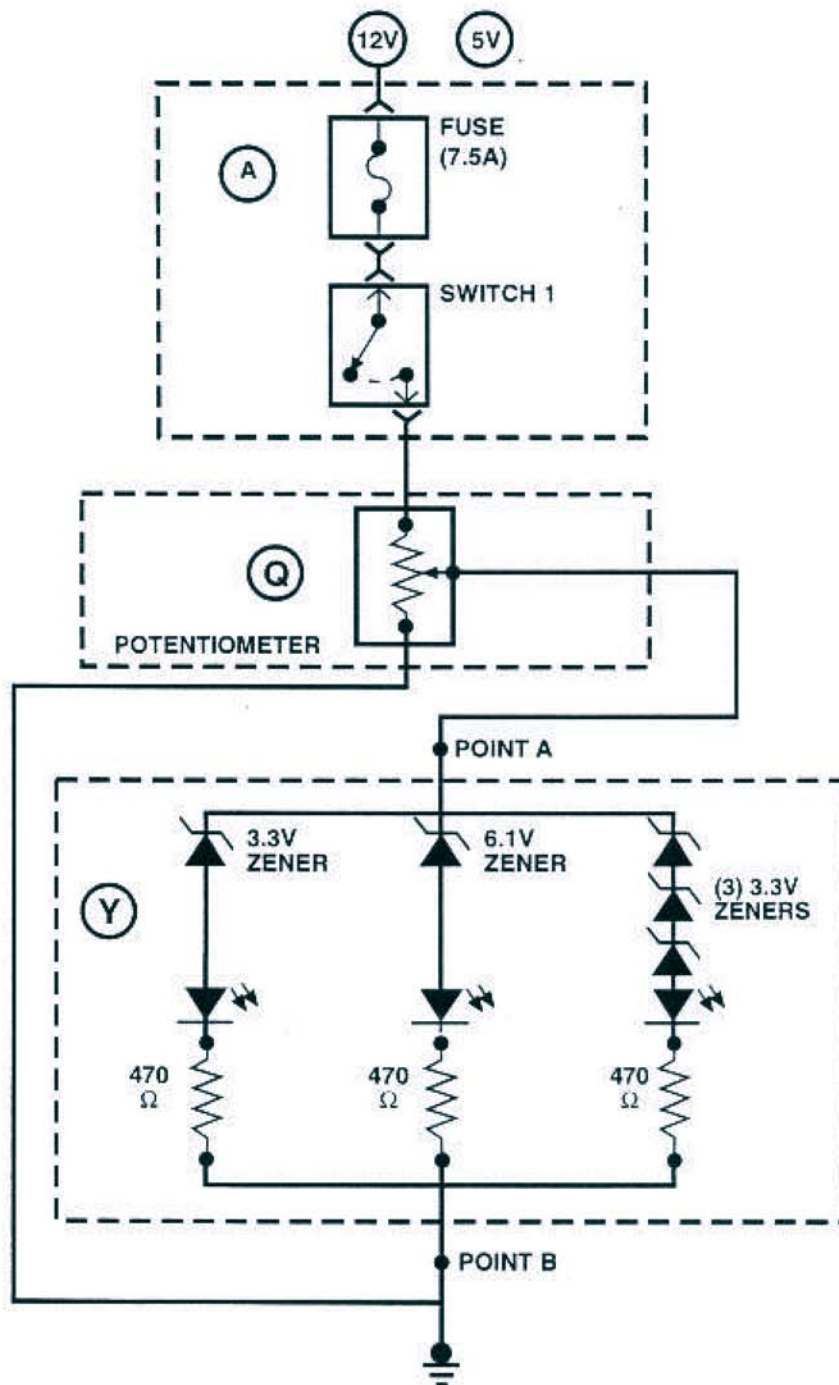


Figure 11-26

Experiment 11-4

Objective: Demonstrate the operation of zener diodes.

1. Assemble the circuit shown in Figure 11-26.
2. Once the circuit is assembled, configure a Fluke 87 DMM to perform a voltage drop test and attach test probes at Points A& B.
3. Make sure the potentiometer knob is at its lowest setting (turned all the way counterclockwise) Power the project board.
4. Rotate the potentiometer knob slowly through its full range of travel.
5. As each LED lights, make note of the voltage.

RED _____

YELLOW _____

GREEN _____

What properties of zener diodes explain the results of the experiment?

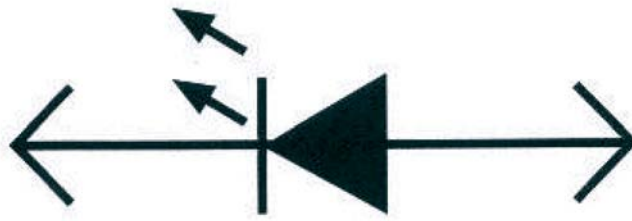


Figure 11-27, Schematic Symbol for LED

Like all diodes, Light-Emitting Diodes or LED's allow current flow in only one direction. The difference is that when forward voltage is applied to an LED, the LED radiates light. Many LED's connected in groups can be arranged to light as numbers or letters in a display.

In most respects, LED's are the same as regular diodes. The best way to think of them is as diodes that happen to give off light when they are forward biased.

- LED's require more voltage to turn ON. Usually 1.5 to 2.5 volts are required to forward bias an LED enough to give off light.
- LED's are much less resistant to high reverse bias voltages (usually less than 7 volts). Slightly higher reverse bias voltages cause the diode to conduct in the reverse direction. Significantly higher reverse voltages cause the diode to fail.
- LED's are very current sensitive, with a maximum forward current of less than 50 milliamps. More current than this may cause the diode to short, open, or even explode. To prevent damage to an LED, a current-limiting resistor is placed in series with it.

Light-emitting diodes are not made of silicon or germanium. These two substances, while quite suitable for *light-sensing*, are too inefficient to make good *light-emitters*. They emit more heat than light. So instead, a compound of elements is used as the semiconductor substance. The most popular one is gallium arsenide. Gallium is a P-type dopant, and arsenic is an N-type dopant. Combined in precisely equal quantities, they exactly cancel out each other's dopant effect and provide a structure much like pure silicon. Gallium arsenide in its pureform has very few positive holes or free electrons. But just as is the case using silicon, the gallium arsenide must be **doped** to produce P-type material in one area of the chip, and N-type material in the other.

Light-emitting diodes simply reverse the effect utilized in light sensors. When a free electron in a piece of semiconductor material meets a hole and falls into it, the process generates a photon of light. The photon is hurled away in some random direction. Countless photons escaping together constitute a ray of light.

Figure 11-28 shows how this effect is used in light-emitting diodes to produce a useful amount of light, so that an LED serves as a sort of semiconductor light bulb. The LED is connected into a circuit with a power supply pumping forward current through it. Electrons injected into the chip at the cathode cross the N region as free electrons, while holes created at the anode by the withdrawal of bound electrons cross the P region. Near the PN junction, free electrons fall into holes, generating photons of light in the process. Given enough forward current, the junction area of the chip glows brightly.

Typical LEDs produce *infra-red light*, a range of color that is invisible to the human eye. But as it turns out, most semiconductor light-sensors are most sensitive to just this color range of light. The result is that these infrared devices lend themselves to such interesting and useful applications as burglar alarms and various automotive applications such as vehicle speed or crank shaft sensors.

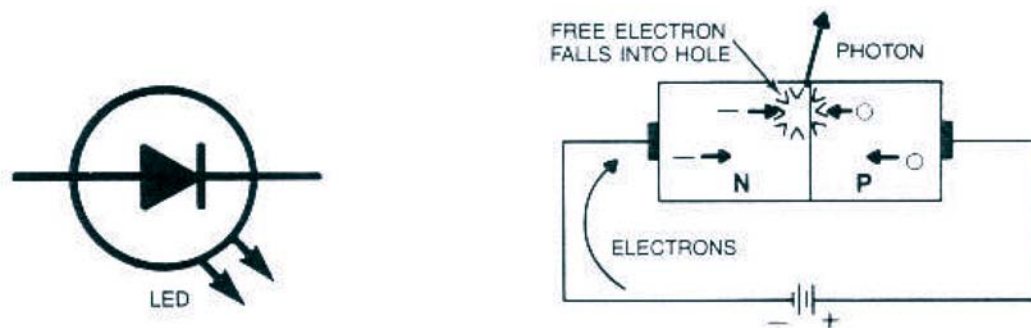


Figure 11-28

LEDs Versus Incandescent Lamps

In complex electrical circuits, LEDs are an excellent alternative to incandescent lamps. They produce much less heat and need less current to operate. They also turn on and off more quickly. Today, technology has advanced LED's brilliance to a point that they are being used for exterior lighting in some applications. They use less current and are more durable than any incandescent bulb produced.

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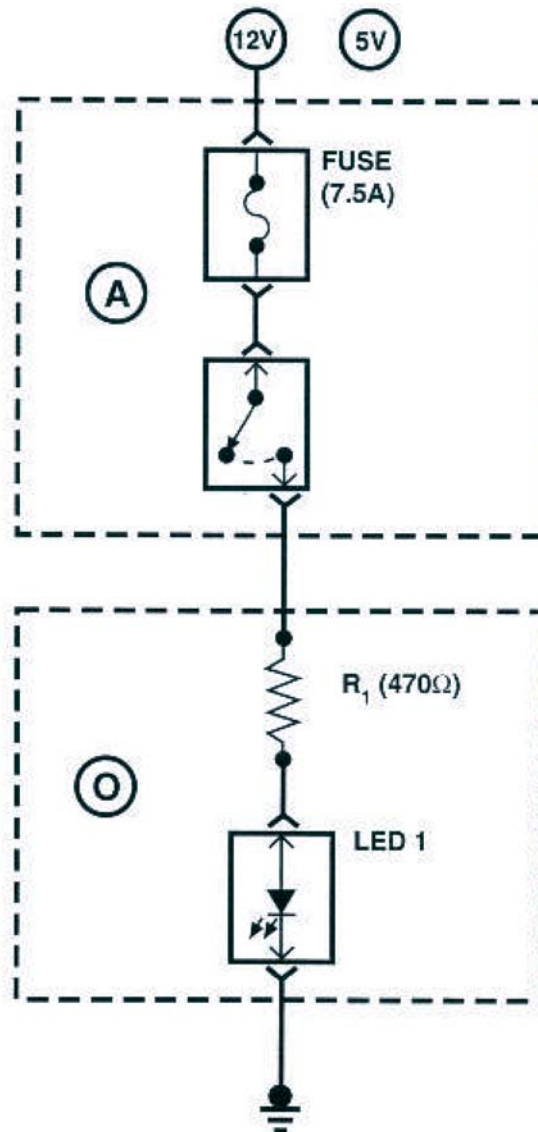


Figure 11-29

Experiment 11-5

Experiment Objective: Demonstrate the operation of an LED on a circuit.

On your project board, assemble the circuit shown in Figure 11-29. When you have the circuit working properly (LED lights when switch is closed), measure the voltage dropped by the LED as well as the current flowing through it. Record your results below.

1. Voltage across the LED (by itself, not with resistor):

2. Current through the LED (LED and resistor): _____
3. Reverse bias the LED. Does the LED illuminate? _____ Why?

4. Does the current flow when the LED is reverse biased?
5. Why does the LED have a current limiting resistor?
6. If used as a test instrument how much voltage difference would need to be present to cause the LED to glow?

Displays

It has been explained that the LED, light emitting diode, can be used as a meaningful indicator device.

LEDs can be used as single indicator lights, such as on the longitudinal Cadillac Sedan DeVille climate control panel. The LED status lights indicate operative condition in the climate-control system, and indicate various status conditions in digital fuel injection diagnostics.

LEDs can also be arranged to display an alpha or numeric character, Figure 11-30. LED displays come in various colors: red, yellow and green.

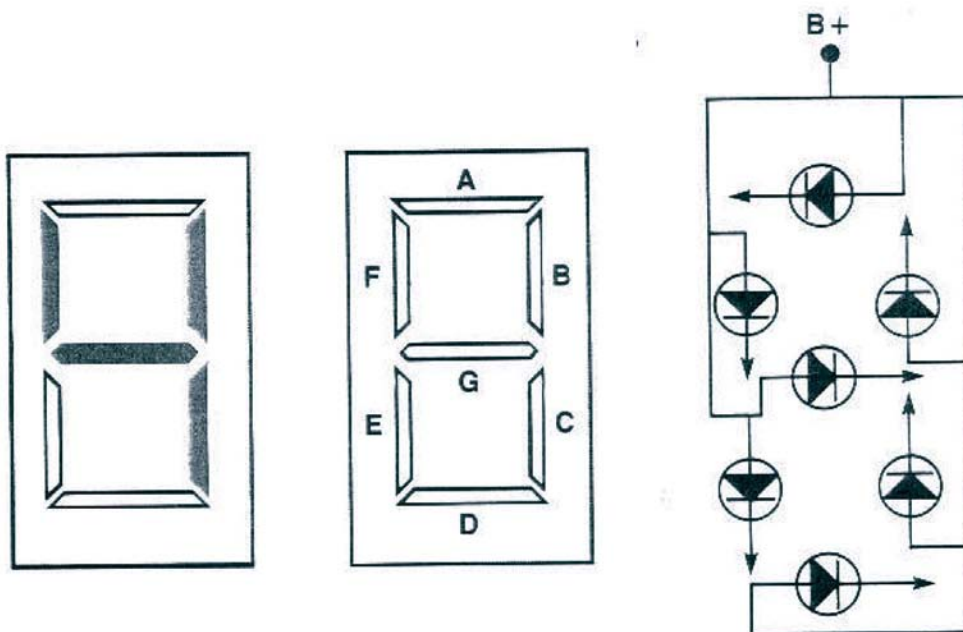


Figure 11-30

Worksheet

This circuit is a typical LED display unit found in many electronic components such as radios and clocks. Its operation is simple.

