Intel® Celeron® Processor 200$^\Delta$ Sequence

Thermal and Mechanical Design Guidelines

— Supporting the Intel® Celeron® processor 220$^\Delta$

October 2007

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Revision History

Revision Number	Description	Revision Date
-001	• Initial Release	October 2007

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Thermal and Mechanical Design Guidelines

1 Introduction

1.1 Document Goals and Scope

1.1.1 Importance of Thermal Management

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

In a system environment, the processor temperature is a function of both system and component thermal characteristics. The system level thermal constraints consist of the local ambient air temperature and airflow over the processor as well as the physical constraints at and above the processor. The processor temperature depends in particular on the component power dissipation, the processor package thermal characteristics, and the processor thermal solution.

All of these parameters are affected by the continued push of technology to increase processor performance levels and packaging density (more transistors). As operating frequencies increase and packaging size decreases, the power density increases while the thermal solution space and airflow typically become more constrained or remains the same within the system. The result is an increased importance on system design to ensure that thermal design requirements are met for each component, including the processor, in the system.

1.1.2 Document Goals

Depending on the type of system and the chassis characteristics, new system and component designs may be required to provide adequate cooling for the processor. The goal of this document is to provide an understanding of these thermal characteristics and discuss guidelines for meeting the thermal requirements imposed on single processor systems using the Intel® Celeron® processor 200 sequence.

The concepts given in this document are applicable to any system form factor. Specific examples used will be the Intel enabled reference solution for a system.

1.1.3   Document Scope

This design guide supports the following processors:

- Intel® Celeron® Processor 200 sequence applies to the Intel® Celeron® processor 220.

In this document the Intel Celeron Processor 200 sequence will be referred to as "the processor".

In this document when a reference is made to "the processor" it is intended that this includes all the processors supported by this document. If needed for clarity, the specific processor will be listed.

In this document, when a reference is made to "datasheet", the reader should refer to the *Intel® Celeron® Processor 200 Sequence Datasheet*. If needed for clarity, the specific processor datasheet will be referenced.

In this document, when a reference is made to the "the reference design" it is intended that this includes all reference designs (D16869-001 and D96271-001) supported by this document. If needed for clarify, the specific reference design will be listed.

Chapter 2 of this document discusses package thermal mechanical requirements to design a thermal solution for the Intel Celeron processor 200 sequence in the context of personal computer applications. Chapter 3 discusses the thermal solution considerations and metrology recommendations to validate a processor thermal solution. Chapter 4 gives information on the Intel reference thermal solution for the processor in a system application.

The physical dimensions and thermal specifications of the processor that are used in this document are for illustration only. Refer to the Datasheet for the product dimensions, thermal power dissipation, and maximum junction temperature. In case of conflict, the data in the datasheet supersedes any data in this document.

1.2 Reference Documents

Material and concepts available in the following documents may be beneficial when reading this document.

Document	Document No./Location
Intel® Celeron® Processor 200 Sequence Datasheet	http://developer.intel.com/design/processor/datashts/318546.htm
Power Supply Design Guide for Desktop Platform Form Factors (Rev 1.1)	http://www.formfactors.org/
ATX Thermal Design Suggestions	http://www.formfactors.org/
microATX Thermal Design Suggestions	http://www.formfactors.org/
Balanced Technology Extended (BTX) System Design Guide	http://www.formfactors.org/
Thermally Advantaged Chassis version 1.1	http://www.intel.com/go/chassis/

1.3 Definition of Terms

Term	Description
T_A	The measured ambient temperature locally surrounding the processor. The ambient temperature should be measured just upstream of a passive heatsink or at the fan inlet for an active heatsink.
T_J	Processor junction temperature.
$T_{S\text{-}TOP}$	Heatsink temperature measured at vicinity to center on the top surface of heatsink base.
Ψ_{JA}	Junction-to-ambient thermal characterization parameter (psi). A measure of thermal solution performance using total package power. Defined as $(T_J - T_A)$ / Total Package Power. Note: Heat source must be specified for Ψ measurements.
Ψ_{JS}	Junction-to-sink thermal characterization parameter. A measure of thermal interface material performance using total package power. Defined as $(T_J - T_S)$ / Total Package Power. Note: Heat source must be specified for Ψ measurements.
Ψ_{SA}	Sink-to-ambient thermal characterization parameter. A measure of heatsink thermal performance using total package power. Defined as

Term	Description
	$(T_S - T_A)$ / Total Package Power. Note: Heat source must be specified for Ψ measurements.
TIM	Thermal Interface Material: The thermally conductive compound between the heatsink and the processor die surface. This material fills the air gaps and voids, and enhances the transfer of the heat from the processor die surface to the heatsink.
P_D	Processor total power dissipation (assuming all power dissipates through the processor die).
TDP	Thermal Design Power: a power dissipation target based on worst-case applications. Thermal solutions should be designed to dissipate the thermal design power.
P_{USAGE}	Maximum usage power of processor when running SysMark utility.

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2 *Processor Thermal/Mechanical Information*

2.1 Mechanical Requirements

2.1.1 Processor Package

The Intel Celeron processor 200 sequence is available in a 479-pin Micro-FCBGA package, as shown in Figure 1 to Figure 3. The processor uses a Flip-Chip Ball Grid Array (FC-BGA6) package technology that directly solder down to a 479-pin footprint on PCB surface.

Mechanical specifications of the package are listed in Table 1. Refer to the datasheet for detailed mechanical specifications. In case of conflict, the package dimensions in the datasheet supersedes dimensions provided in this document.

The processor package has mechanical load limits that are specified in the processor datasheet. The specified maximum static and dynamic load limits should not be exceeded during their respective stress conditions. These include heatsink installation, removal, mechanical stress testing, and standard shipping conditions.

- When a compressive static load is necessary to ensure thermal performance of the thermal interface material between the heatsink base and the processor die, it should not exceed the corresponding specification given in the processor datasheet.

- When a compressive static load is necessary to ensure mechanical performance, it should remain in the minimum/maximum range specified in the processor datasheet.

No portion of the substrate should be used as a mechanical reference or load-bearing surface for the thermal or mechanical solution.

The processor datasheet provides package handling guidelines in terms of maximum recommended shear, tensile and torque loads for the processor substrate. These recommendations should be followed in particular for heatsink removal operations.

Table 1. Micro-FCBGA Package Mechanical Specifications

Symbol	Parameter	Min	Max	Unit	Figure
B1	Package substrate width	34.95	35.05	mm	Figure 2
B2	Package substrate length	34.95	35.05	mm	Figure 2
C1	Die width	11.1		mm	Figure 2
C2	Die length	8.2		mm	Figure 2
F2	Die height (with underfill)	0.89		mm	Figure 2
F3	Package overall height (package substrate to die)	2.022 Max		mm	Figure 2
G1	Width (first ball center to last ball center)	31.75 Basic		mm	Figure 2
G2	Length (first ball center to last ball center)	31.75 Basic		mm	Figure 2
J1	Ball pitch (horizontal)	1.27 Basic		mm	Figure 2
J2	Ball pitch (vertical)	1.27 Basic		mm	Figure 2
M	Solder Resist Opening	0.61	0.69	mm	Figure 2
N	Ball height	0.6	0.8	mm	Figure 2
--	Corner Keep-out zone at corner (4X)	7 × 7		mm	Figure 3
--	Keep-out from edge of package (4X)	5		mm	Figure 3
--	Package edge to first ball center	1.625		mm	Figure 3
P_{die}	Allowable pressure on the die for thermal solution	689		kPa	
W	Package weight	6		g	

NOTE:
1. All dimensions are subject to change.
2. Overall height as delivered. Values were based on design specifications and tolerances. Final height after surface mount depends on OEM motherboard design and SMT process.

