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INTERNATIONAL RECTIFIER CORPORATION

RECTIFIER NEWS

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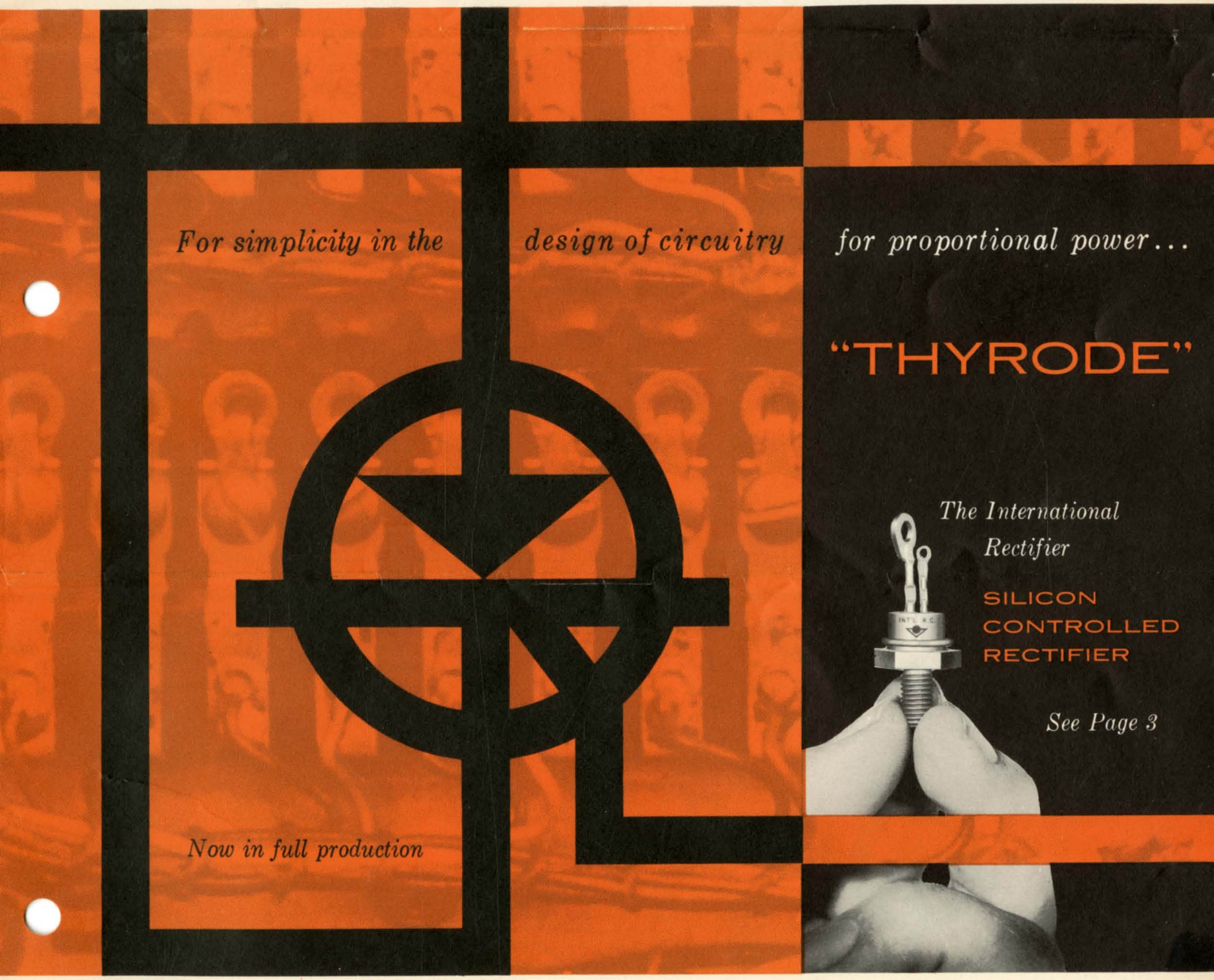
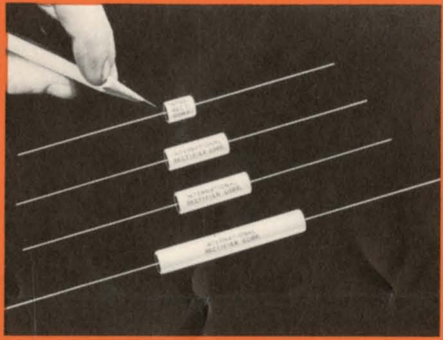


