NEW SCR DEVELOPMENTS

Some of the recent four-layer gate-controlled semiconductor switches are very low in cost, are self-protecting, and are transient-immune. Bilateral SCR's are also readily available.

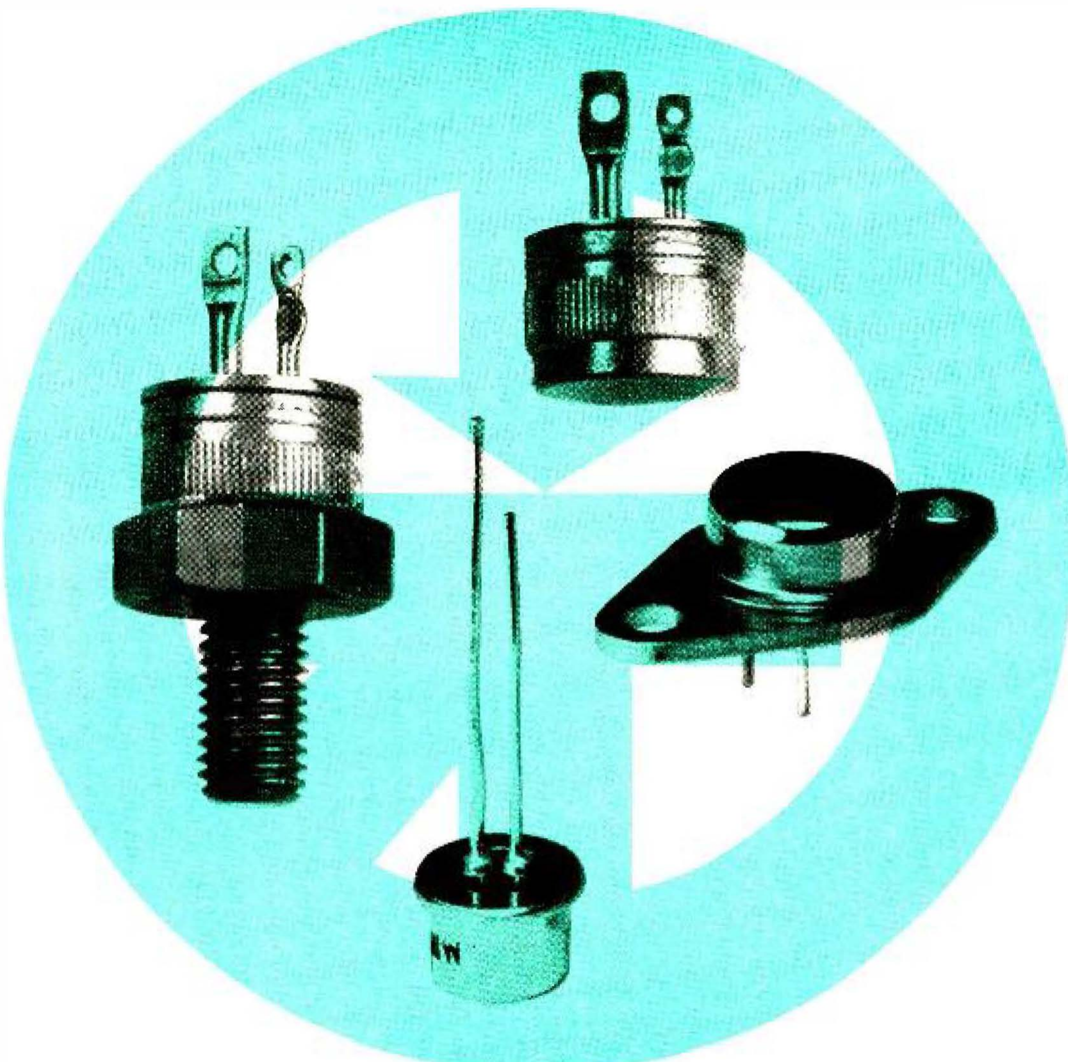
By DONALD LANCASTER

THE silicon controlled rectifier has come of age. These four-layer gate-controlled semiconductor switches are now used in an amazingly diverse range of applications. SCR's are now directly replacing ignitrons, power thyratrons, and other bulky, inefficient devices, operating as high as 1500 volts at current levels exceeding 500 amperes. They are now serving as microminiature, lightweight switches in computer and satellite circuitry, reliably switching milliamperes of current at low voltage levels. They enable power supplies and regulators to operate in switching mode at efficiencies very nearly approaching 100%. SCR's serve in motor and power-tool controls that provide variable speed and variable torque at the turn of a knob. An entire industry has begun with the SCR home light dimmer and workshop power-tool controls. In special circuits, the SCR is an efficient radar modulator, a power inverter, and an effective d.c.-to-d.c. converter.

