



Intel® Pentium® III processor Thermal Metrology for CUID 068h family processors

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1 INTRODUCTION

This document describes the procedure for measuring the core junction temperature on Intel® Pentium® III (068xh family) processors in the following form factors: Single Edge Connector Cartridge 2 (SECC2) or the Flip Chip Plastic Grid Array (FCPGA). The metrology involves use of the High Power Application software Rev 1.0 (“HIPWR30.EXE”) to perform system level analysis of cooling solutions. Using the methodologies described in this document, a system designer will be able to validate system-cooling solutions for compatibility with the specified processor worst-case power consumption.

1.1 Document Goals

The goal of this document is to provide a method to measure and ensure compliance of a heat sinks ability to keep the die temperature of a Pentium III processor in either the SECC2 or FCPGA package, in the 068xH family, within the specification requirements.

1.2 Document Scope

This document discusses techniques in thermal measurement only for Pentium III 068xh family processors in the SECC2 and FC-PGA processors primarily intended for the desktop system

1.3 References

- *Pentium® III Processor Datasheet* (Order Number 244452)
- *Pentium® III Processor for the PGA370 Socket at 500MHz and 550 MHz* (Order number 245264-001)
- *Pentium® III Processor Specification Update*
- SC242 Connector Design Guidelines
- *Datasheets and Specification Updates available at <http://developer.intel.com>*

1.4 Definition of Terms

- **Tambient-LOCAL** - the measured ambient temperature locally surrounding the processor. The ambient temperature should be measured about 0.3” “upstream” of a passive heat sink, or at the 0.3” above the fan inlet for an active heat sink.
- **Tambient external** - the measured ambient temperature outside of the system.
- **Tambient-MAX** - the target worst-case local ambient temperature. This can be determined by placing the system in maximum external temperature conditions and measuring the ambient temperature locally surrounding the processor. Under these conditions $T_{\text{ambient-local}} = T_{\text{ambient-Max}}$. This can also be determined by simultaneously measuring the $T_{\text{ambient-external}}$ and $T_{\text{ambient-local}}$ with the following equation: $T_{\text{ambient-max}} = T_{\text{ambient-OEM}} - T_{\text{ambient-external}} + T_{\text{ambient-local}}$. (This equation assumes a thermally linear system; i.e. No temperature controlled fans)



- $T_{\text{ambient-OEM}}$ - the target worst-case ambient temperature at a given **external** system location as defined by the system designer (OEM).
- $T_{\text{junction-MAX}}$ - the maximum core junction temperature of the processor, as specified in the processor datasheet.
- $T_{\text{junction-HIPWER30}}$ - the measured core junction temperature of the processor while running the High Power Application software ("HIPWR30.EXE").
- $T_{\text{junction-CAL}}$ - the calculated thermal junction temperature obtained when doing a validation test.
- $T_{\text{junction-OFFSET}}$ - the worst-case difference between the thermal reading from the on-die thermal diode and the hottest location in the processor's core, as specified in the processor datasheet.
- $T_{\text{sensor-OFFSET}}$ - the measurement error for a diode connected to a thermal measure device as specified in the appropriate the device datasheet.
- $\theta_{\text{Junction-ambient}}$ - the thermal resistance between the processor's core junction and the ambient air. This is defined and controlled by the system thermal solution.
- P_{max} - the maximum processor power, as specified in the processor's datasheet.
- SC242 Connector - Slot Connector 242 (242 contacts) Formally referred to as "Slot 1". The connector on a baseboard where an Intel® Pentium® III or Pentium II processor in the SECC2 package is installed.
- PGA370 – socket connector that is installed on a baseboard where an Intel FCPGA processor is installed.

2 S.E.C.C.2 and FC-PGA PROCESSOR PACKAGING TECHNOLOGY

The Intel Pentium III processors are delivered in either the SECC2 or FCPGA packaging technology. The following sections provide an overview of each type.

2.1 Single Edge Contact cartridge 2 (SECC2)

The Pentium III processor is available in the SECC2 packaging technology. This is an Organic Land Grid Array (OLGA) package mounted to an SECC2 type package. The OLGA contains the microprocessor silicon with an integrated second level cache, referred to as an "L2". The processor connects to the motherboard through a SC242 socket connector.

2.2 Flip Chip Plastic Grid Array

The Pentium III processor introduced a new packaging technology known as a Flip Chip Plastic Grid Array (FC-PGA). The FC-PGA contains the microprocessor silicon with an integrated second level cache, referred to as an "L2". The processor connects to the motherboard through a socket referred to as PGA370 Socket.



