Semiconductors

Semiconductors are materials that have (typically) four electrons in the valence shell. As such they are neither good conductors, nor are they good insulators. We have here the opportunity for creativity. Silicon, and Germanium, are among the more popular semiconductors we use to make diodes and transistors. In their pure form they take on a crystalline structure.

Pure silicon, or any other semiconductor, has a specific resistance. Depending on purity that resistance may be in the tens of thousands to hundreds of thousands of ohms. Impurities play a major role in the resistance of the crystal. Heat is also a factor. As the crystal gets hot more current carriers (electrons or holes) are freed from their bonds, allowing resistance to flow easier, lowering resistance.

If we deliberately add impurities to the semiconductor material (called doping), we can control how conductive the material is. By doping the Silicon with some element that has three valence electrons we make a silicon material that we call “positive-type, or P-Type”, meaning it is capable of accepting an electron for each impurity atom that we add. If we dope the Silicon with some element that has five valence electrons we make a silicon material we call “negative-type, or N-Type”, meaning that it has an excess of electrons. If we melt these two types together, the junction where they bond forms a region that will allow the extra electrons in the N-type to pass through to the P-type if we apply a voltage across the junction, negative to N-Type and positive to P-type. Resistance drops down to hundreds, tens, or even a fraction of an ohm. If we reverse our voltage the electrons are pulled away from the junction, toward the positive voltage, and the holes are pulled away from the junction, toward the negative voltage, and our resistance of the junction is in the millions of ohms.

This is our basic semiconductor device, called a Diode, meaning that it has two electrodes. If we apply Forward Bias to the diode (Negative voltage to N-type and Positive voltage to P-type) we conduct electricity. If we reverse the voltage (Reverse Bias) we do not conduct electricity.

The terminal on the N-type side we call the Cathode, meaning something that emits electrons. The terminal on the P-type we call the Anode, meaning something that accepts electrons (as viewed from the inside of the device).

Our doping need only be in the parts-per-million to be effective. By changing the doping material, doping percentage, size and structure of the junction, and material of the substrate (in our example, the Silicon), we can have different results.

A closer look

When a diode is forward biased the electrons from the N-type material move toward the junction, and holes from the P-type material move toward the junction. The hole and the electron combine in the area of the junction, allowing current to flow. Our supply of electrons and holes are supplied by our battery, or power supply, or whatever our source of power is.

The combining of the electron and hole releases an electromagnet radiation of some sort, usually in the frequency of heat, and in some cases, light. Silicon produces a radiation in the infrared region. Gallium Arsenide, a semiconductive molecule, produces radiation in the red region.

Before the junction can conduct we have to overcome the resistance of the junction to conduct at all. This voltage and current we must apply makes a Threshold level that must be attained before we see conduction. In Silicon we must have at least 0.60 volts, or so, before the junction will break into conduction. Germanium requires less, about 0.40 volts. Gallium Arsenide requires about 1.20 volts.

Real devices

Diodes used in low level signals (below 100 mA, and below 100 V) are called signal diodes, and we use them in various ways we will discover in circuits to be introduced later.

Diodes designed to work at higher power levels we use to change AC to DC in power supplies. This process of changing AC power to DC power is called rectification, and diodes used in these type of circuits we call rectifiers.

Signal diodes and rectifiers both work in the same way, the only difference is their physical size of the substrate and the case they must be in to dissipate the power.

Silicon signal diodes we see most often are of the part numbers 1N914, 1N4148, and 1N4448. The “1N” at the beginning indicates that the device is a diode (one junction). The numbers that follow have no special meaning that indicates characteristics. A 1N914 made by any company has about the same characteristics. All will be made of Silicon (and thus have a forward voltage of around 0.6 volts). All will carry about 100 mA and still be within a safe operating range. All will be able to withstand about 100 volts when reverse biased before the junction breaks down are the device self destructs.