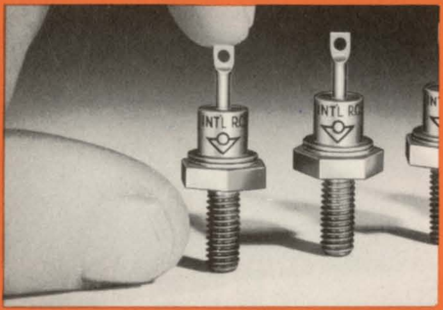
new developments



SILICON RECTIFIERS OPERATE AT ALTITUDES TO 90,000 FT.

A new series of high altitude silicon cartridge rectifiers covering the PIV range from 600 to 10,000 volts are ceramic-encased to prevent surface creepage and minimize flashover problems encountered in high altitude operation. Units tested to 90,000 feet simulated altitude operated at 1600 volts with no evidence of corona.

Designated JEDEC types 1N2373 through 1N2381, this hermetically sealed cartridge series provides dc output currents from 75 to 250 ma (at 25°C). They have an operating temperature range from —55°C to +150°C, and feature wide application to radar power supplies, high voltage bias supplies and airborne and missile instrumentation where miniaturization, high temperature and high altitude operation are called for. Write for Bulletin SR-227.



6 AMP DIFFUSED JUNCTION SILICON DIODES

Designed to bring miniaturization and high efficiency to such applications as miniaturized airborne power supplies, electrical instrument testing, oscilloscopes and other power supply requirements, this series of diffused junction silicon rectifiers will provide currents up to six amperes over an inverse voltage range from 50 to 500 volts. They are operable at diode base temperatures up to 150°C.

To provide optimum reliability over their working temperature range, these hermetically sealed units feature an all-welded construction that is completely free from flux material. In addition, each unit is nickel-plated to provide minimum contact resistance and prevent corrosion. Request Bulletin SR-308.

SOLAR MODULES FOR TRANSISTORIZED EQUIPMENT

High efficiency silicon solar battery modules provide the same power output, watt for watt, as dry cell and mercury cell batteries. The modules are designed for powering transistorized equipment during daylight operation, as well as for charging storage batteries for continuous day and night operation. Applications include power supplies for transistorized radios, telemetering and control circuitry, and numerous communication equipment uses. Direct replacement may be achieved by substituting one SM5-1020B module for each 1.5 volt dry cell battery, and using as many parallel strings as required to supply the necessary load current. Each module will supply a load current of approximately 35 ma in direct sunlight. Write for Bulletin SR-276.

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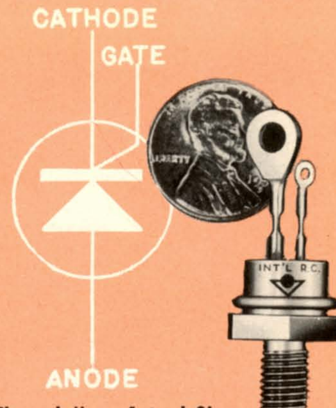
AN INTRODUCTION TO THE

INTERNATIONAL RECTIFIER

"THYRODE"

20 TO 200 VOLT, 10 AMP RATED

SILICON CONTROLLED RECTIFIER



"Thyrode" — Actual Size

BY LOWELL S. PELFREY, *Director of Research*
International Rectifier Corporation

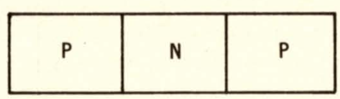
HOW IT OPERATES:

The International Rectifier "Thyrode" Silicon Controlled Rectifier is a three-terminal device capable of performing many of the functions of a thyratron. It opposes the flow of current in both directions until a small amount of power is made to flow between the cathode and the third electrode. When this is done, the resistance in one direction falls to a value about the same as the forward resistance of a simple silicon rectifier of equal current rating. These characteristics are shown in Fig. 1.

In order to explain this property, we may look at the structure of a four-layer diode, which was the controlled rectifier's immediate predecessor and is contained in the new unit.

Part of the basic elements of a four-layer diode consists of two PN junctions in the same wafer and arranged so as to oppose the flow of current in both directions (Fig. 2). This structure has been utilized in some other devices, such as self-compensated zener diodes, but of course is not very useful in rectifier applications.

