Direct RDRAM* Thermal Design Methodology:

Determining Plate Temperature based on Die Test Temperature and Device Power

August 1999

Revision 1.0

Contents

Figures

Revision History

Rev.	Draft/Changes	Date
1.0	• Initial Release	August 1999

1. Introduction

In a system environment, the temperature of a component is a function of the system, module and component thermal characteristics. The system level thermal constraints consist of the local ambient temperature at the component, the airflow over the component and surrounding board as well as the physical constraints at, above, and surrounding the component which may limit the geometry of a thermal enhancement. The component's junction temperature depends on the component power dissipation, size, packaging materials (effective thermal conductivity), the type of interconnection to the substrate and motherboard, the presence of a thermal cooling solution, the thermal conductivity and the power density of the substrate, nearby components, and motherboard.

All of these parameters are stressed by the continued trend of technology to increase performance levels (higher operating speeds, MHz, and data transfer rates, GB/s) and packaging density (more transistors). As operating frequencies increase and packaging size decreases, the power density increases and the thermal cooling solution space and airflow become more constrained. The result is an increased emphasis on system design to ensure that thermal design requirements are met for each component in the system.

Traditionally, the memory subsystem has not required special attention with respect to thermal design. With the increase in sustainable power, this is no longer the case. Detailed thermal design attention must be given at all levels of memory subsystem design, from the component design, through to the system integrator. In order for a system designer to adequately judge whether or not the system environment he has implemented meets the component cooling requirements, he must be able to make a temperature measurement on the memory module. The temperature that the system designer can measure accurately is the plate temperature. The plate temperature (T_p) must be specified by the module vendor in order for the system integrator to assess his environment.

1.1. Document Goals

The goal of this document is to establish a methodology that the module vendor can follow to define the maximum allowable plate temperature, based on the following options they have in designing their module:

1. Device power
2. Thermal interface material
3. Module cover (or heat spreader)
4. Maximum allowable device temperature

This maximum allowable plate temperature, which is dependent on a given module design, will allow the system designer to validate that he has a thermally robust system solution. In general, the higher the plate temperature, the less burden a given module design will be on the system integrator. However, each module vendor must perform tradeoffs between device power, thermal interface material, module cover design, and maximum allowable device temperature, which in turn will affect the plate temperature specification. This document will demonstrate a methodology, once these design details have been established, for the module vendor to quantify the T_P of a given design.

1.2. Importance of Thermal Management

The objective of thermal management is to ensure that the temperature of all components in a system is maintained within functional limits. The functional temperature limit is the range within which the electrical circuits can be expected to meet specified performance requirements. Operation outside the functional limit can degrade system performance, cause logic errors or cause component and/or system damage. Temperatures exceeding the maximum operating limits may result in irreversible changes in the operating characteristics of the component.

1.3. Packaging Terminology

CSP: Chip Scale Package

PCB: Printed Circuit Board

Solder Balls: The features on the base of the CSP that allows the CSP to be soldered to the PCB.

RIMM: Memory module with RDRAM* components.

Heat Spreader: The aluminum plate that is available as a reference design for enhancing thermal performance of the RIMM, as well as providing protection of the bare silicon of the CSP.

Plate Temperature: Temperature at a specified location (see below) on the RIMM heat spreader that is used by the system integrator to ascertain whether or not his system implementation meets the requirements of the implemented RIMM design.

2. Required Equipment

In order to implement this methodology for specifying plate temperature based on the module design chosen, there is a certain minimum set of data acquisition equipment required. This section will outline the minimum set of equipment for following this methodology.

2.1. Intel® ATX Chassis with Fan Duct Installed

This platform serves to provide a standard reference environment in which the testing will take place. The following lists an acceptable configuration:

- An Intel® single processor motherboard with Intel® 820 Chipset
- AGP video card
- Pentium® III-550MHz processor
- Fully loaded memory subsystem, with RIMMs being evaluated
- Operating Fan Duct, operating at 12V

2.2. 36 Gauge Thermocouples with Welded Junctions

36 gauge thermocouples serve to minimize the amount of heat transfer via conduction through the thermocouple leads. Welded thermocouples are available commercially from Omega.