Figure 1. Micro-FCBGA Processor Package Drawing – Isometric View
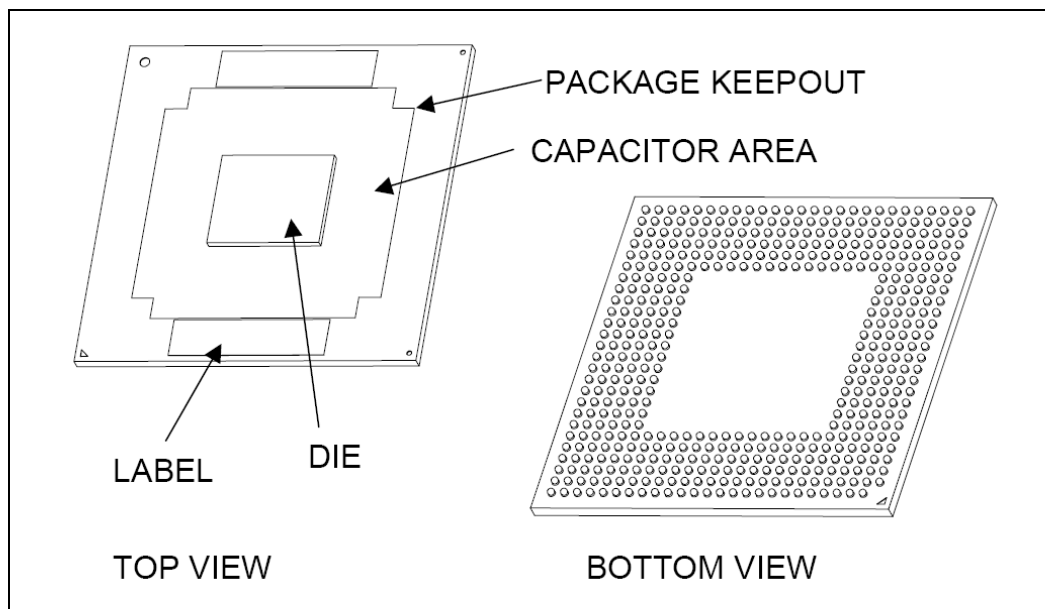
Figure 2. Micro-FCBGA Processor Package Drawing (Sheet 1 of 2)
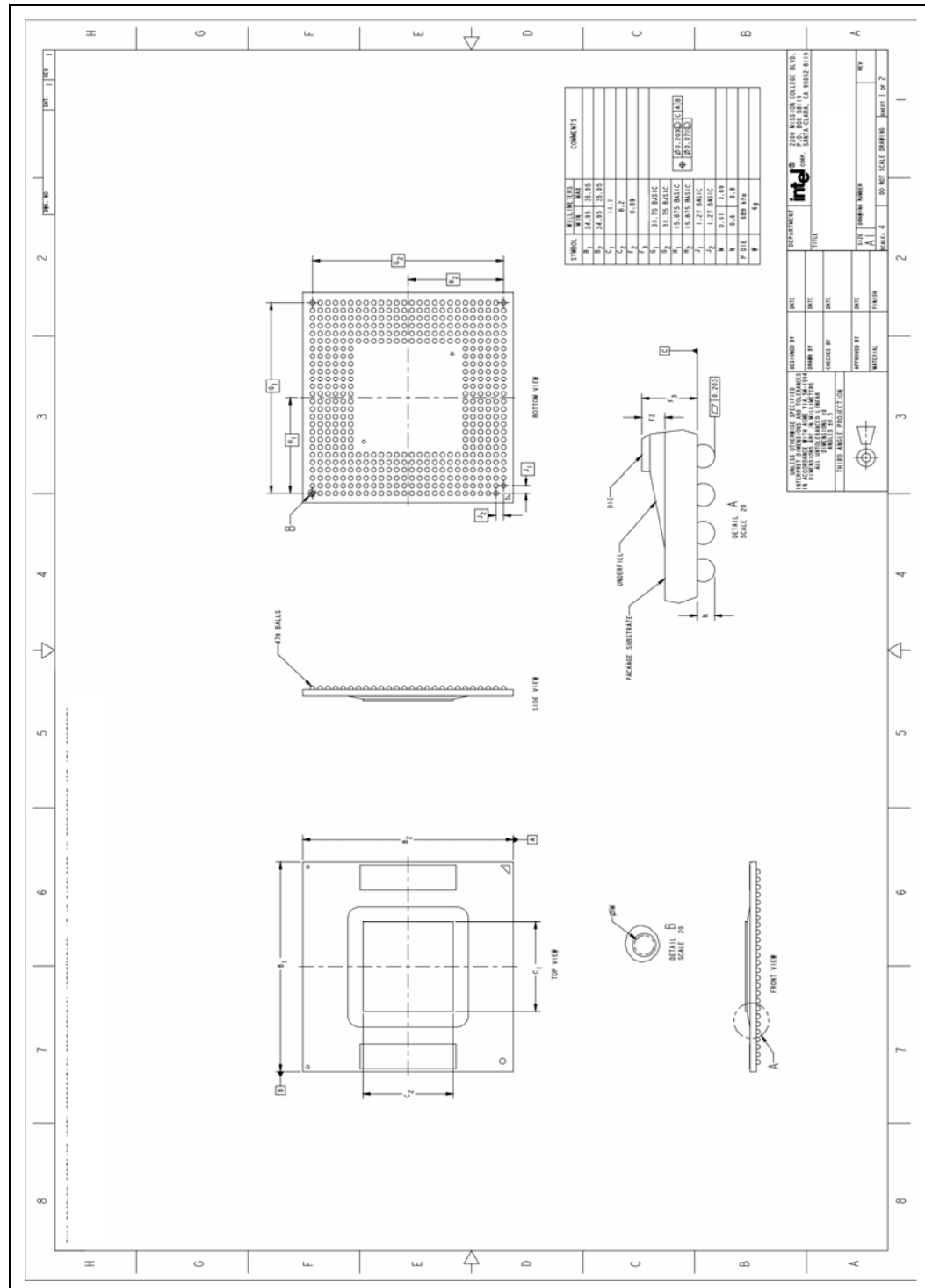
NOTE: All dimensions in millimeters. Values shown are for reference only. See Table 1 for specific details.

Figure 3. Micro-FCBGA Processor Package Drawing (Sheet 2 of 2)
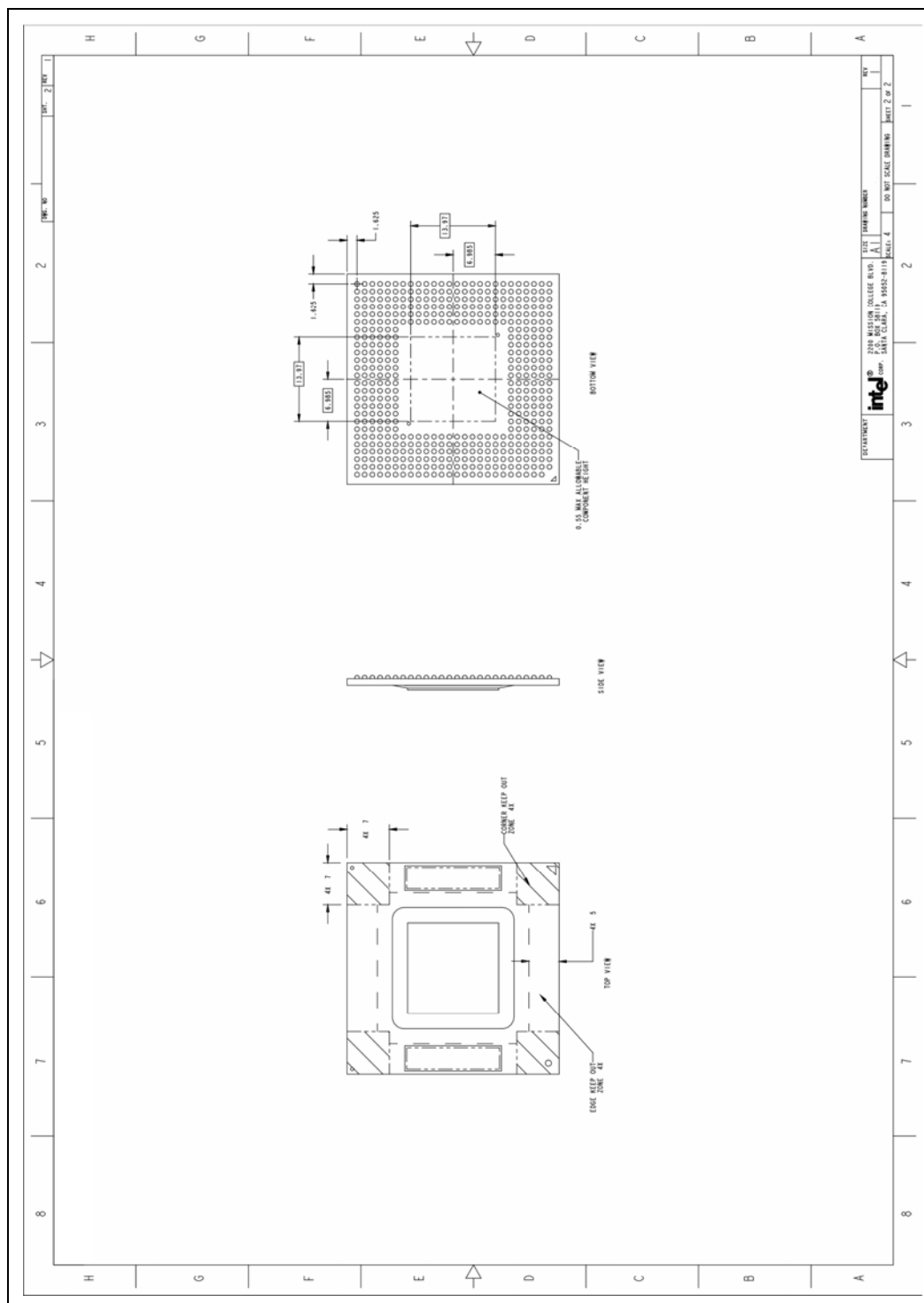
NOTE: All dimensions in millimeters. Values shown are for reference only. See Table 1 for specific details.

2.1.2 Heatsink Attach

2.1.2.1 General Guidelines

The micro-FCBGA package may have capacitors placed in the area surrounding the processor die. The die-side capacitors, which are only slightly shorter than the die height, are electrically conductive and contact with electrically conductive materials should be avoided. The use of an insulating material between the capacitors and any thermal and mechanical solution should be considered to prevent capacitors shorting. A thermal and mechanical solution design must not intrude into the required keep-out zones as specified in the datasheet.

There are no features on the 479-pins micro-FCBGA package for direct heatsink attachment: a mechanism must be designed to attach the heatsink directly to the motherboard. In addition to holding the heatsink in place on top of the processor die, this mechanism plays a significant role in the robustness of the system in which it is implemented, in particular:

- Ensuring thermal performance of the thermal interface material (TIM) applied between the processor die and the heatsink. TIMs based on phase change materials are very sensitive to applied pressure: the higher the pressure, the better the initial performance. Designs should incorporate a possible decrease in applied pressure over time due to potential structural relaxation in retention components (creep effect causing clip to lose its preload and causing anchor pull-out). It is not recommended to use TIMs such as thermal greases onto small bare die package, due to the TIM "pump-out" concern after heatsink is assembled.

- Ensuring system electrical, thermal, and structural integrity under shock and vibration events. The mechanical requirements of the heatsink attach mechanism depend on the mass of the heatsink and the level of shock and vibration that the system must support. The overall structural design of the motherboard and the system should be considered in designing the heatsink attach mechanism. The design should provide a means for protecting the solder joints.

2.1.2.2 Heatsink Clip Load Requirement

The attach mechanism for the heatsink developed to support the processor creates a nominal static compressive preload on the package of 9.9 lbf ± 1.2 lbf throughout the life of the product for designs compliant with the Intel reference design assumptions:

- Using TIM Honeywell PCM45F (pad version).

- 55.88 mm (2.2") x 54.88 mm (2.16") attach pattern. Refer to Figure 21 for heatsink keep-out zone.

- And no board stiffening device (backing plate, chassis attach, etc.).

The minimum load is required to thermal performance while protecting solder joint against fatigue failure in temperature cycling.

Notes the load range above is required to ensure a minimum load of 8.7lbf at end-of-life. The tolerance and nominal load is based on reference design and will slightly differ on alternate thermal solution provided by third party.

It is important to take into account potential load degradation from creep over time when designing the clip or fastener to the required minimum load. This means that,

depending on clip stiffness, the initial preload at beginning of life of the product may be significantly higher than the minimum preload that must be met throughout the life of the product.

Refer to Appendix A for clip load metrology guidelines.

2.1.2.3   Heatsink Attach Mechanism Design Considerations

In addition to the general guidelines given above, the heatsink attach mechanism for the processor should be designed to the following guidelines:

- *Solder joint reliability compliant with INTEL quality specification before & after reliability test such as shock & vibration*. The Critical-To-Function (CTF) corner solder joints of processor package for Intel® Desktop Board D201GLY2 experience high stress concentration during shock and vibration test, therefore the "vertical lock-down" alignment feature is integrated into z-clip design to prevent solder joints failures. Please refer to the datasheet for CTF and NCTF locations.

- Vertical Lock-Down Alignment Feature. Generic z-clip solution should include this feature to improve structural performance during shock and vibration test. The vertical lock-down feature is basically an additional feature (bends etc.) that is incorporated into the z-clip to better constraint the heatsink. The reference thermal solution adds a vertical bend that contacts the heatsink after preload application. This in turn provides a 4 contact constraint as opposed to the 2 contact constraint as shown in Figure 4 (thru z-clip center indentation). Note that the vertical lock feature sizing must be determined thru FOC (First Order Calculation) or FEA (Finite Element Analysis) to ensure it touches the heatsink base just enough to provide the required restraint without causing the center indent feature losing contact. Refer to Figure 4 for further illustration.