Figure 2



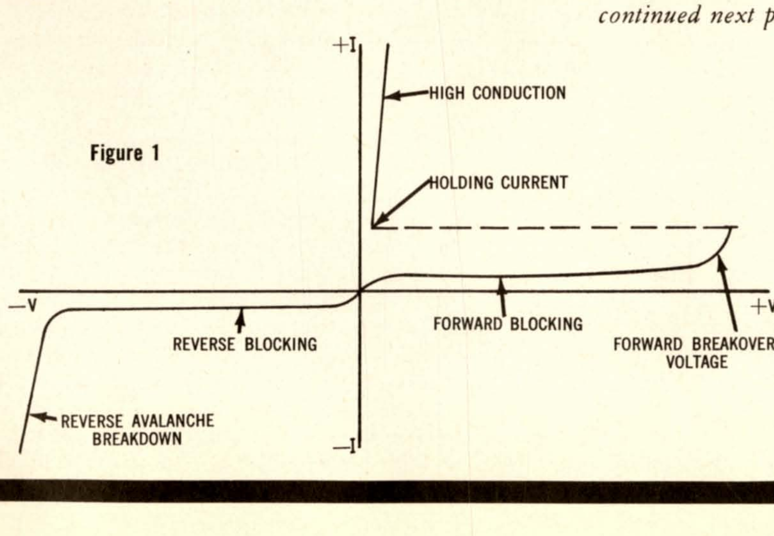
However, the addition of a third PN junction (Fig. 3) enables the device to be operated as a switch or relay, or in AC circuits, as a conventional rectifier.

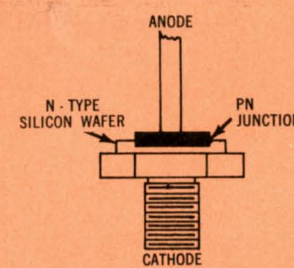
In pulsed circuits the four-layer diode is a very close analogue to a thyratron in that, once the low-resistance path has been established, it will remain in this state until the anode-to-cathode voltage has been reduced to zero.

The facts which make possible the low-resistance conduction of the four-

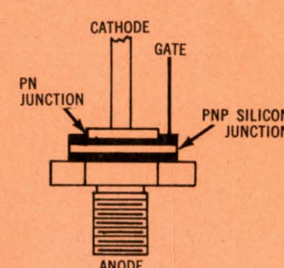
continued next page

Figure 1





Silicon Rectifier



"Thyrode" Controlled Rectifier

CONSTRUCTION

In these illustrations, the internal construction of a Thyrode Controlled Rectifier is compared with an ordinary silicon rectifier. The anode in the silicon rectifier is formed in a wafer of uniform resistivity silicon which is mounted to the stud. The wafer in the Thyrode is made up of N-type silicon with two P-layers diffused into the surfaces. The cathode connection forms a PN junction, and the gate lead is mounted to the diffused P layer.

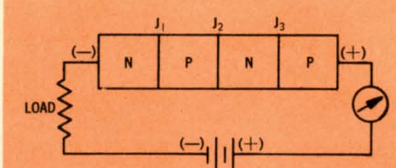


Figure 3

layer diode can be shown as follows: (Fig. 3)

When the three junctions of the diode are biased as shown, the leakage current through J_2 allows forward current to be passed through J_1 and J_3. This forward current is carried through the semiconductor by minority carriers which are injected at the rectifying junctions. The percentage of these minority carriers (injected at J_1 and J_3) which actually reach J_2 is called the "α" of that part of the device. This percentage, or α, depends upon several things, the most significant of which, in an actual device, is the magnitude of the current. Also, it can be shown that when the sum of α_1 and α_2 is very nearly unity, the current through the diode is limited only by the external circuit.

It can be seen that the conduction state will occur when the reverse leakage current through J_2 increases to the point at which $\alpha_1 + \alpha_2$ is substantially unity. This value of leakage can be obtained by increasing either the voltage or the temperature, or both; the same thing that occurs in conventional rectifiers.

It should be noted that this same phenomena will occur when the bias voltages are reversed; that is, leakage current through J_1 and J_3 will inject carriers at J_2 which affect the reverse characteristics of J_1 and J_3, but, since only a single α (which is always much less than unity) is involved, the only observable effect is a slight increase in the leakage currents at J_1 and J_3.