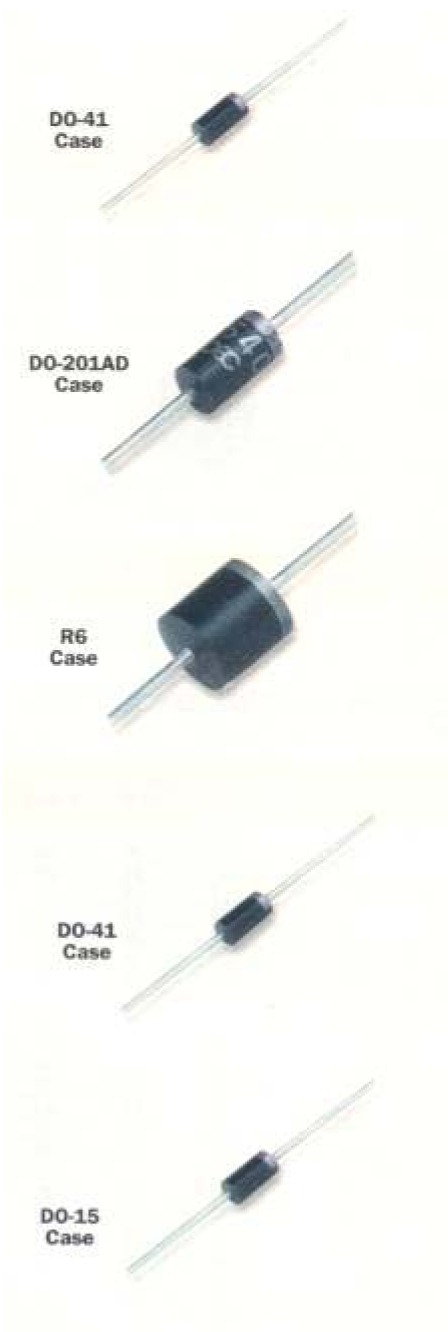
Silicon Rectifiers we often find are numbered 1N400x series of numbers. No matter who makes them, they will all pass 1 Amp of currently safely. All 1N4000’s will have a breakdown voltage of 50 V. 1N4001’s have a breakdown of 100 V. 1N4002’s have a breakdown of 200 V. The list continues as standard part numbers up to 1N4007 with a breakdown of 1000 volts.

1N540x devices are capable of operating at 3 Amps. 1N5400 has a breakdown voltage of 50 V. 1N5401, 100 V. 1N5402, 200 V. And so on.

These part numbers are Industry standards, and are used in home computers, microwaves, stereos, as well as slot machines both reel and video.

The cases are standard sizes also. You can’t tell much by looking at the case, other than judging that is works within a certain power range. Larger cases are required at higher current levels.

The DO-35 case is a standard size for signal diodes. The case is usually clear, or white glass. The banded end is the Cathode. !N914, 1N4148, and such typically look like these.



The DO-41 and DO-15 cases are deices that are rated at around 1 Amp, maximum, and less than 1,000 volts. 1N400x devices look like these.

The DO-201AD size case is physically larger than DO-41 and are capable of handling up to 3 Amps and 1,000 Volts.

The R-6 size case is usually a device rated at 6 Amp, and less than 1,000 volts.

The main difference between the DO-41 and DO-15 cases are not visible on the outside of the device. Between the actual silicon diode substrate itself and the case is a layer of insulation material called Passivation. In DO-15 devices this passivation is plastic. In DO-41 devices this passivation is glass.

Glass passivated devices are capable of working at higher operating temperatures than plastic passivated devices before failure occurs. Typically plastic passivated devices can operate at up to 125 degrees centigrade before failure. Glass passivated devices are rated at 150 degrees centigrade. That is “ambient” temperature. The temperature of the silicon substrate inside the case, not the outside temperature.

In all these circumstances the silicon substrate inside is enclosed in a hard plastic case. The part number is printed on the case. If you want to know the characteristics of the device, you look up the part number in a reference book, or catalog. There are only a few dozen different types of diodes in use in the gaming industry. It isn’t a difficult task getting to know the major players by part number.

Part numbers

The manufacturer of the diode assigns an Industry Standard part number to the device, like 1N4004. When IGT buys these devices they assign their own part number to it (48402190). When Bally uses it they assign their part number (E-587-40). When Wells Gardner uses t in their monitors they assign their number (066X0071-001). Distributors assign their part number (900-2869 for Radio Shack). Happ Controls assigns them their number, as does Aristocrat, Konami, or any other person who uses or distributes the device.

In purchasing the parts for our shop we need not buy a different supply of 1N4004s from each vendor. We can shop around and buy a 1N4004 from whoever has it at the best price. They may all, in the beginning, come from the same manufacturer. We can be sure that all diodes marked 1N4004 will have the same characteristics, and be compatible.