- Figure 5 illustrates solder crack types.

- Heatsink should be held in place under mechanical shock and vibration events and applies force to the heatsink base to maintain desired pressure on the thermal interface material. Note that the load applied by the heatsink attach mechanism must comply with the package specifications described in the processor datasheet. One of the key design parameters is the height of the top surface of the processor die above the motherboard, is expected in the range of 2.73 mm ± 0.125 mm. This data is provided for information only, and should be derived from:
  — The height of the package, from the package seating plane to the top of the die, and accounting for its nominal variation and tolerances that are given in the corresponding processor datasheet.

- Engages easily, and if possible, without the use of special tools. In general, the heatsink is assumed to be installed after the motherboard has been installed into the chassis. Ergo force requirement states that assembly force shall not exceed 15lbf (target is 10lbf).

- Minimizes contact with the motherboard surface during installation and actuation to avoid scratching/damaging the motherboard.

Figure 4. Vertical Lock-Down Alignment Feature
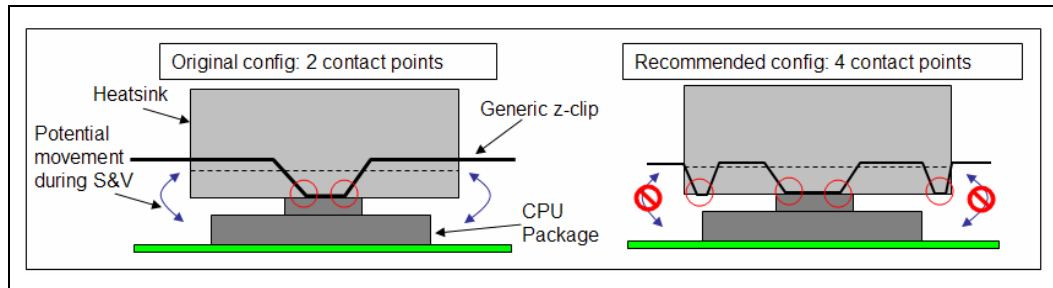
Figure 5. Various Types of Solder Crack
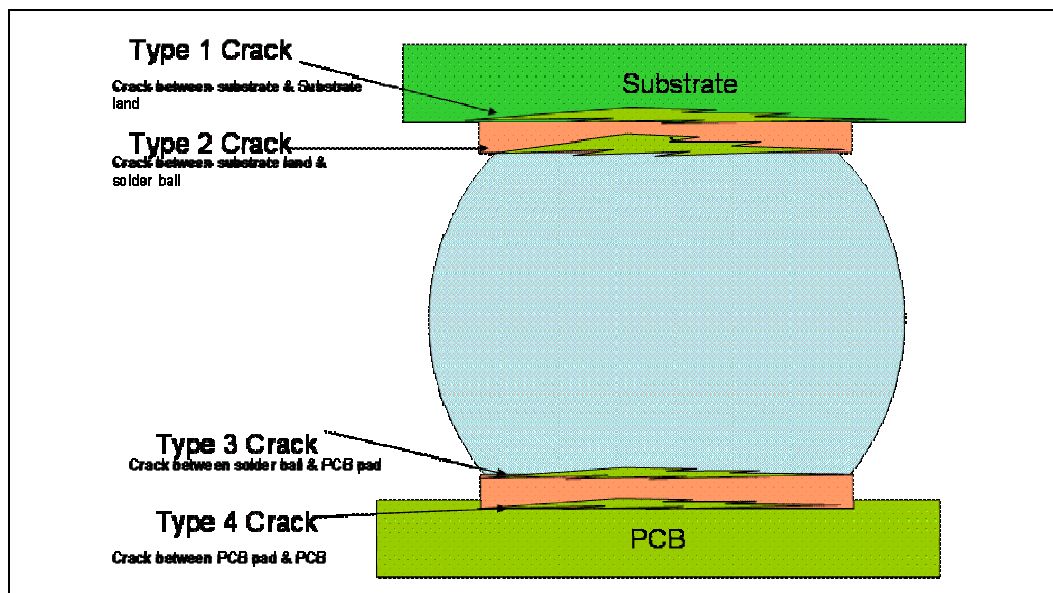
2.2 Thermal Requirements

The processor requires a thermal solution to maintain temperatures within operating limits. Refer to the datasheet for the processor thermal specifications.

To allow for the optimal operation and long-term reliability of Intel processor-based systems, the system/processor thermal solution should remain within the minimum and maximum junction temperature specifications at corresponding thermal design power (TDP) as listed in datasheet.

The thermal limits for the processor are the junction temperature (T_J). The T_J defines the maximum junction temperature as a function of power being dissipated. Designing to this specification allows optimization of thermal designs for processor performance.

2.2.1   Processor Junction Temperature

Table 2. Thermal Specifications for Intel® Celeron® Processor 200 Sequence

Symbol	Processor Number	Core Frequency and Voltage	Cache	Thermal Design Power (W)		Notes
TDP	220	1.20 GHz	512 KB	19		1, 4, 5
Symbol	**Parameter**	**Min**	**Max**	**Notes**		
T_J (°C)	Junction Temperature			0 °C	100 °C	3, 4

NOTE:
1. The TDP is not the maximum theoretical power the processor can generate.
2. Not 100% tested. These power specifications are determined by characterization of the processor currents at higher temperatures and extrapolating the values for the temperature indicated.
3. As measured by the activation of the on-die Intel® Thermal Monitor. The Intel Thermal Monitor's automatic mode is used to indicate that the maximum T_J has been reached. Refer to datasheet for more details.
4. The Intel Thermal Monitor automatic mode must be enabled for the processor to operate within specifications, please refer to datasheet for more details.
5. At T_J of 100 °C.

2.3   Heatsink Design Considerations

To remove the heat from the processor, three basic parameters should be considered:

- **The area of the surface on which the heat transfer takes place**. Without any enhancements, this is the surface of the processor die. One method used to improve thermal performance is by attaching a heatsink to the die. A heatsink can increase the effective heat transfer surface area by conducting heat out of the die and into the surrounding air through fins attached to the heatsink base.

- **The conduction path from the heat source to the heatsink fins**. Providing a direct conduction path from the heat source to the heatsink fins and selecting materials with higher thermal conductivity typically improves heatsink performance. The length, thickness, and conductivity of the conduction path from the heat source to the fins directly impact the thermal performance of the heatsink. In particular, the quality of the contact between the package die and the heatsink base has a higher impact on the overall thermal solution performance as processor cooling requirements become stricter. Thermal interface material (TIM) is used to fill in the gap between the die and the bottom surface of the heatsink, and thereby improve the overall performance of the stack-up (die-TIM-Heatsink). With extremely poor heatsink interface flatness or roughness, TIM may not adequately fill the gap. The TIM thermal performance depends on its thermal conductivity as well as the pressure applied to it. Refer to Section 2.3.3 for further information.

- **The heat transfer conditions on the surface on which heat transfer takes place**. Convective heat transfer occurs between the airflow and the surface exposed to the flow. It is characterized by the local ambient temperature of the

air, T_A, and the local air velocity over the surface. The higher the air velocity over the surface, and the cooler the air, the more efficient is the resulting cooling. The nature of the airflow can also enhance heat transfer via convection. Turbulent flow can provide improvement over laminar flow. In the case of a heatsink, the surface exposed to the flow includes in particular the fin faces and the heatsink base.

Active heatsinks typically incorporate a fan that helps manage the airflow through the heatsink.

Passive heatsink solutions require in-depth knowledge of the airflow in the chassis. Typically, passive heatsinks see lower air speed. These heatsinks are therefore typically larger (and heavier) than active heatsinks due to the increase in fin surface required to meet a required performance. As the heatsink fin density (the number of fins in a given cross-section) increases, the resistance to the airflow increases: it is more likely that the air travels around the heatsink instead of through it, unless air bypass is carefully managed. Using air-ducting techniques to manage bypass area can be an effective method for controlling airflow through the heatsink.

2.3.1   Heatsink Size

The size of the heatsink is dictated by height restrictions for installation in a system and by the real estate available on the motherboard and other considerations for component height and placement in the area potentially impacted by the processor heatsink. The height of the heatsink must comply with the requirements and recommendations published for the motherboard form factor of interest. Designing a heatsink to the recommendations may preclude using it in system adhering strictly to the form factor requirements, while still in compliance with the form factor documentation.

For the ATX/microATX form factor, it is recommended to use:

- The ATX motherboard keep-out footprint definition and height restrictions for enabling components, defined for the platforms designed with the micro-FCBGA of this design guide.

- The motherboard primary side height constraints defined in the ATX Specification V2.2 and the microATX Motherboard Interface Specification V1.2 found at http://www.formfactors.org/.

The resulting space available above the motherboard is generally not entirely available for the heatsink. The target height of the heatsink must take into account airflow considerations (for fan performance for example) as well as other design considerations (air duct, etc.).

2.3.2 Heatsink Mass

With the need to push air cooling to better performance, heatsink solutions tend to grow larger (increase in fin surface) resulting in increased mass. The insertion of highly thermally conductive materials like copper to increase heatsink thermal conduction performance results in even heavier solutions. As mentioned in Section 2.1.2, the heatsink mass must take into consideration the package load limits, the heatsink attach mechanical capabilities, and the mechanical shock and vibration profile targets. Beyond a certain heatsink mass, the cost of developing and implementing a heatsink attach mechanism that can ensure the system integrity under the mechanical shock and vibration profile targets may become prohibitive.

The recommended maximum heatsink mass for the Intel Celeron processor 200 sequence reference thermal solution is 62 g. This mass includes the fan and the heatsink only. The attach mechanism (clip, fasteners, etc.) are not included.

Note: The 62 g mass limit for current solution is based on the capabilities of reference design components that retain the heatsink to the board and apply the necessary preload. Any reuse of the clip and fastener in alternate or derivative designs should not exceed 62 g. Designs that have a mass of greater than 62 g should analyze the preload and retention limits of the fastener.

Note: The chipset components on the board are affected by processor heatsink mass. Exceeding these limits may require the evaluation of the chipset for shock and vibration.

2.3.3 Thermal Interface Material

Thermal interface material application between the processor die and the heatsink base is generally required to improve thermal conduction from the die to the heatsink. Many thermal interface materials can be pre-applied to the heatsink base prior to shipment from the heatsink supplier and allow direct heatsink attach, without the need for a separate thermal interface material dispense or attach process in the final assembly factory.

All thermal interface materials should be sized and positioned on the heatsink base in a way that ensures the entire processor die area is covered. It is important to compensate for heatsink-to-processor attach positional alignment when selecting the proper thermal interface material size.

