SILICON CONTROLLED RECTIFIER
Hobby Manual
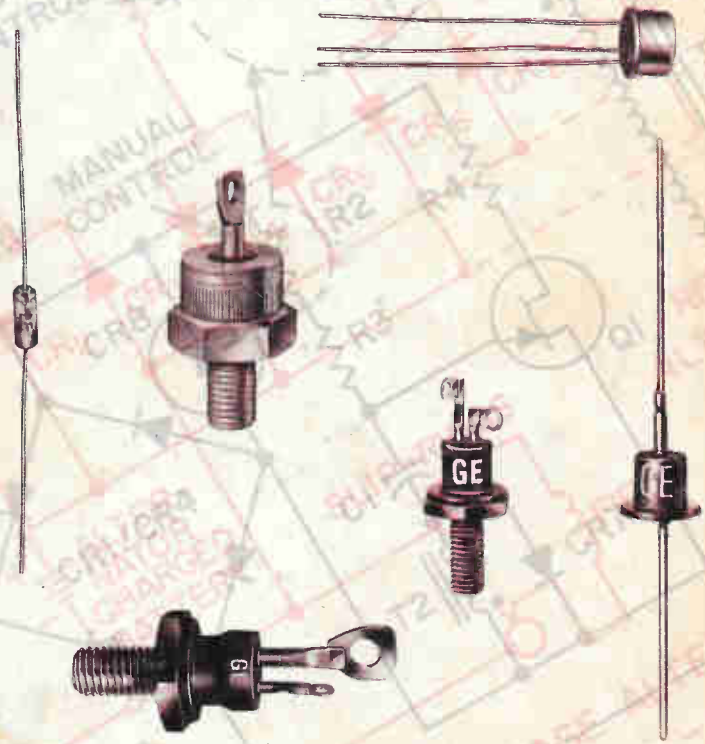
SCR's, Silicon Rectifiers, and other Semiconductor Components in USEFUL and LOW-COST CIRCUITS
for AMATEURS, HOBBYISTS, ENGINEERS

Silicon Controlled Rectifier
Hobby Manual

APPLICATION ENGINEERING CENTER

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GENERAL ELECTRIC

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Developments in power semiconductors have opened a new field for the home experimenter, the hobby man, the do-it-yourself handy man, and others that have never dabbled very much in electronics.

Take a look at the Table of Contents. You can see from the wide variety of projects that electronics with power semiconductors is now capable of performing many useful functions, quite remote from the entertainment field.

Perhaps you have heard of some of the things going on in industrial and military work with electronic brains and muscle controls. Many of the projects included herein are adaptations of some of these developments, made possible by the new power semiconductors and their expanding usage at lower costs. We have certainly come a long way in a few years.

Mechanical switches have been pretty commonly used, in one form or another, for turning off electrical devices. Everything from flashlights to hydro plants uses switches.

General Electric engineer Gordon Hall will go down in history as the developer of the first commercial semiconductor power switch — a switch all bound up in a tiny chunk of silicon. Christened "Silicon Controlled Rectifier" and launched on a massive flood of switching problems that the mechanical switches couldn't handle, this youngster is rapidly making a name for himself (SCR, for short).

The things you can do with an SCR are numerous and varied. Who would have ever thought that a switch could be a lamp dimmer, or could control the speed of a motor, or precisely regulate the voltage of a power supply? SCR's can be used to generate sound, control temperatures, flash lights, produce sparks, convert AC to DC, DC to AC, and AC to AC of a different frequency or DC to DC of another voltage. And yet — the present uses of these switches are still widening.

This book, then, is a unique collection of useful circuits to delight your tinkerer's fancy, amaze your friends, build your knowledge, and increase your prestige in the world of solid-state electronics.

TABLE OF CONTENTS

BASIC SEMICONDUCTOR OPERATION

Since we are getting into a field that is brand new to a lot of people, a brief refresher course is in order.

If we connect a 12 volt battery to a lamp which has a resistance of 24 ohms, Figure 1.1, we can calculate the current by Ohm's law, and find $\frac{1}{2}$ ampere. The power in the lamp is then $P = E\, I$, or 6 watts.

E = 12 VOLT BATTERY   CURRENT I   LAMP R = 24 OHMS $I = \dfrac{E}{R} = \dfrac{12}{24} = 0.5$ AMPERES
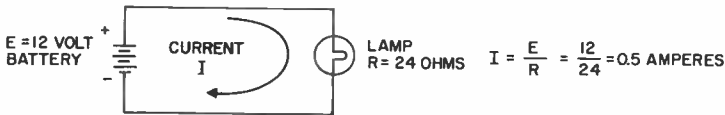
Figure 1.1

If we insert a rectifier, Figure 1.2(a), in the proper polarity, the lamp operates, but if the rectifier is reversed, Figure 1.2(b), the lamp does not light because current can flow only one way through a rectifier.

RECTIFIER

I   I = 0

(a)   (b)

Figure 1.2

120 VOLTS AC   TRANSFORMER   V = 12 VOLTS AC   I = 1/2 AMP   LAMP R = 24 OHMS V_L

WAVEFORMS

$V_L +$ $V_{PEAK} = 1.4V = 16.8v.$ TIME

$I +$ $I_{PEAK} = 1.4\,I = .7a$ TIME

$P = EI = 6$ WATTS
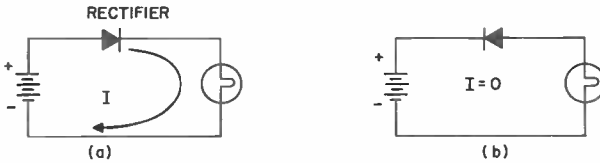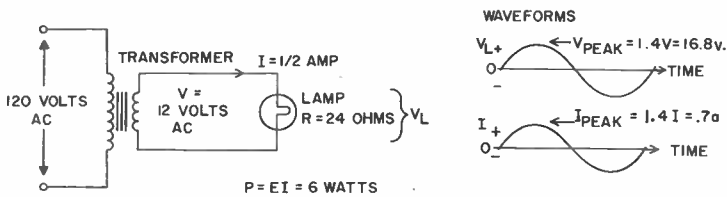
Figure 1.3

When an alternating current supply is used, Figure 1.3, instead of a direct current source, the lamp operates with similar current and power. But if we now insert a rectifier, regardless of polarity, something different happens, Figure 1.4. Since the rectifier can conduct current in only one direction, only half of the AC wave is passed on to the lamp. In this condition, the lamp is operating at $\frac{1}{2}$ power. The effective (or RMS, root-mean-square) value of the voltage is thereby reduced to 0.7 of the full-wave value.

WAVEFORMS

$V_L = .7E = 8.4v$ (RMS)
$I_L = .7 E/R = .35a.$ (RMS)
$P = V_L I_L = 3$ WATTS
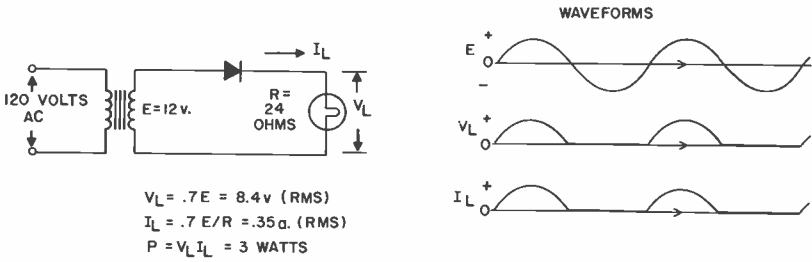
Figure 1.4

This is a simple, easy way to reduce power to $\frac{1}{2}$ normal, and is the basis for some high-low lamp switches now on the market. While this is fine for resistance loads, such as incandescent lamps and heaters, it is a sure way to damage a transformer or induction motor or fluorescent lamp ballast because coils are just a low resistance (resistance of the wire) to unidirectional current.

The major use of rectifiers is for conversion of alternating to direct current. Some of the circuits used for this purpose are included in the project sections.

Rectifiers come in many sizes and styles. Selenium rectifiers consist of flat plates, square or round, which are stacked to provide the desired voltage rating. The stack may be open:

Figure 1.5

or enclosed in a tube:

Figure 1.6

Silicon rectifiers are much smaller, and the little plate, or pellet, of silicon is enclosed in a housing. These look like this:

2
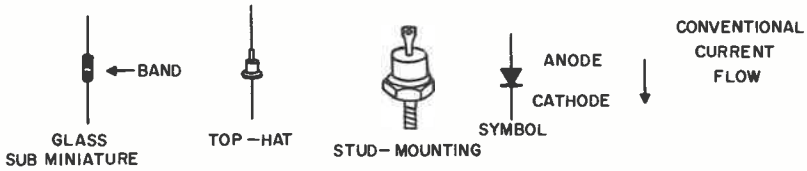
Figure 1.7

Notice that all have the same symbol, and that conventional current flows from anode to cathode (electrons go the other way, but don't let this confuse you). Current can flow in the other direction, 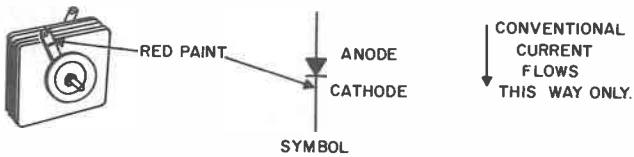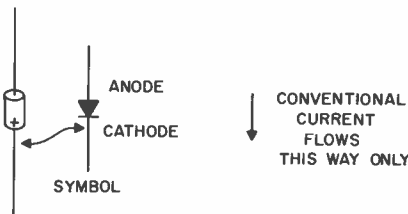but it takes a higher voltage to push it through, and this can, in certain cases, damage the rectifier. To remember direction — current flows from anode to cathode — use the alphabetical sequence A to C.

If we measure the voltage across a rectifier and the current through it, in both directions, and plot this data, we get a curve like this:
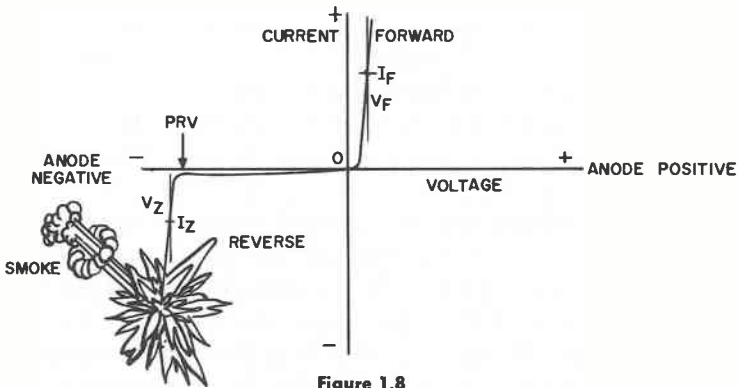
Figure 1.8

All rectifiers have a forward voltage drop, V_F, when conducting a forward (normal) current. The V_F for tubes is on the order of 10 to 50 volts, selenium is about 1.5 volts *per plate,* silicon is about 0.8 volts, and germanium is about 0.5 volts. Multiply current times voltage and you get watts of power being lost in the rectifier, and making it hot. That's why silicon is so popular — the loss is low and the material can stand high temperatures.

The current rating of a rectifier is determined entirely by temperature, which must take into account the power lost in the rectifier and how fast this heat can be taken away. The higher-current devices are mounted on a stud, and must be fastened to a metal plate ("heatsink") to provide proper cooling of the silicon pellet. Low current devices usually rely on air circulating around the case for cooling.

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As you can see on the current-voltage curve, if a reverse voltage is applied that is higher than the rated peak reverse voltage (PRV), a reverse current will begin to flow. Multiply the voltage by the current, and we find the power lost in heating the rectifier. Since the voltage is high, it doesn't take much reverse current to fry the rectifier. That's why you should stay below PRV with ordinary rectifiers, even for brief transients.

Zener diodes are designed to operate in the reverse region, at a specified zener voltage, V_Z, and current, I_Z. The prime attraction of the zener diode is that the voltage across it is very nearly constant for any current within its operating range. This makes it a good regulator or voltage reference element.

Zener Diode
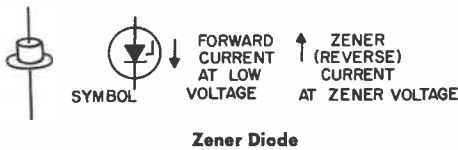
The Thyrector is a selenium rectifier designed for intermittent operation in the reverse direction, and is primarily used to protect other semiconductors from high-voltage transients. The reverse characteristics are not as sharp as the silicon zener diode, hence it is not a very good regulator but is sometimes used as such since it is usually less expensive.

The heart of a silicon rectifier is a small wafer of silicon having two kinds of impurities, one in the top half and one in the bottom half, Figure 1.9. It's something like a blotter used for red ink on one side, blue ink on the other. In the center is the junction where the "P" type impurity meets the "N" type inpurity. It is this junction that permits current to flow from the "P" region to the "N" region but blocks flow in the reverse direction.
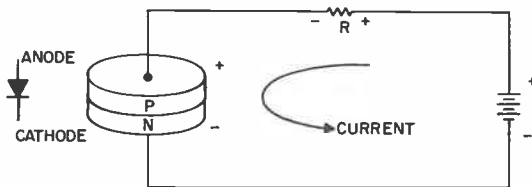
Figure 1.9

We can add another layer of impurities, Figure 1.10, to provide a PNP sandwich, or an NPN sandwich. But you will notice that, no

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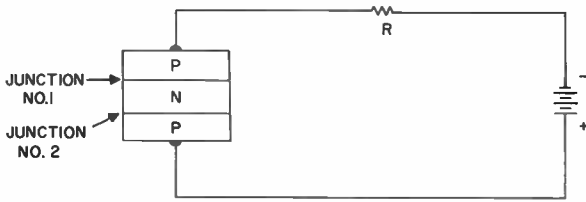
Figure 1.10

matter how we connect the battery to it, one junction would like to permit current flow (from P to N) but the other junction blocks the flow. With connections as shown, #1 junction is "reverse-biased" or "blocking", and #2 junction is "forward-biased" but is not conducting. If we add a connection to the center layer, as in Figure 1.11, we have a transistor!
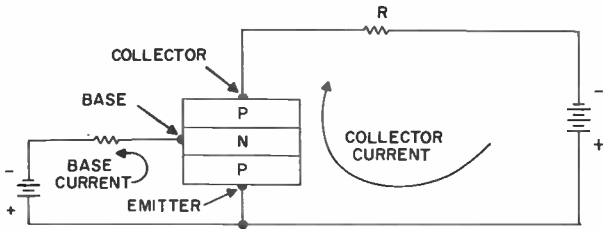
Figure 1.11

The secret of its success is that current flowing through a junction in the forward direction (P to N) gains enough "momentum" to permit a large part of that current to flow through a reverse-biased junction. The small fraction (about three per cent) of the current that cannot penetrate the reverse-biased junction must be removed from the center layer in order to maintain current flow. Thus the collector current in a transistor is very much larger than the base current, and directly proportional to it. This property enables the transistor to amplify a signal.

The major difference between the NPN and the PNP transistor is the polarity of connections, see Figure 1.12, and hence the direction of current flow through it.
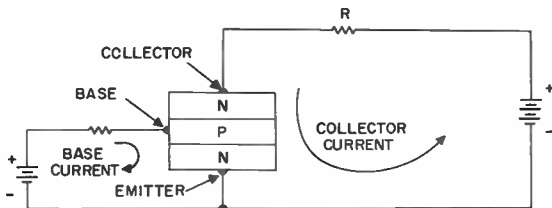
Figure 1.12

Here again, the junction between collector and base is reverse-biased and the base-emitter junction is forward-biased. The same principle applies — current through the forward-biased junction gains enough energy that part of the current can go through the reverse-biased junction. With the NPN transistor, however, you have to remember that the *direction* of current flow is either the flow of positive charges (holes) from P to N, which is the conventional way of looking at it, or the flow of negative charges (electrons) from N to P, in the opposite (but still called "forward" because it is permitted by the junction) direction.

Transistor symbols are shown in Figure 1.13 for both types. The arrow point on the emitter shows the direction of conventional current flow, just as in the rectifier symbol.

Figure 1.13

The most popular of the many transistor case styles are shown in Figure 1.14. Note that the collector is connected to the case in most transistors, so don't get caught "short"!
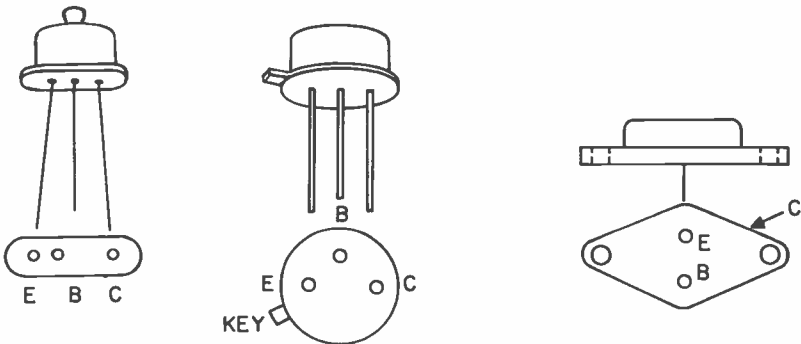
Figure 1.14

Figure 1.15 shows the typical behavior of an NPN transistor.

6
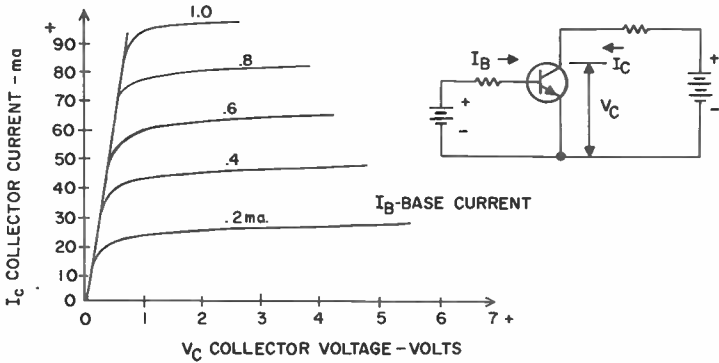
Figure 1.15

For any given base current, the collector current is essentially constant for any collector voltage above the knee. I_C x V_C, the product of collector current times collector voltage, is the power lost in the transistor in the form of heat. This is the prime limiting factor to watch.

Since there are so many variations possible in transistor characteristics, consult the specifications of each type before using.

A very unique transistor used in many SCR circuits is the unijunction. As shown in Figure 1.16, the unijunction transistor (UJT) consists of a bar of N-type silicon with connections at both ends, and a single P-type area on the side of the bar.
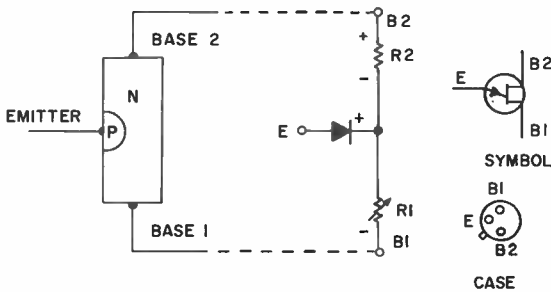
Figure 1.16

The silicon bar behaves as a resistance voltage-divider with the emitter junction tied into the center. A current flow from emitter to B1 (Base 1), through the PN junction, gains enough energy to reach B1 as though there were no resistance in that section of the bar. For this reason, R1 is shown as a variable resistance, which is normally about 20% higher than R2 but collapses to a very low value with current from the emitter. This is shown in the characteristic curve of Figure 1.17.