To make stocking even easier, we can realize that a device rated for a maximum of 200 volts will work fine at all lower voltages as well. So why not just buy a stock of 1,000 volt rated devices and use them for 1N4000, 1N4001,1N4002, and so on?

This is what companies like Philips does in marketing their line of “Replacement Parts”, like the ECG line of components. NTE Electronics does this also with their NTE brand. They stock the components with the highest voltage rating and list it as a substitute for all equal, or lesser, rated devices.

A word of warning here. **SUBSTITUTE** does not mean **EQUAL**. A 1N4007, rated at 1,000 volts, will substitute for a 1N4001 rated at 100 volts. But the 1N4001 will not substitute for the 1N4007.

The higher voltage device may be stocked and used for all lower voltage ratings. In most cases the higher voltage rating may cost you a few cents more per diode. It is a judgment call on the part of the person who purchases the components to choose what is going to be stocked.

Prices can vary greatly. A 1N4004 from one vendor may cost you \$0.05, or \$1.50 from another vendor or distributor. Shop around. Be aware that a real bargain price may be an older component with oxidized leads. When buying a component from a vendor you don’t know, buy in small quantities first just to sample quality and promptness of service. Any of the companies listed herein I would recommend. I can think of none off hand that I would warn you against.

Purchasing in quantity brings the price down somewhat also when purchasing from a distributor, like Happ Controls, or Radio Shack. Usually manufacturers (like IGT or Bally) do not give discounts, and have higher prices than available from distributors. Not many manufacturers want to get into being parts distributors. If they sell a batch of 100 diodes, they may short themselves on a production run. A major error to a manufacturer. Personal experience is highly valuable. In many cases I can get better prices on common parts from IGT than Radio Shack, for instance. Some things are more available from Radio Shack.

Standard Part Numbers

As mentioned a specific component may be known by various part numbers from different game manufacturers or gaming component distributors. Some game manufacturers do not even give you a parts list or a tech manual. To combat this a standard part number list is available at the Bench Techs forum at Delphi Forums.

http://forums.delphiforums.com/benchtech

This list is in constant development and will cross part numbers between various gaming manufacturers and distributors, to Industry Standard part numbers. It also provides an often educational description of what the part is.

Delphi forums is free for basic service, or advanced service and capabilities at a modest fee. There is no charge for access to the Bench Techs forum, or for the parts cross list. Typical size of the file is between 500K and 1 MB. It will fit on a floppy disk for convenience. It is distributed as a Microsoft Excel file, but easily converts to text, if you prefer. Don’t try to print it unless you have a lot of paper and time. It is typically between 2,000 and 3,000 lines long (in Excel) and VERY wide.

This listing is even used by some Distributors who deal with the Gaming Industry, such as DC Supply. So referencing the standard part number assures you of getting the part you want. You and the distributor will always be certain to be talking about the same part.

Suppliers mentioned:

DC Supplies (highly suggested)
431 W. Poplar
Porterville, CA
93257
(559) 359-6710

Happ Controls
(Wholesale Electronics is a division of Happ Controls)
6870 S. Paradise Rd.
Las Vegas, NV 89119
(702) 891-9116
(702) 891-9117 fax
www.happcontrols.com

Radio Shack
(Get the Commercial catalog, not the store catalog)
AKA Tech America
PO Box 1981
Fort Worth, TX 76101-1981
(800) 877-0072
www.techam.com

Others:

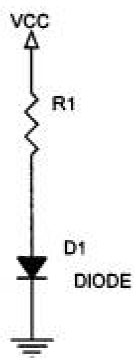
Mouser Electronics
1000 N. Main St.
Mansfield, TX 76063-1511
(800) 346-6873
www.mouser.com

Allied Electronics
7410 Pebble Drive
Fort Worth, TX 76118
(800) 433-5700
www.alliedelec.com

Diode exercise

Our first exercise with semiconductors will be with diodes. We will use the same breadboard we used with making previous circuits and hook up various devices, analyzing what we observe in the process. From these observations we will get an understanding of what proper behavior of the components is. Once we understand normal behavior we will deliberately destroy the device and get a familiarity with what it takes to destroy the device, and what characteristics it takes on when it fails.

We will choose from a variety of diode devices (Silicon, Germanium, and a Light Emitting Diode, at least).

