NEW GENERATION HAST SYSTEM*

Intel Corporation, December 19, 1994

Summary

Improved reliability of non-hermetic electronic components has made traditional 85/85 temperature-humidity-bias (THB) testing inconvenient. HAST has emerged as an equivalent test which can generate data in much shorter times. However, difficulties with HAST equipment on the market have hindered widespread adoption of the HAST test. Two kinds of HAST chamber design are available; one uses natural convection for thermal equilibration of the test volume, while the other uses forced convection. The natural convection design does not scale well to the large chamber volumes needed for production HAST stress. We describe a "New Generation" (NG) large-chamber HAST system which relies on the more effective forced convection design, and which incorporates other control, monitoring and human interface improvements.

Temperature-Humidity-Bias Test Methods

Test Flows

A typical moisture-related reliability test flow is shown in Fig. 1. The first stress simulates the board-mount process in which components are exposed to solder reflow temperatures, typically about 215°C. Next, DUTs are subjected to environmental stresses which simulate service life. One of the stresses is the THB stress. After a prescribed duration under bias in a high-temperature humid atmosphere (typically 1000 hours for the traditional "85/85" stress), the DUTs are removed from the stress and tested. During the THB stress, moisture quickly (tens of hours for 85/85) penetrates the molding compound which encapsulates the active circuit and comes to an equilibrium concentration. It has been demonstrated that, to a good approximation, the equilibrium moisture concentration in the molding compound is a function only of the relative humidity (85%) to which the DUT is exposed during the stress. Since these relative humidities also occur in service (albeit at lower temperatures), saturation of the molding compound is a condition of the DUT which should be preserved when it is tested, since the moisture content of the molding compound may contribute to a valid failure mechanism. This issue is addressed by using a quick ramp-down from stress conditions, so that the DUTs will not bake to dryness, and by testing the DUTs within a 48 hour test window, so that they will not dry out "on the bench". Baking of DUTs is sometimes done as a failure analysis tactic, but only after the DUT has been thoroughly tested.

85/85

The "85/85" test described for example, in JEDEC Test Method 22-A101 "Steady-State Temperature Humidity Bias Life Test" has been used for THB testing of non-hermetic electronic components. Improvements in materials and processes have made it necessary to stress samples in the 85/85 environment for thousands of hours before moisture-related failures are seen. Moreover, the typical 1000 hour (6 weeks) test time is impractical for process monitors, and is the most time-consuming part of any technology certification or product qualification. The major bottlenecks in the test flow are highlighted in Fig. 1.

HAST Testing

HAST (Highly Accelerated Stress Testing) has emerged as a way to shorten the testing time, and produce the same failure mechanisms as would occur in 85/85 testing. In HAST testing, 85% relative humidity is typically used, but the temperatures used can be as high as 165°C. At 85% relative humidity, temperatures higher than 104.6°C require the use of a pressure vessel. HAST pressure vessels are rated at up to 6 atmospheres (gauge).

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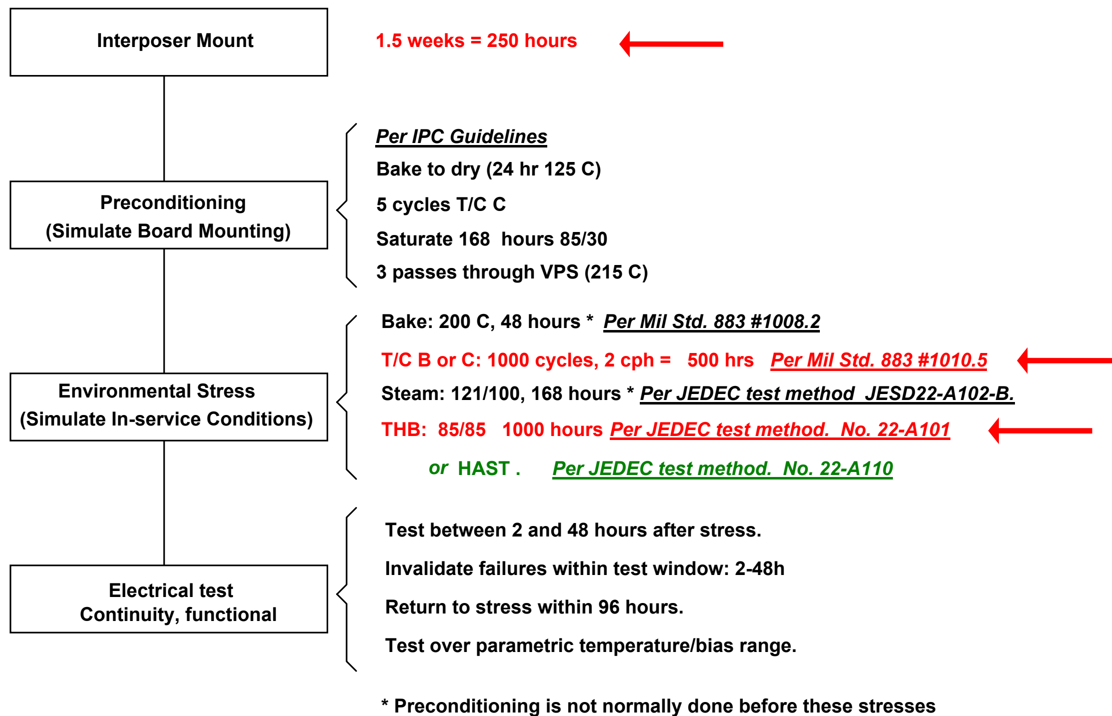

Fig. 1 Typical process reliability certification flow showing major bottlenecks (red arrows).

The HAST test temperature chosen is usually the highest which produces only the same mechanisms observed in (very long) stresses in 85/85. The JEDEC Test Method No. 22-A110 "Highly-Accelerated Temperature and Humidity Stress Test (HAST)" provides guidelines for HAST testing and specifies temperatures of 110°C, 120°C, 130°C and 140°C, all at 85% relative humidity. The test method warns of possible artifacts introduced at 140°C. 140°C exceeds the glass transition temperature of encapsulating molding compounds and so may induce failure mechanisms which do not occur at lower temperatures. However, there is consensus in the electronic industry that temperatures up to 130°C do not introduce artifactual failure mechanisms in a broad class of non-hermetic components. So 130/85 has emerged as a THB standard which can replace 85/85. Higher temperatures are frequently used for accelerated testing of *specific* materials and process modules where it is known that artifacts are not introduced. For example, in wafer-level HAST testing, very high temperatures can be used.