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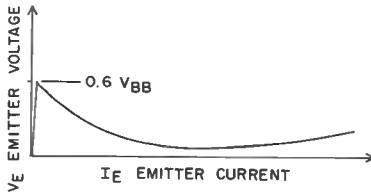
Figure 1.17

A typical application for the UJT is the relaxation oscillator of Figure 1.18.
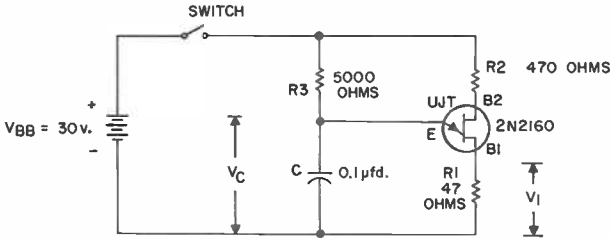
Figure 1.18

When the switch is first closed, the resistance voltage-divider action of the UJT silicon bar produces a voltage of 18 volts between B1 and the N side of the emitter junction. At this same moment, the emitter voltage is zero, being tied to the capacitor C, hence the emitter junction is reverse-biased and no current flows through it. The voltage, V_C, across the capacitor, starts increasing as the current flows through the resistor R3. When V_C reaches 18 volts, the emitter junction becomes forward-biased, current starts to flow through it to B1, thus reducing the internal resistance and voltage drop. This action dumps the energy stored in the capacitor into the B1 load resistor R1, then the cycle repeats with the capacitor re-charging and dumping.

Figure 1.19 shows the waveshape of the capacitor voltage, V_C, and the voltage, V_1, across resister R1. The repetition rate, or frequency, of this action is determined by R3 and C; increasing either one makes it run slower. The pulses appearing across R1 are most useful in controlling SCR's, and you will find many such circuits.

Figure 1.19

8
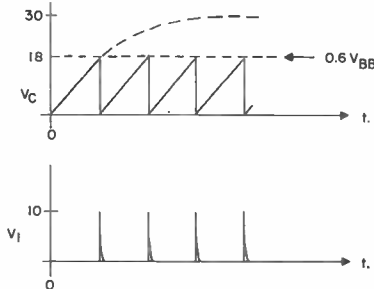
Which leads us to the SCR — the real slugger on this team. Don't give up, we're getting there!

Suppose we take a wafer of silcon and put in' it four layers of impurities, as in Figure 1.20. Then, no matter what polarity of voltage we apply to it, no current can flow, since either one or two of the three junctions will be reverse-biased. For the case of the polarity shown in
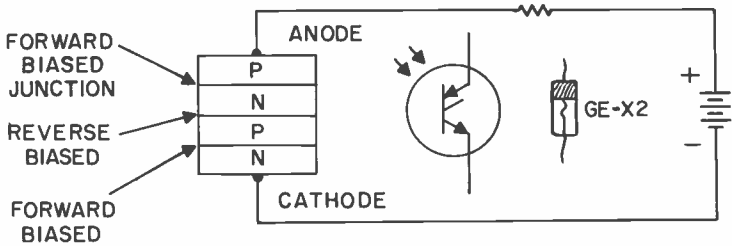
Figure 1.20

Figure 1.20, only the center junction is reverse-biased. If we could only get a little current to flow through one forward-biased junction, most of that current would go through the reverse junction and on across the next forward junction. Current through the second forward junction would then produce more current through the reverse junction. This would cause more current through the first junction and — away we go! The current builds up very rapidly, limited only by the external circuit.

(If we reverse the battery polarity, we have two reverse and one forward junction, which just won't conduct current, unless you run the voltage up too high, of course.)

But, how can we get that first little bit of current started? Two ways: (1) raise the voltage until leakage current is high enough to trigger the breakover; or (2) shine enough light on the right place to excite the electrons and when they cross a junction, it triggers! (There is a third way, and that is to heat up the device, but that is *not* considered very sporting.)

If we plot the voltage/current characteristics of a PNPN device, Figure 1.21, we can see the effect of forward voltage breakover, V_{BO}. Notice that it requires a small current, I_{BO}, to trigger the device, and there is a minimum holding current, I_H, required to keep it going. Once forward current starts flowing, it can continue indefinitely until something in the external circuit reduces it below the I_H value.

+
I
ANODE
CURRENT   FORWARD

PRV I_H $--------------- I_{BO}$
— | | V ANODE
                                                     +   VOLTAGE
                                              V_{BO}

REVERSE

—
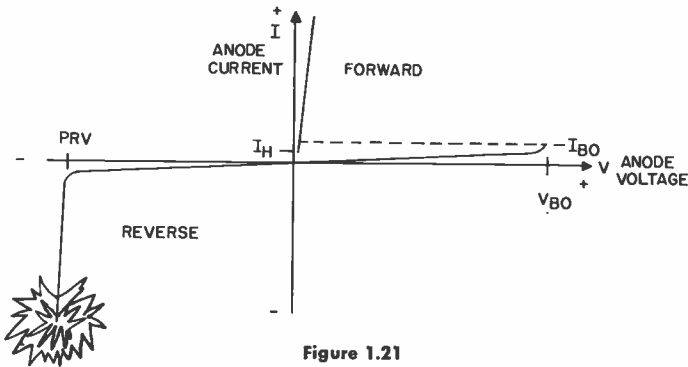
Figure 1.21

As you may have observed, the PNPN device behaves exactly as a rectifier in the reverse direction, and as a rectifier in series with a switch in the forward direction. Sometimes it is called a four-layer diode, or a four-layer switch. Those devices designed for activation by light are called Light Activated Switches.

Notice, they are not called Silicon Controlled Rectifiers! The SCR is of the same type with one notable exception — it has a third lead which serves as the control. Figure 1.22 shows the silicon wafer with the all-powerful GATE lead connected to the P layer next to the cathode. Direct a little current *into* the gate, and the SCR turns on, and stays on as long as the forward current is above I_H.

ANODE   GE-X5   ANODE   ANODE

P
N
P
N

G
C   A

GATE   CATHODE   GATE   CATHODE   GATE   CATHODE

NOTE:
UPSIDE DOWN COMPARED TO
ORDINARY RECTIFIER
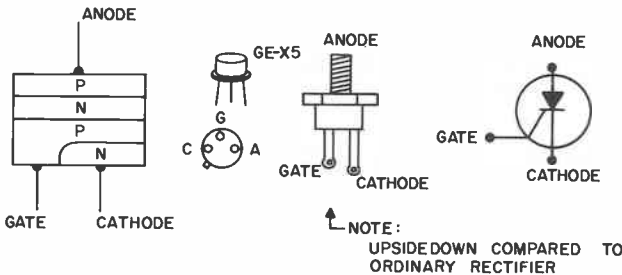
Figure 1.22

The key point is that a small current from gate to cathode can "fire", or trigger, the SCR so that it changes from being nothing (an open circuit) into being a rectifier. The only way to change it back again (to "commutate" it) is to reduce the current through it to a value less than the minimum holding current, I_H. Note that removing the gate current does nothing. This tells us that gate current is required only long enough to be sure the anode current has completely built up, which is about five millionths of a second (5 microseconds) in resistive-load circuits.

Time is also important in commutating an SCR. When the SCR is conducting current, the voltage drop across it is very low, about one volt. As with a rectifier, if we can force the voltage to drop below this, to zero or even to a reverse bias, current ceases to flow through the SCR. If forward bias voltage is re-applied before the charges have re-combined, the current will start up again. Therefore, we must wait at least 50 microseconds, typically, before re-application of forward voltage in order to be sure the SCR will not re-trigger.

Even then, if the voltage rises too abruptly, the change will trigger the device. You will recall that the center junction of the PNPN device is reverse-biased by the normal operating voltage. In other words, the entire forward voltage ("forward" for the device, as a whole) appears across this junction. The N and P layers on either side of the junction are, therefore, the plates of a small capacitor which is charged to this voltage. If forward voltage is applied very rapidly, as with a switch, the current required to charge this capacitor may be enough to trigger the SCR. Consequently, on the application of forward voltage the rate of rise must be slower than 20 volts per microsecond for most SCR's, and less than 1 volt per microsecond for the Light Activated Switch.

To demonstrate the behavior of a PNPN diode or SCR, try some of the following circuits.

In Figure 1.23, a Light Activated Switch, type GE-X2, is connected in series with a pair of flashlight batteries and a flashlight bulb. A beam of light (flashlight, lamp, sunlight) directed in at the angle shown by the arrow should trigger the Light Activated Switch. The lamp won't be as bright as normal because of the voltage drop across the switch, which is about one volt. To turn off the lamp, you can either break the circuit somewhere, or you can short out the Light Activated Switch momentarily by touching its two lead wires together. If you connect the Light Activated Switch in backward, nothing should happen, even with direct sunlight on the unit.

Figure 1.23

11
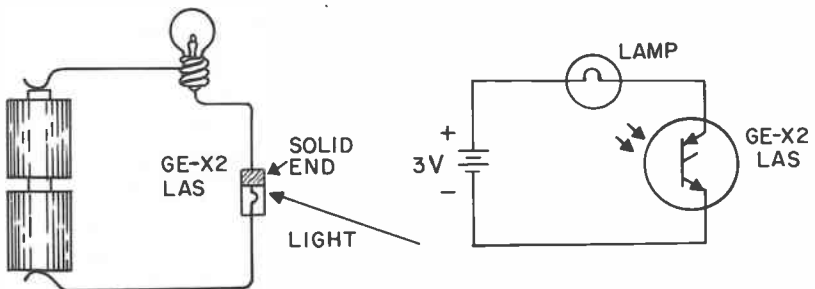
Figure 1.24 is the same circuit except that it uses an SCR, type GE-X1, which requires a gate signal. To turn on the lamp, touch the control wire to the gate terminal very quickly. To turn it off, touch the control wire momentarily to the cathode terminal. Now reverse the batteries and try it again. You should not be able to turn it on.
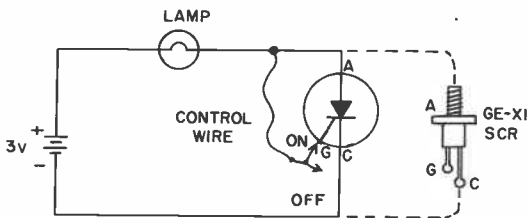
Figure 1.24

Want to light an electric lamp with a match, then blow the lamp out? Try the AC circuit of Figure 1.25.
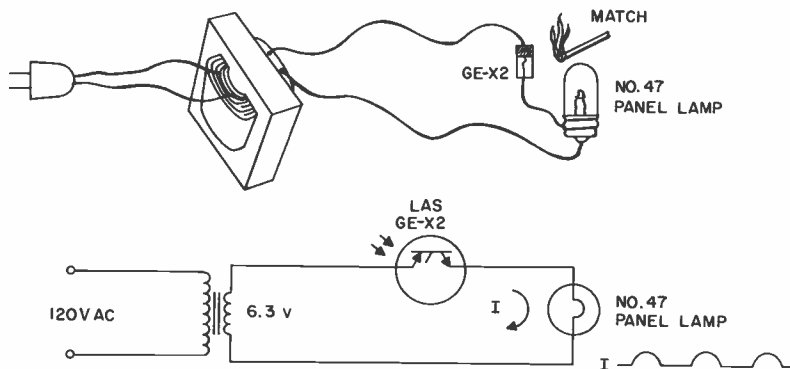
Figure 1.25

Place the Light Activated Switch close to the lamp, hold a match nearby and the lamp should light up. Remove the match — and the light will stay on. To blow out the lamp, shield the Light Activated Switch with your hand while you puff. It is easy enough to see why a match should turn the Light Activated Switch on, but what keeps it on? After all, we are working from an AC supply and the Light Activated Switch can conduct in only one direction. Hence it must turn off every other half-cycle, and we know that we must trigger the Light Activated Switch again if it ever turns off. The secret is the lamp. The filament cannot cool down enough during the time it is off, so that on the next half-cycle, it is still emitting enough light to re-trigger the Light Activated Switch. When your hand blocks the light, the Light Activated Switch is not re-triggered, and the lamp goes out completely.

Set up the same circuit with an SCR, as in Figure 1.26.
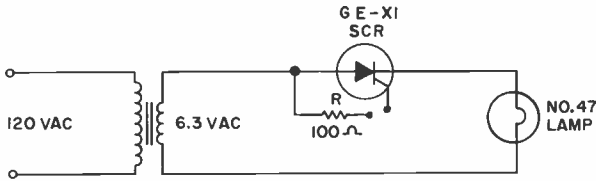
Figure 1.26

Connect one end of a 100 ohm resistor to the anode and touch the other end to the gate terminal. The lamp burns only as long as you hold the resistor on the gate. Remove the gate current and the lamp goes out. After removal of gate current, the SCR is commutated by the next reversal of supply voltage and cannot conduct again until gate current is re-applied.

An interesting variation of the circuit of Figure 1.26 is to replace the 100 ohm resistor with a photoconductor or a thermistor. The lamp can then be turned on and off by light or by heat.

The most popular photoconductors are essentially resistors which are controlled by light. A typical unit, shown in Figure 1.27, uses cadmium sulfide as the photoconductive material and is constructed so that it can conduct current in either direction. The resistance of a cadmium sulfide photoconductor is inversely proportional to light — more light makes less resistance. Typically, a GE-X6 has a resistance of over 5 megohms when completely dark, 20,000 ohms with 1 foot-candle illumination, and about 50 ohms in direct sunlight.
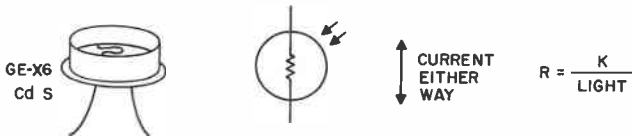
Figure 1.27

A wide variety of thermistors are available, covering an enormous range of sizes, resistances, and power levels. Thermistors have a resistance which is inversely proportional to temperature, but the resistance change is much smaller than in the photoconductors, hence the need for many different types. The PTC (Positive Temperature Coefficient) thermistor is opposite from the ordinary kind because its resistance is a direct function of temperature — that is, higher temperature produces higher resistance.
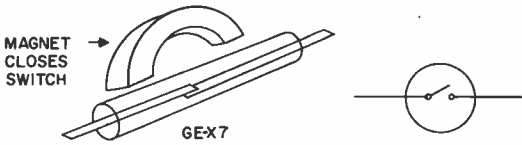
Figure 1.28

Although not a semiconductor, the glass-enclosed magnetic reed switch, Figure 1.28, is often used in SCR circuits. This switch can be easily operated by a permanent magnet or by current through a coil wrapped around the glass tube. For instance, with 1000 turns of #28 wire, a single flashlight cell will close the switch. Since this switch has a very low power rating, its use is quite confined, but it can control high power loads when used with an SCR. If a reed switch is connected between the 100 ohm resistor and the SCR gate in Figure 1.26, a magnetic field will control the lamp. This simple concept may be readily expanded to the control of very large loads.

As you can see, the door is now open to performing a multitude of useful and unusual functions with these new devices.

THE CARE AND HANDLING
OF POWER SEMICONDUCTORS

1. Heatsinks:

Carefully observe the recommended heatsinks for stud-mounted rectifiers and SCR's. If the heat can't get out, damage is likely to result. On lead-mounted devices, be sure air can circulate around them. Also remember that a heatsink is no good unless it can get rid of the heat, usually to the surrounding air. Watch out for excessive high temperatures caused by other components, such as nearby lamps, motors, heaters, etc.

2. Voltages:

Observe voltage specifications. It is generally a good practice to use a Thyrector or zener diode to protect the semiconductors from stray transients which might come in on the power line, or which could be induced from adjacent circuits such as an automobile ignition system.

3. Current:

Do not overload semiconductors, even momentarily. A short-circuit will destroy them immediately. Double check circuits, polarities, component sizes, and wiring BEFORE closing the switch!

4. Mounting:

Stud-mounted rectifiers and SCR's must be fastened to the heatsinks tight enough to assure good heat flow yet not so tight that the copper stud is stretched out or stripped. The best way to know how tight to make it is to use a torque wrench and apply 15 inch-pounds maximum torque to the nut while holding the rectifier steady by its hex. A simple substitute for a torque wrench is to use an ordinary wrench and a weight or a spring scale to turn it. For example, a $2\frac{1}{2}$ pound weight hanging from the end of a 6 inch wrench will produce $2\frac{1}{2}$ x 6 or 15 inch-pounds torque.

The stud (anode) end of stud mounted units normally forms part of the electrical circuitry. Therefore, the heatsink to which the stud is mounted would also be electrically "hot." If this presents any safety hazard or might conceivably create a short circuit, the stud should be electrically insulated from the heatsink. Figure 2.1 illustrates the proper insulated mounting procedure.
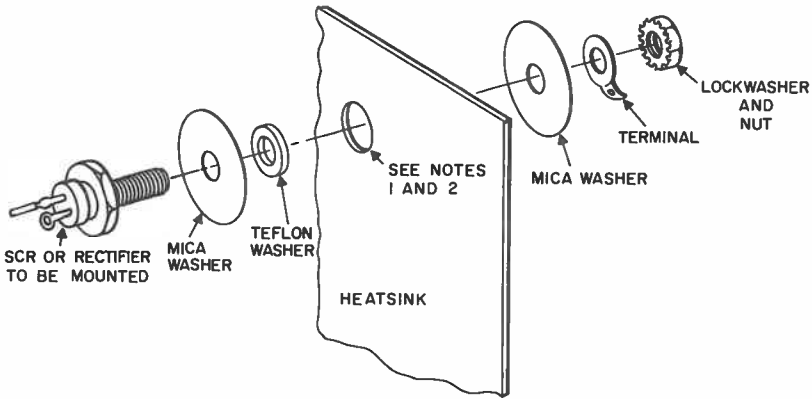
NOTES: I. DRILL HEATSINK HOLE TO TIGHTLY RECEIVE THE TEFLON WASHER.

2. FILE OFF DRILL BURRS TO AVOID DAMAGE TO MICA WASHERS.

3. WASHER, TERMINAL AND NUT ARE INCLUDED WITH EACH SCR OR RECTIFIER DIODE.

Figure 2.1. Insulated Rectifier or SCR Mounting

Conversely, in circuits where it is undesirable to place insulation between the rectifier or SCR and the heatsink, the heatsink itself must be electrically insulated from the case. Figure 2.2 illustrates the proper insulated heatsink mounting procedure.
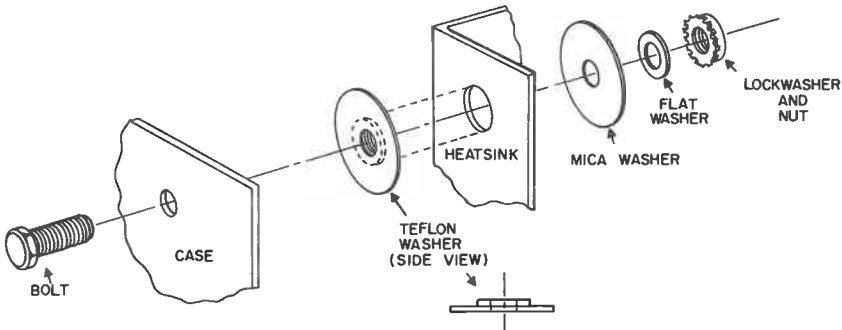
NOTE: FILE OFF ALL DRILL BURRS IN CASE AND HEATSINK.

Figure 2.2. Insulated Heatsink Mounting

Lead-mounted devices may be secured by their leads, such as by being soldered to a terminal strip. This fastening point should be no less than $1/8''$ away from the body of the device. To bend a lead, hold the lead with pliers *between* the body and the bend. Avoid bending too near the body. Do not try to bend the top terminals of stud-mounted devices.

5. Soldering:

Use a small, hot soldering iron and high-quality rosin-core solder. Wrap the clean wire around the other wire or terminal once, to hold it in place, then apply the tip of the iron and the solder to the joint together. As soon as the solder appears to wet the wires or terminal, remove the soldering iron. Solder as quickly as possible, then blow on the joint to cool it quickly. If possible, with lead-mounted devices, use pliers to hold the lead *between* the body and the joint in order to avoid overheating the device. This is particularly important for soldering *germanium* devices. Do not use acid flux. If a wire is tarnished or enameled, clean with fine emery paper before soldering. When stripping insulated wire, use a *dull* knife because a sharp knife is more likely to nick the wire and cause it to break.

