BNL-28664

CONF-801103--45

November, 1980

CONDUCTION COOLING: MULTICRATE FASTBUS HARDWARE

MASTER

D. Makowiecki, W. Sims, R. Larsen, L. Leipuner, W. Morse, T. Rudolf,
J. Fuhrmann, S. Blatt, M. Campbell, H. Kasha, M. Schmidt and W. Zhaungzi

The submitted manuscript has been authored under contract DE-AC02-76CH00016 with the U.S. Department of Energy. Accordingly, the U.S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or allow others to do so, for U.S. Government purposes.

CONDUCTION COOLING: MULTICRATE FASTBUS HARDWARE*

D. Makowiecki, W. Sims, R. Larsen, L. Leipuner, W. Morse, T. Rudolf and J. Fuhrmann
Brookhaven National Laboratory, Upton, New York 11973

S. Blatt, M. Campbell, H. Kasha and M. Schmidt
Yale University, New Haven, Connecticut 06520

W. Zhaungzi
Academia Sinica, Bejing, China

SUMMARY

Described is a new and novel approach for cooling nuclear instrumentation modules via heat conduction. We will show the simplicity of liquid cooled crates and ease of thermal management with conduction cooled modules. While this system was developed primarily for the higher power levels expected with Fastbus electronics, it has many general applications.

INTRODUCTION

It has been the accepted procedure in the past to chill the air in rooms containing electronic equipment and then force this cooled air past the equipment to be cooled. This is both a wasteful and an uncomfortable scheme. We present below a simple and uncomplicated alternative.

We will describe the mechanics of a multicrate modular data gathering system using forced liquid conduction cooling. This system was developed at Brookhaven National Laboratory to handle the larger power requirements (1500 watts per crate) anticipated in FASTBUS crates. The system is presently being used in an experiment at Brookhaven's Alternating Gradient Synchrotron (AGS) to test the extent of the validity of time reversal invariance.

The design goal was to develop a simple and cost effective system that could easily handle the increased thermal load expected from the higher power density FASTBUS modules, without the drawbacks of large noisy air cooled systems. We believe that we have accomplished this.

In larger multicrate systems forced liquid cooling can provide more than a magnitude greater heat transfer per surface area than does forced air cooling. This permits one to construct a very compact cooling system. Typically a complete cooling system will add 3/4 of an inch to the crate height as compared to 12-14 inches for air intake/exhaust plenums. Plastic tubing and a source of tap water are all that are generally required to provide efficient cooling.

Many of the problems associated with moving large amounts of cool air are eliminated. The use of liquid cooling eliminates the accoustic noise and vibrational problems associated with forced air cooling fans. In a zero air flow system many of the dust and dirt related problems are also eliminated.

THE CRATE

The crate is fabricated from two heat conducting water cooled manifolds, side plates, temperature operated flow valve and a printed circuit backplane.

MECHANICAL

Each manifold consists of two identically extruded aluminum plates. (See Figure 1). These plates are aligned and mechanically held together with two aluminum tie bars front and rear. The extruded plates act both as the guide rails for the modules and as heat conducting manifolds.

Figure 1. A water cooled Fastbus Crate

Coolant flowing thru 3/8" copper tubing (embedded in the manifold) removes the heat from the crate. The use of copper tubing eliminates the need for de-ionized water. The tubing is pressed into the extrusions with a special jig which deforms the soft copper until it takes the obround shape of the extruded channel. This shape was chosen to retain the copper within the manifold, and to provide maximum surface contact area for efficient heat transfer. By folding the copper tubing back on itself we can maintain a temperature differential of less that ± 1°C across the crate.

The side panels are stamped out of 0.062" (15.75 mm) flat sheet aluminum stock. The panels are extended in the rear approximately 3.5" (89 mm) beyond the extruded manifolds to protect the backplane and water flow valve. Two hand grips have been provided in the rear of the panels to facilitate easy installation in a rack.

The remainder of the crate is fabricated using standard extrusion and flat stock.

FLOW CONTROL VALVE

One of the major problems associated with liquid cooling is the condensation of water on the cooling manifold whenever the surrounding temperature falls below the dew point. To prevent this from happening we have chosen to restrict the flow of coolant to the crate with a small mechanical temperature actuated flow valve. The arrangement is completely mechanical.

---

*Work performed under the auspices of the U.S. Department of Energy. Contract No. DE-AC02-76CH00016.

The flow control valve (Figure 2) is constructed using a standard rotary or lever operated flow valve and a heat sensitive actuator. The actuator consists of two "Solar Thrust" thermal elements with a common stem between them. The copper actuator elements contain a non-toxic chemical which expands when it melts at a predetermined temperature. (Figure 3). This expansion stretches the diaphragm which pushes against the common stem increasing the overall length of the actuator. The minimum travel is 0.75" (19 mm) with a force of 35 lbs. (16 Kg). The temperature elements can be manufactured with any starting temperature between 15°C and 120°C.

Figure 2. Flow Control Valves. Shown from top to bottom is a rotary control valve, a lever operated control valve and the actuators.