- Omega part SA1-J

2.3. Thermocouple Data Capture Equipment

Instrumentation is required to read the thermocouple output voltage and translate it to a temperature relative to reference. Many companies sell these devices with a built in, “isothermal” reference, thus giving the actual temperature (+/- 2C, typically) at the thermocouple junction. The following lists several acceptable units.

- Fluke Hydra Data Acquisition Unit - 20 channel capacity
- Fluke 52 K/J Hand Held Thermometer - 2 channel capacity

2.4. Special RIMM for Module Power Measurements

The power RIMM should be assembled using the same RDRAM components as on the regular RIMM modules, however, this module will have connections in it for measuring current and voltage.

2.5. Power Equipment

Any of the following equipment can be used to measure power. Power measurements using an oscilloscope will be more accurate but requires a lot more setup time and additional equipment. Equipment brands and P/N are provided as reference only.

- High precision digital multimeter
  - Keithly-Metrabyte - model 2000
  - HP 3487A multimeter
- Oscilloscope
  - Lecroy
  - Differential probes (AP034)
  - Differential amplifier (1850/1855)
- HP Infinium
  - Differential probes

2.6. Support Software

In order to exercise the RDRAM's on the RIMM modules, memory stress software called "Maxband" should be used. Contact your Intel representative for the Stress software.

3. Thermal Measurements and Data Reduction

To ensure proper reliability of the RDRAM devices, the thermal envelope of the module must be such that during normal operation, the devices must remain at or below the temperature at which the component vendor tests and guarantees the device. Since the RIMM will be used in a system environment, and it will be impossible for the system integrator to measure junction temperature of the live components, it is imperative that the module manufacturer quantifies the plate temperature, based on the design chosen by that module manufacturer.

The system integrator then can perform system design tradeoffs (ambient temperature, airflow, power consumption via performance limitations, RIMM pitch) based on maintaining the module Plate Temperature at or below that specified by the module vendor. Because different modules will implement different designs (different devices, which themselves have different power and temperature characteristics, different interface materials, different heat spreader designs, etc), it is important for each module vendor to characterize each RIMM design he makes available. This section will demonstrate reliable techniques for doing this. The RDRAM Thermal Parameter Spreadsheet can be used to aid the process of determining maximum allowable plate temperature. The details of the calculations are provided to aid the module vendor in the event the spreadsheet is not available.

3.1. Maximum Heat Spreader Plate Temperature

The maximum allowable plate temperature of a RIMM is a function of active device power, thermal interface material, heat spreader design, module design, and rate of air flow over the RIMM. The plate temperature can be represented by the following equation:

Equation 1.

$$T_{P,\max} = T_{J,\max} - y_{JP} P_{active,\max}$$

where,

$\mathbf{T_{P,max}}$ = MAXIMUM ALLOWABLE PLATE TEMPERATURE

$\mathbf{T_{J,max}}$ = MAXIMUM ALLOWABLE JUNCTION TEMPERATURE (THERMAL PARAMETER AVAILABLE FROM COMPONENT VENDORS, MAY VARY ACCORDING TO VENDOR)

$\mathbf{Y_{JP}}$ = THERMAL PARAMETER CHARACTERIZING JUNCTION TO PLATE (JP) THERMAL PERFORMANCE, SIMILAR TO Θ_{JC} (THERMAL RESISTANCE FROM JUNCTION TO CASE OF AN IC PACKAGE). THIS METHODOLOGY DOCUMENTS A RELIABLE METHOD FOR A MODULE VENDOR TO DETERMINE Ψ_{JP} FOR A GIVEN MODULE DESIGN.[1]