6. Handling:

Although power semiconductors are much more rugged than tubes, the more careful the handling they receive, the longer will they last. Avoid dropping on hard surfaces. Both the glass and ceramic insulators, as well as the silicon pellet itself, can be fractured by abuse, which will cause eventual failure.

SAFETY PRECAUTIONS

1. Electrical Hazards:

Ordinary 120 volt household power CAN kill. When working on power circuits, turn the power OFF by removing a fuse, pulling a switch, or pulling out a plug. *Never* rely on an SCR to turn off the power because there may be enough current flow through the trigger circuit and leakage of the SCR to be most unpleasant. Then too, a stray transient might possibly turn the SCR ON.

Even a 6 volt automobile battery can be dangerous since it can supply enough current to burn up a ring or watch band, and the skin underneath it.

Be sure your circuits are insulated, and watch the usually electrically hot heatsinks.

Use fuses of proper ratings! (No slow-blow types.)

2. Fire Hazards:

Good joints, proper wire size, and adequate cooling are required to avoid the menace of fire. Keep hot components away from burnable material.

3. Mechanical Hazards:

Solder splashes in the eye or dropped on an arm can be most painful. Safety glasses are recommended, along with lots of caution.

4. Never Work on Electrical Circuits When Alone.

RADIO INTERFERENCE

When an SCR turns ON, it does so very suddenly. The current can, therefore, rise so rapidly that radio-frequency components are present. Under certain circumstances, this can produce radio interference by direct radiation from the circuit or by coupling from the power line.

The art of RF suppression is heavily dependent on specific circumstances. If you do run into an interference problem, you can try some of the suggested remedies below. These have been found to reduce interference, but are not to be considered as positive cure-alls because it is just not that easy.

1. Direct radiation can be reduced by enclosing the complete circuit in a well-grounded metal box. Shielded wire can also help outside the box.

2. Interference conducted down the power line is reduced by an RF filter between the line and the SCR circuit. There are several commercial plug-in type filters you can try, or you can "roll your own."

3. To slow down the rise of current, an inductance coil may be connected in series with the SCR. A capacitor connected across both the coil and the SCR will reduce the sudden step in voltage applied to the line, as shown in Figure 2.3.
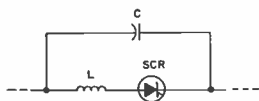
Figure 2.3

Connections should be as short as possible, particularly the capacitor leads. Typical values are: .005 μfd, 1 kv ceramic disc capacitor, and 75 μhy inductance. The inductor must carry the full SCR current, hence should be wound with a large-size wire.

4. To wind your own inductance coil, start with a ferrite rod from a loop-stick antenna (such as Superex 7" x $\frac{1}{4}$"). These rods are generally $\frac{1}{4}$" or $\frac{3}{8}$" diameter, and several inches long. To make the "long-form" coil, cut off a 3" length of rod (by scoring and breaking like glass), then wind a single, tight layer of 65 turns of AWG #18 varnished magnet wire. Use glue or tape to hold wire in position. The "short-form" coil uses a 1" length of rod with a coil consisting of three layers of 16 turns each, with the same size wire as above. These coils should be good for about five amperes. If they get too warm, use a larger wire but keep the number of turns about the same. The "long-form" is preferable, if you have room for it, because it runs cooler and has less capacitance between ends than does the "short-form."

TROUBLESHOOTING

Troubleshooting is easy if you follow the course of logic, as outlined in the following steps:

1. Re-read the project write-up. Be sure you understand what it is supposed to do, and how it does it. Understanding is the key to the whole thing. You might even want to go back and review the chapter on fundamentals to be sure you haven't missed a vital point.

2. Compare the circuit to the diagram. Check every component and connection. Do you have all polarities of semiconductors, electrolytic capacitors and batteries correct? Are sizes and values correct?

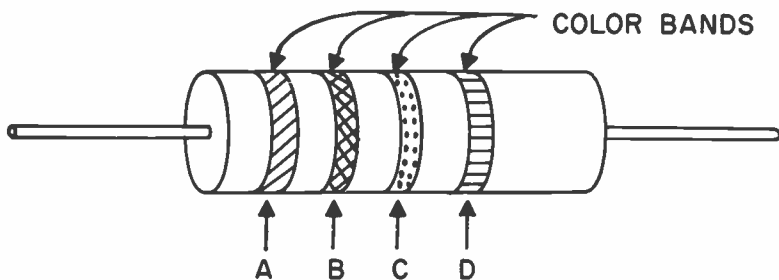3. Check your power source and your load to be sure both are in working order. Remember that a battery may show proper voltage on a meter, with no other load, yet have enough internal resistance that it won't drive the desired load.

4. If you suspect a rectifier or SCR has been damaged, try one of the elementary circuits shown in the chapter on fundamentals. Semiconductors can become shorted or open, depending on what hits them, so check both forward and reverse operation in the test circuit.

5. A multi-meter (volt-ohm-milliamp meter), of at least 5000 ohms-per-volt sensitivity rating, is a most useful tool for analyzing circuits. Check voltages, measure resistors and capacitors.

6. Perhaps it works, but not quite the way it should. This just means you have run up against the case where the normal tolerances on component characteristics have all piled up on one side. This is probably associated with a sensing or triggering circuit. Try changing a resistor or capacitor, larger or smaller in value, examine the effect of this change and decide whether it is right, not enough, too much, or the wrong direction. A variable resistor or potentiometer is handy in this phase, since it enables you to adjust for the best performance.

HANDY REFERENCES

Resistor Color Code:

COLOR BANDS

A   B   C   D

$$\text{Resistance} = (10A + B) \times 10^C \text{ ohms} \pm D$$

A, B, and C		D		Example:
Black	= 0	None	= 20%	
Brown	= 1	Silver	= 10%	A = Red = 2
Red	= 2	Gold	= 5%	B = Violet = 7
Orange	= 3			C = Orange = 3
Yellow	= 4			D = Silver = 10%
Green	= 5			then
Blue	= 6			R = (20 + 7) × 10^3 = 27,000 ohms
Violet	= 7			with a tolerance of ± 10%.
Gray	= 8			Hence, may be anywhere from 24,300
White	= 9			to 29,700 ohms.

Electrical Prefix Terminology:

	Prefix	Example
1,000,000,000,000 =	Terra	Terrohm
1,000,000,000 =	Giga	Gigacycle
1,000,000 =	Mega	Megacycle
1,000 =	Kilo	Kilowatt
0.001 =	Milli	Millivolt
0.000,001 =	Micro	Microamp
0.000,000,001 =	Nano	Nanosecond
0.000,000,000,001 =	Pico	Picofarad

HIGH-LOW SWITCH

CHAPTER 3

Two-level operation of small AC loads can easily be achieved by using a silicon rectifier diode and a three-position switch. This is very handy for use as a:

— Lamp Dimmer: Off — Low — High
— Soldering Iron Life Extender and Economizer
— Small Electric Oven Control
—Two-Speed Control of Small Power Tools

A diode inserted into an AC circuit in series with the load will block half, or one polarity, of all the half-cycles available from the supply line. As a result the load (lamp, motor, etc.) sees only the half-cycles of line frequency that are *not* blocked by the diode. This amounts to a reduction of the applied RMS voltage of about 30% (about 84 volts instead of the full 120 volts supplied). One must be sure, however, that the load will take this type of voltage waveform that contains a DC component. Because of the DC component, this
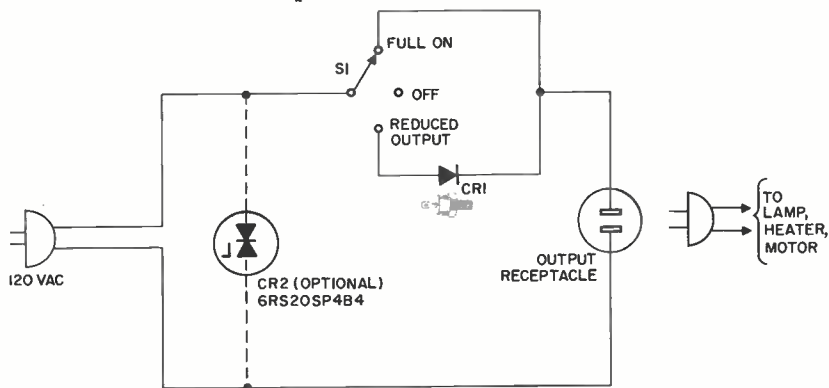
Parts List

CR1—G-E Type 1N1693 rectifier diode for 130 watts output
   —GE-X4 rectifier diode for 300 watts output
CR2—G-E Type 6RS20SP4B4 Thyrector diode (optional transient voltage suppressor)
S1 —SPDT 3 amp, 125 volt AC switch with center "off" position (Allied Radio Type 7140-KG, or equivalent)

Figure 3.1. High-Low-Off Circuit

type of operation is all right for incandescent lamps, resistance heaters, DC motors, and universal motors (commutator motors that work on both AC or DC). It is *not* to be used *for transformer loads* of any type, or *fluorescent lamp ballasts.*

Figure 3.1 shows a simple high-low-off circuit that can be conveniently assembled and wired in a small aluminum minibox. The three-position switch is mounted on top with the line cord on one side and the output receptacle on the other. The diode is mounted between the proper switch terminal and the output receptacle as shown.

Use a G-E Type 1N1693 "top hat" diode for an output rating of up to 130 watts. This device is lead-mounted and has an overall length of about 3 inches. It can be wired directly between the switch and the receptacle — point to point. The GE-X4 should be used if a larger output rating is desired. Unlike the 1N1693, this is a stud-mounted device, but it has a higher rating.

It is recommended that a Thyrector diode be wired into the circuit as indicated in the schematic. It is shown dotted because its presence is not essential to the operation of the circuit. However, it is a good idea to use the Thyrector to protect the silicon diode against voltage transients that may be present on the supply line.

DUAL VOLTAGE
TRANSMITTER POWER SUPPLY
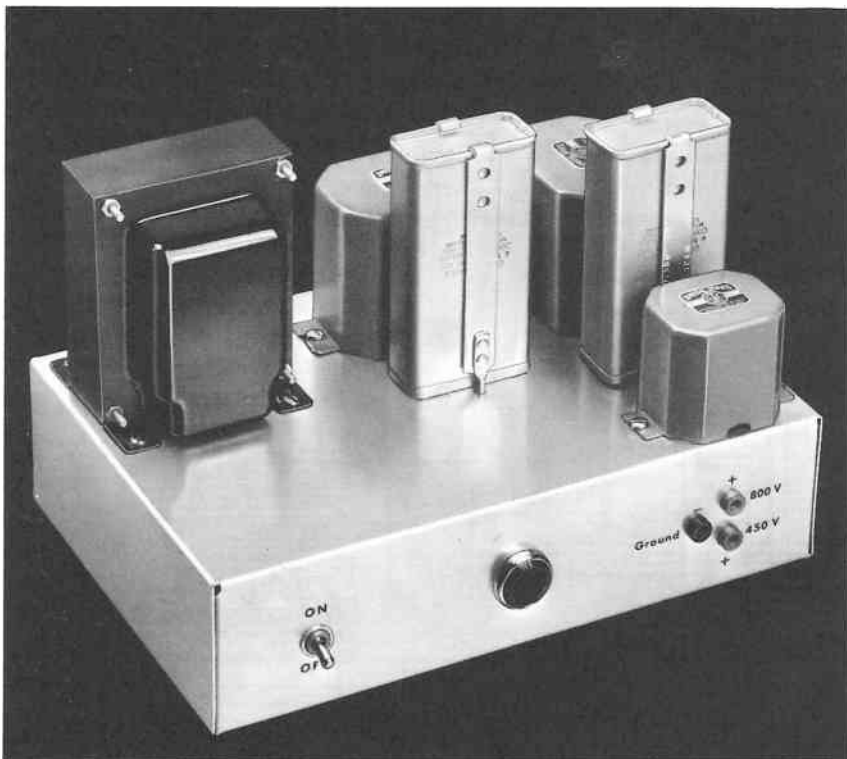
The key-happy ham need no longer sweat out 30 seconds for his mercury vapor rectifiers to warm up before answering that intriguing CQ. Silicon rectifiers have no filaments . . . they start their rectifying job the instant power is applied. Here is a simple silicon power supply ample for handling a typical 100 watt transmitter. Thanks to the simplicity of silicon rectifier circuits, this supply provides two voltage outputs from a single circuit:

  —800 volts at 175 ma, 1% ripple, 16% load regulation, for a final amplifier, and

  — 450 volts at 25 ma, 0.02% ripple, for preamplifier and oscillator circuits.

Both supplies have a common ground. With an adjustable transformer in the line ahead of the step-up transformer, this circuit makes an excellent variable voltage power supply for laboratory experimental use.

Figure 4.1 illustrates the circuit of the dual voltage power supply. The four legs of silicon rectifier CR1 form a rectifier bridge for the high voltage V1 supply. The two right hand legs of CR1 also double as a full wave centertap rectifier furnishing DC to the lower voltage supply V2. A terminal strip makes an excellent means of mounting the 16 individual pigtail rectifiers. A choke input filter is employed for V1 in order to achieve optimum load regulation. The V2 supply uses a capacitor input filter for minimum ripple content. The current rating for the low voltage supply V2 can be increased by selecting L3 with a higher current rating. The voltage of V2 can be lowered to approximately 375 volts by removing C3 from the circuit. Both of these changes will result in somewhat higher ripple on V2.

Figure 4.1. Dual Voltage Power Supply

Thyrector CR2 protects the silicon rectifiers against voltage transients generated by switching the transformer primary. Bleeder resistors R1 and R2 discharge the filters when the circuit is de-energized and also improve load regulation. A pilot light is particularly desirable for safety reasons in solid-state power supplies because of the absence of tube filament or gas glow to indicate that the circuit is energized. For the same reason, door interlocks are a wise precaution.

Parts List

C1, C2—4μf, 1000 volt capacitor (Cornell-Dubilier 10040)
C3, C4—20μf, 600 volt electrolytic capacitor
CR1 —16 G-E Type 1N1696 silicon rectifier diodes connected in groups of four
CR2 —G-E Type 6RS20SP4B4 Thyrector diode (optional transient voltage suppressor)
F1 —3AGC fuse, 3 amps
I1 —120 volt, 6 watt pilot lamp
L1 —5/25 henry choke, 175 ma (UTC S-30, or equivalent)
L2 —10 henry choke, 175 ma (UTC S-29, or equivalent)
L3 —30 henry choke, 25 ma (UTC S-25, or equivalent)
R1 —50,000 ohm, 25 watt resistor
R2 —110,000 ohm, 4 watt resistor (2-220K, 2 watt resistors in parallel)
S1 —DPST switch
T1 —200 ma transformer: primary, 120 volt AC, 60 cps; secondary, 800 volt (Stancor PC-8412, or equivalent)

Figure 4.2. Wiring Diagram

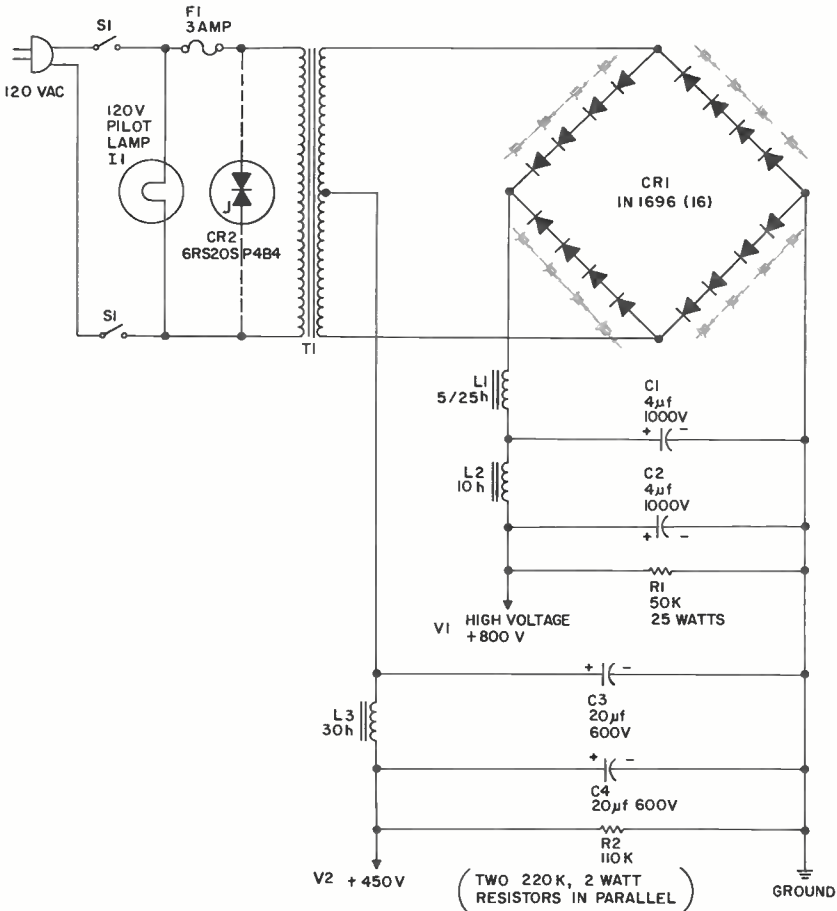# CHAPTER 5

DIRECT CURRENT METER PROTECTION

Low current, low cost, low voltage silicon rectifiers, such as the G-E Type 1N1692 are easily usable as a protective shield for DC meter movements where heavy fault currents are possible.

In a large majority of applications (where unusual accuracy is not required), the following simple circuit is all that is needed.
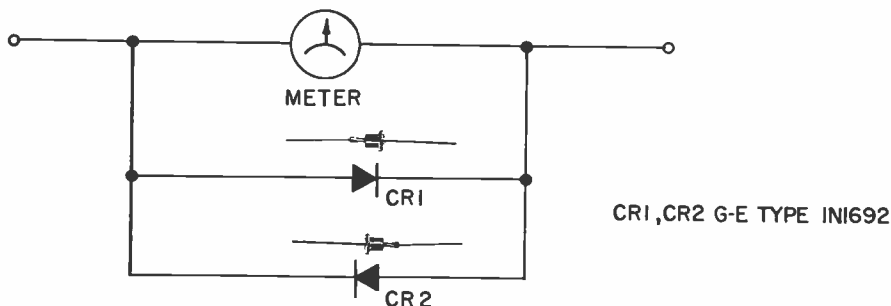

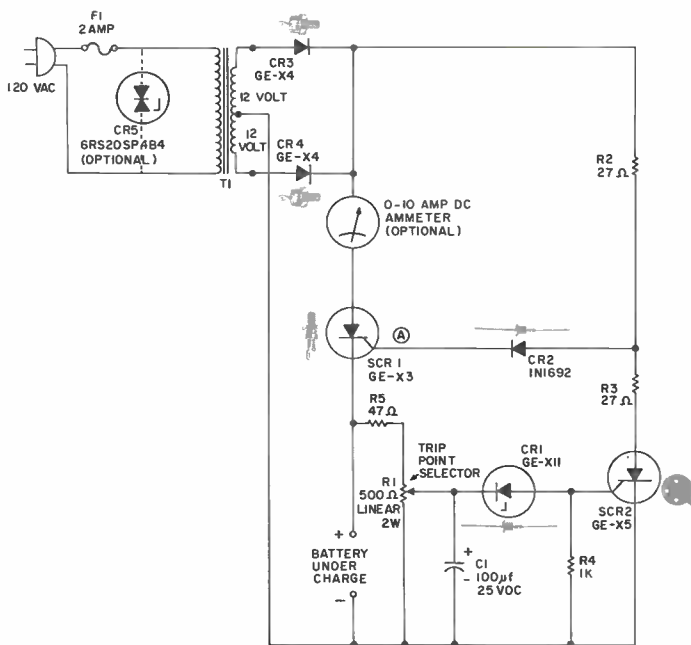CR1, CR2 G-E TYPE 1N1692

Figure 5.1. Meter Protection Circuit

The silicon rectifiers will not begin conducting heavily until the voltage across them exceeds .5 to .7 volts. When the voltage across the meter, which is the same as the voltage across the rectifiers, exceeds .5 to .7 volts, the rectifier which is forward biased will shunt most of the current around the meter, thereby very effectively protecting it.