HAST Testing Problems

In spite of the potential advantages of HAST testing, difficulties with the actual equipment available have hindered its widespread adoption. Major issues are:

1. *Control of Ramp-Up.* Temperature gradients (and therefore relative humidity profiles) during the ramp up to the test condition are often insufficiently characterized. If the temperature at some point in the test volume falls below the wet bulb temperature (the temperature of the water reservoir), then condensation at that point will occur. The ramp-up stage is particularly vulnerable to this problem because the temperature of the test volume tends to lag the rest of the system. The severity of the effect depends on the mass loading of the chamber. Ramp-up must be slow enough, with sufficient convective mixing, to avoid steep temperature gradients across the test volume. Otherwise moisture condensation will occur at some time in some part of the load. Liquid water provides a medium for corrosion and transportation of contaminants, reacts with solder causing pin-to-pin leakage etc. This is often unknown to the user, and "mysterious" incidents of fixture or DUT corrosion, pin-pin leakage, etc. give the test method a troublesome reputation.

2. *Control of Ramp-Down.* During ramp-down, even natural cooling (and consequent depressurization) may be rapid enough to allow pressure differentials between the inside and outside of the DUT

package to occur. These pressure differentials can cause artifacts such as package delamination or other mechanical damage. Moreover, if the ramp-down rate is uncontrolled, it will depend on mass loading. Thus a light load may allow the vessel to cool more quickly, leading to more delamination artifacts than would occur in a fully-loaded run. Therefore to prevent mechanical artifacts and load-to-load variability, it is desirable always to use a slower-than-natural ramp down with a duration longer than the moisture diffusion time constant of a package - a 3 hour ramp to atmospheric pressure (100°C) is a good choice. It is also desirable to maintain the relative humidity at the set point (typically 85% relative humidity) during ramp-down in order to maintain the moisture content of the DUTs. The rationale for this is that equilibrium moisture content of molding compound is proportional to relative humidity and nearly independent of temperature. It is only necessary to control the ramp down until a wet bulb temperature of slightly above 100°C is reached. The water reservoir can then be drained, with help from the slightly positive gauge pressure, and then the vessel can be vented. DUTs are unaffected by the rest of the ramp-down since the chamber is dry, and the kinetics of moisture diffusion in molding compound (that is, dry-out) are negligibly slow below this temperature.

3. *Large Chambers.* Only a few vendors offer large chambers. Large (about 6 cubic feet) cylindrical chambers with aspect ratio of about 1 are needed to replace 85/85 production equipment, but the larger the chamber, the less uniform are the temperature (and therefore, humidity) profiles.

4. *Monitoring Systems.* The condition of the system, the chamber ambient, and the condition of the DUTs should be monitored and logged continuously to a disk file. In real time these data enable automatic response to out-of-specification conditions to preserve the integrity of DUTs. After the stress, the data can be used to prove the validity of the stress. Before the NG HAST system, this level of control has not been available in turn-key HAST systems.

5. *Power Supply Systems.* Multiple independently controllable power supplies are needed in order to manage the bias supply to many test boards (typically 30) in the test chamber. In-house systems built from commercial power supplies are usually expensive and supply multiple boards in parallel. This leads to lack of flexibility and control.

6. *Chamber Fixtures.* There is no widespread consensus on materials and ratings of components (boards, sockets, components for in-chamber ancillary driver circuits, etc.) which will survive the severe ambient in the chamber.

7. *Vendor Issues.* There has been no vendor capable of supplying a "turn-key" HAST system which addresses all of the above issues. This leads to equipment designed differently at each company performing THB testing. These companies vary in the level of resources they are willing to devote to setting up a THB test, which leads to uneven application of the test method.

This report describes the characteristics of a "New Generation" HAST system which addresses most of these issues. Issues relating to chamber fixturing will be discussed separately.

Test Chamber Design

Two distinct kinds of HAST chambers are available. They differ in the kind of convective mixing used to make the temperature profile uniform across the test volume.

1. *Natural Convection* is employed in dual-vessel HAST systems in which the superheated test chamber and the steam generator are separate, but communicate by piping. A heater in the bottom of the test chamber induces natural convective mixing of water vapor.

2. *Forced Convection.* Single vessel chambers employ a fan which forces vapor, superheated by flowing over a heater element, into the test volume. The vapor returns to the heater element after flowing over a water reservoir in the vessel.

The cost efficiency of HAST testing increases as the test volume increases. Today, practical HAST chambers used in production testing are cylinders with a diameter of approximately 24" and an aspect ratio of 1. We compare the performance of the two designs for large production vessels of the same size (24"x24"), and show that the forced-convection design has important advantages.

Natural Convection Chamber Design

The principle of operation of this type of chamber is illustrated in Fig. 2. The chamber has two vessels: A "steam generator", and a "test vessel". The test vessel is maintained at a temperature (corresponding to the desired relative humidity) slightly above the steam generator by heaters with carefully chosen wattage and location. In Fig. 2 a "band" heater on the outside of the test vessel prevents condensation on the vessel wall, and a "plate" heater provides heating beneath the test volume, which induces convective mixing to distribute the heat in the test volume. Careful profiling of a commerially available 24" (deep) x 24" (diameter) natural convection dual-vessel HAST chamber has shown that, although temperature profiles meet the JEDEC test method A110 (+/- 2°C across the test volume) during the steady-state part of the test cycle, large top-to-bottom temperature gradients across the test volume, and consequent condensation, can occur particularly during ramp-up. The control problems with this type of chamber design become greater as the volume of the test chamber becomes larger, especially for the ramp-up to test conditions.

At Intel, we modified the dual vessel HAST chamber to alleviate these problems. The wattage of the plate heater was increased, dual temperature sense in the test volume, independent plate and band heater control, and sophisticated control software were added. Dissipation in the band and plate heaters were carefully balanced during the ramp up to test conditions to optimize the uniformity of the temperature profile. Temperature sensors in the hottest and coldest parts of the test volume provide feedback to the control software to prevent condensation and excessive temperature gradients through the test volume. This degree of control requires sophisticated control with specially-written software. The computer and the software must be in the control loop. This control capability is not available from any vendor, and must be developed by the user. The characteristics of this system are summarized in the 4th column of Table I below. We found it possible to provide a non-condensing ramp-up of a large (about 70 lb) load in a large-vessel (6 cu ft) chamber within the limits of the JEDEC test method.