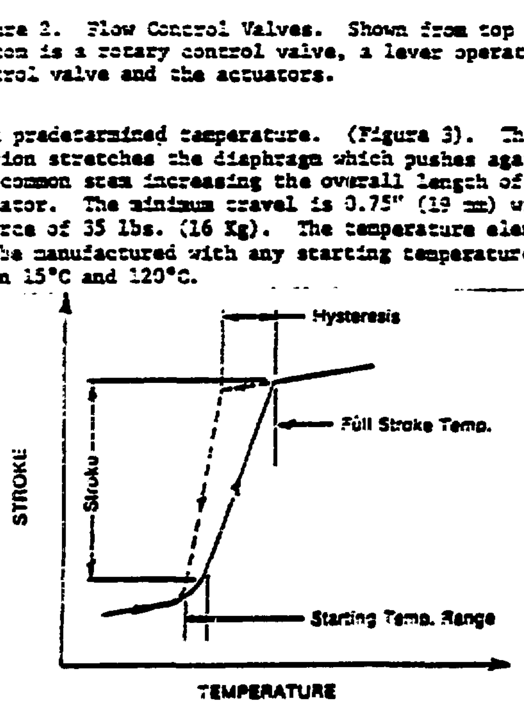


Figure 3. Temperature-stroke curve of a "Solar Thrust" actuator.

Figure 4 is a curve of power versus manifold temperature. The crate was disassembled and a single manifold was tested. The pressure was 3 PSI and the flow rate was 1/2 gallon per minute. Curve "A" is without a flow control valve. Curve "B" and "C" are with the rotary and lever actuated valves.

Figure 4. Shows power for a single manifold vs. temperature. Crate power levels (2 manifolds) should be scaled accordingly.

BACKPLANE

The FASTBUS backplane is constructed as a 3 layer printed circuit board containing signal lines, power busses and ground planes.

The unloaded signal lines appear as an 80 Ω microstrip. A ground connection is provided at every fifth pin on the connector. This provides the low impedance, high frequency ground return path necessary for ECL signals.

A high quality brush contact type mating connector (130 pin) manufactured by Bendix Electrical Components Division was chosen for the backplane. The connector has a high current capacity (5 amps per contact), low insertion force and tolerance to misalignments of greater than 0.04" (1 mm) in both horizontal and vertical directions.

The high current carrying capacity allows the total power requirements for a module to be carried by a single pin.* This eliminates the problems associated with current sharing over many pins.

CRATE SPECIFICATIONS

The crate is 15 3/4" (400 mm) high, 18.375" (466.7 mm) deep and accepts a standard 19" rack mounting. Twenty modules at a pitch of 0.850" (21.6 mm) can be housed. The complete crate with backplane, copper tubing and flow valve weighs 35 lbs (16 Kg).

CONDUCTION COOLING (A PRIMER)

Electronics components produce heat. As the heat is generated the temperature of these components increase. The heat attempts to flow thru any path it can find. Assuming a constant heat source, the temperature of the components will continue to rise until the rate of the heat being generated is equal to the rate of the heat flowing away from the components. At this point steady state heat transfer exists.

---

*On board *switching regulators power conversion assumed.*

Heat always flows from high temperature areas to low temperature areas. When a system is in operation, the electronic components will generally be the hottest part of the system. In order to control the component temperatures, the heat flow path must be controlled. If this is not done properly, the component temperatures will be forced to rise in an attempt to balance the heat load. Eventually the temperature may become so high that the components will be destroyed.

There are many techniques presently available to optimize these heat flow paths. For low power modules a heavy copper ground plane may be sufficient to remove the heat. Modules that dissipate more power may transfer their heat from the top of the IC's via a heat conducting median to a side plate or cover plate. Still higher power modules may require a heat conducting lattice, aluminum core printed circuit boards or heat pipes. Some of these methods are more practical and less expensive than others. The techniques are left to the designers.

THE MODULE

Each module consists of a .0625" (15.75 mm) aluminum cover plate, two "T" extrusions, spacers, printed circuit boards, wedging mechanism and front panel. A heat conducting lattice and rear panel are optional. Thermal contact is made between the modules cover plate and the crates cooling manifold by actuating a top and bottom wedging mechanism. (See Figure 5.)

Figure 5. Detail of wedging mechanism. Rotating the locking knob swings out the cams and forces the module tightly against the crates manifold.

WEDGING MECHANISM

The wedging mechanism is an integral part of the top and bottom "T" extrusions, which with the cover plate form the basic module. The wedge consists of a draw bar. cam, stop blocks and a captivated nut actuating knob. By turning the locking knob, the five cam's rotate out and force the modules cover plate tightly against the crate's manifold. This then provides a heat conducting path between the module and crate. Reversing the direction of rotation releases the module.

A TYPICAL CONDUCTION COOLED MODULE

Figure 6 shows a typical conduction cooled module. The heat is transferred from the top of the IC's via a silicone rubber sheet (thermal coefficient .004 - .01 watts/inch °C) to the cover plate. The silicone rubber has a low durameter index (approx. 30) thus allowing for slight differences in the heights of the integrated circuits. The IC's are located between the printed circuit board and the cover plate/silicone rubber sheet. The extrusion and spacers complete the sandwich type arrangement. Separate mounting screws for the cover plate and printed circuit board allow one to repair the unit without disassembling the entire module. Module power levels of up to 40 watts can be handled with this arrangement.

Figure 6. A Fastbus conduction cooled module. The heat is transferred from the top of the IC's via a silicone rubber sheet to the cover plate.

Higher power levels (up to 80 watts) can be handled. with a lattice arrangement. (See Figure 7). Each IC straddles the lattice. Heat is transferred from the bottom of the integrated circuits via the heat conducting aluminum lattice. Aluminum rails are placed at regular intervals between the lattice and cover plate. These serve the dual purpose of defining the gap between the printed circuit board and cover plate and of transferring heat to the cover plate. Additional heat paths can be provided by placing silicone rubber pads between the IC's and cover plate. Combinations of the two proceeding cooling schemes are also possible.

