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QUARTERLY PROGRESS REPORT

FOR

THE RESEARCH AND DEVELOPMENT

OF

HIGH CURRENT AND HIGH VOLTAGE SILICON CONTROLLED RECTIFIERS

THIS REPORT COVERS THE PERIOD
1 JANUARY 1963 TO 31 MARCH 1963

RECTIFIER

COMPONENTS

COPY NUMBER 28

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RECTIFIER COMPONENTS DEPARTMENT
GENERAL ELECTRIC COMPANY
WEST GENESEE STREET
AUBURN, NEW YORK

NAVY DEPARTMENT BUREAU OF SHIPS ELECTRONICS DIVISIONS
CONTRACT NUMBER: NObsr-87648
PROJECT SERIAL NUMBER: SF-013-11-05
CONTRACT DATE: 30 JUNE 1962

ABSTRACT

A study of the relationship between SCR design parameters and electrical characteristics has been made and a discussion of the pertinent points is presented.

A computer analysis of the affects of differing sizes of internal emitter shorts has been completed and is summerized.

A number of the test procedures and the nomenclature which is used are included.

PART I

1.1 Purpose

The research and development being conducted under the provisions of this contract is directed toward the development of two silicon controlled rectifiers. The first, Device B, is a 70 ampere, 1000 volt device. The other, Device C, is a 155 ampere, 1300 volt controlled rectifier. Specification objectives for these two devices are given in Table 1 (page 2, PART I).

CHARACTERISTIC	SYMBOL	DEVICE B CONDITION	DEVICE B VALUE	DEVICE C CONDITION	DEVICE C VALUE
Average Forward Current (Min.)	I_0	T_C - 90°C (Note 1)	70 amps.	180° half sine wave condition T_C - 80°C	155 amps.
Peak Surge Current (Min.)	I_{FM} (surge)	(Note 1)	1000 amps.	A non-recurrent of 180° half sine wave conduction immediately preceeded and followed by I_0 = 155 amps.	2500 amps.
Peak Forward and Peak Reverse Blocking Voltage (Min.)	V_{FOM} V_{ROM}	(Note 1)	1000 volts	Over the workable temperature range of the device	1300 volts
Turn-Off Time (Max.)	t_{off}	(Note 1)	20 μ sec	Initially at 155 amps into resistive load with mounting inter-face surface at 80°C steady state (Fig. 10, MIL-S-19500/204)	25 μ sec
Turn-On Time (Max.)	$t_{G\ on}$	(Note 1)	15 μ sec	Turn-on with a square wave gate current pulse. I_0 may be limited to 50 amps. through non-inductive load (Fig. 12, MIL-S-19500/204)	15 μ sec
Rate of Rise of Anode to Cathode voltage (Min.)	$\frac{d(v_{FO})}{dt}$ or dv/dt	(Note 1)	20 v/μ sec (Note 2)	Test circuit similar to Fig. 11, MIL-S-19500/204 shall be used, (T_A = 125°C)	200 v/μ sec
Peak Reverse Surge Power (non-repetitive)	P_{ROM} (surge)			100 microsecond sinusoidal current pulse at 25°C.	10 K watts

Notes: 1) The requirements of MIL-S-19500/204 shall apply to the extent practicable.
2) This is an important characteristic in the design of static inverters, and warrants reasonable effort toward improvement consistent with the primary objectives of current and voltage.

Table 1 - Device specifications

2.1 GENERAL FACTUAL DATA

2.1.1 Identification of Technical Personnel

The names of engineers and technicians, together with a summary of the manhours of work performed for each device, are as listed below.

PROJECT DIRECTOR - F.E. Gentry, Manager - Advance Engineering

(a) Device B

Engineers	Technicians
R. Knaus	M. C. Brown
	K. B. Catchpole
	M. H. Curtin
	M. H. Lindner
	A. L. Smith

(b) Device C

Engineers	Technicians
R. L. Davies	A. Bolger
R. Kokosa	J. Brunner
R. P. Lyon	J. B. Crooks
	B. Tuft
	M. Yaworsky

(c) Manhours

Engineers	Technicians
942	3778

2.1.2 References

See attached sheets, pages 4 and 5, PART I.

2.1.3 Tables and Illustrations

All tables and illustrations referenced in PART I of this Quarterly Report and not included therein are appended to PART III of this Report.

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5) N. Mapham, "The Rating of SCR's When Switching into High Currents", A.I.E.E. Conference Paper, CP63-498, I.E.E.E. Winter General Meeting, Jan. 27 - Feb. 1, 1963.

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14) C. T. Sah, R. N. Noyce and W. Shockley, "Carrier Generation and Recombination in P-N Junctions and P-N Junction Characteristics", Proceedings of I.R.E., Vol. 45, No. 9, Sept. 1957.

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17) J. J. Ebers, "Alloyed Junction Avalanche Transistors", Bell System Technical Journal, Vol. 34, Sept. 1955.

18) M. A. Melahy, "Minimum Time for Turn-Off in Four-Layer Diodes", Proceedings of I.R.E., Vol. 49, No. 9, Sept. 1961, pp. 1424.

19) J. C. Irvin, "Resistivity of Bulk Silicon and of Diffused Layers in Silicon", Bell System Technical Journal, Vol. 41, Mar. 1962.

2.1.4 Conferences

On April 12, 1963, R. Wade, Bureau of Ships, Washington D. C. and C. Marcus, Naval Material Laboratory, Brooklyn, New York, visited Auburn, New York, for discussions with F. Gentry, R. Knaus, R. Lyon, B. Tuft and R. Davies. The status of Devices "B" and "C" was reviewed and new courses of action planned. Turn-off time was given particular attention.

As specified in the contract, turn-off time is to be measured according to MIL-S-19500/204. However, it was agreed that it would be very desirable to have Device B meet a turn-off time specification of 20 microseconds with the forward voltage of 1000 volts reapplied at a rate of 20 volts per microseconds. Consequently, it was decided that the delivery schedule for Device B, design samples and final report, should be extended by two months in an attempt to meet this criteria.

3.1.1 Statement of the Problem (General)

Both devices, B and C, are very high voltage silicon controlled rectifiers which must be optimized to achieve high speed and moderately high currents. Many of the characteristics are interrelated and, as a consequence, the design changes which result in lower power dissipation often are in direct conflict with those required for high speed and high voltage. A simplified summary of some of the design parameters for each characteristic are given in the following paragraphs.

3.1.1.1 Voltage

The blocking voltage capability of a silicon controlled rectifier is determined by the following factors:

1) The electric field within the body of the blocking junction.
2) The "effective" base widths and lifetime of minority carriers in those regions of the device contributing to transistor action.
3) The emitter efficiency of the injecting junctions at low current density levels.
4) The stability and breakdown voltage capability of the surface.

The breakover voltage of a silicon controlled rectifier is related to device design parameters by the equation

$$V = V_{(BR)}(1 - \alpha_{PNP} - \alpha_{NPN})^{\frac{1}{m}} \quad (1)$$

where m has a value between 3 and 6, depending upon the breakdown voltage and junction impurity gradient. α_{PNP} and α_{NPN} are the current gain factors for the PNP and NPN transistor portions of the device.
As an example, consider the structure shown in Figure 1. With the application of forward voltage, junction J2 becomes the blocking junction. If the junctions were of a step junction nature then the space charge layer width will be given by the relation

$$W_{SC} = K_1\sqrt{\frac{V}{N_I}} \quad (2)$$

where K_1 is constant, V the applied voltage and N_I the number of impurities on the high resistivity side of the junction. Thus, as the number of donor or acceptor impurities on the high resistivity side of the junction increases, the depletion region width at the blocking junction decreases and the electric field increases. As a consequence, the alphas of both sections of the device increase, with that portion containing the high resistivity base region increasing more rapidly. When the sum of the alphas are equivalent to unity the breakover voltage is reached.
Avalanche breakdown will occur when the relationship

$$V_{BD} \cong K_2 N_I^{-n} \tag{3}$$

is satisfied.[1] For silicon, $K_2 = 5.6 \times 10^{13}$ and $n = 3/4$ for voltages in excess of 100 volts. If it is assumed that the device is to operate at some fraction F of the avalanche voltage then using Equations (2) and (3), the space charge width for a junction optimized for high voltage becomes

$$W_{SC} \cong K_1 (FK_2)^{-\frac{1}{2}n} (V)^{n+\frac{1}{2}n} \tag{4}$$

Note that the width of the depletion region increases rapidly with increasing voltage. This factor has several implications. It requires wider base widths in the high resistivity section of the device in order to prevent the effective base width, W_B, from becoming zero which will result in "punch-through" by the depletion region. Although such a condition is not destructive, punch-through will cause the device to switch to the conducting state.
The conditions mentioned above relate to breakover voltage for internal body effects. Surface breakdown plays a strong role in determining the structure which can be used at high voltage. To avoid surface degradation, or surface breakdown, the electric field at the junction-to-surface interface must be made quite low as compared to that within the body of the device. This requirement is obvious since the silicon lattice is badly disrupted in the vicinity of a surface. As a consequence a lower voltage gradient is required to cause avalanche at the surface than within the body of the junction. Moreover, if avalanche does occur at a surface, it is very likely to result in permanent damage since it is

virtually impossible to obtain a surface sufficiently homogeneous to prevent localized breakdown. The heat generated as a result of localized breakdown is usually sufficient to cause permanent damage to the blocking characteristic

Since the electric field at the surface edge of a p-n junction is strongly affected by the surface contour in the vicinity of the depletion region, the shape and impurity concentration gradients near the surface must be carefully designed to provide a low surface field. These requirements tend to seriously limit the structural dimensions which can be used within the body of the device.

Two distinct disadvantages accompany high voltage devices. With the wider base width required, higher minority carrier lifetime is essential if the forward conducting drop is to reamin as low as that usually found in lower voltage devices. An increase in minority carrier lifetime will result in longer turn-off times as will be discussed in a later section. If the forward conducting drop is permitted to rise, the heat dissipated will rise also, and in addition the surge current capability will diminish. Secondly, the time required for turn-on will increase with wider base regions.

3.1.1.2 Current

High current applications necessitate large pnpn devices with large junction areas. A number of problems arise as the junction area is increased. Some of the more troublesome ones are:

1) Junction cooling
2) Mechanical and thermal stresses
3) Thermal fatigue
4) Maintaining parellel, uniform junctions
5) Non-uniform current density during turn-on

The current through a reverse biased p-n junction increases exponentially with increasing temperature. Unless the blocking current is kept low, severe heating will occur resulting in thermal runaway.[2] As a consequence, attention is focused on maintaining the junction as cool as is practical. To minimize the junction to heat-sink temperature drop, the semiconductor junctions must not be separated from the heat-sink by any more material than is absolutely necessary. This requires either a solder which can be plastically deformed during temperature cycling or a hard solder and transition plates to prevent the silicon from fracturing due to stress. Since this device is to be used in military applications a hard solder is highly desirable, even though thicker transition plates than would be necessary for a soft solder design are required. By the use of "hard solders" the thermal fatigue problem can be overcome.[3] A "hard solder" is one which is not strained beyond its elastic limits during cyclical operation. To use such a solder requires the use of transition plates, such as molybdenum or tungsten which have a high thermal conductivity, a high modulus of elasticity and a coefficient of thermal expansion near that of silicon. To keep the thermal resistance as low as possible, the transition plate must be made thin. Becuase the solder solidifies at high temperature during fabrication, mechanical stress builds up as the temperature is lowered due to the differences in thermal contraction of the copper heat sink, the semiconductor and its transition plate. Thus, the semiconductor material is mechanically strained. The problem then becomes one of selecting the transition plate between the pnpn device and the heat-sink, such that it is thin enough for good thermal resistance yet thick enough to prevent the semiconductor material from fracturing at the low end of the operating temperature range.[4] In addition, the transition plate on top of the semiconductor should generally be thinner than the bottom one to minimize the strain in the device. This construction is illustrated in Figure 2. Thus, one finds that the larger the area of the device the thicker the bottom transition plate must be. One consequence of this is that thermal resistance per unit current density does not drop linearly with increasing junction area.

Another serious problem with large area, three-therminal, pnpn devices is one of non-uniform current distribution during the period when the device is switching to the conducting state.[5] This problem commonly referred to as the dI/dt effect becomes more troublesome on high voltage devices because of the increased transient times resulting from wide base widths.

3.1.1.3 dv/dt - Rate of Rise of Reapplied Forward Voltage

The dv/dt capability of an SCR is controlled by the following factors.

1) The"effective" emitter efficiency of the emitter junctions at low current density levels.
2) The "effective" base widths and lifetimes of minority carriers within the device.
3) The capacitance of the center junction.
4) The uniformity of the junction.

The dv/dt effect in an SCR can be observed by applying a rapidly rising voltage across the structure in the forward blocking direction.[6,7] If the voltage pulse is of sufficient magnitude and has a sufficiently steep wave front, or dv/dt, then the device will switch to the conducting state. This phenomenon can be particularly troublesome when pnpn circuits are first energized.

To gain an elementary understand of this phenomenon consider the structure pictured in Figure 3. When a positive voltage is applied between anode and cathode of the device, junction J1 and J3 become forward biased whereas J2 is reverse biased. The center junction acts as a nonlinear capacitor which for an abrupt junction would have a capacitance of

$$C = \frac{K}{\sqrt{V + V_o}} \qquad (5)$$

where V is the applied voltage, V_o the built in voltage of the junction and K a constant. To charge this capacitance current must flow through junctions J1 and J3. Current flow through the two end junctions result in minority carrier injection into the base regions of the device. If the charge injected is of sufficient magnitude and of a duration comparable to or shorter than the minority carrier lifetime the emitter efficiencies of the two junctions will rise. Since the pnpn will trigger into the conducting state when the sum of its alphas is unity,[8] i.e. when the equation

$$I = \frac{I_s}{1 - \gamma_1 \beta_1 - \gamma_2 \beta_2} \qquad (6)$$

tends toward infinity as a result of the rising emitter efficiencies of Junction J1 and J3. α_m is the emitter efficiency and β_m the transport factor for junction m, and I_s is the saturation current for junction J_2, and $\alpha = \gamma\beta$.

A practical solution to the rise in emitter efficiency with increasing current is the use of a "shorted emitter" as shown in Figure 4.[9] Calculation of emitter shorts is described in section 3.1.2.3. At low current densities the current required to charge junction J2 will by-pass junction J3 so that the effective emitter efficiency is essentially zero. At higher current levels the lateral voltage drop in the base of the device will be sufficient so that current will choose to flow through the junction resulting in minority carrier injection in regions that are remote from the shorted area. This structure effetively solves the dv/dt problem in most applications. However, it does reduce the effective emitter area thus necessitating a larger silicon wafer or higher dissipation.

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3.1.1.4 Turn-off Time

Turn-off time is determined principally by the minority carrier lifetime within the device. In addition the rate of rise of re-applied forward voltage following the recovery phase also affects the turn-off time.

The turn-off time or recovery time problem is one inherent with all minority carrier devices. In the case of a pnpn device it means that if the device is in the conducting state and the applied voltage is removed or reversed, a period of time called the turn-off time must elapse before forward voltage can be reapplied without having the device return to the conducting state.[10,11]

The recovery time process can be visualized by considering the following simple model. Let the emitter efficiency of all the junctions be unity. By this we assume that when a forward bias is imposed across a junction it injects minority carriers into the lower impurity region but not the higher impurity region. For our case holes would be injected across portion J1 into the n-type base and essentially no electrons into the p-type emitter; J2 would inject holes into its adjacent n-type base, but negligible electrons into the p-type base; J3 would inject electrons into its adjacent p-type base, but very few holes into the n-type emitter. Immediately following a period of forward conduction both base regions are saturated with excess carriers having a distribution as shown in Figure 4. With reversal of the applied voltage, current flow through the device is reversed and we have a net flow of charge out of each region proportional to current. In each base region the numbers of excess holes and electrons (i.e., above equilibrium values) are essentially equal. Thus, when the voltage is reversed those minority carriers in the immediate vicinity of the end junctions are swept out of the bases and the two end junctions become reverse biased as shown in Figure 5. However, as holes are swept out of base region n_1, they leave behind excess electrons which tend to lower the potential of n_1 with reppect to p_2, thus forward biasing J2 so that it injects holes from p_2 to n_1. As a consequence, holes leave base region n_1 on one side and are injected into it on the other side. In diffusing across the base, holes recombine with electrons at a rate proportional to minority carrier lifetime so that the quantity of excess electrons and holes in the base layer decreases exponentially with time. Since the current flow through the device is proportional to the excess charge in the base regions, the current decreases as the charge decreases. Thus for the case in consideration, the current is determined by the minority carrier lifetime of the device and decays exponentially with time according to the relation

$$I = K_1 + K_2 \exp(-t/\tau) \qquad (7)$$

where K_1 and K_2 are constants and τ is the minority carrier lifetime.

To decrease the decay time the carrier lifetime must be lowered. This is being achieved by diffusing gold into the base regions. However, lifetime reduction must be carefully controlled because too much reduction will cause the forward conducting drop and the gate current required for triggering to increase severely. A compromise can be achieved by reducing the base widths of the device as lifetime is decreased, thus maintaining good forward and triggering characteristics; unfortunately, the maximum blocking voltage attainable is also limited as a consequence. It appears that both devices B and C are very near to that theoretically achievable if full forward voltage is to be reapplied at the specified dv/dt level immediately following the recovery. Since many inverter applications require this type of operation, an attempt is being made to satisfy these much more severe conditions instead of those specified in MIL-S-19500/204.

3.1.2 Design Fabrication and Optimization

3.1.2.1 Introduction

As initially outlined, the program was to modify and improve the structure and the process used in fabricating the 2N1916W rectifier in order to meet the requirements of "Device B". "Device C" was to be a complete re-design, utilizing new processes on a radically different structural design.

Turn-off time has proven to be the most serious limitation in realizing reasonable yield processes. To meet all the requirements except turn-off time is in itself quite a problem but not as critical. However, as the minority carrier lifetimes of an SCR are reduced to lower turn-off time, the accompanying rise in forward drop causes the internal heat generation to rise. The problem can be solved by optimization of all the other design variables such as surface concentration, junction uniformity, surface contours, base resistivities and widths. However, such tight tolerances are required on each parameter that a very low yield is the result if the modified process of the 2N1916W is used. Consequently, it was decided that instead of continuing work with the alloy-diffused process for "Device B" and the all-diffused process for "Device C", the requirements of both devices could best be met by combining the two programs and making both devices by the same process; i.e., by the all-diffused process.

Because both turn-off time and dv/dt effects play such a significant role in the design of both "Device B" and "C", much of the work during this past quarter has been directed toward optimizing and analyzing lifetime,and the shorted emitter.

3.1.2.2 Lifetime Effects

3.1.2.2.1 Basic Effects of Lifetime

The device characteristics which are affected by lifetime are as follows:

1) Reverse Blocking Current
2) Forward Blocking Current
3) Gate Current to Fire
4) Gate Voltage to Fire
5) Holding Current
6) dv/dt
7) Turn-on Time
8) Turn-off Time
9) Forward Voltage Drop

These are the characteristics which shall be analyzed here; but before doing this, let us summarize the basic effects of lifetime (recombination) in a semiconductor device. Carrier lifetime is lowered by the introduction of additional recombination centers by diffusing gold or some other lifetime killer into the silicon.

Recombination has the effect of either limiting the build-up of excess charge or causing the decay of excess charge in the bases. Recombination also partially determines the magnitude of diffusion current and together with the base width also determines the transport factor of the base.[12,13] C. T. Sah et al,[14] have shown that recombination in the space charge layer of a forward biased junction at low current densities limits the emitter efficiency of the junction. The emitter efficiency, γ, of a junction is limited by recombination in another way since

$$\gamma = \frac{\int_0^{W_E} P_P \, dx}{\int_0^{W_E} P_P dx + \int_0^{W_B} N_N dx} \tag{8}$$

for a P-type emitter, where W_E and W_B are the emitter and base widths, respectively. However, if the diffusion length, L, for minority carriers is less than W_E or W_B, then the appropriate integral is taken over the diffusion length. Thus, if the limit of $L \rightarrow 0$, $\gamma \longrightarrow 1/2$ regardless of the impurity distributions in the emitter and base. Note that the above equation determines the maximum value of γ for a given impurity distribution.