When pre-applied material is used, it is recommended to have a protective film applied. This film must be removed prior to heatsink installation.

The recommended TIM for the Intel Celeron processor 200 sequence reference thermal solution is Honeywell PCM45F (pad version). It is not recommended to use TIMs such as thermal greases onto small bare die package as specified in Section 2.1.2.1.

2.4　System Thermal Solution Considerations

2.4.1　Chassis Thermal Design Capabilities

The reference thermal solution for the Intel Celeron processor 200 sequence on the Intel Desktop Board D201GLY2 is a passive heatsink design, which requires chassis to deliver sufficient airflow cooling to ensure stability and reliability of processor. The **maximum allowable heatsink temperature** ($T_{S\text{-}TOP\text{-}MAX}$) is set to **91 °C** for processor to ensure the capability of a chassis in providing sufficient airflow for processor cooling. $T_{S\text{-}TOP\text{-}MAX}$ is the maximum limit value for heatsink which is similar to $T_{CASE\text{-}MAX}$ for lidded processors.

The "**usage power consumption**" ($P_{CPU\text{-}USAGE}$) of the Intel Celeron processor 200 sequence was quantified at maximum of **16 W** based on measurement done on Intel® Desktop Board D201GLY2 when tested with SYSMark04. The reference thermal solution for processor is designed at $P_{CPU\text{-}USAGE}$ for performance & cost optimal considerations. Do not mistaken $P_{CPU\text{-}USAGE}$ with processor's TDP as documented in datasheet.

Table 3. System Thermal Solution Design Requirement

1.	System Thermal Solution Design Requirement	Note
	3.　$T_{S\text{-}TOP\text{-}MAX} \leq 91°C$	4.　1

NOTE:
1. Based on processor maximum Usage Power Consumption (P_{USAGE}) of 16 W measured on Intel® Desktop Board D201GLY2 when tested with SYSMark04.

To evaluate the system thermal capability of a given chassis, the system designer is recommended to conduct in-chassis system thermal test. The data to be collected are both processor power consumption (P_{CPU}) and heatsink temperature ($T_{S\text{-}TOP}$) with the above mentioned processor load at 35 °C external ambient condition. The $T_{S\text{-}SYSTEM}$ can be estimated using Equation 1. The thermal pass requirement for a given chassis can be met if $T_{S\text{-}SYSTEM} \leq T_{S\text{-}TOP\text{-}MAX}$.

Equation 1　$T_{S\text{-}SYSTEM} = T_A + (T_{S\text{-}TOP} - T_A) \times 16/P_{CPU} \leq T_{S\text{-}TOP\text{-}MAX} = 91°C$

2.4.2　Improving Chassis Thermal Performance

The heat generated by components within the chassis must be removed to provide an adequate operating environment for the processor and all other components in the system. Moving airflow through the chassis brings in fresh cool air from the external ambient environment and transports the heat generated by the processor and other system components out of the system. Therefore, the number, size and relative position of fans and vents determine the chassis thermal performance, and the resulting ambient temperature around the processor.

It is particularly important to choose a thermally advantaged chassis for the reference thermal solution for Intel Celeron processor 200 sequence on the Intel Desktop Board D201GLY2, which is a passive heatsink design.

By analyzing airflow condition in an μATX chassis, a case study in Figure 6 shows that a chassis layout is critical to components cooling in the system. The alignment of system fan (80×80mm^2) with power supply fan results in pass-through airflow which bypasses the motherboard region. The cooling airflow from external environment is not able to reach motherboard region to cool critical components on the motherboard. Vents located at chassis top and side causes thermal gradient that induces natural convection flow (blue arrow) for processor and MCH. Majority of regions are dominated by natural convection or low flow eddies (yellow lines).

For a Chassis Air Guide Design Guide (Rev 1.1) compliant μATX chassis, such as in Case Study #1, it is recommended to relocate system fan to CAG (Chassis Air Guide) venting to provide impingement airflow to processor and MCH on motherboard as well as improving overall airflow within chassis. Figure 7 shows a Case Study #2 by relocating system fan to CAG venting location for airflow improvement.

System exhaust fan located at rear side of chassis (at motherboard input/output back panel) will effectively improve chassis thermal by exhausting hot air heated by components on board, and regulating cool air from environment into chassis via chassis venting. Figure 8 shows Case Study #3 of an μATX chassis with two exhaust fan installed for system cooling.

Additionally, mounting position and type of power supply unit with fan could assist to improve system thermal performance. Figure 9 shows that a "top mount fan" power supply located next to processor is able to direct airflow to heatsink for cooling. Refer to Power Supply Design Guide (Rev 1.1) for power supply selection.

Figure 6. Case Study #1: Top view — Poor μATX Chassis Layout Design for Intel®
Celeron® Processor 200 Sequence on Intel® Desktop Board D201GLY2
(chassis cover removed for illustration)
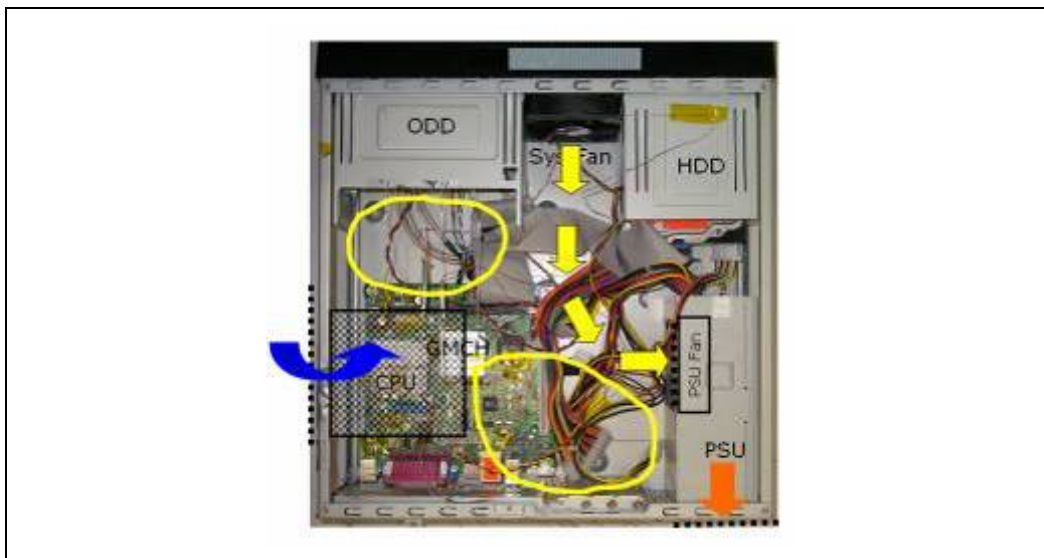
Figure 7. Case Study #2: Relocate System Fan to CAG Venting for Airflow Improvement
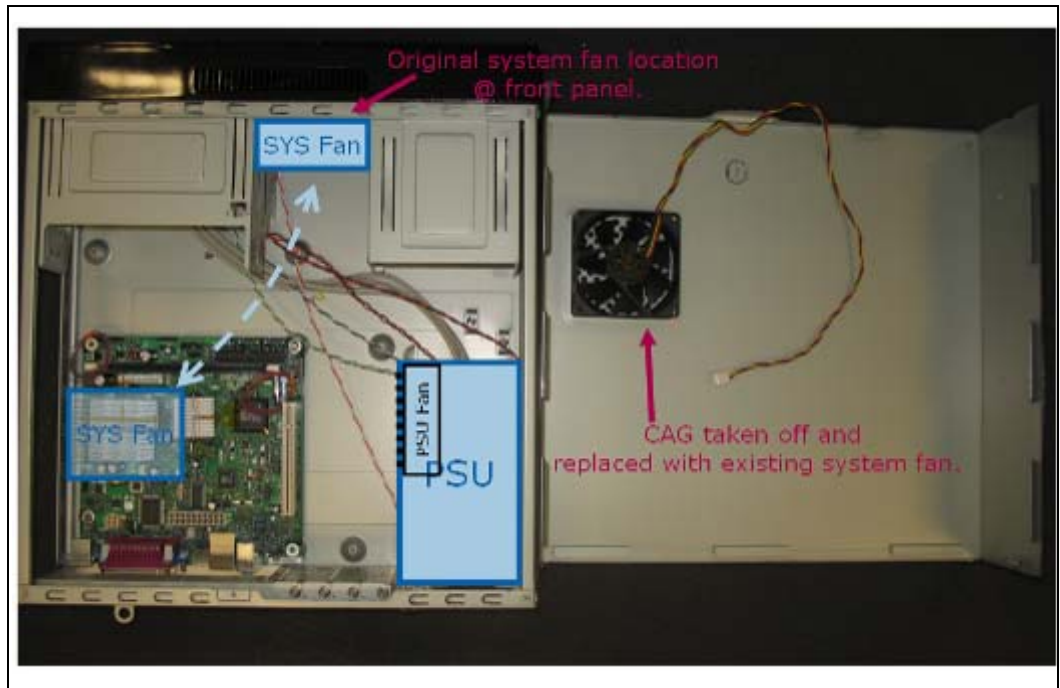
Figure 8. Case Study#3: An µATX Chassis Equipped with Two Exhaust Fans
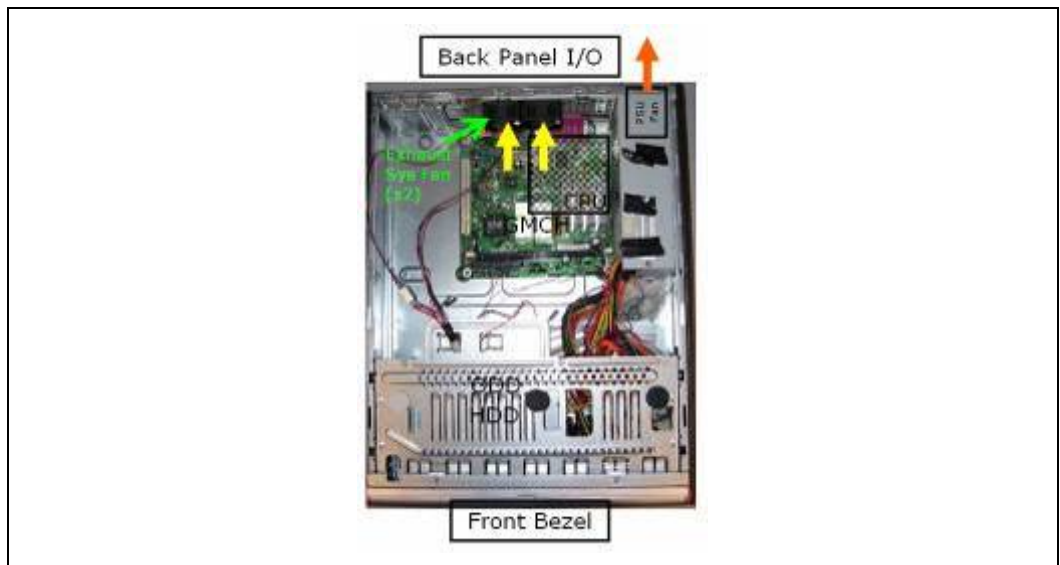
Figure 9. Case Study #4: A "Top Mount Fan" PSU is located next to Processor in μATX Chassis for System Thermal Performance Improvement

2.4.3   Summary

In summary, heatsink design considerations for the Intel Celeron processor 200 sequence on the Intel Desktop Board D201GLY2 include:

- The heatsink temperature $_{TS-TOP-MAX}$ which is a function of system thermal performance must be compliant in order to ensure processor reliability.