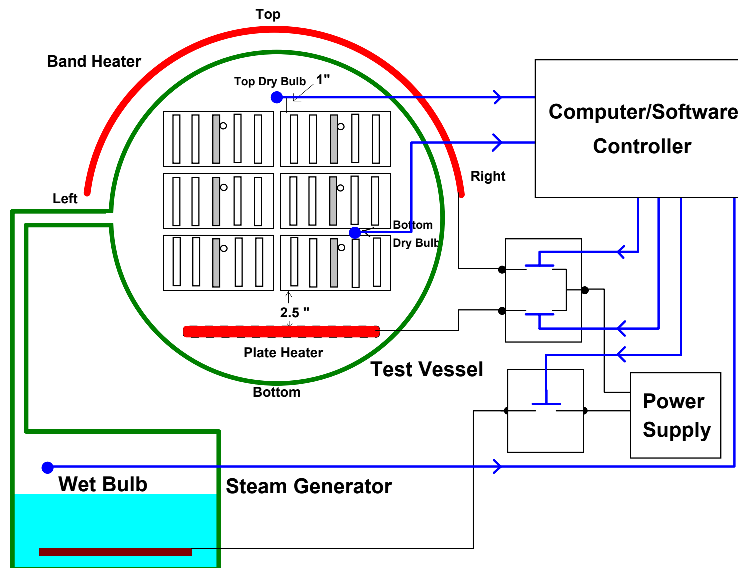

Fig. 2 Design principle of dual vessel natural-convection dual-vessel HAST chamber. Steam generator provides water vapor. Devices under test (DUTs) are mounted in cylindrical test volume (end view shown) which is heated by an internal plate heater and an external band heater. The plate heater generates convective mixing which evens-out the temperature profiles, but the band heater (needed to prevent condensation on vessel walls) tends to prevent heat loss from the top of the vessel, causing "stratification". Careful tuning of independent heater control, and multiple point temperature monitoring is required to ramp up within 3 hours without condensation.

Forced Convection Chamber Design

Difficulties experienced with operation of the dual-vessel natural convection design HAST system led Intel to consider the forced convection single-vessel design for its "New Generation" HAST systems. The primary requirement was that the test volume be the same as the dual-vessel natural-convection system

already in service; an aspect ratio 1 cylinder of diameter 24". The test vessel in this NG system operates on the principle of forced convection, illustrated in Fig. 3. The single vessel contains a water reservoir and a fan. The fan drives water vapor through a heater, superheating it to the humidity set point. Reliability of the mechanical coupling of the fan through the vessel wall is a major design issue. Magnetic coupling is used to avoid breaching the vessel wall. Additionally, the internal bearing of the fan which must be oil-free and operate reliably in the hot, humid ambient. Despatch and Espec-Tabai are vendors whose fan design has been proven by many hours of service.

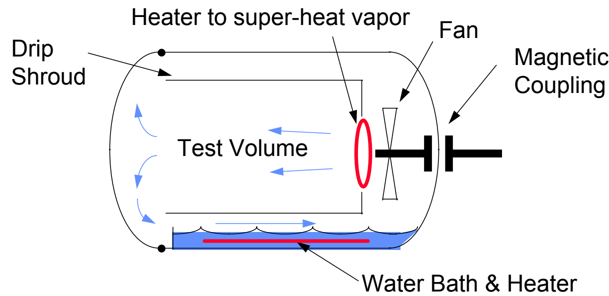

Fig. 3 The NG HAST chamber operates on the principle of forced convection. This ensures efficient mixing, minimizing temperature gradients across the test volume. Reliability of the fan drive is ensured by a proven design of magnetic coupling feed through.

Characteristics of the New Generation HAST System

Despatch built a prototype large-chamber forced-convection HAST system to Intel's specifications, and Micro Instrument Co. added an Intel-specified power-supply, instrumentation and software package. The system developed is available today as the Micro Instrument Model 8442 HAST test system. We report in this section characteristics of the NG HAST equipment, and compare the NG system to the natural-convection dual-vessel system.

Profile Characteristics

The effects of the fan capacity, mass loading, and other variables were characterized during the final stages of development of the NG test chamber at Despatch. The results of the characterization are given in this section.

In nearly all HAST[*] testing, with either forced or natural convection, the test volume is filled entirely with water vapor, undiluted by air. Differentials in total pressure are rapidly equilibrated (at the speed of sound), and pressure differentials due to vapor flow (Bernoulli effects) are small. Since the total pressure is water vapor pressure, *water vapor pressure differentials throughout the HAST test volume are negligible*. If the water vapor pressure is the same throughout the test vessel, then the local relative humidity at a point in the test volume *depends only on the local temperature* at that point. So for HAST, with no mixing of air, it is entirely adequate to measure temperature profiles in the test volume to determine the humidity profile. In contrast, 85/85 has the additional complication of mixing of air and water vapor. For 85/85, the *total* pressure is accurately constant, but the *partial* pressure of water vapor depends on details (baffles, etc.) of mixing and diffusion of air and water vapor. Thus, HAST profile characterization requires only distribution of temperature sensors throughout the test volume, *not wet bulb sensors*, as in the case of 85/85 profiling.

The NG HAST system has four "built-in" temperature sensors (RTDs) in the test volume. One supplies a controlling signal to a Watlow 1500 controller. Another, the "bottom RTD", is used to monitor the coolest

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[*] Exceptions occur for low temperature HAST testing (eg. < 105°C at 85% RH) when the chamber must be pressurized with N_2 to keep the total gauge pressure positive. This situation is infrequent since it defeats the rationale for HAST testing.

location in the test volume (near the bottom, front) as determined empirically from test profiles. A third, the "top RTD" is at the hottest test volume location, near the top. The top and bottom RTDs are placed so that the temperature at all points in the load is intermediate between the temperatures read by these RTDs. The fourth sensor is an RTD in the water bath which records the "wet bulb" temperature. The RTD in the water bath only reads the true dew point when it is actually immersed in water.

To characterize the HAST temperature/humidity profile, we distributed additional thermocouples throughout a load with the maximum likely mass. The mass of material in the test volume strongly affects the temperature and humidity profile, particularly during the ramp up to and ramp down from the test conditions. In operation, it is desirable to minimize the mass of the load, but characterization of the chamber profile should be done with the maximum loading. The loading used in this characterization was a 30-board card cage (weighing 30 lb) filled with typical 1.5 lb 4" x 18" test boards, for a total maximum load of 75 lb. The card cage, board load, and profiling thermocouple distribution used was the same as for the system shown in Fig. 2. Thermocouples were distributed throughout the load by attaching them to some of the boards. The shaded boards in Fig. 2 had two thermocouples attached; one towards the rear of the chamber and one towards the front, for a total of 12 thermocouples beyond the four built-in temperature sensors in the test volume. To explore the effect of loading, the 24 unshaded boards shown in Fig. 2 were removed without disturbing the thermocouples on the remaining 6 boards. This 39 lb load is referred to as a "partial load" in Figs. 4 to 10.