Now with these considerations in mind, let us analyze the effect of lifetime on the above device characteristics assuming that all other device parameters (resistivity, geometry, etc.) are held constant.

3.1.2.2.2 Reverse Blocking Current

The reverse blocking current which flows through an SCR at voltages low enough so that "punch through" and "avalanche" effects need not be considered is affected by lifetime (recombination) by the following mechanisms:

1) Minority carrier diffusion in the bases towards the reverse biased junction J_1 and J_3 (see Figure 6). This current component is proportional to the reciprocal of the square root of the minority carrier lifetime;[12] i.e., proportional to $\frac{1}{L}$ where $L = \sqrt{D\tau}$ and L is the minority carrier diffusion length. Lowered lifetime increases this current component.

2) The component of current due to transistor action is determined by the current gain, $\alpha = \gamma\beta$, where γ is the emitter efficiency of J_2 in this case and β is the transport factor of the base in question. It is easily shown that $\beta = \text{sech}\,\frac{W}{L}$ and therefore lowered lifetime decreases this current component. The lifetime dependence of γ is mainly that described by C. T. Sah et al; i.e., its variation with emitter current. The maximum value of γ is determined from impurity distributions.

3) A third component is due to generation of hole-electron pairs in the space charge regions of the reverse biased junctions J_1 and J_3. This causes a generation current as described by C. T. Sah et al. Lowered lifetime increases this current component.

At device junction temperatures of 125°C, all three effects are important.

3.1.2.2.3 Forward Blocking Current

The forward blocking current which flows through an SCR at voltages low enough so that "punch through" and "avalanche" effects need not be considered is affected by lifetime by the same mechanisms which apply to reverse blocking current; differing only with respect to the areas to which the mechanisms apply. The current components of these mechanisms are as follows:

1) Minority carrier diffusion currents in the bases toward the reverse biased junction J_2 which are proportional to

$$\frac{1}{L} = \frac{1}{\sqrt{D\tau}}$$

2) Transistor action current determined by the alphas of the transistors formed by J_1 and J_2 and by J_3 and J_2.

3) Space charge generated current in the space charge region of J_2.

At operating temperatures of 125°C, effects 1) and 3) should be the most important. Transistor action is more important here than in the case of the device being reverse biased since the emitter efficiencies in this case are much higher.

3.1.2.2.4 Gate Current to Fire

The gate current to fire is measured by placing across the SCR an anode-to-cathode voltage which is half the rated voltage. A pure DC voltage is then applied to the gate. The voltage is increased until the device fires completely. The gate current to fire (I_{GT}) is then taken as the gate current corresponding to this voltage (V_{GT}).

In order to understand the turn-on mechanism of an SCR in terms of charge analysis, consider Figure 7, which gives the approximate minority carrier charge distributions for the "off" and "on" states of an SCR. Since one normally assumes charge neutrality to exist in the bases, we must also have an equal excess of majority carrier charge.[15] In the "off" state, a small amount of excess charge exists in the bases since we have a small forward blocking current flowing through the device. In order for the SCR to switch to the "on" state, the bases must be saturated with a sufficient amount of charge so that J_2 becomes forward biased. The bases may be forced into saturation by any one of the following methods:

1) Application of a sufficiently large gate current.[16]
2) Application of an anode to cathode voltage equal to or greater than the static $V_{(BR)FO}$ of the device, so that the avalanche multiplication effects can occur,[17,18] and
3) Application of an anode to cathode voltage having a sufficiently large dv/dt.

At the moment, we are interested only in the case of gate turn-on. If space charge generated current is neglected, the forward blocking current which will flow through an SCR at forward voltages low enough so that avalanche may be neglected is given by[18]

$$I = \frac{I_{CO}}{1 - \alpha_{NPN} - \alpha_{PNP}}$$

where I_{CO} is the leakage current through J_2 if J_2 is reverse biased and isolated from J_1 and J_3. From this it can be seen that if $(\alpha_{NPN} + \alpha_{PNP}) \geq 1$, then the above equation is invalid and the device has switched to its on state. The current gain α, is a function of emitter current as shown in Figure 8. The SCR is constructed such that $(\alpha_{NPN} + \alpha_{PNP}) < 1$ for low current levels, but allows $(\alpha_{NPN} + \alpha_{PNP})$ to become greater than unity by the mechanism described by C. T. Sah et al, when a sufficient amount of gate current is applied.

F om the above comments one concludes that the effect of lifetime on gate current to fire is quite dependent on the effect of lifetime on α_{PNP} and α_{NPN}. In other words a decrease in the alphas will cause an increase in the gate current to fire. A decrease in lifetime will cause a decrease in $\alpha = \gamma\beta$ as follows:

1) The maximum value of the γ's will change slightly.
2) The limiting effect of recombination in the space charge layers of J_1 and J_3 on the γ's will increase.
3) The transport factor, β, will decrease.

3.1.2.2.5 Gate Voltage to Fire

The gate voltage, V_{GT}, to fire was defined in the previous section and the effects of lifetime on it will be the same as the effects of lifetime on gate current to fire, I_{GT}, since I_{GT} is proportional to $e^{KV_{GT}}$.

3.1.2.2.6 Holding Current

The holding current of an SCR is defined as that forward conducting current below which the SCR reverts to its forward blocking state with the gate open. In terms of charge this means that just enough charge at some current level is being injected into the bases as is being recombined such that Junction J_2 just barely stays forward biased.

In terms of current, this means that the current level has fallen to the point at which $\alpha_{NPN} + \alpha_{PNP} = 1$. Since the holding current depends on α_{NPN} and α_{PNP} in the same way as does the gate current to fire, we would expect the same dependence of holding current and gate current to fire on lifetime; therefore, decreased lifetime increases the holding current.

3.1.2.2.7 dv/dt

The dv/dt capability is defined as the maximum rate of rise of forward voltage that the SCR will support without triggering.

Basically, dv/dt firing is the rapid charging of junction J_2 causing a release of charge into the bases, which with subsequent transistor action, results in device turn-on. This effect may be decreased by decreasing lifetime since this will cause:

1) more recombination of charge in the bases and a subsequent decrease in the transport factors, and
2) more recombination in the space charge regions of J_1 and J_3 and thus decrease the emitter efficiencies of these junctions.

3.1.2.2.8 Turn-on Time (Gate commutated)

The turn-on time of an SCR is defined as the time interval between the initiation of the gate signal and the time when the resulting forward current reaches 90% of its final value while switching to the "on" state by gate firing.

Turn-on time is increased as lifetime is decreased. The relative effects of lifetimes on turn-on time are now being studied.

3.1.2.2.9 Turn-off Time

When turn-off time is measured under standard test conditions, the SCR is initially in an "on" state, then a small reverse bias is applied and finally a forward voltage is reapplied with a fixed rate of rise. The turn-off time is defined as the time measured from the point at which the reverse voltage is applied to that point at which the SCR starts to block the reapplied forward voltage.

In order to understand what this means in terms of the device, we must remember that when the device is in the "on" state the two bases of the SCR are "saturated"; i.e. contain enough excess charge to switch the center junction to a forward biased condition. While the device is in the reverse bias condition, most of this excess charge must be removed from the two bases, so that the device will block the reapplied forward voltage.

While the device is reverse biased the excess charge is removed from the bases by a number of ways, the most important of these are as follows:

1) When the device first sees the reverse voltage, J_1 and J_3 will collect a large number of minority carriers until J_1 and J_3 can support the reverse voltage after which the current passing through these junctions will be a decaying minority carrier current the magnitude of which is dependent upon the concentration and lifetime of minority carriers in their respective bases.
2) The excess charge is continuously recombining in the two bases at a rate which is dependent upon the concentration of excess minority carriers and their lifetime.
3) Majority carriers in the P-type base have an opportunity to leak out through the gate circuit. The magnitude of this current is, of course, dependent on the impedance of the gate circuit.
4) Since J_2 is forward biased, it acts as an injecting junction of minority carriers. Its injection efficiency is dependent to some extent upon base lifetime; however, it is, in general, quite high in the direction of injection from the P-type base to the N-type base.
5) Some recombination in the space charge layer of J_2 may occur, the magnitude of which depends on the current going through the device. This effect probably has a negligible effect on turn-off time.

Considering the above factors one sees that turn-off time is limited mainly by the inability of the N-type base to discharge itself quickly, since this discharge is controlled predominately by factors 1) and 2); that is, current flow through the device is determined by the minority carrier lifetime of the device. (See also section 3.1.1.4) The lower the lifetime, the faster the rates at which 1) and 2) occur and the faster the decay of the current flow.

3.1.2.2.10 Forward Voltage Drop

Forward voltage drop of an SCR is defined simply as the voltage drop from anode to cathode of the device in the "on" state. This includes lead and contact drop, of course, which we shall not consider, since they are not a function of lifetime. Inside of the device we have voltage drops across each of the three junctions and across each of the four regions shown in Figure 6. The voltage drops across the junctions should not be lifetime dependent since the limiting effect of recombination in the space charge layers is reduced significantly at the normal operating currents. Now we must remember that a field current has a voltage drop associated with it, while a diffusion current does not. Also, field current is not lifetime dependent while diffusion current is. The currents in the emitter regions are almost entirely field dependent so that there are voltage drops in these regions but they are not lifetime dependent. However, the currents in the bases are both field and diffusion currents. Now, if we take all our measurements of voltage drops at the same current level, which is only reasonable, the more recombination we have in the bases, the more field current we will have in the bases. Thus, as lifetime decreases, the voltage drop in the bases and also the total voltage drop of the device will increase.

3.1.2.2.11 Summary

In summary turn-off time can be decreased by lowering the carrier lifetime and maintaining the base widths at a minimum compatable with the voltage capacity required. Of the other transient properties dv/dt will be improved and turn-on time increased slightly. Other device characteristics such as blocking currents, gate triggering current and voltage, holding current and forward voltage drop will be increased but the increases will not be serious except in the case of forward voltage drop. An excessive increase in the forward voltage drop could hamper the current carrying capacity of the device.

Experiments are being conducted using gold diffusion to optimize the carrier lifetime for device characteristics. Gold diffusion temperatures between 800°C and 900°C are being used. A curve of lifetime as a function of gold diffusion temperature from the Bell System Technical Journal (January 1960) is shown in Figure 9.

3.1.2.3 Calculation of Emitter Shorts (See also section 3.1.1.3)

The purpose of an emitter short is to prevent significant injection of minority carriers by the PN junction in the neighborhood of the short at low current levels. As this low level current increases it approaches the forward current necessary to turn-on the SCR. The value of the current necessary to turn-on the SCR should be greater than the displacement current of the SCR under the highest expected dv/dt conditions. Calculation of the amount of shorting needed is dependent, therefore, upon the emitter characteristics at the temperature under consideration, and the displacement current.

Perhaps the place to start is to determine what is a significant injection of minority carriers. It will be assumed that steady state emitter junction characteristics apply. Figure 10a shows the familiar alpha vs. current curve for a junction transistor. The current at point p where $\alpha_1 + \alpha_2 = 1$ will just turn-on an SCR.

When the emitter is partially shorted as shown in Figure 10b, the total forward current necessary to turn-on the SCR increases from p' to q' . (Note that the combined characteristic at much higher current levels has not been altered by the presence of a short.) This higher forward current necessary to turn-on the SCR means larger allowable displacement currents and higher allowable dv/dt ratings for the SCR.

For small area SCR's where transverse resistance in the base layers is negligible, the short can be placed between cathode and gate, internal or external to the package. The conductance of this short could be

$$Y = \frac{I_{q'} - I_{p'}}{V_{p'}} \tag{10}$$

where $I_{q'}$ is the displacement current C dv/dt, $I_{p'}$ is the junction current which is assumed equal to $I_o\left[e^{\frac{q(V_D - V_{app})}{kT}} - 1\right]$, $(1 \leq \eta \leq 2)$,

where V_D is the built-in voltage and V_{app} is the applied voltage, and $V_{p'}$ is the voltage across the emitter junction. C is the barrier capacitance of the middle junction. Substitution gives

$$Y = \frac{C\frac{dv}{dt} - I_{p'}}{V_D - \frac{\eta kT}{q} \ln\left(1 + \frac{I_{p'}}{I_o}\right)} \tag{11}$$

The usual voltage reapplied across an SCR has a dv/dt that decreases as the voltage increases. The barrier capacitance C also decreases as the voltage across the SCR increases. The value of $I_{p'}$ decreases at the voltage increases because of the narrowing of the base widths. Furthermore, the temperature dependence of the V_D, $I_{p'}$, I_o is very strong. $I_{p'}$ also varies rapidly with minority lifetime. For these reasons, an exact solution giving the necessary short conductance is not easily obtainable even for the case of negligible cross-biasing in the base. Once Y is obtained its temperature dependence will likely differ from that of the short conductivity. Any practical determination of short conductivity will, therefore, be based upon a number of judicious assumptions. For large area devices like "Device B" or "Device C" the effectiveness of emitter shorts is also dependent upon the transverse field in the base layer. This relationship is not too difficult to determine analytically. Therefore the design of a shorted emitter will be based upon this calculation plus reasonable assumptions made about the junction characteristics discussed above.

Assumptions (Refer to Figure 11)

a) The displacement current enters the base layer uniformly across the base area.

b) All the displacement current leaves the base layer via the short path.

c) The base layer is extremely thin compared to its diameter so that it can be characterized by a sheet conductivity, σ s.

d) Negligible injection occurs when the voltage across the PN emitter junction is less than Ve.

Solution

The voltage drop between points b and a, (V_{ba}) in Figure 11, must be less than Ve to keep the SCR from turning on by a rapid rise in anode voltage. Using cylindrical coordinates this voltage drop is

$$V_{ba} = R \frac{J_D}{\sigma s} \tag{12}$$

Where R is the geometry factor

$$R = \frac{1}{16} \left\{ d^2 + D^2 \left[2 \ln \left(\frac{D}{d} \right) - 1 \right] \right\} \tag{13}$$

and J_D is the displacement current

$$J_D = C \frac{dv}{dt} \tag{14}$$

Solving Equation (13) for R and substituting

$$R = \frac{\sigma s \ Ve}{C \frac{dv}{dt}} \qquad (15)$$

The value for σs can be calculated from a knowledge of the diffusion profiles.[21] Reasonable values of Ve and C are 0.5 volts and 800 pf/cm^2 respectively. Equations (13) and (15) define a relationship between d and D which satisfy the above conditions for any particular value of dv/dt. The output from a calculation of this type performed on a General Electric model 225 Computer is shown in Figure 12. This output was calculated for "Device C" and shows the required short dimensions. It is interesting to note that the percentage of contact area used by the shorts reduces as the dimensions of the short becomes less. There is a practical limit, however, to the smallest size of short that can be made.

3.1.3 Rating, Testing and Characterization

Both device B and C are being tested and rated according to the criteria and methods listed in the following sections. Parameters for Device B will be used as examples. The symbols used are shown in Appendix A, PART III.

3.1.3.1 Voltage (V_{FOM}, V_{ROM}, and V_c)

The SCR's are characterized at 25°C and 125°C for voltage blocking ability by applying a half sine wave, forward or reverse voltage, and monitoring current by means of an E-I trace on an oscilloscope. The voltage is increased until one of the following events occur:

1) Break over - The device goes into the "on" state in the forward direction.
2) Break down - The device avalanches.
3) Blocking current reaches a predetermined value (10 ma)
4) Erratic E-I trace (reject).

The lowest of the four voltages (V_{ROM} at 25°C, V_{FOM} at 25°C, V_{ROM} at 125°C and V_{FOM} at 125°C) determines the test or classification voltage. In order to be classified a 1000 volt unit, the lowest of the four voltages must be at least 1,100 volts. Blocking currents are remeasured at the maximum operating junction temperature and classification voltage (V_c). They must be significantly lower than that required to cause thermal runaway. A pictorial representation of the blocking characteristic is shown in Figure 13.

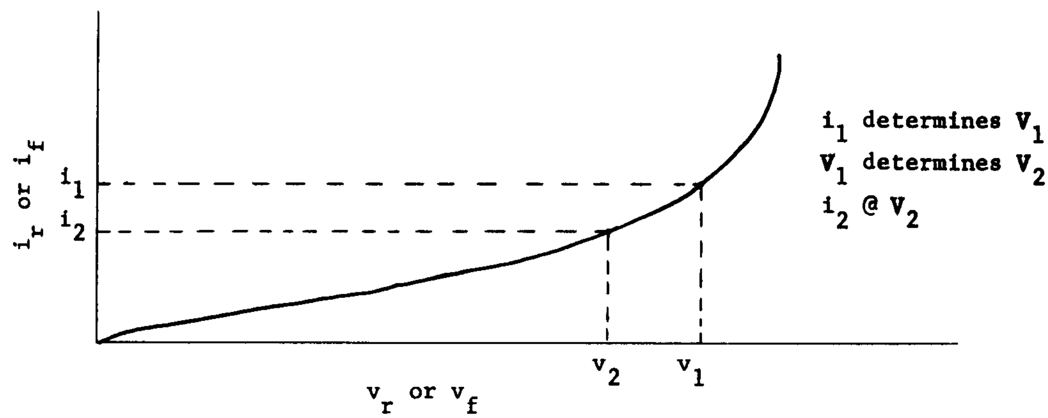


Figure 13 - Blocking characteristic

3.1.3.2 Current Carrying Capability (I_0 at T_C)

The maximum average current a device can carry is determined by the maximum permissable peak junction temperature, the power dissipation within the device (total losses), and the heat dissipation capability (transient and steady state).

A computer rating program is being used to determine the maximum limits of effective thermal resistance and conduction losses so that T_J will never exceed 125°C when I_0 = 70 amperes at T_C = 90°C.

a) The maximum permissible junction temperature was set at 125°C which is the generally accepted maximum operating temperature for SCR's. All high temperature testing was done at this point.

b) Power dissipation within the device is composed of the following components:

   (1) Gate Power

   The average gate power is determined by the maximum gate voltage and current (V_{GF} and I_{GF}).

(2) Blocking Losses

The average blocking losses are determined from the blocking current limits.

(3) Conduction Losses

The on-voltages were measured on a number of units at current levels from 1 amp to destruction at 25°C and 125°C. All units must have on-voltages less than the maximum curve as determined by the computer calculations.

(a) Low current level on-voltage at 25°C (refer to E50 GX-15-S1 included in PART III). The 1 ampere V_f is obtained by first firing the device into a high current (approximately 50 amperes), by reducing the current without interruption to 1 ampere DC and by reading the DC voltage across the unit.

(b) High current level on-voltage (forward drop) at 25°C (E50 GX-14-S1, PART III). A 2 m sec half sine wave current pulse of 500 amperes peak is passed through the device; the on-voltage is displayed on an oscilloscope.

c) Heat dissipation ability

(1) Thermal Resistance

A number of devices are tested for transient thermal impedance per E50 GX-30-S1 (PART III), and the maximum reading of all these devices is used as the maximum transient thermal impedance.

(2) All devices are tested for Effective Thermal Resistance per E50 GX-28-S1 (PART III). Units which fail to meet the maximum thermal resistance as determined by the computer program are rejected.

3.1.3.3 Speed

Three speed characteristics; turn-on time, turn-off time, and dv/dt are measured as described in the following paragraphs.

3.1.3.3.1 Turn-on Time at 25°C

The circuit shown in Figure 14 is used to measure the turn-on time (t_{on}). The SCR is triggered-on at a peak voltage of approximately 6 volts. The gate current is monitored with a current probe and amplifier to insure that it does not exceed 80 ma. The gate voltage and the load current are displayed on an oscilloscope to measure the turn-on time; this is the time from when the gate voltage reaches 50% of the final value to when the resultant current through the device rises to 90% of final value.