3 THERMAL SPECIFICATIONS

The processor power dissipation and the processor T_j-offset can be found in the *applicable processor datasheet*; please refer to this document to verify the actual thermal specifications for a particular processor. Document can be found at <http://developer.intel.com/design/PentiumIII/datashts/>. While the processor core dissipates the majority of the thermal power, the system designer should also be aware of the thermal power dissipated by the second level cache. Systems should design for the highest possible thermal power, even if a processor with a lower power requirement is planned, this will allow the design to accept future processors interchangeably.

3.1 Thermal Junction Temperature

The core thermal junction temperature reading is used to evaluate the system's thermal solution. The measurement of the core junction temperature of a live processor using either the SECC2 packaging technology or the FC-PGA processor core is critical to the validation of a OEM chassis and heat sink thermal designs. A thermal diode is independently routed off the processor core to the SC242 connector or the PGA370 socket to assist in evaluating the junction temperature. This is the same diode that has been used by DMI client software to monitor processor temperature since the introduction of the Intel SC242 processor. For more information on the thermal diode, refer to the processor datasheet.

3.2 Power

The processor core dissipates the majority of the thermal power, however, the system designer should also be aware of the thermal power dissipated by the second level cache. Systems should design for the highest possible thermal power. In the SECC2 and FC-PGA packages, the L2 cache is integrated into the die, so heat is dissipated only through the die. The processor power is the total of heat dissipated from the core and L2 cache. As described in the processor datasheet, system thermal designers should assume that the bulk of the power must be removed from the core area, which is smaller than the entire processor's die area.

4 SECC2/FC-PGA Metrology

This section describes the procedure for measuring the core junction temperature for Pentium III processors in the Single Edge Contact Cartridge 2 (SECC2) package with OLGA core packaging technology and for processors in the Flip Chip Plastic Grid Array package (FC-PGA). The metrology involves use of the High Power Application software ("HIPWR30.EXE") to perform system level analysis of cooling solutions. Using the methodologies described in this section, a system designer will be able to validate system-cooling solutions for compatibility with the specified processor worst-case power consumption

Note:

While it is tempting to place a measurement device on the top of the OLGA package the results can not be correlated to T_{junction}. Extensive experiments conducted by Intel using a top of the OLGA package measurement method proved the results were very erratic.



4.1 THERMAL JUNCTION MEASUREMENT TECHNIQUE

Note:

The purpose of this procedure is to explain how to take junction (die) level temperature measurements on Intel processors using the Analog Devices EVAL-AD1021 Kit. A different kit could be used in place of the Analog Devices Kit, however it is the responsibility of the user to ensure the correct offsets are determined.

4.2 Background

The measurement of the junction temperature of a live processor using SECC2 packaging technology and OLGA processor core, or the FC-PGA package, is critical to validate an OEM chassis and heat sink thermal design. A thermal diode is independently routed off the processor core to the SC242 connector/PGA370 Socket to assist in evaluating the junction temperature. In order to simplify the measurement of the diode temperature, use the Analog Devices EVAL-AD1021 Kit. The Analog Devices EVAL-AD1021 kit requires no diode calibration.

The Analog Devices EVAL-AD1021 Kit is a tool provided by Analog Devices that includes the AD1021 temperature sensor IC and all the additional circuitry and software needed to take temperature measurements with the AD1021 and a typical PC (see Figure 1 for layout of the EVAL kit). The AD1021 is essentially an 8 bit A/D converter and integrated controller which measures the difference between the voltage drop across a diode using 2 exciting currents to derive a junction temperature. The 8 bit temperature data is accessed by external applications via the 2-wire SMBus. The EVAL kit conditions the output from the AD1021 to be read by a standard 25 pin parallel port terminal on a PC. Software is included with the EVAL kit to display temperature measurements on a PC running Windows 3.1 or Windows 95/98 OS. See the AD1021 and Analog Devices EVAL-AD1021 Kit datasheets for more detailed information on the measurement tools.