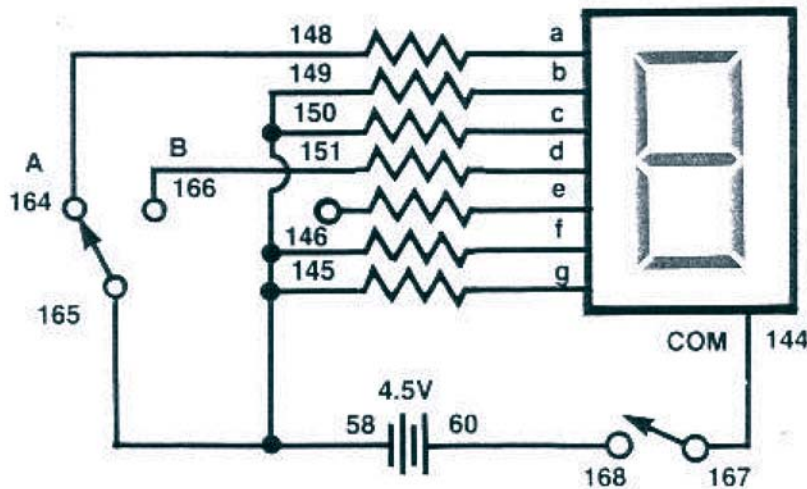


Figure 11-31

Wiring sequence: 58-165-149-150-145-146, 60-168, 144-167, 148-164, and 151-166.

1. Why is there a resistor on each of the segment leads?

2. From your observations, can you tell if this particular LED is a common anode or a common cathode configuration?

3. Name some household appliances that use this type of information display.

Take a few minutes and experiment on your own to see what other numbers or letters you can generate. Write down in this space, the letters or numbers that you can generate:

Liquid Crystal Displays - LCD

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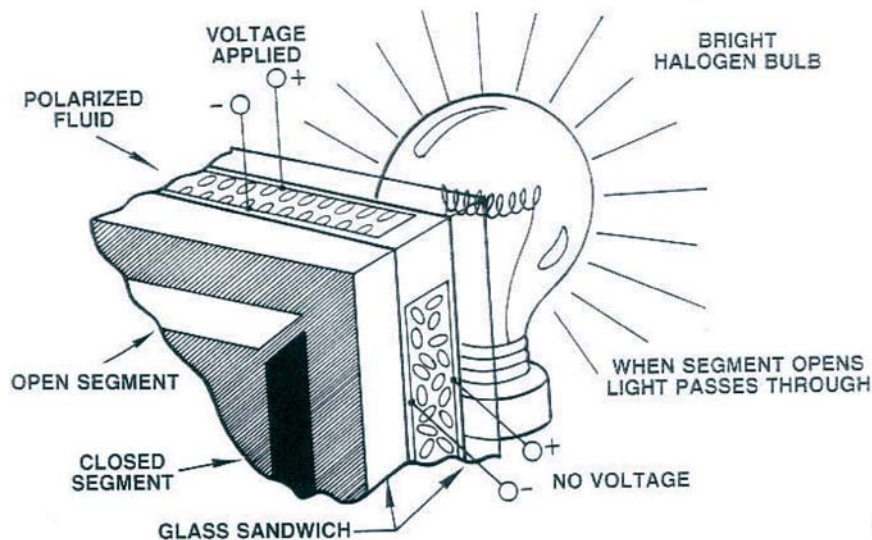


Figure 11-32

Liquid crystal displays (Figure 11-32) have been used in some automotive applications. Chevrolet had a 250-segment display on an older Corvette for its instrumentation. This is one of the most exotic and dramatic displays ever used in automotive instrumentation.

Liquid crystal displays are composed of sandwiches of special glass and polarized fluid, hence the name liquid. The display has electrodes placed on the glass. When there is no voltage, light cannot pass through the fluid because of the random arrangement of the light slots in the fluid. The segment is considered closed. When a voltage is applied to the electrodes, the slots will align and light will pass through the segment. The segment is now said to be open. Because of the density of the crystal display sandwich and the filters placed in front of the display to provide the dramatic colors, a very bright lamp is required. Halogen lamps, which are known, for their high light-output-per-watt are used. Halogen lamps are under high pressure and cannot be roughly handled. Lamp ampules must not be touched with fingers. Finger oils on the glass can cause uneven heat dispersion throughout the ampule. This shortens lamp life. The glass can also crack. The benefit of LCD is that the segments don't require high current to operate. They can be microprocessor driven through an interfacing output circuit.

A disadvantage is that LCDs do not like cold ambient temperatures. The opening and closing action slows down in cold temperatures. Considerations for temperature are a key design factor. The driver circuits are slowed down to compensate for the display action.

The displays are also physically delicate. They must be properly aligned in their holders. When cleaning, care must be taken not to push on them. This distorts the display and could cause permanent damage and cracking of the display assembly.

Vacuum Tube Fluorescent Displays

Student Workbook

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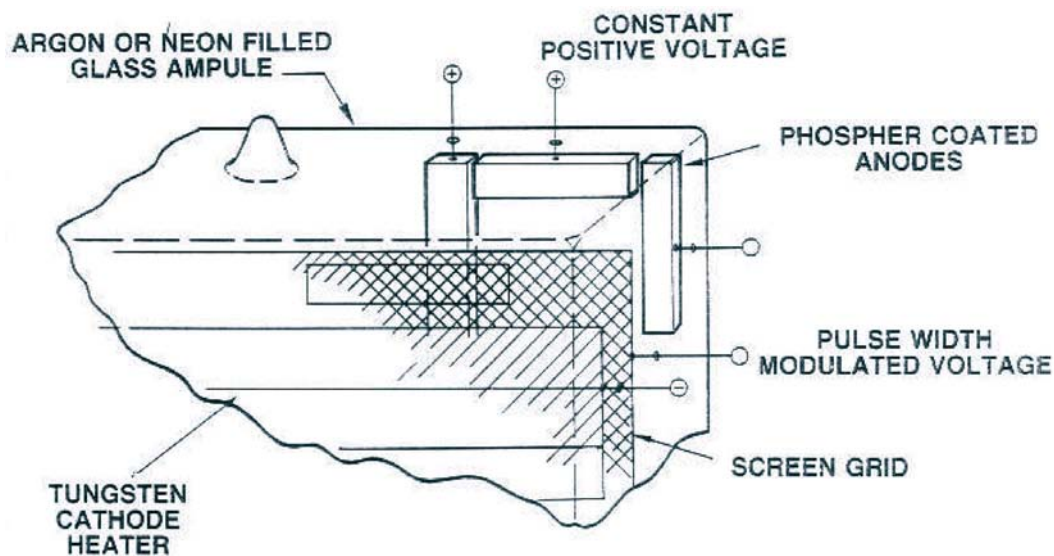


Figure 11-33

Because of their durability and bright display qualities, vacuum tube fluorescent displays (Figure 11-33) have been recently used on automobiles. Display brightness is abundant enough to require dense filtering for ease of viewing. The display uses principles established long ago when electronic equipment used vacuum tubes.

The ampule, made of strong glass, is highly evacuated and then filled with a special gas. This gas is either argon or neon. A current is passed through a tungsten cathode. The cathode is a series of very fine wires strung across the display. These wires are generously coated with tungsten. Tungsten, when heated, gives off abundant amounts of electrons. The current passing through the cathode wires heats the wires to red hot temperatures. The wires are thin and heat easily. This literally boils off the tungsten electrons. As the electrons boil, a cloud of electrons — like steam — accumulates around the cathode. If a voltage with a positive potential were placed on the anode, the electron “cloud” would be attracted to the anode like the “steam” off a boiling pot being drawn to a wall exhaust fan.

The anodes are coated with a fluorescent material like phosphorous. When the electrons “hit” the phosphorous the material glows very brightly. This is seen through the front of the glass ampule. When the segments are impressed with voltage in a specific arrangement, alpha and numerical characters can be created. If there is no voltage on the anode it does not attract electrons and it does not glow. The anodes are controlled by voltage supply circuits. These supply circuits are controlled by the microprocessor. It applies the correct sequences of voltage at the anodes to create the desired display.

Since the display is very bright, a method is necessary to control the intensity of the display for night viewing. In between the cathode and anode is a very fine screen mesh called the grid. If a modulated control voltage is placed on the grid, it would control the electrons flowing to the anode. Therefore, the grid acts like a valve controlling the flow of electrons. In vacuum tube fluorescent displays, the circuit is designed to allow maximum brightness when the duty cycle is low and minimum brightness when the duty cycle is at maximum.

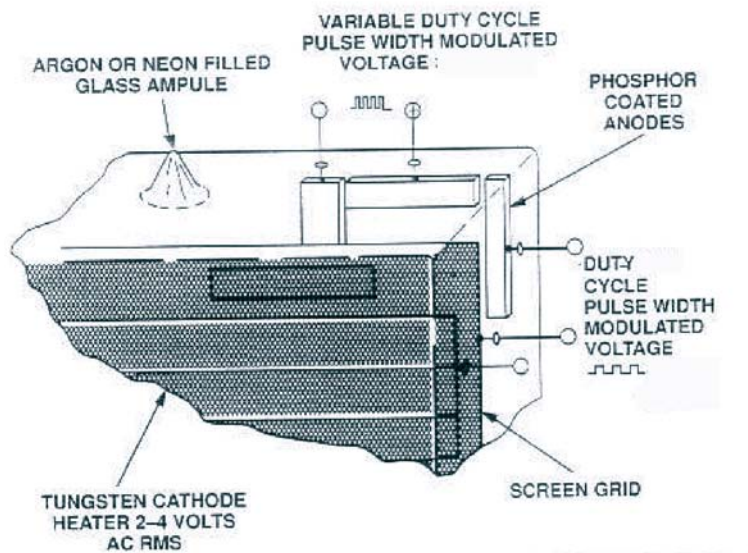
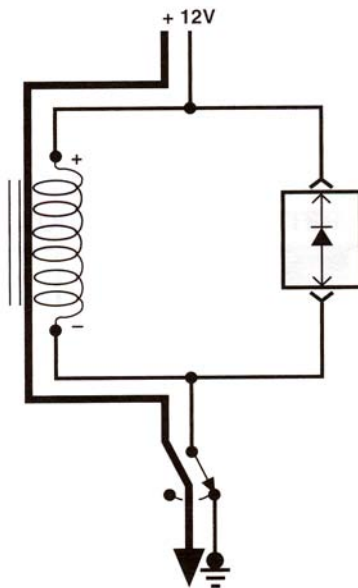


Figure 11-34

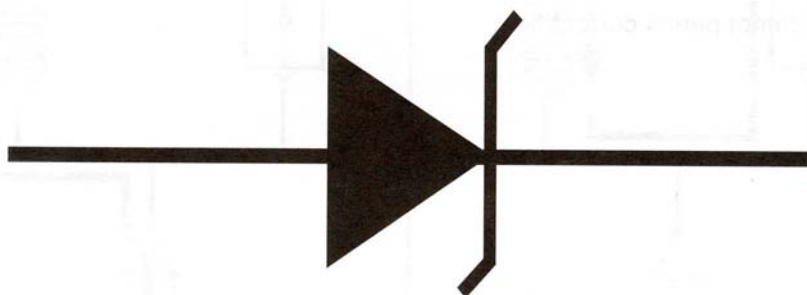
Exercise

Read and answer each question carefully.

1. A diode is made of
 - a. One P-type and one N-type
 - b. Two P-types or two N-types
 - c. Both answers are true
 - d. Neither answer is true
2. diodes do not permit current flow.
 - a. Doped
 - b. Forward biased
 - c. Reverse biased
 - d. Zener
3. The diode in this illustration is _____ as the switch is opened.
 - a. reverse biased
 - b. forward biased
 - c. incorrect
 - d. faulty



4. How would you go about testing the diode in the previous illustration?
- Test with a DMM ohmmeter with the circuit powered.
 - Test with a DMM ohmmeter with the circuit unpowered.
 - Test with a test lamp with the circuit unpowered or with Min max function while cycling the circuit.
 - Remove diode from circuit and test with DMM voltmeter.
5. This is the symbol for a
- LED
 - Zener diode
 - transistor
 - thermistor



6. Rectifiers change _____.
- alternating current (AC) to direct current (DC)
 - direct current (DC) to alternating current (AC)
 - zener current to direct current (DC)
 - avalanche current to direct current (DC)
7. The most common use of a rectifier in today's automotive systems is in
- LEDs
 - solenoids
 - generators
 - spike protector circuits

Lesson 4 - Transistors

Objectives:

- List the two groups of transistors.
- Identify the three legs of a bi-polar transistor.
- List the three legs of a field effect transistor.
- Identify NPN and PNP transistors.
- Identify transistor applications.
- Identify transistor uses.
- Determine the proper current flow through a transistors base/collector and collector/emitter circuits.
- Describe how bi-polar transistors operate.
- Construct circuits with a transistor to operate as a switch.
- Construct circuits using a transistor to operate as an amplifier.
- Relate transistor inputs to pull up and pull down type inputs.
- Relate transistor outputs to hot and ground switched outputs.

NATEF Area VI-A-15

- Inspect and test switches, connectors, relays, solid state devices, and wires of electrical/electronic circuits; perform necessary action.

NATEF Area VI-F-4

- Inspect and test sensors, connectors, and wires of electronic instrument circuits; determine necessary action.