- Heatsink interface to die surface characteristics, including flatness and roughness.

- The performance of the thermal interface material used between the heatsink and the die.

- The required heatsink clip static load, 9.9 lbf ± 1.2 lbf, throughout the life of the product (refer to Section 2.1.2.2 for further information).

- Surface area of the heatsink.

- Heatsink material and technology.

- Volume of airflow over the heatsink surface area.

- Development of airflow entering and within the heatsink area.

- Physical volumetric constraints placed by the system.

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Thermal and Mechanical Design Guidelines

3 *Thermal Metrology*

This section discusses guidelines for testing thermal solutions, including measuring processor temperatures. In all cases, the thermal engineer must measure power dissipation and temperature to validate a thermal solution. To define the performance of a thermal solution the "thermal characterization parameter", Ψ ("psi") will be used.

3.1 Characterizing Cooling Performance Requirements

The idea of a "thermal characterization parameter", Ψ ("psi"), is a convenient way to characterize the performance needed for the thermal solution and to compare thermal solutions in identical situations (same heat source and local ambient conditions). The thermal characterization parameter is calculated using total package power.

Note: Heat transfer is a three-dimensional phenomenon that can rarely be accurately and easily modeled by a single resistance parameter like Ψ.

The junction-to-local ambient thermal characterization parameter value (Ψ_{JA}) is used as a measure of the thermal performance of the overall thermal solution that is attached to the processor package. It is defined by the following equation, and measured in units of °C/W:

Equation 2 $\Psi_{JA} = (T_J - T_A) / P_D$

Where:

Ψ_{JA} =   Junction-to-local ambient thermal characterization parameter (°C/W)

T_J =   Processor junction temperature (°C)

T_A =   Local ambient temperature in chassis at processor (°C)

P_D =   Processor total power dissipation (W) (assumes all power dissipates through the processor die)

For reference thermal solution of Intel Celeron processor 200 sequence on Intel Desktop Board D201GLY2, the junction-to-local ambient thermal characterization parameter of the processor, Ψ_{JA}, is comprised of Ψ_{JS}, the thermal interface material thermal characterization parameter, Ψ_{HS_BASE} the thermal characterization parameter of the heatsink base from bottom center of heatsink base to top center of heatsink base surface, and of $\Psi_{S\text{-}TOP\text{-}A}$, the sink-to-local ambient thermal characterization parameter:

Equation 3 $\Psi_{JA} = \Psi_{JS} + \Psi_{HS\_BASE} + \Psi_{S\text{-}TOP\text{-}A}$

Where:

Ψ_{JS}	=	Thermal characterization parameter of the thermal interface material (°C/W)
Ψ_{HS_BASE}	=	Thermal characterization parameter of the heatsink base (°C/W)
$\Psi_{S\text{-}TOP\text{-}A}$	=	Thermal characterization parameter from heatsink top to local ambient (°C/W)

Ψ_{JS} is strongly dependent on the thermal conductivity, thickness and performance degradation across time of the TIM between the heatsink and processor die.

Ψ_{HS_BASE} is a measure of the thermal characterization parameter of the heatsink base. It is dependent on the heatsink base material, thermal conductivity, thickness and geometry.

$\Psi_{S\text{-}TOP\text{-}A}$ is a measure of the thermal characterization parameter from the top center point of the heatsink base to the local ambient air. $\Psi_{S\text{-}TOP\text{-}A}$ is dependent on the heatsink material, thermal conductivity, and geometry. It is also strongly dependent on the air flow through the fins of the heatsink.

Equation 4 $(\Psi_{JA} - \Psi_{JS} - \Psi_{HS\_BASE}) \times P_D + T_A = T_{S\text{-}TOP\text{-}MAX}$

With a given processor junction-to-local ambient requirement (Ψ_{JA}) and TIM performance (Ψ_{JS}) and processor power consumption (P_D), the processor's heatsink requirement ($T_{S\text{-}TOP\text{-}MAX}$) could be defined by Equation 4.

Figure 10 illustrates the combination of the different thermal characterization parameters.

Figure 10. Processor Thermal Characterization Parameter Relationships
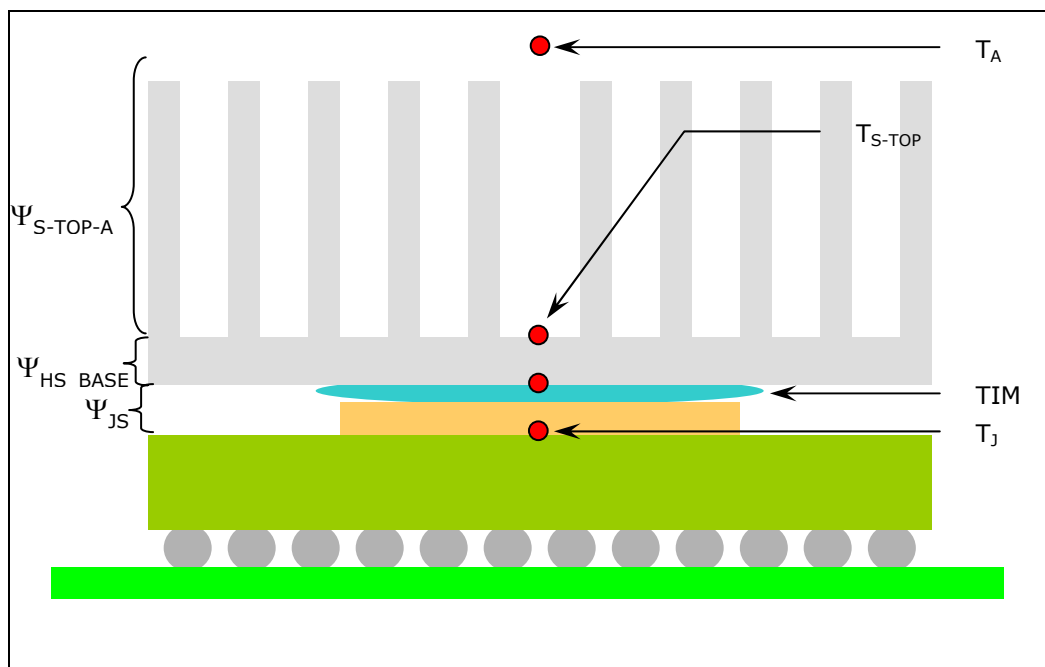
3.1.1 Example

The cooling performance, Ψ_{JA}, is then defined using the principle of thermal characterization parameter described above:

- The junction temperature $_{TJ\text{-}MAX}$ and thermal design power TDP given in the processor datasheet.

- Define the allowable heatsink temperature for processor, $T_{S\text{-}TOP\text{-}MAX}$.

The following provides an illustration of how one might determine the appropriate not related to any specific Intel processor thermal specifications, and are for illustrative purposes only.

Assume the TDP, as listed in the datasheet, is 20 W and the maximum junction temperature 20 W is 90 °C. Assume as well that the system airflow has been designed such that the local ambient temperature is 42 °C, and $\Psi_{HS\_BASE} = 0.3$ °C/W. Then the following could be calculated using Equation 2:

$$\Psi_{JA} = (T_J - T_A) / TDP = (90 - 55) / 20 = 1.75 \text{ °C/W}$$

To determine the required heatsink performance, a heatsink solution provider would need to determine Ψ_{JS} performance for the selected TIM and mechanical load configuration. If the heatsink solution were designed to work with a TIM material performing at $\Psi_{JS} \leq 0.50$ °C/W, solving for Equation 3 from above, the performance of the heatsink would be:

$\Psi_{SA} = \Psi_{JA} - \Psi_{JS} = 1.75 - 0.50 = 1.25$ °C/W

The heatsink temperature requirement can be obtained from Equation 4.

$T_{S\text{-TOP-MAX}} = (\Psi_{jA} - \Psi_{jS} - \Psi_{HS\_BASE}) \times P_D + T_A = (1.25 - 0.30) \times 20 + 55 = 74$ °C

3.2 Local Ambient Temperature Measurement Guidelines

The local ambient temperature T_A is the temperature of the ambient air surrounding the processor. For a passive heatsink, T_A is defined as the heatsink approach air temperature; for an actively cooled heatsink, it is the temperature of inlet air to the active cooling fan.

It is worthwhile to determine the local ambient temperature in the chassis around the processor to understand the effect it may have on the die temperature.

T_A is best measured by averaging temperature measurements at multiple locations in the heatsink inlet airflow. This method helps reduce error and eliminate minor spatial variations in temperature. The following guidelines are meant to enable accurate determination of the localized air temperature around the processor during system thermal testing.

For **active heatsinks**, it is important to avoid taking measurement in the dead flow zone that usually develops above the fan hub and hub spokes. Measurements should be taken at four different locations uniformly placed at the center of the annulus formed by the fan hub and the fan housing to evaluate the uniformity of the air temperature at the fan inlet. The thermocouples should be placed approximately 3 mm to 8 mm [0.1 to 0.3 in] above the fan hub vertically and halfway between the fan hub and the fan housing horizontally as shown in Figure 11 (avoiding the hub spokes). Using an open bench to characterize an active heatsink can be useful, and usually ensures more uniform temperatures at the fan inlet. However, additional tests that include a solid barrier above the test motherboard surface can help evaluate the potential impact of the chassis. This barrier is typically clear Plexiglas*, extending at least 100 mm [4 in] in all directions beyond the edge of the thermal solution. Typical distance from the motherboard to the barrier is 81 mm [3.2 in]. For even more realistic airflow, the motherboard should be populated with significant elements like memory cards, graphic card, and chipset heatsink. If a barrier is used, the thermocouple can be taped directly to the barrier with a clear tape at the horizontal location as previously described, half way between the fan hub and the fan housing. If a variable speed fan is used, it may be useful to add a thermocouple taped to the barrier above the location of the temperature sensor used by the fan to check its speed setting against air temperature. When measuring T_A in a chassis with a live motherboard, add-in cards, and other system components, it is likely that the T_A

measurements will reveal a highly non-uniform temperature distribution across the inlet fan section.

