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NEW DEVELOPMENTS IN POWER SEMICONDUCTORS

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This paper represents an overview of some recent power semiconductor developments and spotlights new technologies that may have significant impact for aircraft electric secondary power. Primary emphasis will be on NASA-Lewis-supported developments in transistors, diodes, a new family of semiconductors, and solid-state remote power controllers. Several semiconductor companies that are moving into the power arena with devices rated at 400 V and 50 A and above are listed, with a brief look at a few devices.

Advanced power electronic component development for space applications has been going on at NASA Lewis for more than a decade, as shown in figure 1. A wide range of development work has been done, including transformers and inductors, semiconductor devices such as transistors and diodes, remote power controllers, and supporting electrical materials development. Present power component capability for space applications is about 25 kW. Work in the early and middle 1980's should raise this capability to 100 kW and begin to move toward a megawatt capability.

Industrial Research & Development Magazine recognized the D60T high-power switching transistor as one of the 100 outstanding new products introduced in 1978. The D60T - a triple-diffused, NPN silicon transistor - introduces a combination of expanded power ranges, low energy losses, and fast switching speeds. Rated at 400 to 500 V and 100-A continuous (200 A peak) collector currents, these transistors have reduced transistor switching times by a factor of 2 to 5. Therefore they are used in 50-kHz inverter designs. Principal applications are dc-dc inverters, dc motor controllers, and solid-state remote power controllers. Research devices based on this technology have proven feasible to 1200 V, and with larger area silicon wafers, power-handling capability to 100 kW will soon be available.

Against the backdrop of a circuit diagram for a solid-state remote power controller a technician holds a D60T ready for assembly in a stud package (fig. 2). In her right hand the interdigitated silicon wafer can be seen inside the base. The emitter-base contacts are visible in the ceramic-to-metal top held in her left hand. To the left are shown three package types: a special flat-base package (a modification of the stud package), a stud package, and a disk package.

Figure 3 shows the Westinghouse D7ST, which is now being marketed as a direct transfer of technology from a research contract supported and directed by NASA Lewis. The two package types available are shown in the center photograph. Around the photograph are listed the features and applications of the D7ST. The primary benefit of the new transistor to NASA is the extension of the power-handling capability to 50 kW without paralleling of transistors. This opens new areas of application and direction for future space power system design.

The main ratings and characteristics for a 1000- to 1200-V transistor developed by Westinghouse under contract to NASA Lewis are as follows:

Voltage, V	1000 to 1200
Current, A	25 to 40 (gain of 10); 120 peak
Power handling, kW	30
Power dissipation at 75° C, kW	1.25
Rise and fall times, μsec	0.5
Storage time, μsec	3

Westinghouse successfully completed the program by delivering 50 transistors that met the listed specifications. The 33-mm-diameter wafer used the same emitter-base geometry as the D7ST.

The ratings and main characteristics for augmented power transistors to be developed in a research contract now under way at Westinghouse are as follows:

Voltage, V	800 to 1000
Current, A	70 to 112 (gain of 10); 400 peak
Power handling, kW	75
Power dissipation at 75° C, kW	1.25
Rise and fall times, μsec	0.5
Storage time, μsec	2.5

Transistors from this program should be available by the fall of 1982. The two significant developments of this program will be demonstration of glass passivation of the wafer to provide hermetic sealing of the junctions and a new package that isolates the thermal and electrical interfaces.

Figure 4 shows the benefits to NASA, the features, and the general applications of a newly developed 50-A, 1200-V fast-recovery power diode. Power Transistor Company developed the new diode on contract to NASA Lewis. Because of the large commercial demand for such a device in motor controllers, Power Transistor Company is already marketing the product as their PTC 900 series power rectifier.

Figure 5 is a copy of a data sheet showing both bipolar and Darlington transistors rated at 450 V and 100 A. They are encased in an innovative package with separate electrical and thermal interfaces. The transistors can be easily paralleled. Fuji has recently introduced a new 1000-V, 100-A transistor to add to a growing family of power semiconductors.

One of Motorola's new MJ series of Darlington transistors is shown in this partial copy of a data sheet (fig. 6). This is a totally new package with isolated electrical and thermal interfaces. This model is produced in three ratings: 850 V, 50 A; 450 V, 100 A; and 250 V, 200 A.

Figure 7 shows one of several models of bipolar and Darlington transistors available from Power Transistor Company. They are working on a new low-cost package, a 1000-V transistor, and a gate turnoff thyristor for 460-V ac motor control applications. They are also developing a 150-A, 1200-V fast-recovery diode on contract to NASA Lewis. This will be a higher current version in a DO-8 size package of the PTC 900 series described previously.

Table I shows the ratings of three new Darlington transistors under development at the GE Discrete Semiconductor Device Center in Syracuse, N.Y. The three devices (ZJ504E, ZJ604E, and ZJ704E) are compared with an existing device, the ZJ504. These new Darlingtons are being developed as the primary switches for a pulse-width-modulated (PWM) inverter-motor controller in an advanced electric vehicle power train program. This effort, supported by the DOE and managed by NASA Lewis, is under contract to Ford Motor Co. with General Electric as the major subcontractor.

Table II shows the specifications in greater detail for the 604E/704E versions of the new ZJ series under development by General Electric. Also given are specifications for a high-power flyback diode used in the PWM inverter-motor controller. New packaging concepts are also being explored in this work.

Several companies that have, or soon will have, bipolar, Darlington, or metal oxide semiconductor field effect (MOSFETS) transistors in the 400-V, 50-A and above power ranges are listed here.

(1) Fuji Electric Co. Ltd., Dallas, Texas (Japan)
(2) General Electric Co., Auburn, New York
(3) Hitachi Ltd., Japan
(4) International Rectifier, El Segundo, California
(5) Motorola Semiconductors, Phoenix, Arizona
(6) Power Tech, Fairlawn, New Jersey
(7) Power Transistor Company, Torrance, California
(8) Siemens AG, West Germany
(9) Solitron Devices, Riviera Beach, Florida
(10) Thomson CSF, Canoga Park, California (France)
(11) Toshiba Corp., Japan
(12) Westcode Semiconductors, Fairlawn, New Jersey (England)
(13) Westinghouse Semiconductor, Youngwood, Pennsylvania

In the case of foreign companies the city and state of the U.S. distributor is given where known.

Thermal Associates has introduced a new concept in packaging high-power semiconductor chips (fig. 8). This package is lighter than conventional packages, yet it provides compression bonding of electrical leads without soldering or other point-contacting methods. Of primary importance is the separation of the thermal and electrical interfaces of the package.

Figure 9 shows a new invention, the FET-gated transistor (FGT), by Dr. Daniel Chen of Virginia Polytechnic Institute and State University. NASA Lewis is presently supporting a grant to VPI/SU to prove feasibility and to develop the concept. On the figure Q_1 is the main bipolar power transistor, Q_2 and Q_3 are power field effect transistors (FET's), and D is a Zener diode. The Q_2 is in a Darlington, and the Q_3 is an emitter-open configuration with Q_1. Conduction in Q_1 is controlled by signals to the gate terminals of Q_2 and Q_3. Dr. Chen is presenting a paper entitled "FET-Gated High Voltage Bipolar Transistors" at the upcoming IEEE Industrial Applications Society Meeting in San Francisco, October 4-7, 1982.