$\mathbf{P_{active,\ max}}$ = MAXIMUM SUSTAINABLE DEVICE POWER (AVAILABLE FROM COMPONENT VENDORS, MAY VARY ACCORDING TO VENDOR)

---

[1] The parameter Ψ_{JP} is a function of the local airspeed, as airspeed increases, so does this parameter. If too low an airspeed is used (hence too low a value for Ψ_{JP}), the maximum allowable plate temperature will be overstated. If too high an airspeed is used, excessive margin will be provided for. Recommended airspeed is 300lfm (1.5m/s).

3.2. Die Temperature Measurement

The die temperature is the temperature of the backside of the CSP. It is assumed that this is an accurate representation of the device junction temperature. This temperature is a function of the module layout, thermal interface material, heat spreader design, ambient temperature, local flow field, component power, and background (other devices on the module) power distribution. This section will demonstrate a reliable technique of measuring die temperature.

The concept is simply to attach a thermocouple to the backside of the CSP on the completed module assembly.

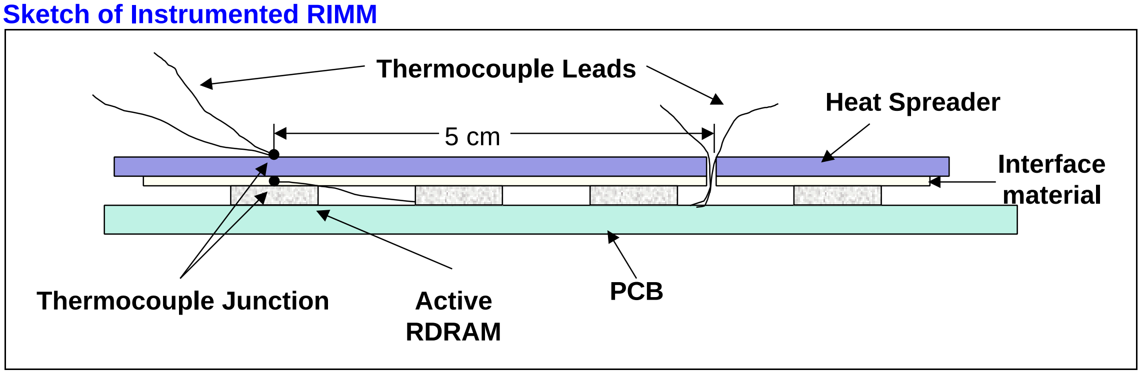
Note: The entire module assembly should only be modified from the product version of the assembly to allow the thermocouple lead to escape from beneath the heat spreader.

Measurement Technique

The thermocouple should be a 36-gage thermocouple, with a "flat" welded junction, such as Omega part SA1-J (with the pre-applied tape removed). A small amount of grease should be applied to the thermocouple to ensure good thermal contact between the junction of the thermocouple and the backside of the CSP[2]. (See the Direct RDRAM Thermal Stress Software Application Note for which device is active during the system operation.) Next, run the thermocouple lead along the PCB of the module, and route it through a small **(~1mm diameter)** hole drilled at least **5cm** from the active device (Figure 1), making sure not to dislodge the thermocouple junction from its original location. Also, ensure that the bare metal of the thermocouple does not touch anything other than the CSP and thermal interface material.

Note: Do not use tape to secure this thermocouple, as this will give erroneous plate temperature measurements later!

Figure 1. Sketch of Instrumented RIMM



[2] If thermally conductive grease is not used for this measurement, significant measurement errors can be introduced. Even with grease, at maximum power levels, there is likely to be up to 2°C or 3°C error between the actual junction temperature and that measured at the backside of the die.

3.3. Plate Temperature Measurement

This is the temperature that the system integrator can reliably measure to perform thermal design tradeoffs at the system level, to ensure that the RIMM operates reliably over the lifetime of the system. Like the die temperature, this temperature is a function of the RIMM design and device power, as well as the system environment in which it operates.