RESULTS

Several modules with power dissipation levels ranging between 35 and 85 watts have been constructed. With the exception of a thermometer test module, the case temperatures of the IC's have been measured with a temperature probe.

The method was to construct a power dissipation profile of each module based upon the IC manufacturers "worst case" power levels. Potential hot spots were defined and a small 1/8" diameter hole was drilled thru the cover plates directly above each IC to be measured. Temperatures were measured by inserting a small temperature probe directly against the IC cases. Case temperatures ranged from ambient to 52 °C.

Figure 7. A Fastbus Conduction Cooled Module with Lattice. The heat is transferred from the bottom of the IC's via the heat conducting lattice. Cross rails are provided to transfer the heat from the lattice to the cover plates.

Additional tests were performed using a specially designed thermometer test module. Plastic DIP IC packages containing transistor arrays and resistor packs were configured as emitter followers. By controlling the base and collector voltages the power dissipation level in the packages could be well defined. The junction temperature was determined by calibrating the base-emitter voltage of a separate transistor (located on the same substrate as the emitter follower transistors) as a function of temperature.

Figure 8. A junction temperature profile using a thermometer test module. 75 watt power load.

Figure 8 is a junction temperature profile obtained with fifty of the emitter follower circuits (100 DIP packages) constructed on a Fastbus printed circuit board. The 75 watt power load was distributed evenly betwen all 100 DIP packages.

Figure 9 gives the range of junction temperatures for three module power levels 25W, 50W and 75W. The effects of adjacent modules is also shown.

Figure 9. Junction temperature range as a function of total module power.

CONCLUSION

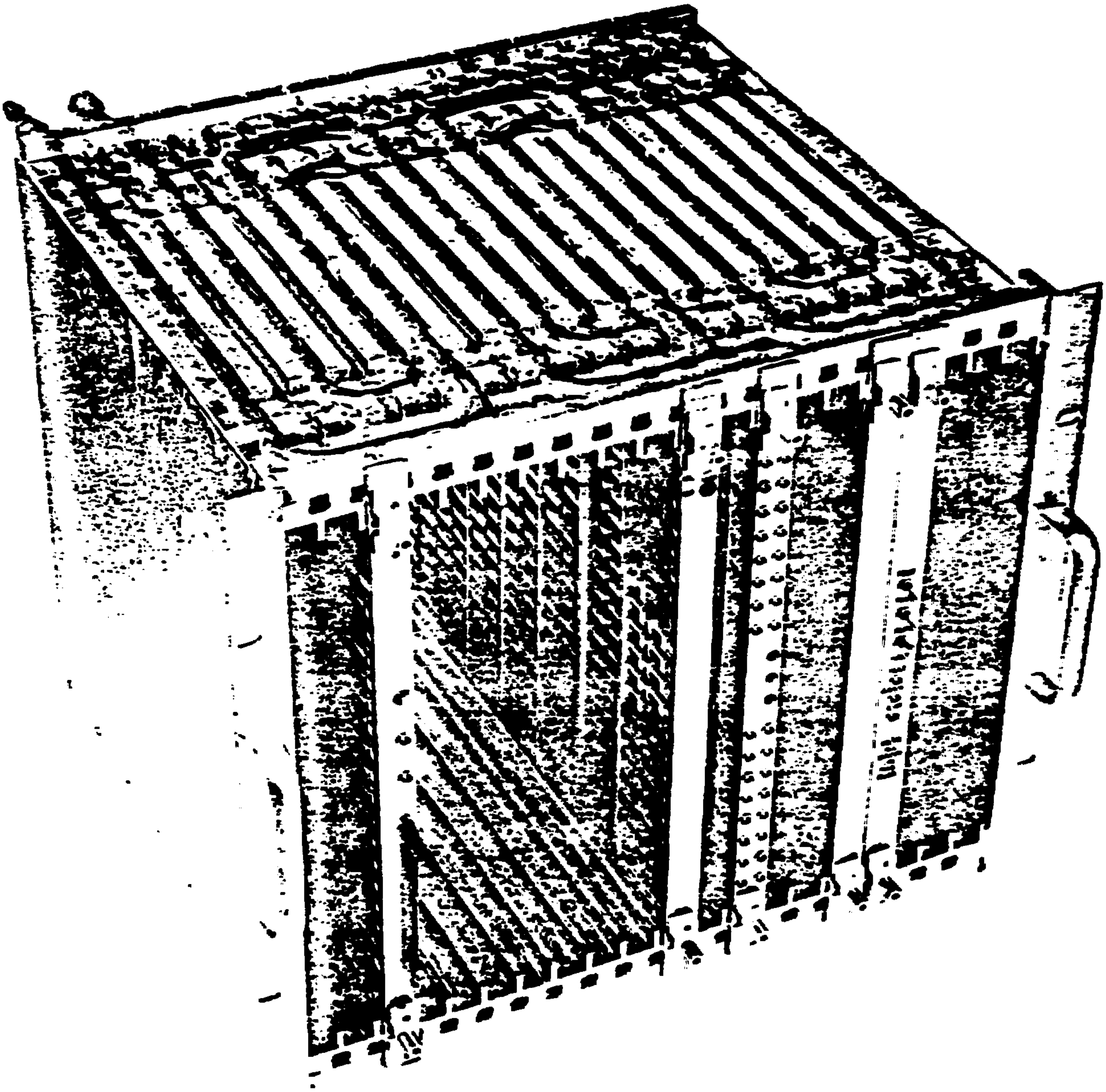
Seventeen conduction cooled modules and three water cooled crates have been constructed. The modules contained both printed circuit layouts and wire wrap "KLUDGE" boards. The majority of the modules contain ECL logic. Module power dissipation levels ranged between thirty-five (35) and eighty (80) watts. Every effort was made to handle the thermal management via conduction cooling and to fabricate the modules for ease of repair and maintenance. In no instance did IC case temperature exceed 53°C. The crates were cooled with either tap water or the coolant discharge from the beam transport magnets cooling system.