The primary advantages of the FGT are fast switching, no reverse-bias second breakdown (RBSB), very simple drive requirements, and good use of the semiconductor chip area. The use of emitter-open switching essentially eliminates the bipolar storage time delay and gives very fast switching speeds. It also eliminates RBSB problems and thereby reduces the need for energy-wasting snubber circuits. The FET bipolar combination enables the bipolar to be operated safely at the V_{CEO} sustaining rating. This fact reduces the bipolar chip area required such that the total chip area of the combination will be comparable to that of a bipolar transistor.

A new family of semiconductors, called deep-impurity devices, is being investigated at the University of Cincinnati with NASA Lewis support. In understanding how deep-impurity devices work, we must look at bulk effects in silicon (or some other semiconductor material) rather than typical p-n junction characteristics. We are interested in what happens in silicon doped with a deep impurity such as gold between charge-injecting electrodes. We are investigating the addition of impurities to silicon that add one or more energy levels at or very near the center of the energy band. The center lies at 0.55 eV from both the conduction and valence bands in silicon. We use shallow impurities to compensate the material (that is, to adjust the Fermi level) but do not form conventional p-n junctions. Three types of gating are possible and have been explored in this work. Switching can be accomplished by light gating, injection gating (the addition of an injection gate in the space between anode and cathode), or MOS-voltage gating (metal-oxide-semiconductor gate).

Switching devices and transducers are the areas in which most of the effort to date has been focused. The primary interest now is in switching devices with gate-controlled threshold voltages (limited only by the breakdown voltage of silicon), controllable holding voltage giving evidence of zero forward voltage drop, thyristor-like switching with both turnon and turnoff capability, logic functions, PWM controllers, discriminators, and optical switches. Of secondary interest has been the demonstration of several very sensitive, miniature transducers: gas flowmeters, magnetic field Hall-type probes, temperature-to-frequency thermometers, and infrared detectors. The gas flowmeter is a hot-wire anemometer type, but only 0.2 mm on a side, with response times of a second and much greater sensitivity than a p-n junction device. The multiple-internal-reflection extrinsic infrared detectors have demonstrated quantum efficiencies greater than 34 percent, a flat detectivity curve out to 160 K, and multiple frequency ranges when using silicon-germanium alloys.

The capabilities of voltage-controlled oscillators and detectors, voltage-controlled pulse width modulators and delay lines, and a temperature-to-frequency thermometer are based on preand postbreakdown oscillations in devices with certain doping characteristics. Because of the possibility of charge storage in the deep levels, an exciting possibility has been predicted for very small, vertically integratable memory devices having an excellent immunity to radiation.

The upper part of figure 10 shows a cross section of a double-injection, deep-impurity device. The bulk material is gold-doped silicon compensated by a shallow donor such as phosphorus. The energy level diagram is shown in the lower part of figure 10 as a reminder. The gold acceptor level at 0.54 eV is the level activated and predominates in the device behavior.

Also shown in the upper part of the figure are the anode and cathode formed by diffusing p^+ and n^+ regions into the bulk material. These regions provide efficient ohmic contacts and the appropriate band bending at the surface to promote high Thus this is called a double-injection device. If only an n^+ region were produced, the device would be a single-injection device with characteristics following Murray Lampert's traps-filled-limit behavior as shown in the next figure.

The upper part of figure 11 shows a double-injection, gold-doped, n-type silicon diode with two gates added. We refer to them as MOS (metal oxide semiconductor) voltage gates. Applying a positive voltage to the cathode gate (or negative to the anode gate) decreases the threshold voltage from V_{TH} to V_{TH}, or it may turn the diode off from a conducting state. We have demonstrated that the cathode gate is more effective in controlling the switching behavior. Therefore, in practice, both gates have been replaced by one gate located near the center of the channel but closer to the cathode. As the gate voltage is increased positively, V_{TH} decreases and vice versa. The holding voltage is not much affected by the gate voltages.

Figure 12 shows two oscilloscope traces of the switching characteristics of the injection-gated device. Both photographs show current on a scale of 10 mA per division versus voltage at 20 V per division. Figure 12(a) shows a threshold voltage of about 155 V and a holding voltage of 16 to 20 V depending on the current level; the gate voltage is zero. The remarkable result of an injection gate is shown in the superposition of several traces in figure 12(b). As the gate-to-cathode voltage V_{GC} is made more negative in increments of -4 V, the holding voltage decreases. In fact, with $V_{GC} = -16$ V, the holding voltage is at or near zero. This presents the very exciting possibility of a device with zero forward voltage drop leading to a very energy-efficient switch. Obviously there is some power loss in the gate, but experimental data have shown these losses to be less than 10 percent of the primary conduction losses. Additional efforts in processing of the bulk silicon have reduced V_H by a factor of 4 or 5.

Now keeping in mind the basic physics of the deep-impurity device and its switching capabilities with the ability to vary both the threshold and holding voltages, we want to look at the voltage limitations in silicon. Figure 13 shows threshold voltage as a function of length in or across a slab of silicon. The breakdown limit is shown as a linear function of length in bulk silicon. The calculated curve for p-n junction devices is quite conservative in that it calculates the breakdown limit across the depletion region by assuming one side of the junction to be very lightly doped. This gives an upper limit in the region of about 10 000 V. Deep-impurity devices also have a square-law breakdown threshold but a smaller coefficient. The calculated curve for the deep-impurity material lies to the right of the p-n junction curve and shows a factor of 10 or more higher breakdown limit. If surface effects and material defects are neglected, there appears to be a very real possibility of devices with threshold voltages from 10 to 100 kV. Recent experimental data confirm the curve up to 800 V.

Another area of work that Lewis is supporting is solid-state remote power controllers. Figure 14 shows a hermetically sealed, fully operational remote power controller (RPC) along with the header assembly and enclosure of the RPC ready for final assembly and hermetic sealing. The hybrid version used semiconductor chips, individual piece parts, optical isolation, and thick-film manufacturing techniques. On the left is the header assembly substrate that contains the power transistor drive circuit, current-limiting resistor, and side rails for support and electrical contact to the upper control substrate shown just to the right. On the right side is the enclosure soldered to the substrates for hermetic sealing. The RPC is about 4.5 cm on a side and weighs 3.5 oz.

Figure 15 shows the 30-A version of the 120-V dc solid-state RPC developed for NASA Lewis by Westinghouse Aerospace Division. This version incorporates I^2t trip characteristics rather than current limiting. This version has a single-layer substrate (6 cm by 7 cm) and weighs about 7 oz.

Figure 16 lists several advantages of solid-state remote power controllers developed by NASA Lewis. With the new high-power transistors now available we have extended the power range to 25 to 50 kW and the voltage to 1000 V. The technology has been developed and is not dependent on a particular component. Actually, 1000-V, 25-A solid-state power controllers have been demonstrated using thyristors, transistors, and an array of FET's. Gate-turnoff thyristors (GTO's) could also be used.