For **passive heatsinks**, thermocouples should be placed approximately 3 mm away from the heatsink as shown in Figure 12.

Note: Testing an active heatsink with a variable speed fan can be done in a thermal chamber to capture the worst-case thermal environment scenarios. Otherwise, when doing a bench top test at room temperature, the fan regulation prevents the heatsink from operating at its maximum capability. To characterize the heatsink capability in the worst-case environment in these conditions, it is then necessary to disable the fan regulation and power the fan directly, based on guidance from the fan supplier.

Figure 11. Locations for Measuring Local Ambient Temperature, Active Heatsink
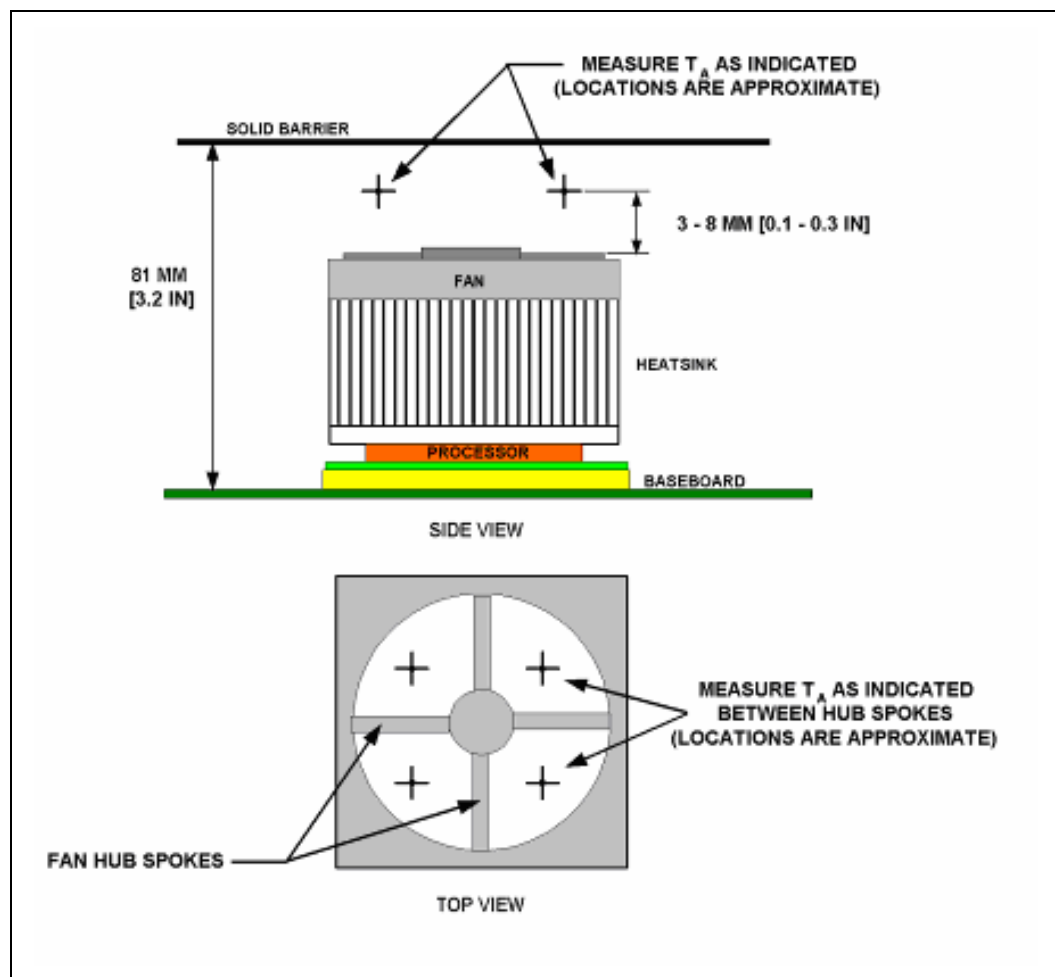
NOTE: Drawing Not to Scale

Figure 12. Locations for Measuring Local Ambient Temperature, Passive Heatsink
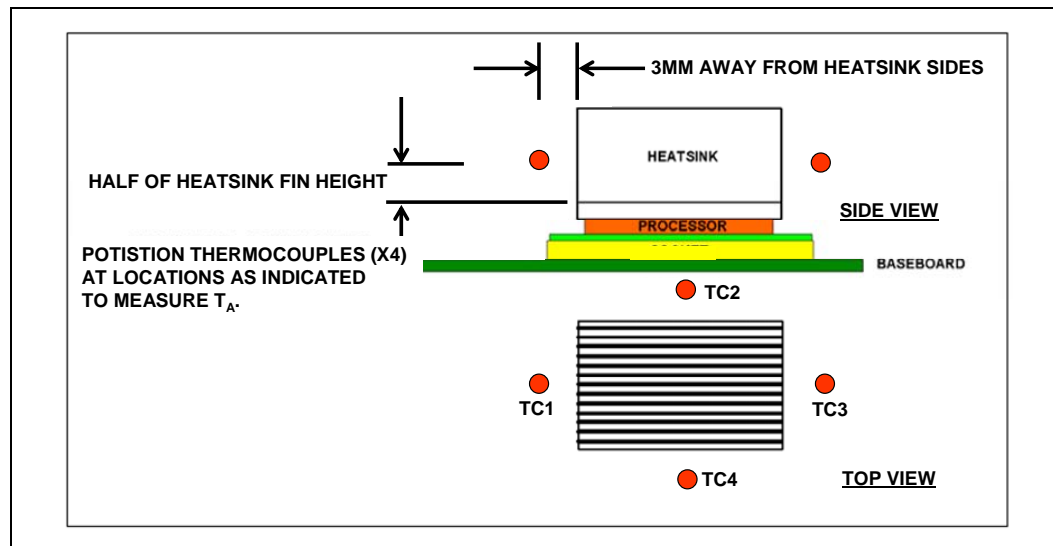
NOTE: Drawing Not to Scale

It is recommended that full and routine calibration of temperature measurement equipment be performed before attempting to perform temperature measurement. Intel recommends checking the meter probe set against known standards. This should be done at 0 ºC (using ice bath or other stable temperature source) and at an elevated temperature, around 80 ºC (using an appropriate temperature source).

Wire gauge and length also should be considered as some less expensive measurement systems are heavily impacted by impedance. There are numerous resources available throughout the industry to assist with implementation of proper controls for thermal measurements.

3.3   Processor Power Measurement Metrology Recommendation

This section recommends a metrology to measure power consumption of the Intel Celeron processor 200 sequence on the Intel Desktop Board D201GLY2. Should there be any modification of motherboard layout or design, contact Intel field sales representative or product marketing staff for clarification of this metrology.

3.3.1 Sample Preparation

In order to accurately measure the processor power consumption, it is required to attach sense resistor and replace one of the motherboard resistors. Schematic diagram in Figure 13 illustrates the precision resistor (R_{SENSE}) attached in series with processor circuitry. The processor power consumption can be estimated by Equation 5.

Equation 5 $P_D = V_{CC} \times (V_i / R_{SENSE})$

Where:

P_D = Processor total power dissipation (W) (assumes all power dissipates through the processor die)

V_{CC} = Processor core voltage.

V_i = Voltage measured across precision sense resistor.

R_{SENSE} = Given resistance value of precision resistor.

The Isotek 4 terminal (Kelvin) precision resistor (with resistance of 1 mΩ and Tol=0.1%) is recommended to be used for processor power measurement. Locate the inductor L1VR inductor (near processor) on motherboard and attach the Isotek precision resistor in-series with inductor as illustrated in Figure 13 schematic and Figure 14 board layout schematic diagram. Additionally, it is required to replace R27VR chip resistor (near processor) with a 19.6 KΩ rated chip resistor as illustrated in Figure 15. The Walsin chip resistor (WR06X1962FTL) is one of the recommended chip resistors for the rework.

Table 4. Test Accessories

5. Description	Q uantity	7. Part Number	N otes
9. Isotek 4 terminal (Kelvin) precision resistor	10. 1	11. P/N A-N-R001-F1-K2-0.1. R=1 mΩ, Tol=0.1%, P=2W, TCR<10 ppm/°C	12. 1
13. Walsin chip resistor	14. 1	15. WR06X1962FTL. R= 19.6 KΩ, Tol =1%, P=0.1W, TCR<200 ppm/°C.	16. 2

NOTE:
1. http://www.isotekcorp.com/productDisplay.asp?CatID=1&SubCatID
2. http://www.passivecomponent.com/lh3/search.asp

Figure 13. Precision Resistor Connected in-series with Processor Circuitry for Power Measurement
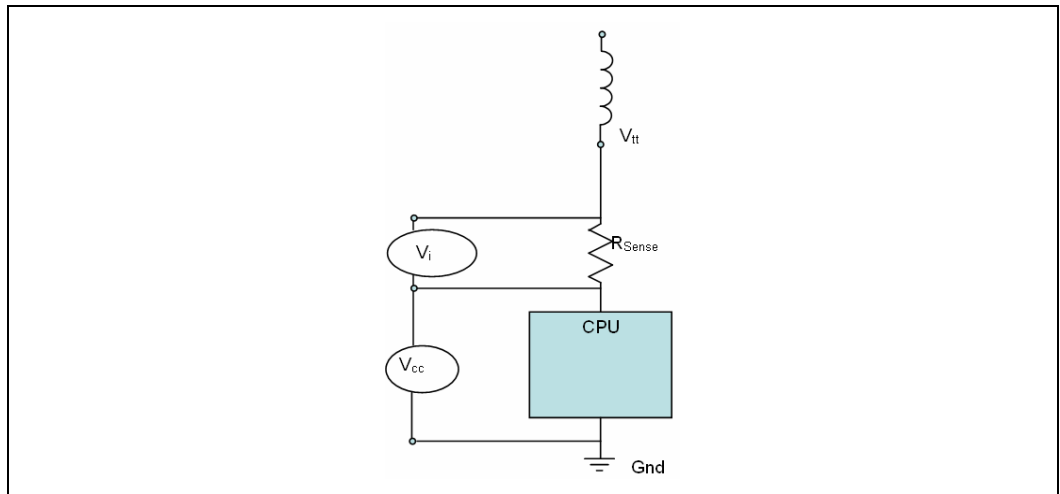
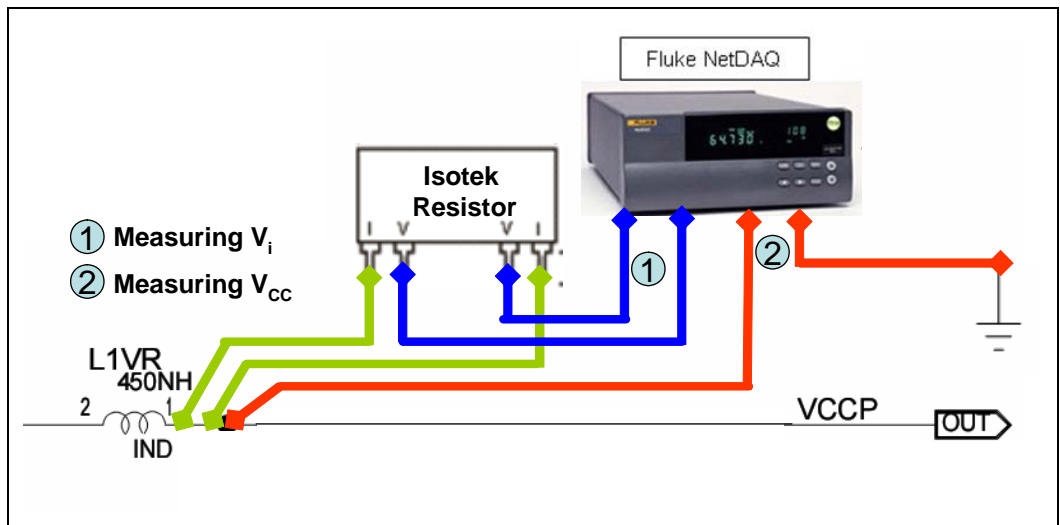**Figure 14. Installation of Isotek Resistor on Intel® Desktop Board D201GLY2 to Setup Connection for Power Measurement**