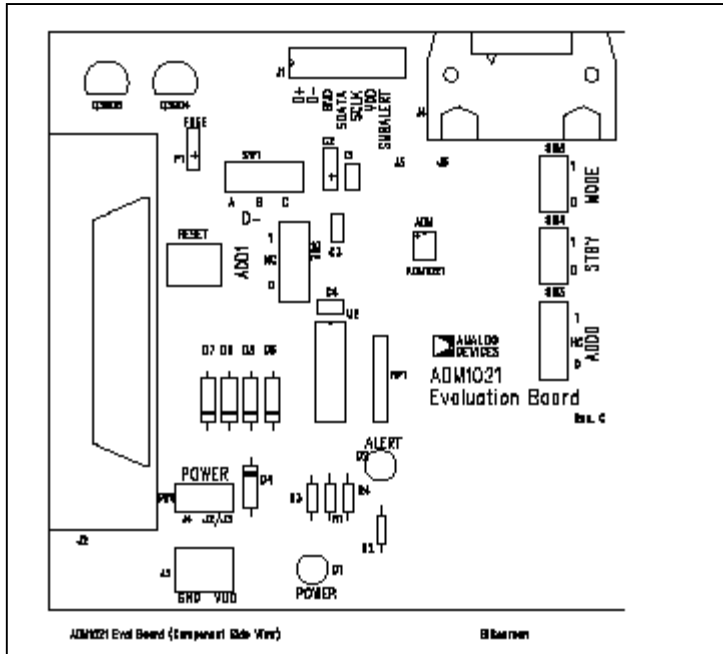


Figure 1 Layout of Analog Devices EVAL-AD1021 Kit

Equipment Needed

- 1 Analog Devices EVAL-AD1021 Kit from Analog Devices Products¹ (software included)
- 1 Pentium® class PC with available parallel port and Windows* 3.1 or Windows 95/98 OS to take temperature measurements (measuring PC)
- 1 standard printer cable
- 1 twisted, shielded pair cable, up to 56" long, 24 gauge stranded copper (this wire can, & should, be shorter than the maximum length. The longer the wire, the more error is introduced.)
- 1 insulated wire, 24 gauge stranded copper, same length as the shielded pair cable (up to 56" long)
- 1 soldering iron

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- 1 live chassis with processor diode to be evaluated (test PC)
- HIPWR30.EXE application (available from your local Intel Representative)

4.2.1 Procedure Overview:

The exact procedure used to perform a test may vary slightly depending on the measurement kit used and whether the software has already been installed on a test/host system. Please vary procedure as appropriate.

The recommended procedure for an Analog Devices test kit that has not been previously used is as follows

- Establish electrical connections
- Install the measurement software on the test PC
- Perform a No-power test
- Perform a power test
- Perform a validation test
- Complete calculation to determine if thermal solution is keeping processor within specified T_j .

4.2.1.1 Electrical Hookups for SECC2 processors

This section outlines the electrical connectivity for the Analog Devices EVAL-AD1021 Kit to measure the on-die diode. Figure 2 Measurement Setup is a diagram of the test setup. For details on locating SC242 pins refer to Figure 8 of the SC242 Connector Design Guidelines.

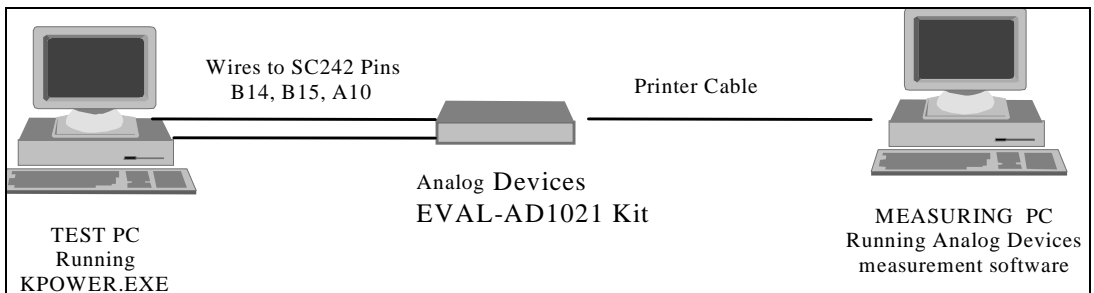


Figure 2 Measurement Setup

- 1) Remove motherboard from test PC.
- 2) Strip insulation off ends of insulated wire and twisted, shielded pairs, and tin wire tips.
- 3) Solder the 56" insulated wire (again, this wire can be shorter) to the SC242 connector ground pin A10 (Vss).