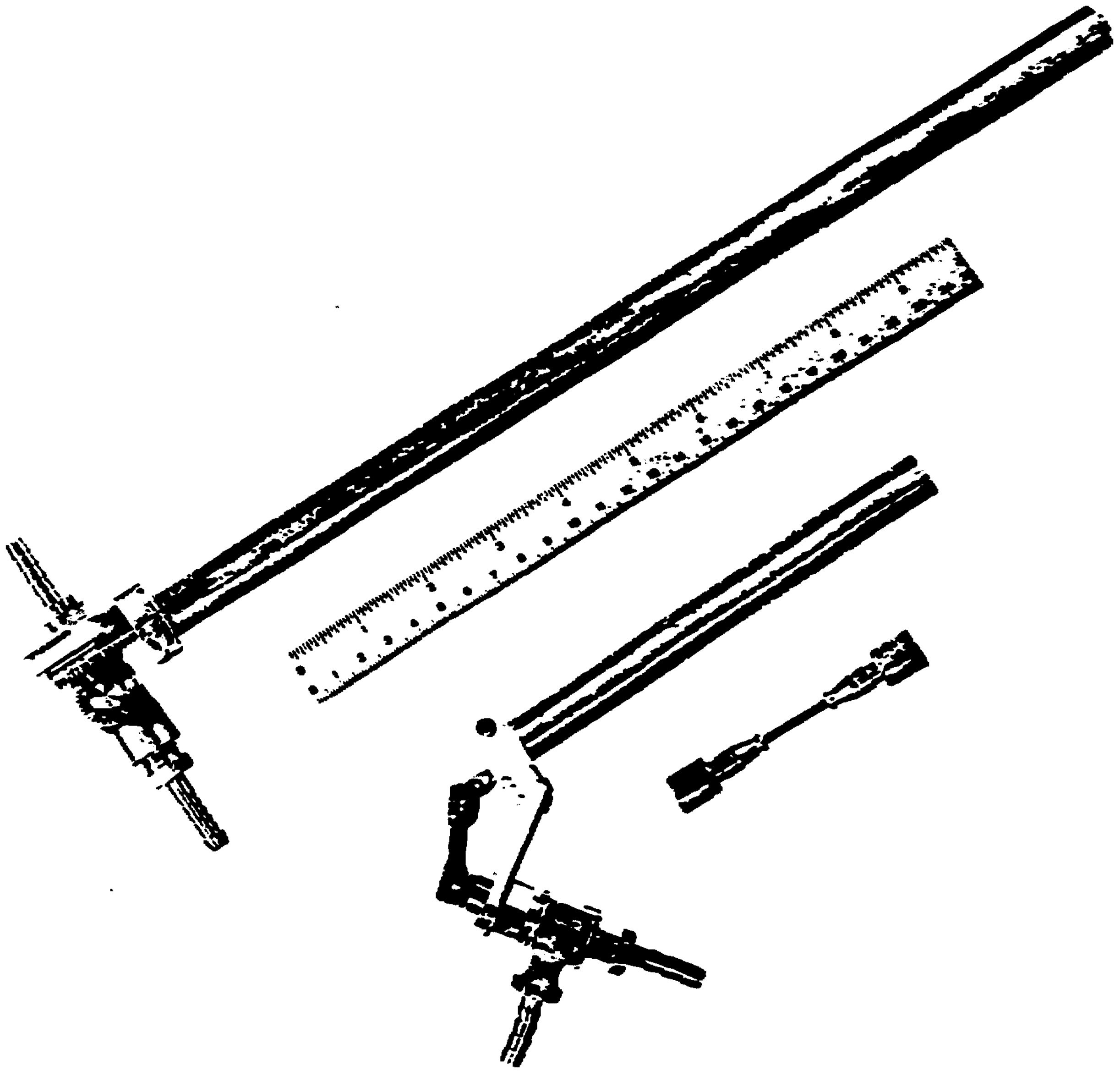
The units were in continuous operation for a period of two months during the summer of 1980 in an experiment at Brookhaven's AGS. In no case were any component failures attributed to overheating.

In conclusion our operating experience with the conduction cooling of Fastbus Modules has been a positive one. We have demonstrated the feasibility and cost effectiveness of such an approach, for both low and high power modules, in small and large systems. It is our intension to continue with the development and refinement of this approach.

ACKNOWLEDGMENTS

The authors would like to express their appreciation to the many people at Brookhaven for their interest in, and support of this project. In particular to Al Roebuck in the Physics machine shop who did much of the original prototyping work. To Tim Tuttle and Bill Lenz for their work on the temperature flow valve, and to Pat Labitski who has typed the many papers and reports associated with this project.