STC Tasks

F. Capacitors and Semiconductors

2. Identify the characteristics of semi-conductors/transistors

A. Electrical Components

2. Identify the characteristics of transistors

Transistors

A diode is only one type of semiconductor. By combining several kinds of semiconductor material, we can create transistors. Like diodes, transistors control current flow. Transistors can perform practically all the functions which were once performed by vacuum tubes, but in much less space and without creating as much heat. Transistors are used in many automotive applications, including radios, IPCs, Body Controllers and other solid state switches.



Transistor Types

There are many kinds of transistors. They can be divided into two major groups: bipolar and unipolar (also called Field Effect Transistors, or FET's). While there are several differences between the two types, the most important difference for our purposes is this:

- Bipolar transistors vary current to control overall current flow
- Field effect transistors vary voltage to control current flow

Bipolar transistors are more common in automotive circuits, so we'll concentrate on them.

Transistor Construction

Like diodes, transistors contain a combination of N-type and P-type material. However, transistors contain three groupings of material instead of two. The three groups are arranged so that N-type and P-type materials alternate (either as an NPN or a PNP group). In practical terms, this means that diodes have two leads while transistors have three. Figure 11-37 is a symbolic representation of transistor construction.

Emitter, Base, and Collector

In the illustration, the material on the left is called the emitter. The material sandwiched in the middle is the base. The material on the right is the collector.

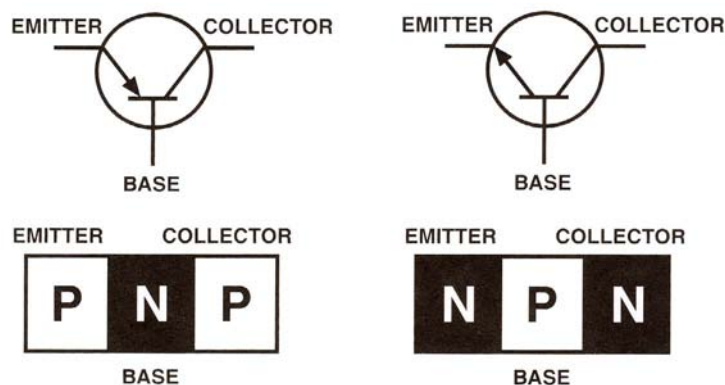


Figure 11-37

Basic Function

A transistor works by using the base to control the current flow between the emitter and the collector. When the transistor is “turned on,” current can flow in the direction of the arrow only. When the transistor is ‘off,’ current can’t flow in either direction due to the vacant depletion zone in the junctions.

When the base emitter circuit is energized, the depletion zones are filled with corresponding holes or electrons allowing collector emitter current to flow. Think of the base of the transistor as a finger on a switch.

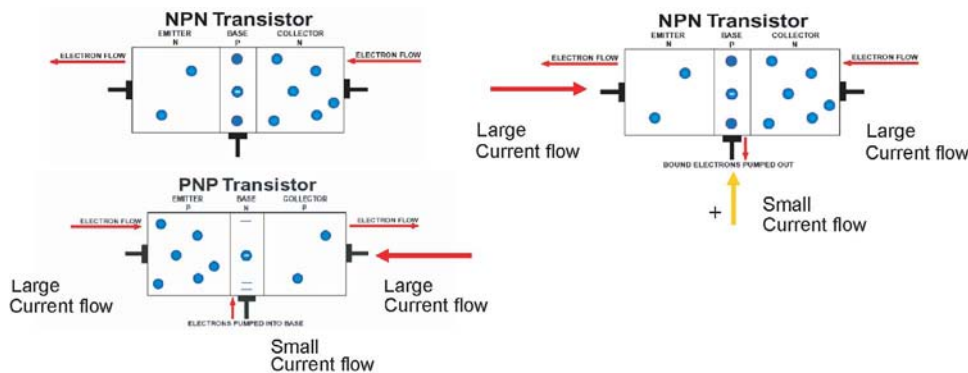


Figure 11-36

Base Paths

It’s important to realize that the base leg of a bipolar transistor controls the flow of current. Although it accounts for only a small amount of the total current, it is current flow through the base/emitter that allows and controls current to flow from emitter to collector.

PNP or NPN Transistors?

There’s an easy way to identify the kind of transistor without thinking about the movement of electrons or electron holes. Just remember that the arrow always points towards the N material and away from the P material. So, for a PNP transistor, the arrow points inward towards the base (the emitter arrow is **P**ointing **i**N **P**ointer). For an NPN transistor, the arrow points away from the base (the emitter arrow is **N**ot **P**ointing **i**N). In automotive circuits, NPN transistors are much more common than PNP.

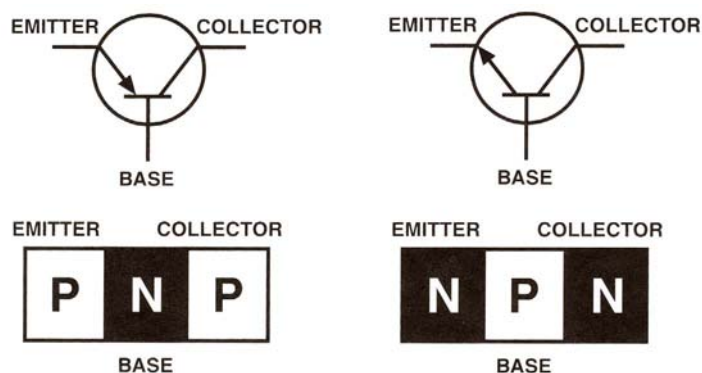


Figure 11-37

Transistor Operation

When you're trying to understand how a transistor functions in a specific circuit, there are two facts you must remember. First, an NPN transistor is turned on by applying voltage to the base leg, and turned off by removing voltage from the base leg. This is very similar to the operation of a relay, which is turned on and off by applying and removing voltage to the coil.

Second, the current through the base circuit is always much smaller than the current across the collector circuit. Changing the base current a little results in a big change in the collector current. The current through the emitter circuit is always the largest of all. In fact, the emitter current must be equal to the base current added to the collector current. Put another way, the current in the emitter circuit is split between the base circuit and the collector circuit.

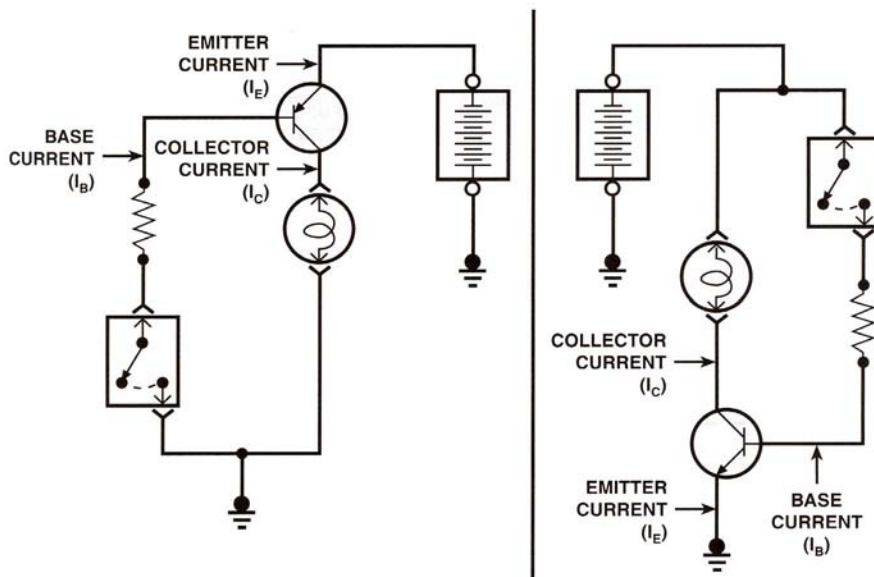


Figure 11-38

Saturation – When the base emitter carries the max current that the diode can handle. The collector emitter circuit will also be maxed.

Gain – The ratio of the change in base current to the corresponding change in collector current is the gain of the transistor. Referred to as H_{fe} -beta or AC gain.

Load placement — All bi-polar transistors are designed to operate with the load in the collector circuit. If the load is placed in the emitter circuit the transistor will not operate properly.

Transistor Uses

Transistors can be used as switches or amplifiers.

As a Switch

The illustration in Figure 11-39 shows a PNP and NPN transistor with the bases controlled by a switch. Notice that the load is always connected to the collector and current flows in the direction of the emitter arrow. Due to the construction and design they will not operate if connected in any other fashion. The resistor in the base circuit must be there to protect the base/emitter junction just as a diode P/N junction must be protected from over-current. When the base is energized, the transistor turns on a predetermined amount, so the transistor is either on or off.

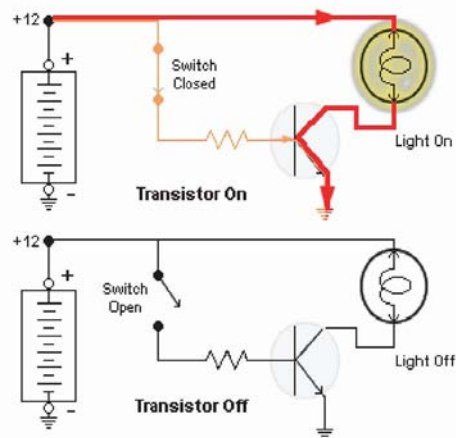
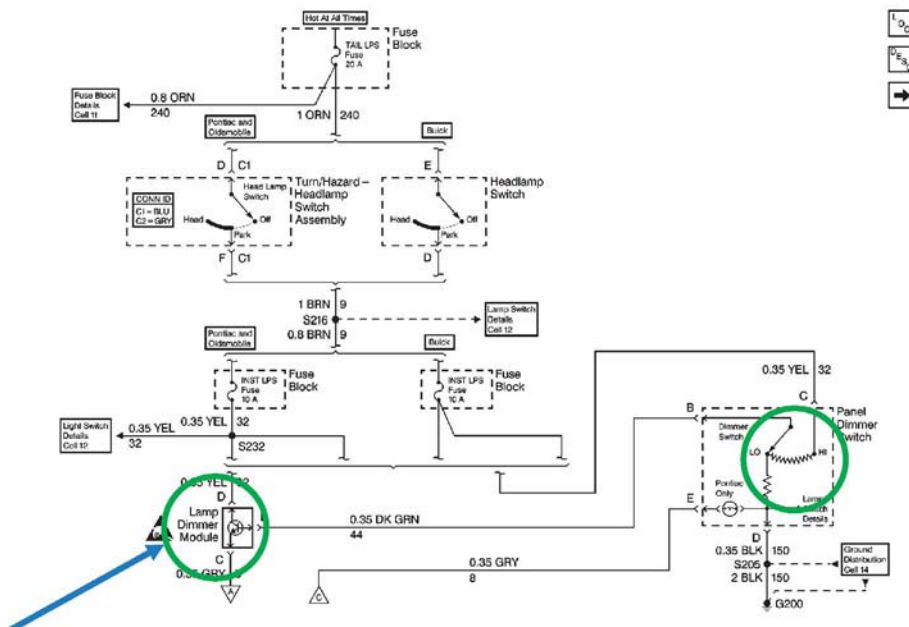


Figure 11-39

As an Amplifier

A variable resistance can also be used on the base circuit to control the collector/emitter in between “cutoff” and “Saturation”, in an analog fashion. See the example of this in the schematic below for a 1998 Olds Achieva- Doc #529950.



Transistor as a Switch

(Hot Switched, Pull Up Input)

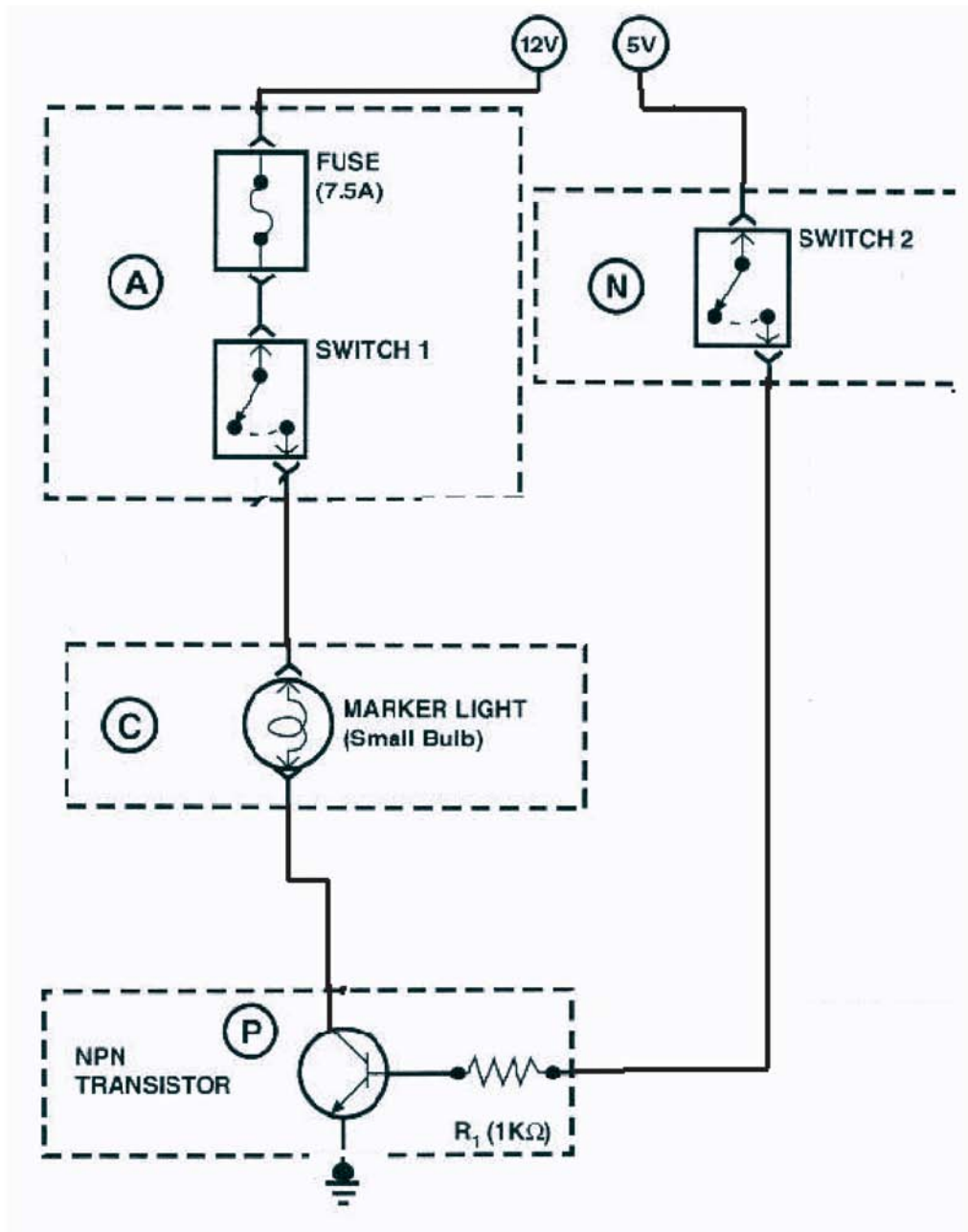


Figure 11-40, Experiment 11-6

Experiment 11-6 Transistor Operation and Characteristics

Student Workbook

Objective:

To help the student understand the operating characteristics of transistors, and their use as switches or amplifiers. Also to help them form a bridge to link together the input/output functions of basic electronic devices.