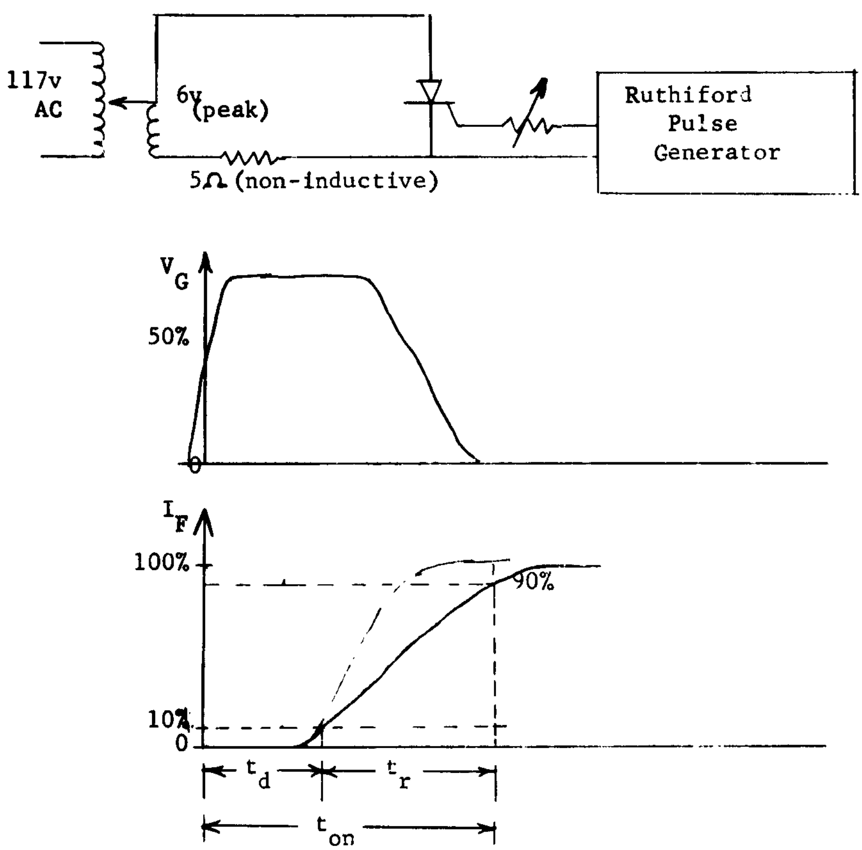
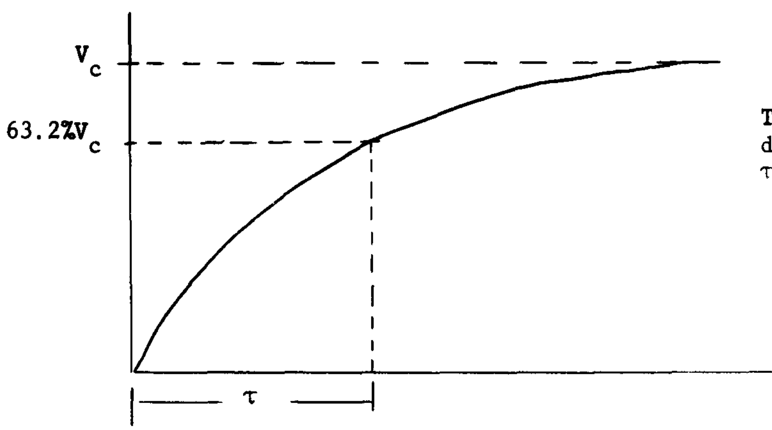


Figure 14 - Turn-on time measurement

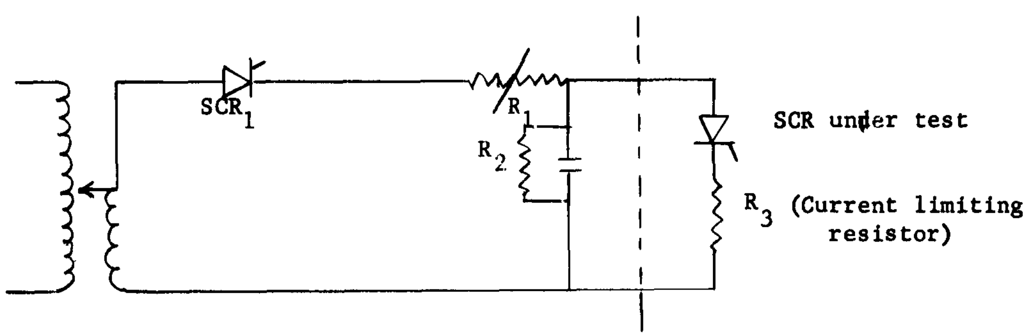
3.1.3.3.2 dv/dt (Rate of Rise Test)

The circuit shown below is used to dermine the maximum rate of rise of forward blocking voltage the device can withstand.

The device is placed in a heated block at 125°C. The voltage is increased until the peak voltage across the SCR under test is the Rated Voltage. SCR_1 is triggered at the peak of the line voltage. The voltage across the capacitor and SCR under test exponentially increases with a time constant of $R_1 C_1$. The voltage across the SCR under test is viewed with an oscilloscope. $R_1 C_1$ is decreased until the device switches into the on-state; $R_1 C_1$, is then increased until the SCR can regain blocking ability.

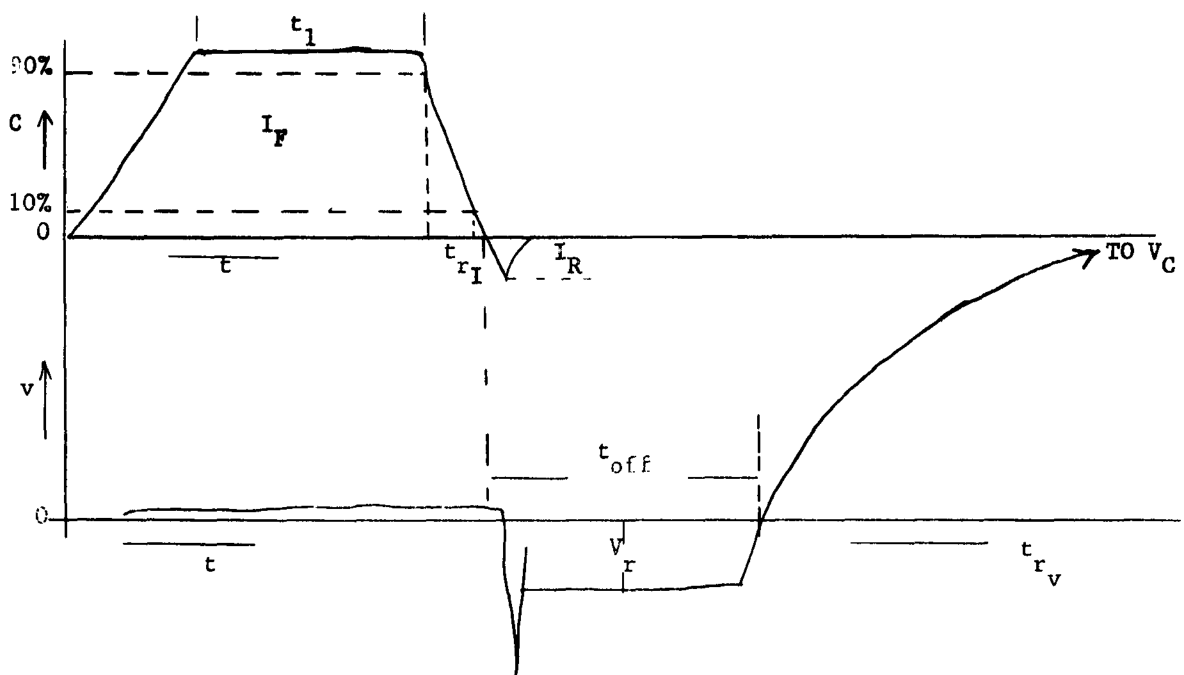


The time that it takes the device to reach $.632V_c$ is τ and is recorded.



3.1.3.3.3 Turn-off Time

With the device in a heat sink at 125°C, the current and voltage shapes shown in Figure 15 below are generated.



I_F = 50 amps

I_R = 12 amps

t_{r_I} = 20 u sec

t_1 = 100 u sec

V_r = 50 v max.

t_{r_V} = (2.2)50 = 110 u sec

V_C = 1000 volts

Figure 15 - Turn-off time generation

Turn-off time is the time between the current crossing down through **zero, and voltage** crossing up through zero.

These shapes are generated by the circuit shown below in Figure 16.

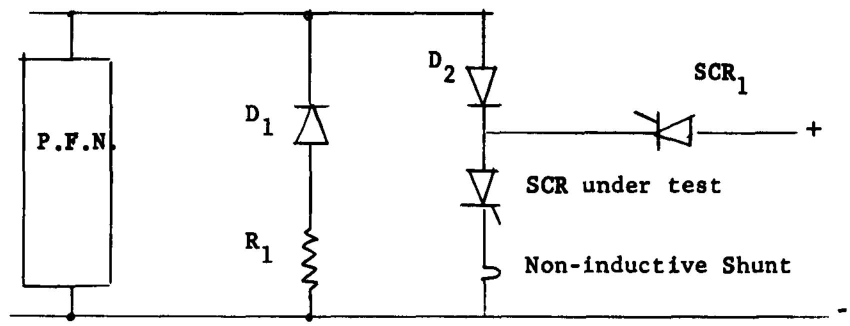


Figure 16 = Turn-off time test circuit

When the SCR being tested is triggered, the pulse forming network discharges through D_2, the SCR under test, and the current shunt. The current reversal goes through the parallel paths D_1, R_1, D_2, and the SCR under test, and the shunt. When either D_1 or SCR_1 recovers reverse blocking ability, all reverse current goes through R_1 and D_1.

The voltage drop across D_1 and R_1 is applied in the reverse direction across D_2 and SCR_1. The recovery times of D_2 and the SCR under test must be reasonably well matched in order to measure t_{off} accurately.

At some time after the SCR being tested has triggered, SCR_1 is fired applying an exponentially increasing voltage across the SCR under test. This time is decreased until the SCR under test can not block this forward voltage, then increased until it regains blocking ability. This latter time is the measured turn-off time.

3.1.3.4 Other Characteristics

3.1.3.4.1 Holding Current

I_H,the holding current is measured at 25°C and 125°C using the circuit shown in Figure 17. The unit is initally fired into a load of 500 ma DC.

PART II

4.1 Program for the Next Quarter

Optimization of design parameters will continue with increased emphasis on turn-off time and forward conducting drop. Final design samples of Device B will be constructed, evaluated and delivered. Fabrication and evaluation of the final design devices will be the primary goal for the next quarter.

Theoretical work on Device C will be continued.

APPENDIX A

PNPN TYPE SWITCH LETTER SYMBOLS

1. Abbreviations

Quantity Symbols

Current	I, i
Voltage	V, v
Power	P, p
Thermal Resistance	θ
Time	t (lower-case only)
Temperature	T (upper-case only)

Subscripts

Anode	A, a
Cathode	K, k
Gate	G, g
Forward	F, f
Reverse	R, r
Maximum Value	M
Average Value	(AV)

2. Convention to be Used Where "*" is Shown (See Table):

O, O Gate terminal is open-circuited or device has no gate terminal.

S, s Gate terminal is short-circuited to the terminal of the adjacent region.

X, x Gate terminal is returned to the terminal of the adjacent region through a stated impedance and/or bias voltage.

3. Specific Letter Symbols

NOTE: * means additional subscript must be used here. (See Section 2)

Quantity	Total RMS Value	DC Value, No Alternating Component	DC Value, With Alternating Component	Instantaneous Total Value	Maximum (Peak) Total Value
Forward Current, on State	I_f	I_F	$I_{F(AV)}$	i_F	I_{FM}
Forward Current, On State 180° conduction angle, 60 c.p.s., Half Sine Wave Current	–	–	I_O	–	–
Repetitive Peak Forward Current	–	–	–	–	I_{FM}(rep)
Peak Surge Forward Current	–	–	–	–	I_{FM}(surge)
Forward Breakover Current	–	$I_{(BR)F*}$	–	$i_{(BR)F*}$	–
Forward Blocking Current	I_{f*}	I_{F*}	$I_{F*(AV)}$	i_{F*}	I_{F*M}
Reverse Blocking Current	I_{r*}	I_{R*}	$I_{R*(AV)}$	i_{R*}	I_{R*M}
Reverse Breakdown Current	–	$I_{(BR)R*}$	–	$i_{(BR)R*}$	–
On Voltage	V_f	V_F	$V_{F(AV)}$	v_F	V_{FM}
Forward Breakover Voltage	–	$V_{(BR)F*}$	–	$v_{(BR)F*}$	–
Forward Blocking Voltage	V_{f*}	V_{F*}	$V_{F*(AV)}$	v_{F*}	V_{F*M}

3. Specific Letter Symbols (Con't)

Quantity	Total RMS Value	DC Value, No Alternating Component	DC Value, With Alternating Component	Instantaneous Total Value	Maximum (Peak) Total Value
Reverse Blocking Voltage	V_{r*}	V_{R*}	$V_{R*(AV)}$	v_{R*}	V_{R*M}
Working Peak Reverse Blocking Voltage	—	—	—	—	$V_{R*M}(wkg)$
Repetitive Peak Reverse Blocking Voltage	—	—	—	—	$V_{R*M}(rep)$
Non-Repetitive Peak Reverse Blocking Voltage	—	—	—	—	$V_{R*M}(non\text{-}rep)$
Reverse Breakdown Voltage	—	$V_{(BR)R*}$	—	$v_{(BR)R*}$	—
Holding Current	—	I_H	—	i_H	—
Gate Trigger Current	—	I_{GT}	—	i_{GT}	I_{GTM}
Gate Turn-off Current	—	I_{GQ}	—	i_{GQ}	I_{GQM}
Forward Gate Current	I_{gf}	I_{GF}	$I_{GF(AV)}$	i_{GF}	I_{GFM}
Reverse Gate Current	I_{gr}	I_{GR}	$I_{GR(AV)}$	i_{GR}	I_{GRM}
Gate Trigger Voltage	—	V_{GT}	—	v_{GT}	V_{GTM}
Gate Turn-off Voltage	—	V_{GQ}	—	v_{GQ}	V_{GQM}
Forward Gate Voltage	V_{gf}	V_{GF}	$V_{GF(AV)}$	v_{GF}	V_{GFM}
Reverse Gate Voltage	V_{gr}	V_{GR}	$V_{GR(AV)}$	v_{GR}	V_{GRM}
Gate Power Dissipation	—	P_G	$P_{G(AV)}$	P_G	P_{GM}

Ambient temperature	T_A
Case temperature	T_C
Junction temperature	T_J
Storage temperature	T_{stg}
Thermal Resistance	θ
Thermal Resistance, Junction to Ambient	θ_{J-A}
Thermal Resistance, Junction to Case	θ_{J-C}
Transient Thermal Impedance	$\theta_{(t)}$
Transient Thermal Impedance, Junction to Ambient	$\theta_{J-A(t)}$
Transient Thermal Impedance, Junction to Case	$\theta_{J-C(t)}$
Delay Time	t_d
Rise Time	t_r
Fall Time	t_f
Storage Time	t_s
Pulse Time	t_p
Turn-On Time, Gate Commutated ($t_d + t_r$)	$t_{G\ on}$

Turn-Off Time, Circuit Commutated	t_{off}
Rate of Rise of Forward Blocking Voltage	$\frac{d(v_{FO})}{dt}$
Peak Reverse Surge Power	P_{ROM} (surge)
Applied Anode - to - Cathode Voltage	v_{app}
Classification Voltage	V_c
Diffusion Voltage (Built-in Voltage)	V_D