There have been some recent developments in the SCR field that promise to make these components even more useful and may possibly create a whole new class of circuitry that has no present counterpart. These same developments can also greatly simplify currently popular devices as well as contribute to reduced cost.

These recent developments take several directions, the most significant of which are extremely low-cost SCR's, self-protecting SCR's, and transient-immune SCR's. Of equal importance are newly

Some typical examples of low-cost silicon controlled rectifiers showing their simple case design.



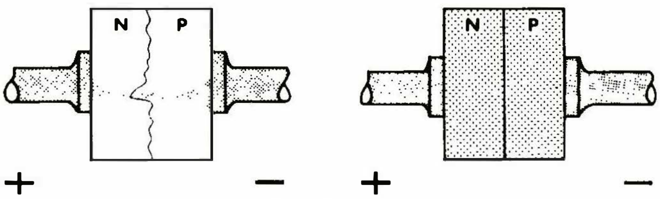


Fig. 1. When the reverse breakdown of a non-uniform p-n junction (left) is exceeded, it breaks down at its weakest point. High current density at this point melts the structure and creates a short. A uniform, controlled-avalanche structure breaks down uniformly across the entire surface. Under these conditions, the current density is low and no damage is done.

available SCR "offspring." These include a class of SCR's that can be turned *off* by a gate pulse as well as on, and new bilateral SCR's that work equally well in either current direction. The former may be operated from an uninterrupted, uncommutated d.c. source. The latter are capable of operating directly off the a.c. line, allowing a single bilateral SCR to provide full-wave, non-inverted proportional a.c. control without the use of other power components.

We will assume that the reader has a basic familiarity with the conventional SCR and its operation. (See "Silicon Controlled Rectifiers" in the October 1963 issue of this magazine, one of the SCR manuals, or design information provided by virtually all the SCR manufacturers, *Motorola, Texas Instruments, General Electric, RCA, Transitron, Sarkes Tarzian, International Rectifier, SSPI, Westinghouse*, among others.) Suffice it to say that the SCR is a four-layer semiconductor switch that is capable of switching large amounts of current through the use of minute control signals applied to a third or gate electrode. This article will investigate these new developments which promise to make the new silicon controlled rectifiers intrinsically more useful.

Economy SCR's

One of the most welcome developments is the creation of a line of economy SCR's which are designed for the consumer electronics market for use in appliances and dimmers. SCR's are now available, in quantity, for less than $1.00 apiece and singly for slightly over $1.50. These SCR's can control 5 amperes at 200 volts, while lower voltage SCR's are available at even lower cost. The new SCR economy has been achieved by employing several techniques. One is planar construction, a more efficient method of fabricating the silicon structure which is the heart of the SCR. A second factor is sheer volume of production and high production yields made possible by volume markets and automatic equipment.

The most significant contribution to reduced cost has been the redesign of the case. Since a large fraction of any semiconductor's cost is in the case, the leads, and the assembly, the hermetically sealed, stud-mounted design has been abandoned in favor of cases which are merely tabs or small cups of metal. These inexpensive packages are entirely adequate for the environmental conditions encountered in consumer products.

Each manufacturer has his own approach to an ideal economy package. Some of these are shown in the photographs. *RCA* uses a flat diamond-shaped washer and a small metal cup. This is similar to the typical power-transistor case, although much lighter and smaller. This package is usually bolted or riveted to a heat sink. *Texas Instruments* uses the top-hat diode case, now with two leads out the top. It is soldered directly to a heat sink (usually with a disc solder preform and an oven) or glued to a beryllium oxide insulating washer. The anode connection is by way of a spring clip or directly through the heat sink. The *Transitron* package is a simple cup, somewhat similar to the *TI* design.