The measurement technique is similar to that used on the CSP, as well as that used for PC100 modules.

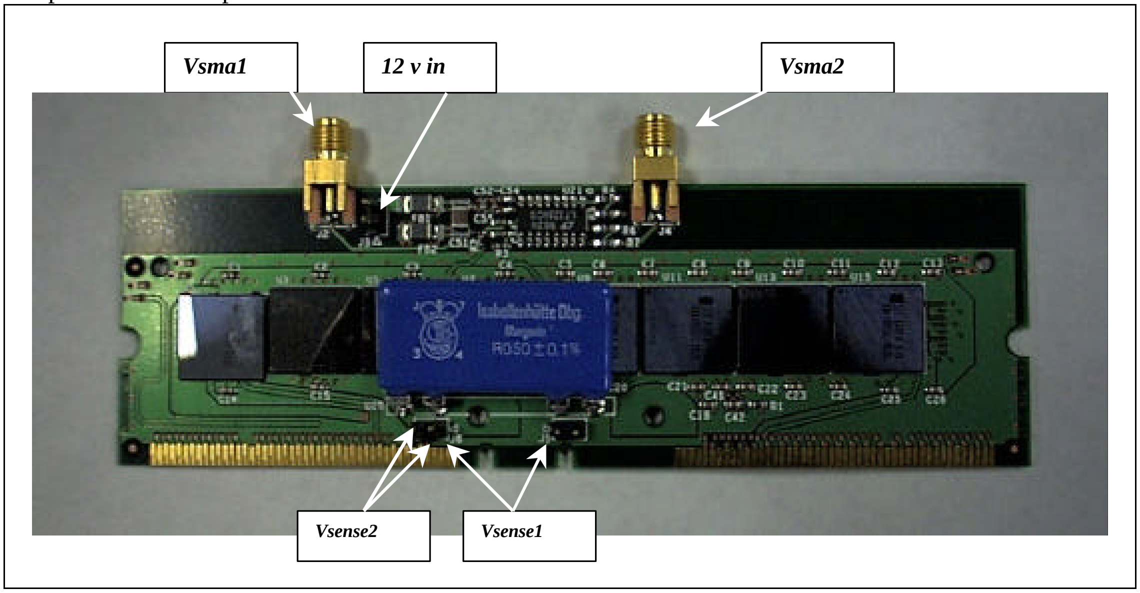
Measurement Technique

Again, the thermocouple should be a 36-gage thermocouple with a welded junction. It is recommended that a thermocouple with pre-applied tape be used for this measurement (like OMEGA part # SA1-J). Next, attach the thermocouple to the heat spreader plate directly above the geometric center of the active device (see the Direct RDRAM Thermal Stress Software Application Note for which device is active during the system operation). This will serve as the plate temperature, T_P, measurement. See Figure 1 for a sketch of this thermocouple location.

3.4. Active Device Power Measurement

This is the power of the active device in the system, running the software distributed with the Direct RDRAM Thermal Stress Software Application Note. Accurate measurement of this power is essential, because this power will be used to scale the results obtained in these tests to the maximum power that can be consumed by a vendor's device. Currently implemented system hardware limits this power to less than can be achieved with future hardware combinations. The concept here is to infer the active device power from several module power measurements.

The following calculations are incorporated in the RDRAM Thermal Parameter Spreadsheet. The details are provided if the spreadsheet is not available.