Figs 4 to 10 all show the same kind of data: In addition to the set-point dry bulb and wet bulb temperatures, we show the *envelope* of the 12 temperature profiles distributed though the load. In the figures this load profile is delimited by T_{db}(min) and T_{db}(max) and is shaded (or yellow). Also shown is the corresponding relative humidity set point profile, calculated from the dry and wet bulb set point profiles, and the relative humidity envelope of the load, delimited by RH(min) and RH(max), calculated from the load temperature envelope. All of the graphs have a horizontal (blue) line drawn at 100% RH (or °C) so that it is easy to see if the relative humidity exceeds 100%. Note that the initial high humidity at room temperature on these plots is of no consequence. It is only when condensation occurs with a hot load that test artifacts occur. When ramp-down reaches a wet bulb temperature of about 104°C, the drain valve is opened so that the slightly positive chamber pressure (2 psig) empties the water reservoir, then the chamber is vented to the atmosphere. Thus, after the wet bulb reaches 104°C, the wet bulb temperature sensor does not indicate the true dew point. The test volume is actually dry after the chamber is drained and vented during ramp-down.

Effect of Fan and Ramp-Up Effects. The first configuration of the fully loaded NG HAST chamber to be tested had an inadequately designed fan. The graph at the top of Fig. 4 shows that forced convection was not strong enough to prevent the temperature of some of the load (in the lower part of the test volume) from lagging the dry bulb set point ramp enough to fall below the wet bulb temperature. Thus, condensation occurred on part of the load for approximately 30 minutes during the ramp up. The bottom graph in Fig. 4 shows how a fan with increased flow characteristics eliminated this problem. Since reliability of the fan is a major issue, we also explored (Fig. 5) the effect of deliberately stopping the fan. The fan might stop because of drive belt or bearing failure. Fig. 5 shows that, when the fan stops, the top of the test volume gets hotter than the set point, but the bottom of the test volume stays at the set point. This is a desirable characteristic, since condensation does not occur, and the temperature differential across the vessel is easily detected by control software. A shutdown can be initiated without destroying the material being tested. This automatic shutdown capability is provided by the control software in the Micro Instrument Model 8442 HAST test system.

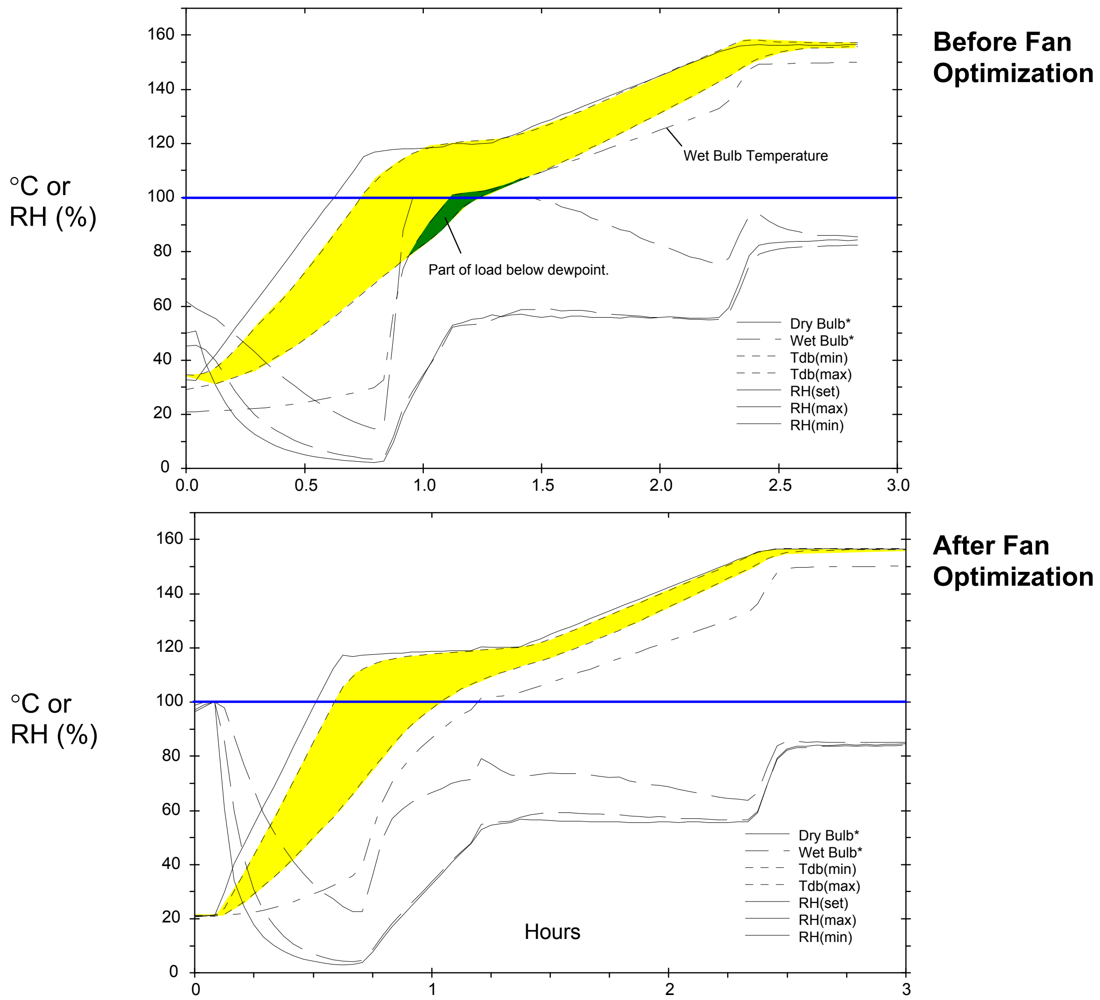

Fig. 4 Full-load ramp-up profile to 156/85 before (top) and after (bottom) optimization of fan. After optimization, the wet-bulb temperature is always below temperature at any point in the load.