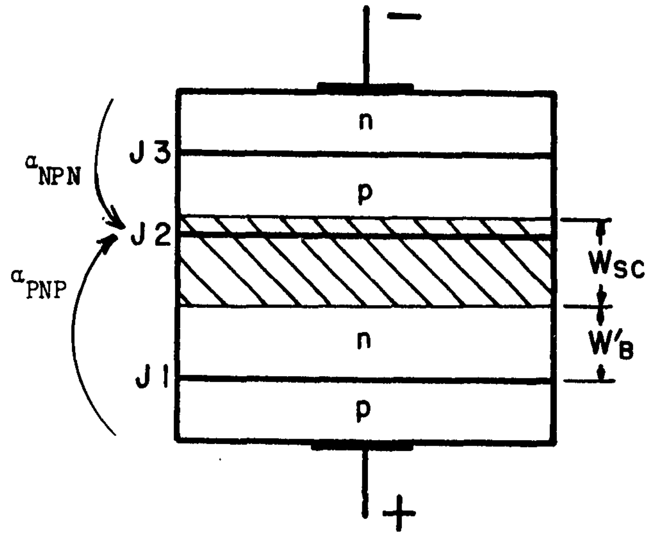


Figure 1a - Space charge layer resulting from forward blocking voltage

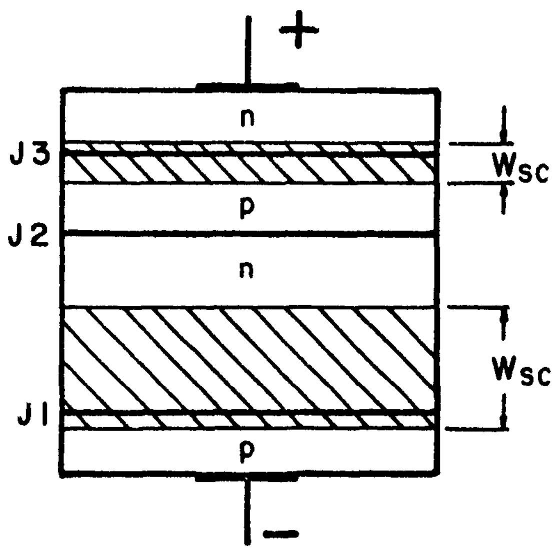


Figure 1b - Space charge layer resulting from reverse blocking voltage

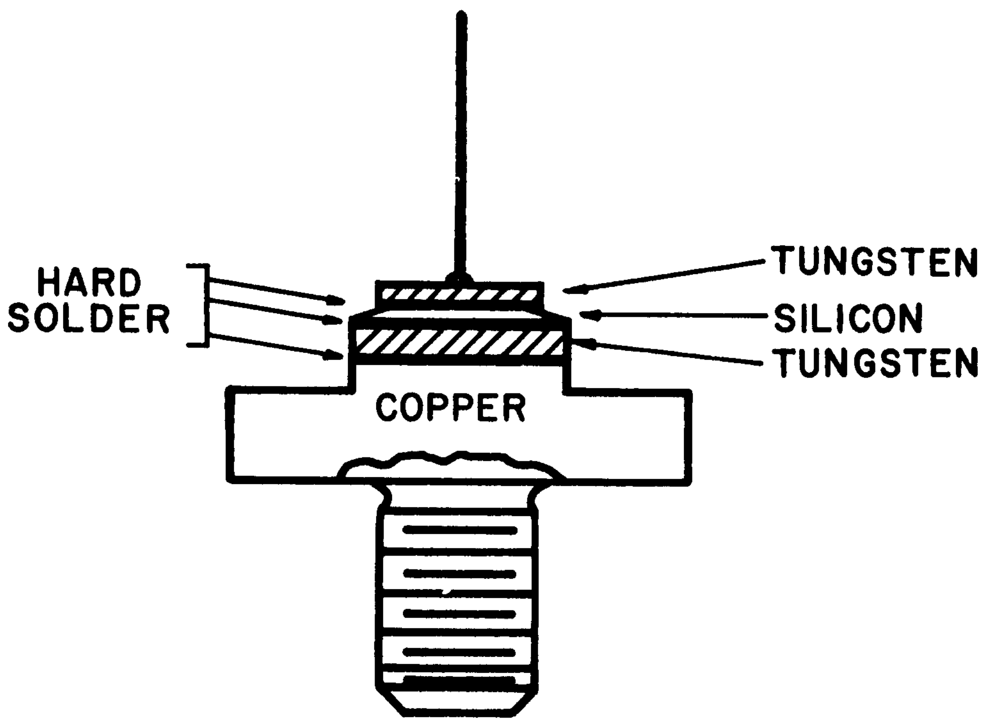


Figure 2 - Silicon device utilizing transition plates and hard solder

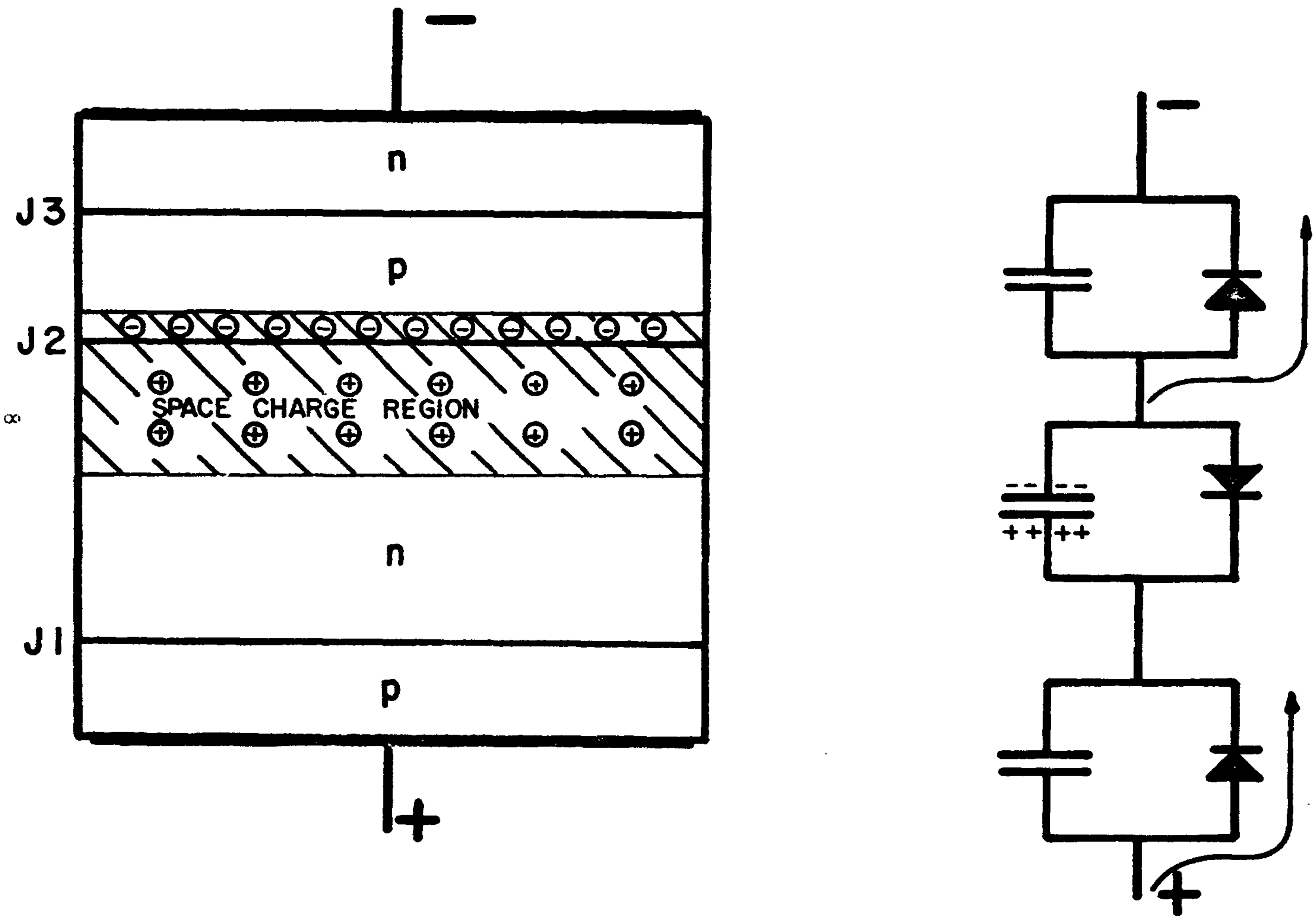


Figure 3 - Space charge layer visualized as capacitance which must be charged through emitting cathode and anode junctions

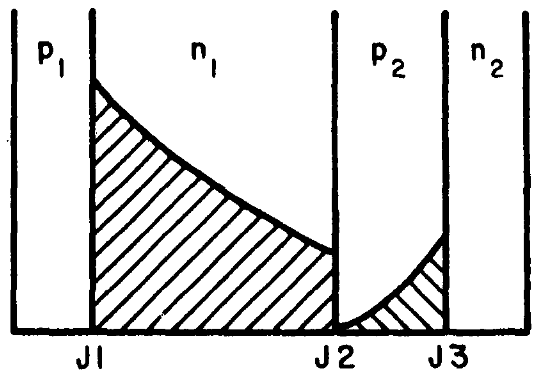


Figure 4 - Excess hole and electron distribution in base regions during forward current flow

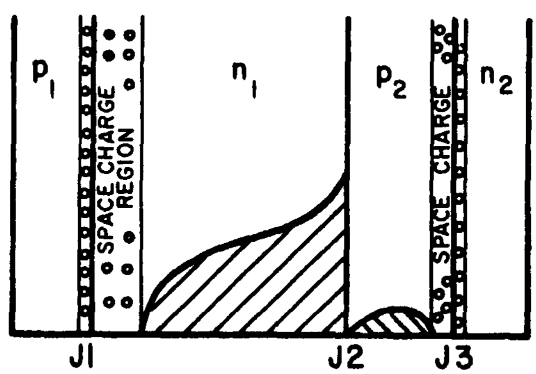


Figure 5 - Hole and electron distribution during recovery current phase

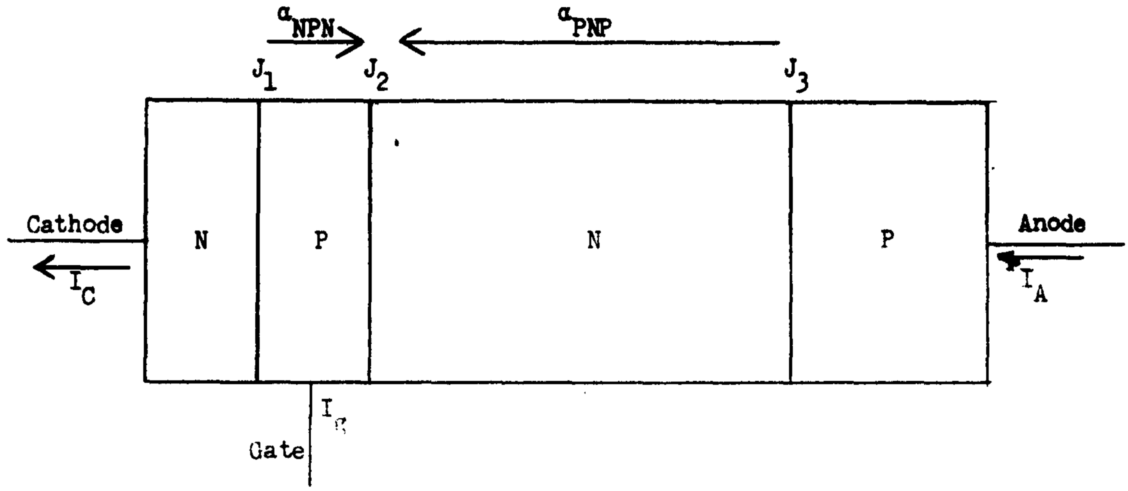


Figure 6 - Schematic diagram of an SCR

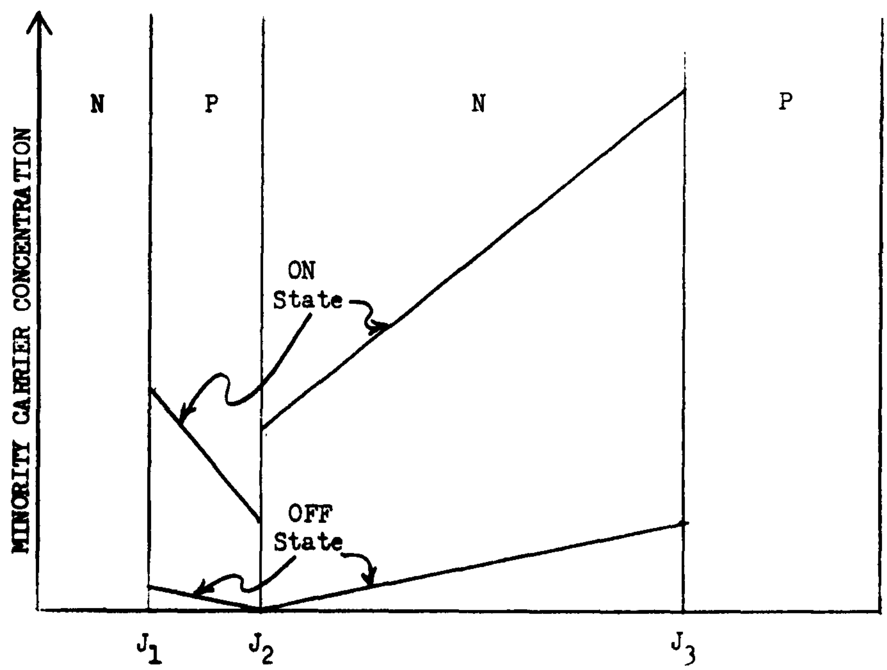


Figure 7 - Minority carrier distributions

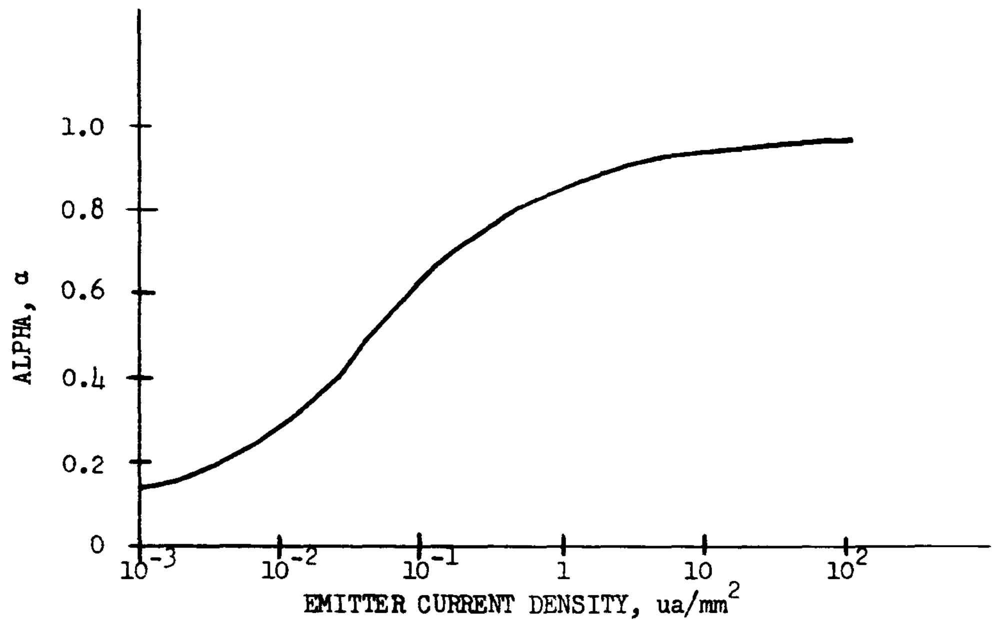


Figure 8 - Alpha as a function of emitter current

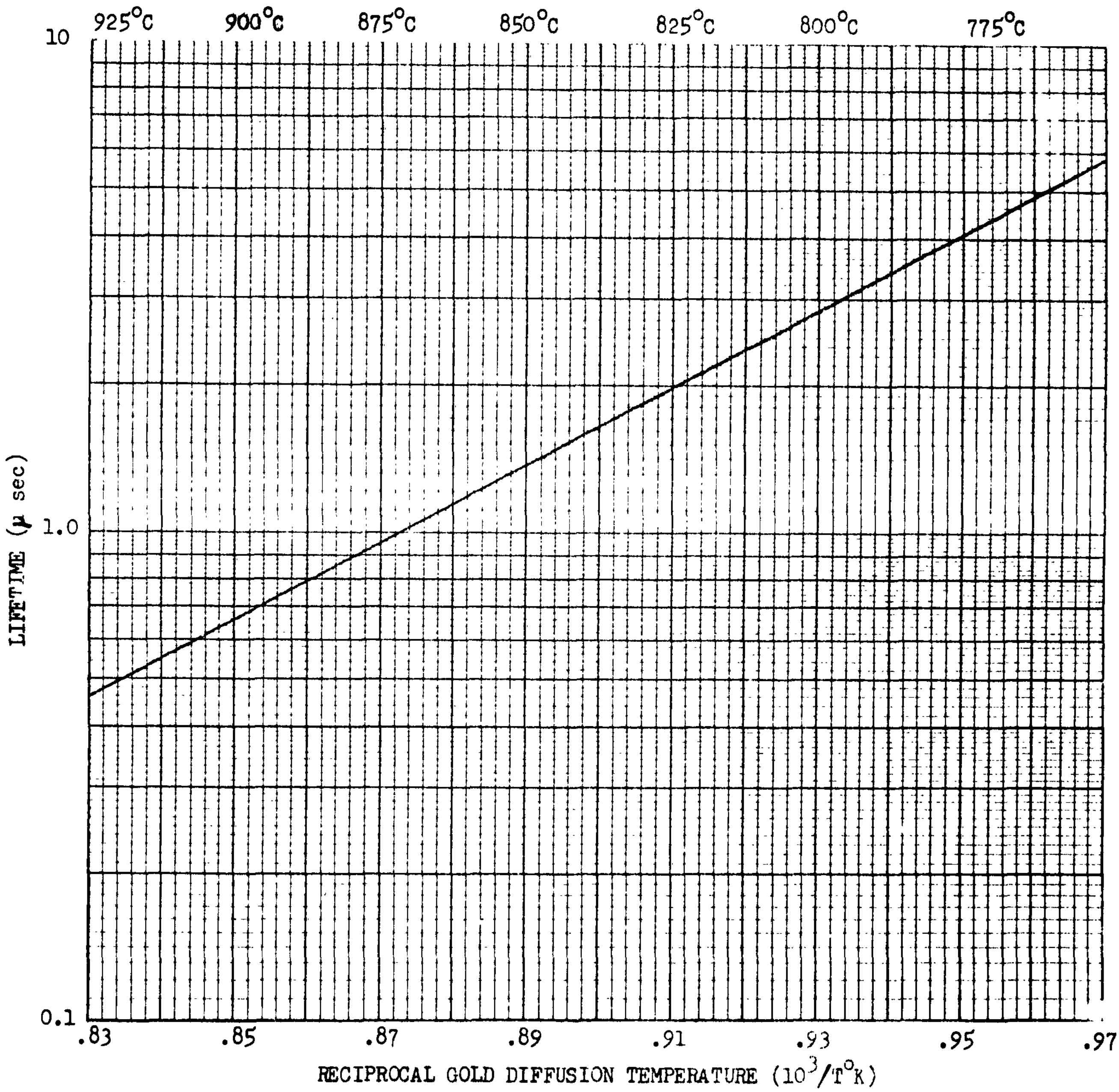


Figure 9 - Lifetime in silicon as a function of gold diffusion temperature

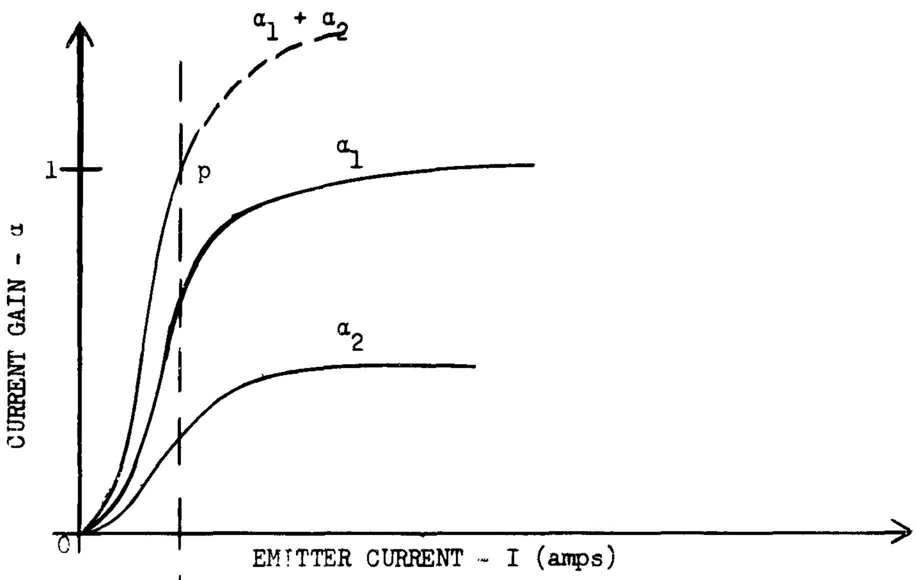


Figure 10a - Current gain in a transistor as a function of emitter current at a constant collector voltage

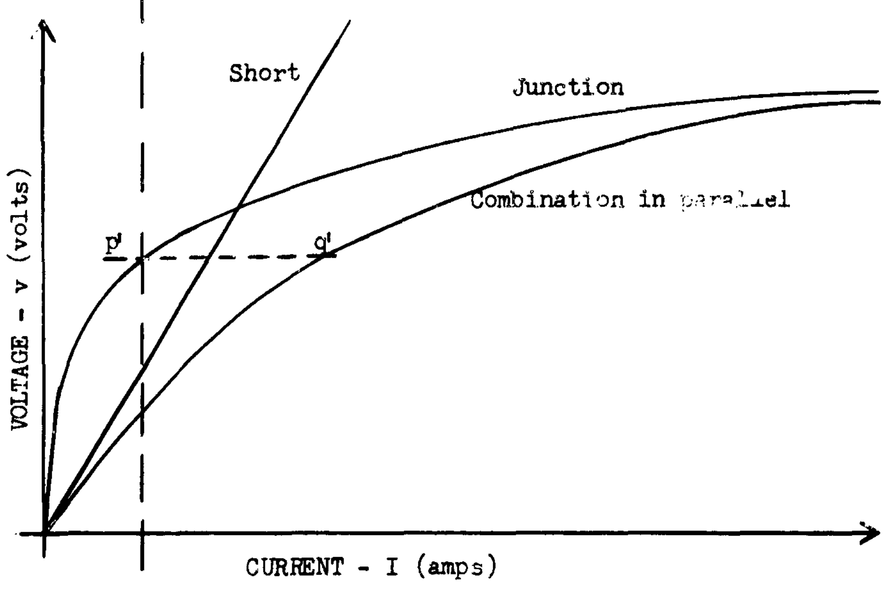


Figure 10b - E-I characteristics of an emitter that has an ohmic short

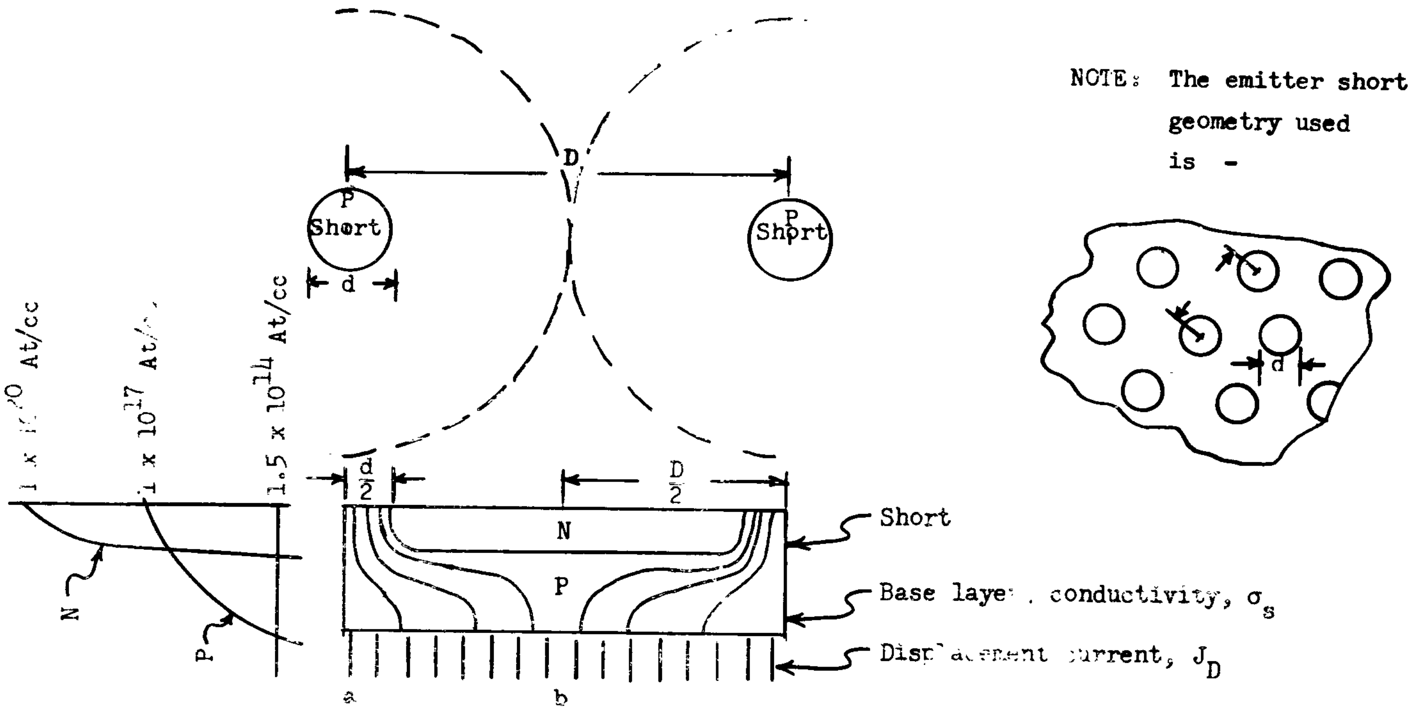


Figure 11 - The emitter short

SHORTED EMITTER GEOMETRY

INPUT DATA--

SURFACE CONC	BASE CONC	JUNCTION DEPTH	T REGION
.09999999 18	.14999994 15	.76199999 -2	.50799999 -2

DVDT	CAPACTACE	VOLTAGE DROP	AVE-COND.
.20000000 9	.79999828 -9	.49999952	.05440262 1

OUTPUT FOR TRIANGULAR DOT SHORTS

SHORT DIAM.	SPACING C-C	AREA OF SHORTS
20	92	.042
30	107	.070
40	123	.095
50	139	.116
60	153	.138
70	162	.168
80	173	.193
90	182	.221
100	190	.250