For a typical multitester with a meter movement resistance of 1200 ohms and a full-scale current rating of 50 μa, the rectifiers will introduce less than 1% error into the meter reading, and at the same time will limit the meter movement current to less than one milliampere for a one-ampere fault current. This is a long way below the destructive value for most multi-tester meters.

Where higher fault currents may flow, higher-current rectifiers, such as the General Electric type GE-X4 could be used for CR1 and CR2.

REGULATED BATTERY CHARGER

Here is a simple, yet highly effective regulated 12 volt battery charger. This inexpensive device will rapidly charge a 12 volt lead-acid battery (other voltages to 200 volts may be attained by suitable choice of components) at the maximum possible design amperage until the battery is fully charged; it will then automatically switch itself off. If

F1
2 AMP

120 VAC

CR3
GE-X4
12 VOLT

CR5
6RS20SP4B4
(OPTIONAL)

12
VOLT

CR4
GE-X4

T1

0-10 AMP DC
AMMETER
(OPTIONAL)

R2
27 Ω

SCR 1
GE-X3

Ⓐ

CR2
1N1692

R3
27 Ω

R5
47 Ω

TRIP
POINT
SELECTOR

CR1
GE-X11

R1
500 Ω
LINEAR
2W

SCR2
GE-X5

BATTERY
UNDER
CHARGE

C1
100 μf
25 VOC

R4
1K

Parts List

C1—100 μf, 25 volt capacitor

CR1—GE-X11 Zener diode

CR2—G-E Type 1N1692 rectifier diode

CR3, CR4—GE-X4 rectifier diode

CR5—G-E Type 6RS20SP4B4 Thyrector diode (optional transient voltage suppressor)

F1—2 amp fuse

R1—500 ohm, 2 watt linear potentiometer

R2, R3—27 ohm, 3 watt resistor

R4—1000 ohm, ½ watt resistor

R5—47 ohm, 1 watt resistor

SCR1—GE-X3 Silicon Controlled Rectifier

SCR2—GE-X5 Silicon Controlled Rectifier

T1—Transformer: primary, 120 volts AC; secondary, 24 volts AC center-tapped (UTC-FT10, Triad F41X, or equivalent)

Figure 6.1. 12 Volt Regulated Battery Charger

the battery should become discharged while the charger remains connected, the charger will automatically switch itself back on again! This particular feature makes the device ideal for maintaining emergency stand-by power supplies in continuous tip-top condition. In less exotic applications — auto and boat battery charging etc. — the charger allows rapid time-saving charging while preventing battery overcharge damage from occurring.

The main charging circuit consists of a basic full wave center-tapped DC power supply and SCR1 (in series with the battery) acting as the automatic switch. As long as the battery voltage is low, SCR1 receives a gate signal via resistor R2 and diode CR2. SCR1 is thus able to turn on during each cycle of the supply voltage, and load current flows to charge the battery. When the battery voltage approaches its fully charged value, however, the voltage developed across capacitor C1 becomes sufficient enough to turn on SCR2 through zener diode CR1. At this point, the available voltage at point A (the gate of SCR1) is suddenly dropped to a value *below* the battery terminal voltage due to the voltage divider action of R2 and R3. SCR1 is thus unable to receive a positive gate signal and cannot turn on. Battery charging then ceases until the battery becomes discharged. The circuit is set-up for use by adjusting R1 with a *fully charged battery connected* so that charging just ceases.

CONTINUOUSLY VARIABLE AC CONTROL

CHAPTER 7

FOR LAMP DIMMING AND CONTROL OF SMALL DC MOTORS AND HEATERS

SWITCHES PHOTOCONTROL ONLY

Output Control

On
Off
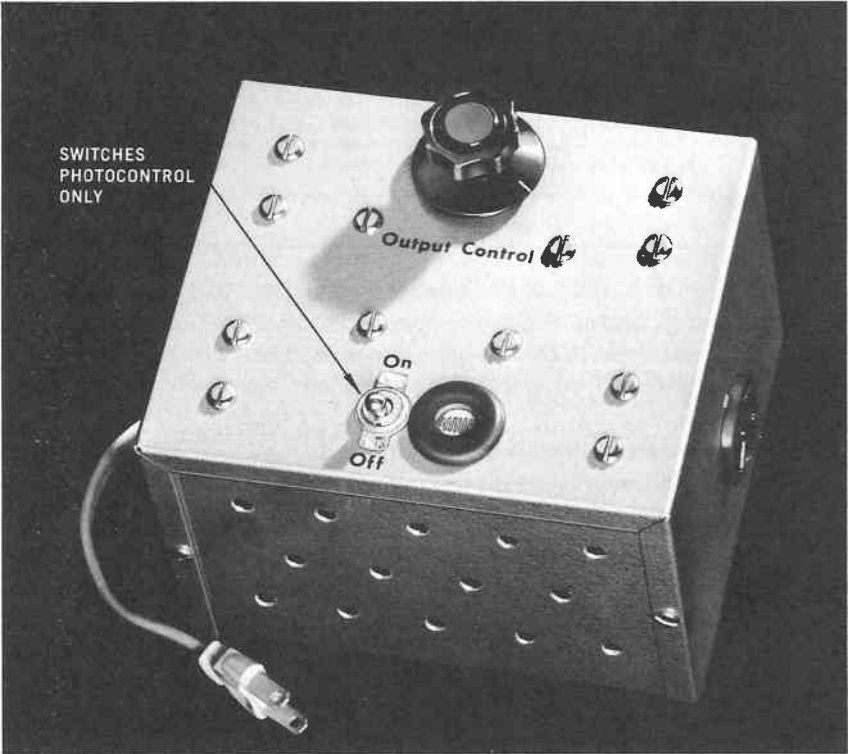
A single SCR in an AC circuit will deliver "half-wave" control. Output voltage, in other words, can be varied from zero to about 70% of full line voltage (up to about 84 volts from a 120 volt AC line.) Figure 7.1 illustrates this type of control.

If, however, the SCR is "put to work" on every half-cycle of applied line voltage it will control the AC load from zero to essentially 100% of line voltage. The circuits of Figure 7.2 and Figure 7.3 accomplish this control by placing the SCR in a diode bridge which makes all of the line voltage half-cycles appear in a positive polarity on the anode of the SCR. Since the SCR can control current as long as its anode is positive, it will, in this circuit arrangement, give complete (or full-wave) control over the output voltage.

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Figure 7.2 includes a very simple SCR control circuit giving quite adequate performance. This performance can be further improved by adding a unijunction transistor as in Figure 7.3.
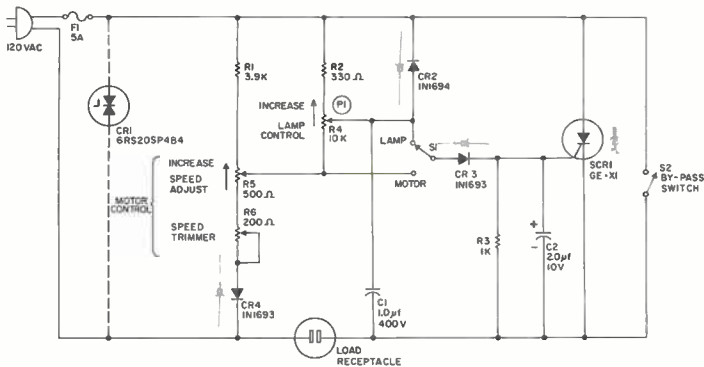
Parts List

C1—1.0 μf, 400 volt capacitor	R3—1000 ohm, 1 watt resistor
C2—2.0 μf, 10 volt electrolytic capacitor	R4—10,000 ohm, 2 watt potentiometer
CR1—G-E Type 6RS20SP4B4 Thyrector diode (optional transient voltage suppressor)	R5—500 ohm, 2 watt potentiometer
	R6—200, 2 watt potentiometer
CR2—G-E Type 1N1694 rectifier diode	S1—SPDT 3 amp switch
CR3, CR4—G-E Type 1N1693 rectifier diode	S2—SPST 3 amp switch (on speed and lamp adjust potentiometers)
F1—5 amp Littelfuse	SCR1—GE-X1 Silicon Controlled Rectifier mounted on 3" x 3" x 1/16" copper cooling fin
R1—3900 ohm, 2 watt resistor	
R2—330 ohm, 1 watt resistor	

Figure 7.1 Combination Half-Wave Motor Speed and Lamp Control
   Use for:
   Portable Tools or Household Appliances with small Universal (DC) Motors (up to 2 amp max motor nameplate rating)
   Incandescent Lamps (up to 500 W)
   Small Heating Elements (up to 500 W)

Half-Wave Circuit – Figure 7.1. With S1 in position LAMP the SCR is controlled by potentiometer P1. An incandescent lamp plugged into the load receptacle will be controlled by P1 from zero brightness to about 30% of its normal visual light output. By-pass switch S2 is closed when the SCR is fully on (lamp control in its zero resistance position). This action turns the lamp on to its full brightness since switch S2 then by-passes the entire control.

When S1 is switched to position MOTOR and S2 is open, the SCR is controlled by a slightly different circuit better suited to universal motor operation. This circuit incorporates a "feedback" feature which tends to maintain constant motor speed as the load on the motor is

increased. Feedback is particularly important with power hand tools, and the circuit of Figure 7.1 is especially recommended for this type of use over the circuits of Figures 7.2 and 7.3.

The TRIMMER potentiometer allows adjustment for smooth speed control for a particular motor. Due to variations between different motors it is quite likely that various power tools will work best with different settings of the TRIMMER. The best setting can be determined experimentally.

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CAUTION—Do not use the circuit of Figure 7.1 for controlling fluorescent lamps, transformers, or AC type motors (e.g., capacitor-start, induction, or shaded pole motors). Check to see that the motor used has a commutator as found in DC or AC-DC universal motors. Use either the circuits of Figures 7.2 or 7.3 for AC type shaded pole motors.

Full-Wave Circuit — Figure 7.2. This circuit, in contrast to that of Figure 7.1, gives full symmetrical control from zero to 100% over an AC load. It therefore does a more complete job of dimming lamps, and is suitable for controlling AC motors. However, the circuit does *not* have the desirable feature of feedback for motor control as in Figure 7.1.

When the load is a shaded-pole fan motor, the speed range that can be expected is about 2:1 depending on the condition of the fan and the amount of voltage required to start it. For fan operation, it may be desirable to place a 10,000 ohm, 2 watt resistor directly across the SCR in order to improve its starting performance.

Closing switch S1 will make the lamp dimmer operate as a Lamp Sentinel. S1 connects a cadmium sulphide photoconductor across part of the control circuit. When no light shines on the photoconductor, its electrical resistance is high and the control circuit is unaffected. When light shines on the device, however, its resistance is low and, as a result, it tends to reduce the output of the control. Placed near the window of your home, the device will automatically turn on any lights plugged into its receptacle as it becomes dark. Would-be prowlers will be discouraged from entering a home equipped with a Lamp Sentinel!

Best operation is achieved when the Sentinel (switch S1 closed) is set up in the brightest part of the day. The control potentiometer is adjusted so that the lamp plugged into the outlet is just off. Then, as it gets darker, the light will turn on. It may be, depending on all the prevailing conditions, that even when it is completely dark the lamp will only be lit at a "dim" intensity. This is possible — due to the great simplicity of the circuit, but some experimentation will achieve satisfactory performance. If improved performance is required, the circuit of Figure 7.3 is recommended.

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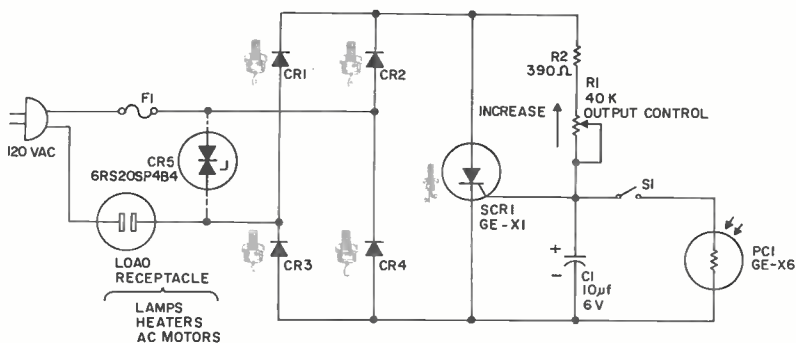
Parts List

Type Load	Outlet Rating[3]	CR1, CR2, CR3, CR4	SCR1[2]	F1-3AG Littelfuse
Lamps & Heaters	600 watts 150 watts	GE-X4[1] G-E Type 1N1693	GE-X1 GE-X1	5 amp 1.5 amp
Shaded Pole AC Universal Motors	2 amp Nameplate	GE-X4[1]	GE-X1	5 amp

[1]*Each rectifier diode mounted on a 1½" x 1½" x 1⁄16" copper cooling fin.*
[2]*SCR mounted on a 3" x 3" x 1⁄16" copper cooling fin.*
[3]*Ambient temperature not to exceed 77°C.*
C1—10 μf, 6 volt electrolytic capacitor
CR5—G-E Type 6RS20SP4B4 Thyrector

diode (optional transient voltage suppressor)
PC1—GE-X6 cadmium sulfide photoconductor
R1—40,000 ohm, 2 watt potentiometer
R2—390 ohm, 1 watt resistor
S1—SPST switch

Figure 7.2 Combination Full-Wave Lamp Dimmer, Lamp Sentinel, and AC Motor Control
 Use for:
  Incandescent Lamps (up to 600 W)*
  Small Heating Elements (up to 600 W)*
  Small AC Motors (up to 2 amp nameplate rating)

Improved Performance — Figure 7.3. The addition of circuit gain by means of a unijunction transistor, Q1, in the trigger circuit of the SCR leads to improved performance for both the Lamp Sentinel and the control of *AC motors* (shaded-pole and universal). Furthermore, the Lamp Sentinel is easier to adjust over a wider range of ambient light conditions, and greater speed range can be obtained with AC motors, particularly the universal type motor. However, the circuit does *not* have the feedback feature of Figure 7.1, and — as in Figure 7.2 — a 10,000 ohm, 2 watt resistor across the SCR may be found helpful with the shaded-pole motor.

*For use as a Lamp Dimmer, Lamp Sentinel, and Heater Control with output up to only 150 watts, substitute four G-E Type 1N1693 rectifier diodes for the GE-X4 rectifier diodes.
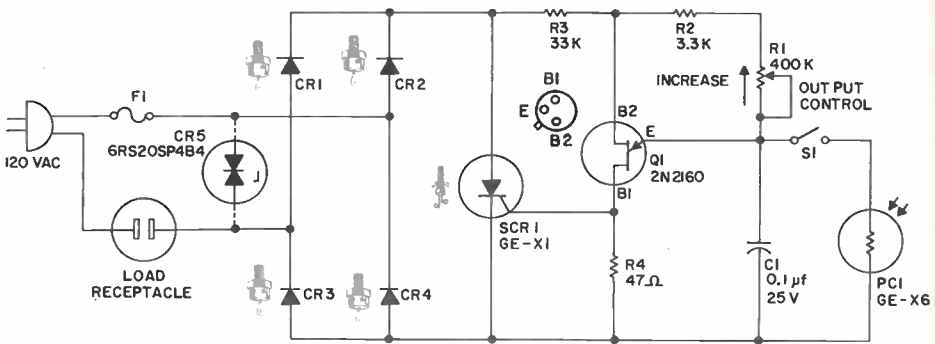
Ports List

See *Figure 7.2 Parts List for Rectifier Diode, SCR and Fuse ratings and specifications.*

C1 —*0.1 μf, 25 volt capacitor*

CR5 —*G-E Type 6RS20SP4B4 Thyrector diode (optional transient voltage suppressor)*

PC1 —*GE-X6 cadmium sulfide photoconductor*

Q1 —*G-E Type 2N2160 unijunction transistor*

R1 —*400,000 ohm, ½ watt potentiometer*

R2 —*3300 ohm, ½ watt resistor*

R3 —*33,000 ohm, 1 watt resistor*

R4 —*47 ohm, ½ watt resistor*

S1 —*SPST switch*

Figure 7.3. Improved Performonce Version of Figure 7.2

SEE CHAPTER 2 MOUNTING INSTRUCTIONS FOR PROPER INSULATION OF HEATSINK FROM THE CASE.
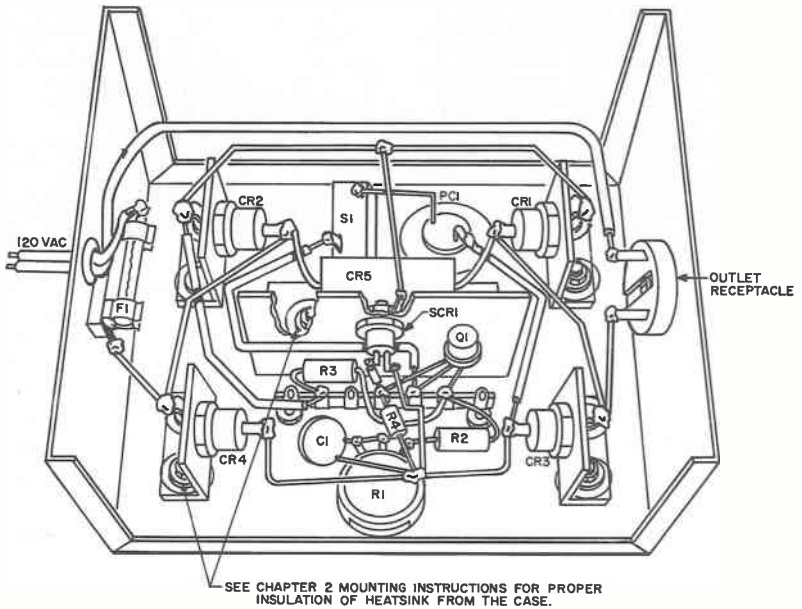
**Figure 7.4. Wiring Diogram for the Improved Performonce Version**

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A PLUG-IN SPEED CONTROL FOR STANDARD PORTABLE TOOLS AND APPLIANCES

Many of the standard household appliances and portable tools can be adapted to variable speed operation by use of the simple half-wave SCR phase control. A single "black box" of this type, see Figure 8.1, can be used as the speed control unit for anyone of the following typical loads provided they employ series universal (brush type) motors.