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TABLE I. - TRANSISTOR DESIGN TRADE-OFFS

	504	504E	604E/704E
I_C, A	200	133	150
H_{FE}	200 at 2 V	100 at 2 V	100 at 2.5 V
V_{CE}	280 V at 200 A	350 V at 133 A	400 V at 150 A
V_{CE}	500 V at 1 A	500 V at 1 A	550 V at 1 A
Size, cm^2	2.41	2.41	3.04

TABLE II. - CHARACTERISTICS OF POWER DARLINGTON TRANSISTOR AND FLYBACK DIODE

(a) Power Darlington transistor

Continous current rating, A	150
Turnoff state of the art, V:	
V_{CE} at I_C = 150 A, $\pm I_{B1}$ = 1.5 A, $V_{BE1(off)}$ = -5 V, V	400
V_{CE} at I_C = 1 A, $\pm I_{B1}$ = 1.5 A, $V_{BE1(off)}$ = -5 V, V	550
H_{FE} at I_C = 150 A, V_{CE} = 2.5 V, T_J = 100° C	100
$V_{CE(sat)}$ at I_C = 150 A, I_{B1} = 1.5 A, T_J = 100° C, V	2.5
t_s (inductive) at I_C = 150 A, $\pm I_{B1}$ = 1.5 A, μsec	4
t_f (inductive) at I_C = 150 A, $\pm I_{B1}$ = 1.5 A, μsec	2
Maximum chopping frequency, Hz	3000
R_{OSA}, °C/W	0.15
T_A, max, °C	50
Number of transistors in parallel in power module	3

(b) Flyback diode

Average current rating, A	150
Reverse blocking voltage, repetitive, V	550
V_{FM} at I_{FM} = 400 A, T_J = 125° C, V	2.0
t_a = I_F = 400 A, di/dt = 200 A/μsec, T_J = 125° C, nsec	500
t_b = I_F = 400 A, di/dt = 200 A/μsec, T_J = 125° C, nsec	500
R_{OSA}, °C/W	0.15
T_A, max, ° C	50
Number of diodes in power module	1

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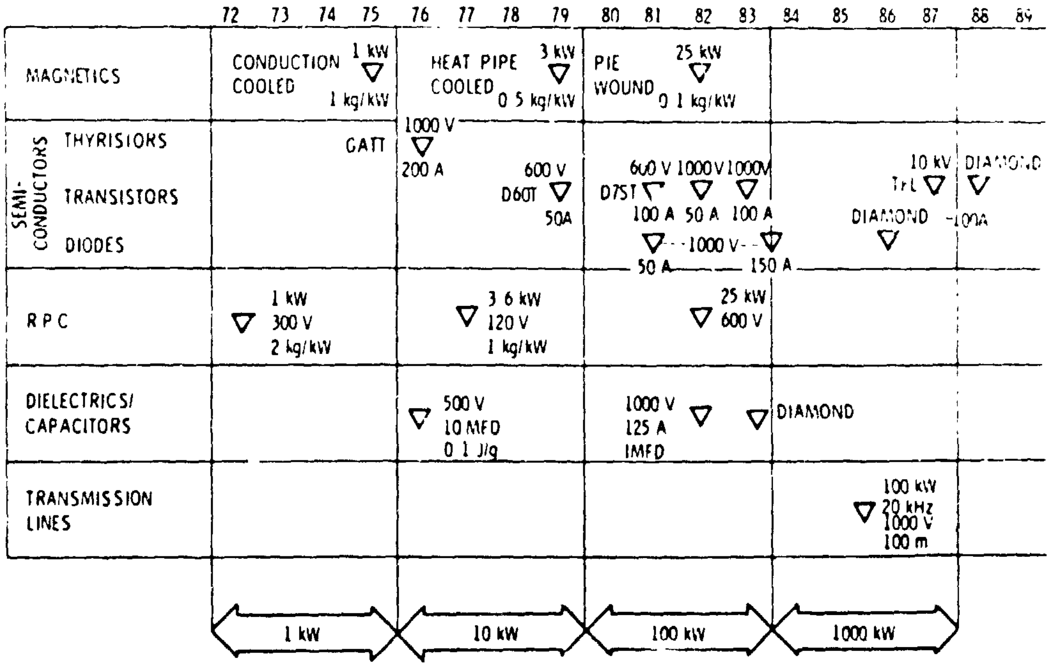
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
MAGNETICS
CONDUCTION COOLED
1 kW
1 kg/kW
HEAT PIPE COOLED
3 kW
0 5 kg/kW
PIE WOUND
25 kW
0 1 kg/kW
SEMI-CONDUCTORS
THYRISTORS
TRANSISTORS
DIODES
GATT
1000 V
200 A
600 V
D60T
50A
600 V
1000 V
1000 V
D7ST
100 A
50 A
100 A
1000 V
50 A
150 A
10 kV
TFL
DIAMOND
DIAMOND
100A
RPC
1 kW
300 V
2 kg/kW
3 6 kW
120 V
1 kg/kW
25 kW
600 V
DIELECTRICS/ CAPACITORS
500 V
10 MFD
0 1 J/g
1000 V
125 A
1MFD
DIAMOND
TRANSMISSION LINES
100 kW
20 kHz
1000 V
100 m
1 kW
10 kW
100 kW
1000 kW

Figure 1. - Power electronics development at Lewis Research Center.

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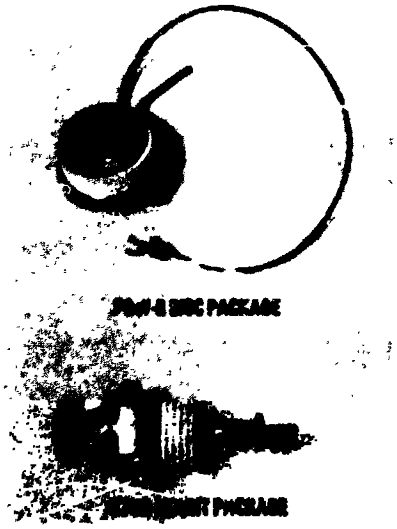
Figure 2. - High-power switching transistor D60T.

FEATURES

- VOLTAGE: 400 TO 500 VOLTS
- CURRENT. 100 TO 150 AMPERES @ GAIN OF 10
  400 AMPERES PEAK
- POWER HANDLING. 50 KILOWATTS
- POWER DISSIPATION: 2 kW @ 75°C
- RISE AND FALL TIMES. 0.75 MICROSECOND
- STORAGE TIME: 4 MICROSECONDS
  LOW SATURATION AND PER CYCLE SWITCHING
  LOSSES



APPLICATIONS

- 25-50 kW HIGH FREQUENCY INVERTERS
- VSCF CONVERTERS IN MILITARY AIRCRAFT
- ELECTRIC VEHICLE MOTOR CONTROLLERS
- DC MOTOR CONTROLLER FOR SPACE SHUTTLE ACTUATOR
- 100 kW VLF TRANSMITTERS
- 50 kHz RF INDUCTION HEATERS
- POWER SUPPLIES FOR CONSUMER AND INDUSTRIAL APPLICATIONS

BENEFITS TO NASA

- DOUBLES CAPABILITY OF PREVIOUS IR-100 AWARD WINNING D60T TRANSISTOR
- COMMERCIALLY AVAILABLE IN QUANTITY AT REASONABLE COST
- MAKES POSSIBLE 50 kW SPACE POWER SYSTEM CONVERTERS AND POWER CONTROLLERS WITHOUT PARALLELLING OF TRANSISTORS
- EXPECT IMPORTANT USES ALSO IN AIRCRAFT POWER DISTRIBUTION AND CONTROL
- ESTABLISHES TECHNOLOGY FOR LARGER AREA, HIGHER POWER TRANSISTORS

Figure 3. - High-power switching transistor D7ST.