Motorola uses a special cartridge type case designed to fit into a fuse clip or be soldered directly to a heat sink. This is one of the smallest SCR packages presently available at the 8-ampere current level. *General Electric* uses a press-fit cup for its economy SCR's, similar to the diodes used on automotive alternators. Many other manufacturers use this same package on their 18- to 25-ampere medium-power SCR's. This type of package lends itself to easy mounting as it is simply pressed into a .500-inch hole in a heat sink. An arbor press is normally used for this operation, but an ordinary bench vise works just as well.

Manufacturers, in their volume packaging, haven't forgotten the small-quantity manufacturer or the experimenter. Almost all of the types shown have modified designs which provide studs or additional leads to allow the traditional nut-and-bolt type of assembly. Obviously, these additions increase the SCR cost, but in many instances the modified case is priced only 10 to 25 cents above the production case.

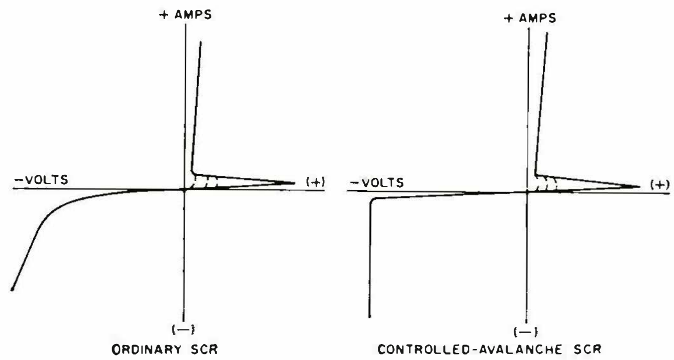


Fig. 2. The sharp zener knee in the reverse direction of the controlled-avalanche SCR makes this device self-protecting. Transients are absorbed without local destructive breakdown.

SCR's are now available from many manufacturers in a choice of case connections. In the older SCR's, the case was invariably connected to the anode of the structure to permit rapid dissipation of heat. The new planar construction eliminates this requirement as heat sinking at the cathode is just as efficient. The price of the SCR with either connection is the same. This leads to greatly simplified heat-sink design in circuits operating two SCR's back-to-back or in circuits using multiple SCR's. This, in itself, can drastically reduce complexity and assembly time in many circuits.

There is a tremendous hidden significance in this new SCR economy. Previous SCR applications replaced the thyratron,

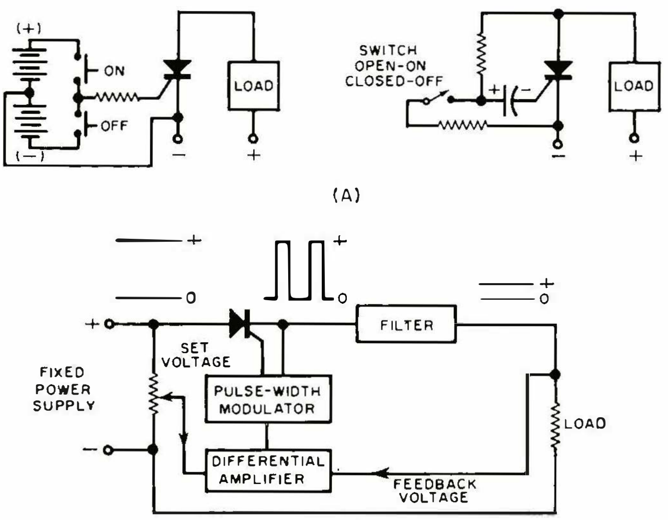


Fig. 3. (A) Using gate turn-off SCR as a latching relay. When the gate is pulsed positive, the SCR turns on. With a negative pulse, SCR turns off. (B) A switching-mode regulated supply with very high operating efficiency. Varying the on time compared to off time of the fixed power input results in a variable power output. The filter smooths out the on-off-on-off waveform so that resultant output is a smooth d.c. voltage.

the ignitron, the variable autotransformer, the magnetic amplifier, and others. Practically all present SCR applications have had their earlier counterparts. The new SCR economies and small sizes open the way for a host of new industrial and consumer applications that have been impractical or prohibitively expensive until now.