— Drills   — Food mixers   — Fans
— Sewing machines   — Food blenders   — Lathes
— Saber saws   — Movie projectors   — Vibrators
— Portable band saws   — Sanders

(Do not use this on other type AC or DC motors such as found in washers, dryers, refrigerators or vacuum cleaners.)
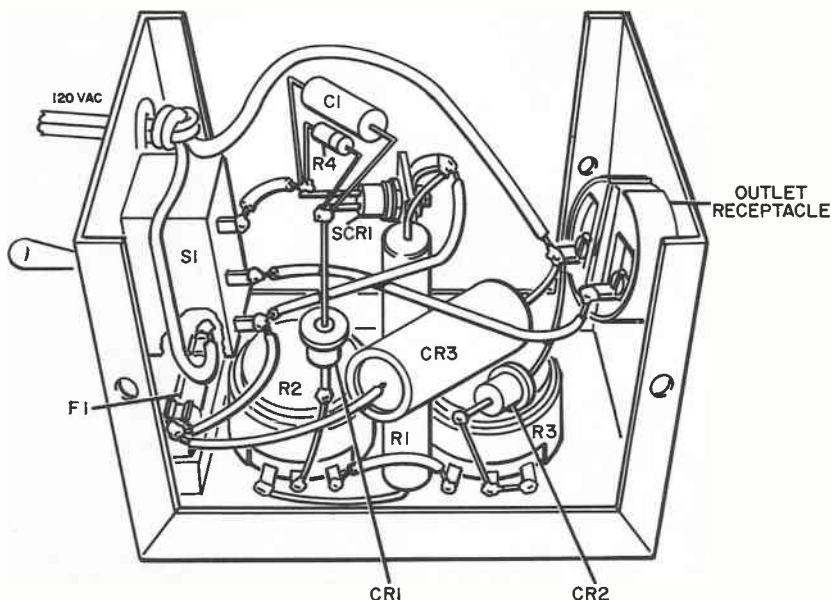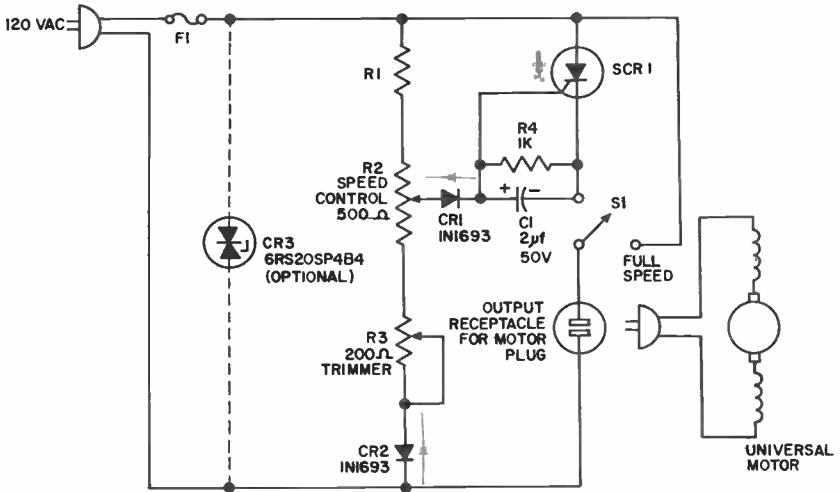
SEE CHAPTER 2 "MOUNTING" FOR INSULATING SCR I

Figure 8.1. The Motor Speed Control

In each of these applications, speed control permits optimized matching of the tool to the specific type of load. The main advantage of this circuit lies in the fact that no rewiring of the motor is necessary. This "black box" can be plugged into a 120 volt outlet, and the tool or appliance can in turn be plugged into the "black box" directly.

A circuit diagram is shown in Figure 8.2. The circuit uses the counter EMF of the motor armature due to residual field as a feedback signal of motor speed to maintain essentially constant speed characteristics with varying torque requirements. There will be some variation in the effectiveness of speed control from one motor to another depending on the magnitude of the residual field for the particular motor.

	GENERAL PURPOSE APPLICATIONS (APPROX. 2 AMP MAX MOTOR NAMEPLATE RATING)	HEAVIER DUTY TOOLS
SCR1	GE-X1	G-E C37B
R1	2500Ω, 4 WATT RESISTOR	700Ω, 10 WATT RESISTOR
F1	3 AMP	5 AMP

Parts List

C1   —2 μf, 50 volt capacitor
CR1, CR2—G-E Type 1N1693 rectifier diode
CR3   —G-E Type 6RS20SP4B4 Thyrector diode (optional transient voltage suppressor)
R2   —500 ohm, 2 watt potentiometer
R3   —200 ohm, 1 watt potentiometer
R4   —1000 ohm, ½ watt resistor
S1   —SPDT switch

Figure 8.2. Circuit Diagram

During the positive half cycle of the supply voltage, the arm on potentiometer R2 taps off a fraction of the sine wave supply voltage and compares it with the counter EMF of the motor through the gate of the SCR. When the "pot" voltage rises above the armature voltage, current flows through CR1 into the gate of the SCR, triggering it, and thus applying the remainder of that half cycle of supply voltage to the motor. If load is applied to the motor, its speed tends to decrease, thus

decreasing counter EMF in proportion to speed. The sine wave "pot" voltage thus causes current to flow into the SCR gate earlier in the cycle. The SCR triggers earlier in the cycle, and additional voltage is applied to the armature to compensate for the increased load and to maintain the preset speed. The particular speed at which the motor operates can be selected by R2. Stable operation is possible over approximately a 3 to 1 speed range.

Normal operation at maximum speed can be achieved by switching S1 to FULL SPEED, thus bypassing the SCR. Rectifier CR1 prevents excessive reverse voltage on the gate of SCR. CR2 prevents the inductive field current in the motor from "free-wheeling" in the SCR gate circuit. R3 can be used to set the minimum motor speed at a stable non-hunting level. R4 and C1 also improve stability by bypassing commutator hash around the gate of the SCR.
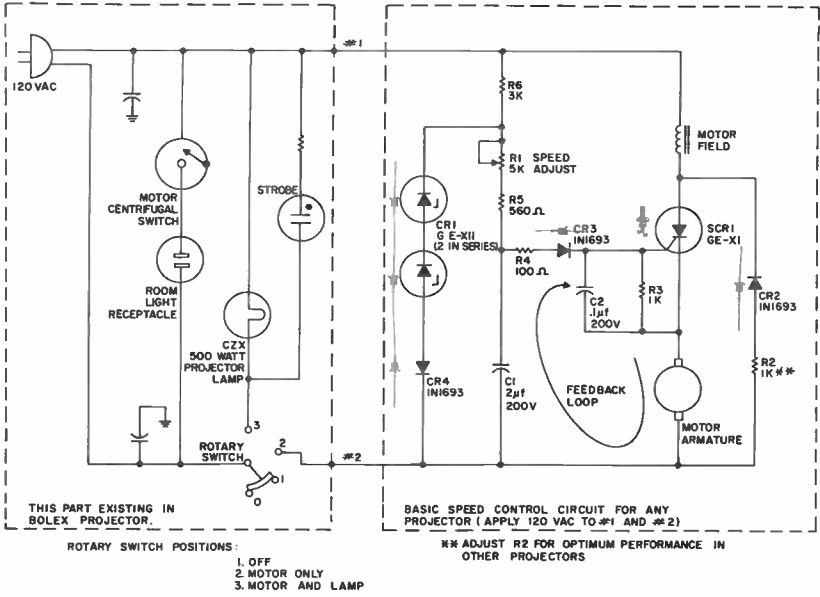
Careful attention should be given to proper heatsinking of the SCR. For intermittent duty applications typical for most tools, it will generally suffice to attach the SCR to an internal projection of the metallic enclosure case by means of the mica washer insulation kit provided with G-E SCR's. The enclosure will thus serve as a heatsink for the SCR. A 1½" x 1½" slug of aluminum or brass with a tapped hole for mounting the SCR also makes an excellent heatsink provided it is electrically insulated from the case.

In applications where stalling of the motor is unlikely, such as in sabre saws, the smaller SCR type GE-X1 will suffice. When stalling is likely to occur, such as in drills, a larger SCR G-E type as indicated in Figure 8.2 is recommended. In small hand drills under stalled conditions the motor current may reach 10 amperes RMS. Such high currents for periods in excess of 1 second may result in overtemperature of the small silicon pellet and eventual destruction of the smaller GE-X1 type SCR.

The transient protection selenium Thyrector 6RS20SP4B4 is definitely recommended where there is a possibility that the "black box" would remain plugged into the AC outlet for an extended period of time. This transient protection of the SCR is a good insurance against trouble from line surges such as caused by opening and closing of furnace contactors, lightning, etc.

A WIDE RANGE, STABILIZED MOVIE PROJECTOR SPEED CONTROL

CHAPTER 9

Fed-up with lousy home movies? Cut projection time in half (or more!) with this deluxe SCR speed control. The circuit is actually a higher-performance, wider-range version of the ubiquitous "black-box" described in Chapter 8, and is eminently suitable for installation in any 8 mm or 16 mm home type movie projector presently equipped with an AC/DC motor. The prototype fitted nicely into the motor housing of a Bolex M8 and gave stepless and smooth control of speed from zero to about 36 frames per second. A special speed-feedback loop lessens the effects of annoying line voltage variations on film speed — speed


Parts List

C1—2 μf, 200 volt capacitor	R2—1000 ohm, 5 watt resistor
C2—.1 μf, 200 volt capacitor	R3—1000 ohm, ½ watt resistor
CR1—2 GE-X11 Zener diodes in series	R4—100 ohm, ½ watt resistor
CR2, CR3, CR4—G-E Type 1N1693 rectifier diode	R5—560 ohm, ½ watt resistor
	R6—3000 ohm, 2 watt resistor
R1—5000 ohm, 2 watt linear potentiometer	SCR1—GE-X1 Silicon Controlled Rectifier

Figure 9.1. Projector Control As Fitted to Bolex M8

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jumped alarmingly every time the furnace or refrigerator switched with the original rheostat control — enabling 400 foot movies to be shown in comfort with little or no readjustment of film speed required.
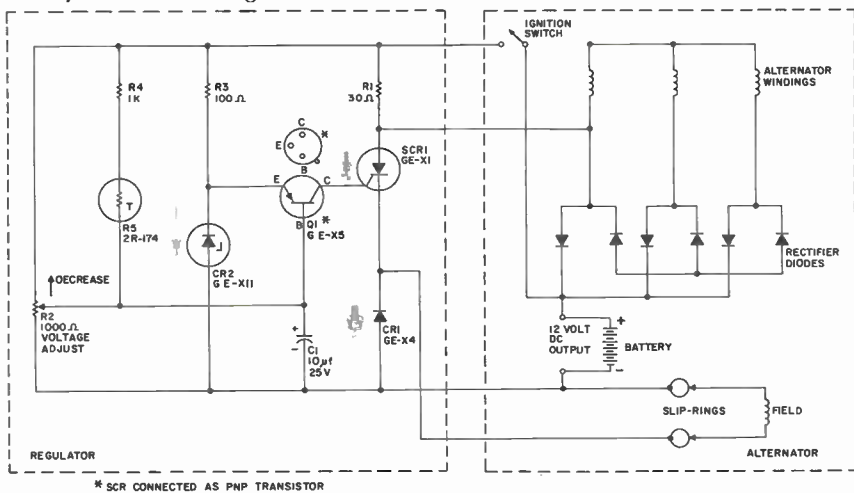
The GE-X1 SCR (SCR1) is inserted *between* the motor armature and its series field, and supplies half-wave rectified DC to the motor armature*. The average value of voltage applied to the motor armature (and hence motor speed) depends therefore on SCR1's firing angle. This is controlled in turn by the variable resistor R1 which determines the rate of charge of capacitor C1 towards SCR firing potential. (SCR1 fires when V_{C1} reaches a critical value.) Speed feedback is achieved by charging C1 in the *reverse* direction with a speed-sensitive voltage derived from the spinning armature while SCR1 is blocking. (During periods when the supply voltage is negative and SCR1 is blocking, resistor R2 and diode CR2 provide negative field current, so that this negative speed-dependent voltage may be induced across the armature.)

*In the Bolex projector (as in most types) the field is in two sections with the armature connected in-between. Rearrange wiring thus:

(Before) (After)
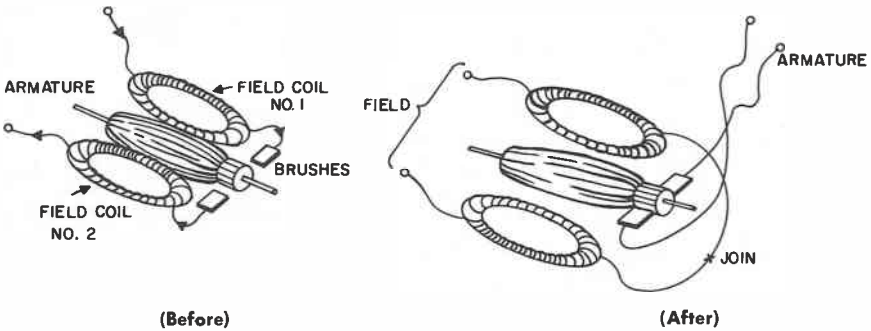
ALTERNATOR REGULATOR

Cars using alternators (in addition to anything else which uses an AC generator) lend themselves very well to simple, trouble-free solid state voltage regulation. Probably the simplest such circuit available today is shown in Figure 10.1.
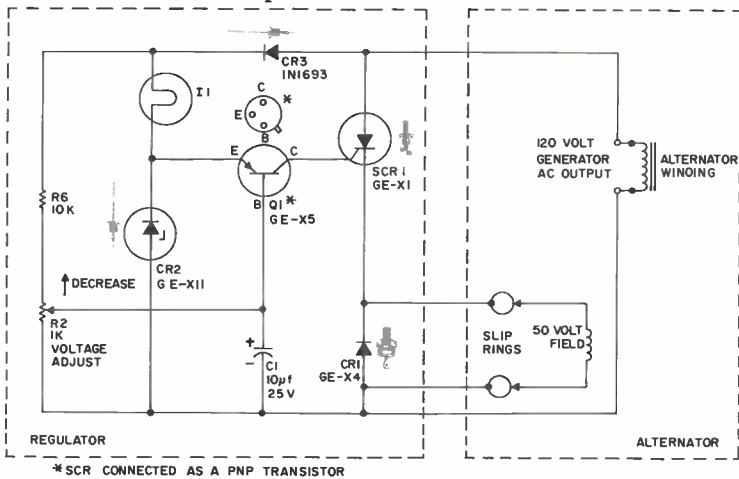

* SCR CONNECTED AS PNP TRANSISTOR

Parts List

C1—10 μf, 25 volt capacitor
CR1—GE-X4 rectifier diode
CR2—GE-X11 Zener diode
Q1—GE-X5 Silicon Controlled Rectifier operated as a PNP transistor
R1—30 ohm, 10 watt resistor

R2—1000 ohm, 2 watt potentiometer
R3—100 ohm, 2 watt resistor
R4—1000 ohm, ½ watt resistor
R5—G-E Type 2R-174 Thermistor
SCR1—GE-X1 Silicon Controlled Rectifier

Figure 10.1. The Automobile Regulator

Regulation of the alternator voltage output is achieved by controlling the signal fed to the gate of the SCR, which in turn controls field current. The voltage across zener CR2 is a reference. When the voltage at the arm of R2 drops below the reference voltage, Q1 applies a signal to the gate of the SCR, turning it on and applying a pulse of power to the alternator field. The SCR will turn off when the voltage across it goes negative. Thermistor R5 and resistor R4 provide the correct temperature compensation to keep the battery fully charged in any weather.

To set the regulator voltage on cars with 12 volt systems, connect a voltmeter across the battery, turn R2 to minimum voltage and start the car engine. Turn R2 back toward a higher voltage until the battery voltage starts rising slowly. Rev up the engine slightly and adjust the voltage setting, R2, until the battery voltage levels off at 14.5 volts, if the temperature near the battery is close to comfortable room temperature of 72°F . (At 0°F, this setting must be 15.0 volts.) This is the complete set-up procedure.

The same circuit is adaptable to any other applications where alternator output must be closely regulated. Examples of other such cases are in emergency power supplies for home or business use, outboard motor alternator regulators, mobile AC generators, etc. As a typical example, a circuit for use on a 120 volt motor-generator set using residual flashing is given in Figure 10.2. The operation of this circuit is identical to that above, except that temperature compensation is not shown, and the resistor, R1, which is necessary to flash the field from a battery is not shown. In any specific application, careful attention must be paid to the ratings of the SCR and CR1 as compared with the alternator field requirements.


Parts List

C1—10 μf, 25 volt capacitor	Q1—GE-X5 Silicon Controlled Rectifier operated as a PNP transistor
CR1—GE-X4 rectifier diode	
CR2—GE-X11 Zener diode	R2—1000 ohm, 2 watt potentiometer
CR3—G-E Type 1N1693 rectifier diode	R6—10,000 ohm, ½ watt resistor
I1——G-E 25 watt, 120 volt incandescent lamp	SCR1—GE-X1 Silicon Controlled Rectifier

Figure 10.2. The Home Regulator

APPLYING HEAT WITH PRECISION

CHAPTER 11
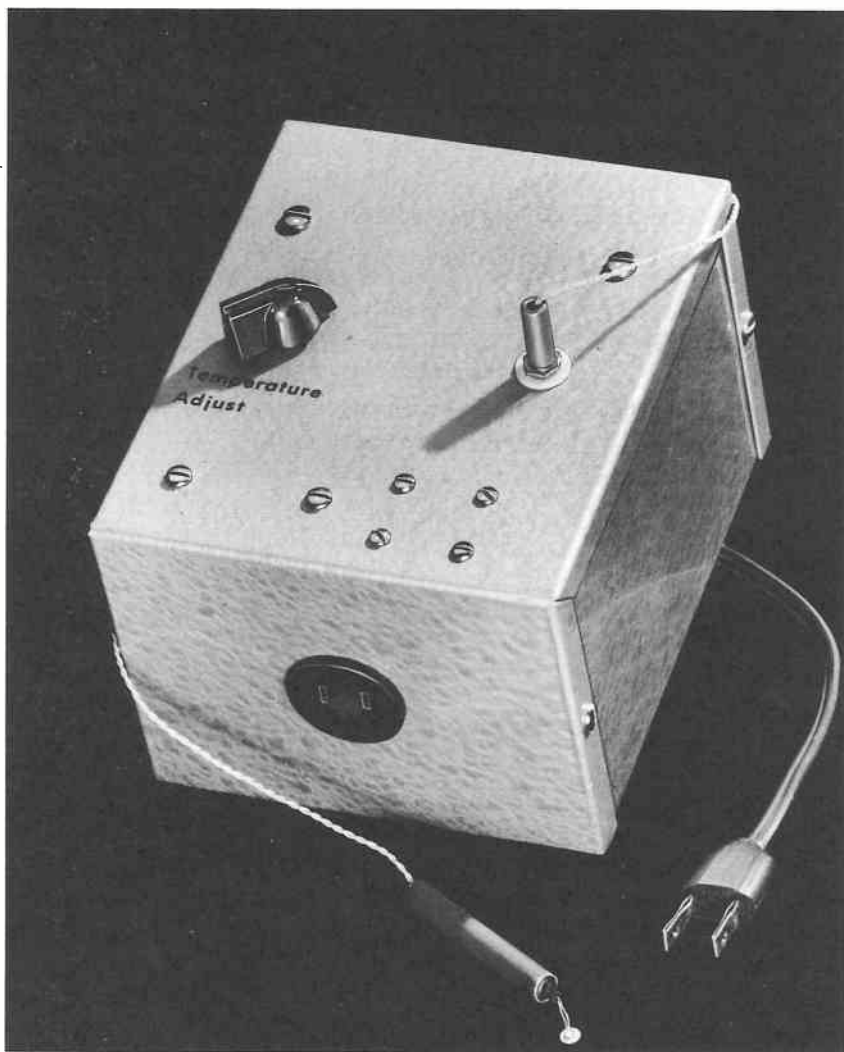
With the turn of a knob, you can bring your soldering iron up to the temperature you want and keep it there. Or perhaps you want a tub of tepid water, or to turn on a fan when the room gets too hot, or to turn on the furnace when it gets too cold. These things plus innumerable others are possible with simple SCR temperature-controlled circuits.