If the foregoing were the only way to produce the conduction state, such a device would have very limited usefulness. However, by the introduction of a separate circuit, called a gate circuit (Fig. 4), the conduction state may be induced even if the leakage currents and voltages through J_1 and J_3 are allowed to remain very small. This is done by establishing a contact to the P region, which is below the end N region, and passing current through J_1. The effect of this current is to increase α beyond its normal value so that conduction can be obtained at essentially any anode-to-cathode voltage. The power needed to effect the required "gating" current is about 50 milliwatts (for a 10 to 15 amp device), so power gains of 200,000 (about 53 db) can be obtained.

The "Thyrode" Controlled Rectifier has some significant advantages over devices now being used in switching and control circuits. For instance, its efficiency is about 99% as compared to 60% for a transistor, with other parameters being about equal. It is many times smaller than a thyratron, requires no warm-up, has much lower de-ionization time and, it is believed, has much longer operating life.

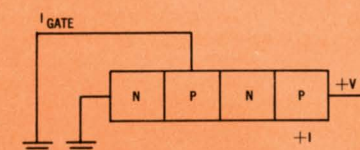


Figure 4

THYRODE OPERATING CHARACTERISTICS

The operation of the controlled rectifier may also be compared to the operation of two transistors—an NPN and a PNP, connected as shown in Fig. 5. The collector current of the NPN unit feeds the base of the PNP, and the collector current of the PNP feeds the base of the NPN. Thus, a positive feedback loop is created, and when the product of the gains of the two transistors exceeds unity, the system will be self-regenerative. By combining these two transistor structures into the Thyrode Controlled Rectifier PNPN configuration, the total current flowing in the PNPN structure may be visualized as the sum of the currents flowing in the individual transistor sections.

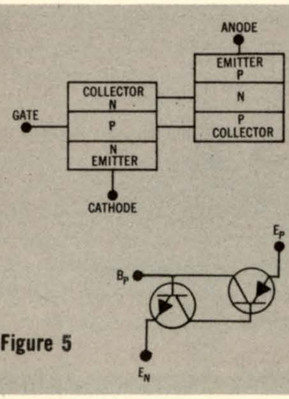


Figure 5

"Off" Condition

When the base of the NPN transistor (which corresponds to the gate) is reverse biased, only a very small leakage current will flow from cathode to anode (when junction 2 is reverse biased). The current gain of the two transistors at this low current level is also extremely low, thus their product is less than unity. This corresponds to the "off" condition of the Thyrode Controlled Rectifier.

"On" Condition

With the application of a small forward bias current to the base of the NPN transistor (gate), the current gains of the two transistors will rise. If this signal current exceeds a certain minimum value, the total of the two current gains will exceed unity, and the configuration will become self-regenerative. The current level from cathode to anode will then increase rapidly, limited only by the external load. This is the equivalent of the "on" condition of the Controlled Rectifier. Once the signal applied to the gate has "fired" the Controlled Rectifier into the conducting state, it no longer has control over the device. Current flow through the Controlled Rectifier can then be halted, if desired, by reversal or removal of the anode voltage, or reduction of the anode current below the sustaining level.

Breakover Voltage

When the Controlled Rectifier is in the "off" or forward blocking state, increasing the forward voltage does not tend to increase current until the point is reached where avalanche or "zener break-down" starts to take place. Past this point, the Controlled Rectifier will go into the "on" or conducting state, so long as the current through the device remains greater than a minimum sustaining value called the holding current. Should the current through the Controlled Rectifier drop below this minimum holding current, the device will return to its forward blocking state. In the reverse direction, the unit has essentially two back-biased PN junctions in series, and thus exhibits characteristics similar to standard back-biased silicon rectifiers.

Typical Reverse Characteristics

Fig. 6 illustrates typical reverse characteristics of the Controlled Rectifier over a temperature range from —30 to +100°C. The curves illustrated represent the various voltage grades to which the device is now being offered. Units are separated into these voltage classifications according to their reverse breakdown voltage, as well as their reverse leakage current at a given reverse voltage. As can be seen, this procedure is similar to that used in the selection of standard silicon power rectifiers.