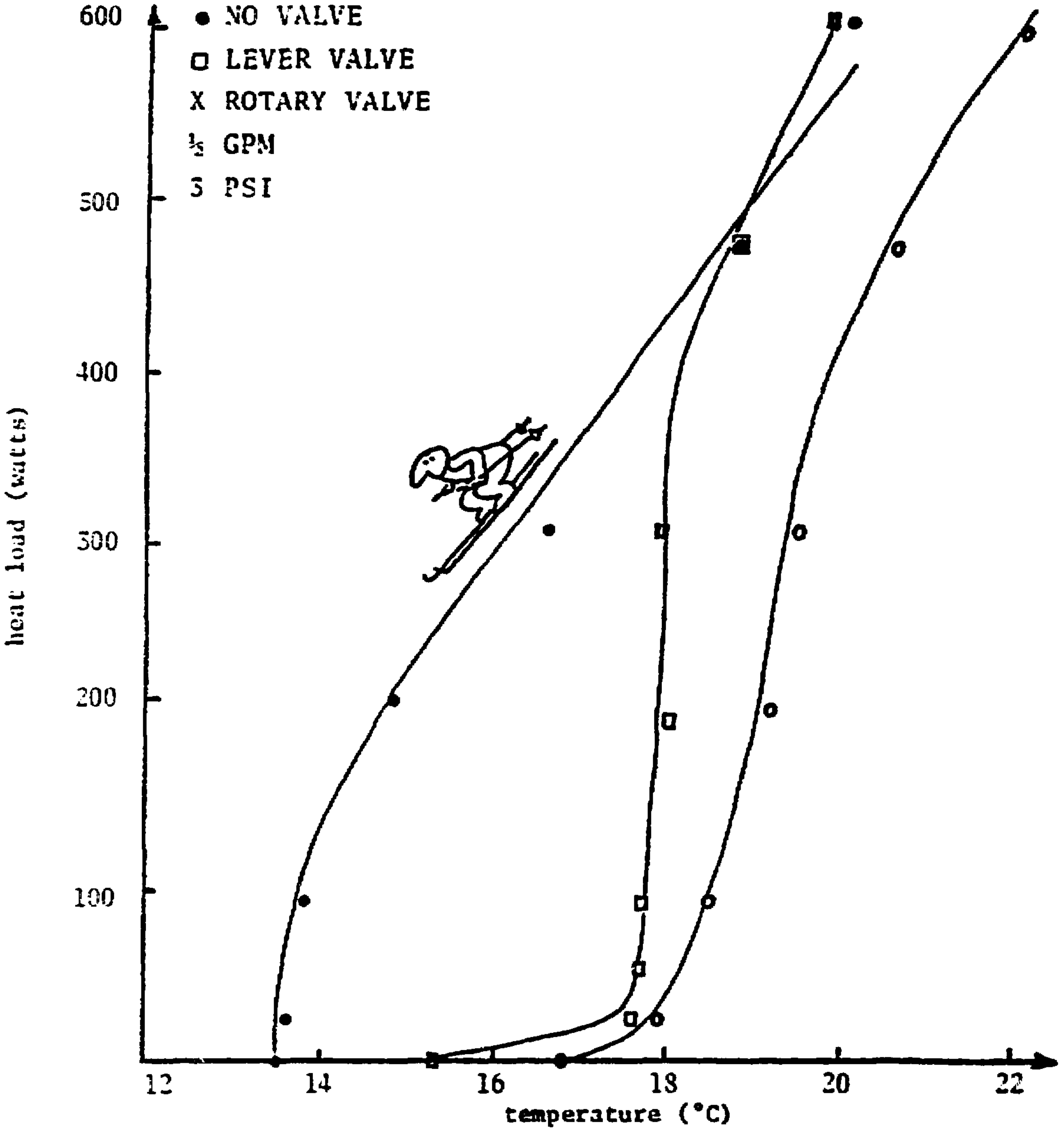
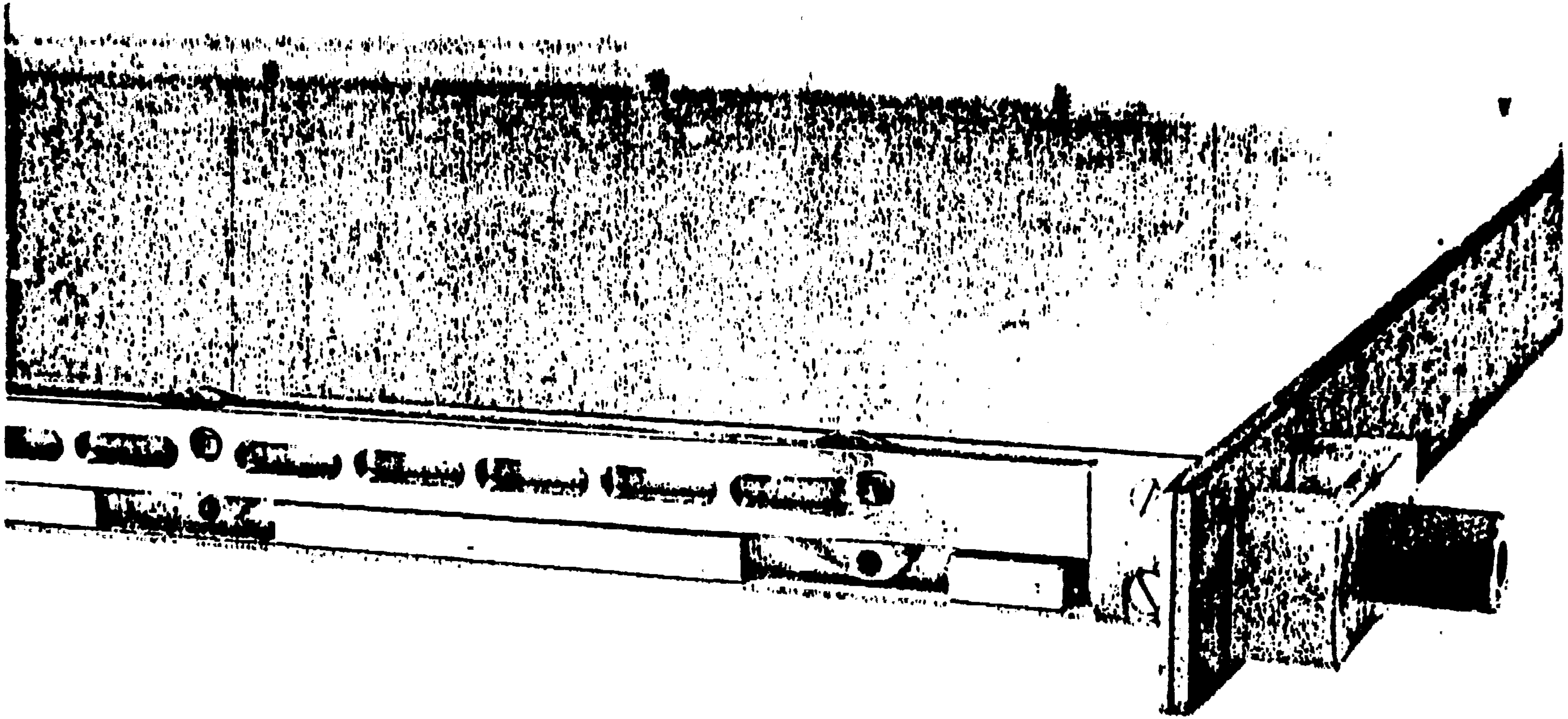