ASE 6 - Electrical
Electronic Systems

Module 11 -
Operation of Solid
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I. Hot Switched Base Circuit

- A. Build the circuit as shown in the corresponding illustration making sure to connect the emitter of the transistor to ground.

Caution:
The transistor is not large enough to
handle the current needs of a large bulb.
Do not connect to one of the large bulbs.

- B. Operate the toggle switch to make the lamp light up.

1. Is the switch opened or closed? _____
2. What type of input is the signal to the base of the transistor?(digital or analog) _____
3. Does the input to the transistor a pull the voltage up or pull the voltage down? _____
4. What should the volt drop be from the base to emitter of the transistor (bias voltage)? _____
5. Measure the base to emitter volt drop. To correctly get the true base voltage you will have to use your DVOM probe to touch the post of the transistor inside the resistor. _____
6. Was the volt drop close to what you expected? _____
7. Measure the collector/emitter volt drop. _____
8. Judging from the collector emitter volt drop measured above, do you think that the transistor is "partially turned on" or "saturated"? _____
9. Why is there a resistor in the base circuit? _____



Transistor as a Switch

(ground switched, pull down input)

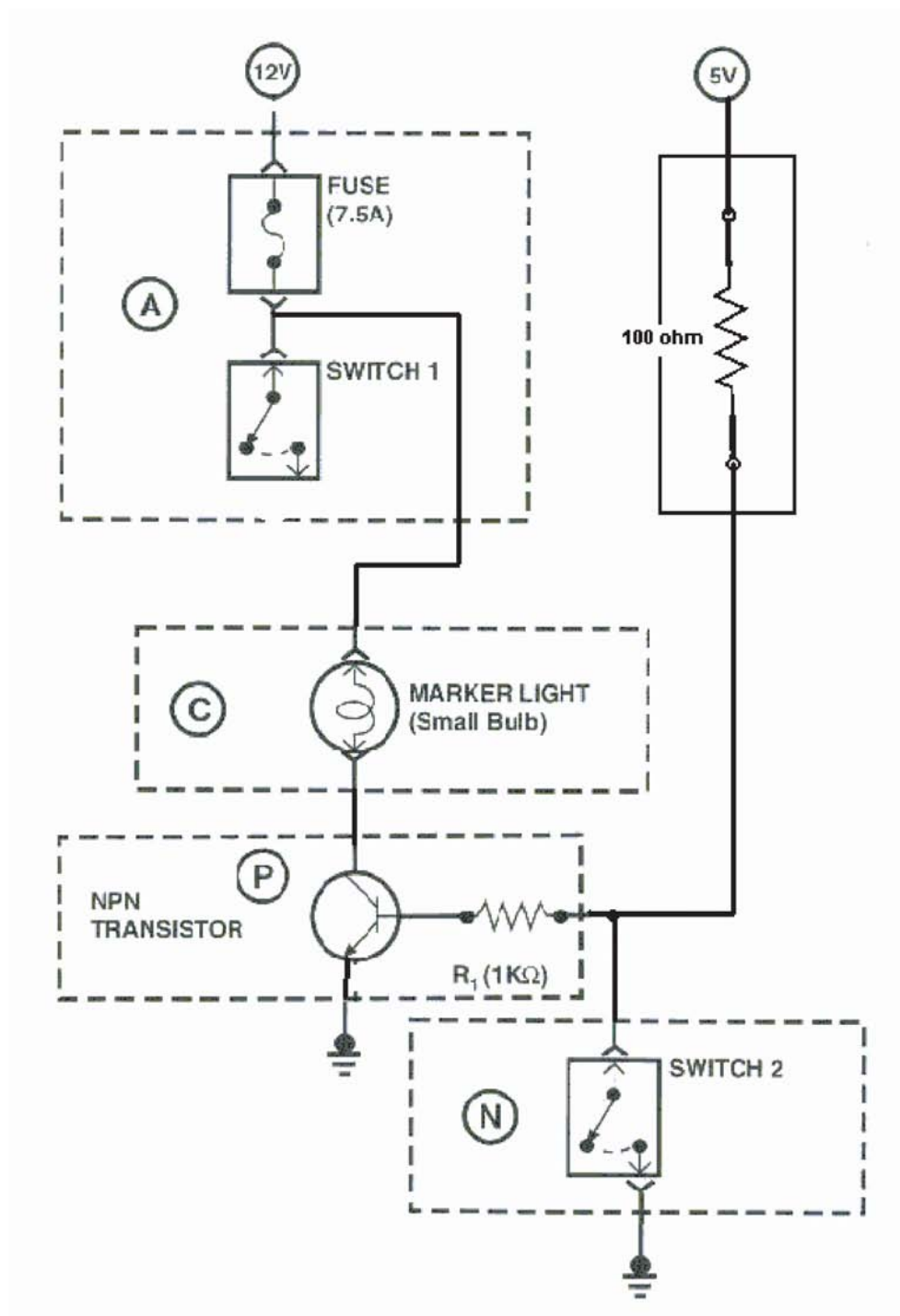


Figure 11-41

II. Ground Switch Controlled Base Circuit

1. Rebuild the control circuit to match the corresponding illustration.
2. Operate the toggle to cause the lamp to light. Is the switch open or closed? _____
3. Does the switch pull the voltage in the base circuit pull the voltage up or does it pull the voltage down? _____
4. List some types of automotive electronic input circuits from sensors that send the same type of digital pull up or pull down signal to computers or modules.

Output Control

The transistor is being used to control the negative side of the load. This is called a **low side driver** in applications where the PCM applies a ground to solenoids. Most of the drivers are of this type. A few drivers are set up to control the positive side of the loads and are called **high side drivers**. High side drivers have been used for fuel pump relay controls and some indicator lamps.

1. Can this NPN transistor be used to control the High side or positive side of a load? _____
2. What type of bi-polar transistor could be used for controlling the high side of a load?

3. If the load was shorted causing a very low resistance, what do you think may happen to the transistor?

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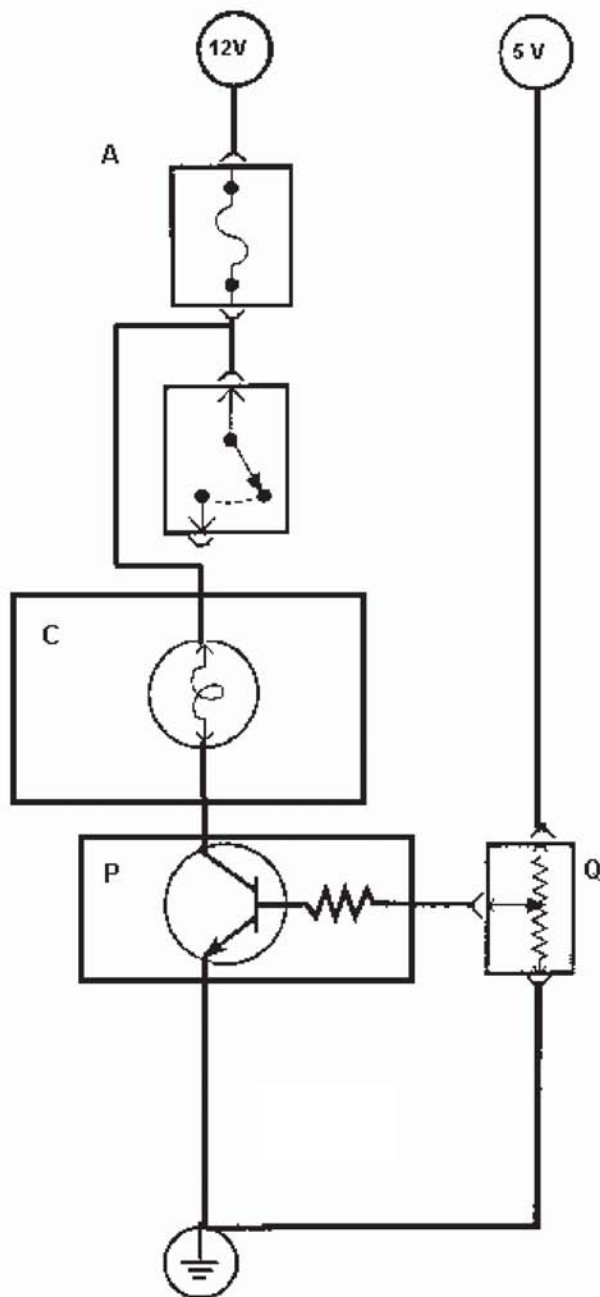


Figure 11-42

III. The Transistor as an Amplifier

1. Remove only the switch and resistors from the previous setup and build a voltage divider circuit to feed the base of the transistor using the two transistors and potentiometer identified in the above illustration.

Caution: The potentiometer is very low wattage rated and will overheat if connected directly to a lamp.

2. Turn the knob on the potentiometer slowly back and forth noting the operation of the lamp. How does it respond?

3. Now adjust the pot so the lamp barely glows. Measure the base voltage and record.

4. Now adjust the pot until the lamp just glows at full brightness. Notice that after a certain point the intensity of the bulb does not change. The transistor is saturated at that point. Measure the base voltage and record.

5. What is the difference in base voltage from step 2?

IV. Understanding Gain

1. Now connect an ammeter in the lamp circuit and another ammeter in the base circuit. Adjust the pot until the collector current(lamp current) is .01A(10mA).

Measure Base current _____

2. Adjust the pot so the collector current is 100 mA.

Measure Base Current _____

Calculate the gain and record _____

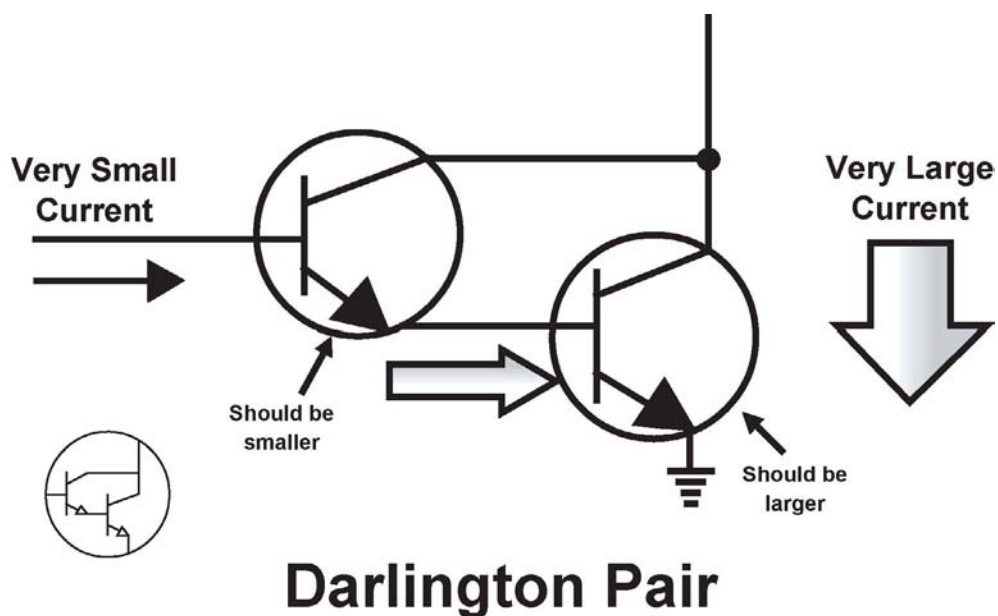
3. At what base current is the transistor fully saturated? Adjust the pot so that the collector current just reaches maximum. At this point, additional base current, will not cause additional collector current flow.

Measure Collector current _____

Measure Base current _____

4. Add the collector and base current flow measurements above together and record your calculated emitter current flow.

5. Your calculation should match the measured emitter current flow. Measure the emitter current and see.

*Figure 11-43*

In some circuit applications, the control circuit is too sensitive or small to render the desired effect at the output. Causing a control circuit to operate at higher-than-specified currents can produce undesired effects. To utilize the control circuit as it is and still get the larger effect at the other end, a special “piggy-back” transistor was designed. This transistor is called a Darlington Pair (Figure 11-43).

The first transistor is a pre-amplifier that makes a larger base current for a second transistor called a final amplifier. The second transistor can handle the larger current flow and is isolated from the control circuit.