For instance, dimmers built directly into conventional desk and table lamps will allow the brightness of the lamp to be varied to suit individual needs. Power tools whose speed or torque increases as the trigger pressure is increased are now possible, as is soldering equipment with instantly and continuously variable temperature control. Also in the cards are store lighting fixtures that can automatically compensate for increases and decreases in daylight levels, photographic lighting that provides exact shadow control—the list is limited only by the imagination of the designer. These are not expensive "dream devices" but currently feasible low-cost devices which should be available soon.

The currently popular wall-mounting dimmers and home workshop power tool controls offer just a hint of the vast possibilities of economical SCR a.c. proportional control.

Self-protecting SCR's

Protecting SCR's against voltage transients has been a severe design problem ever since their introduction. The problem becomes especially critical in high-voltage, high-current industrial motor and process controls. Transient protection is mandatory in reversing motor drives where a shorted SCR can destroy a motor, or perhaps an entire production line.

The specific problem is reverse breakdown. A voltage transient in the forward direction merely turns the SCR on. In the reverse direction, when the peak inverse voltage of the SCR was exceeded, violent breakdown occurred, ruining the SCR and perhaps the rest of the circuit. Previously, SCR controls had to have protecting varistors, thyristors, and other transient suppression circuitry.

A new technique eliminates all of this. Called "controlled avalanche" this new breed of SCR's is made to behave like a zener diode when its peak inverse voltage is exceeded. The transient is simply absorbed by the SCR and dissipated as heat. Not only is the SCR not damaged, but it has eliminated a transient that could do further circuit damage.

To explain controlled avalanche we must delve into a bit of solid-state physics. The troublemaker in this case is temperature. If the instantaneous temperature of any part of a semiconductor gets too hot, it simply melts and loses its semiconducting properties. The cause of temperature is heat and, in this case, the cause of the heat is current. It is not current itself, but *current density* (amps./sq. in.) that causes the destructive temperature rise.

This effect can be demonstrated by first passing a 5-amp current through a #14 wire and then repeating the experiment with #40 wire. Although both wires passed the same current, one is still at room temperature while the other has disintegrated in a wisp of smoke.

By the same token, a substantial current can flow through a semiconductor *if it flows through the entire available cross section*. On the other hand, if that same current is concentrated in a small area, the temperature rise may be destructive. This is shown in Fig. 1, where a uniform and a non-uniform p-n junction is diagrammed. The non-uniform junction will reverse breakdown at the defect shown. The resultant high current density will destroy the junction at this point. Since the other semiconductor regions around the defect have not broken down, they conduct no current. The short produced exists only over a very small area, but it is still a short. The uniform junction breaks down uniformly. The same current as before is now distributed over the entire surface. The resultant current density is very low. Although the same amount of heat is produced in both cases, the uniform junction temperature remains at a safe level.