**Figure 15. Probing Resistance of the Soldered Walsin Resistor (R =19.6 KΩ) on Intel®
Desktop Board D201GLY2 to Ensure Proper Attachment**

**Figure 16. Precision Resistor Soldered on on Intel® Desktop Board D201GLY2, and
Connected to netDAQ for Voltage Measurement**

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Thermal and Mechanical Design Guidelines
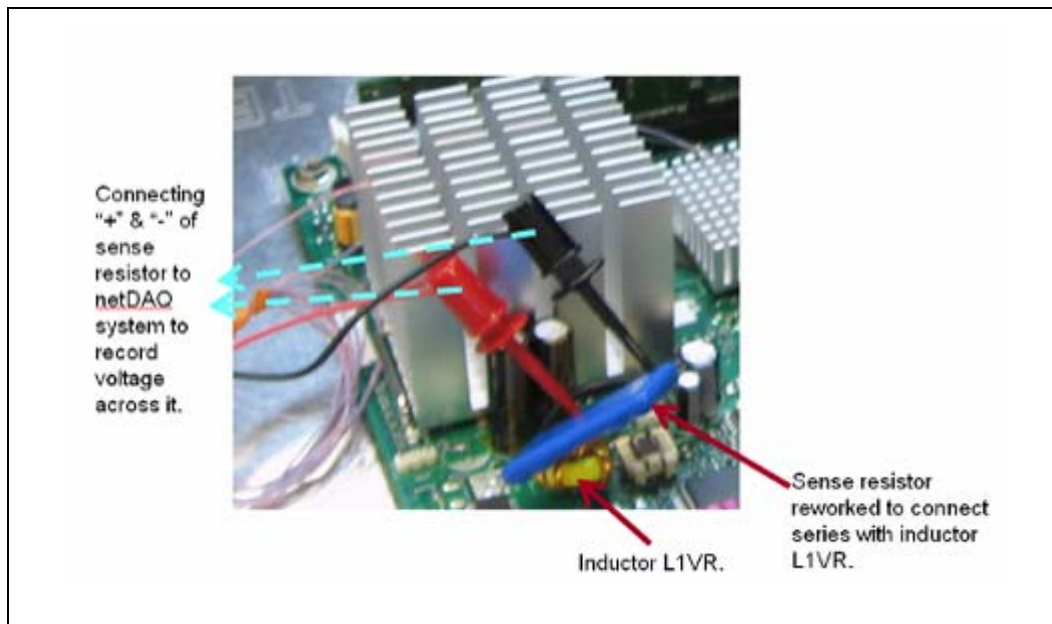
4 System Thermal/Mechanical Design Information

4.1 Overview of the Reference Design

This chapter will document the requirements for designing a passive heatsink that meets the maximum usage power consumption that mentioned in Section 2.4. The Intel® Boxed Processor thermal solution E21953-001 satisfies the specified thermal requirements.

Note: The part number E21953-001 provided in this document is for reference only. The revision number -001 may be subject to change without notice. OEMs and System Integrators are responsible for thermal, mechanical and environmental validation of this solution (refer to Sections 4.1.2 and 4.2).

The Intel® Boxed Processor thermal solution E21953-001 takes advantage of cost savings. The thermal solution supports the unique and smaller desktop PCs including small and ultra small form factors, down to a 5L system size.

The motherboard keep-out and height recommendations shown in Section 2.1 remain the same for a thermal solution for the Intel Celeron processor 200 sequence in the micro-FCBGA package.

4.1.1 Altitude

Many companies design products that must function reliably at high altitude, typically 1,500 m [5,000 ft] or more. Air-cooled temperature calculations and measurements at the test site elevation must be adjusted to take into account altitude effects like variation in air density and overall heat capacity. This often leads to some degradation in thermal solution performance compared to what is obtained at sea level, with lower fan performance and higher surface temperatures. The system designer needs to account for altitude effects in the overall system thermal design to make sure that the $T_{S-TOP-MAX}$ requirement for the processor is met at the targeted altitude.

4.1.2 Heatsink Thermal Validation

Intel recommends evaluation of the heatsink within the specific boundary conditions based on the methodology described in Chapter 3.

Testing is done on bench top test boards at ambient laboratory temperature.

The test results, for a number of samples, are reported in terms of a worst-case mean + 3σ value for thermal characterization parameter using real processors.

4.2 Environmental Reliability Testing

4.2.1 Structural Reliability Testing

Structural reliability tests consist of unpackaged, board-level vibration and shock tests of a given thermal solution in the assembled state. The thermal solution should meet the specified thermal performance targets after these tests are conducted; however, the test conditions outlined here may differ from your own system requirements.
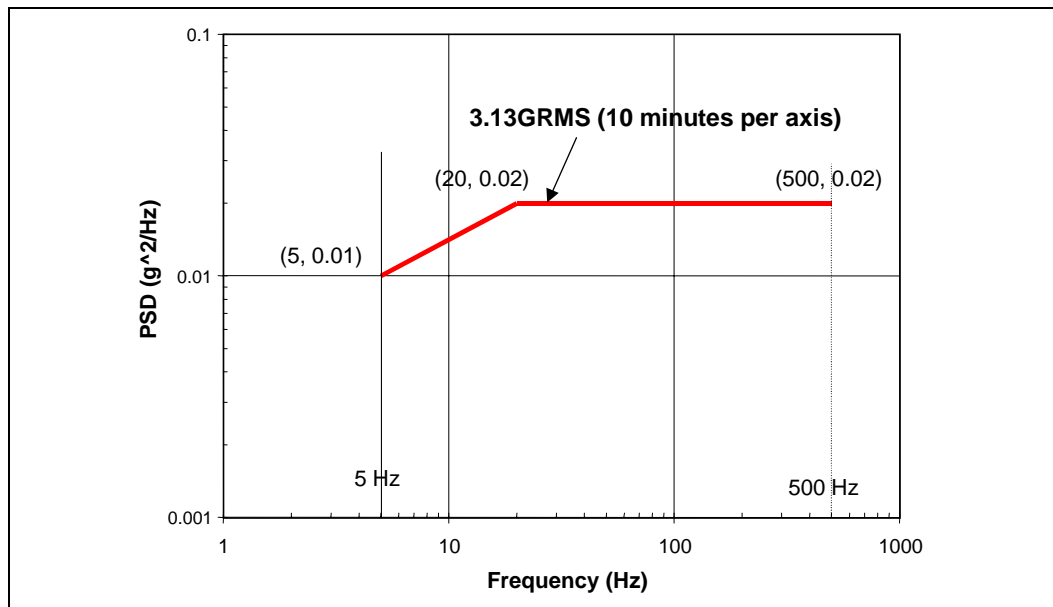
4.2.1.1 Random Vibration Test Procedure

Duration: 10 min/axis, 3 axes

Frequency Range: 5 Hz to 500 Hz

Power Spectral Density (PSD) Profile: 3.13 G RMS

Figure 17. Random Vibration PSD

4.2.1.2 Shock Test Procedure

Recommended performance requirement for a motherboard:

- Quantity: 3 drops for + and - directions in each of 3 perpendicular axes (i.e., total 18 drops).
- Profile: 50 G trapezoidal waveform, 170 in/sec minimum velocity change.
- Setup: Mount sample board on test fixture.

Figure 18. Shock Acceleration Curve
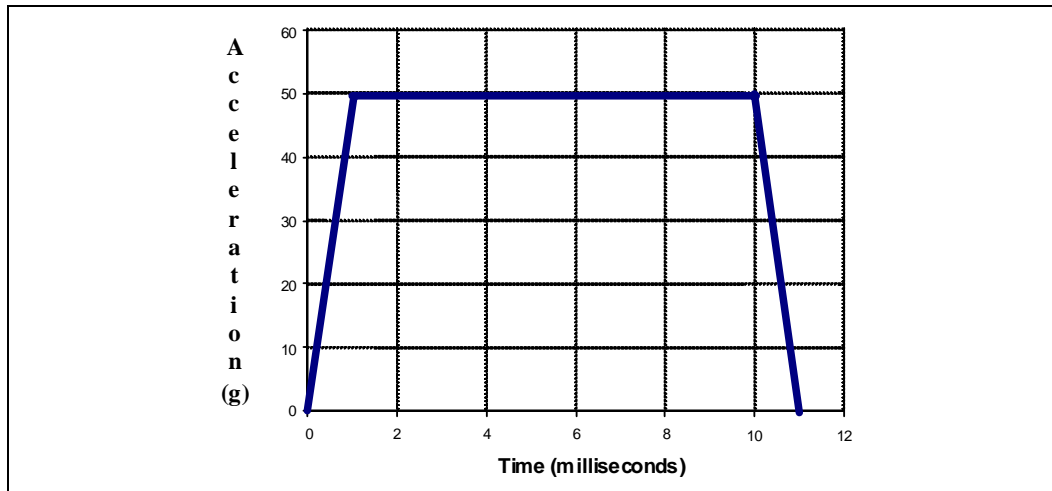
4.2.1.2.1 Recommended Test Sequence

Each test sequence should start with components (i.e. motherboard, heatsink assembly, etc.) that have never been previously submitted to any reliability testing.