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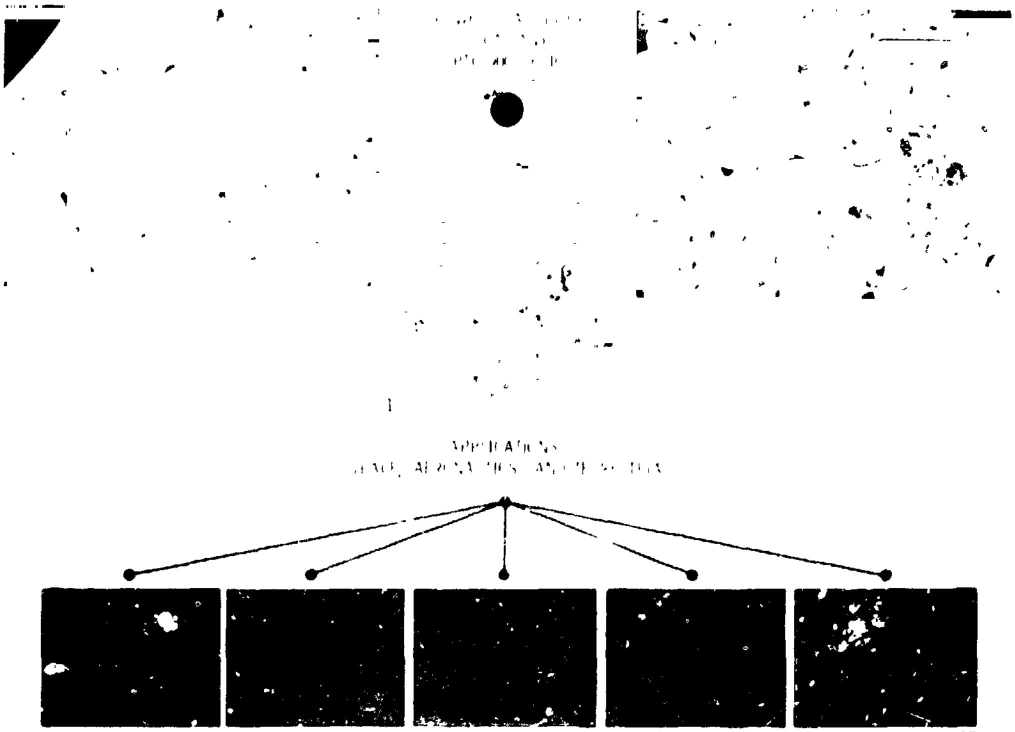
APPLICATIONS
SPACE, AERONAUTICS, AND TERRESTRIAL

CD-81-12697

Figure 4. - Fast-recovery, high-voltage power diode.

BBT

Building Block Transistors

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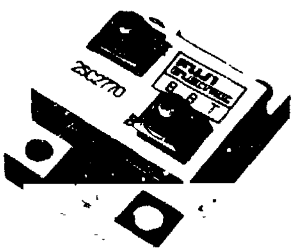

2SC2770
FUJI
B B T

REVOLUTIONARY NEW POWER TRANSISTORS

These are the power transistors whose performance have attracted so much attention both in Japan and elsewhere. These have been manufactured using the planar process techniques specially improved by FUJI and can be recommended with confidence

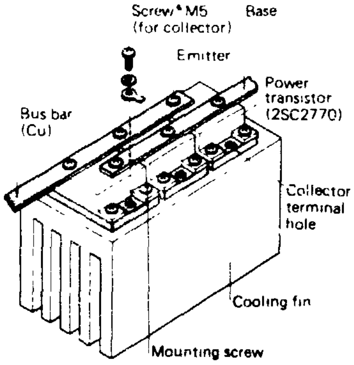
Only one element is sufficient to carry such a heavy current as 100A (V_{CEO} (sus) 450V) and they are suitable for inverters for the speed control of AC or DC motors up to the 10kW class and for constant voltage power supply equipment. BBTs have uniform characteristics and can be connected in parallel to provide capacities up to 60kW.

Applications

- Industrial inverters
- Power supply equipment

Features

- High voltage, large capacity (V_{CEO}(sus) 450 volts, Ic cont. 100 Amps)
- The scattering effect is reduced to a minimum as a result of employing the planar process of manufacture.
- Uniform characteristics allows units to operate in parallel and to be applied to motors drawing 60kW. (The FUJI transistor inverter series FRENIC5000G have already incorporated this element in the series up to 22kW).
- In addition to the single (2SC2770) and Darlington (2SD1066) a compound type (ET102) with a built-in fast recovery diode is also available.
- The molded package protects the unit from humidity and heat.
- Easily connected to heat sinks. (Cooling fin)
- Screw terminals for the emitter and base grouped conveniently together to simplify connection.
- Compactly designed

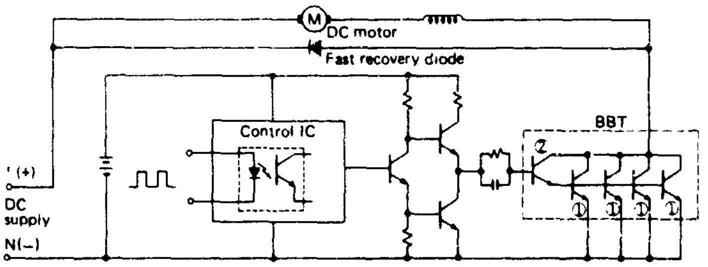

Screw* M5
(for collector)
Base
Emitter
Power transistor (2SC2770)
Bus bar (Cu)
Collector terminal hole
Cooling fin
Mounting screw

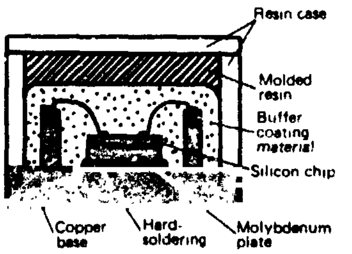
Example for parallel connection

Note *When the heat sink is isolated from the base use the collector terminal

Specifications

Type	V_{CBO} volts	V_{CEO} volts	V_{CE} (SUS)	Ic amps	Pc watts	h_{FE} min	Ic amps.	V_{CE} volts	Switching time ton µs	ts µs	tf µs
2SD1066	600	600	450	100	770	100	100	5	4	12	4
2SC2770	600	600	450	100	770	8	60	5	4	8	3


M
DC motor
Fast recovery diode
Control IC
BBT
②
①
①
①
①
(+)
DC supply
N(−)
① 2SC2770 ② 2SD1066


Resin case
Molded resin
Buffer coating material
Silicon chip
Copper base
Hard-soldering
Molybdenum plate

BBT internal construction diagram

Fuji Electric Co.,Ltd.

New Yurakucho Bldg.,
12-1 Yurakucho 1-chome, Chiyoda ku,
Tokyo, 100 Japan
Phone. Tokyo 211-7111
Telex J22331 FUJIELEC
Cable Address. DENKIFUJI TOKYO

Figure 5. - Data sheet showing revolutionary new power transistors.