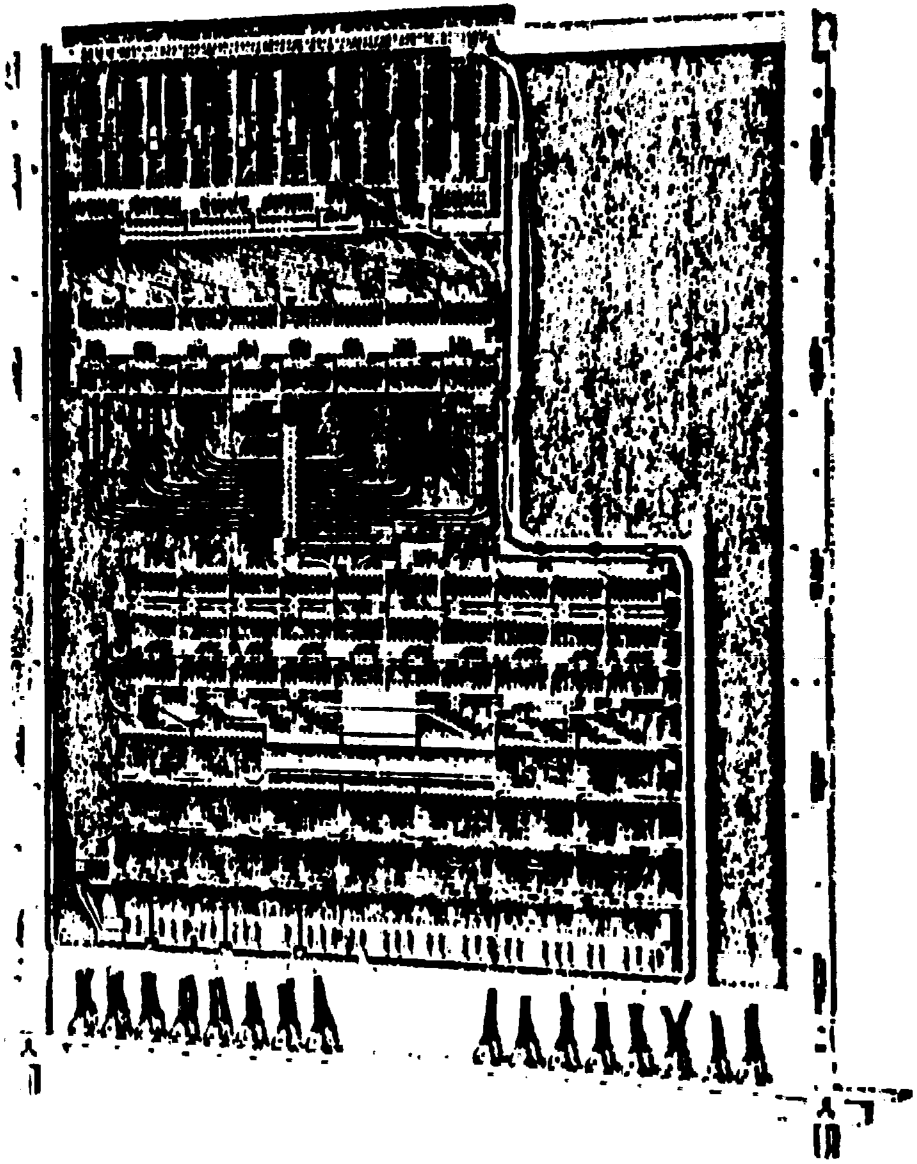