Typical Forward Characteristics

The forward voltage and current characteristic of the Controlled Rectifier, as has already been stated, is capable of two distinct states: the blocking or non-conducting mode and the conducting or low resistance state. The forward blocking characteristic is essentially the reverse characteristic of the center PN junction, and therefore behaves in a similar manner. By changing the titles on the axis of Fig. 6 to read "Instantaneous Forward Voltage" and "Instantaneous Forward Current," the curves become typical for the forward blocking characteristics for the various voltage ranges shown. Thus it can be seen that the variation in the value of forward leakage current with temperature is identical to that of the reverse characteristic.

One substantial difference exists between the reverse characteristic and the forward blocking characteristic. Should the maximum allowable peak inverse voltage (PIV) rating of the Controlled Rectifier be exceeded to a sufficient degree, the device will eventually destroy itself as a result of the avalanche currents that would develop. Exceeding the breakover voltage (VBO), however, of the forward characteristic will not destroy the unit, but will simply cause the device to switch over from the blocking to conducting mode of operation.

Switching Characteristics and Switching Speeds

The speed at which the Controlled Rectifier is capable of switching from the blocking mode to the conducting mode is approximately 1 microsecond for typical cells and approximately 5 microseconds for the slowest cells. This figure includes a slight delay time of about 0.5 to 1.0 microseconds over the actual switching time. This delay characteristic is an inherent property of the device . . . one that can be minimized by proper regulation of the pulse width and value of the gate signal.

Turn-off Time

The time interval required for the gate to recover control after the forward current has been interrupted is termed the "turn-off time." This interval necessary for turn-off is somewhat longer than that required for turn-on, and varies to a substantial degree with temperature and applied inverse voltage for a typical unit. Forward current before turn-off is not a factor here, since for the units under discussion (1 to 10 amp rated) current affects the turn-off time to only a slight degree. Higher forward currents do cause a small increase in turn-off time.

Junction Temperature

The Thyrode Controlled Rectifier has an operating base temperature range from —30°C to +100°C. Storage temperature range is from —30°C to +125°C. These temperature limitations are principally due to the necessity of limiting stress in the silicon crystal to safe values. As manufacturing problems and production techniques are refined in the manufacture of this highly complex device, substantially higher operating temperatures will be forthcoming.

Power Dissipation

In Figure 7 power loss is illustrated as a function of average current for

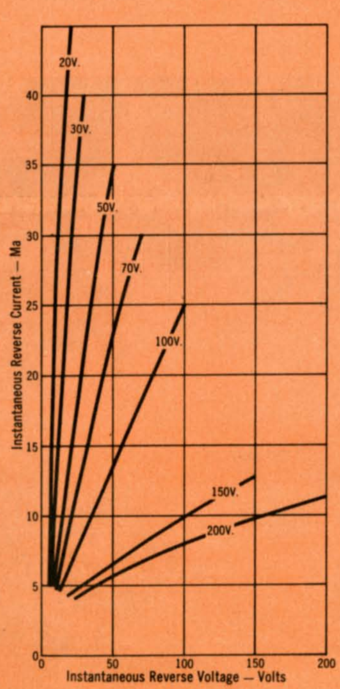
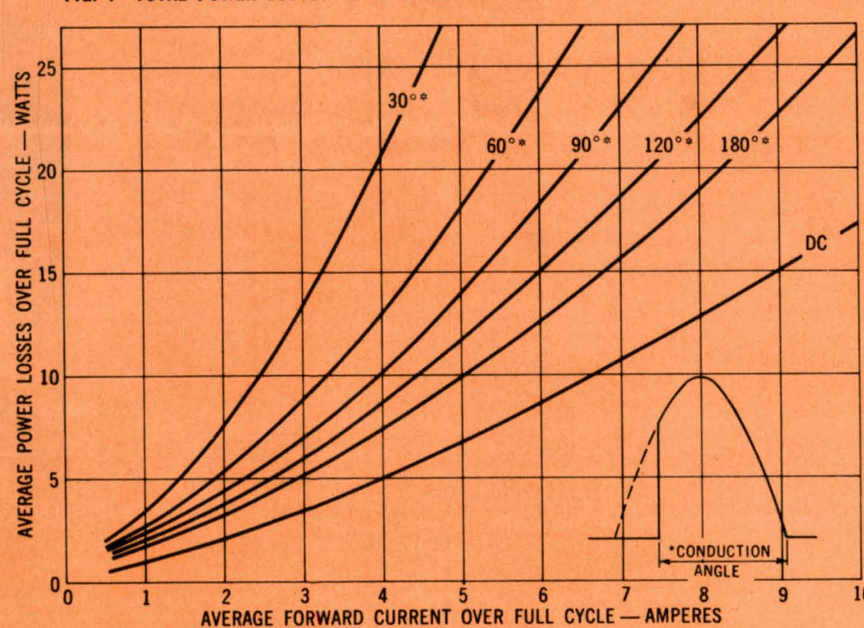


FIG. 6—MAX. REVERSE AND FORWARD LEAKAGE CURRENT Vs. VOLTAGE (Junction temp. range: —30°C to 100°C; gate open or shorted to cathode).