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The basic temperature operated relay is detailed in Figure 11.1. Transformer T1 has two 12.6 volt secondary windings, W1 furnishing voltage to the relay MR1 through SCR1, the other winding W2 furnishing AC voltage to the trigger circuit of SCR1. Temperature sensing thermistor R1 is electrically connected into a bridge formed by it and R2, R3, and adjusting potentiometer R4. When the resistance of thermistor R1 equals the resistance setting on R4, the bridge is balanced and none of the AC voltage introduced into the bridge by winding W2 is applied to the gate of SCR1. Hence, relay MR1 remains de-energized and its normally closed contacts apply power to the heating elements connected to the load receptacle. If temperature increases, the resistance of thermistor R1 decreases, unbalancing the bridge in a direction such that trigger current flows to SCR1 while its anode is

Parts List

C1—0.05 μf, 200 volt capacitor

CR1, CR2, CR3—G-E Type 1N1693 rectifier diode

F1—1 amp fuse

J1—Temperature probe jack

MR1—Relay, DPDT 5 amp contacts with 6 volt DC GPD coil (Potter & Brumfield GP11, or equivalent)

P1—Temperature probe plug
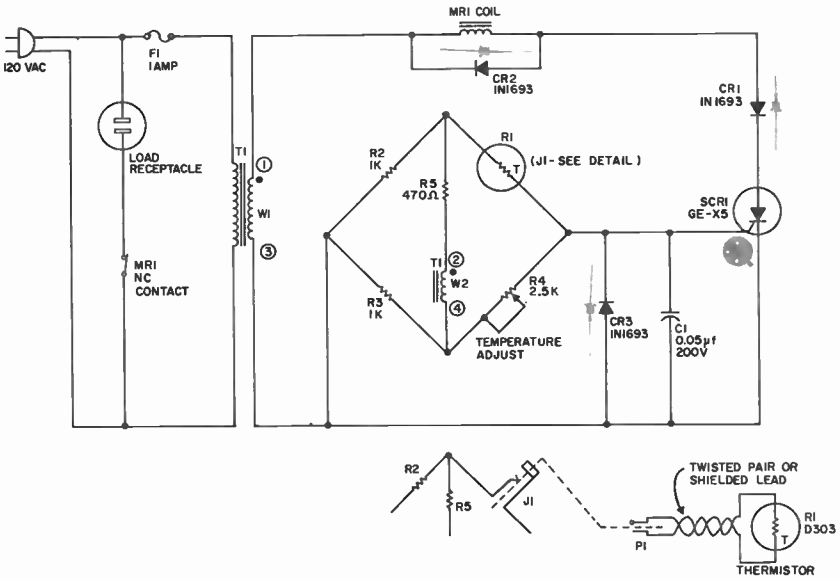
R1—G-E Type D303 thermistor, 0.3 inch dia., 1000 ohm at approximately 170°F

R2, R3—1000 ohm, 2 watt resistor

R4—2,500 ohm, 4 watt wire wound potentiometer

R5—47 ohm, 2 watt resistor

SCR1—GE-X5 Silicon Controlled Rectifier

T1—Transformer: primary, 120 volts AC; secondary, W1 12.6 volts and W2 12.6 volts (UTC-FT10, or equivalent)

Figure 11.1. Basic Temperature Operated Relay

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positive. This turns on SCR1 and energizes the relay, thereby discon-necting power from the connected load. Below the preset temperature setting, R1 unbalances the bridge in the opposite direction so a nega-tive signal is applied to the gate of SCR1 when its anode is positive, thus inhibiting it from firing and allowing power to continue to flow to the heating elements.

Locating the thermistor on the soldering iron, in the bath water or in any other zone that must be temperature controlled will provide the necessary feedback information. If the thermistor is to control a cooling system such as a fan or air conditioner rather than a heating system, opposite action can be secured by either connecting the load to a normally open contact on the relay or by reversing the leads on the secondary winding W2.

This circuit will control the temperature at thermistor R1 within approximately one degree over the temperature range from 20°F to 150°F. For most precise temperature control in this and other ranges, SCR1 should be kept at a relatively stable ambient temperature. For other temperature ranges, thermistor R1 should have approximately 1000 ohms resistance in the center of the desired control range.
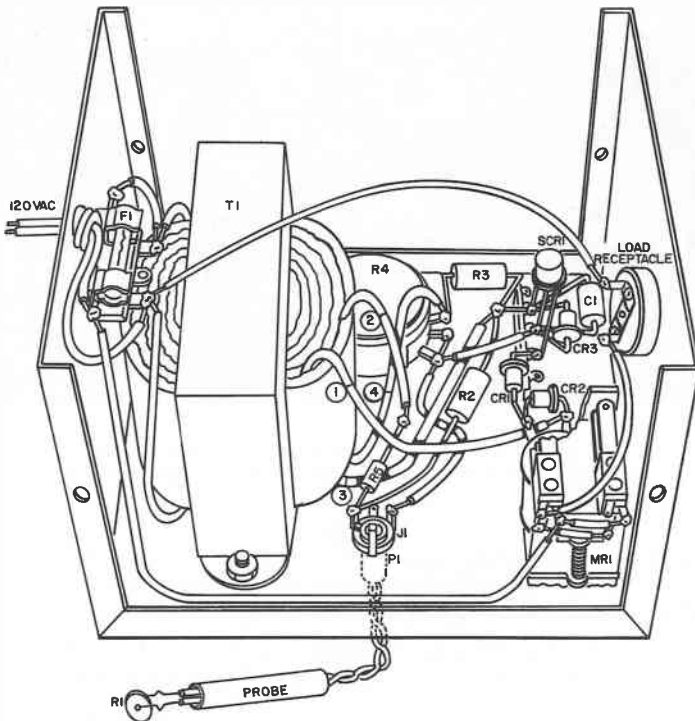

Figure 11.2. Wiring Diagram for Basic Relay

SCR1 is rated to handle 1/2 ampere maximum and the contacts of relay MR1 are rated for 5 amperes at 120 volts AC. Heavier loads can be handled by using MR1 as a pilot relay to pick up a larger contactor. Alternately, 6 volt coils or other loads requiring currents of several amperes can be directly controlled by SCR1 if a larger device than the GE-X5 is used. For instance, the GE-X1 can control at least 4 amperes directly if adequately cooled. However, since its gate triggering sensitivity is inadequate for the previous circuit, a stage of transistor amplification is necessary as shown in Figure 11.3. Two separate single-secondary transformers can be substituted for T1.

Other types of sensing resistors can be substituted for R1. For instance, a cadmium sulfide light sensitive photoconductor in this control will turn on a lighting load when the ambient light drops below a preset level.
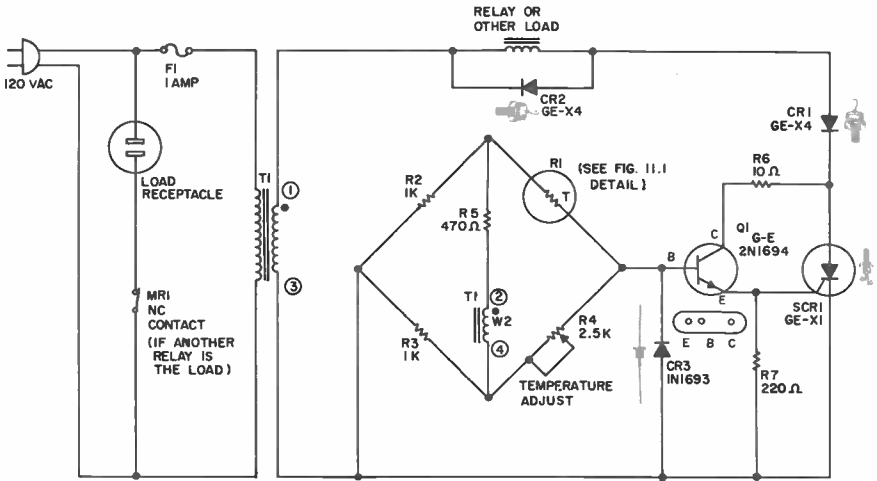
Parts List

CR1, CR2—GE-X4 rectifier diode
Q1   —G-E Type 2N1694 transistor
R6   —10 ohm, 2 watt resistor
R7   —220 ohm, 2 watt resistor
SCR1   —GE-X1 Silicon Controlled Rectifier
                Remaining parts are the same as those listed in Figure 11.1.

Figure 11.3. Temperature Operated Control for Higher Current Loads
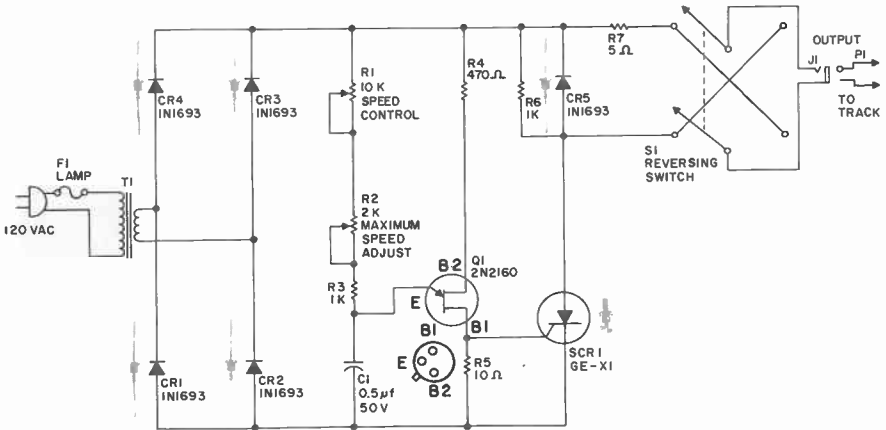
MODEL RAILROADING
WITH SCR ELECTRONICS
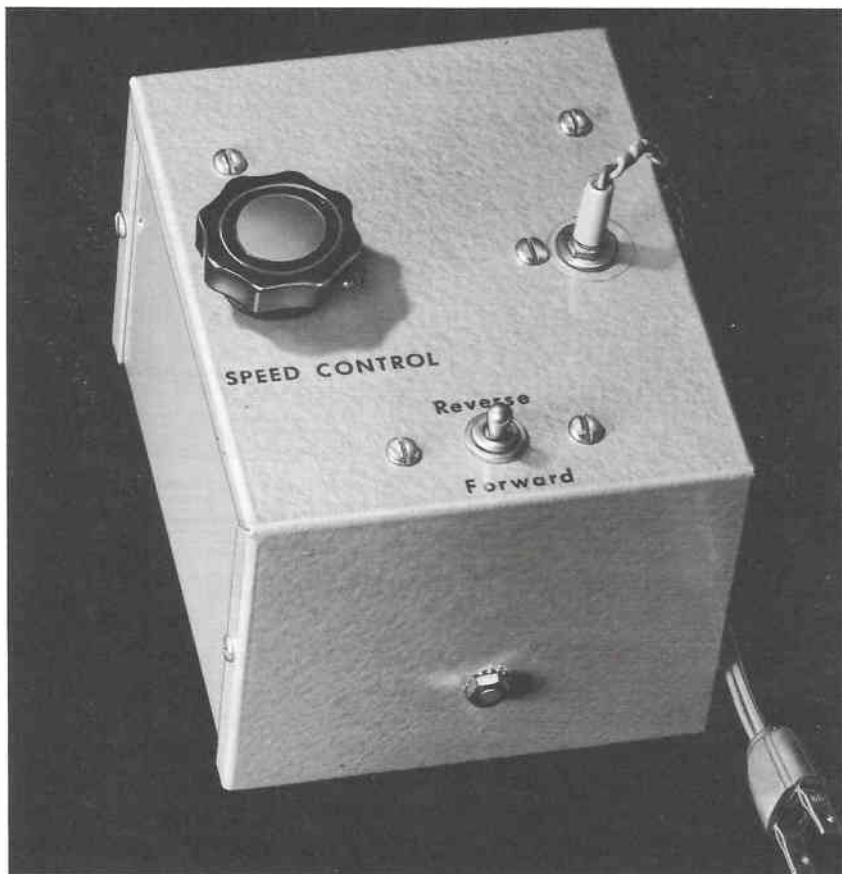
Serious model railroaders have been continuously plagued with problems of staggering magnitude from the earliest days of the development of this fine art.

The control of a train which the hobbyist could not sit on (without crushing) was nearly impossible before the advent of electronics. When electric trains appeared, a new and fascinating era had begun. The control of the train became simple, if not realistic, but scale speeds were difficult to obtain accurately and smoothly. Starting and stopping were really headaches. The truly serious hobbyist cringed at the thought of turning up that rough, hot dial and watching his scale-tons of steel jounce up to a scale speed of several hundred miles per hour.

Then appeared the SCR, and another era had begun. Model trains could be controlled coolly, simply and inexpensively.

The secret of the SCR's success is the ability to apply power to the engine in pulses, and to control the width of these pulses. Correct scale speeds are practical, and ultra-smooth starting and stopping are no longer an unattainable fantasy. A simple control is shown in Figure 12.1.

The bridge (CR1 - CR4) supplies pulsating DC to the firing circuit (Q1, R1-R5, C1) which phase controls the SCR. The SCR is in series with the train power and thereby controls the amount of current it receives. For a more detailed explanation of the unijunction trigger — see page 7.

Parts List

C1—0.5 µf, 50 volt capacitor

CRI, CR2, CR3, CR4, CR5—G-E Type 1N1693 rectifier diode

F1—½ amp fuse

J1—Output jack

P1—Output plug to track connections

Q1—G-E Type 2N2160 unijunction transistor

R1—10,000 ohm, 2 watt potentiometer

R2—2000 ohm, 2 watt potentiometer

R3, R6—1,000 ohm, ½ watt resistor

R4—470 ohm, ½ watt resistor

R5—10 ohm, ½ watt resistor

R7—5 ohm, 20 watt resistor or two 10 ohm, 10 watt resistors in parallel

S1—DPDT switch

SCR1—GE-X1 Silicon Controlled Rectifier

T1—Transformer: primary, 120 volts AC; secondary, 25 volts AC (Stancor P-6469, or equivalent)

All resistors 10% tolerance

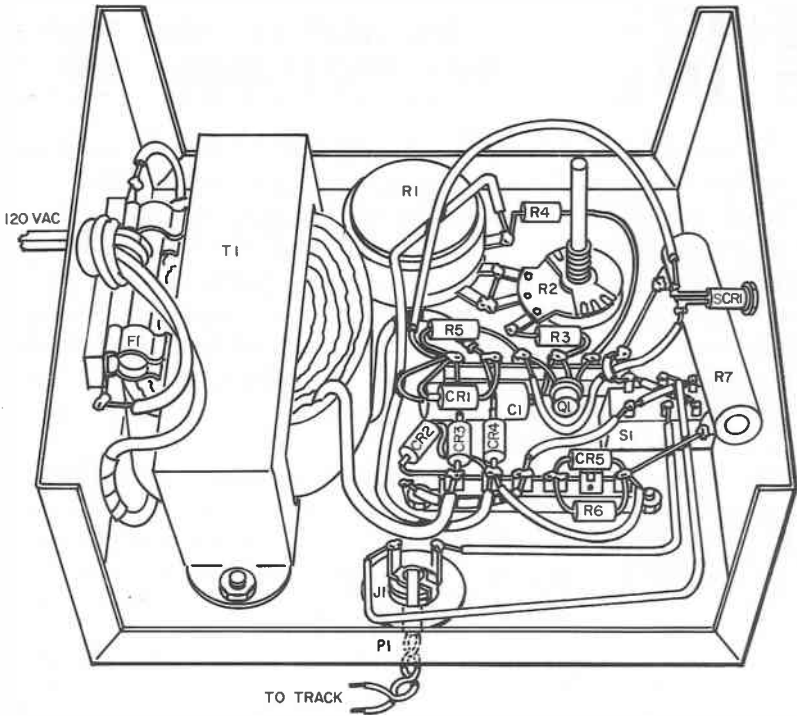**Figure 12.1. Model Railroad Speed Control**

Figure 12.2. Wiring Diagram

1000 WATT AC LAMP FLASHER WITH PHOTOELECTRIC CONTROL

This control can be used to actuate warning lights on towers, piers, or construction hazards. Attention-getting lights for advertising signs or alarm systems, as well as Christmas and other decorative lighting arrangements can also be controlled. The controlled devices may consist of motors, sirens, neon signs, incandescent lamps, etc. up to a total power load of 1000 watts. Operation of the control may be by its photoelectric cell which could start the lamp (or other load) flashing after sunset and turn it off at dawn. In addition, a highly sensitive remote control of the flasher is available by merely adding a neon lamp to actuate the photoelectric cell from an isolated source.

(See Chapters 14 and 15 for battery-operated flashing controls.)

Rectifiers CR1, CR2, CR3, and CR4 form a bridge circuit with the SCR across the DC legs. With light falling on the photoconductor PC1, capacitor C1 charges through resistor R1 to the peak of the
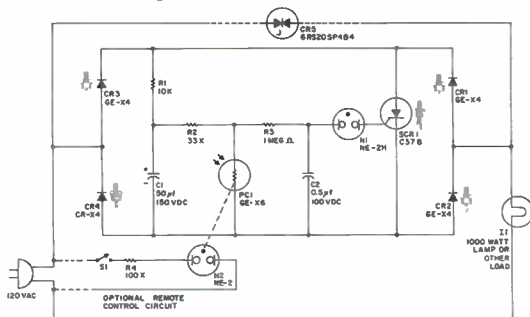
Parts List

C1—50 μf, 150 working volts DC electro-lytic capacitor

C2—0.5 μf, 100 volt DC paper capacitor

CR1, CR2, CR3, CR4—GE-X4 rectifier diode

CR5—G-E Type 6RS20SP4B4 Thyrector diode (optional transient voltage suppressor)

I1—1000 watt lamp or other load

N1—G-E Type NE-2H neon lamp

N2—G-E Type NE-2 neon lamp (optional)

PC1—GE-X6 cadmium sulfide photo-conductor

R1—10,000 ohm, ½ watt resistor

R2—33,000 ohm, ½ watt resistor

R3—1 megohm, ½ watt resistor

R4—100,000 ohm, ½ watt resistor (optional)

S1—SPST switch

SCR1—G-E Type C37B Silicon Controlled Rectifier

Note: For 300 watt maximum load, use GE-X1 SCR.
For 100 watt maximum load, use GE-X1 SCR and G-E Type 1N1693 rectifier diodes.

Figure 13.1. 1000 Watt Flasher

supply voltage, about 150 volts DC. Since the resistance of PC1 is low when illuminated, very little voltage appears across it or capacitor C2. When PC1 is dark, C2 charges through R2 and R3 toward 150 volts, however when it reaches about 90 volts, the neon lamp N1 fires, discharging C2 into the gate of the SCR. The SCR then conducts, turning on the load. This also starts discharging C1 through R1 and the SCR. The discharge current from C1 provides, for a time, a continuous current through the SCR that is above its holding current. The SCR cannot, therefore, turn OFF until C1 is almost completely discharged.

When current from C1 drops below holding current, the SCR turns OFF during the interval line voltage is near zero. The full supply voltage then appears across the bridge and C1 charges again to a high voltage. The voltage on C2 also starts rising until the neon lamp fires and the cycle repeats. Thyrector CR5 protects the circuit from transient voltage surges.

An alternative remote control can be made by adding a second neon lamp, N2, and masking the photocell so that it sees only N2. A very sensitive remote control is thus obtained that is completely isolated from the load circuit. For low-voltage remote control, a flashlight lamp may be used, instead of N2, and operated at about $\frac{1}{2}$ its normal voltage thus giving exceptionally long life.

The performance of the photoelectric control may be inverted (that is, made to flash when the photoconductor is illuminated) by merely interchanging PC1, and R2 as shown below:
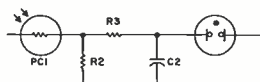

Figure 13.2. Inverted Operation

Sensitivity to light in either the normal or inverted modes can be decreased by partially masking PC1, and can be increased by increasing resistor R2 to about 470 K ohms. To increase on time, make C1 larger. To increase off time, make R3 larger.

When constructing the control, mount rectifiers CR2 and CR4 on a $2\frac{1}{2}$″ x 3″ x $\frac{1}{16}$″ aluminum plate. Rectifiers CR1 and CR3 and the SCR are mounted on a 5″ x 3″ x $\frac{1}{16}$″ aluminum plate. These two plates serve both as heatsinks and electrical connections to the studs. Mount the plates vertically, with room for air to circulate around them, and insulate well from all other metal parts. The other components may be mounted on terminal strips. Avoid repeated bending or flexing of leads on all components, particularly N1, N2 and PC1. The entire device may be mounted in a weather-proof metal box, with a small plastic window for the photoconductor. The box itself should be grounded, as a safety precaution.