There are situations in which a relay-type circuit is desirable (Figure 11-44). Here, a switch with very small current flow controls a light that consumes a large amount of current. Study this circuit.

It works like a mechanical relay. The benefit of this circuit is that it won't wear out like a relay with mechanical contacts, joints, and springs. This electronic relay can switch faster than a mechanical unit, which is desirable in fast-operating computer circuits.

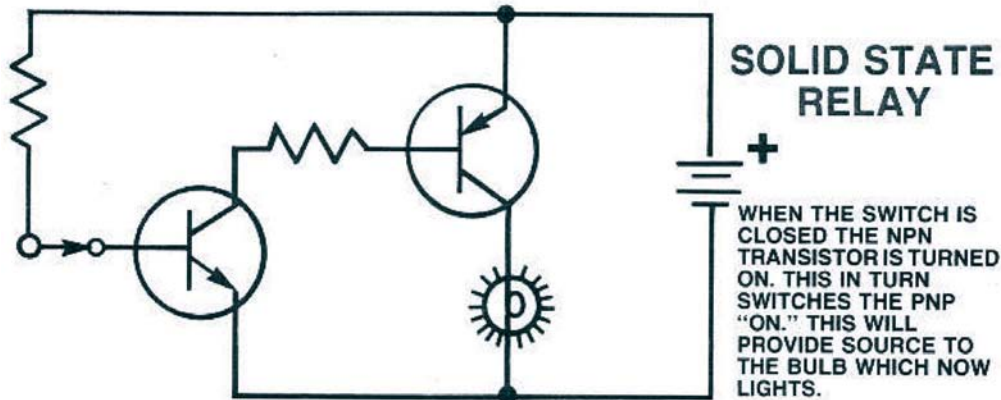


Figure 11-44

Silicon Controlled Rectifiers (SCRs)

Another type of transistor is the Silicon Controlled Rectifier, or SCR. This is a specialized type of transistor that is made to imitate a "latching" relay.

See Figures 1-20 and 1-21 ... An SCR requires a momentary positive voltage applied to the gate circuit. This is similar to the base of a transistor. Once this gate has been triggered, the SCR turns ON like a switch. The SCR then stays turned ON, even after the voltage is removed from the gate circuit.

The "legs" of an SCR are not labeled the same as transistor legs. The ANODE is the positive side of the "switch" circuit. The CATHODE is the negative side of the "switch." The GATE is the leg that must be triggered with a momentary positive voltage. This current-limited voltage turns the SCR ON.

Once the SCR is ON it stays ON, even after the gate voltage is removed. The only way to turn the SCR OFF is to remove the source voltage or ground path from the ANODE/CATHODE circuit.

SCRs are used often in alarm and theft-deterrent systems because of their “latching” ability.

To shut off the SCR, the main source of voltage must be removed from the circuit. Once the main current flow stops, the SCR is turned off. To reactivate the SCR, the gate must be triggered as in the initial switching “on.”

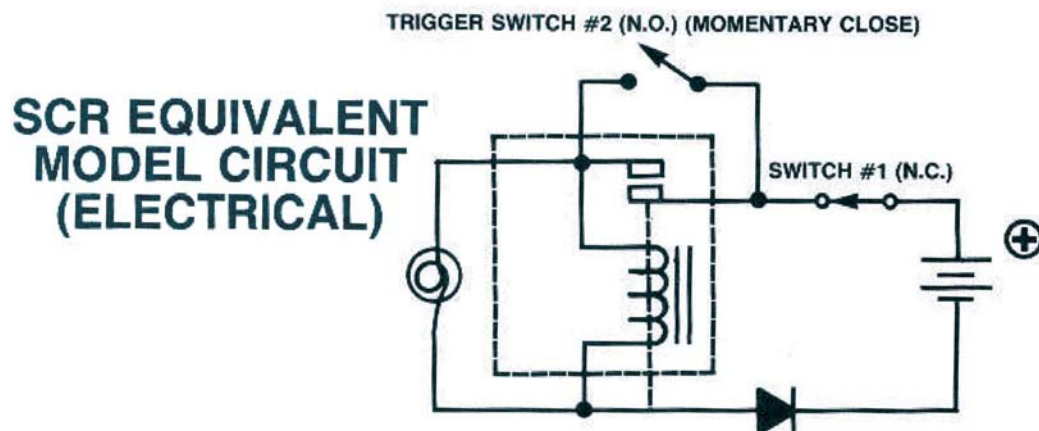


Figure 11-45

SCR circuit operation is described in Figure 11-45. The bulb is the control device to be turned “on.”

Switch #1 is normally closed (N.C.). Switch #2 is a normally open switch which is closed when depressed but opens upon letting go of the button. The relay contacts are normally open, and close when the relay is energized. The diode assures that the circuit current flows in only one direction. If the battery was reversed, the circuit would not work.

When Switch #2 is closed, current flows to the coil of the relay, closing the relay contacts. Once the contacts close, Switch #2 is not needed. When Switch #2 is released, the relay keeps itself energized and the bulb lights. To deactivate the circuit, Switch #1 must be opened, breaking the main circuit current flow. After the circuit is shutoff, closing Switch #1 does not turn on the circuit. The trigger Switch #2 must be closed again to restart the circuit and relight the bulb.

**ASE 6 - Electrical
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**Module 11 -
Operation of Solid
State Devices**

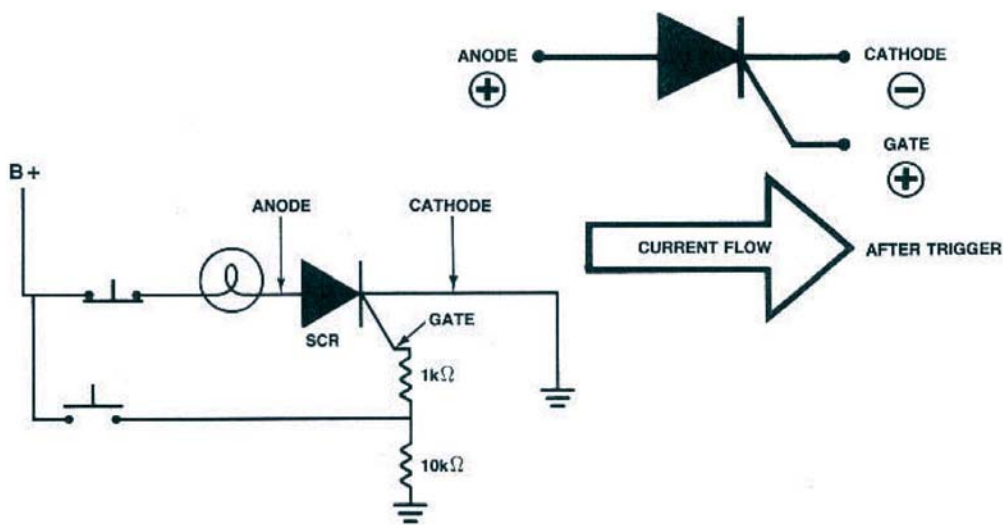


Figure 11-46

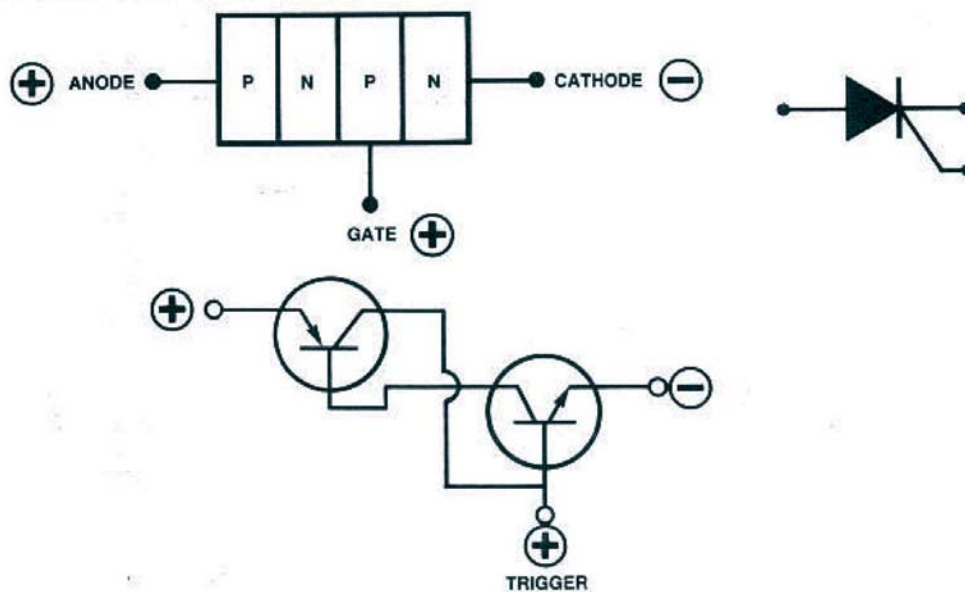


Figure 11-47

Field Effect Transistors (FET)

See Figure 11-48.

In most cases, Field Effect Transistors (FETs) are used the same way bipolar transistors are. They function to turn ON or OFF current to a load in the circuit.

FETs are a basic part of Integrated Circuit (IC) technology. They are much smaller and simpler to build, making them less expensive than bipolar transistors. FETs are **unipolar**, referring to the fact that the working current flows through only one type of semiconductor material as it flows from source to drain. A bipolar transistor has current flowing through regions of both N and P polarity.

The parts of an FET perform much the same function as the corresponding parts of a transistor:

- The source acts as the emitter.
- The gate acts as the base.
- The drain acts as the collector.

Instead of using a base current for control, as in bipolar transistors, FETs use voltage to control how much current flows through the drain/source circuit. Applying a voltage to the gate creates an electric field, which has the effect of attracting or repelling electrons, depending on whether the transistor is a P-channel or N-channel type. This is where the term “Field Effect” comes from.

Two types of FETs are: the Junction Field Effect Transistor (JFET) and the Metal Oxide Semiconductor Field Effect Transistor (MOSFET). JFETs are normally ON. This means that JFETs allow current to pass through without activating the gate circuit.

Applying a positive voltage to the gate of a P-channel JFET repels and chokes off current.

Controlling an N-channel JFET may seem a little backward at first. We must apply a negative voltage to the gate to turn the JFET OFF. The gate voltage is negative with respect to the source voltage. This is like reverse biasing a diode. This has the effect of repelling free electrons and throttling their flow.

Zero volts turn the JFET ON.

**ASE 6 - Electrical
Electronic Systems**

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Operation of Solid
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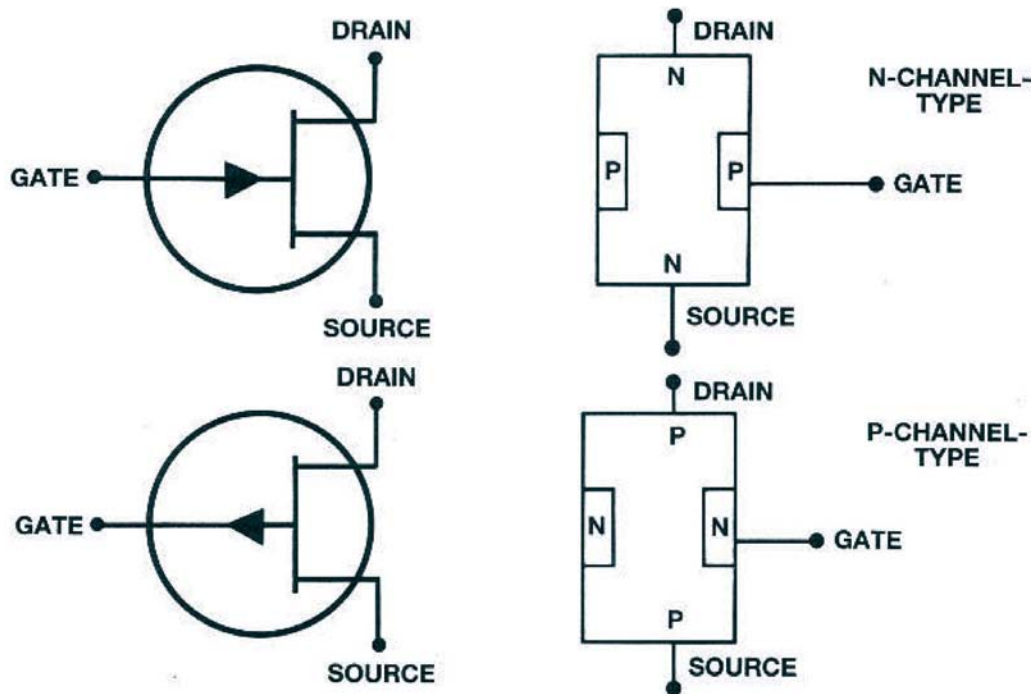


Figure 11-48

N-CHANNEL FET: Gate voltage must be lower than source voltage to turn OFF

P-CHANNEL FET: Gate voltage must be higher than source voltage to turn ON

Metal Oxide Semiconductor Field Effect Transistors (MOSFET5)

See Figure 11-49.

MOSFETs are a special type of JFET, and have gained wider applications in vehicles. The gate is insulated from the source/drain material by a film of silicon dioxide. These are also known as Insulated Gate Field Effect Transistors

Like the FETs, MOSFET5 come in two varieties N-channel and P-channel. The action of each is the same. The polarity is different.

With zero volts at the gate, the channel is conductive and the MOSFET is ON.