FIG. 7—TOTAL POWER LOSSES Vs. AVERAGE FORWARD CURRENT.



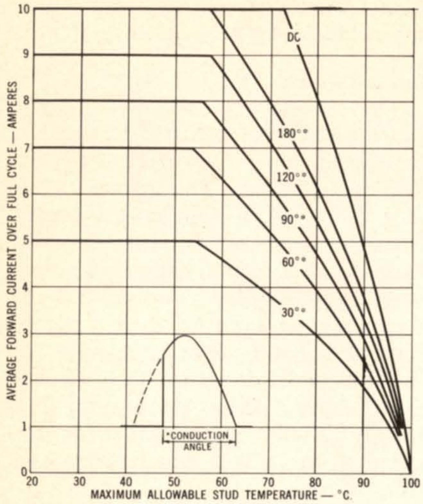


FIG.8— MAX. ALLOWABLE STUD TEMPERATURE Vs. AVERAGE FORWARD CURRENT.

various conduction angles. These ratings are based on a current waveform which is the remainder of a half-sine wave which results when delayed angle firing is used. The length of each curve represents the permissible range of current for the particular angle of firing.

Figure 8 shows maximum allowable stud temperature versus average current. These ratings are calculated for an operating frequency range of 50 to 400 cycles per second. They become more conservative at higher frequencies, since the junction temperature variation, within a particular cycle, becomes less. This advantage will be overcome at some unspecified higher frequency by the heating effect of switching power dissipation.

Cooling Data

To hold the Thyrode Controlled Rectifier junction temperature to the limits specified in Fig. 8 an adequate heat sink is required. Figure 9 gives the necessary cooling fin size as a function of average current and conduction angle, along with the specified cooling parameters.

For any other operating conditions, measurement of the stud temperature with a thermocouple can determine whether the unit is obtaining adequate cooling.

Thermal Resistance

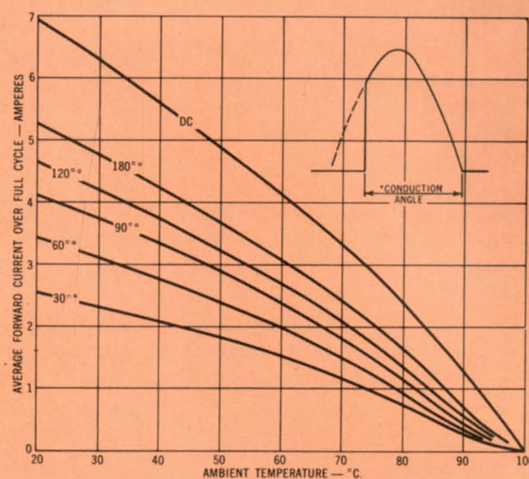
Internal thermal resistance of the Controlled Rectifier is defined as the degrees centigrade per watt temperature rise of the junction above the mounting stud. This value is 2°C/watt maximum.

Voltage Transients

Due to the extremely fast switching speeds of which the Controlled Rectifier is capable, transient voltages can be a problem in circuits using these new devices. If voltage transients cross the rectifier in the forward direction, the device may fire harmlessly to the conducting state, merely causing a malfunction of the circuit. Transients crossing in the blocking direction, however, may cause destructive breakdown. In circuits where transients are encountered, the peak value should not surpass the continuous PIV rating of the particular unit. Exceptions may be made when adequate transient filters are designed into the circuitry.

* * *

FIG. 9— MAXIMUM FORWARD CURRENT VS. AMBIENT TEMPERATURE
(Thyrode mounted directly on 4 x 4 x 1/16″ copper fin. Contact area lubricated with silicone grease. Free convection cooling, resistive or inductive load, 50 to 400 CPS. Minimum fin spacing: 1″. Emmissivity of fin: 0.90.)