- 4) Ensure that any motherboard thermal sensor is disconnected from the processor. If the motherboard provides zero ohm resistors for this purpose, remove them, otherwise cut the traces going to pin B14 and B15.
- 5) Solder 1 wire of 56" twisted, shielded pair to SC242 connector pin B14/THERMDP (diode anode)
- 6) Solder the other wire of 56" twisted, shielded pair to SC242 connector pin B15/THERMDN (diode cathode) See Figure and Figure.

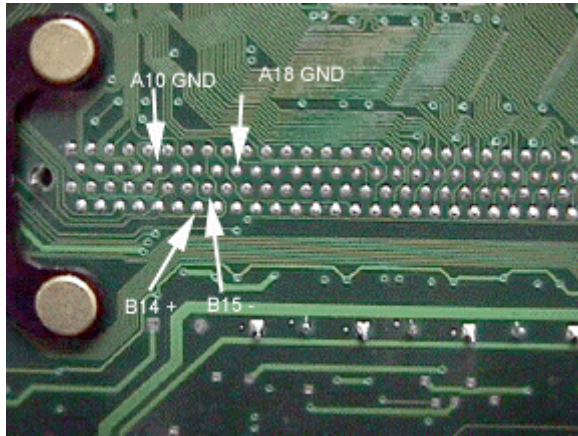


Figure 3 SC242 connector pins

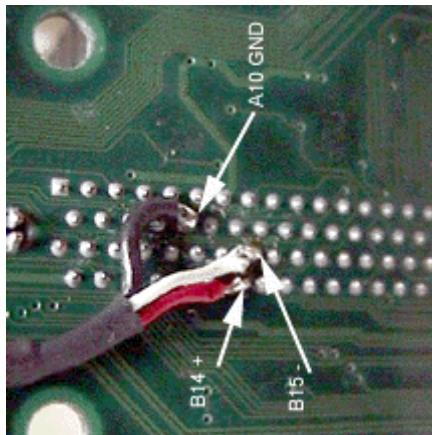


Figure 4 Connecting insulated wire to SC242 pin connector

- 7) For reduced noise conditions it is recommended to solder the shield of the twisted pair to ground on the processor side. An alternate V_{ss} pin on the SC242 connector, such as A18, can be chosen.



- 8) Tape the ground wire and twisted, shielded pair wires to the backside of the motherboard to relieve stress on the solder joints. Route wires out to edge of motherboard which has enough clearance to allow wires to pass through
- 9) Replace motherboard in chassis (you may wish to take room temperature measurements on processor before replacing all chassis components to verify good solder joints)
- 10) Route the wires out of the chassis through a PCI slot (or other convenient hole in chassis), taking care to ensure the wires do not obstruct any critical airflow paths
- 11) Verify that the switch # 1 SW1 (See Figure 5) in the ADM1021 is in the C position for remote monitoring of temperature.