BATTERY-OPERATED FLASHING BUOY LIGHT WITH PHOTOELECTRIC CONTROL

Here is a small, battery-powered flasher for use in isolated locations, such as buoys, piers, or towers which are far from a convenient 120 volt source. The flasher is fully automatic — it starts itself operating at night and shuts off at dawn. A long cycle conserves battery power and lamp life.
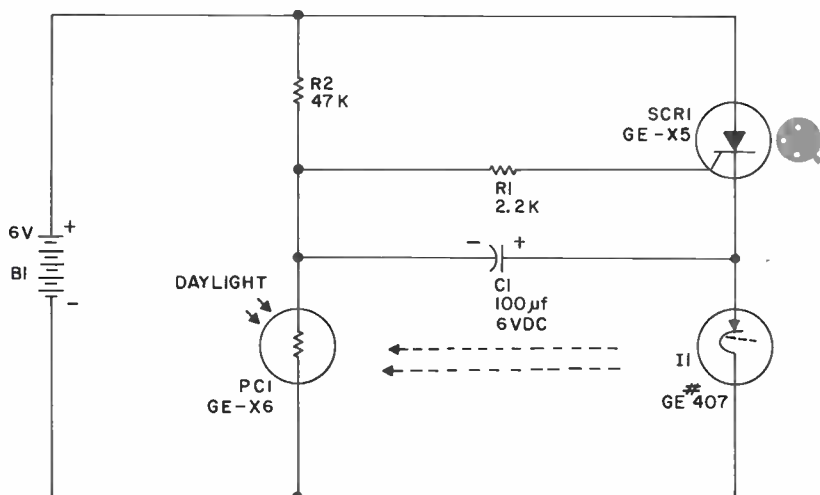
Parts List

C1   — 100 µf, 6 volt DC electrolytic capacitor
B1   —6 volt lantern battery
I1   — G-E #407 flasher lamp
PC1   — GE-X6 cadmium sulfide photoconductor
R1   —2200 ohm, 1/2 watt resistor
R2   — 47,000 ohm, 1/2 watt resistor
SCR1 — GE-X5 Silicon Controlled Rectifier

Figure 14.1. Battery-Operated Flasher

With daylight on the photoconductor PC1, its resistance is very low, hence very little voltage appears at the gate of the SCR. When PC1 is dark its resistance is higher, and current through R2 can charge capacitor C1 to about 1 volt, then current through R1 and into the gate of the SCR will cause it to fire, turning the lamp on. Light from the lamp also illuminates the photoconductor, thus lowering its resistance.

Capacitor C1 can then charge through PC1 and the SCR to about 5 volts, with the polarity shown in the diagram. The flasher lamp has, built into it, a small bi-metal switch which opens when the lamp heats up and closes when the lamp cools. Therefore, after the lamp has been on for a second or two, this internal switch opens, turning off the lamp and the SCR, and thereby making PC1 dark again. When the bi-metal switch re-closes, about $\frac{1}{2}$ second later, we find that the SCR cannot turn on because the gate voltage is about 5 volts negative as a result of the charge on C1. Current flow through R2 into C1 then slowly reverses the charge on C1, reaching firing voltage of 1 volt positive on the gate in about 5 seconds. The SCR then fires and the cycle repeats until daylight is again strong enough to disable the system.

This circuit, therefore, greatly spreads out the normal cycle of the flasher lamp, and also provides automatic ON-OFF control by daylight.

When constructing this circuit, place the photoconductor so that it receives as much lamp light as possible without interfering with visibility of the lamp. All of the components are lead-mounted and are easily fitted into a small, weather-proof metal box. As is usual with lead-mounted devices, avoid excessive bending and flexing of the leads.

HIGH-POWER, BATTERY-OPERATED FLASHER WITH PHOTOELECTRIC CONTROL

Want to build your own navigational beacon for pier, boat, or plane, or mark your driveway at night? Ever had the urge to make like a rookie cop? A minimal investment in two SCR's, a unijunction transistor and a few other small parts can realize your fondest dreams! Plus features of this superior flasher are its generous 36-40 watt output, variable flash rate up to 60 flashes/sec, *independent* control of on and off times, and photoelectric daylight control. This latter feature is a real battery saver — it turns the flasher on at night and shuts it off during the day; untouched by human hand!

SCR1 and SCR2 form a basic DC flip-flop as described on page 97 in the G-E SCR Manual, 2nd Ed. The lamp load, however is connected in the *cathode* leg of one SCR so that one side of the load may be at ground (negative) potential — required in some applications. Flip-flop timing is controlled by an (almost) conventional UJT oscillator arrangement (Q1, R1, C3, etc.) as explained on page 7. Potentiometer R2 and diode CR1 are added however, to give the required on/off timing independence. Cadmium sulphide photoconductor R3 locks out the UJT firing circuit during hours of daylight.
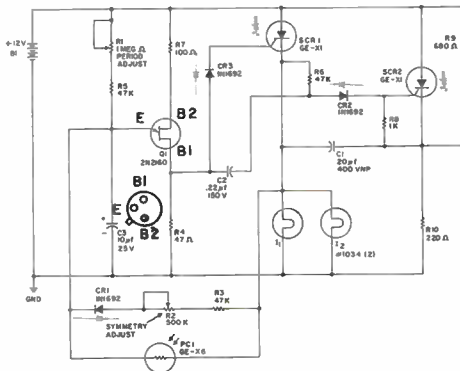
Parts List

B1—12 volt battery	R1—1 megohm, 2 watt potentiometer
C1—2 10 µf, 400 volt VNP capacitors in parallel (Sprague "Atoms" #TVAN 1650, or equivalent)	R2—500,000 ohm, 2 watt potentiometer
C2—.22 µf, 150 volt capacitor	R3, R5, R6—47,000 ohm, ½ watt resistor
C3—10 µf, 25 volt capacitor	R4—47 ohm, ½ watt resistor
CR1, CR2, CR3—G-E Type 1N1692 rectifier diode	R7—100 ohm, ½ watt resistor
I1, I2—G-E #1034 lamp	R8—1000 ohm, ½ watt resistor
PC1—GE-X6 cadmium sulfide photoconductor	R9—680 ohm, ½ watt resistor
Q1—G-E Type 2N2160 unijunction transistor	R10—220 ohm, ½ watt resistor
	SCR1, SCR2—GE-X1 Silicon Controlled Rectifier

Figure 15.1. High-Power, Battery-Operated Flasher
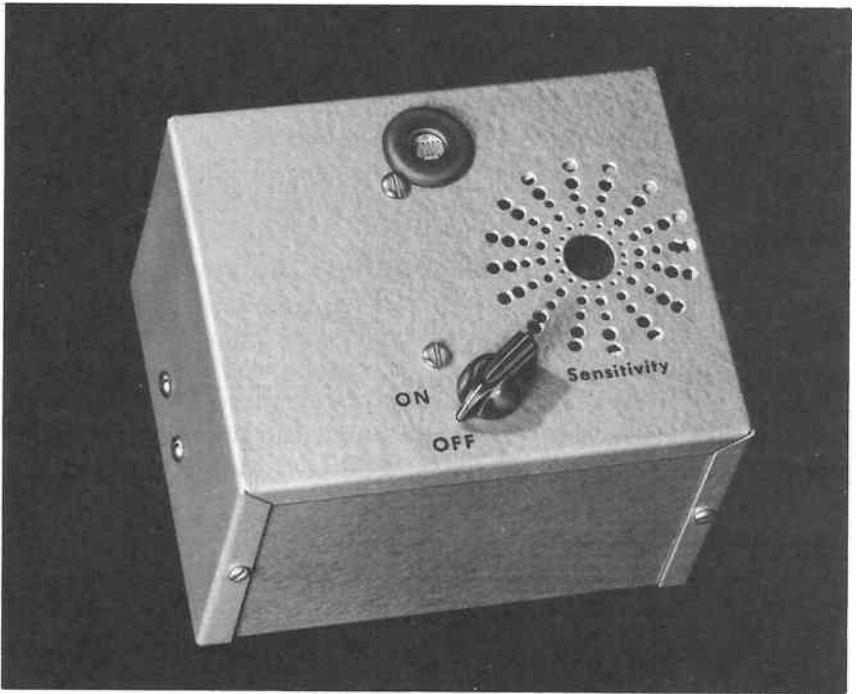
THE WATCH-BOX

One of a watch dog's greatest services to man is to sound off in case of smoke, fire, or intruders. The "Watch-Box" uses a semiconductor to do the same thing, and needs only to be fed a few electrons to keep it going.

The basis of this circuit is the GE-X5 SCR driving a small speaker or earphone in a simple relaxation oscillator circuit, shown in Figure 16.1.
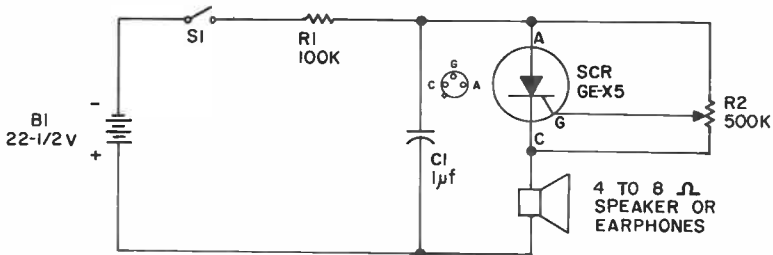

Figure 16.1. Basic Relaxation Oscillator Circuit

Capacitor C1 is charged by current through resistor R1, and is discharged by the SCR into the speaker voice-coil, producing a click or pop sound. The SCR is fired by gate current, derived from the pot R2. As gate bias current increases, a point is reached where the SCR triggers. This point is determined by the setting of potentiometer R2 and the voltage across C1.

If the pot is set for a bias current just below the firing level, a very small increase in current will cause the SCR to fire and discharge C1. The voltage across C1 is then small, therefore the bias current is very low. As C1 recharges, the voltage and gate current rise until the firing level is reached. With a higher current setting of R2, the capacitor is discharged at a lower voltage, producing a faster clicking rate in the speaker.

By inserting a GE-X6 cadmium sulfide photoconductor, PC1, in series with the pot, as shown in Figure 16.2, the clicking rate can be made dependent on light falling on the photocell. If R2 is adjusted to a point just below the threshold, a slight increase in light on PC1 will cause the speaker to start clicking. More light will make the clicking faster and faster. By setting the clicking rate fast enough to produce an audio tone, very small changes in light level are easily and quickly detected.
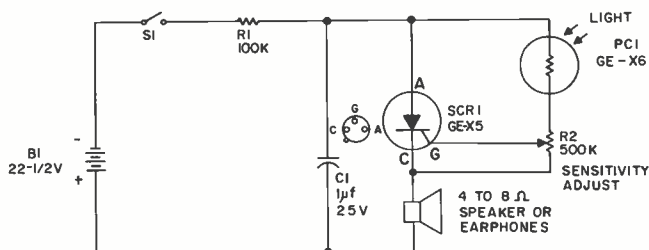
Parts List

C1	—1 μf, 25 volt (minimum) capacitor
PC1	—GE-X6 cadmium sulfide photoconductor
R1	—100,000 ohm resistor
R2	—500,000 ohm potentiometer
S1	—SPST switch (on R2)
SCR1	—GE-X5 Silicon Controlled Rectifier
SPKR1	—4 to 8 ohm speaker
B1	—22-1/2 volt battery

Figure 16.2. Light-sensitive Oscillator Circuit

The cadmium sulfide does not, however, respond well to infra-red. By using a cadmium selenide cell, good sensitivity is obtained to the near infra-red, such as produced by flames. A lead sulfide cell, although much more expensive, covers the visible spectrum and extends well out into the infra-red region, reaching the emission from a hot soldering iron. An inexpensive plastic lens, of one-inch diameter or more, can be used with any of the photoconductors to greatly improve the sensitivity in one direction. The sharper the focusing, however, the more narrow becomes the field of view.
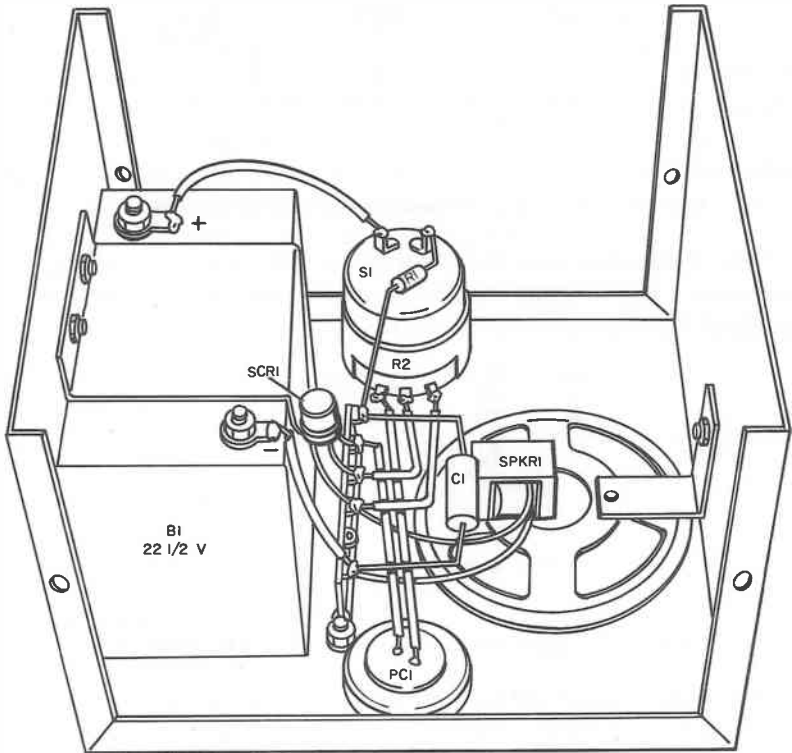

Figure 16.2a. Wiring Diagram for Figure 16.2

Another method of detecting long-wave infra-red, and ambient temperature as well, is to use a high-resistance bead-type thermistor in place of the photoconductor. The thermistor should have a resistance on the order of 100,000 ohms at room temperature. By carefully mounting the bead at the focal point of a good flashlight reflector, fairly respectable sensitivity to hot objects may be obtained. Since the thermistor is also senstive to ambient temperature, it also serves to warn of overheating in the room.

The variable-resistance type humidity sensors can be used, in place of photoconductors, to provide warning of high humidity. To invert this function, that is to sense lowering of humidity, light or temperature, place the sensing element in parallel with the pot R2, and add a fixed 100,000 ohm resistor, R3, where the sensor would normally be, as shown in Figure 16.3. For best results, R3 should be made variable.
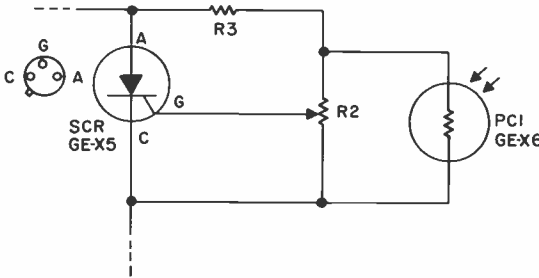

Figure 16.3. Reversed-mode Connection for Light-sensitive Oscillator

The Watch-Box may also be used for indication of noise level by connecting a high-output ceramic or crystal microphone from gate to cathode of the SCR, as in Figure 16.4.
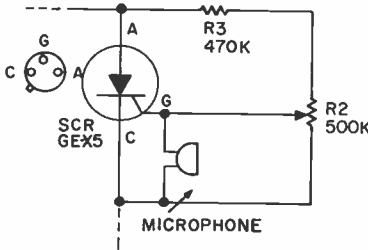

Figure 16.4. Sound or Vibration Sensitive Control far Oscillator

A ceramic contact microphone or phonograph pickup connected in the same place and placed on the floor, or on a wall, will give an indication of vibration, such as footsteps.

To detect smoke, the cadmium sulfide detector of Figure 16.2 can be used in an arrangement shown in Figure 16.5.

The inside surfaces of the chimney, collar, and cup should be painted a flat black, preferably by spray, or may be lined with black velveteen to reduce reflected light to as low a value as possible. Heat from the lamp creates a gentle air flow up the chimney, thus continually moving the room air. Smoke in the air will reflect light from the lamp back into the photoconductor to actuate the Watch-Box. The photoconductor should be shielded from direct light and heat from the lamp.
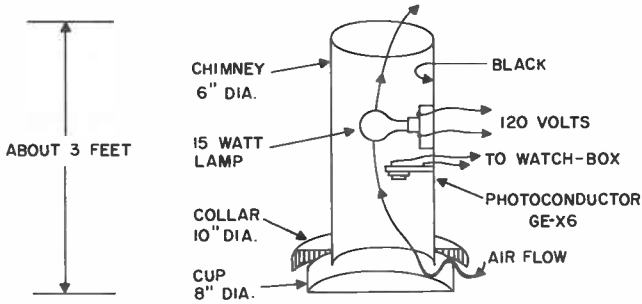
Figure 16.5. Cross-section View of Smoke Detector

An alternate method of smoke detection is to use the inverted circuit of Figure 16.3 and place the photoconductor at the bottom of the chimney, looking up at the lamp. It will be necessary to place an aperture disc near the lamp, however, in order to reduce light on the cell to a low level, such as in Figure 16.6. The smoke in this case will absorb light, thus raising resistance of the photoconductor.
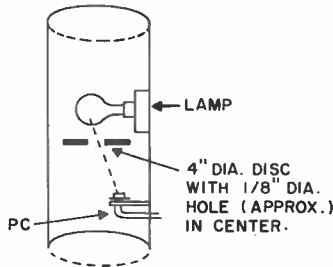

Figure 16.6. Alternate Arrangement for Smoke Detector

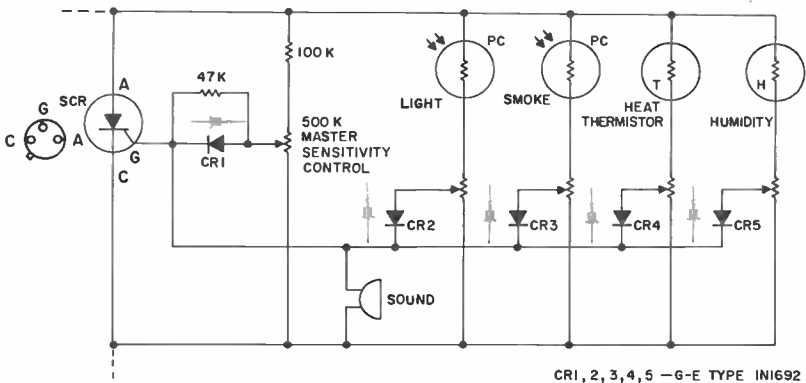For multiple input signals in one unit, diodes may be used for proper mixing, Figure 16.7.

CRI, 2, 3, 4, 5 —G-E TYPE IN1692

Figure 16.7. Multiple Input Circuit

You can now build your Watch-Box just as simple or as complex as you desire. The circuit of Figure 16.2 can be built in a little plastic case with PC1 exposed, and used as a portable fire alarm in your bedroom or hotel room. If you leave the blinds open slightly, the little gem will awaken you with the birds in the early dawn.
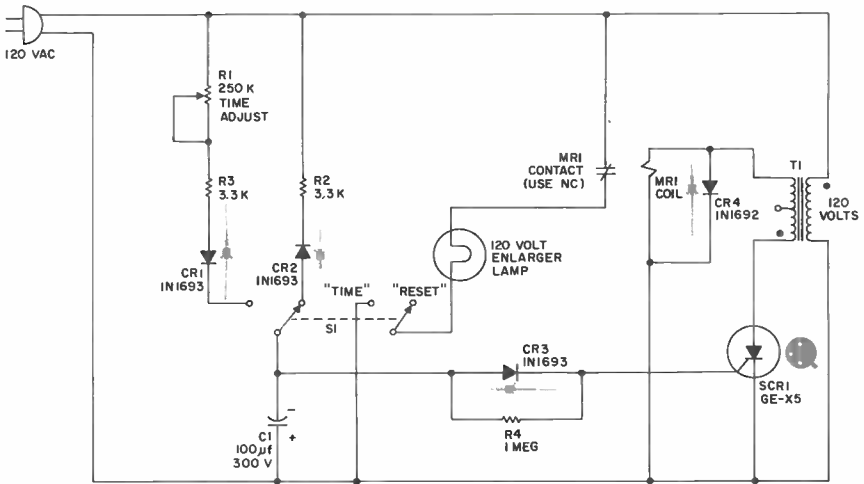
For greater peace-of-mind when using an intercom as a baby-sitter, the full complement of light, smoke, heat, sound, and humidity detectors can be employed. Just place the Watch-Box speaker near the intercom, or run out separate wires for a remote speaker.