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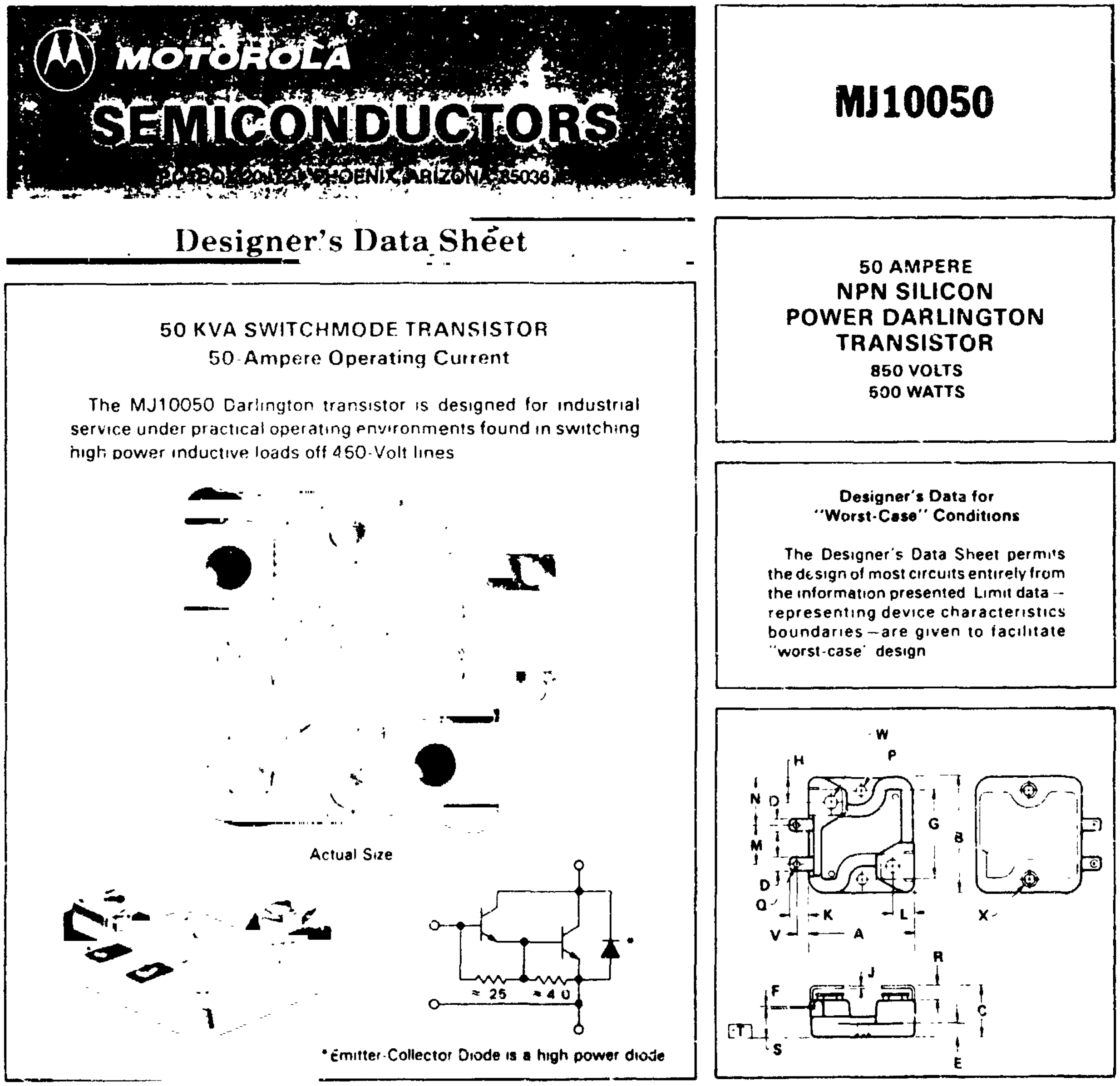

MOTOROLA

SEMICONDUCTORS

P.O. BOX 20912 • PHOENIX, ARIZONA 85036

MJ10050

Designer's Data Sheet

50 KVA SWITCHMODE TRANSISTOR

50-Ampere Operating Current

The MJ10050 Darlington transistor is designed for industrial service under practical operating environments found in switching high power inductive loads off 460-Volt lines

Actual Size

*Emitter-Collector Diode is a high power diode

50 AMPERE
NPN SILICON
POWER DARLINGTON
TRANSISTOR
850 VOLTS
500 WATTS

Designer's Data for "Worst-Case" Conditions

The Designer's Data Sheet permits the design of most circuits entirely from the information presented. Limit data — representing device characteristics boundaries — are given to facilitate "worst-case" design.

Figure 6. - Data sheet showing Darlington power transistor.

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POWERLITHIC™ MODULE

PPM series

ELECTRICAL SPECIFICATIONS

	I_C MAX Note 1	I_C CONT Note 2	I_C SAT Note 3	I_B MAX	V_{CEO} (SUS)	MAX. OPER. FREQ.	Without Antisaturation Diode			With Antisaturation Diode (See Figure 1)		
							t_r	t_s	t_f	t_r	t_s	t_f
PPM30015A	300A	175A	150A	4A	150V	10KHZ	1 μs	5 μs	1 μs	1 μs	2 μs	1 μs
PPM40015A	400A	250A	200A	4A	150V	10KHz	1 μs	5 μs	1 μs	1 μs	2 μs	1 μs
PPM60015A	600A	375A	300A	4A	150V	10KHz	1 μs	5 μs	1 μs	1 μs	2 μs	1 μs
PPM12040A	120A	75A	60A	4A	400V	10KHz	1 μs	10 μs	2 μs	1 μs	4 μs	2 μs
PPM20040A	200A	125A	100A	4A	400V	10KHz	1 μs	10 μs	2 μs	1 μs	4 μs	2 μs
PPM30040A	300A	185A	150A	4A	400V	10KHz	1 μs	10 μs	2 μs	1 μs	4 μs	2 μs
PPM4090A	40A	30A	20A	4A	900V	10KHz	1 μs	20 μs	4 μs	1 μs	8 μs	4 μs
PPM6090A	60A	45A	30A	4A	900V	10KHz	1 μs	20 μs	4 μs	1 μs	8 μs	4 μs
PPM8090A	80A	60A	40A	4A	900V	10KHz	1 μs	20 μs	4 μs	1 μs	8 μs	4 μs

NOTE 1: I_C MAX measured at V_{CE} − [V_{CEO} (sus)].
I_B with Base Drive is [$I_B - I_{B1} - I_{B2} - I_B$ MAX]
at V_{EB} − 5v for duration (t − 10 μs single pulse)

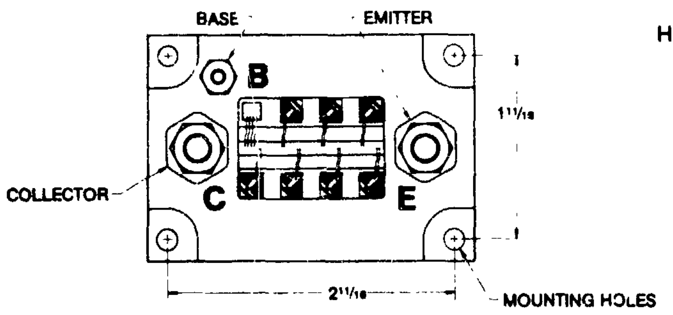
NOTE 2: $I_{C\,CONT}$ is defined as the continued current obtained
at V_{CE} − 10v when Maximum Base Current
$I_{B1} - I_B$ MAX is applied at the Base.