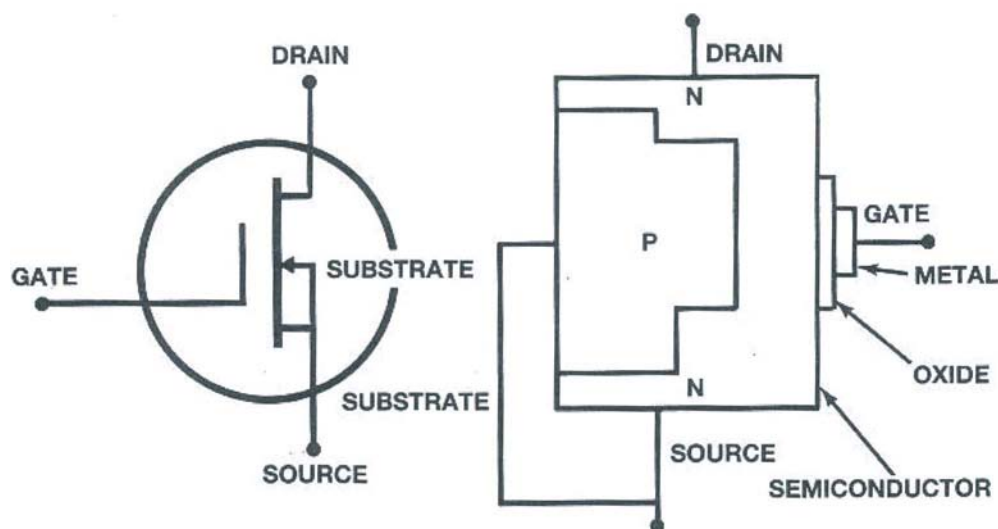


Figure 11-49

Lesson 4 Review Questions

Read and answer each question carefully.

1. The two groups of transistors are called _____ and _____
2. The three legs of a bipolar transistor are called the _____ and _____
3. The three legs of a field effect transistor are called the _____, _____ and _____
4. A bipolar transistor works by using the _____ to control current flow through the emitter.
 - a. base
 - b. collector
 - c. emitter
 - d. effector
5. In a transistor circuit, the _____ circuit has the lowest current.
 - a. base
 - b. emitter
 - c. collector
 - d. effector
6. In a transistor, the _____ circuit has the highest current.
 - a. base
 - b. collector
 - c. emitter
 - d. effector

7. Transistors are groups of three:
 - a. emitters
 - b. semiconductor materials
 - c. diodes
 - d. resistors

8. A transistor functions most like a
 - a. lamp
 - b. capacitor
 - c. resistor
 - d. relay

9. Transistors have which of these advantages over mechanical circuit components?
 - a. They can vary current, instead of only turning it on or off.
 - b. They react faster than mechanical devices.
 - c. They are smaller.
 - d. They do not wear.
 - e. All the above.

10. Resistors in transistor circuits are used to
 - a. turn the transistor on and off.
 - b. protect the transistor from excess current
 - c. both a and b
 - d. neither a nor b

11. _____ are likely automotive applications of transistors.
 - a. Light dimming modules
 - b. Switches.
 - c. both a and b.
 - d. neither a nor b.

Lesson 5 - Capacitors

Objectives:

- Identify the basic function of a capacitor.
- Identify the units of capacitance.
- Describe the construction of a typical capacitor.
- Identify three ways capacitors are used in electrical circuits.
- Describe how capacitors affect current flow in a DC circuit.
- Describe how capacitors affect current flow in an AC circuit.
- Construct a timing circuit using a capacitor to simulate theater dimming.
- Construct a circuit to simulate auto lamp controls using a capacitor.
- Identify methods to change time delays of timers using capacitors.

NATEF Area VI-A-15

- Inspect and test switches, connectors, relays, solid state devices, and wires of electrical/electronic circuits; perform necessary action.

NATEF Area VI-F-4

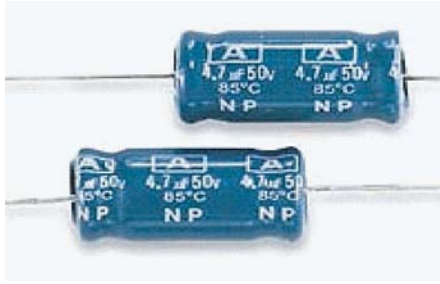
- Diagnose the cause of incorrect operation of warning devices and other driver information systems; determine necessary action.

STC Tasks

F. Capacitors and Semiconductors

1. Identify the characteristics of capacitors used in automotive electrical circuits
5. Select processes for testing automotive solid state devices

Capacitors



A capacitor is a device that can store an electrical charge, thereby creating an electrical field which can in turn store energy. The measurement of this energy storing ability is called “capacitance.” In automotive electrical systems, capacitors are used to store energy, as timer circuits, and as filters. The tachometer filter and the theatre dimming timer are both capacitors.

There are many kinds of **CAPACITORS** in various automotive applications. The term **CONDENSER** is synonymous with **CAPACITOR**, meaning an electron storage device. A **CONDENSER** was the first term used and slowly was replaced with **CAPACITOR**. All **CAPACITORS** do the same thing, and that is, store electrons.

Construction methods vary, but a simple capacitor can be made from two plates of conductive material separated by an insulating material called a “dielectric.” Typical dielectric materials are air, paper, plastic and ceramic.

The simplest form of a capacitor is two conductors separated by some form of insulation. The insulation material is referred to as the **DIELECTRIC**. The **DIELECTRIC** can be made of paper, plastic film, Mica, glass, Ceramic Polystyrene or air. The conductive plates can be made of a thin metal applied to opposite sides of the dielectric material, forming a sandwiched arrangement. The amount of plate surface of the conductive plates pertains to the rating of the capacitor. The thickness of the conductive plates and the dielectric material pertains to the voltage rating of the capacitor. Refer to Figure 11-50.

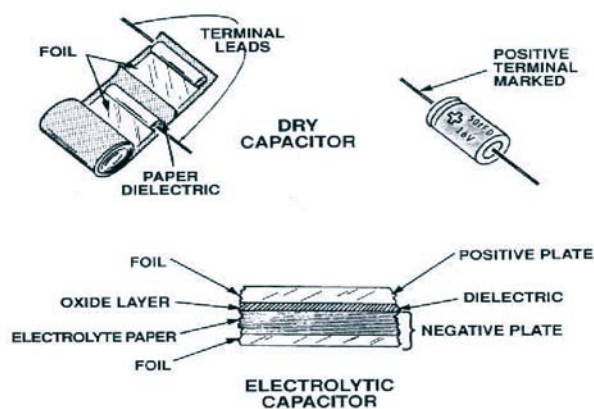


Figure 11-50

Capacitor Energy Storage

In some circuits, a capacitor can take the place of a battery. If a capacitor is placed in a circuit with a voltage source, current flows in the circuit briefly while the capacitor “charges.” That is, electrons accumulate on the surface of the plate connected to the negative terminal and move away from the plate connected to the positive terminal. This continues until the electrical charge of the capacitor and the voltage source are equal. How fast this happens depends on several factors, including the voltage applied and the size of the capacitor; it usually happens quickly.

When the capacitor is charged to the same potential as the voltage source, current flow stops. The capacitor can then hold its charge when it is disconnected from the voltage source. With the two plates separated by a dielectric, there is nowhere for the electrons to go. The negative plate retains its accumulated electrons, and the positive plate still has a deficit of electrons. This is how the capacitor stores energy.

A charged capacitor can deliver its stored energy just as a battery would (although it is important to note that, unlike a battery, a capacitor stores electricity, but does not create it). When used to deliver a suitable small current, a capacitor has the potential to deliver voltage to a circuit for as long as a few weeks.

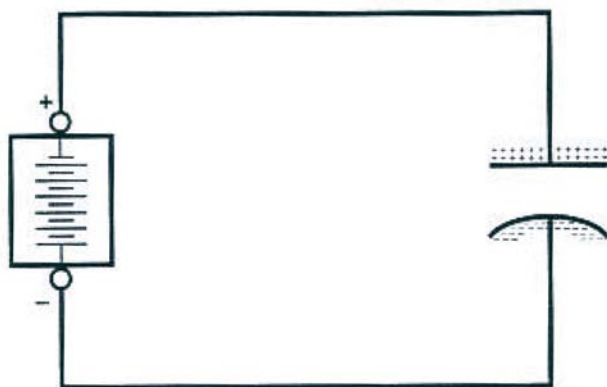


Figure 11-51

Types of Capacitors

Capacitors fall into three basic categories: the first is a **FIXED** type, which has a permanent rating, a maximum voltage rating, and is not polarity sensitive. The second is also a fixed rating and has a maximum voltage rating, but is polarity sensitive. This type is referred to as an **ELECTROLYTIC** capacitor. The third type is a **VARIABLE** capacitor, but this type is not found in automotive applications since the introduction of digital radio tuners.

ELECTROLYTIC CAPACITORS have a thin oxide layer formed on ALUMINUM or **TANTALUM** foil which is used for the dielectric. This type of capacitor has a much higher capacitance than the non-electrolytic types. **TANTALUM** has a higher capacity per size and longer life than **ALUMINUM OXIDE ELECTROLYTICS**. **ELECTROLYTICS** are polarized just like a battery and must have the negative lead go to the negative side of a circuit and positive go to the positive side of the circuit. Refer to Figure 11-52.

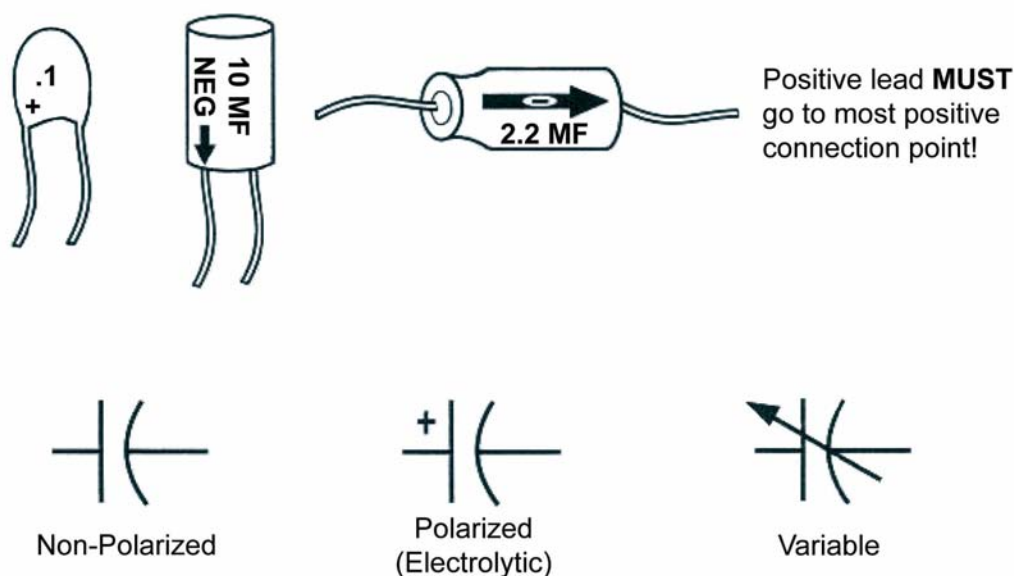


Figure 11-52

Capacitor Specs and Ratings

The maximum charge of a capacitor is its capacitance. Capacitance is specified in **FARADS**, **MICROFARADS** or **PICOFARADS**. The name **FARAD** comes from the last name of its discoverer, **MICHAEL FARADAY**. A one Farad capacitor connected to a one volt source will store **6,280,000,000,000,000,000 ELECTRONS** or 6.28×10 to the 18th power. One Micro-farad (1 μF) equals 0.000001 Farad (F) or one millionth of a Farad. One Picofarad (1 pF) equals 0.000000000001F or 10 to the minus 12 power. Refer to Figure 11-53.

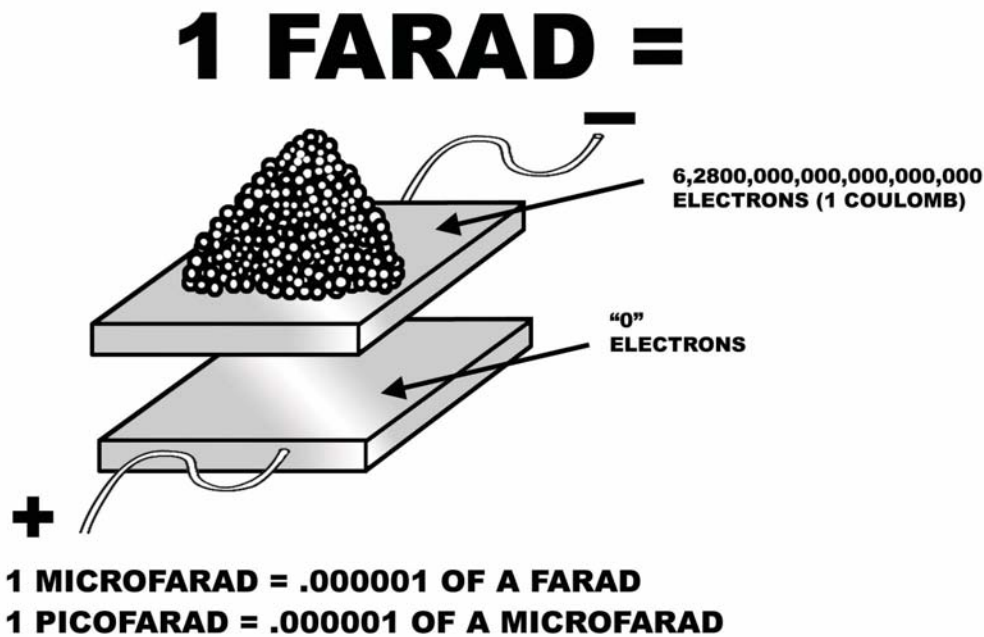


Figure 11-53

In addition to being rated in farads, capacitors are also rated according to the maximum voltage that they can handle. When replacing a capacitor, never use a capacitor with a lower voltage rating.