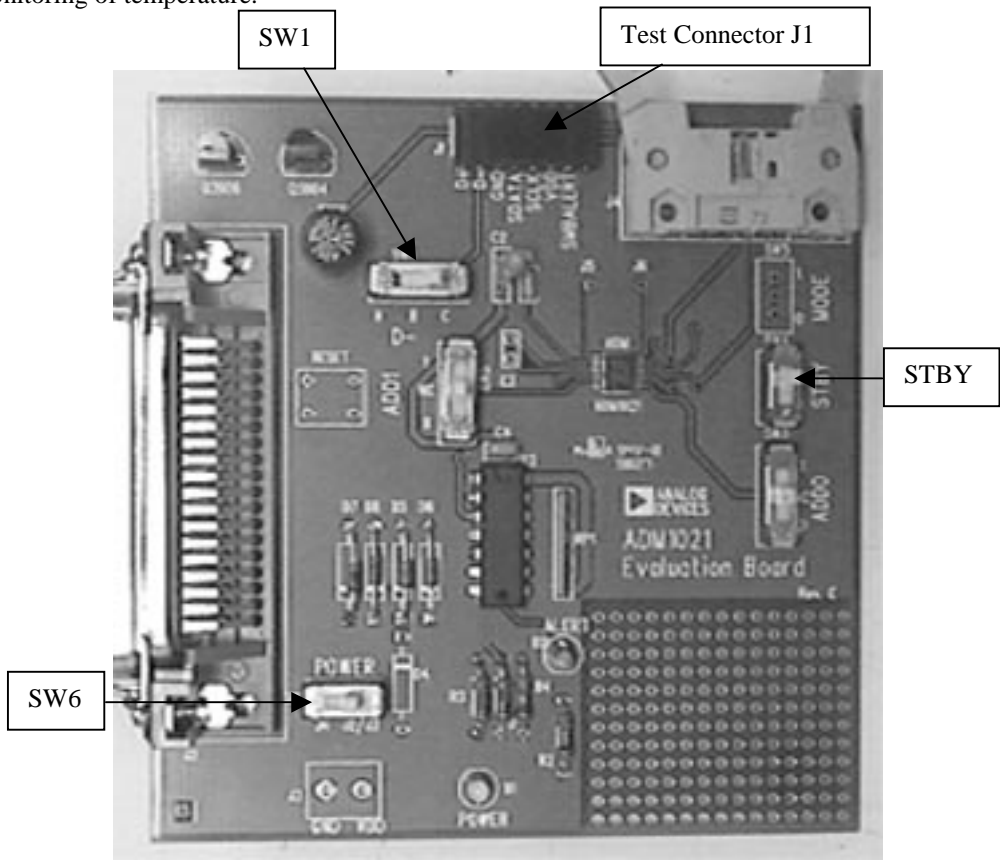


Figure 5 Eval-1021 Test Board

- 12) Switch # 6 (SW6 or POWER) must be in J2/J3 position for printer cable power. See
- 13) Switch # 3 (SW3 or STBY) must be in 1 position. See Figure.



14) Solder a Three-pin jumper connector to J1. See Figure 6 and Figure 7.

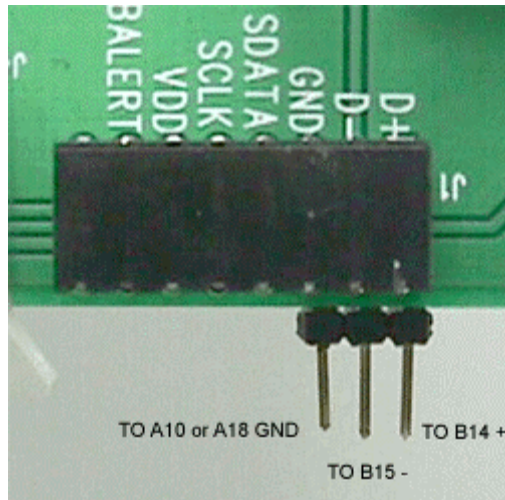


Figure 6 Test board with jumper connections. Top side view

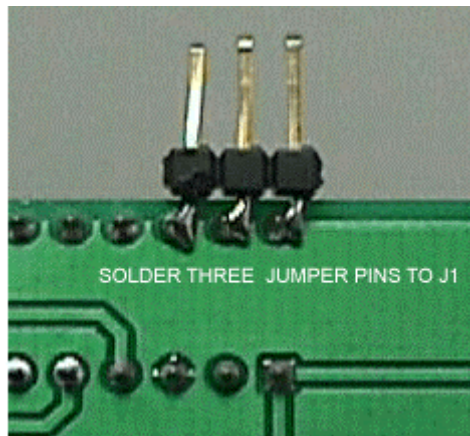


Figure 7 Test board with jumper connections. Bottom side view



- 15) Connect the other end of the twisted pair cable to the three jumper pins on J1 on the ADM1021 card.
The positive lead (coming from B14) to D+, the negative lead (coming from B15) to D- and the shield to GND. See , Figure 6 and Figure 7
- 16) Using the parallel port cable, connect measuring PC to kit
- 17) Proceed to software installation.

4.2.1.2 Electrical Connections for an Intel FCPGA processor

- 1) Remove motherboard from test PC.
- 2) Strip insulation off ends of insulated wire and twisted, shielded pairs, and tin wire tips.
- 3) Ensure that any motherboard thermal sensor is disconnected from the processor. If the motherboard provides zero ohm resistors for this purpose, remove them, otherwise cut the traces going to AL31 and AL29.
- 4) Solder a shielded twisted pair cable to the PGA370 socket on the target MB. AL31 (+), AL29 (-) and the shield to AM30 (ground). See Figure 8 and Figure 9.