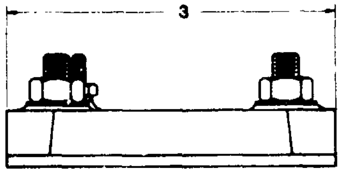
NOTE 3: Saturation Current $I_{C\,SAT}$ is obtained when
$I_B - I_B$ MAX and V_{CE} − 2.5V. Duty cycle − 2% (@300 μs pulse width)
measured by using a KELVIN Bridge.

MECHANICAL SPECIFICATIONS (Dimensions in inches)

$R_{\theta JC}$: Non-isolated copper base plate, 0.12°C/W. Isolated black anodized aluminum base plate, 0.30°C/W.

HIGH POT: 1500 Volts minimum between collectors and heat-sink mounting of isolated case (black anodized alum, case).





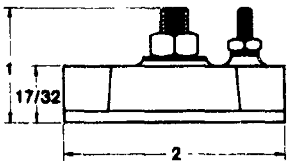


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Figure 7. - Data sheet showing electrical specifications of power transistors.

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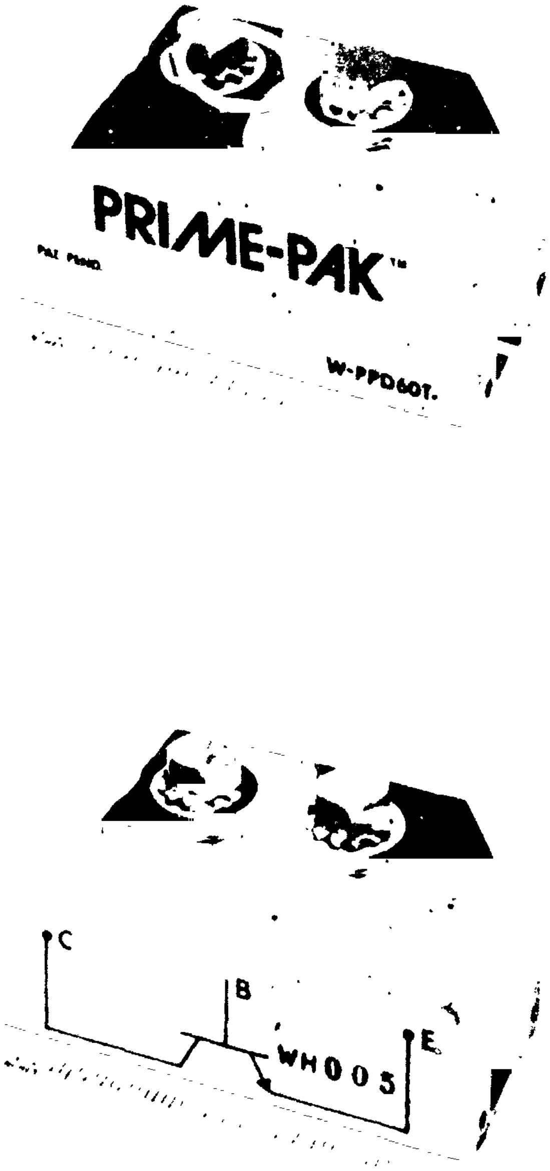
PRIME-PAK™
W-PPD60T.
C
B
E
WH005

Figure 8. - Thermal Associates' "Prime-Pak."

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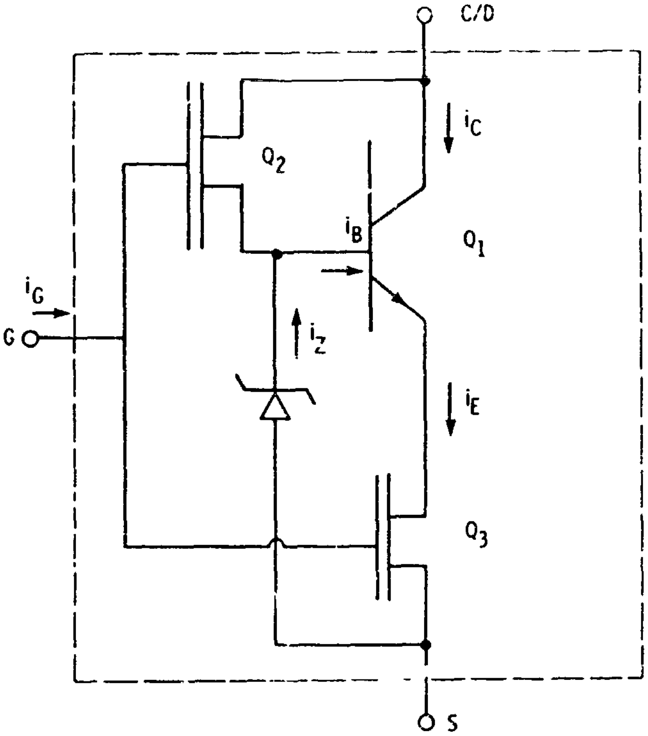
C/D
i_C
Q_2
i_B
Q_1
i_G
G
i_Z
i_E
Q_3
S

Figure 9. - FET-gated bipolar power transistors (FGT).

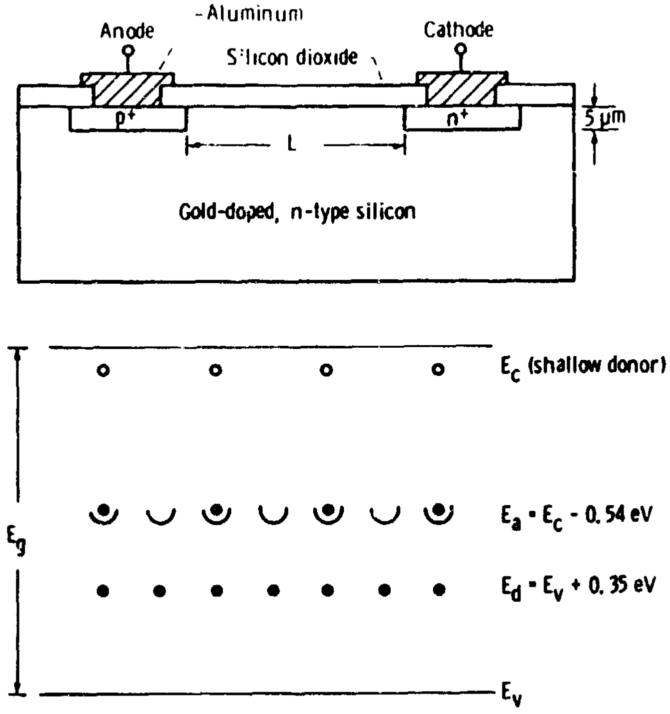
Anode
Aluminum
Cathode
Silicon dioxide
p^+
n^+
L
5 µm
Gold-doped, n-type silicon
E_C (shallow donor)
E_g
$E_a = E_C - 0.54$ eV
$E_d = E_V + 0.35$ eV
E_V

Figure 10. - Cross section and energy level diagram of double-injection deep-impurity switch.