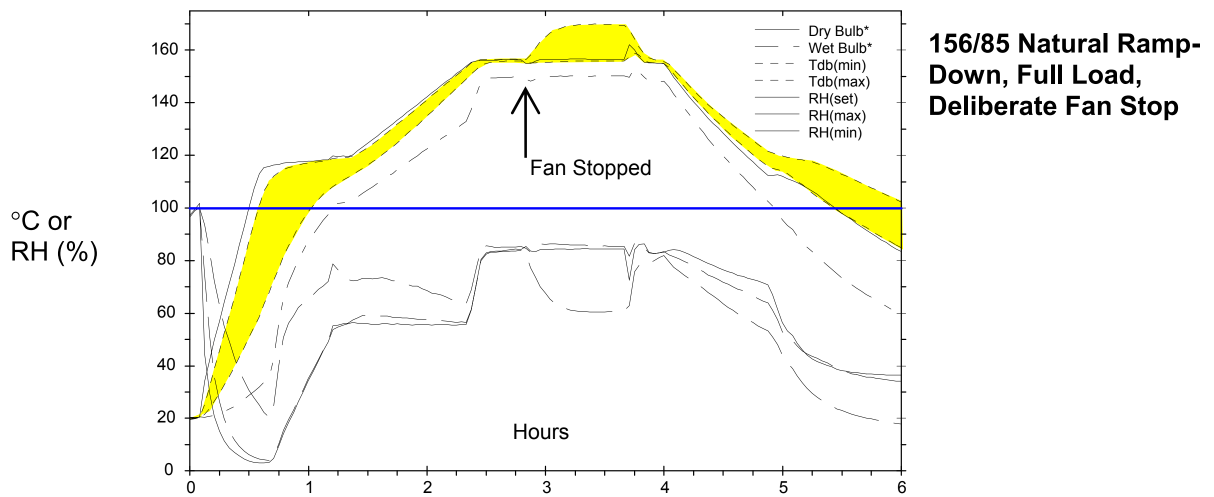

Fig. 5 Full load, 156/85 test run showing the effect of deliberately stopping the fan. The temperature gradient across the load increases. No condensation occurs, but the temperature at top of the test volume increases by 7°C (with a corresponding decrease in relative humidity) when the fan stops

Ramp-Down Effects. Fig. 6 (top) shows a fully-loaded ramp-down from 156/85 in which all heaters are simply shut off at the end of the steady-state stress. It is apparent that the load always lags the dry and wet bulb temperatures, so that condensation on the load never occurs. It takes about one hour for the temperature to drop from 156°C to 100°C and for the pressure to drop from 3.38 atm (gauge) to atmospheric pressure. In some cases, one hour is not sufficient for internal water vapor pressure in a DUT to dissipate (by diffusion through molding compound), so that cracking or internal delamination of devices can occur. This damage is an artifact of the test, since these pressure differentials would not occur in use. This problem can be alleviated by employing a controlled ramp-down while maintaining the relative humidity at the set point. An example is shown in Fig. 6 (bottom). Maintenance of the set point relative humidity during ramp down is important because this will maintain the moisture content of the molding compound, while slowly relieving internal mechanical pressure without generating cracks and delamination.

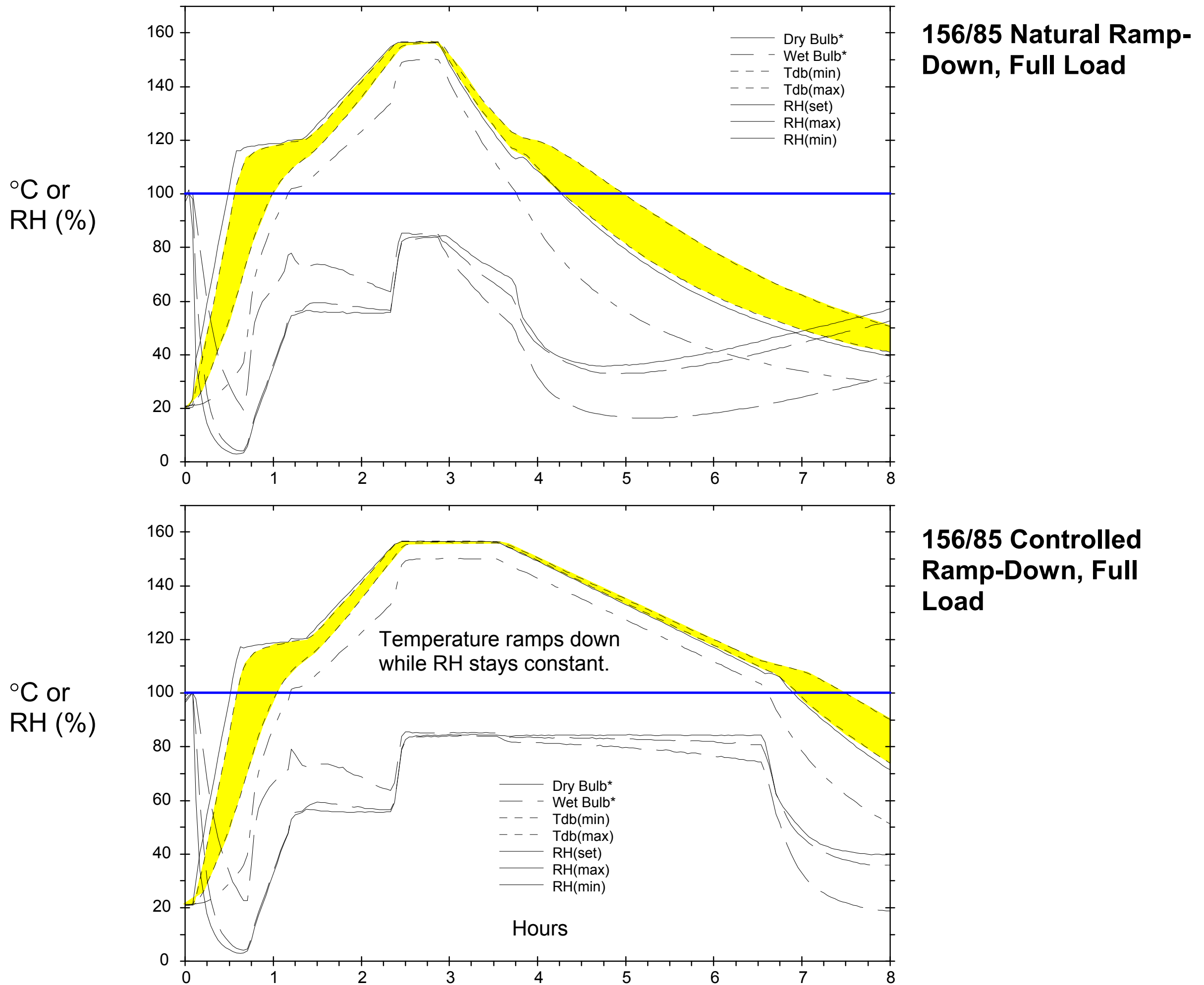

Fig. 6 Full-load 156/85 test runs with natural as-rapid-as possible cool-down (top), and with controlled ramp-down (bottom). Notice that relative humidity is controlled at the set point (85% in this case) during the controlled ramp-down.