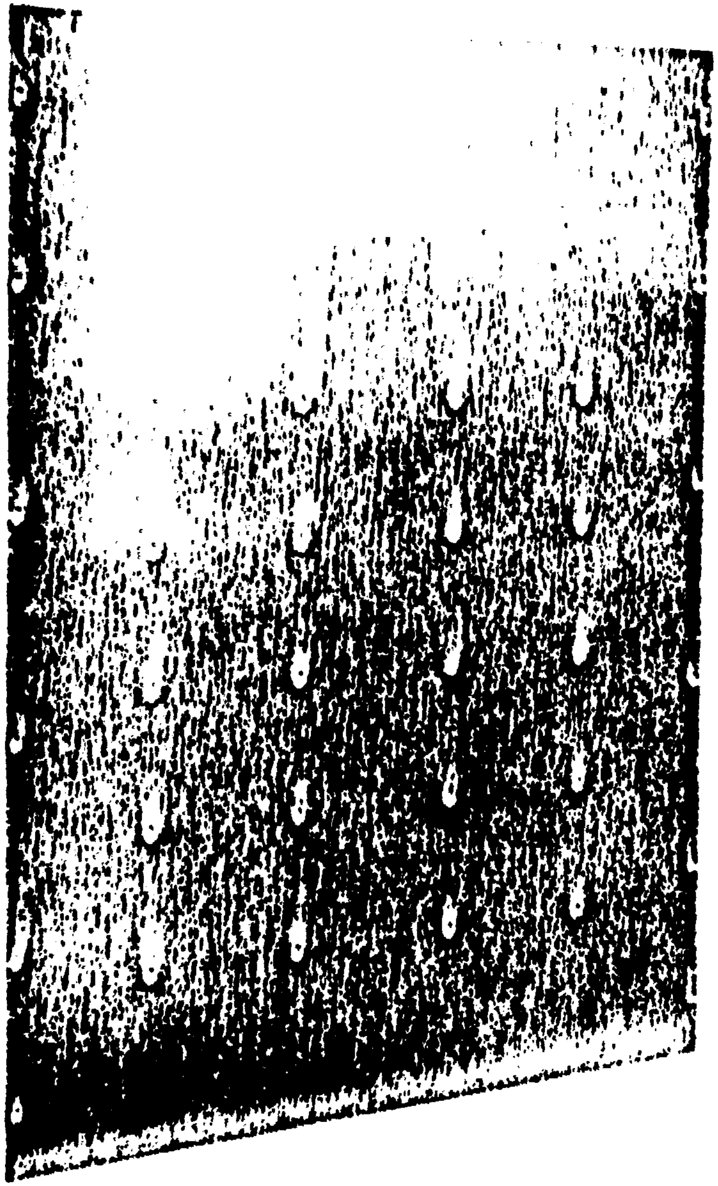
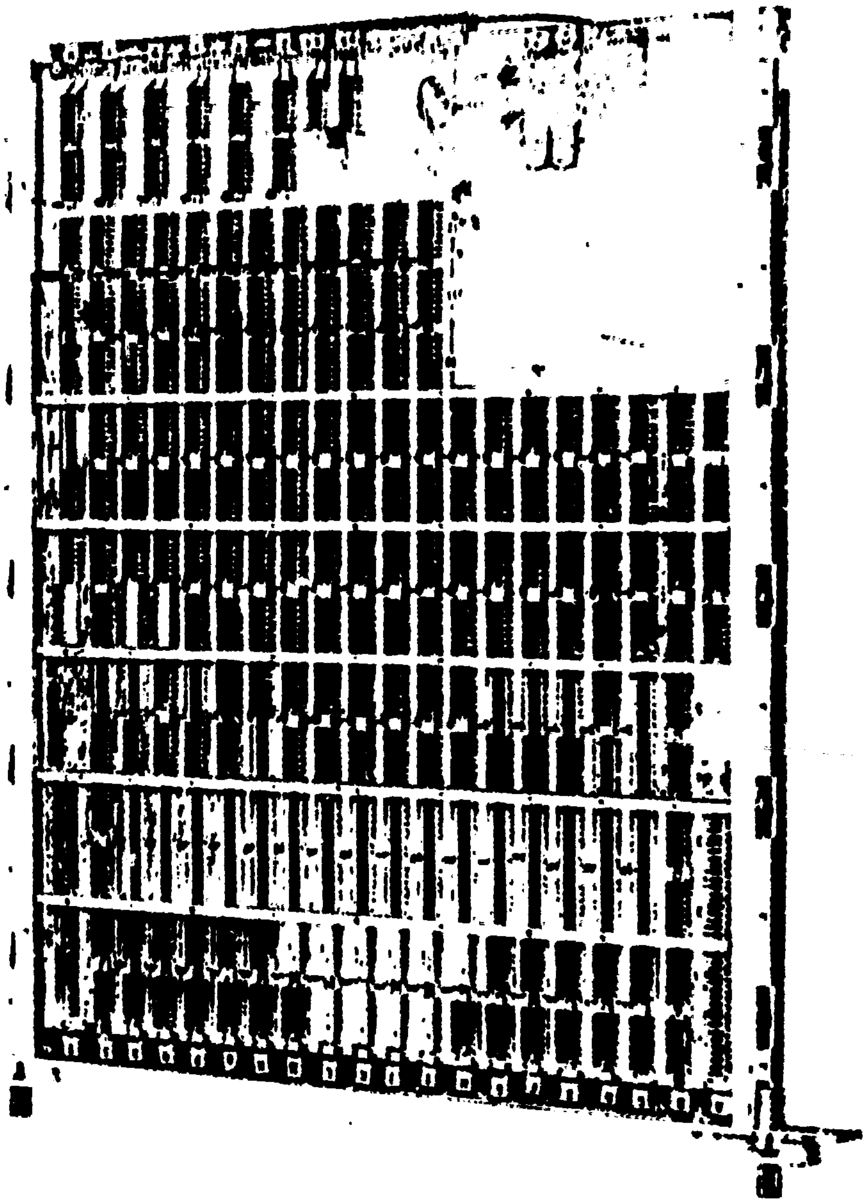