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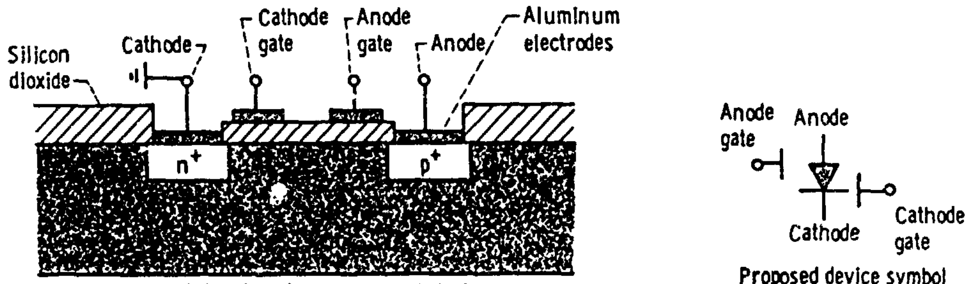
Silicon dioxide
Cathode
Cathode gate
Anode gate
Anode
Aluminum electrodes
n+
p+
Anode gate
Anode
Cathode
Cathode gate

Gold-doped, n-type silicon substrate

Proposed device symbol

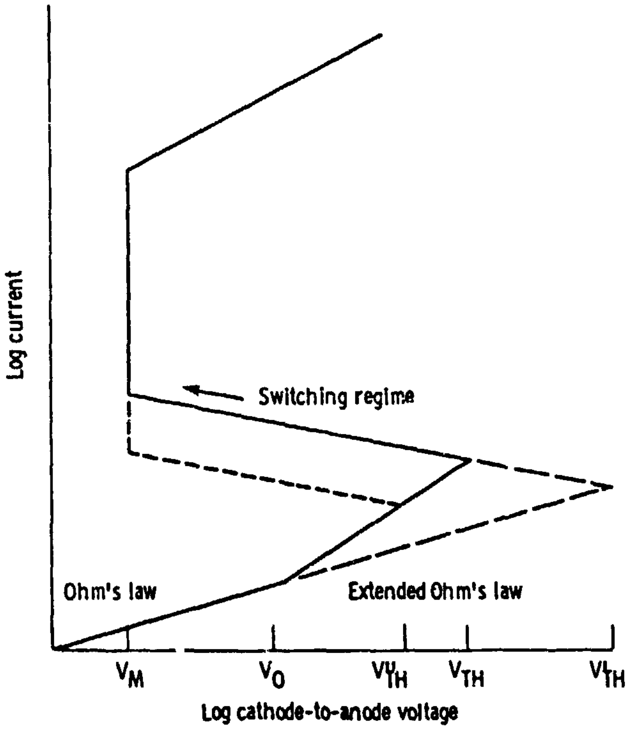

Figure 11. - Volt-ampere characteristic showing voltage gating.

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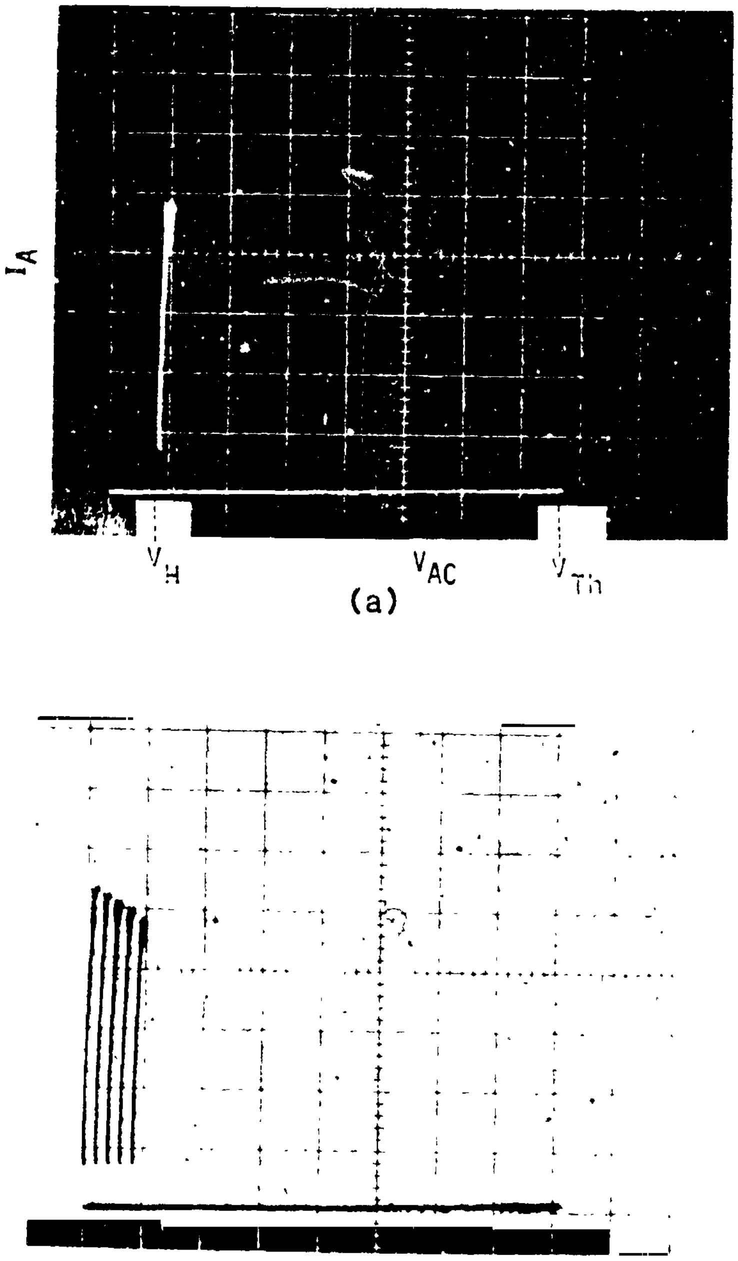

(a)

(b)

igure 12. - Oscilloscope traces showing switching characteristics of injection-gated device.

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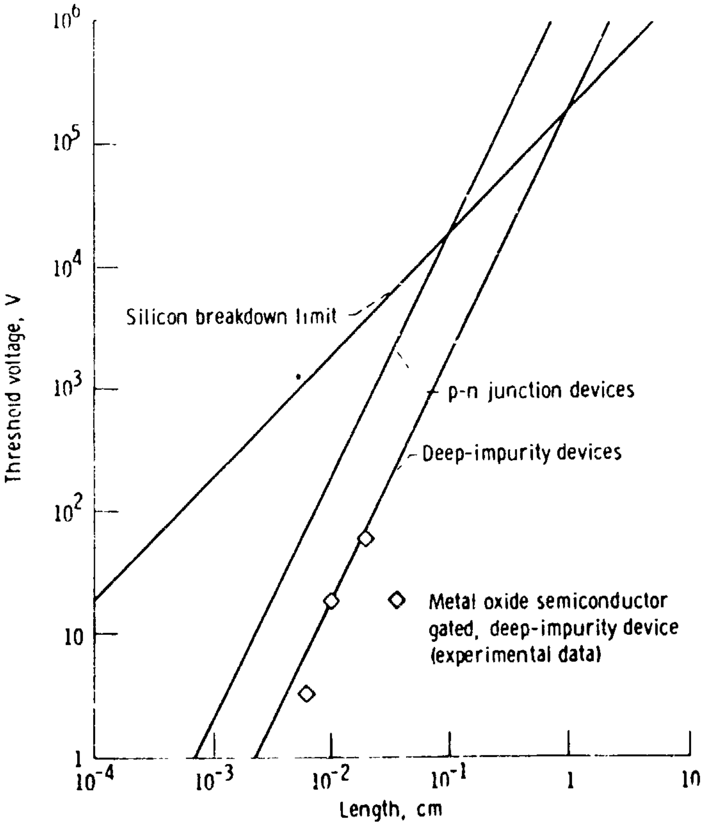

Figure 13. - Voltage limitations in silicon.