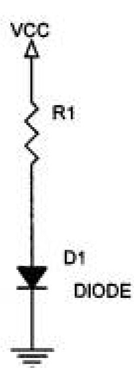


Select a diode to do the exercise with.

1N914 Silicon signal diode
1N270 Germanium signal diode
1N5819 Schottky diode
1N400x 1 Amp rectifier
Zener Any Zener diode of a low voltage (below what ever VCC is used)
LED, red
LED, yellow
LED, green
LED, blue or white

Select a resistor within the safe limits of the diode. Reference a data book that contains operating characteristics for the diode. If no data is available keep the maximum current below 100 mA, but higher than 1 micro-Amp.

Make a simple series circuit using a diode with the cathode connected to ground and a resistor connecting to a positive voltage, VCC (4.5 Volts to 12 volts).



Measure the voltage at VCC.

Measure the voltage across the diode.

Calculate the voltage across the resistor. (VCC – V diode). (This step is for an exercise in Ohm’s Law. You could just measure the voltage across the resistor directly.)

Find the current through the diode. We can find this by finding the current through the resistor (V / R = I). Since this is a simple series circuit, the current through the resistor will be the same as the current through the diode.

Calculate the effective resistance of the diode at that current. (V diode / I = R).

Repeat the exercise using different resistors. Keep the current in the safe operating range of the diode.

Graph the voltage across the diode at different currents.

Graph the effective resistance of the diode at different currents.

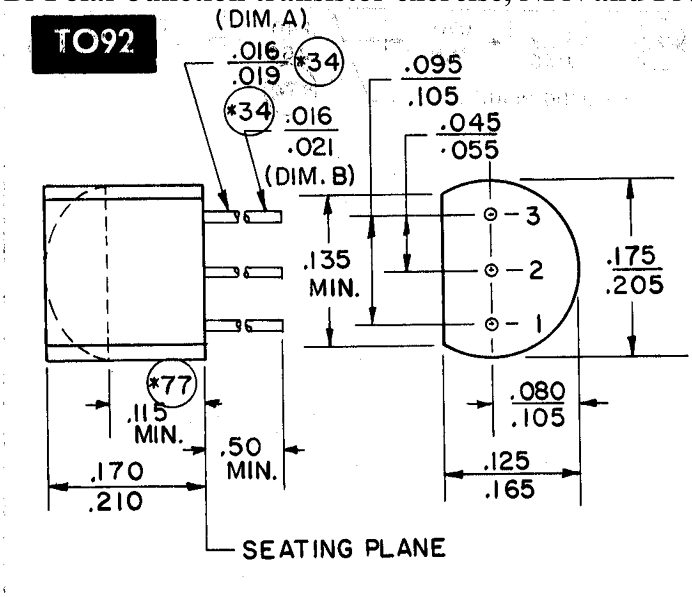
Repeat the whole exercise using different diodes.

What can we tell from the exercise?

Different types of diodes have a different pattern of forward voltage.

At different currents the voltage across the diode changes to some degree. These changes reflect the changing resistance of the diode at various currents. Below a certain level the change is major. Once the diode has sufficient operating current the voltage across the diode stays fairly flat, but its resistance still changes as current through the diode changes.

Bi-Polar Junction transistor exercise, NPN and PNP

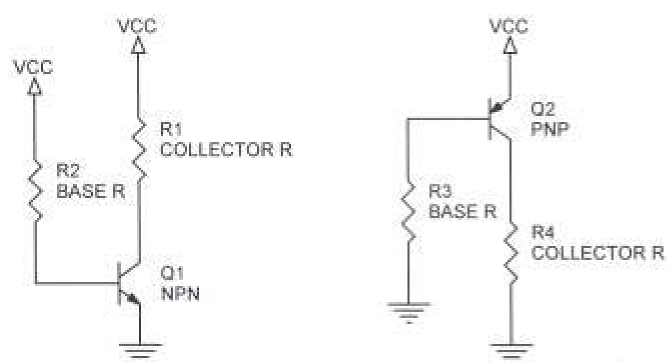


Select a transistor for the exercise:

Transistor	Type	Pinout 1 2 3
2N2222A	NPN	E B C
2N2907A	PNP	E B C
2N3904	NPN	E B C
2N3906	PNP	E B C
2N4401	NPN	E B C
2N4403	PNP	E B C
PN2222	NPN	E B C
PN2907	PNP	E B C

(For other possibilities, other reference material may be required.)