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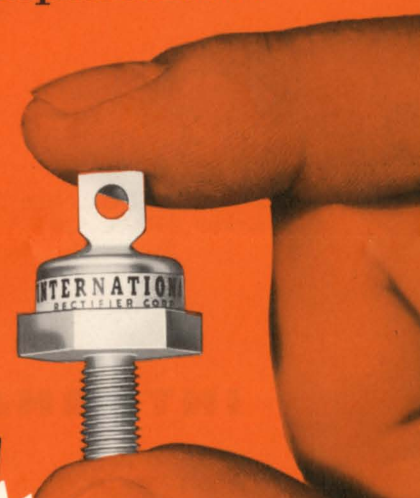

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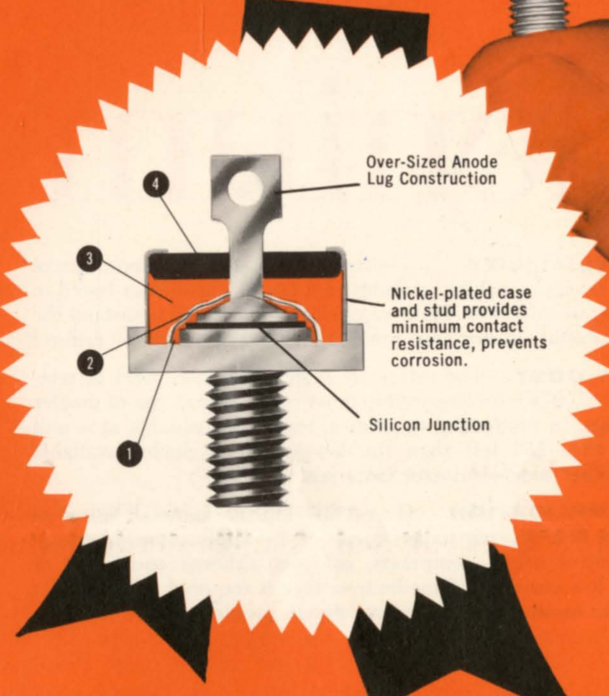

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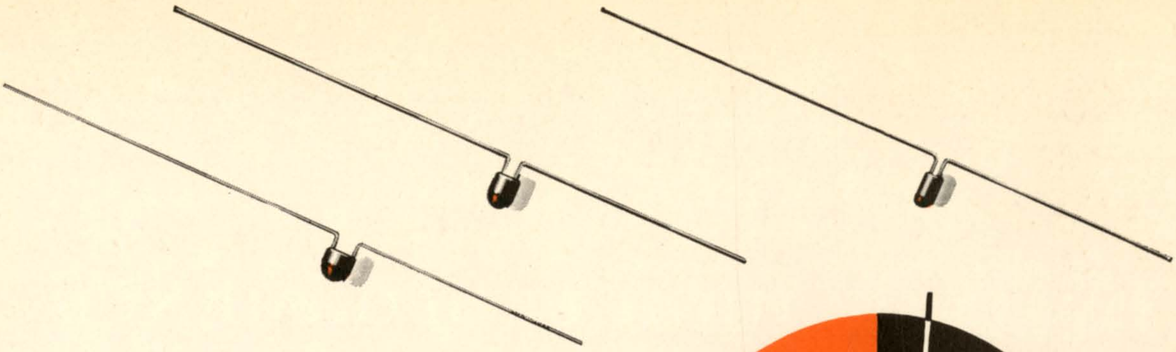

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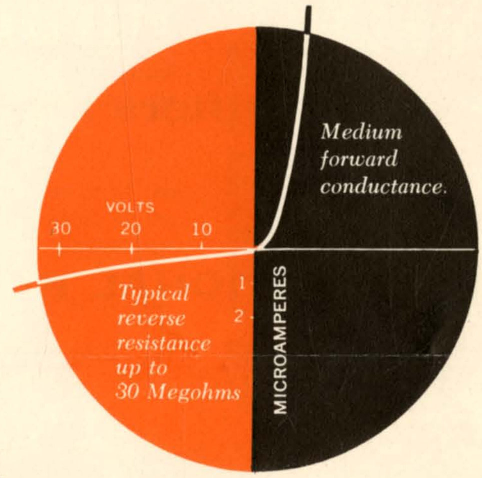

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