Three factors combine to determine the capacitance of a given capacitor:

1. The area of the conductive plates
2. The distance between the conductive plates
3. The material used as the dielectric

Calculating Total Capacitance

The total capacitance of a circuit is dependent on how the capacitors are designed in the circuit.

When capacitors are in parallel, total capacitance is determined by the following equation:

$$C_T = C_1 + C_2 \dots$$

When capacitors are in series, total capacitance is determined by this equation:

$$C_T = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2}}$$

Note: Always short across the terminals of a capacitor before connecting it to a circuit or meter. This discharges any residual charge that might be stored.

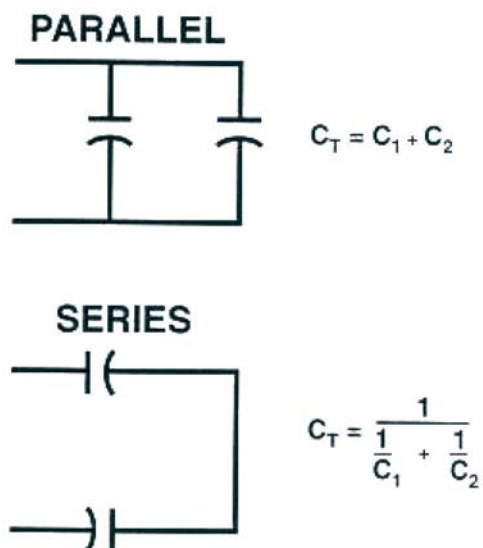


Figure 11-54

Capacitors store voltage for a period of time depending on how it is wired in a circuit and the rating of the capacitor. When a capacitor is the physical size of a Double “A” battery or larger it should not be touched, as an unwanted shock is definitely possible. Capacitors can discharge voltage quicker than they charge up in most cases and as a result make good voltage suppression devices.

Capacitor Effects

Capacitors block DC Current

Capacitors naturally will block DC voltages as they will quickly charge up and depending upon their capacitance, will stop the flow of electrons in a corresponding time.

Capacitors do not block AC Current

Because AC current constantly switches polarity, a capacitor will continue to charge each direction allowing a certain amount of electrons to cycle back and forth. The actual amount of AC current that is passed will depend on the size or capacitance of the capacitor.

Since a smaller capacitor would allow less AC current than a larger capacitor, they can be used to filter out unwanted AC interference on a DC circuit when hooked in parallel to the circuit.

Capacitor Uses

Spike Suppression

A capacitor may be used in parallel to a set of contacts or load coils in a inductive circuit. The capacitor will act as an electrical shock absorber to dampen out unwanted voltage surges.

Noise Filtering

A capacitor can be used in a parallel to a DC circuit to dampen out unwanted AC interference such as noise filtering in audio system circuits.

Supplemental Power Source

A very large capacitor is used in the power feed to high wattage stereo amplifiers to supply short bursts of current for driving the sub-woofers. The capacitor helps to prevent intermittent loss of battery power, which could cause the engine to die.

Timer Circuits

Capacitors are used in electronic devices to act as timers. Window defoggers, theater dimming, pulse wipers and auto day/night headlamps are some examples of systems that may use capacitors to control the timing of their events.

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Module 11 - Operation of Solid State Devices

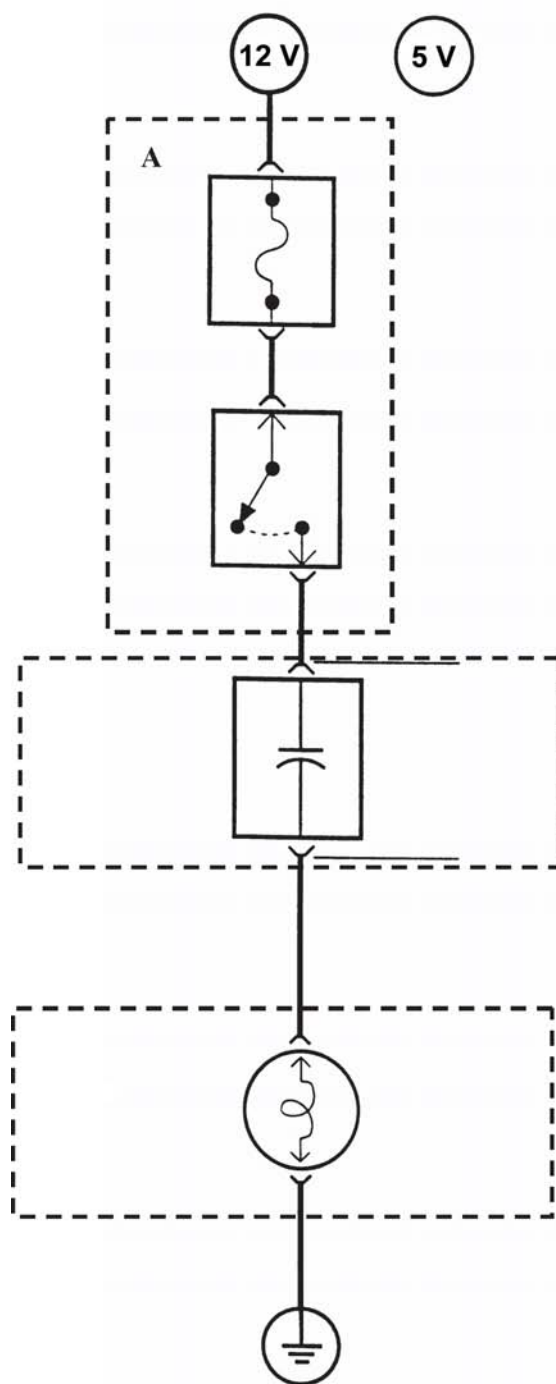


Figure 11-55, Experiment 11-7

Experiment 11-7

Experiment Objective: Demonstrate the effects that a capacitor has on a DC powered circuit. The purpose of the bulb in the circuit is to show current flow. Record your results below.

1. Assemble the circuit shown in figure 11-55.
2. Capacitor voltage after charging _____
3. Capacitor voltage after discharging _____
4. Does the bulb light? Why?

5. Does a capacitor block the flow of direct current? _____

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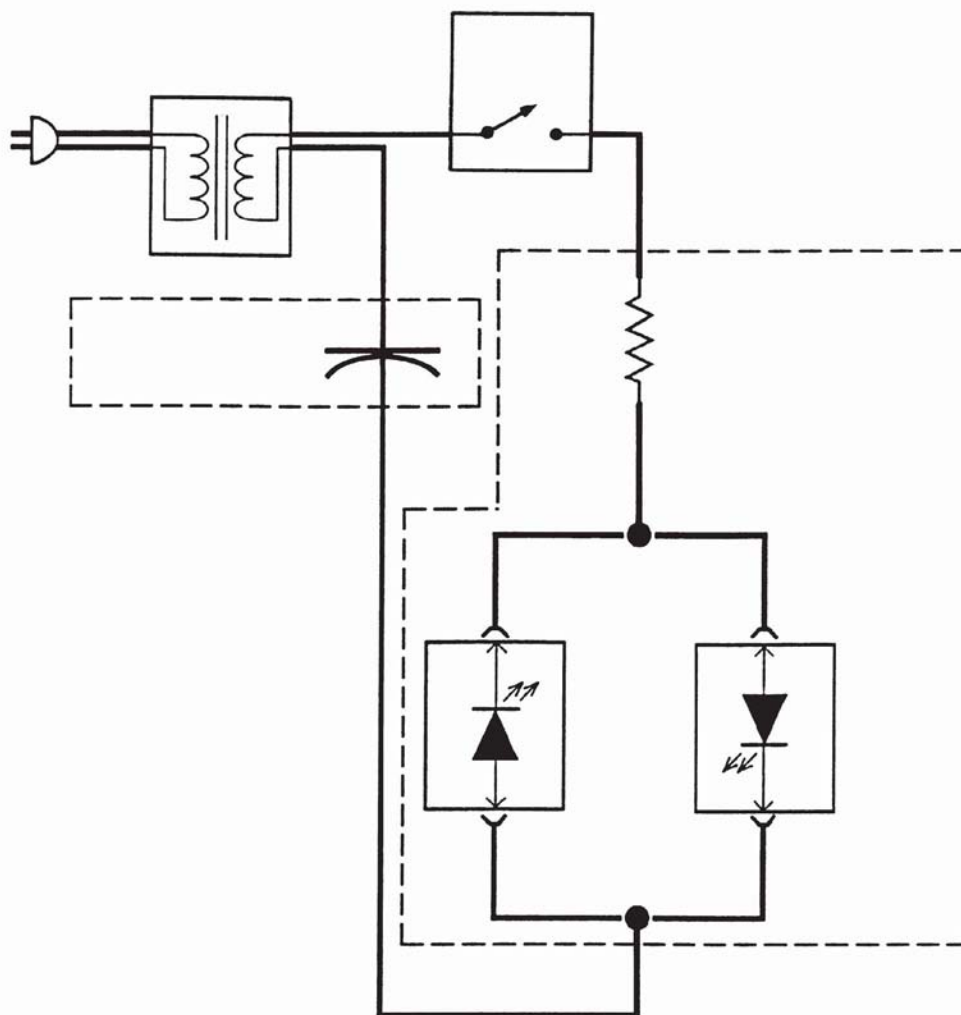


Figure 11-56, Experiment 11-8

Experiment 11-8

Experiment Objective: Demonstrate the effect that a capacitor has on an AC powered circuit.

Connect the circuit shown in Figure 11-56 to the 12 volt AC power supply on your project board.

When you apply power to the circuit which LEDs light?

BOTH _____

ONLY LED 1 _____

ONLY LED 2 _____

Turn off the project board power, turn around Module M and re-connect (reversing the voltage to the module).

Reapply power and check to see which LEDs light.

BOTH _____

ONLY LED 1 _____

ONLY LED 2 _____

Does a capacitor block the flow of alternating current? _____

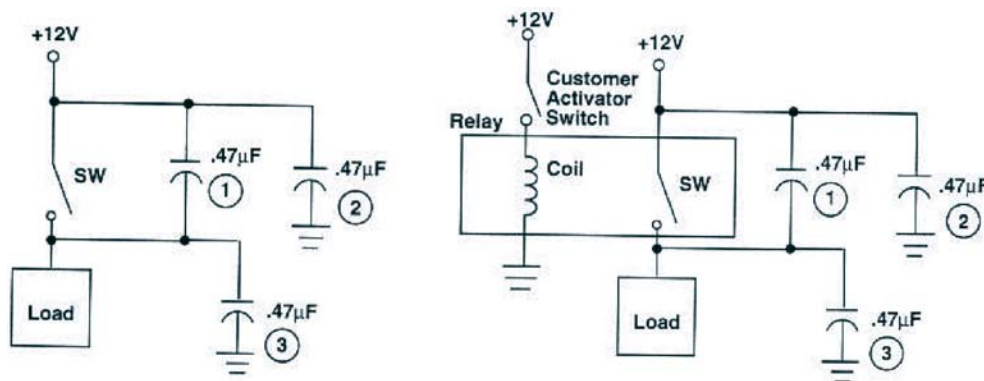


Figure 11-57, Where to add capacitors to control pop switch

To use these charts, first determine the type of device that is causing the "pop"; i.e. direct switch activated or relay activated. Next, add capacitors one at a time, and then test to see if each capacitor adequately controls the "pop." If the capacitor in position 1 does not control the "pop," then add the capacitor in position 2, etc.

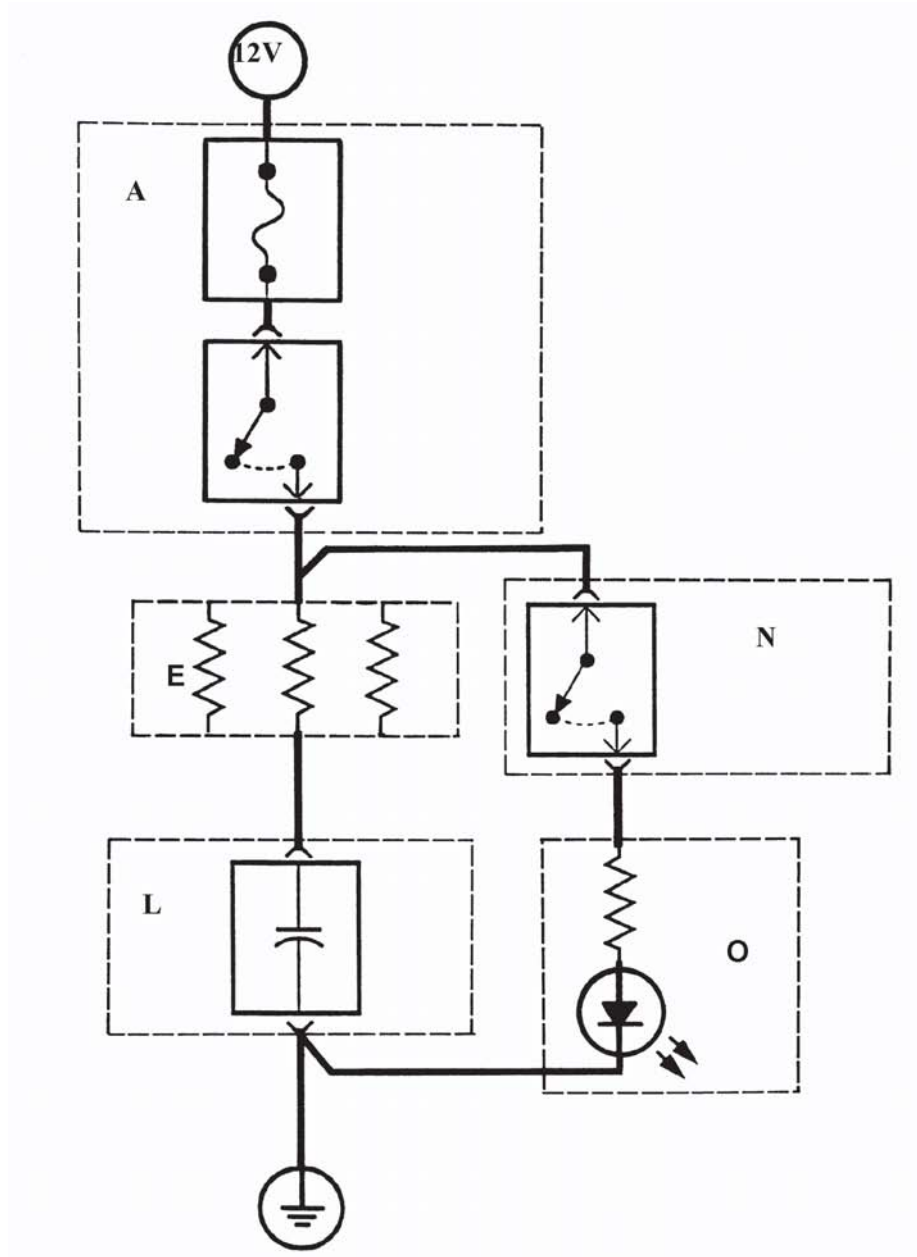


Figure 11-58 Experiment 11-9

Capacitor Timer

If a charged capacitor is placed in a circuit with a resistor, current flows in a predictable way. That is, the amount of time it takes to charge and discharge the capacitor is predictable and accurately repeatable. Because of this property, capacitors can be used to make up timer circuits.