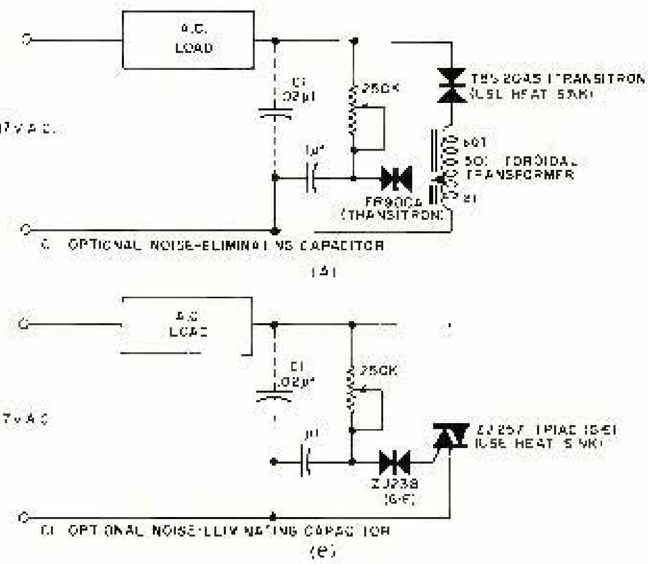
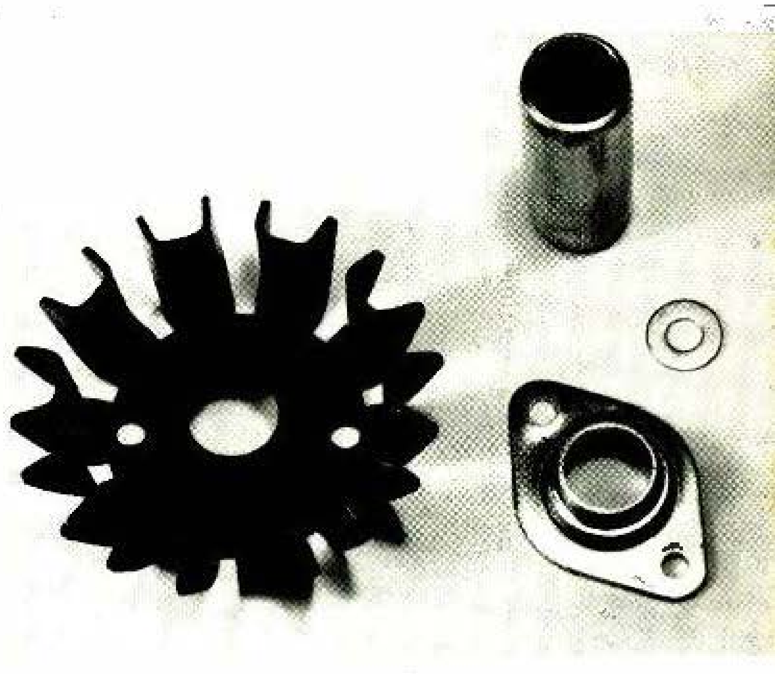


Fig. 4. (A) The new bilateral SCR's extremely simple light-dimmer and power-control circuitry. This circuit uses gateless bilateral SCR to give full-range 600-watt proportional control. (B) The gated bilateral SCR allows 600-watt a.c. proportional control with only four parts. Performance and cost are about the same as circuit shown at (A). Both types of bilateral SCR are available in much higher power ratings.



Typical mounts for press-fit SCR's. Half-inch hole is used.

In an ordinary diode or SCR, reverse breakdown first takes place in one or two small regions, damaging the device. In a zener diode, and in the new controlled-avalanche SCR's, reverse breakdown is uniform across the entire junction, preventing damaging local temperature rise. Fig. 2 compares the reverse breakdown of a regular and a controlled-avalanche SCR.

Controlled avalanche results from careful SCR design and improved control of the SCR properties during fabrication. Beveling the silicon structure in a critical manner helps create the required uniform breakdown. Passivating the silicon structure (coating with a "paint" of oxide or nitride) also prevents edge or surface contamination that could encourage uneven breakdown.

The significance of the controlled avalanche SCR lies in its inherent self-protection. The SCR is now a *transient-eliminating* device instead of a (Continued on page 70)

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transient-susceptible one. This makes the SCR comparable in self-healing properties to the ignitron, selenium rectifier, and other older self-protecting devices.

As a sidelight, controlled-avalanche SCR's can be used in place of high-voltage, high-current zener diodes and as protection devices for other circuits in certain cases.

Transient Immunity

A closely related problem of SCR's is transient turn-on. A voltage much lower than the forward anode breakover voltage of the SCR could turn the SCR on if the rise time of the applied forward voltage was short enough. This is called the "*dv/dt*" problem. As an SCR turns on in a short time and produces a transient, it can easily turn on other SCR's on the same power line. The effects of this on a production line could range from amusing to disastrous. The traditional means of eliminating *dv/dt* turn-on was to isolate the various circuits with transformers or to use inductance to limit the rate of rise of applied current. Thyrite and other varistors were also used.

The new SCR's are virtually *dv/dt*-proof. The rate of rise of anode voltage must be faster than 200 volts per microsecond before *dv/dt* turn-on can occur. Transients on industrial lines simply are not usually that fast. The exact manufacturing techniques required to make an SCR *dv/dt*-proof are not easily explained and are proprietary with certain companies.

Taken together, controlled avalanche and *dv/dt* immunity make the SCR more transient-immune and self-protecting. These are essential features of any industrial high-current control system.