- Run the batch file RIMM_XB.bat device # (should be 8) (x=E or C). This will be supplied with the software. This batch file will run the memory stress program with the following parameters:
  - Worst case data pattern(All 1's)
  - Runs the stress program on the middle device (8^{th}).
- Power measurement

1.Voltage measurement at the output SMA connector: V_{SMA1} {for Vdd}, V_{SMA2} {for voltage drop}

a. For this measurement approach, there is a need to supply a 12V to the jumper (on pin 2) that locate next to the SMA connector V_{SMA1}

2. Differential measurement across the current sense resistor: V_{Sense1} {The jumpers @ pin 1&2 and pin 3&4 of sense resistor}, V_{Sense2} {Jumper @ pin 1&2 of sense resistor or just the pin 2 of the sense resistor and reference ground; this is the Vdd}.

a. For this measurement approach, the V_{Sense1} {the voltage drop across the sense resistor} can be measure by probing at pin 2 and 3 of the sense resistor or at pin 1 of each jumper located below the sense resistor.

b. For V_{Sense2} {the Vdd voltage} measurement, the probing can be at pin 1 or 2 of the sense resistor or pin 1 of the jumper directly below it. Make sure to have a reference ground for this measurement. Pin 2 on each jumper is a reference ground.

- Active device power calculation:

I. Voltage measurement at the SMA connectors

- Module power at stress (running Maxband) W2 = $\left[\ \left[\left(Vsma2 \div Gain\right) \div Rsense\right] \times Vsma1\ \right]$
- Module power at DOS idle W1 = $\left[\ \left[\left(Vsma2 \div Gain\right) \div Rsense\right] \times Vsma1\ \right]$
  - Module power at DOS idle must be measured after running the Maxband software

Gain =10

Rsense = 50mΩ

V_{SMA2} = voltage drop across sense resistor

V_{SMA1} = Vdd

- Active device power P_{active}= W2-W1 +I/O power

I/O power _X18 = $\left[576mw \times \left[Maxband\_BW \div Peak\_BW\right]\ \right]$

I/O power _X16 = $\left[512mw \times \left[Maxband\_BW \div Peak\_BW\right]\ \right]$

Note: Maxband_BW = BW reported by Maxband program

II. Differential measurement across current sense resistor

- Module power under Stress (running Maxband) W2 = $\left[\left[(Vsense1) \div Rsense \right] \times Vsense2 \right]$
- Module power at DOS idle W1 = $\left[\left[(Vsense1) \div Rsense \right] \times Vsense2 \right]$
  - Module power at DOS idle must be measured after running the Maxband software

Rsense = 50mΩ

V_{Sense1} = Voltage drop across sense resistor (pin 2 and 3; or using pin 1 of each jumper)

V_{Sense2} = Vdd (pin 1 or 2 of the sense resistor with reference ground)

- Active device power P_{active}= W2-W1 +I/O power

I/O power _X18 = $\left[576mw \times \left[Maxband\_BW \div Peak\_BW \right] \right]$

I/O power _X16 = $\left[512mw \times \left[Maxband\_BW \div Peak\_BW \right] \right]$

Note: Maxband_BW = BW reported by Maxband program

3.5. Data Reduction / Determination of Ψ_{JP}

The described measurements thus far will be used to characterize a specific module design, and aid the module vendor in specifying a maximum allowable heat spreader temperature. The following calculations are incorporated in the RDRAM Thermal Parameter Spreadsheet. The details are provided if the spreadsheet is not available. Ψ_{JP} (discussed above) is determined according to the following equation:

Equation 2

$$y_{JP} = \frac{T_J - T_P}{P_{active}}$$

where,

1. T_J = Measured die temperature
2. T_P = Measured plate temperature
3. P_{active}= Measured active device power

Once the value of Ψ_{JP} has been determined, the maximum plate temperature, $T_{P,max}$, can be determined from Equation 1 by using:

- the maximum active device power from the device manufacturer, $P_{active,\ max}$
- the maximum allowable die temperature from the device manufacturer, $T_{J,max}$
- the experimentally determined value of Ψ_{JP} (Equation 2) that depends on the module design.

It is this value of $T_{P,max}$ that the system integrator needs in order to validate whether or not his system meets the module design requirements, and it is this value that the module manufacturer needs to specify.