Construct the circuit below using appropriate resistors.



Select a base resistor to give about 1 micro amp of base current. (VCC/ 1 micro amp)

Select a collector resistor to give about 100 mA, maximum, if the transistor should turn all the way on. (VCC / 100 mA)

Connect the transistor up in a Common Emitter circuit (as shown).

Measure the voltage on the base.

Measure the voltage on the collector.

Find the voltage across the collector resistor. (Calculate or measure).

Calculate the collector current. (V R3 / R3 = I).

Calculate the gain of the transistor (IC / IB).

Calculate the effective resistance between the Emitter and the Collector of the transistor. (V collector / I = R e-c).

Calculate the wattage being dissipated by the transistor. (V c-e x I).

Repeat the exercise using a different base resistor and the same collector resistor.

Repeat the whole exercise using a different collector resistor.

Note how gain changes under different base and collector currents.

Characteristics of the transistor:

Gain must be stated under a certain condition.

Voltage at the collector during saturation varies with different collector currents.

Wattage rating of the transistor can be exceeded even while within the safe operating range of collector currents and voltages.

Transistor exercise

Select an NPN transistor for the exercise.

Select a base resistor to give about 1 micro amp of base current. (VCC/ 1 micro amp)

Select a collector resistor to give about 100 mA, maximum, if the transistor should turn all the way on. (VCC / 100 mA)

Connect the transistor up in a Common Emitter circuit (as shown).

Measure the voltage on the base.

Measure the voltage on the collector.

Find the voltage across the collector resistor. (Calculate or measure).

Calculate the collector current. (V R3 / R3 = I).

Calculate the gain of the transistor (IC / IB).

Calculate the effective resistance between the Emitter and the Collector of the transistor. (V collector / I = R e-c).

Calculate the wattage being dissipated by the transistor. (V c-e * I).

Repeat the exercise using a different base resistor and the same collector resistor.

Repeat the whole exercise using a different collector resistor.

Note how gain changes under different base and collector currents.

Characteristics of the transistor:

Gain must be stated under a certain condition.

Voltage at the collector during saturation varies with different collector currents.

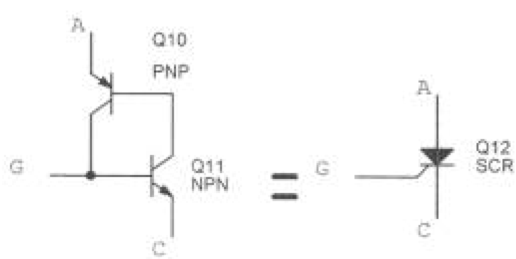
Wattage rating of the transistor can be exceeded even while within the safe operating range of collector currents and voltages.

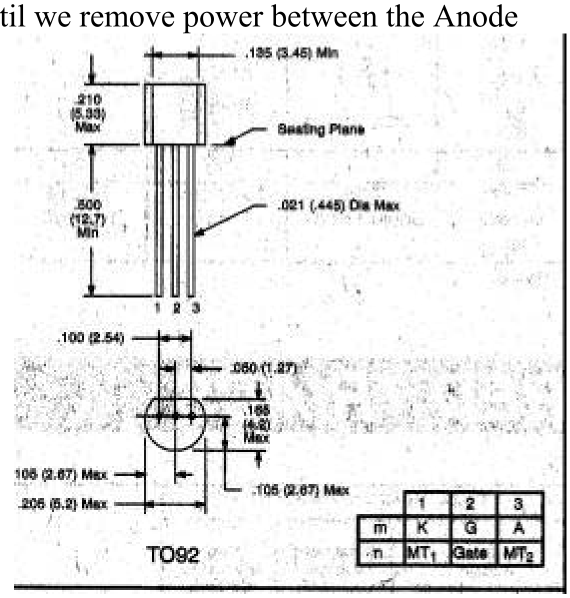
SCR exercise

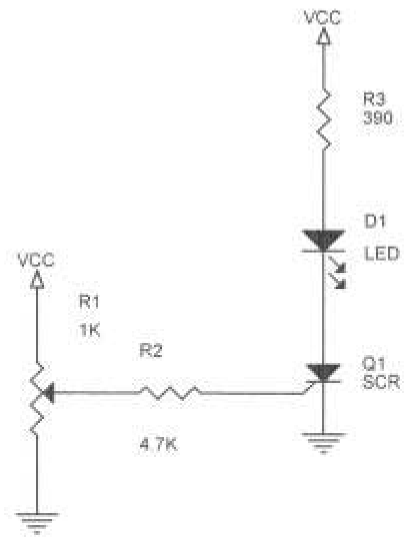
An SCR (Silicon Controlled Rectifier) is exactly what the name implies. A rectifier (diode), made of silicon, that we can control with an input. SCRs are a member of a class of components called Thyristors. They all have the characteristic that once triggered on, they stay on until power is removed on the output. The SCR is a thyristor that will pass current in only one direction (DC only).