Figure 12 - Computer data for shorted emitter geometry

DEVICE B DATA SHEET

Lot No. E-75

Date 30 April 1963

Unit Nr	$T_J = 25°C \pm 3°$						$T_J = 125°C \pm 3°$						$T_J = 25°C \pm 3°$				$T_J = 125°C \pm 3°$				
	$V_{(BR)RO}$ or V_{RO}	$i_{(BR)RO}$ or i_{RO}	$V_{(BR)FO}$ or V_{FO}	$i_{(BR)FO}$ or i_{FO}	I_{GT}	V_{GT}	$V_{(BR)RO}$ or V_{RO}	$i_{(BR)RO}$ or i_{RO}	$V_{(BR)FO}$ or V_{FO}	$i_{(BR)FO}$ or i_{FO}	I_{GT}	V_{GT}	V_F (a)	V_F (b)	$t_{G\ on}$	I_{RO}	I_{RO}	t_{off}	/ v_{app}	$\frac{d(v_{FO})}{dt}$	/ v_{app}
1	110	10	1250	0.3	-	-	125	10	1050	20	-	-	-	-	-	-	-	30	900	45	900
2	140	10	1275	0.5	47	1.7	160	10	1100	25	-	-	.95	2.08	20	22	-	-	-	4	900
3	100	10	1250	0.2	48	1.4	140	10	1125	20	-	-	.90	2.08	15	15	-	30	900	150	900
4	275	8	1300	1.5	26	1.0	150	10	870	9	-	-	.89	1.81	-	-	-	-	-	-	-
5	280	4	1275	10	47	1.5	130	10	1100	25	-	-	1.05	1.98	12	21	-	30	700	475	700
6	560	10	980	20	32	1.0	160	3	930	16	-	-	1.0	2.30	8	30	-	16	900	60	800
7	360	6	1050	20	25	0.9	185	5	1000	22	-	-	1.12	2.39	8	36	-	7	900	128	900
8	175	2	980	20	36	1.1	150	2	940	20	-	-	1.25	2.3	11	>50	-	11	900	90	800
9	90	1.5	1050	20	-	-	175	4	1000	22	-	-	-	-	-	-	-	12	900	180	900
10	200	10	1050	20	42	1.5	200	10	1000	17	-	-	1.13	2.09	10	>50	NOT MEASURED	15	900	65	900
11	900	10	920	20	40	1.0	810	10	910	30	20	.7	.94	2.2	2	21		15	900	25	800
12	1000	4	1050	20	-	-	610	10	1000	50	-	-	-	-	-	-		-	-	150	900
13	1080	10	1080	10	53	1.3	1050	25	990	25	22	1.0	1.05	2.4	14	39		14	900	150	900
14	1050	10	1050	10	50	1.2	1020	25	915	25	21	1.0	1.20	2.6	15	>50		8	900	150	900
15	940	5	960	20	29	1.0	810	10	920	21	30	1.1	1.1	1.95	9	36		12	900	45	800
16	800	10	920	20	43	1.2	720	10	750	14	-	-	1.06	1.9	6	44		13	700	58	600
17	900	5	920	20	39	1.0	740	10	900	30	19	.7	.94	2.5	6	24		14	900	175	800
18	880	10	900	20	90	1.4	250	10	870	20	-	-	1.09	2.5	-	-		15	800	116	700
19	1000	10	1020	9	36	1.0	420	10	990	13	-	-	1.09	2.85	-	37		13	900	90	800

NOTES: (a) — $I_F = 1$ ampere
(b) — $i_F = 500$ amperes

TABLE 2

Lot No. E-76

DEVICE B DATA SHEET

Date 30 April 1963

Unit No.	$T_J = 25^{\circ}C \pm 3^{\circ}$						$T_J = 125^{\circ}C \pm 3^{\circ}$						$T_J = 25^{\circ}C \pm 3^{\circ}$				$T_J = 125^{\circ}C \pm 3^{\circ}$				
	$v_{(BR)RO}$ or v_{RO}	$i_{(BR)RO}$ or i_{RO}	$v_{(BR)FO}$ or v_{FO}	$i_{(BR)FO}$ or i_{FO}	I_{GT}	V_{GT}	$v_{(BR)RO}$ or v_{RO}	$i_{(BR)RO}$ or i_{RO}	$v_{(BR)FO}$ or v_{FO}	$i_{(BR)FO}$ or i_{FO}	I_{GT}	V_{GT}	V_F (a)	V_F (b)	$t_{G\ on}$	I_{HO}	I_{HO}	t_{off} /	v_{app}	$\frac{d(v_{FO})}{dt}$ /	v_{app}
1	940	10	960	10	37	1.0	860	10	790	12	10	0.6	.98	1.7	8.	26	NOT MEASURED	17	700	100	600
2	920	10	960	20	30	1.0	860	10	820	25	11	0.6	1.0	2.2	5.2	24		13	800	125	700
3	710	10	700	50	-	-	630	10	340	20	-	-	.79	1.9	6.8	21		-	-	285	200
4	>1000	10	920	40	-	-	>1000	10	640	20	-	-	1.2	2.3	15.0	41		10	600	250	500
5	960	10	860	40	22	1.0	860	10	600	20	10	0.6	1.0	2.2	7.2	32		14	600	170	500
6	800	10	840	25	-	-	740	10	800	15	-	-	.9	2.2	-	22		17	700	170	500
7	910	10	780	50	21	0.8	840	10	520	25	10	0.6	1.0	2.5	7.0	21		10	500	170	500
8	>1000	10	860	45	22	0.9	920	10	650	30	10	0.6	1.0	2.6	8.0	27		10	600	200	600
9	880	10	910	25	59	1.5	800	10	820	15	23	1.0	-	2.1	23.0	41		13	800	140	600
10	780	10	840	55	25	0.8	740	10	790	30	11	0.6	.8	2.0	7.0	20		-	-	185	500
11	500	10	990	30	-	-	440	10	820	25	-	-	1.3	2.6	10.8	35		8	800	250	800
12	920	10	940	25	25	0.9	850	10	700	10	12	0.6	1.0	2.5	7.0	34		12	600	200	600
13	880	10	900	40	20	0.9	700	10	760	25	9	0.6	.9	2.3	6.6	21		17	700	23	500

NOTES: (a) — $I_F = 1$ ampere
(b) — $i_F = 500$ amperes

TABLE 3

DEVICE B DATA SHEET

Lot No. E-77 Date 30 April 1963

Unit Nr	$T_J = 25^\circ C \pm 3^\circ$						$T_J = 125^\circ C \pm 3^\circ$						$T_J = 25^\circ C \pm 3^\circ$				$T_J = 125^\circ C \pm 3^\circ$				
	$v_{(BR)RO}$ or v_{RO}	$i_{(BR)RO}$ or i_{RO}	$v_{(BR)FO}$ or v_{FO}	$i_{(BR)FO}$ or i_{FO}	I_{GT}	V_{GT}	$v_{(BR)RO}$ or v_{RO}	$i_{(BR)RO}$ or i_{RO}	$v_{(BR)FO}$ or v_{FO}	$i_{(BR)FO}$ or i_{FO}	I_{GT}	V_{GT}	V_F (a)	V_F (b)	$t_{G\ on}$	I_{HD}	I_{HD}	t_{off}	/ v_{app}	$\frac{d(v_{FO})}{dt}$	/ v_{app}
1	1300	10	1260	10	9	0.8	820	10	720	7.5	-	-	.99	2.85	5	15		18	600	30	600
2	1150	10	1100	9	13	0.8	860	10	660	8.	5	0.5	1.1	3+	9	21		19	500	25	500
3	920	10	990	20	-	-	660	10	620	10.	-	-	1.0	2.6	-	-		30	500	25	500
4	1190	1	1050	20	-	-	990	10	980	10.	-	-	-	-	-	-		9	800	-	-
5	1080	10	1080	10	64	1.3	1050	25	1050	25.	42	1.1	2.6	-	-	-		5	400	8	400
6	1140	2	1070	20	41	1.2	700	10	830	15.	35	1.1	2.3	3+	-	-	NOT MEASURED	6	900	360	900
7	1230	1	1095	10	59	1.4	1140	24	1080	22.	28	1.1	1.63	5.0	16	-		7	700	350	700
8	1350	10	1200	12	10	0.8	1065	15	900	12.	5	0.6	1.0	3.2	4	15		20	800	36	800
9	1140	10	1150	20	-	-	880	10	640	10.	-	-	.97	2.45	-	11		20	400	8	400
10	930	10	1290	10	-	-	800	10	650	20.	-	-	.76	1.85	3	-		30	400	10	400

NOTES: (a) — $I_F = 1$ ampere
(b) — $i_F = 500$ amperes

TABLE 4

DEVICE "B" DATA SHEET

Lot No. E-78

Date 30 April 1963

Unit Nr	$T_J = 25^oC \pm 3^o$						$T_J = 125^oC \pm 3^o$						$T_J = 25^oC \pm 3^o$				$T_J = 125^oC \pm 3^o$				
	$v_{(BR)RO}$ or v_{RO}	$i_{(BR)RO}$ or i_{RO}	$v_{(BR)FO}$ or v_{FO}	$i_{(BR)FO}$ or i_{FO}	I_{GT}	V_{GT}	$v_{(BR)RO}$ or v_{RO}	$i_{(BR)RO}$ or i_{RO}	$v_{(BR)FO}$ or v_{FO}	$i_{(BR)FO}$ or i_{FO}	I_{GT}	V_{GT}	V_F (a)	V_F (b)	$t_{G\ on}$	I_{HO}	I_{HO}	t_{off}	/ v_{app}	$\frac{d(v_{FO})}{dt}$	/ v_{app}
1	1220	10.	1230	7.0	46	1.2	740	10.	1260	7.5	-	-	.98	2.5	13.	47		20	1000	1233	740
2	1490	10.	1220	1.5	32	1.0	1240	8.	1180	5.	-	-	1.13	1.8	8	25		30	1000	1000	400
3	1420	10.	1220	10.	46	1.0	1260	7.5	1220	10.	-	-	.88	2.7	-	>50		17	1000	-	-
4	1470	0.1	1290	3.	18	0.8	1290	10.	1245	10.	5	0.6	.87	2.2	4	22		40	1000	46.	1000
5	1440	0.2	1350	4.	73	1.5	1200	10.	1320	10.	23	1.0	1.16	2.5	-	-		22	1000	667	1000
6	1440	0.1	1230	10.	18	1.0	1170	10.	1320	10.	5	0.6	.94	2.6	5	25		32	1000	80	800
7	1470	0.1	1260	6.	28	1.0	1350	10.	1140	10.	11	0.7	.95	2.3	8	36		30	1000	112	900
9	1390	5.0	1270	11.	36	1.0	600	10.	1230	10.	-	-	-	2.4	9	>50		30	1000	411	740
10	1440	0.1	1230	10.	36	1.1	1380	10.	1350	10.	13	0.8	1.3	2.8	10	>50		16	1000	320	800
11	1490	0.2	1200	15.	34	1.1	1260	10.	740	15.	-	-	0.8	2.8	8	30	NOT MEASURED	23	700	750	600
12	1500	0.1	1080	12.	19	.9	1350	16.	970	23.	4	0.5	0.8	2.0	9	22		-	-	21	640
13	1490	0.1	780	5.5	13	.8	1290	8.	270	1.	-	-	1.1	2.1	4	-		-	-	33	100
14	1440	0.1	960	25.	48	1.2	1200	10.	780	30.	-	-	.9	2.7	-	-		22	700	1.7	400
15	1450	0.1	1270	8.5	10	.8	1050	10.	960	7.5	-	-	-	1.9	4	14		43	900	28	600

NOTES: (a) -- I_F = 1 ampere
(b) -- i_F = 500 amperes

TABLE 5

DEVICE "B" DATA SHEET

Lot No. E-79 Date 30 April 1963

Unit Nr	$T_J = 25^oC \pm 3^o$						$T_J = 125^oC \pm 3^o$						$T_J = 25^oC \pm 3^o$				$T_J = 125^oC \pm 3^o$				
	$v_{(BR)RO}$ or v_{RO}	$i_{(BR)RO}$ or i_{RO}	$v_{(BR)FO}$ or v_{FO}	$i_{(BR)FO}$ or i_{FO}	I_{GT}	V_{GT}	$v_{(BR)RO}$ or v_{RO}	$i_{(BR)RO}$ or i_{RO}	$v_{(BR)FO}$ or v_{FO}	$i_{(BR)FO}$ or i_{FO}	I_{GT}	V_{GT}	v_F (a)	v_F (b)	$t_{G\ on}$	I_{HO}	I_{HO}	t_{off}	/ v_{app}	$\frac{d(v_{FO})}{dt}$	/ v_{app}
1	1410	0.2	1260	10.	84	1.6	1260	10	1350	10.	39	1.2	1.6	3.2	-	-	NOT MEASURED	16	1000	5000	1000
2	1500	0.2	1245	2.	46	1.2	1350	10	1290	10.	21	1.0	1.6	3.0	10.2	>50		17	1000	250	1000
3	1440	10.	1320	10.	45	1.2	1200	10	1350	10.	14	.8	1.0	2.4	17.0	>50		25	1000	625	1000
4	1500	0.2	1260	1.	78	1.6	1320	10	1320	10.	26	1.1	1.2	2.2	-	-		22	900	45	900
5	1420	0.1	1200	5.	44	1.1	1240	10	920	10.	18	0.8	1.4	2.8	12.0	>50		20	800	320	800
6	1490	0.1	330	0.2	58	1.3	1350	10	330	2.5	-	-	1.5	3.0	-	-		22	250	31	250
7	1450	10.	600	10.	68	1.4	1290	10	450	20.	25	1.0	1.8	2.2	24.0	-		-	-	12	500
8	1500	0.1	1290	25.	88	1.4	1380	10	1410	10.	33	1.0	1.0	2.6	-	-		-	-	-	-
9	1500	0.1	960	25.	52	1.2	1350	10	640	15.	-	-	1.0	2.9	-	<50		32	500	750	600
10	1420	10.	1190	25.	82	1.4	1230	10	1110	35.	20	0.8	1.0	2.7	26.0	-		30	900	41	900
11	1490	0.1	1260	20.	93	1.5	1390	10	1380	20.	-	-	-	2.2	-	-		16	1000	166	1000
12	1380	0.1	180	0.1	36	1.0	1350	10	390	10.	-	-	1.0	3.0	13.0	40		30	150	66	400
13	1500	0.1	1275	3.	24	1.1	1320	10	1260	7.	10	0.7	.9	2.2	10.8	>50		48	1000	31	1000
14	1490	0.1	960	10.	70	1.3	1360	10	810	15.	-	-	-	-	-	-		-	-	-	-
15	1500	0.1	1290	25.	-	-	1380	10	1360	25.	-	-	-	-	-	-		-	-	333	1000
16	1410	0.1	1260	10.	50	1.5	1290	10	1365	10.	22	1.0	1.3	2.3	12.0	>50		15	1000	40	1000
17	1410	0.3	1260	10.	39	1.2	1290	10	1350	9.	12	0.8	1.2	2.5	11.2	43		18	1000	333	1000
18	1500	0.1	1260	8.	52	1.2	1380	10	1120	10.	19	1.0	1.3	2.4	17.0	>50		23	1000	1667	1000
19	1120	0.1	800	5.	60	1.7	1200	10	660	50.	17	1.0	1.6	3.0	25.0	28		12	500	115	700
20	1060	10.	390	8.	34	1.2	1110	10	270	50.	-	-	1.6	3.8	-	>50		10	200	90	500
21	1090	10.	690	25.	26	1.0	1170	10	460	25.	-	-	1.1	2.9	9.0	-		13	400	50	400
22	1080	0.1	1000	12.5	26	1.1	1200	25	885	12.	7	0.6	1.2	2.2	22.0	20		-	-	140	700
23	1120	0.7	900	10.	18	0.9	1230	10	600	10.	-	-	1.0	2.6	5.6	-		22	400	50	400

NOTES: (a) — I_F = 1 ampere
(b) — i_F = 500 amperes

TABLE 6

Lot No. E-80

DEVICE B DATA SHEET

Date 30 April 1963

Unit Nr	$T_J = 25^oC \pm 3^o$						$T_J = 125^oC \pm 3^o$						$T_J = 25^oC \pm 3^o$				$T_J = 125^oC \pm 3^o$				
	$V_{(BR)RO}$ or V_{RO}	$i_{(BR)RO}$ or i_{RO}	$V_{(BR)FO}$ or V_{FO}	$i_{(BR)FO}$ or i_{FO}	I_{GT}	V_{GT}	$V_{(BR)RO}$ or V_{RO}	$i_{(BR)RC}$ or i_{RO}	$V_{(BR)FO}$ or V_{FO}	$i_{(BR)FO}$ or i_{FO}	I_{GT}	V_{GT}	V_F (a)	V_F (b)	$t_{G\ on}$	I_{HO}	I_{HO}	t_{off}	/ V_{app}	$\frac{d(V_{FO})}{dt}$	/ V_{app}
1	1500	.1	1260	10	58	1.3	1380	10	1395	8.0	20	.9	1.4	-	NOT MEASURED	80	NOT MEASURED	28	1000	3333	1000
2	1380	.1	885	10	38	1.2	1200	10	840	10.	10	.7	1.0	2.2		60		43	700	233	700
4	1440	.1	1260	10	73	1.4	1320	10	1170	10.	29	1.2	1.3	2.4		100		25	1000	333	1000
5	1500	10.	1140	10	84	1.8	450	10	510	10.	50	1.5	1.7	2.5		80		25	300	-	-
6	1140	10.	1020	10	18	.8	450	10	495	10.	8	1.0	1.5	2.8		15		18	300	50	500
12	1500	.5	1260	10	36	1.0	1185	10	1140	10.	14	.6	1.3	3.0		7		39	900	-	-
14	1110	.2	450	10	6	1.1	1200	10	330	10.	6	.7	1.2	2.6		19		22	250	192	250
16	1100	.2	660	10	20	1.0	1200	10	510	10.	7	.7	1.1	2.8		13		15	400	300	400