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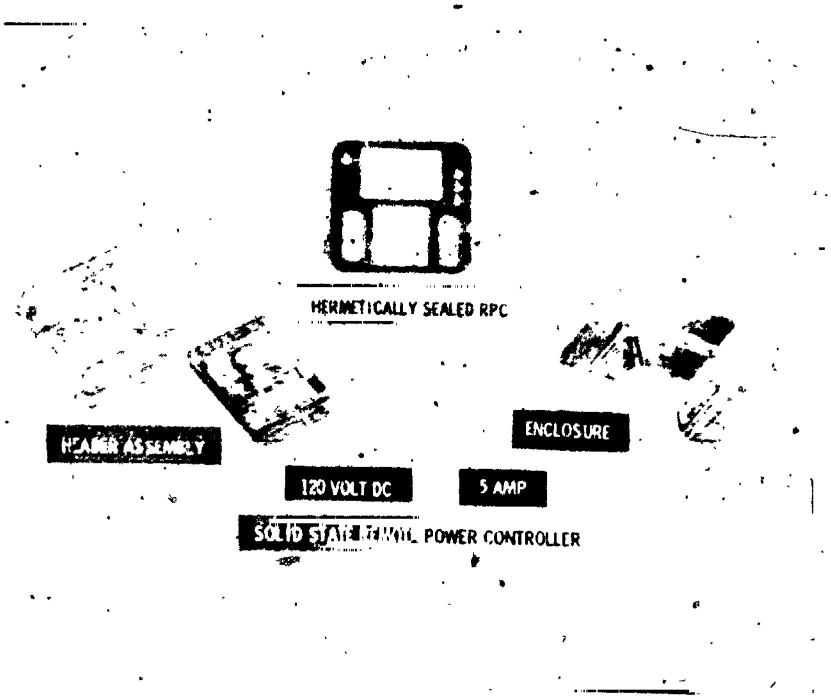
HERMETICALLY SEALED RPC
HEADER ASSEMBLY
ENCLOSURE
120 VOLT DC
5 AMP
SOLID STATE REMOTE POWER CONTROLLER

Figure 14. - 120-V, 5-A solid-state remote power controller.

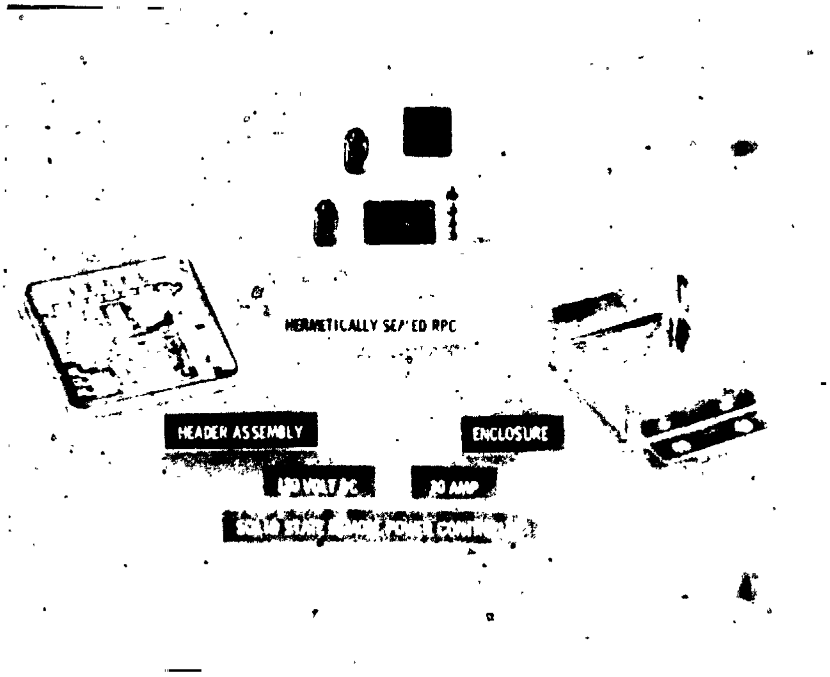
HERMETICALLY SEALED RPC
HEADER ASSEMBLY
ENCLOSURE
120 VOLT DC
30 AMP

Figure 15. - 120-V, 30-A solid-state remote power controller.

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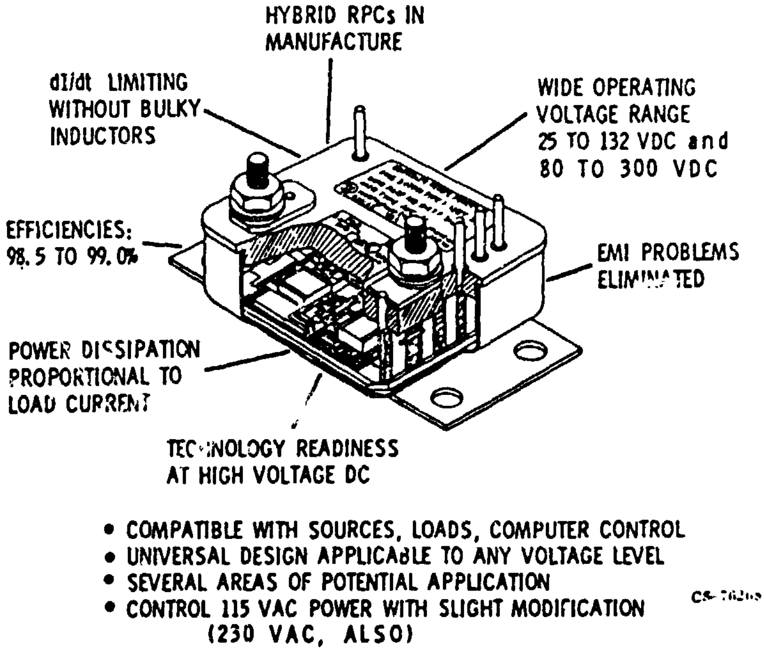
HYBRID RPCs IN MANUFACTURE
dI/dt LIMITING WITHOUT BULKY INDUCTORS
WIDE OPERATING VOLTAGE RANGE 25 TO 132 VDC and 80 TO 300 VDC
EFFICIENCIES: 98.5 TO 99.0%
EMI PROBLEMS ELIMINATED
POWER DISSIPATION PROPORTIONAL TO LOAD CURRENT
TECHNOLOGY READINESS AT HIGH VOLTAGE DC
• COMPATIBLE WITH SOURCES, LOADS, COMPUTER CONTROL
• UNIVERSAL DESIGN APPLICABLE TO ANY VOLTAGE LEVEL
• SEVERAL AREAS OF POTENTIAL APPLICATION
• CONTROL 115 VAC POWER WITH SLIGHT MODIFICATION (230 VAC, ALSO)

Figure 16. - Advantages of solid-state remote power controller.