Experiment 11-9

Experiment objective: Demonstrate the operation of a capacitor in a timing circuit.

Assemble the circuit shown in Figure 11-59 using the 10k Ohm resistor. Record your results below. Repeat the procedure several times to check your accuracy.

1. Monitor the Capacitor voltage, close the "A" switch and determine how many seconds it takes for the capacitor to charge.
Open the "A" switch, push the "N" switch and determine how many seconds it takes for the capacitor to discharge.

Time required for LED to go out. _____

2. How many seconds for the capacitor to charge.

Seconds for capacitor to discharge. _____

Time required for LED to go out. _____

3. How many seconds for the capacitor to charge.

Seconds for capacitor to discharge. _____

Time required for LED to go out. _____

Replace the 10k ohm resistor with the 1k ohm resistor.

4. How many seconds for the capacitor to charge.

Seconds for capacitor to discharge. _____

Time required for LED to go out. _____

Replace the 1k ohm resistor with the 100 ohm resistor.

5. How many seconds for the capacitor to charge.
Seconds for capacitor to discharge.
Time required for LED to go out.

What characteristics of a capacitor make it useful in a timer circuit?

Theater Dimming Circuit

Student Workbook

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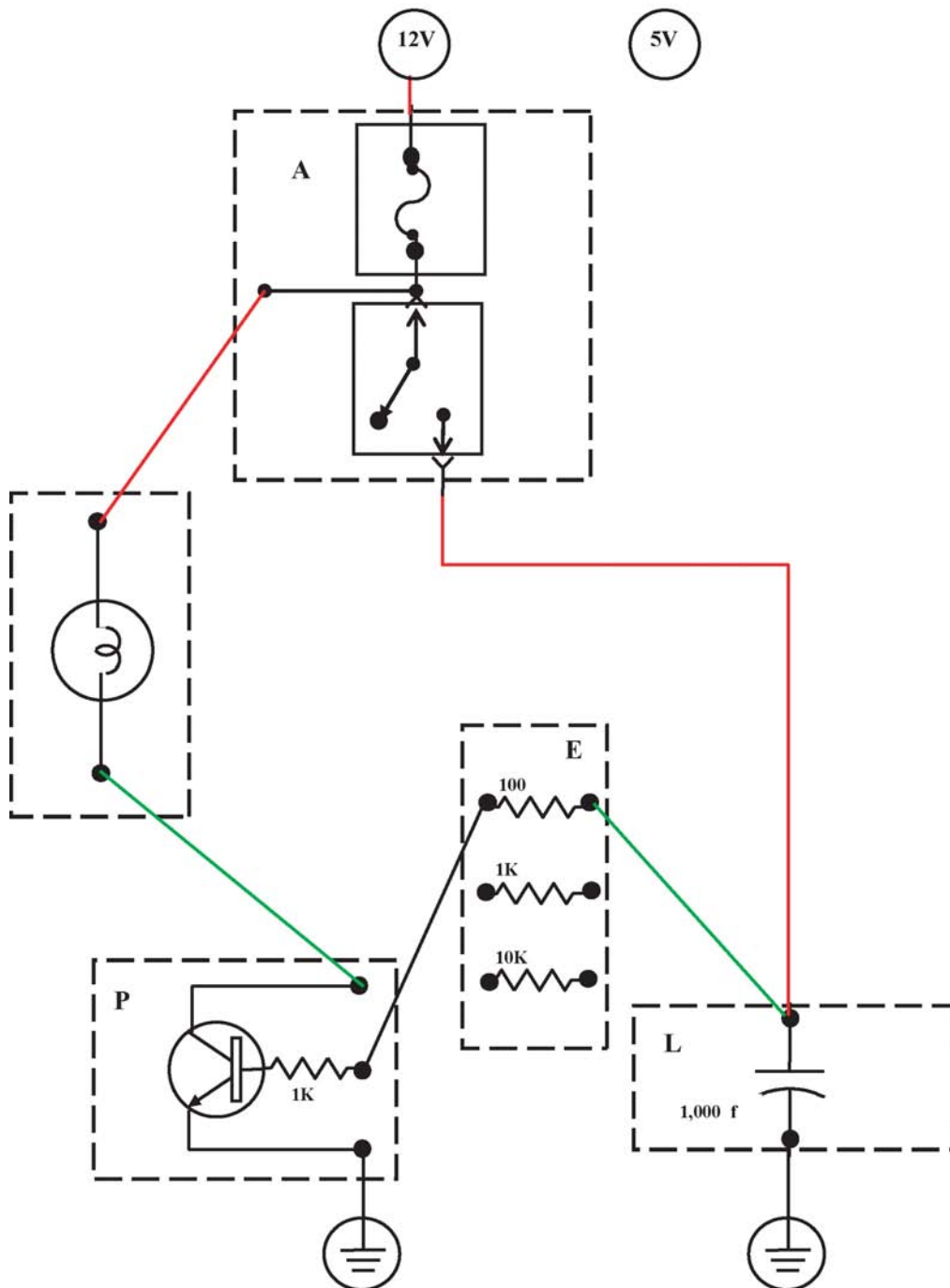


Figure 11-59, Experiment 11-10

Experiment 11-10 – Theater dimming circuit

Objective: To help the student understand how capacitors can be used with transistors to create theater dimming effects on the lamp and how the time out can be changed.

Build the circuit shown on the corresponding diagram and operate it to make sure that the lamp operates when the switch is turned on and delays when the switch is turned off.

1. Turn the switch on and off. Begin timing the dimming of the lamp as soon as the switch is turned off. Record the seconds it takes for the lamp to go completely out. Also note the intensity of the lamp while the switch is on.

2. Change the wires, which connect the capacitor to the base of the transistor, from the 100 ohm resistor to the 10K ohm resistor. Time the period it takes for the bulb to completely go out again. Also note the intensity of the bulb while the switch is on.

3. Why is the lamp intensity dimmer when the 10K ohm resistor is in the circuit compared to the 100 ohm resistor?

4. Why does the lamp stay on longer when the 10k ohm resistor is in the circuit?

5. Try some other variations on your own to lengthen or shorten the on time of the bulb such as two capacitors in parallel or in series. Record your findings.

Automatic Lamps Circuit

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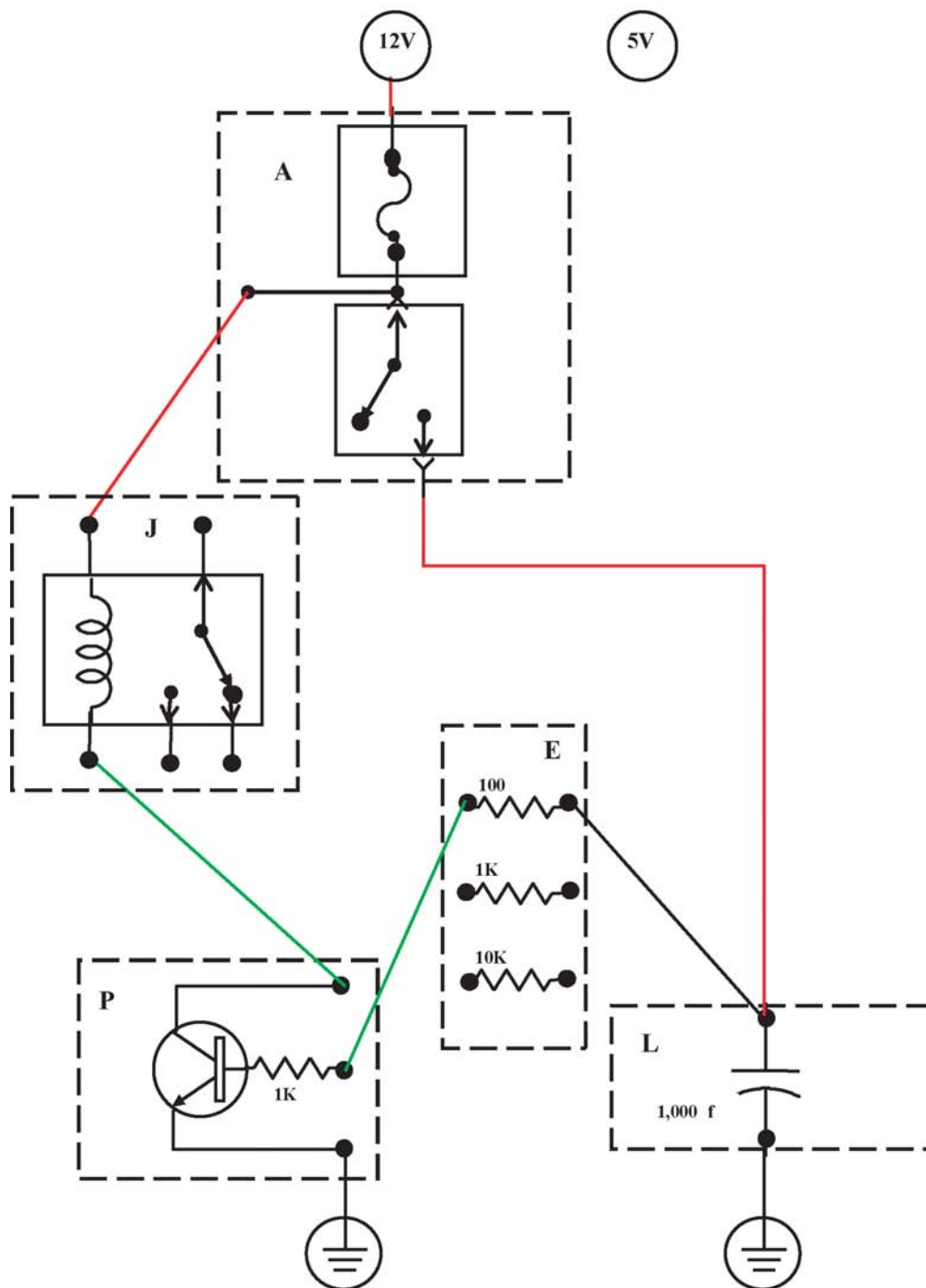


Figure 11-60, Experiment 11-11

Experiment 11-11 – Timed off relay (auto lamp control)

Goal: to help the student understand how accessories such as retained accessory power, rear window defogger and auto lamp controls achieve the discrete on-off timer effect.

Remove only the bulb from your previous circuit and install the relay as shown in the corresponding illustration. Make sure to start with the 100 ohm resistor wired in Figure 11-60, as shown also.

1. Monitor the voltage across the relay primary. Turn the switch on and off. Record the voltage across the relay:

While the switch is on _____

At the point when the relay just clicks off _____

2. Record the time period for the relay to click off: _____
3. Switch to using the 10k ohm resistor in the base circuit of the transistor and record the same as above:
Voltage across the primary with switch on. _____
Voltage across the primary as relay clicks off. _____
Time period for relay to click off _____
4. Why does it take longer for the relay to click off when the 10K ohm resistor is in the circuit?

5. How much voltage do you think it would take for the relay to click on?

Will it take more than the click off voltage or the same? _____

Why?

Lesson 5 Review Questions

1. Capacitors are commonly used as, _____ and _____.
 - a. Voltage supplies, DC filters.
 - b. Resistors, DC filters.
 - c. Rheostats, potentiometers.
 - d. Timers, resistors.
2. A charged capacitor acts like a _____.
 - a. Switch.
 - b. Battery.
 - c. Terminal.
 - d. Resistor.
3. The basic unit of measurement for capacitor ratings is the _____.
 - a. Joule.
 - b. Ohm.
 - c. Farad.
 - d. Cochrane.
4. A battery _____ electricity while a capacitor only _____ electricity.
 - a. Stores, creates.
 - b. Creates, stores.
 - c. Distributes, collects.
 - d. Collects, distributes.
5. Capacitors block the flow of _____ current but allow current to pass.
 - a. Strong, weak.
 - b. Weak, strong.
 - c. AC, DC
 - d. DC, AC
6. Capacitors placed in parallel will:
 - a. Decrease the total capacity.
 - b. Increase the total capacity.
 - c. Leave the capacity the same but increase the voltage which can be tolerated.
 - d. Lower the voltage tolerance.
7. A capacitor used for spike suppression will normally be placed in _____ to the load or circuit.