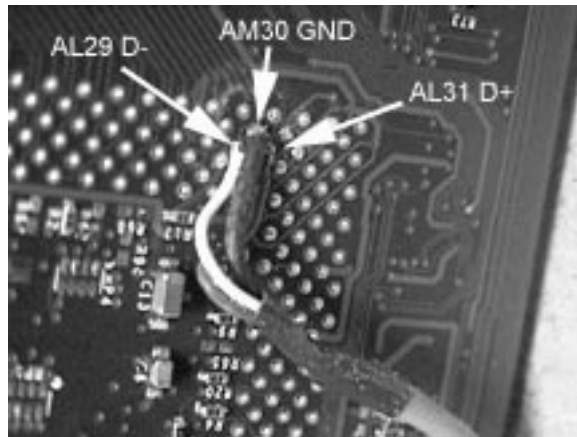


Figure 8 Back side motherboard connections to PGA370 Socket

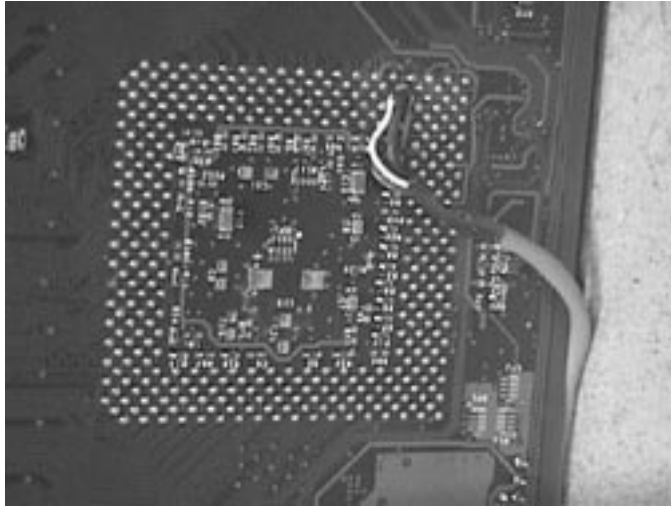


Figure 9 Back side of motherboard with PGA370 connections

- 5) Tape the ground wire and twisted, shielded pair wires to the backside of the motherboard to relieve stress on the solder joints. Route wires out to edge of motherboard which has enough clearance to allow wires to pass through
- 6) Replace motherboard in chassis (you may wish to take room temperature measurements on processor before replacing all chassis components to verify good solder joints)
- 7) Route the wires out of the chassis through a PCI slot (or other convenient hole in chassis), taking care to ensure the wires do not obstruct any critical airflow paths
- 8) Connect the other end of the twisted pair cable to the three jumper pins on J1 on the ADM1021 card. The positive lead (coming from AL31) to D+, the negative lead (coming from AL29) to D- and the shield to GND. See Figure 6 and Figure 7.
- 9) Using the parallel port cable, connect measuring PC to Analog Devices EVAL-AD1021 kit
- 10) Proceed to Software Installation.

4.2.1.3 Software Installation

- 1) Install the software for the Analog Devices EVAL-AD1021 Kit according to the directions that come with the kit. The document is titled Evaluation Board for Microprocessor System Temperature Monitor or EVAL-ADM1021. This documentation should come in the box with the test kit. Please contact Analog Devices for additional copies of the documentation.
<http://products.analog.com/products/info.asp?product=ADM1021>
- 2) Proceed to No-Power measurement



4.2.1.4 No-Power (test PC) Measurement

This section is optional and describes how to take no-power (on the test PC) temperature measurements on the processor diode. It is useful to gain confidence in the Analog Devices EVAL-ADM1021 kit.

- 1) Start the test program from the floppy or hard drive by starting the Analog Devices application
- 2) Follow the directions supplied by Analog Devices in the document titled Evaluation Board for Microprocessor System Temperature Monitor or EVAL-ADM1021.
- 3) If there are no addressing problems, a window containing the temperature measurement and data collection control features will start up (If there are slave addressing problems, check to make sure that all electrical connections are properly made and electrical switches are in their correct positions. If that does not solve the addressing problem, please refer to the Analog Devices EVAL-ADM1021 data sheet to resolve the problem)
- 4) Select a measurement rate of 1 Hz
- 5) The temperatures displayed should read ambient temperature (provided the test processor has not been heated up).
- 6) Proceed to Power-On Temperature Measurement

4.2.1.5 Power-On (test PC) Temperature Measurement

This process outlines how to use the processor diode to take temperature measurements while the processor is powered on. This is the procedure that should be used to validate chassis and heat sink thermal designs while running the high power application software.

- 1) Turn on the test PC and run the high power application software
- 2) Allow the High Power Application software to run for at least 1 hour to allow all chassis components to come to thermal equilibrium
- 3) Note temperature displayed in the “remote” box. This is the test processor T_{junction-HIPWR30} temperature.
- 4) You are now ready to perform a validation test.