NOTES: (a) — I_F = 1 ampere
(b) — i_F = 500 amperes

TABLE 7

DEVICE B DATA SHEET

Lot No. B1

Date 30 April 1963

Unit No	$T_J = 25°C \pm 3°$						$T_J = 125°C \pm 3°$						$T_J = 25°C \pm 3°$				$T_J = 125°C \pm 3°$				
	$v_{(BR)RO}$ or v_{RO}	$i_{(BR)RO}$ or i_{RO}	$v_{(BR)FO}$ or v_{FO}	$i_{(BR)FO}$ or i_{FO}	I_{GT}	V_{GT}	$v_{(BR)RO}$ or v_{RO}	$i_{(BR)RO}$ or i_{RO}	$v_{(BR)FO}$ or v_{FO}	$i_{(BR)FO}$ or i_{FO}	I_{GT}	V_{GT}	v_F (a)	v_F (b)	$t_{G\ on}$	I_{HO}	I_{HO}	t_{off}	$/ v_{app}$	$\frac{d(v_{FO})}{dt}$	$/ v_{app}$
1	1395	10	1170	10	10	.8	1080	15	990	20	4	.5	1.1	2.4	NOT MEASURED	17	NOT MEASURED	22	800	129	800
6	1290	10	720	24	14	.9	990	25	410	14	3	.6	1.0	2.8		25		25	300	58	300
7	1260	10	1170	10	55	1.2	1110	15	1110	15	26	1.0	2.5	-		80		12	900	180	900
9 (c)	1140	10	1020	8	17	10	840	25	720	22	6	.6	2.0	-		12		10	600	150	600
10 (c)	870	25	1110	7	10	.8	840	25	750	25	6	.6	1.2	3.4		7		19	600	10	600
11 (c)	1260	10	1110	4	8	.7	1170	15	600	8	2	.5	1.2	3.0		7.5		13	500	9	500
12	1080	10	960	6	46	1.3	1170	10	1050	7	20	.8	1.1	2.6		35		15	800	138	800
13	1065	.1	1050	16	42	1.2	1170	10	1110	10	20	1.0	1.2	2.8		60		16	900	161	900
14	1120	10	1020	12	51	1.2	1215	10	840	8	21	.8	1.1	2.7		80		15	700	121	700
15	1500	7.0	1320	7	38	1.1	1110	10	1140	10	14	.7	1.1	2.4		100		35	900	180	900
16	1455	.1	1260	10	67	1.4	1080	10	1140	10	26	.9	1.2	2.8		60		28	900	1800	900
17	1410	.1	1230	10	76	1.6	1365	10	1350	10	37	1.2	2.0	-		140		15	1000	2500	1000
18	1470	.4	1275	3	14	.8	1335	10	1170	8	7	.5	.8	1.7		17		-	400	17	400
19	1440	.2	780	9	6	.7	1350	10	510	9	2	.4	.8	1.8		7		-	-	-	-
20	1320	10	1200	10	21	.9	1245	10	1020	8	9	.6	1.0	2.0		21		-	800	107	800
21	1470	.3	1140	10	10	.7	1260	10	780	9	3	.8	.8	1.9		4		-	-	4	600

NOTES: (a) — I_F = 1 ampere
(b) — i_F = 500 amperes
(c)-- Gold Diffused

TABLE 8

DEVICE B DATA SHEET

Lot No. B2

Date 30 April 1963

Unit Nr	$T_J = 25^oC \pm 3^o$						$T_J = 125^oC \pm 3^o$						$T_J = 25^oC \pm 3^o$				$T_J = 125^oC \pm 3^o$				
	$v_{(BR)RO}$ or v_{RO}	$i_{(BR)RO}$ or i_{RO}	$v_{(BR)FO}$ or v_{FO}	$i_{(BR)FO}$ or i_{FO}	I_{GT}	V_{GT}	$v_{(BR)RO}$ or v_{RO}	$i_{(BR)RC}$ or i_{RO}	$v_{(BR)FO}$ or v_{FO}	$i_{(BR)FO}$ or i_{FO}	I_{GT}	V_{GT}	V_F (a)	V_F (b)	t_G on	I_{HO}	I_{HO}	t_{off}	/ v_{app}	$\frac{d(v_{FO})}{dt}$	/ v_{app}
1	1380	.07	1280	10.0	12	.8	1260	10	860	5.0	4	.5	.9	1.9	4.5	12	NOT MEASURED	NOT MEASURED	NOT MEASURED	23	700
2	1420	.02	1180	3.0	25	1.2	1540	10	740	1.8	25	1.2	.9	1.8	5.5	10				15	600
3	1320	.2	1280	.5	29	1.1	1320	10	1340	10.0	14	1.0	1.5	2.3	5.0	80				312	1000
4	1300	.03	1260	7.0	26	1.1	1400	10	1200	10.0	10	7.5	1.2	2.5	5.5	17				500	1000
5	1400	.05	1120	10.0	6	.7	1400	10	760	6.0	3	.5	.9	2.0	4.5	6				40	600
6	1340	.05	800	10.0	21	1.3	1420	10	640	10.0	10	1.0	2.1	2.4	5.0	30				83	500
7	1280	3.0	1100	5.0	14	.9	1280	10	620	4.0	6	.6	.95	2.3	4.5	15				10	500
8	1240	.2	1060	9.0	9	.8	1320	10	640	4.0	4	.5	.94	2.5	4.0	7				16	500
9	1320	.1	1160	.5	17	.95	1360	10	1100	6.0	7	.6	1.4	3.4	5.5	11				75	900
10	1200	.2	1040	10.0	18	1.1	1260	10	840	8.0	6	.7	1.6	3.6	6.0	20				87	700

NOTES: (a) — I_F = 1 ampere
(b) — i_F = 500 amperes

TABLE 9

DEVICE "B" DATA SHEET

Lot No. C

Date 30 April 1963

Unit Nr	$T_J = 25^oC \pm 3^o$						$T_J = 125^oC \pm 3^o$						$T_J = 25^oC \pm 3^o$				$T_J = 125^oC \pm 3^o$				
	$v_{(BR)RO}$ or v_{RO}	$i_{(BR)RO}$ or i_{RO}	$v_{(BR)FO}$ or v_{FO}	$i_{(BR)FO}$ or i_{FO}	I_{GT}	V_{GT}	$v_{(BR)RO}$ or v_{RO}	$i_{(BR)RO}$ or i_{RO}	$v_{(BR)FO}$ or v_{FO}	$i_{(BR)FO}$ or i_{FO}	I_{GT}	V_{GT}	V_F (a)	V_F (b)	$t_{G\ on}$	I_{HO}	I_{HO}	t_{off}	/ v_{app}	$\frac{d(v_{FO})}{dt}$	/ v_{app}
C4	1100	0.1	900	10	24	.9	1200	10	780	10	-	-	1.2	2.9	5.5	13	24	19	700	116	700
C6	1280	0.08	1000	10	14	.8	1360	10	740	6	-	-	.77	1.6	4.3	4	6	-	-	23	300
C9	1120	0.8	800	10	38	1.1	1200	10	680	10	-	-	1.2	2.7	7.	11	20	15	700	116	700

NOTES: (a) — I_F = 1 ampere
(b) — i_F = 500 amperes

TABLE 10

DEVICE B DATA SHEET

Lot No. P1-P2-P3-P4-P5 | Date 30 April 1963

Lot No.	Unit Nr	$T_J = 25°C \pm 3°$						$T_J = 125°C \pm 3°$						$T_J = 25°C \pm 3°$				$T_J = 125°C \pm 3°$				
		$v_{(BR)RO}$ or v_{RO}	$i_{(BR)RO}$ or i_{RO}	$v_{(BR)FO}$ or v_{FO}	$i_{(BR)FO}$ or i_{FO}	I_{GT}	v_{GT}	$v_{(BR)RO}$ or v_{RO}	$i_{(BR)RC}$ or i_{RO}	$v_{(BR)FO}$ or v_{FO}	$i_{(BR)FO}$ or i_{FO}	I_{GT}	v_{GT}	v_F (a)	v_F (b)	$t_{G\ on}$	I_{HO}	I_{HO}	t_{off}	/ v_{app}	$\frac{d(v_{FO})}{dt}$	/ v_{app}
P1	2	520	.2	120	.6	19	1.1	600	10	80	3.0	-	-	.96	2.0	5.8	5	8	-	-	-	-
	3	1500	.1	1340	1.0	10	.75	1300	10	880	3.0	-	-	.82	1.8	4.	2	4	>100	-	14	700
	8	1480	4.0	1300	.1	23	1.1	1200	10	1160	6.0	-	-	.95	2.0	4.5	4	11	26	800	43	950
P2	1	1420	.04	1200	.02	13	.8	1540	10	220	.5	-	-	.70	1.6	4.8	-	-	-	-	-	-
	4	1520	.05	1300	3.0	14	.7	1480	10	780	1.5	-	-	.72	1.5	4.	2	3	-	-	2.5	200
	8	1320	.05	1200	3.0	9	.7	1460	10	380	1.4	-	-	.73	1.9	4.	2	3	-	-	-	-
P3	2	1240	.03	1140	.1	5	.65	1360	10	320	.7	-	-	.83	2.4	4.	2	2	-	-	-	-
	3	1280	.03	1160	.5	5	.7	1380	10	720	1.3	-	-	.85	2.5	4.	2	3	-	-	7.5	600
	11	1240	.4	1160	3.0	-	-	1400	10	1040	4.0	-	-	-	-	4.8	3	7	-	-	16	900
	12	1280	.3	1140	1.3	60	1.5	1360	10	800	3.0	-	-	.93	2.4	8.	2	6	35	600	4	600
P4	1	1100	.9	120	1.3	48	1.1	840	10	60	2.0	-	-	2.0	4.2	7.5	18	35	-	-	-	-
	3	1000	.06	1000	.1	34	1.1	840	10	860	10.0	-	-	1.0	2.4	4.8	9	21	-	-	116	700
	4	1140	.7	1060	3.0	53	1.2	960	10	920	10.0	-	-	1.5	3.8	6.2	12	24	5	900	900	900
	5	1240	1.0	720	5.0	38	1.0	640	10	460	10.0	-	-	2.2	5.8	7.0	5	12	7	400	500	400
	6(c)	1280	.6	1160	2.0	44	1.1	620	10	660	10.0	-	-	2.3	5.0	8.5	7	13	20	400	500	400
	7(c)	1280	1.0	1140	1.0	31	1.0	560	10	640	10.0	-	-	1.9	4.2	7.	6	17	11	400	333	400
P5	2	1340	.4	1260	.3	6	.7	940	10	160	2.0	-	-	.85	2.0	4.8	3	3	-	-	-	-
	3	1280	.2	1160	1.0	21	1.0	1080	10	800	10.0	-	-	1.1	2.8	6.	3	12	25	400	22	400
	4	1160	.5	1000	7.0	8	.7	860	10	460	5.0	-	-	.85	2.0	3.8	2	4	-	-	-	-

NOTES: (a) — I_F = 1 ampere
(b) — i_F = 500 amperes
(c)-- Gold Diffused

TABLE 11

DEVICE: SCR DATA SHEET

Unit No. P6

Date 30 April 1963

Unit No.	$T_J = 25°C \pm 5°$ $V_{(BR)RO}$ or V_{RO}	$I_{(BR)RO}$ or I_{RO}	$V_{(BR)FO}$ or V_{FO}	$I_{(BR)FO}$ or I_{FO}	I_{GT}	V_{GT}	$T_J = 125°C \pm 5°$ $V_{(BR)RO}$ or V_{RO}	$I_{(BR)RO}$ or I_{RO}	$V_{(BR)FO}$ or V_{FO}	$I_{(BR)FO}$ or I_{FO}	I_{GT}	V_{GT}	$T_J = 25°C \pm 5°$ V_F (a)	V_F (b)	t_D on	I_{HO}	$T_J = 125°C \pm 5°$ I_{HO}	t_{off} /	V_{app}	$\frac{d(V_{FO})}{dt}$ /	V_{app}
1	1320	0.2	1160	0.2	35	1.2	1320	10.0	1240	10.0	-	-	1.7	4.6	-	-	-	-	-	-	-
2	1300	0.07	1160	2.0	25	1.1	1300	10.0	1120	10.0	-	-	1.5	3.7	7.0	7	17	13	900	1800	900
3	400	0.3	1120	0.4	91	2.4	320	2.0	1220	9.0	-	-	1.2	3.2	10.0	-	-	-	-	40	100
4	1300	0.05	1200	0.7	50	1.5	1380	10.0	1200	8.0	-	-	1.2	3.5	6.5	3	11	18	1000	240	950
5	220	0.02	1160	2.0	29	1.3	360	5.0	660	4.0	-	-	1.2	3.7	6.5	4	10	18	600	1000	600
6	1420	0.05	180	5.0	35	1.2	1360	10.0	120	5.0	-	-	1.1	2.9	7.0	11	28	-	-	43	100
7	1360	0.1	1080	0.04	35	1.4	1320	10.0	840	4.0	-	-	1.1	3.6	6.0	3	8	-	-	20	400
8	1320	0.13	80	0.6	16	0.9	1240	10.0	80	5.0	-	-	1.2	3.8	5.8	-	-	-	-	-	-
9	1420	0.03	1240	0.03	35	1.2	1480	10.0	1380	6.0	-	-	1.1	3.0	6.0	6	9	24	1000	430	950
10	1300	0.06	860	3.0	58	2.6	1360	10.0	820	6.0	-	-	1.4	5.4	-	-	-	-	-	-	-
11	1400	0.3	1180	10.0	76	2.6	1320	10.0	960	10.0	-	-	1.3	4.0	8.0	6	10	17	800	340	800
12	1380	0.04	760	0.4	13	0.9	1500	10.0	740	2.5	-	-	.95	2.6	5.0	2	7	-	-	26	600
13	1400	0.05	560	0.1	11	0.85	1400	10.0	540	1.8	-	-	1.0	3.7	5.0	5	7	27	400	180	400
14	1300	0.2	860	1.0	54	2.0	1260	10.0	720	9.0	-	-	1.4	5.6	-	-	-	-	-	-	-

NOTES: (a) — I_F = 1 ampere
(b) — I_F = 500 amperes

TABLE 12

Lot No. P7

DEVICE "B" DATA SHEET

Date 30 April 1963

Unit Nr	$T_J = 25^oC \pm 3^o$						$T_J = 125^oC \pm 3^o$						$T_J = 25^oC \pm 3^o$				$T_J = 125^oC \pm 3^o$				
	$v_{(BR)RO}$ or v_{RO}	$i_{(BR)RO}$ or i_{RO}	$v_{(BR)FO}$ or v_{FO}	$i_{(BR)FO}$ or i_{FO}	I_{GT}	V_{GT}	$v_{(BR)RO}$ or v_{RO}	$i_{(BR)RC}$ or i_{RO}	$v_{(BR)FO}$ or v_{FO}	$i_{(BR)FO}$ or i_{FO}	I_{GT}	V_{GT}	v_F (a)	v_F (b)	$t_{G\ on}$	I_{HO}	I_{HO}	t_{off}	/ v_{app}	$\frac{d(v_{FO})}{dt}$	/ v_{app}
1	1380	0.5	100	0.3	12	0.8	1400	10	40	0.7	-	-	0.8	2.0	4.0	2	6	-	-	-	-
2	1280	0.01	1140	0.01	12	0.75	1360	10	1040	4.0	-	-	0.80	2.0	4.2	2	5	<28	-	25	300
3	1360	0.05	1200	0.8	11	0.8	1440	10	1040	5.0	-	-	0.8	1.9	4.5	2	4	55	500	22	500
4	1160	0.02	1100	0.6	26	0.9	1280	10	1000	4.0	-	-	1.0	2.6	5.0	3	9	23	800	40	800
5	1360	0.03	1200	0.08	27	1.0	1420	10	1300	7.0	-	-	1.0	2.3	5.5	6	14	18	900	220	900
6	1440	0.05	1200	0.03	24	1.0	1440	10	1320	8.0	-	-	1.0	2.5	4.5	6	11	18	1000	118	950
7	1400	0.04	1200	0.6	30	1.1	1400	10	1280	9.0	-	-	0.90	2.5	6.0	5	11	16	1000	126	950

NOTES: (a) — $I_F = 1$ ampere
(b) — $i_F = 500$ amperes

TABLE 13

DEVICE B DATA SHEET

Lot No. P8 — Date 30 April 1963

Unit Nr	$T_J = 25^oC \pm 3^o$						$T_J = 125^oC \pm 3^o$						$T_J = 25^oC \pm 3^o$				$T_J = 125^oC \pm 3^o$				
	$v_{(BR)RO}$ or v_{RO}	$i_{(BR)RO}$ or i_{RO}	$v_{(BR)FO}$ or v_{FO}	$i_{(BR)FO}$ or i_{FO}	I_{GT}	V_{GT}	$v_{(BR)RO}$ or v_{RO}	$i_{(BR)RO}$ or i_{RO}	$v_{(BR)FO}$ or v_{FO}	$i_{(BR)FO}$ or i_{FO}	I_{GT}	V_{GT}	v_F (a)	v_F (b)	$t_{G\ on}$	I_{HO}	I_{HO}	t_{off}	/ v_{app}	$\frac{d(v_{FO})}{dt}$	/ v_{app}
1	1200	.3	600	10	61	1.9	1280	10	500	10	-	-	2.0	6.4	12	22	-	12	900	180	900
2	1240	.08	60	2.0	14	.9	1300	10	40	1.3	-	-	1.1	3.2	4.5	6	15	-	-	-	-
3	500	6.0	10	-	6	.6	320	5.0	-	-	-	-	.92	2.5	4.2	-	-	-	-	-	-
4	1220	.05	1040	4.0	5	.6	1320	10.0	720	3.0	-	-	.87	2.4	3.5	2	4	-	-	-	-

NOTES: (a) — I_F = 1 ampere
(b) — i_F = 500 amperes

TABLE 14

DEVICE B DATA SHEET

Lot No. P10

Date 30 April 1963

Unit Nr	T_J = 25°C ± 3°						T_J = 125°C ± 3°						T_J = 25°C ± 3°				T_J = 125°C ± 3°			
	$v_{(BR)RO}$ or v_{RO}	$i_{(BR)RO}$ or i_{RO}	$v_{(BR)FO}$ or v_{FO}	$i_{(BR)FO}$ or i_{FO}	I_{GT}	V_{GT}	$v_{(BR)RO}$ or v_{RO}	$i_{(BR)RO}$ or i_{RO}	$v_{(BR)FO}$ or v_{FO}	$i_{(BR)FO}$ or i_{FO}	I_{GT}	V_{GT}	V_F (a)	v_F (b)	$t_{G\ on}$	I_{HO}	I_{HO}	t_{off} / v_{app}		$\frac{d(v_{FO})}{dt}$ / v_{app}	
1	1360	.07	1060	10	250	3.2	1380	10	880	10	47	1.8	-	2.2	20	25	NOT MEASURED	NOT MEASURED	NOT MEASURED	700	700
2	1240	.03	1060	.03	96	3.0	1320	10	1180	2.5	42	1.8	3+	5.8	15	44				900	900
3	1280	.05	1140	.02	93	2.8	1340	10	1260	6.0	30	1.5	1.3	4.2	10	18				750	900
4	1240	.5	1120	.2	46	1.1	1020	10	840	10	14	.7	1.8	4.4	9	14				250	700
5	1220	.3	1120	.08	250	3.0	1050	10	1100	10	33	1.5	2.2	4.7	14	28				800	800
6	1300	.3	1180	.1	150	3.7	1080	10	980	8.0	20	1.5	1.5	4.0	12	14				40	800
7	1280	.3	1160	.1	22	1.0	1060	10	1100	10	-	-	1.8	4.2	6	17				133	800
8	1240	2.0	1120	2.0	27	.9	1200	10	920	5.0	10	.6	1.2	2.4	6	15				133	800
10	1200	.2	1120	.08	58	2.1	1240	10	1220	10	26	1.4	1.9	4.2	8.5	35				450	900
12	1260	.05	1200	.05	23	1.1	1300	10	1120	5.0	10	.7	1.1	2.3	6	11				90	900
14	1240	.08	1100	.3	22	.9	1280	10	1020	4.0	7	.5	.97	2.2	5.5	8				-	-
15	1260	.06	1160	.04	23	.85	1320	10	1020	4.0	8	.5	.97	2.5	5	6				22	800