An SCR is made up of two transistors, as shown below. When we draw current from the base lead of the NPN transistor (called a Gate), we begin to turn the NPN transistor on. The NPN transistor turning on starts drawing current through the emitter and collector of it. This circuit just happens to include the base circuit of the PNP transistor. As the NPN transistor turns on it turns on the PNP transistor, which starts to conduct. The collector of the PNP transistor feeds back to the base of the NPN transistor. As the PNP transistor conducts it turns on the NPN transistor even more.

All we have to do is send a pulse to the base of the NPN transistor, and the SCR latches in the ON condition. It will stay on until we remove power between the Anode (the emitter of the PNP side) or the Cathode (the emitter of the NPN side).







Construct the above circuit. Start with 0V out at the slider of the pot. As we increase voltage at the pot the SCR will come on at some point. We want to note at what voltage and current level the SCR turns on. After it is on, we will return the Gate current we apply back to 0 V, and observe that the SCR stays on until we remove power at the output.

1) Monitoring the voltage at the slider of the pot, increase the voltage out by 0.10 V.

2) Measure the voltage at the gate of the SCR.

3) Calculate the gate current.

4) Is the SCR ON?

5) Repeat steps 1) through 4) until the SCR turns on.

6) Note the voltage on the gate and the current through it when it first turned on.

7) Return the voltage at the slider back to 0V.

8) What is the voltage on the Gate?

9) Did the SCR stay on?

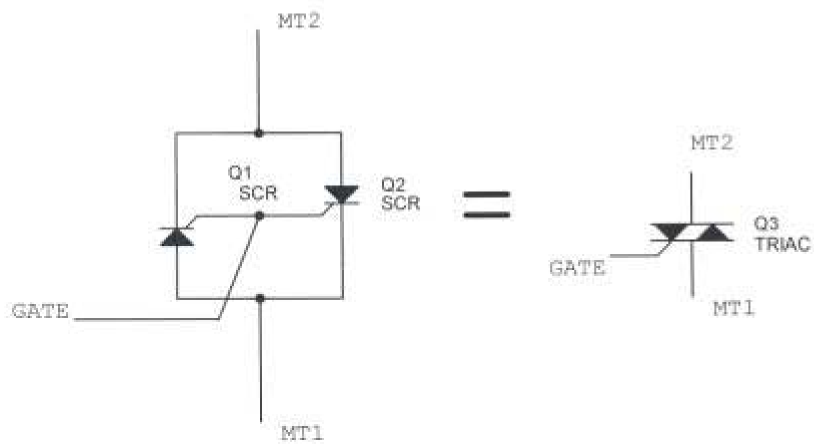
10) Remove one side of resistor R3.

11) The SCR should turn off and stay off after R3 is reconnected.

Triacs

A Triac is another member of the Thyristor family. The Triac is essentially two SCRs placed back to back, allowing the device to operate on AC. We have a Gate input, common to both SCRs, and two Main terminals, MT1, and MT2.