These techniques are expensive and, at present, are available only on premium devices where this type of protection is mandatory for the intended application. Generally, 117-volt circuits are immune from either problem due to the "softness" of most 117-volt lines. As a result, controlled-avalanche and high *dv/dt* devices are confined to applications requiring 220-volt or higher line voltages.

Gate Turn-Off SCR's

The conventional SCR is turned on by a positive current pulse at its gate. The only way it can be turned off is by removing or reversing the anode voltage. In many cases, this is either inconvenient or impractical. There are a number of applications for a gate-controlled switch which can turn the load current *off* as well as on simply by applying a negative current pulse to the gate.

Small (250 ma. or less) gate-controlled *p-n-p-n* devices have been available for some time. These devices behave like a conventional SCR during turn-on and conduction and as a linear charge controlled amplifier in the turn-off mode. A charge (current pulse) introduced at the gate electrode cancels the charge caused by the load current and the device turns off.

A new type of power SCR is based on the operation of these low-current switches. Gate-controlled switches that can switch 5 amps at 400 volts have recently become available. A positive gate pulse turns them on and a negative gate pulse turns them off. They will also turn off when the supply voltage is removed, just like an ordinary SCR.

Quite a substantial pulse of current is required for turn-off in the present models. Turn-off current gain is around ten. Actually, this low current gain in no way limits the utility of this SCR, for considerable power gain is achieved during turn-off. The turn-off *voltage* only has to be 3 volts or so, but will directly switch 400 volts. Also, the turn-off signal has to exist for only a small part of a millisecond. The usual method of turn-off is to discharge a capacitor into the gate, as the required high-current pulse is easily provided in this way. The gate may also be turned off by direct connection to a low-impedance negative voltage using a transistor, four-layer diode, or other switch.

There are quite a few possibilities for this device which heretofore had no high-voltage counterpart. Two typical circuits are shown in Fig. 3. Small gate pulses will operate the SCR as a d.c. latching switch. Pulse it to turn on, pulse it to turn off. A 2-kw. load may be controlled with two small, low-energy gate pulses. A second possibility is to use the gate controlled SCR in a voltage-variable power supply. By varying the ratio of on-time to off-time, various amounts of load power can be provided. This is done in a rapid off-on-off-on-off-on sequence. Filtering this output waveshape retains only the d.c. component, providing a smooth, continuously variable output. As this SCR operates in the switching mode, the efficiency of this design is very high and can approach 100 percent. The heat produced is substantially less than that produced in vacuum-tube or transistor dissipation-type regulators. A small differential amplifier will adjust the output to hold the voltage constant for varying load, making the supply a regulated one.

The fabrication of a gate turn-off SCR is much more difficult than an ordinary SCR. Because of this, they are not, at present, low-cost devices and probably never can approach the price of the economy SCR's. But, the circuit simplification and the new circuit possibilities can reduce over-all equipment cost using the gate-controlled SCR, thus justifying the higher cost of this component.

Bilateral SCR's

All regular SCR's are unilateral; they only work in one current direction. To operate off the a.c. line, SCR's must be used in pairs or the line must be inverted with diodes. Other alternatives are half-wave, half-range operation and mechanical switching of an ordinary diode to provide full-range control.

Bilateral SCR's eliminate this problem. They simply go in series with the a.c. line and the a.c. load. They work in either current direction and turn off automatically every a.c. zero. There are two newly introduced devices that accomplish bilateral a.c. control at substantial power levels.

Transitron's "Biswitch" is a gateless bilateral SCR. It is turned on by avalanche breakdown. This is done by applying a 400-volt spike to the "Biswitch" to turn it on. An autotransformer steps up a small trigger pulse to trigger the Biswitch. As the Biswitch is turned off during triggering, very little trigger energy is required, giving a very high turn-on gain. Fig. 4A shows a dimmer circuit using a Biswitch. With proper heat-sinking, it can control 600 watts of light or motor load.

General Electric's "Triac" is a bilateral gate controlled SCR. Using this device, a full-range dimmer or power-tool control can be built using only four parts. The circuitry cost, using a Triac or Biswitch, is about the same. The Triac is more expensive, but requires no trigger transformer. A Triac dimmer is shown in Fig. 1B.

For more information on new SCR's, such as the ones discussed in this article, their circuits, and their capabilities, consult manufacturers' data sheets and design-information supplements. ▲