4.2.2 Validation Method

This section assumes a familiarity with the terms defined in Section 1.4. This section describes the validation Method for CPUID Model 068x processors using the SECC2 or FCPGA package.

4.2.2.1 Validation Method for CPUID Model 068x processors using the SECC2 packages.

Performing a simplified validation of the cooling solution on the junction temperature for maximum specified processor power dissipation values requires the measurement of T_{junction-hipwr30} and T_{ambient-local} temperatures while executing the High Power Application software.



- 1) The system and processor under analysis should be prepared to gather $T_{\text{junction-hipwr30}}$ temperature measurement as described in Section 4 and the $T_{\text{ambient-local}}$ temperature just “upstream” of a passive heat sink or at the fan inlet for an active heat sink (measured 0.3 inches above the fan hub).
- 2) Once the system is ready for data collection, the “HIPWR30.EXE” High Power Application software should be executed.
- 3) With “HIPWR30.EXE” executing, allowing system temperatures to stabilize for one hour, gather the $T_{\text{junction-HIPWR30}}$ and $T_{\text{ambient-local}}$ temperature measurements.
- 4) Calculate the Final Value of T_{junction} using Equation 1 & compare it to the datasheet junction temperature specification.

Equation 1

$$T_{\text{junction-HIPWR30}} (\text{diode}) + (T_{\text{ambient-max}} - T_{\text{ambient-local}}) + T_{\text{junction-offset}}^1 + \text{Measurement Error}^2 \leq \text{datasheet } T_j \text{ specification}$$

1. $T_{\text{junction-offset}}$ is available from the processor datasheet
2. Measurement error is the diode kit measurement error. It can be determined through the course of a measurement capability study or estimated by the diode kit datasheet.

Note:

For systems with non-linear thermal behavior, like those with thermally controlled fan(s), the system designer should exercise caution to ensure that the processor temperature specifications are met given the dependencies on airflow and different fan activation patterns. The change in airflow effectively changes the $\theta_{\text{junction_ambient}}$ of the processor’s thermal solution. Therefore, the various system conditions should be evaluated when determining the worst-case target $T_{\text{ambient-Max}}$, $T_{\text{ambient-local}}$ and $T_{\text{junction-HIPWR30}}$.

For example, in determining compliance of a 600MHz processor to the $T_{\text{junction-max}}$ specification as stated in the processor’s datasheet, the following illustrates the approach:

Stated Conditions:

Processor Core Frequency = 600 MHz

$T_{\text{junction-Max}} = 82^{\circ}\text{C}$ (T_{junction} that is found in the appropriate Intel processor datasheet)

$T_{\text{junction-HIPWR30}} = 68.0^{\circ}\text{C}$ (measured temperature running HIPWR30.EXE)

$T_{\text{ambient-max}} = 45^{\circ}\text{C}$ (the target worst-case local ambient temperature)

$T_{\text{ambient-local}} = 35.0^{\circ}\text{C}$ (measured ambient temp.)

$T_{\text{offset}} = 2.9^{\circ}\text{C}$ (This values is found in the appropriate Intel processor datasheet)

Measurement Error = 1°C (Measurement Error for Analog Devices EVAL-ADM1021 Kit.



Using the equation:

$T_{\text{junction-CAL}} = T_{\text{junction-HIPWR30}} + (T_{\text{ambient-max}} - T_{\text{ambient-local}}) + T_{\text{junction-offset}} + \text{Measurement Error}$

$T_{\text{junction-CAL}} = 68.0^{\circ}\text{C} + (45^{\circ}\text{C} - 35^{\circ}\text{C}) + 2.9^{\circ}\text{C} + 1^{\circ}\text{C}$

$T_{\text{junction-CAL}} = 81.9^{\circ}\text{C}$

Because $T_{\text{junction-CAL}} (81.9^{\circ}\text{C}) \leq T_{\text{junction-MAX}} (82^{\circ}\text{C})$ this thermal solution example is within the guidelines.



5 Appendix

5.1 BACKGROUND ON THERMAL RESISTANCE

5.1.1 Thermal Resistance

The thermal resistance value for the core-to-ambient (Θ_{JA}) in SECC2/FC-PGA packages is used as a measure of the cooling solution's thermal performance. Thermal resistance is measured in units of °C/W. The thermal resistance of the core junction-to-ambient, Θ_{JA} , is comprised of the processor core (OLGA) thermal resistance and the sink-to-local ambient thermal resistance (Θ_{SA}). Θ_{SA} is strongly dependent on the thermal conductivity and thickness of the thermal interface material and the heat sink's thermal characteristics .