Load Sensitivity. Fig. 7 shows a 156/85 natural ramp-down test run done under the same conditions as the run shown at the top of Fig. 6, except that a partial load of only 6 boards was used. As expected, the temperature differential across the load (and the corresponding humidity differential) is less for the partial load, particularly during ramp-up and ramp-down. Corresponding results for the ramp-up to 130/85 are shown in Fig. 8. For the extremes at which the system will routinely be used, 130/85 and 156/85, variation of the load between 39 lb (partial) and 75 lb (full) caused only slight changes in the ramp-up and ramp-down profiles.

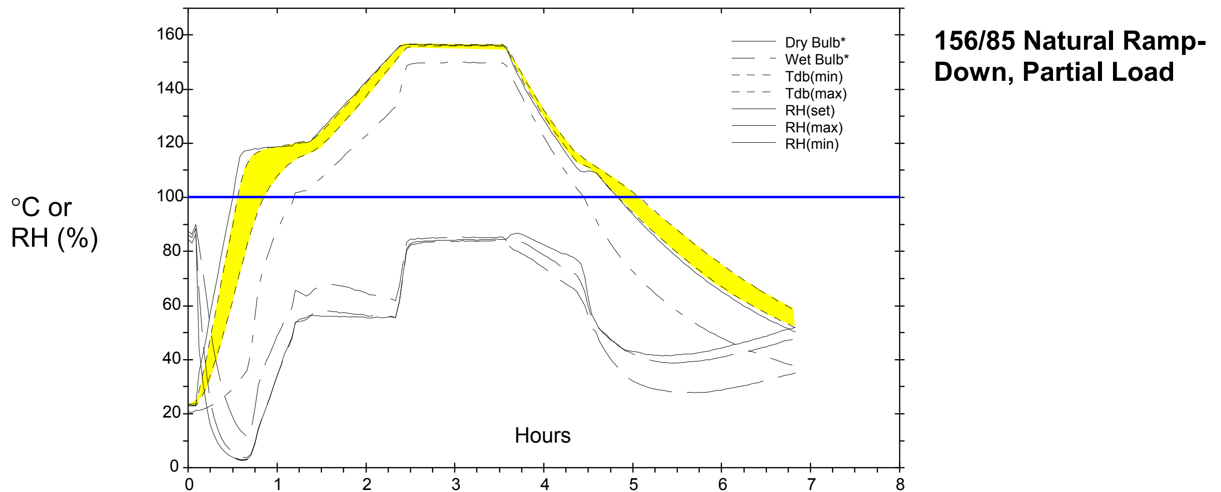

Fig. 7 156/85 partial load (6 boards), natural cool-down run. Compare with Fig. 6, top. Only subtle differences in profile are apparent - especially in the relative humidity profiles. This demonstrates load-insensitivity.

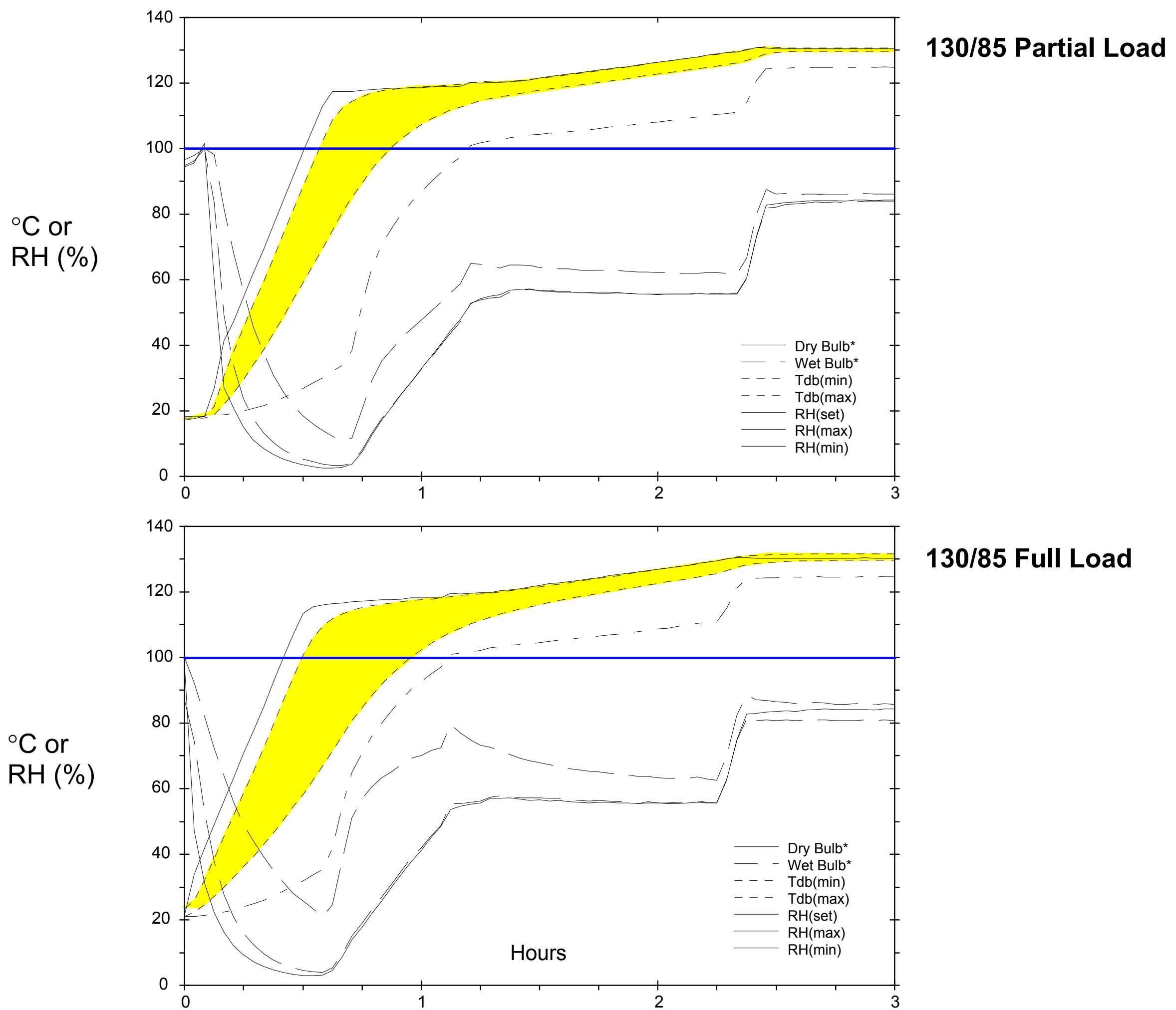

Fig. 8 Comparison of ramp-up to 130/85 for partial-load (top) and full-load (bottom). 130/85 is more difficult than 156/85 to control. This demonstrates a condensation-free, full-load ramp up to 130/85 in less than 3 hours, as required by the JEDEC test method.