Should an input signal get so high that the system hangs-up, a push-button switch to momentarily short out the SCR should bring it back into operation. In normal operation, the SCR is commutated (turned off) by the tendency of the capacitor, C1, and inductance of the speaker coil to oscillate. A large drive on the SCR gate can cause it to fail to commutate and thus hang up. The push-button switch is also handy to check out the system to be sure it is ready to operate.

You may want to try some of the hundreds of other variations of these circuits, such as replacing the speaker with a relay, or using the pulse developed across the speaker to drive a larger SCR and so control lamps, larger relays, motors, fans, etc.

ENLARGER PHOTOTIMER

ENLARGER PHOTOTIMER

Here is a precision "solid-state" time delay relay, that can readily replace those troublesome clock-operated and other electro-mechanical timing devices in common use around the darkroom. In addition, its versatile 5 amp relay output makes it ideally suited for switching far higher power loads than a darkroom lamp, if so desired. Both delayed "off" and delayed "on" switching functions are interchangeably available, by the simple expedient of swapping relay contacts. The proto-type circuit is presently being used as a print-exposure timer (for a Durst 606 enlarger), and time delays from a fraction of a second up to nearly one minute are easily attainable with the values of R1 and C1 shown. Depending on the quality of the electrolytic timing capacitor C1 employed, timing repeatability can be better than 2%.

Parts List

C1—100 µf, 300 volt capacitor (Mallory type FP129.1 or equivalent)
CR1, CR2, CR3—G-E Type 1N1693 recti-fier diode
CR4—G-E Type 1N1692 rectifier diode
R1— 250,000 ohm, 2 watt potentiometer
R2, R3—3300 ohm, ½ watt resistor
R4— 1 megohm, ½ watt resistor

MR1–24 volt AC relay (Potter & Brumfield #MR5A, or equivalent)
S1—DPDT switch
SCR1—GE-X5 Silicon Controlled Rectifier
T1—Filament transformer: primary, 120 volts AC; secondary, 12.6 volts AC center-tapped (TRIAD F25X, or equivalent)

Figure 17.1. Enlarger Phototimer

The GE-X5 SCR functions as a very sensitive (yet extremely reliable) relay in this circuit; its purpose is to supply sufficient current to energize the output relay coil while it itself is being triggered by a few microamps output current available from the very high impedance timing network, R1 and C1. With switch S1 on RESET, capacitor C1 quickly charges up to the *peak negative* value of the input supply voltage (about 165 volts) through diode CR2 and resistor R2. In this position the lamp load is off. When S1 is thrown to TIME, however, the lamp comes on and capacitor C1 starts to discharge toward the *positive peak* supply voltage through CR1, R1, and R3 at a rate determined by the setting of potentiometer R1. Since the time constant associated with the C1, R1 network is numerically long, and current only flows for part of each cycle, this charging process takes many complete cycles of the supply voltage. In practice, the voltage across C1 never attains its ultimate value, since once it has become positive enough (about + 2 volts) to trigger SCR1, SCR1 energizes the relay and terminates the cycle.

REPLACING RECTIFIER TUBES
WITH SILICON RECTIFIERS

Many hobbyists may desire to replace tube rectifiers with silicon rectifiers. Direct substitution of gas, mercury or vacuum type tube rectifiers may be done if certain precautions are observed.

With the low forward drop of the silicon rectifier, the DC output voltage will increase when replacing tubes. When substituting for gas or mercury rectifiers this increase will be approximately 10 volts and is not usually objectionable. In rare cases it may cause excess heating of resistors, or excessive voltage on capacitors, etc. With vacuum tube rectifiers, however, the tube drop may be as high as 50 volts at rated load. Some resistance must therefore be added either in series with each silicon rectifier or in the DC output to reduce the DC voltage to the desired value. Figure 18.1 b and c are examples of where the resistance may be placed. Note also that this added resistance acts as a surge current suppressor for capacitor input filters.

The value of this resistance will depend upon the voltage drop of the rectifier tube and the current flowing. As a first approximation, this resistance could be calculated from the voltage drop of the tube rectifier (which is usually given in the tube rating sheet) divided by the output current. In the Tube Handbook, the 5U4GB has a 44 volt drop at 225 ma DC output. Under these maximum rated conditions, the tube resistance would be: $\frac{44}{.225} = 195$ ohms. Figure 18.1b shows that adding 200 ohms in each leg or 200 ohms in the load, Figure 18.1c, gave very nearly the same DC output. Generally, the added resistance will run between 150 and 500 ohms. For exact duplication of output voltage we suggest the use of a tapped wire wound resistor.

In our example the wattage may be calculated from either I^2R or E^2/R, where I is the RMS current through R, and E is the RMS voltage across R. In a capacitor input filter, these RMS values may be difficult to determine. For the resistor added in the load ahead of the filter, use an RMS voltage and current approximately twice the DC average values. For the resistor added in each leg, the wattage will be half that necessary for the load resistor. It is suggested that somewhat higher wattage than that calculated be used to assure cool and safe operating temperature. 25 watts minimum is recommended for the resistor added in the load, and 15 watts minimum is recommended for the resistors in each leg.

A transient voltage suppressor, such as a Thyrector diode (tubular type 6RS20SP4B4 or clip type 6RS20SC4B4), is suggested across the primary of the input transformer to absorb any switching or line transients that might occur. These Thyrector diode transient voltage suppressors are small and quite economical insurance against excessive voltage appearing across the silicon rectifier.

The Thyrector diodes suggested, 6RS20SP4B4 and 6RS20SC4B4 are for use from 90 to 120 volts RMS. For voltage between 120 and 150 volts RMS, the next higher rated voltage Thyrector, 6RS20SP5B5 or 6RS20SC5B5, should be used. If economy and space are not critical, placing the Thyrector diode of the proper RMS voltage rating (units available up to 600 Vrms) in the secondary is preferred, because the smaller transformer KVA would help limit the peak transient current.

Thyrector diodes begin to suppress transients at about 150% of their peak rated voltage. It is therefore recommended that the transient voltage rating of the silicon rectifier be at least 150%, preferably 175%, above the transformer secondary peak voltage. In many cases, this may necessitate using two silicon rectifiers in series. In the example in Figure 18.1a, the peak reverse voltage on each anode of the 5U4GB is $650 \sqrt{2} = 920$ volts. 175% of 920 volts $= 1610$ volts. Note that two 600 volt rectifiers (1N1697), each with a transient rating of 800 volts (total 1600 volt transient capability), are suggested. (For more detailed discussion of the Thyrector diode voltage suppressors, refer to General Electric Application Note 200.5 or the General Electric Rectifier Componets Guide, Chapter 11.)

Added transient protection may also be obtained by adding a .005 μfd ceramic bypass capacitor from point A of Figure 18.1 b or c to ground.

The silicon rectifier supplies output power immediately after turn-on. This immediate DC voltage applied to the plates (anodes) of other vacuum tubes in the circuit, might possibly strip the cathode coating and eventually destroy vacuum tubes. For this reason, many circuit designers have selected a rectifier tube with an indirectly heated cathode such that the rectifier cathode heats at the same rate as other cathodes in the circuit. We have therefore not listed silicon rectifier replacements for indirectly heated cathode vacuum rectifiers such as the 6X4, 6Z5, 6V4, 25Z6, 35Z6 and many others. Special precautions are needed that will delay the DC power from the silicon rectifier 5 or 10 seconds after filament power is applied to other tubes in the circuit. Special time delay switches such as an Amperite thermal delay relay or a temperature activated switch could be used. With this precaution, silicon rectifiers could be substituted for the indirectly heated cathode vacuum rectifiers similar to that for the filamentary type.
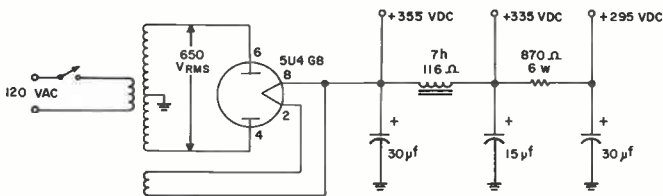
NOTE: PEAK STEADY STATE REVERSE VOLTAGE ACROSS ANODE TO CATHODE OF 5U4G8 IS 650 √2 = 920 VOLTS.

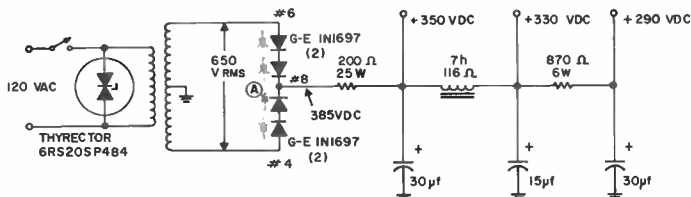**Figure 18.1a. Original Circuit**

Figure 18.1b. Alternate Silicon Rectifier Replacement Circuit—Resistance in Load
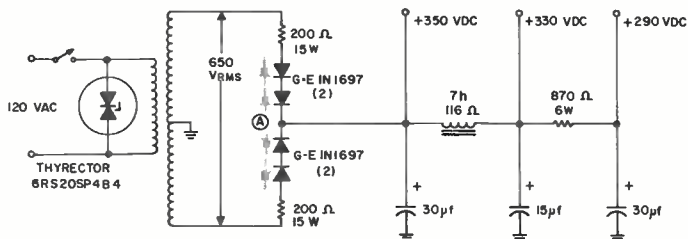

Figure 18.1c. Alternate Silicon Rectifier Replacement Circuit—Resistance in Each Leg

Figure 18.1. Suggested Silicon Rectifier Replacement for Vacuum Tube 5U4GB and Similar Tube Rectifiers Found in a Typical Radio Power Supply Circuit

For the filamentary type tube rectifier (directly heated), the warmup time is very fast, and the original equipment designer has usually taken special precautions to prevent any possible detrimental effect on other tubes in the circuit.

When silicon rectifiers replace tube rectifiers, the filament power supply may, of course, be removed. With directly heated filamentary type tube rectifiers, the positive DC output lead may be made to mid tap of the filament transformer. This lead should now be connected to the cathode of the silicon rectifier. If the filament power is still left on the socket, make sure when making this connection that half the filament transformer is not shorted out. As shown in Figure 18.1a for the 5U4GB, DC output voltage is usually taken from one side of the filament, and the above does not have to be considered.

65

When the peak reverse voltage of the circuit exceeds approximately 1000 volts, direct substitution of a single silicon rectifier cell is not recommended. This is beyond the reverse voltage rating of the general purpose silicon device. Two or more silicon rectifiers may be connected in series for higher voltages. In the example given, each anode of the 5U4GB was subjected to a steady state peak reverse voltage of 920 volts. With a possible 10% increase in supply voltage, this peak reverse voltage could reach 1012 volts. Two 600 volt rectifiers (1N1697) were therefore selected in series. These have a combined reverse rating of 1200 volts. This gives a satisfactory 17% voltage margin. However, as noted in the section above on transient voltage suppressors, the governing factor in selecting the proper rectifier will probably be the transient rating.

CHART I   SUGGESTED SILICON RECTIFIER REPLACEMENTS FOR VACUUM RECTIFIERS, DIRECTLY HEATED FILAMENTARY TYPE

TUBE RECTIFIER	SYMBOL	TUBE RATING				SILICON RECTIFIER REPLACEMENTS						
		Max. RMS Voltage	PK Reverse Voltage	PK Current Amps	Max. DC Current Amps Per Anode	SYMBOL	Type[1]	Max. RMS Voltage Transformer Sec.[3]	PK Reverse Voltage Rating	Max. Transient Voltage Rating	Max. DC Current 100° C Ambient	Thyrector For Secondary
5T4 5U4G 5U4GA 5U4GB 5V3 5V3A 5W4, GT 5Y3 5Y3GA, GT		450 450 450 450 425 550 350 350 350	1550 1550 1550 1550 1400 1550 1400 1400 1400	.675 .8 .9 1.0 1.2 1.4 .3 .375 .44	.113 .113 .125 .138 .175 .208 .050 .063 .063							
5X4G 5X4GA 5Y4 5Y4GA, GT		450 450 350 350	1550 1550 1400 1400	.675 .9 .375 .4	.112 .125 .063 .063		1N1693 1N1694 1N1695 1N1696 1N1697 1N560 1N561	140 180 240 282 325 385 485[2]	200 300 400 500 600 800 1000[2]	350 450 600 700 800 960 1200[2]	.250 .250 .250 .250 .250 .250 .250	6RS20SP or 6RS20SC —5B5 —6B6 —8B8 —9B9 —11B11 —13B13 —16B16
5Z3 80		450 350	1550 1400	.675 .400	.113 .063							
81		235	700	.5	.085							

NOTES:
[1]Any of the silicon rectifiers listed will handle the current. Select on the basis of voltage.
[2]For higher voltages, use rectifiers in series.

[3]The maximum RMS voltage of the transformer secondary has been calculated from the rating of the Thyrector diode (6RS20SP4B4), if used on the 120 volt AC transformer primary. Transient voltages will be suppressed below 175% of the rated peak ($\sqrt{2}$ RMS) transformer primary and secondary voltages.

Replacing Rectifier Tubes With Silicon Rectifiers

CHART II SUGGESTED SILICON RECTIFIER REPLACEMENTS FOR GAS OR MERCURY TUBE RECTIFIERS

TUBE RECTIFIER	TYPE	CATHODE	SYMBOL	TUBE RATING			SILICON RECTIFIER REPLACEMENT (One Diode Per Leg)						Thyrector For Secondary
				Peak Reverse Volts	Peak Current Amps	DC Current Amps Per Anode	SYMBOL	Type[1]	Max RMS Voltage of Transformer Sec.[4] (end to end)	Peak Reverse Voltage Rating	Max Transient Voltage Rating	DC Current Max Amps 100° C Ambient	
OY4 & OY4G	Gas	Cold		300	.500	.075							
OZ4, OZ4G	Gas	Cold		880	.200	.075							
(OZ4A)	Gas	Cold		880	.330	.110							6RS20SP or 6RS20SC
								1N1694	180	300	450	.250	—6B6
								1N1695	240	400	600	.250	—8B8
								1N1696	282	500	700	.250	—9B9
82	Hg	Hot		1550	.6	.060		1N1697	325	600	800	.250	—11B11
83	Hg	Hot		1550	1.0	.115		1N560	387	800	960	.250	—13B13
								1N561	480[2]	1000[2]	1200[2]	.250	—16B16
816	Hg	Hot		5000	.5	.125							

TUBE RECTIFIER	TYPE	CATHODE	SYMBOL	TUBE RATING			SILICON RECTIFIER REPLACEMENT (One Diode Per Leg)						
				Peak Reverse Volts	Peak Current Amps	DC Current Amps Per Anode	SYMBOL	Type[1]	Max RMS Voltage of Transformer Sec.[4] (end to end)	Peak Reverse Voltage Rating	Max Transient Voltage Rating	DC Current Max Amps 100° C Ambient	Thyrector For Secondary
866/866A	Hg	Hot	ANODE / FILAMENT	10000 / 2500	1.0 / 2.0	.25 / .50	ANODE [5] / TO MIDTAP OF FIL. TRANSF.	4JA10C / 4JA10D / 4JA10E / 4JA10M	150 / 210 / 262 / 315[2]	300 / 400 / 500 / 600[2]	400 / 525 / 650 / 775[2]	.650[3] / .650[3] / .650[3] / .650[3]	6RS20SP or 6RS20SC / —5B5 / —7B7 / —9B9 / —11B11

NOTES:

[1] Any of the silicon rectifiers listed will handle the current. Select on the basis of voltage.
[2] For higher voltages, use rectifiers in series.
[3] Average current reduced to .4 amps for 300 μfd capacitor load and 3.3 ohm surge resistor.

[4] The maximum RMS voltage of the transformer secondary has been calculated from the rating of the Thyrector diode (6RS20SP4B4), if used on the 120 volt AC transformer primary. Transient voltages will be suppressed below 175% of the rated peak (√2 RMS) transformer primary and secondary voltages.
[5] A 15 to 20 second time delay of the rectified power output is suggested where one is not already present to protect other vacuum tubes in the circuit from the possible detrimental affect of immediate DC voltage.

GENERAL ELECTRIC EDUCATIONAL PROJECTS

Complete electrical and electronic kits are available from General Electric. These educational and useful projects include all parts, wire, and necessary tools. Easy to follow assembly directions are combined with instructions in basic electronics and the operating principles of the unit being constructed.

Advanced Electronics Lab — Over 50 experiments teach principles of electronics through construction of radio receivers, voice transmitters, public address system, and more.

Project: Transistor Radio — Construct a self-contained radio receiver with built-in air loop antenna and earphone.

Project: Intercom — Building this master and remote station intercom will illustrate the principles of transistor amplifiers.
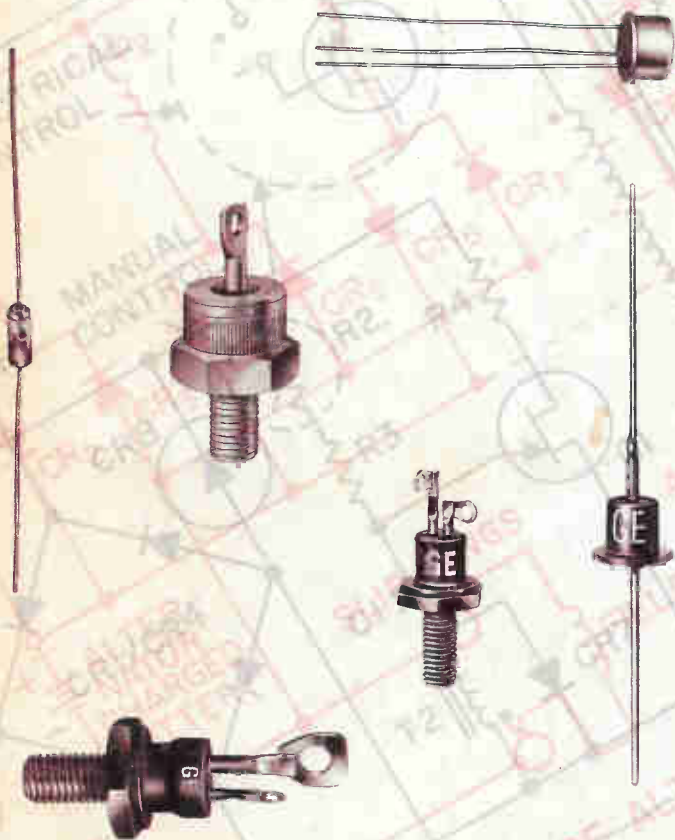
Project: Analog Computer — Learn both electronics and mathematics by constructing and using this computer in solving problems. Includes memory panels and audio indicator with 3-transistor oscillator and amplifier.

Project: Shortwave Radio — Receive international, amateur, and police broadcasts on this 5-transistor standard shortwave band radio. Instructions include the technique of soldering.

General Electric Educational Projects are sold through hobby shops, toy and department stores, and electronic dealers. Further information on these and other kits is available from General Electric Company, Radio Receiver Department, 1001 Broad St., Utica, New York.

GENERAL ⚡ ELECTRIC

Rectifier Components Department/Auburn, New York