NOTES: (a) — I_F = 1 ampere
(b) — i_F = 500 amperes

TABLE 15

Lot No. BT-30 CONTROL

DEVICE B DATA SHEET

Date 30 April 1963

Unit Nr	$T_J = 25^oC \pm 3^o$						$T_J = 125^oC \pm 3^o$						$T_J = 25^oC \pm 3^o$				$T_J = 125^oC \pm 3^o$				
	$v_{(BR)RO}$ or v_{RO}	$i_{(BR)RO}$ or i_{RO}	$v_{(BR)FO}$ or v_{FO}	$i_{(BR)FO}$ or i_{FO}	I_{GT}	V_{GT}	$v_{(BR)RO}$ or v_{RO}	$i_{(BR)RO}$ or i_{RO}	$v_{(BR)FO}$ or v_{FO}	$i_{(BR)FO}$ or i_{FO}	I_{GT}	V_{GT}	V_F (a)	v_F (b)	$t_{G\,on}$	I_{HO}	I_{HO}	t_{off}	/ v_{app}	$\frac{d(v_{FO})}{dt}$	/ v_{app}
1	1180	10	1180	10	10	.8	1120	20	1020	20	-	-	.75	1.9	-	-	-	>100	1000	-	-
2	1600	.1	1360	.1	-	-	1600	10	1400	15	-	-	.75	2.0	-	-	-	>100	1000	-	-

NOTES: (a) — I_F = 1 ampere
(b) — i_F = 500 amperes

TABLE 16

Lot No. BT-30 AuDiffused

DEVICE "B" DATA SHEET

Date 30 April 1963

Unit Nr	$T_J = 25^oC \pm 3^o$						$T_J = 125^oC \pm 3^o$						$T_J = 25^oC \pm 3^o$				$T_J = 125^oC \pm 3^o$				
	$v_{(BR)RO}$ or v_{RO}	$i_{(BR)RO}$ or i_{RO}	$v_{(BR)FO}$ or v_{FO}	$i_{(BR)FO}$ or i_{FO}	I_{GT}	V_{GT}	$v_{(BR)RO}$ or v_{RO}	$i_{(BR)RC}$ or i_{RO}	$v_{(BR)FO}$ or v_{FO}	$i_{(BR)FO}$ or i_{FO}	I_{GT}	V_{GT}	V_F (a)	V_F (b)	$t_{G\ on}$	I_{HD}	I_{HD}	t_{off}	/ v_{app}	$\frac{d(v_{FO})}{dt}$	/ v_{app}
1	120	10	1500	10	20	1.1	360	20	1280	12	-	-	1.2	3.2	-	-		47	1000	-	-
2	1400	10	1390	10	20	1.0	1260	20	1280	20	-	-	1.45	3.3	-	-		29	1000	-	-
4	240	10	1340	10	20	1.0	360	20	1200	20	-	-	1.32	3.4	-	-		29	1000	--	-
5	1200	10	1260	4	30	1.1	1100	20	1280	20	-	-	1.41	3.5	-	-		30	1000	-	-
6	1400	10	1400	10	45	1.4	1350	20	1350	20	-	-	1.45	3.4	-	-		31	1000	-	-
7	1520	10	1500	10	40	1.5	1320	20	1360	20	-	-	1.3	2.9	-	-		26	1000	-	-
8	1420	10	1420	10	40	1.2	1400	20	1400	20	-	-	1.55	2.9	-	-		25	1000	-	-
9	1240	10	1260	10	30	1.4	1240	20	1240	20	-	-	1.35	3.1	3.5	15		29	1000	-	-
12	1320	10	1320	10	91	2.0	1140	25	1100	20	40	1.3	1.2	2.75	8.	30		25	900	2500	1000
13	1200	10	1200	10	-	-	1080	25	1040	25	-	-	1.12	2.4	-	-		-	-	2250	900
14	1160	10	1220	10	36	1.2	1040	25	1040	25	16	0.8	1.25	2.7	5.5	32	NOT MEASURED	32	900	2250	900
15	1260	10	1300	10	40	1.0	1120	25	1120	25	19	0.7	1.15	2.7	5.	34		35	900	2500	1000
17	130	10	900	10	-	-	260	25	360	20	-	-	-	-	-	-		-	-	330	300
18	1240	10	1260	10	-	-	1120	25	1080	25	-	-	1.09	2.45	-	-		-	-	2500	1000
19	1120	10	1000	5	30	1.1	1180	25	720	10	14	0.7	1.25	2.5	5.5	31		25	600	1500	600

NOTES: (a) — I_F = 1 ampere
(b) — i_F = 500 amperes

TABLE 17

DEVICE "B" DATA SHEET

Lot No. BT-43 Control

Date 30 April 1963

Unit Nr	$T_J = 25^\circ C \pm 3^\circ$						$T_J = 125^\circ C \pm 3^\circ$						$T_J = 25^\circ C \pm 3^\circ$				$T_J = 125^\circ C \pm 3^\circ$				
	$v_{(BR)RO}$ or v_{RO}	$i_{(BR)RO}$ or i_{RO}	$v_{(BR)FO}$ or v_{FO}	$i_{(BR)FO}$ or i_{FO}	I_{GT}	V_{GT}	$v_{(BR)RO}$ or v_{RO}	$i_{(BR)RO}$ or i_{RO}	$v_{(BR)FO}$ or v_{FO}	$i_{(BR)FO}$ or i_{FO}	I_{GT}	V_{GT}	v_F (a)	v_F (b)	$t_{G\ on}$	I_{HO}	I_{HO}	t_{off} /	v_{app}	$\frac{d(v_{FO})}{dt}$ /	v_{app}
1	1200	0.5	1260	0.4	30	1.0	1200	15	1200	10	12	0.7	.85	1.9	5	52	-	>100	1000	-	-
2	1080	10	1000	10	82	1.6	1040	25	1000	25	45	1.1	.96	2.2	12	110	-	>100	900	-	-
3	420	10	420	10	51	1.0	420	25	420	25	27	0.8	.86	2.5	7	108	-	>100	300	-	-
4	840	10	860	10	62	1.1	820	25	840	25	25	0.8	.85	1.9	7	110	-	>100	700	-	-

NOTES: (a) — I_F = 1 ampere
(b) — i_F = 500 amperes

TABLE 18

Lot No. BT-43 Au Diffused

DEVICE "B" DATA SHEET

Date 30 April 1963

Unit Nr	$T_J = 25^oC \pm 3^o$						$T_J = 125^oC \pm 3^o$						$T_J = 25^oC \pm 3^o$				$T_J = 125^oC \pm 3^o$				
	$v_{(BR)RO}$ or v_{RO}	$i_{(BR)RO}$ or i_{RO}	$v_{(BR)FO}$ or v_{FO}	$i_{(BR)FO}$ or i_{FO}	I_{GT}	V_{GT}	$v_{(BR)RO}$ or v_{RO}	$i_{(BR)RO}$ or i_{RO}	$v_{(BR)FO}$ or v_{FO}	$i_{(BR)FO}$ or i_{FO}	I_{GT}	V_{GT}	v_F (a)	v_F (b)	$t_{G\ on}$	I_{HO}	I_{HO}	t_{off}	$/ v_{app}$	$\frac{d(v_{FO})}{dt}$	$/ v_{app}$
2	1000	10	1000	10	69	1.4	880	25	920	25	30	1.0	1.73	2.8	-	200	-	17	800	-	-
3	1080	10	1100	10	39	0.9	940	25	980	25	28	0.8	1.46	3.2	5	200	-	23	800	-	-
4	600	10	620	10	42	1.1	580	25	600	25	19	0.8	1.5	2.2	6	160	-	-	-	-	-

NOTES: (a) — I_F = 1 ampere
(b) — i_F = 500 amperes

TABLE 19

DEVICE "B" DATA SHEET

Lot No. BT-44 Control

Date 30 April 1963

Unit Nr	$T_J = 25^\circ C \pm 3^\circ$						$T_J = 125^\circ C \pm 3^\circ$						$T_J = 25^\circ C \pm 3^\circ$				$T_J = 125^\circ C \pm 3^\circ$				
	$V_{(BR)RO}$ or V_{RO}	$i_{(BR)RO}$ or i_{RO}	$V_{(BR)FO}$ or V_{FO}	$i_{(BR)FO}$ or i_{FO}	I_{GT}	V_{GT}	$V_{(BR)RO}$ or V_{RO}	$i_{(BR)RO}$ or i_{RO}	$V_{(BR)FO}$ or V_{FO}	$i_{(BR)FO}$ or i_{FO}	I_{GT}	V_{GT}	V_F (a)	V_F (b)	$t_{G\ on}$	I_{HO}	I_{HO}	t_{off} /	v_{app}	$\frac{d(v_{FO})}{dt}$	/ v_{app}
1	1440	0.01	1400	0.01	-	-	1200	12	1220	10	-	-	-	-	-	-	-	-	-	5000	1000
2	1440	0.01	240	9.	16	0.8	1200	10	280	25	8	0.6	0.78	1.75	5	40	-	>100	1000	-	-
3	760	10	1420	0.01	17	0.8	1180	25	1200	10	7	0.7	0.76	1.7	4	70	-	>100	1000	5000	1000
4	1400	10	1360	0.03	17	0.8	1200	15	1200	22	8	0.6	0.78	1.9	5	80	-	>100	1000	3300	1000
5	1400	10	1360	0.04	18	0.8	1200	11	1200	25	8	0.5	0.78	1.9	5	80	-	>100	1000	-	-

NOTES: (a) — I_F = 1 ampere
(b) — I_F = 500 amperes

TABLE 20

Lot No. BT-44 AU DIFFUSED

DEVICE B DATA SHEET

Date 30 April 1963

Unit Nr	$T_J = 25^oC \pm 3^o$						$T_J = 125^oC \pm 3^o$						$T_J = 25^oC \pm 3^o$				$T_J = 125^oC \pm 3^o$				
	$v_{(BR)RO}$ or v_{RO}	$i_{(BR)RO}$ or i_{RO}	$v_{(BR)FO}$ or v_{FO}	$i_{(BR)FO}$ or i_{FO}	I_{GT}	V_{GT}	$v_{(BR)RO}$ or v_{RO}	$i_{(BR)RO}$ or i_{RO}	$v_{(BR)FO}$ or v_{FO}	$i_{(BR)FO}$ or i_{FO}	I_{GT}	V_{GT}	V_F (a)	v_F (b)	$t_{G\ on}$	I_{HO}	I_{HO}	t_{off} /	v_{app}	$\frac{d(v_{FO})}{dt}$	/ v_{app}
2	1010	10	1440	10	92	1.5	560	10	1290	20	43	1.2	1.3	2.4	8	80	NOT MEASURED	28	1000	> 20	1000
4	1580	10	1400	.05	60	1.2	1200	16	1200	10	28	.9	1.4	2.7	7	160		20	1000	2500	1000
5	840	10	1260	.06	24	1.0	640	20	1200	25	12	.7	1.3	2.8	6	100		24	1000	> 20	1000
11	1440	10	1420	10	30	1.1	1160	25	1200	21	-	-	-	-	-	-		27	1000	-	-
12	1440	10	1440	10	31	1	1200	20	1200	12	-	-	-	-	-	-		27	1000	-	-
13	1480	1	1360	10	25	1.3	1200	20	1200	14	-	-	-	-	-	-		28	1000	-	-
14	1480	3	1360	.1	34	1.7	1200	21	1200	14	-	-	-	-	-	-		28	1000	-	-
15	1480	1.5	1440	10	21	1.1	1200	16	1200	9	-	-	-	-	-	-		35	1000	-	-
16	1480	.5	1380	10	22	1.1	1200	18	1200	13	-	-	-	-	-	-		33	1000	-	-
17	1280	10	1300	10	22	1.0	1080	25	1140	20	-	-	-	-	-	-		32	1000	-	-
18	1480	.5	1400	10	17	.9	1200	17	1200	9	-	-	-	-	-	-		32	1000	-	-
19	120	10	1260	10	27	.9	980	25	1160	25	-	-	-	-	-	-		28	1000	-	-
20	1480	1	1420	10	25	.9	1200	20	1200	11	-	-	-	-	-	-		32	1000	-	-
21	1480	.5	1400	10	32	1.0	1200	21	1200	10	-	-	-	-	-	-		28	1000	-	-
22	1320	10	1360	10	35	1.1	1120	25	1200	22	-	-	-	-	-	-		30	1000	-	-

NOTES: (a) — I_F = 1 ampere
(b) — i_F = 500 amperes

TABLE 21

DEVICE "B" DATA SHEET

Lot No. BT-45 AuDiffused

Date 30 April 1963

Unit Nr	T_J = 25°C ± 3°						T_J = 125°C ± 3°						T_J = 25°C ± 3°				T_J = 125°C ± 3°				
	$v_{(BR)RO}$ or v_{RO}	$i_{(BR)RO}$ or i_{RO}	$v_{(BR)FO}$ or v_{FO}	$i_{(BR)FO}$ or i_{FO}	I_{GT}	V_{GT}	$v_{(BR)RO}$ or v_{RO}	$i_{(BR)RO}$ or i_{RO}	$v_{(BR)FO}$ or v_{FO}	$i_{(BR)FO}$ or i_{FO}	I_{GT}	V_{GT}	V_F (a)	v_F (b)	$t_{G\ on}$	I_{HO}	I_{HO}	t_{off}	/ v_{app}	$\frac{d(v_{FO})}{dt}$	/ v_{app}
1	1280	0.1	1280	0.06	15	1.9	1200	16	1200	15	6	1.0	1.35	2.2	6.5	30	NOT MEASURED	>60	1000	2500	1000
2	1420	0.05	1400	0.9	7	0.8	1200	10	1200	7	3	0.5	1.1	2.8	4.5	15		25	1000	2500	1000
3	1400	0.05	1420	5.0	22	1.0	1200	15	1200	16	10	0.6	1.3	3.0	5.5	35		21	1000	3333	1000
4	1380	3.0	1160	5.0	28	1.7	1200	13	920	7.5	12	1.1	1.16	3.0	6.5	25		45	1000	2500	1000
5	1400	0.6	1340	4.0	14	1.1	1200	16	1180	11	7	0.7	1.27	2.7	5.0	23		50	1000	3333	1000
6	1420	0.05	1400	5.0	59	3.7	1240	10	1200	9	23	2.4	1.17	3.0	8.5	19		27	1000	2500	1000
11	1360	0.04	1300	0.07	21	1.1	1200	17	1200	17	9	0.75	1.28	3.0	4.0						
12	1460	0.05	1320	0.5	72	4.2	1200	10	1020	10	31	2.9	1.13	2.8	10.0						
13	800	0.01	1000	0.01	23	1.3	1020	17	1080	25	9	0.85	1.15	2.5	4.5						
14	1380	0.05	1340	0.03	16	0.95	1200	14	1200	17	7	0.65	1.25	3.3	4.0						
15	1420	0.05	1220	0.02	12	1.0	1280	10	300	3.0	5	0.65	1.2	3.7	5.0						
16	1400	0.04	1340	1.0	12	0.95	1200	13	1200	10.0	5	0.60	1.2	2.6	4.5						
20	1400	0.01	1380	0.5	27	1.6	1200	11	1200	10.0	11	1.0	1.3	2.8	7.0						
22	1460	4.0	1440	6.0	31	1.1	1200	14	1200	10.0	14	0.75	1.2	2.5	5.0	-NOT	-	MEASURED		----------	
23	1260	0.07	1360	0.4	19	0.9	1200	22	1200	21	8	0.6	1.1	2.3	5.0						
24	1400	0.04	1360	0.06	20	1.1	1200	14	1200	12	10	0.8	1.1	2.5	6.0						
25	1400	0.03	1380	0.04	16	1.1	1200	10	1240	10	7	0.75	1.2	2.3	5.0						
28	1360	0.02	1400	0.3	15	0.9	1200	17	1200	15	6	0.6	1.1	2.8	5.0						
31	1400	0.03	1360	0.05	13	0.85	1200	13	1220	10	5	0.55	1.0	2.6	5.5						
32	1360	0.03	1360	2.0	19	1.0	1200	20	1200	20	8	0.65	1.2	2.8	4.5						
33	180	5.0	1440	0.3	30	1.5	200	10	1200	14	12	0.95	1.2	3.2	5.5						

NOTES: (a) — I_F = 1 ampere
(b) — i_F = 500 amperes

TABLE 22

DEVICE "B" DATA SHEET

Lot No. BT-45 Au Diffused

Date 30 April 1963

Unit Nr	$T_J = 25^oC \pm 3^o$						$T_J = 125^oC \pm 3^o$						$T_J = 25^oC \pm 3^o$				$T_J = 125^oC \pm 3^o$		
	$v_{(BR)RO}$ or v_{RO}	$i_{(BR)RO}$ or i_{RO}	$v_{(BR)FO}$ or v_{FO}	$i_{(BR)FO}$ or i_{FO}	I_{GT}	V_{GT}	$v_{(BR)RO}$ or v_{RO}	$i_{(BR)RO}$ or i_{RO}	$v_{(BR)FO}$ or v_{FO}	$i_{(BR)FO}$ or i_{FO}	I_{GT}	V_{GT}	v_F (a)	v_F (b)	$t_{G\ on}$	I_{HO}	I_{HO}	t_{off}/v_{app}	$\frac{d(v_{FO})}{dt}$ / v_{app}
36	1400	1.4	940	0.01	10	1.0	1260	10	960	3.0	4	0.7	1.1	2.6	5.0				
37	1220	0.07	1320	10.0	24	1.1	1180	25	1120	25.0	10	0.8	1.3	2.8	6.0				
40	1140	0.02	1160	1.0	40	2.0	1100	25	1100	25.0	16	1.2	1.5	3.0	7.0				
41	1180	0.1	1200	0.02	15	1.0	1125	25	1140	25.0	6	0.65	1.2	2.7	5.0				
43	1540	0.1	1360	0.07	50	0.9	1400	10	1220	3.0	25	0.6	1.1	2.6	6.0				
44	1320	0.03	1360	0.05	17	0.95	1200	15	1200	14.0	7	0.6	1.1	2.8	5.0				
46	1360	0.04	1360	1.2	19	1.1	1200	15	1200	15.0	8	0.75	1.3	3.0	5.5				
47	1340	0.05	1100	10.0	19	1.0	1200	15	840	9.0	8	0.7	1.2	2.7	5.2				
48	920	10.0	1320	0.1	22	1.0	1160	25	1200	14.0	9	0.7	1.3	3.0	5.5				
49	1320	0.05	1360	0.4	10	1.0	1200	23	1140	14.0	4	0.65	1.2	2.2	4.8	NOT MEASURED			
50	1080	0.03	1100	0.03	22	1.1	1080	25	1080	25.0	9	0.7	1.0	2.5	5.0				
51	1240	0.02	1360	0.05	16	0.95	1200	15	1200	12.0	7	0.65	1.0	2.6	5.5				
52	1420	0.05	1360	0.05	20	0.85	1200	11	1240	10.0	8	0.6	0.95	2.4	5.8				
53	1400	0.05	1340	0.13	16	0.9	1200	14	1240	9.0	7	0.6	0.97	2.3	5.0				
54	1480	0.05	1400	0.08	12	0.8	1200	7	1220	6.0	5	0.55	1.2	2.6	5.8				
55	1320	0.04	1340	0.07	11	0.85	1200	10	1260	10.0	4	0.6	1.1	2.8	5.0				