The thermal parameters are related by the following equations (S.E.C.C.2/FC-PGA):

$$\Theta_{JA} = (T_{\text{junction}} - T_{LA}) / P_D$$
$$\Theta_{JA} = \Theta_{JS} + \Theta_{SA}$$

Where:

Θ_{JA} = Thermal resistance from junction-to-local ambient (°C/W)

T_{junction} = Processor thermal plate temperature (°C)

T_{LA} = Local ambient temperature in chassis around processor (°C)

P_D = Device power dissipation (W) (assume no power goes to the other side)

Θ_{JS} = Thermal resistance from junction-to-sink (°C/W)

Θ_{SA} = Thermal resistance from heatsink-to-local ambient (°C/W)

5.1.2 Thermal Solution Performance

For SECC2 packages, all processor thermal solutions should attach to the processor cartridge. The FC-PGA thermal solution is similar to the Plastic Pin Grid Array (PPGA) Thermal solutions, with the heatsink attached to the top of the substrate. The lower the thermal resistance between the processor and the local ambient air, the more efficient the thermal solution. The required Θ_{ja} is dependent upon the maximum allowed processor temperature (T_{junction}), the local ambient temperature (T_{LA}) and the processor power (P_{max}). This can be expressed in the following mathematical equation:

$$\Theta_{JA} = (T_{\text{junction}} - T_{LA}) / P_{\text{max}}$$

T_{LA} is a function of the system design.

Table 1 provides the example resultant thermal solution performance for Intel SECC2 processor at different local ambient air temperatures around the processor.



**Table 1 Thermal Solution Performance for an S.E.C.C.2 Processor
at Processor Core Power of 28 Watts¹**

Thermal Solution Performance	T _{ambient}		
	35°C	40°C	45°C
Θ _{JA} (°C/watt)	1.25	1.42	1.61

¹ See applicable processor datasheet for required power specifications

5.2 About the HIPOWER Application

The High Power Application software (a.k.a. “HIPWR30.EXE”) is intended for thermal evaluation purposes only. This software is not a general-purpose application. The software does not generate the absolute worst-case thermal power dissipation as defined in the processor’s datasheet. This software does provide system designers with an application nearing worst-case power consumption for the analysis and validation of system cooling solutions.

All systems should be designed with the ability to dissipate the worst case thermal power indicated in the datasheet. The High Power Application software, utilizing the methodologies presented in this document, can enable system designers to design and validate robust cooling solutions that can adequately cool the processor at the maximum specifications.

The High Power Application software maximizes the current consumption of the processor core. All execution stages and various functional units of the core and L1 cache are fully utilized. The software performs minimal system bus accesses and with minimal L2 cache utilization newer High Power Application (“HIPWR30.EXE”) incorporates the functionality of the “HIPWR30.EXE” utility and a L2 cache exerciser. “HIPWR30.EXE” can be run in 2 modes, one in which it only exercises the processor’s core power and another where it only runs L2 cache utilization code. The mode that concentrates on the processor’s core is the same application as HIPWR30.EXE and can be run by executing “HIPWR30 /P” at the DOS command window. For the purpose of this document and the procedures that involve the use of a High Power Application “HIPWR30.EXE” is equivalent to using “HIPWR30 /P”. For all references to “HIPWR30.EXE”, “HIPWR30 /P” can be used alternatively.

The “HIPWR30.EXE” utility also has a mode for L2 cache utilization that can be used to produce a large amount of thermal power from the L2 cache BSRAMS. To execute this utility in the L2 cache mode execute “HIPWR30 /L” at the DOS command window.



5.2.1 Executing the High Power Application Software

The High Power Application software is a 32 bit Windows* NT or Windows* 95/98 application. The application **should be executed from a DOS window command prompt from within the Windows NT or Windows 95/98 environment, and not from a DOS only environment.** The High Power Application software puts the processor into an infinite loop and locks the command prompt environment. The “HIPWR30.EXE” utility has an on-screen message with version number information and usage help. To halt execution of the application, use the Windows NT Task Manager* or Windows 95/98 Task Bar* to stop execution of the command prompt environment. For maximum processor power consumption, the software should be the **only application executing on the system under evaluation.** It is recommended that the Windows NT or Windows 95/98 operating environment be configured to the default OS settings.



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