● NO VALVE
□ LEVER VALVE
X ROTARY VALVE
½ GPM
5 PSI
600
500
400
300
200
100
heat load (watts)
12
14
16
18
20
22
temperature (°C)

figure #4

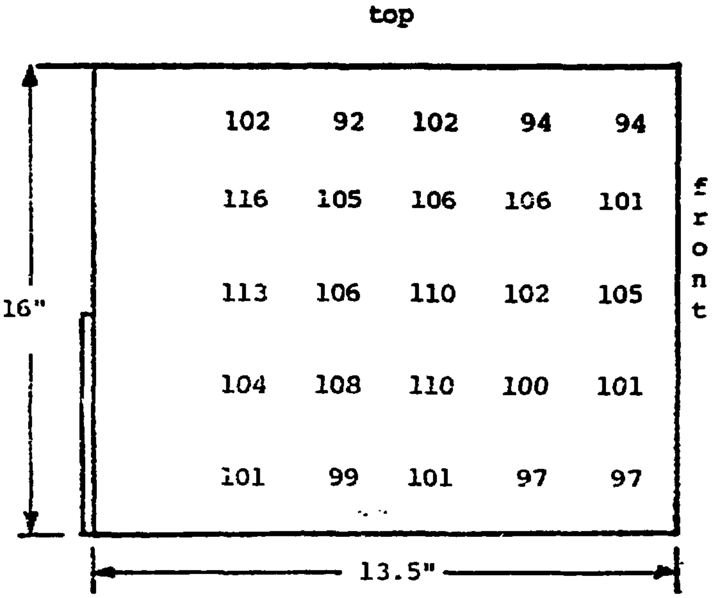






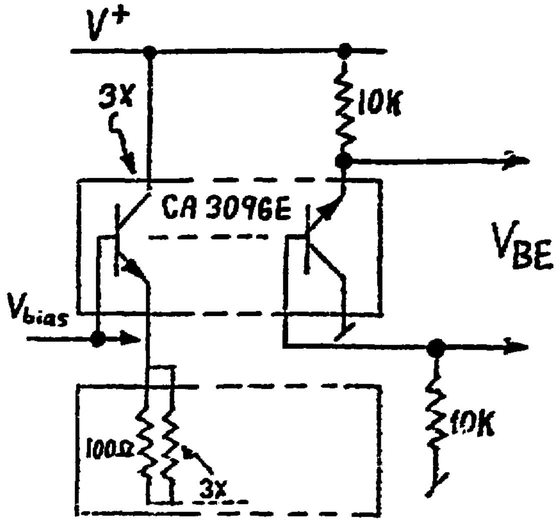


JUNCTION TEMPERATURE PROFILE °C



102	92	102	94	94
116	105	106	106	101
113	106	110	102	105
104	108	110	100	101
101	99	101	97	97

TEST CIRCUIT (50X)



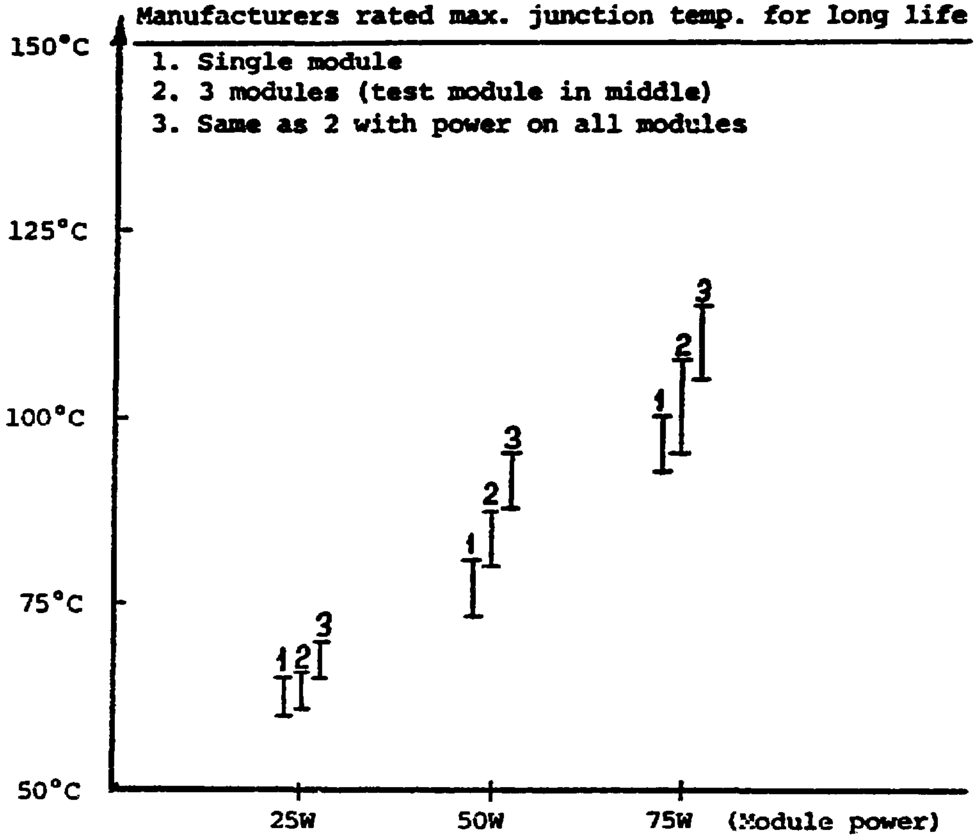

Manufacturers rated max. junction temp. for long life
1. Single module
2. 3 modules (test module in middle)
3. Same as 2 with power on all modules
150°C
125°C
100°C
75°C
50°C
1
2
3
25W
50W
75W
(Module power)

figure #9