NOTES: (a) — I_F = 1 ampere
(b) — i_F = 500 amperes

TABLE 23

DEVICE "B" DATA SHEET

Lot No. BT-46 Control

Date 30 April 1963

Unit Nr	$T_J = 25^{\circ}C \pm 3^{\circ}$ $v_{(BR)RO}$ or v_{RO}	$i_{(BR)RO}$ or i_{RO}	$v_{(BR)FO}$ or v_{FO}	$i_{(BR)FO}$ or i_{FO}	I_{GT}	V_{GT}	$T_J = 125^{\circ}C \pm 3^{\circ}$ $v_{(BR)RO}$ or v_{RO}	$i_{(BR)RO}$ or i_{RO}	$v_{(BR)FO}$ or v_{FO}	$i_{(BR)FO}$ or i_{FO}	I_{GT}	V_{GT}	$T_J = 25^{\circ}C \pm 3^{\circ}$ v_F (a)	v_F (b)	$t_{G\ on}$	I_{HO}	$T_J = 125^{\circ}C \pm 3^{\circ}$ I_{HO}	t_{off}	/ v_{app}	$\frac{d(v_{FO})}{dt}$	/ v_{app}
1	1360	0.5	1310	0.05	22	1.0	1200	16	1200	25	-	-	0.8	1.5	4	-	-	>100	1000	5000	1000
2	1380	0.2	1250	10.	15	1.0	1200	14	1200	10	-	-	0.78	1.7	4	-	-	>100	1000	5000	1000

NOTES: (a) — I_F = 1 ampere
(b) — i_F = 500 amperes

TABLE 24

DEVICE "B" DATA SHEET

Lot No. BT-46 Au Diffused

Date 30 April 1963

Unit Nr	$T_J = 25^oC \pm 3^o$						$T_J = 125^oC \pm 3^o$						$T_J = 25^oC \pm 3^o$				$T_J = 125^oC \pm 3^o$				
	$v_{(BR)RO}$ or v_{RO}	$i_{(BR)RO}$ or i_{RO}	$v_{(BR)FO}$ or v_{FO}	$i_{(BR)FO}$ or i_{FO}	I_{GT}	V_{GT}	$v_{(BR)RO}$ or v_{RO}	$i_{(BR)RO}$ or i_{RO}	$v_{(BR)FO}$ or v_{FO}	$i_{(BR)FO}$ or i_{FO}	I_{GT}	V_{GT}	v_F (a)	v_F (b)	$t_{G\ on}$	I_{HO}	I_{HO}	t_{off} /	v_{app}	$\frac{d(v_{FO})}{dt}$ /	v_{app}
1	1390	0.05	1170	10	40	1.6	1200	15	900	10	-	-	1.86	4.4	6.5	-	-	15	600	860	600
2	370	0.05	1320	10	74	4.0	320	2	1200	13	-	-	1.7	3.4	10.0	-	-	30	1000	2500	1000
3	1400	0.05	1320	10	75	2.1	1200	25	1200	20	-	-	2.1	3.3	8.0	-	-	18	1000	3300	1000

NOTES: (a) — $I_F = 1$ ampere
(b) — $i_F = 500$ amperes

TABLE 25

GENERAL ELECTRIC E50GX14-S1

RECTIFIER COMPONENTS DEPARTMENT

TEST METHOD

ON-VOLTAGE TEST, HIGH LEVEL

SCR AND LIGHT ACTIVATED SWITCH

COMMUNICATIONS MUST SPECIFY COMPLETE NUMBER

A. GENERAL

On-voltage (formally called forward voltage drop, conducting state) of a controlled rectifier is an extremely important parameter in establishing the current vs. temperature rating of the device. Measurements of on-voltage are usually made at two current levels. The high level test is made in the region of the forward characteristic where the voltage drop is primarily determined by the effects of resistance of the device including the pellet, back-up plates, solder joints, tubulation joints, terminals, etc.

B. PROCEDURE

This test is normally performed at room temperature ambient. In order to prevent excessive junction heating, a single pulse of current shall be used, approximately half sine wave in shape and with a specified base width. In order to eliminate errors caused by the effects of resistance in the power supply circuit, the voltage measurement shall be made by employing four point connections (separate voltmeter and current connections to each terminal). The location of the voltmeter connections shall be as specified. Care must be taken to eliminate ground loops within the equipment. The voltage measurement shall be made at the peak of the voltage waveform that occurs at the same point in time as the peak of the current pulse. If a distinct peak on the voltage waveform does not occur at the same time point as the peak of the current waveform, erroneous readings will result. For controlled rectifier testing the device may be either triggered from a separate gate supply or from the anode by means of a resistor connected from gate to anode terminals. For light activated switch testing the device may be triggered from any appropriate light source. For either SCRs or light activated switches extreme care must be taken to eliminate the effects of zero shift on the device voltage measurement caused by the presence of triggering signal when the voltage measurement is made.

C. TEST CONDITIONS

DIST:

To perform this test, the following conditions shall apply unless superceded by the product test drawing.

1. Fixed

(a)	Forward Current Pulse Shape	Half Sine Wave (approx.)
(b)	Forward Current Pulse Base Width	max. 4.0 m sec.
		min. 0.5 m sec.

PREPARED BY R F Dyer APPROVED BY Ervin E. [illegible]

DATE Feb 26 1963 SUPERSEDES ISSUE OF ______ CONT. ON SH. NO. 2 SH. NO. 1

C. TEST CONDITIONS (Cont'd)

2. Variable

(a) Temperature (Specify Case or Ambient) ________°C (±5°C)

(b) Peak Forward Current ________Amperes (±2%)

(c) Gate Trigger Pulse (SCR) ________ volts (±50%) and ________ ohms (±10%)

(d) Effective Light Trigger Intensity (Light Triggered Switch)
Minimum ________ watts/cm^2
Maximum ________ watts/cm^2

(e) Location of Voltmeter Connections
Anode: ________
Cathode ________

D. TEST LIMIT

1. Factory ________ Volts Peak Max.

2. Customer ________ Volts Peak Max.

DISTI

E50GX15-S1

TEST METHOD

ON-VOLTAGE TEST, LOW LEVEL SCR AND LIGHT ACTIVATED SWITCH

COMMUNICATIONS MUST SPECIFY COMPLETE NUMBER

A. GENERAL

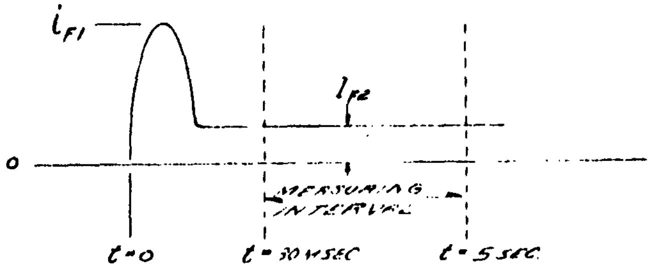
On-voltage (formerly called forward voltage drop, conducting state) of a controlled rectifier is an extremely important parameter in establishing the forward current vs. temperature rating of the device. Measurements of on-voltage are usually made at two current levels. The low level test is made in the region of the forward characteristic where the voltage drop is primarily determined by the effects of the junctions only and, as predicted by theory, generally follows a logarithmic relationship with the current. Since SCR's exhibit more than one state of conduction, it is necessary to establish the lowest conduction state (lowest on-voltage) by means of an anode current pulse prior to voltage measurements.

B. PROCEDURE

SCR's and Light Activated Switches -

This test is normally performed at room temperature using the waveforms shown below. In order to minimize junction heating, the width of the initial pulse must be limited and the voltage measurement should be made between 30 milliseconds and 5 seconds after the start of the initial pulse.

The device under test is to be switched to the on-state by using the specified trigger pulse or light intensity. The trigger pulse width shall not be less than 10^{-5} seconds or more than 10^{-1} seconds. The specified gate bias conditions shall be observed during the measurement interval. Four point connections (separate voltmeter and current connections to each terminal) shall be used to minimize errors due to contact resistance.



FORWARD CURRENT WAFEFORM

E50GX15-S1

ON-VOLTAGE TEST, LOW LEVEL SCR
AND LIGHT ACTIVATED SWITCH

COMMUNICATIONS MUST SPECIFY COMPLETE NUMBER

C. TEST CONDITIONS

To perform this test, the following conditions shall apply unless superceded by the product test drawing:

1. Fixed

a. Test Time, minimum 30 m sec.
maximum 5.0 sec.

b. Initial Forward Current Duration, Minimum 0.1 m sec.
Maximum 10 m sec.

2. Variable

a. Temperature (specify case or ambient) ________ °C (±5°C)

b. Test Current ________ mAdc (±2%)

c. Gate Trigger Pulse ________ volts (±50%) and ________ ohms (±10%)

d. Effective Light Trigger Intensity (Light Activated Switch)
Minimum ________ w/cm^2
Maximum ________ w/cm^2

e. Initial Forward Current, i_{f1} ________ A (±5%)

D. TEST LIMIT

1. Factory ________ Vdc max.

2. Customer ________ Vdc max.

DISTR

PREPARED BY [signature] APPROVED BY [signature]
DATE [handwritten] SUPERSEDES ISSUE OF ________ CONT. ON SH. NO. 3 SH. NO. 2

GENERAL ELECTRIC E50GX28-S1

RECTIFIER COMPONENTS DEPARTMENT

TEST METHOD

SCR EFFECTIVE THERMAL RESISTANCE

COMMUNICATIONS MUST SPECIFY COMPLETE NUMBER

A. GENERAL

Faulty processing such as poor solder wetting will increase the thermal resistance from junction to stud. An upper limit on θ_{J-C} is necessary in order to keep junction temperature within the published limit for rated operating conditions.

The temperature dependence of the on-voltage with the low level current flowing is used to measure junction temperature rise while a constant power is being dissipated under constant cooling conditions.

B. PROCEDURE

The SCR shall first be completely switched on with a high level forward current pulse approximately equal to rated value and of 10^{-5} to 10^{-1} seconds duration which is then lowered to a low level dc metering current of negligible heating value. The on-voltage V_{FO} is then measured.

The device is then heated with a forward current which is interrupted periodically for measurement of on-voltage with only the low level metering current flowing. Heating watts shall be maintained constant during the heating time. Devices rated 50 amps and above should be water-cooled with a constant flow of cooling water in order to permit reaching thermal stability in a reasonably short time.

After a specified heating time, the on-voltage measured during the intervals when only the low level metering current is flowing is compared with the previously measured low level on-voltage (before application of heating current). The voltage decrease shall be no greater than the specified limit. The forward current shall be lowered without interruption to the low level metering value at the end of the heating interval, and the on-voltage observed. If the on-voltage does not return to the valve measured just prior to application of heating current, the test shall be re-run without interruption of low-level metering current. In other words, if the low-level on-voltage does not return to the starting value, there has been a change in conduction state and the test should be re-run without interruption of forward current.

C. TEST CONDITIONS

To perform this test, the following conditions shall apply unless superseded by the product test drawing.

1. Variable

a. Low level metering current ________ A ±2%

PREPARED BY W. Warburton APPROVED BY R. P. Lyons

DATE Feb 14, 1963 SUPERSEDES ISSUE OF ________ CONT. ON SH. NO. 2 SH. NO. 1

C. TEST CONDITIONS (cont'd)

b. Forward heating current waveform (300° conduction with 60° interval for low level measuring current reading as in a 6-phase star circuit with one phase by-passed, has been found satisfactory). ________

c. Forward average power ________ Watts ±5%

d. Heating time ________ sec ±1 sec.

e. Time interval between start of reference current interval and measurement of low level reference current on voltage ________ MS Min. ________ MS Max.

f. Temperature sensitivity ________ mv/°C

g. Mounting torque or force ________ In. Lbs. or ________ Lbs.

h. Water flow rate ________ GPM ±10%

D. TEST LIMITS

1. Factory *

2. Customer *

* The test circuit readings are in millivolts change in low level on-voltage. This can be converted to thermal resistance in °C/W by multiplying the millivolt reading by the appropriate conversion factor. This reading will be thermal resistance from junction to cooling medium. True thermal resistance junction to case will be less by the amount of case to cooling medium thermal resistance.

GENERAL ELECTRIC E50GX30-S1

RECTIFIER COMPONENTS DEPARTMENT

TEST METHOD

SCR TRANSIENT THERMAL IMPEDANCE

(LABORATORY TEST)

COMMUNICATIONS MUST SPECIFY COMPLETE NUMBER

A. GENERAL

The measurement of effective thermal impedance is included in the measurement of transient thermal impedance outlined below, since it is the steady-state valve of the curve of transient thermal impedance.

The thermal capacity of the various materials used in the construction of a semiconductor device precludes the use of effective thermal impedance in predicting device performance under transient conditions. The response of junction temperature to a constant power input, as a function of time, provides a curve of transient thermal impedance which can be used for this purpose.

B. PROCEDURE

The transient thermal impedance of an SCR may be measured by utilizing the temperature dependence of the on-voltage. The valve measured is that between junction and ambient (cooling medium) for a particular heat sink and cooling medium flow. Transient thermal impedance from junction to case cannot be measured directly, since the case temperature will change during the test, but can be interpolated, as shown in the figure. The measurement may be made by the heating method or by the cooling method:

1. Heating or Pulse Method

Measure the on-voltage V_{F1} with a low level metering current flowing and with the junction at various specified temperatures. The measurement shall start with the highest temperature recommended by the manufacturer and shall be preceded by conduction of a high level of forward current which is lowered smoothly to the metering current, to insure a fully switched condition. Plot on voltage V_{F1} against junction temperature and calculated slope (M) in volts per degree centigrade. Any large steps in the curve will invalidate the use of the slope (M).

Heat the device with a pulse of pure dc current and measure the peak power P_{F1}. At the end of the pulse record the on-voltage V_{F2} with the low level metering current flowing. The transient thermal impedance from junction to cooling medium for the time corresponding to the particular pulse duration is then calculated from:

$$\theta_{J-A}(t) = \frac{(V_{F2} - V_{F0})}{(M)\ P_{F1}}$$

Where $(M) = V_{F1}/T_J$ from the previous plot.

PREPARED BY W. Warburton APPROVED BY R. L. Lyon

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V_{F0} is the on voltage at the metering current level just prior to application of forward heating current. (Junction at cooling medium temperature).

V_{F2} is the on voltage with the metering current flowing immediately following the heating current pulse. *

Repeat with current pulses of different time duration until enough points are obtained for a plot. See Fig. 1.

* This measurement must be made with an oscilloscope and the trace extrapolated back to the time corresponding to the end of heating current pulse. The extrapolation must exclude non-thermal transients such as recovery voltage and the effects of iron in the housing. When using this pulse method the junction must be allowed to cool back to equilibrium temperature between pulses. An off-time of at least 100 times the pulse width shall be used.

2. Cooling Method

As an alternative test procedure, the low-level on-voltage at the end of the current pulse of sufficient duration to bring the device to thermal equilibrium may be monitored until the device has cooled to thermal equilibrium under constant cooling conditions. An oscilloscope shall be used to record the beginning of the cooling cycle, and manual readings with a stop watch may be used after the cooling rate has slowed sufficiently. Calculations are the same as in the pulse method above, except that the value of transient thermal impedance calculated corresponds to the time interval between switching and the reading of V_{F2}.

Since this is a cooling cycle, the calculated values of transient thermal impedance must be subtracted from the effective thermal resistance (the value calculated for the time when the forward heating current is cut off).

The advantages of this cooling method are:

1. Simpler circuitry.
2. Any discontinuities due to imcomplete firing are readily seen.

The disadvantages are:

1. The necessity for a calibrated oscilloscope and attached camera.
2. Plotting from the pictures is tedious and may be inaccurate due to parallax or insufficient amplification of the trace.

2. Cooling Method (cont'd)

The cooling method shall be used on large devices, particularly for times of 1 second or longer. The heating method offers the greatest accuracy at the short time end of the curve and shall be used on all small devices (up to 50 amperes rating).

C. TEST CONDITIONS

To perform this test the following conditions shall apply unless superseded by the product test drawing:

1. Variable

a. Low level metering current ________ A ±2%

b. Forward heating current
(usually 50-100% rated current for cooling method, higher for short pulses in heating method). ________ A ±3%

c. Method of extrapolation of scope trace back to time when forward heating current is cut-off. ________

D. TEST LIMITS

Specify time intervals to be checked and transient thermal impedance limit values (Factory and Customer).

GENERAL ELECTRIC

RECTIFIER COMPONENTS DEPARTMENT

TEST METHODS

SCR TRANSIENT THERMAL IMPEDANCE

(LABORATORY TEST)

COMMUNICATIONS
MUST SPECIFY
COMPLETE NUMBER

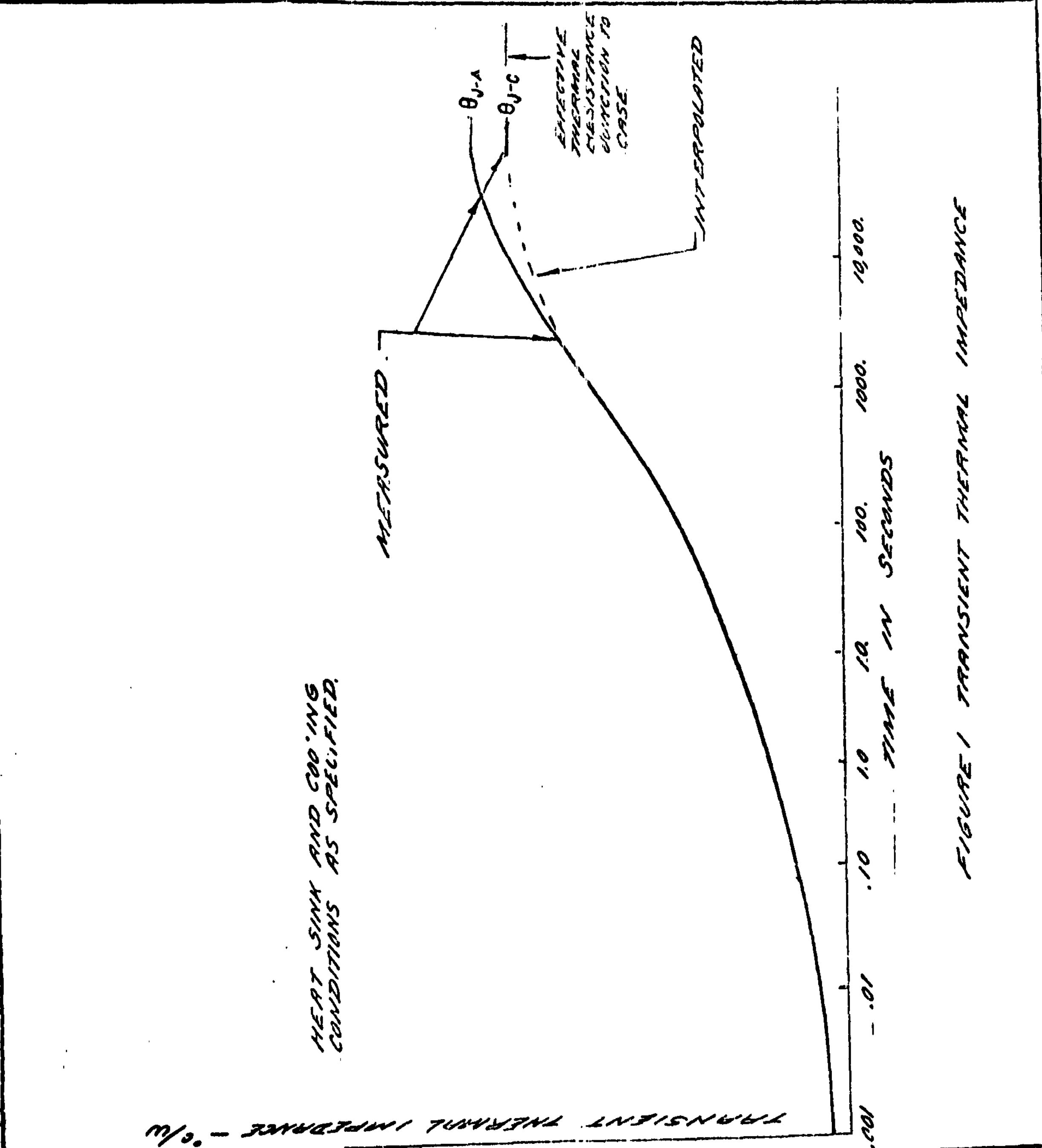

FIGURE 1 TRANSIENT THERMAL IMPEDANCE

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Δ DENOTES CHANGES