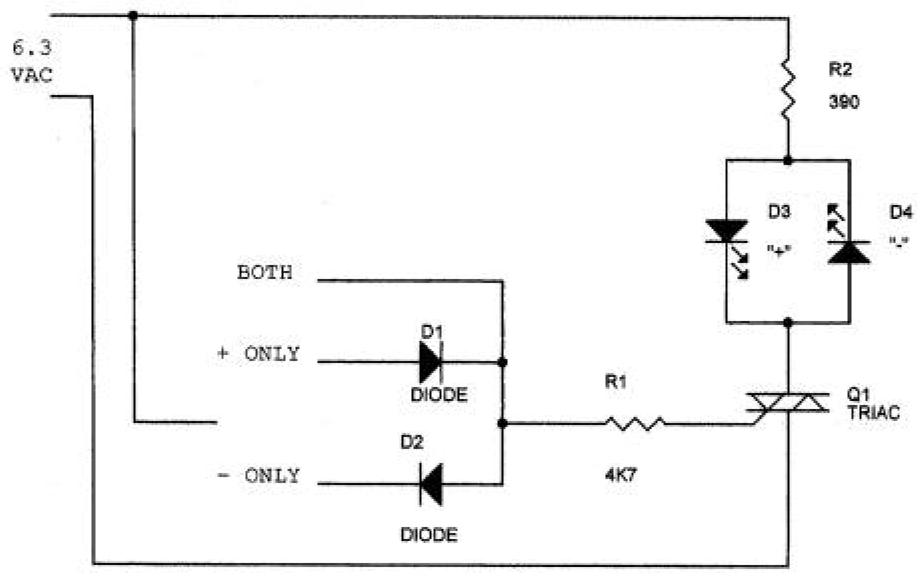
While SCRs are used on logic boards to control DC devices, SCRs are used to control AC devices. Operation is the same.

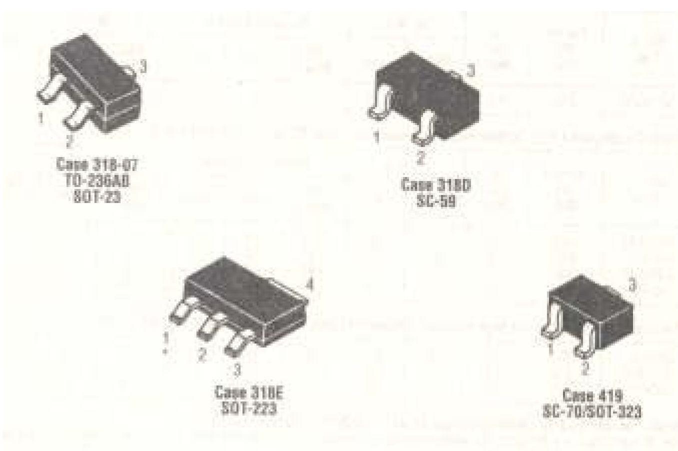


Like any other transistor, SCRs and Triacs may come in various packages. The larger the package, the higher the power it can control. Larger cases allow for more heat to be dissipated, meaning more current may be passed through the device, and higher voltages may be tolerated.

Triac exercise

Construct the circuit below, leaving the jumper shown to be attached in one of three places. It may be attached to D1 to have Q1 pass only the positive sides of the AC signal, to D2 to pass only the negative side of the AC signal, or directly to the gate to pass both sides of the AC signal.

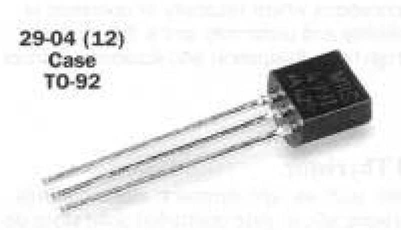




Surface Mount Device Case styles

(Not shown in proportion to real size. The SOT-223 case is about the size of a capitol “E” shown here. The SOT-23 would be about the size of a lower case “a”. SC-70 is even smaller.

The cases are so small only a two or three character code is used to describe the part. You can’t tell from the case what part is inside. It may be a diode, two diodes, a transistor, or an Integrated Circuit.
Ratings are typically less than 50 V and less than 1 Amp.



Leaded components tend to be somewhat larger than surface mount devices

The TO-92 case (dimensions shown in the previous SCR lesson) is less than ¼” cubed. The leads are 0.050” apart. Voltage is usually less than 100 V. Current is seldom over 1 Amp.

You can’t tell from the case what’s inside. The case is usually large enough for a full part number.

The TO-126 case is usually rated at a little higher power than the TO-92, but less than the TO-220. Ratings of a few hundred volts are typical at usually an Amp or Two.

And again, no, you can’t tell from the case what is inside. The case is large enough for a part number, manufacturer’s logo, and a manufacturing date.

The TO-220 case is large enough to handle a few hundred volts at up to five or ten Amps.

And again, no, you can’t tell from the case what is inside. The case is large enough for a part number, manufacturer’s logo, and a manufacturing date.

In applications where the device dissipates above a few watts, a heat sink is used to pull the heat away from the package.

Typical cases of leaded components (not shown in proportional size).