Testing at 95% RH. Moisture acceleration studies sometimes require testing at higher (or lower) relative humidities than 85%. It is important to know how close to 100% relative humidity a test can be done without condensation occurring somewhere in the load. Fig. 9 shows a 156/95 test run with a full 75 lb load in which there was no condensation at any time. Thus testing at 95% (and probably higher) relative humidity can be done with confidence.

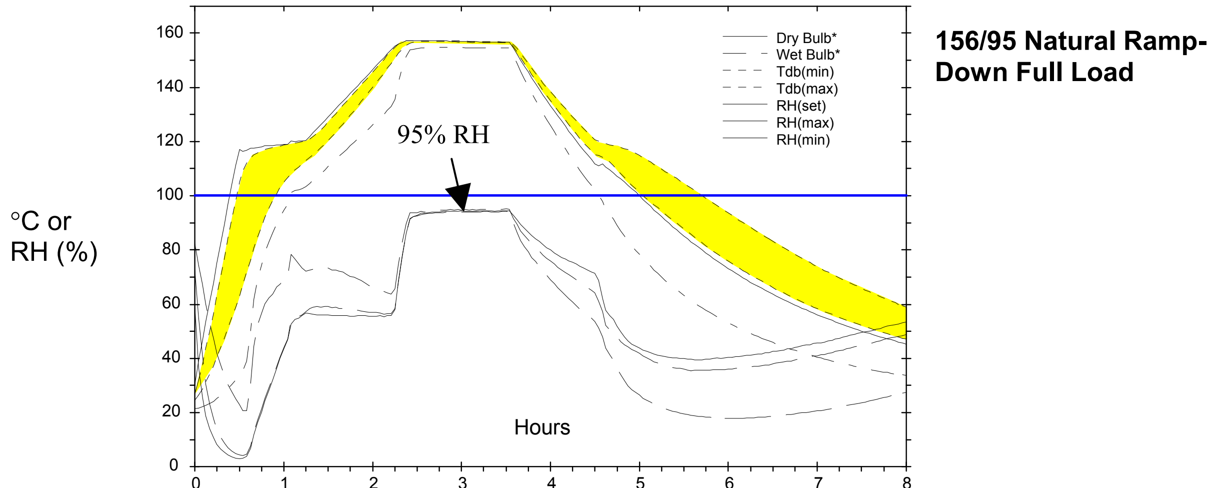

Fig. 9 Full-load 156/95 natural ramp-down profile. Demonstrates freedom from condensation even when humidity set point is as high as 95%.

Steady-State Characteristics. Fig. 10 shows results of a typical fully-loaded 40-hour 130/85 test run, with a controlled 3-hour ramp down. The top graph shows all of the data, while the bottom graph shows a magnified view in the temperature range 122°C to 132°C. There is a 0.5°C 2-hour overshoot in all temperatures at the start of the steady state, after which all temperatures remain flat. The across-load temperature differential is 1°C (+ 0.2°C/ - 0.8°C). This is well within the JEDEC guideline of ±2°C and better than the natural convection cahmber capability of ±1°C.

Power Supply Subsystem Characteristics

The card cage in the test volume has 30 slots for test boards. Each slot has two programmable power supplies, called V_{cc} and V_{dd}. In the usual application illustrated in Fig. 11, V_{cc} supplies the DUTs and V_{dd} supplies the on-board driver circuits. The turn-on characteristics of V_{cc} and V_{dd} can be programmably synchronized to within 2 msec. For example, V_{dd} can be delayed relative to V_{cc} for V_{dd} to activate a driver circuit which provides a reset sequence to DUTs which were previously powered up by V_{cc}. V_{cc} and V_{dd} have a 10V maximum output with 2A and 1A steady-state (4A and 2A momentary) current capability, respectively. Each supply has an autoranging voltage and current read back capability. The current resolution on the lowest range is 10 μA. The currents and voltages read back are logged to a disk file for later analysis. In addition to programmable turn-on characteristics, maximum and minimum current limits can be programmed for each supply so that an out-of-limit current can be flagged and acted on. The action to be taken is programmable, ranging from "do nothing" to "shut down the system". All error codes are also logged to the disk file.

The JEDEC HAST test method specifies that cyclical bias should be used if it is not possible to apply electrical bias to the DUTs without dissipating significant power. Power supplies can be programmed to cycle on and off with a specific period and duty cycle to provide the maximum possible stress. Whenever the power supplies turn on in a cyclical stress, they use the programmed turn-on characteristics for V_{cc} and V_{dd}.

130/85 40-Hour Test Run, Partial Load

°C or RH (%)

Dry Bulb*
Wet Bulb*
Tdb(min)
Tdb(max)
RH(set)
RH(max)
RH(min)

130/85 40-Hour Test Run, Partial Load, Magnified View

°C or RH (%)

ΔT_{load}

$T_{dry\ bulb}$

$T_{wet\ bulb}$

Dry Bulb*
Wet Bulb*
Tdb(min)
Tdb(max)
RH(set)
RH(max)
RH(min)

Hours

Fig. 10 40-hour 130/85 controlled ramp-down (partial-load) run stability test. 40 hours is a typical stress time for a 130/85 stress. The magnified view (bottom) shows that time variation of wet bulb, dry bulb and load is less than 0.5°C, mostly due to overshoot at start, and shows that gradient across load is about 1°C.

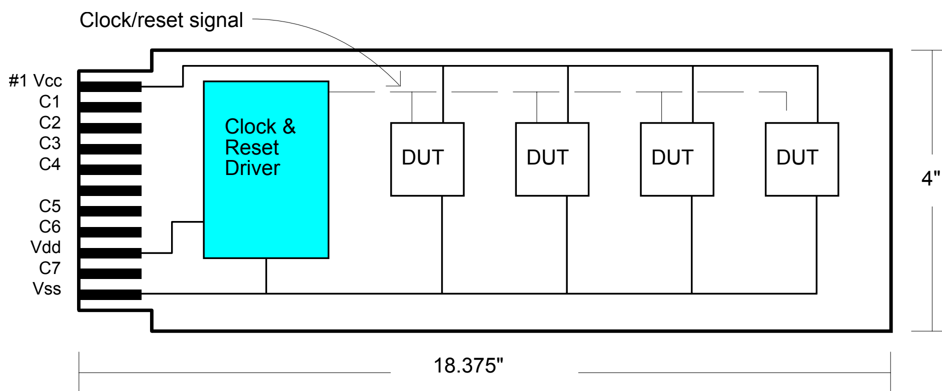

Fig. 11 A typical test board with DUTs and on-board driver circuitry. Typically V_{cc} supplies DUTs, and Vdd supplies the driver. When V_{dd} is turned on the driver circuit generates a programmed clock/reset sequence which puts the DUTs into a power-down state.

Human Interface

The human interface is a Visual Basic program with 3 major sections: Program Editing, Slot Setup, and Start Test.

Program Editing. There are two types of programs to be edited: Bias Programs, and Environmental Programs. Bias Programs contain the voltage, current limit, turn on characteristics, cyclical bias parameters and error action information described above. Bias Programs can be created, edited and saved with a name. Later, during Slot Setup, the named program will be assigned to a board slot. Environmental Programs contain steady-state set point and duration information, and ramp-down duration. Environmental Programs may also be created, edited, and saved with a name. The Environmental Program name is used when a test is started. Access to Bias and Environmental program editors requires a password, to provide change control.

Slot Setup. Preliminary to any test run, test boards containing DUTs will be mounted in card cage slots. Bias Programs must be assigned to the correct card cage slots. The boards must be checked to verify whether they are operating correctly before closing the chamber door and initiating a test run. The software provides a select/cut/paste/copy mechanism for assigning and reassigning programs to single slots or groups of slots, and specifying how many DUTs are on each test board (in case the test board is not fully populated). Then there is a way to test the functionality of specifically selected boards. A color panel gives a quick indication of the current test status (on/off and pass/fail) of any board. The operator can focus troubleshooting attention on any boards that fail. There are various utilities disabling "bad" slots and "locking" program assignments to selected slots so that subsequent operators loading different experiments into the chamber will not interfere with previously set up slots. The objective of "Slot Setup" is to have all slots with test boards show up "blue" (passed/off) on the status panel before starting a test.

Start Test. Once all boards are verified to be functioning and the chamber door is closed, the "Start Test" function is invoked at the main menu. This allows the operator to select a previously defined environmental program, and choose to either start the test immediately, or to have it *end* at some future time. The end-time option is useful to minimize the time between end of stress and availability of functional test of the DUTs, and so minimize dryout of the DUTs. During the run which is initiated, the operator can choose, by a screen toggle button, to display either the environmental profile (temperature, humidity, or pressure) or the electrical state of the boards under test. Various manual interventions are also available to abort the test or shut off a specific slot. (All interventions are logged to a disk file.)

Data Logging

A design objective for the NG system is to acquire run data which can verify that the applied stress is valid. All setup information for a run is logged, not just including program names (e.g. environmental and bias programs), but including all parameters defined in the programs. This is necessary in case program contents change but the program names don't. A complete record of temperatures, humidities, pressures, voltages, currents, error codes etc. is recorded to a disk file. Run-time printing of the data is also an option. This data can be uploaded to a mainframe to generate reports for a particular test run. Data for multiple test runs are compiled by mainframe software to generate control charts of important system parameters.

Summary and Conclusions

System characteristics from both the NG HAST system and the dual-vessel natural convection system are summarized and compared in Table I. It is apparent that the NG system provides much improved temperature profile performance relative to the natural convection chamber. This is a consequence of the forced convection design which provides much better thermal mixing, and load-independence for the large-vessel HAST chambers needed in production THB testing. The NG HAST system also has a much improved power supply subsystem, and control and monitoring software.

Equipment problems with large-vessel HAST chambers have been the main barrier to widespread adoption of HAST as the standard THB test method replacing 85/85. We expect that the NG HAST's improvements over previous equipment will make HAST testing an uneventful routine activity. Equally important, this capability is available to anyone, not just Intel, as a turn-key system. This facilitates propagation of the

improved test method throughout the industry, and not least, relieves Intel from the burden of engineering development and support of HAST equipment.

Table I Comparison of dual-vessel natural convection HAST systems (modified by Intel) with Micro Instrument Model 8442 (NG) system.

Item	Parameter	NG HAST (Single Vessel, Forced Convection)	Dual Vessel, Natural Convection
Vessel Design	Design Principle	Forced Convection	Natural Convection
	Test Volume	24" x 24"	24" x 24"
	Maximum Pressure	90 psig	55 psig
	Maximum Stress	166/85	156/85
	Footprint	6' 7"Wx 3' 7"D	5'2"W x 3'8"D
Ramp Up Profile	Time (hours)	< 2.25	2.5 ±0.5
	ΔT_{Load}	5 - 20°C	40 -80°C
Steady State Profile	ΔT_{Load}	±0.50°C	+1.5°C
	ΔRH_{Load}	±1.0 %	- 3 %
Ramp Down Profile	Controlled at constant relative humidity.	Yes	Yes
Board Capacity	18" x 4" board slots	30	30
	Zones	N/A	6
	Slots per zone	N/A	5
	Mass	30lb cage + 45lb load	30lb cage + 45lb load
Power Supplies	Total Number	60, 30 V_{cc} and 30 V_{dd}. Two *per slot*.	12, 6 V_{cc} and 6 V_{dd}. Two *per zone*.
	Voltage (Vcc)	0-10V/2A, 4A momentary, *per slot*	0-20V, 5A, *per zone*.
	Voltage (Vdd)	0-10V/1A, 2A momentary, *per slot*.	0-7, 5A, *per zone*.
	Current Readback Resolution	10µA, per slot V_{cc} and V_{dd}, Autoranging.	1mA, per slot V_{cc} only. One range only.
	Cyclical Bias	Yes	No
Software	Named Environmental Programs	Yes	No
	Environmental Logfiles	Yes	Yes
	Named Bias Setup	Yes	Yes
	Board Checkout	Yes	Yes
	Voltage, current logfiles	Yes	No
	Interface to Profiling & Control Chart Software	Yes	Yes
Machine Support		Micro Instrument Co.	Intel

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