The test sequence should always start with a visual inspection after assembly, and BIOS/CPU/Memory test (refer to Section 4.2.1.2.2).

Prior to the mechanical shock & vibration test, the units under test should be preconditioned for 72 hours at 45 ºC. The purpose is to account for load relaxation during burn-in stage.

The stress test should be followed by a visual inspection and then BIOS/CPU/Memory test.

4.2.1.2.2 Post-Test Pass Criteria

The post-test pass criteria are:

1. No significant physical damage to the heatsink attach mechanism (including such items as clip and motherboard fasteners).
2. Heatsink must remain attached to the motherboard.
3. Heatsink remains seated and its bottom remains mated flatly against die surface. No visible gap between the heatsink base and processor die. No visible tilt of the heatsink with respect to its attach mechanism.
4. No signs of physical damage on motherboard surface due to impact of heatsink or heatsink attach mechanism.
5. No visible physical damage to the processor package.
6. Successful BIOS/Processor/memory test of post-test samples.
7. Thermal compliance testing to demonstrate that the case temperature specification can be met.

4.2.2 Power Cycling

Thermal performance degradation due to TIM degradation is evaluated using power cycling testing. The test is defined by 7500 cycles for the heatsink temperature from room temperature (~23 ºC) to $T_{S-TOP-MAX}$ at usage power consumption.

4.2.3 Recommended BIOS/CPU/Memory Test Procedures

This test is to ensure proper operation of the product before and after environmental stresses, with the thermal mechanical enabling components assembled. The test shall be conducted on a fully operational motherboard that has not been exposed to any battery of tests prior to the test being considered.

Testing setup should include the following components, properly assembled and/or connected:

- Appropriate system motherboard
- Processor
- All enabling components, including socket and thermal solution parts
- Power supply
- Disk drive
- Video card
- DIMM
- Keyboard
- Monitor

The pass criterion is that the system under test shall successfully complete the checking of BIOS, basic processor functions and memory, without any errors.

4.3 Material and Recycling Requirements

Material shall be resistant to fungal growth. Examples of non-resistant materials include cellulose materials, animal and vegetable based adhesives, grease, oils, and many hydrocarbons. Synthetic materials such as PVC formulations, certain polyurethane compositions (e.g., polyester and some polyethers), plastics which contain organic fillers of laminating materials, paints, and varnishes also are susceptible to fungal growth. If materials are not fungal growth resistant, then MIL-STD-810E, Method 508.4 must be performed to determine material performance.

Material used shall not have deformation or degradation in a temperature life test.

Any plastic component exceeding 25 grams must be recyclable per the European Blue Angel recycling standards.

4.4 Safety Requirements

Heatsink and attachment assemblies shall be consistent with the manufacture of units that meet the safety standards:

- UL Recognition-approved for flammability at the system level. All mechanical and thermal enabling components must be a minimum UL94V-2 approved.
- CSA Certification. All mechanical and thermal enabling components must have CSA certification.
- All components (in particular the heatsink fins) must meet the test requirements of UL1439 for sharp edges.
- If the International Accessibility Probe specified in IEC 950 can access the moving parts of the fan, consider adding safety feature so that there is no risk of personal injury.

4.5 Reference Attach Mechanism

4.5.1 Structural Design Strategy

Structural design strategy for the Intel reference thermal solution is to minimize upward board deflection during shock.

The design uses a high clip stiffness that resists local board curvature under the heatsink, and minimizes, in particular, upward board deflection.

4.5.2 Mechanical Interface to the Reference Attach Mechanism

The attach mechanism component (E21952-001) from the Intel Boxed Processor thermal solution can be used by other 3rd party cooling solutions. The attach mechanism consists of:

- A metal clip that interfaces with the heatsink, see Figure 22 for the component drawings.
- Heatsink/fan mass ≤ 62 g

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Thermal and Mechanical Design Guidelines

Appendix A Heatsink Clip Load Metrology

A.1 Overview

The primary objective of the preload measurement is to ensure the preload designed into the retention mechanism is able to meet minimum of 8.7lbf at end-of-line and does not violate the maximum specifications of the package.

A.2 Test Preparation

A.2.1 Heatsink Preparation

The following components are required to validate a generic z-clip solution:

1. Thermal solution heatsink (for example, PN: D96271-001 for the Intel Celeron processor 200 sequence on Intel® Desktop Board D201GLY2)
2. Z-clip (for example, PN: D96271-001 for the Intel Celeron processor 200 sequence on Intel® Desktop Board D201GLY2)
3. 2X Anchors (IPN: A13494-008 if using Intel's part)
4. Customized top plate to allow anchor attachment and package simulator

A.2.2 Typical Test Equipment

For the heatsink clip load measurement, use equivalent test equipment to the one listed Table 5.

Table 5. Typical Test Equipment

7. Item	18. Description	Part Number (Model)
20. Load cell 21. Notes: 1, 5	22. Honeywell*-Sensotec* Model 13 subminiature load cells, compression only 23. Select a load range depending on load level being tested. 24. www.sensotec.com	25. AL322BL
26. Data Logger (or scanner) 27. Notes: 2, 3, 4	28. Vishay* Measurements Group Model 6100 scanner with a 6010A strain card (one card required per channel).	29. Model 6100
30. Clip Force Measurement machine 31. Notes: 644	32. Customized machine that houses load cell for force measurement. Top side plate can be modified to accommodate various attach pattern	33. CFM-001 (Cool Star Technology)

NOTES:
1. Select load range depending on expected load level. It is usually better, whenever possible, to operate in the high end of the load cell capability. Check with your load cell vendor for further information.
2. Since the load cells are calibrated in terms of mV/V, a data logger or scanner is required to supply 5 volts DC excitation and read the mV response. An automated model will take the sensitivity calibration of the load cells and convert the mV output into pounds.
3. With the test equipment listed above, it is possible to automate data recording and control with a 6101-PCI card (GPIB) added to the scanner, allowing it to be connected to a PC running LabVIEW* or Vishay's StrainSmart* software.
4. **IMPORTANT**: In addition to just a zeroing of the force reading at no applied load, it is important to calibrate the load cells against known loads. Load cells tend to drift. Contact your load cell vendor for calibration tools and procedure information.
5. When measuring loads under thermal stress (bake for example), load cell thermal capability must be checked, and the test setup must integrate any hardware used along with the load cell. For example, the Model 13 load cells are temperature compensated up to 71°C, as long as the compensation package (spliced into the load cell's wiring) is also placed in the temperature chamber. The load cells can handle up to 121 °C (operating), but their uncertainty increases according to 0.02% rdg/°F.
6. Clip force measurement machine is recommended to be calibrated before usage. Standard weights should be used to check for preload cell accuracy and consistency.

A.3 Test Procedure Examples

The following procedure is for a generic z-clip solution using the clip force time0 measurement machine at room temperature:

1. Install anchors onto top plate. Anchor can be secured using epoxy or glue.

2. Fasten top plate onto the clip force measurement machine. Place package simulator on top of the preload cell as well.

3. Place the heatsink (remove any TIM material) on top of the package simulator. Power on the clip force measurement machine.

4. Install the z-clip and record down the measured preload. Make sure measurement is taken after the reading stabilized. Remove the z-clip and repeat 2 times (in total 3 times) to ensure consistency.

5. Repeat step4 for remaining clip samples. Recommended minimum samples are 10 z-clip samples.

Figure 19. Top Plate and Package Simulator Fasten onto Clip Force Measurement Machine

Figure 20. Anchors Installed and Glued Down the BTX Base Plate — for reference only

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Thermal and Mechanical Design Guidelines
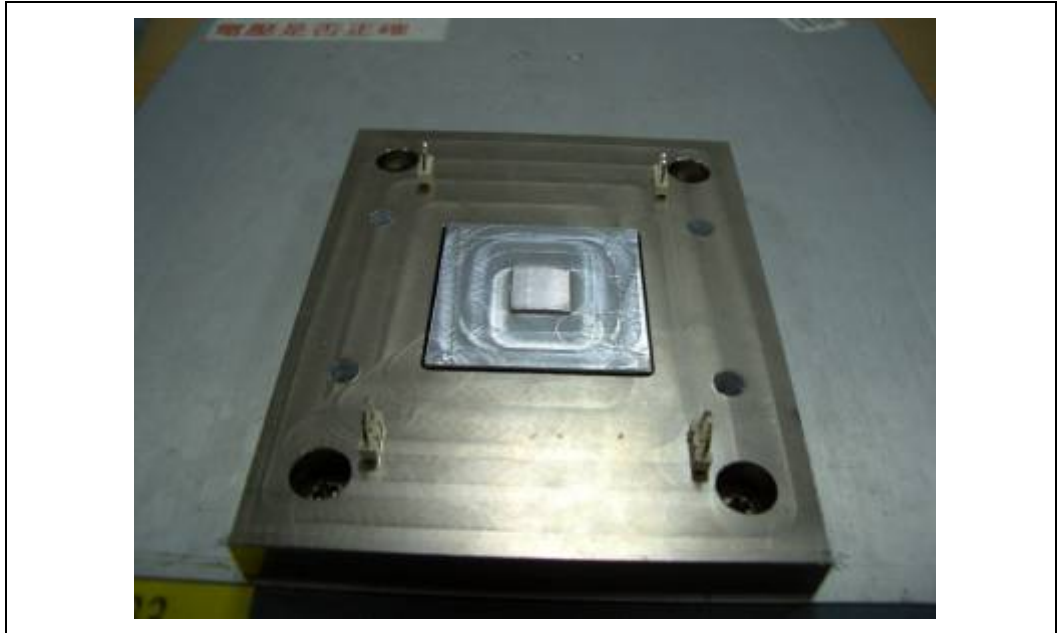
Appendix B Intel® Enabled Boxed Processor Thermal Solution Information

This appendix includes supplier information for Intel enabled vendors.

Table 6 lists suppliers that produce Intel® Boxed Processor thermal solution E21953-001 components. The part numbers listed below identifies these reference components. End-users are responsible for the verification of the Intel enabled component offerings with the supplier. OEMs and System Integrators are responsible for thermal, mechanical, and environmental validation of these solutions.

Table 6. Intel® Boxed Processor Thermal Solution Providers

Supplier	Part Description	Part Number	Contact	Phone	Email
40. CCI	41. CPU Heatsink Assembly	42. E21953-001	43. Monica Chih	44. +886-2-2995-2666 ext. 1131	45. monica_chih@ccic.com.tw
			46. Cindy Zhang	47. +886-2-2995-2666 ext. 1140	48. cindy_zhang@ccic.com.tw

These vendors and devices are listed by Intel as a convenience to Intel's general customer base, but Intel does not make any representations or warranties whatsoever regarding quality, reliability, functionality, or compatibility of these devices. This list and/or these devices may be subject to change without notice.
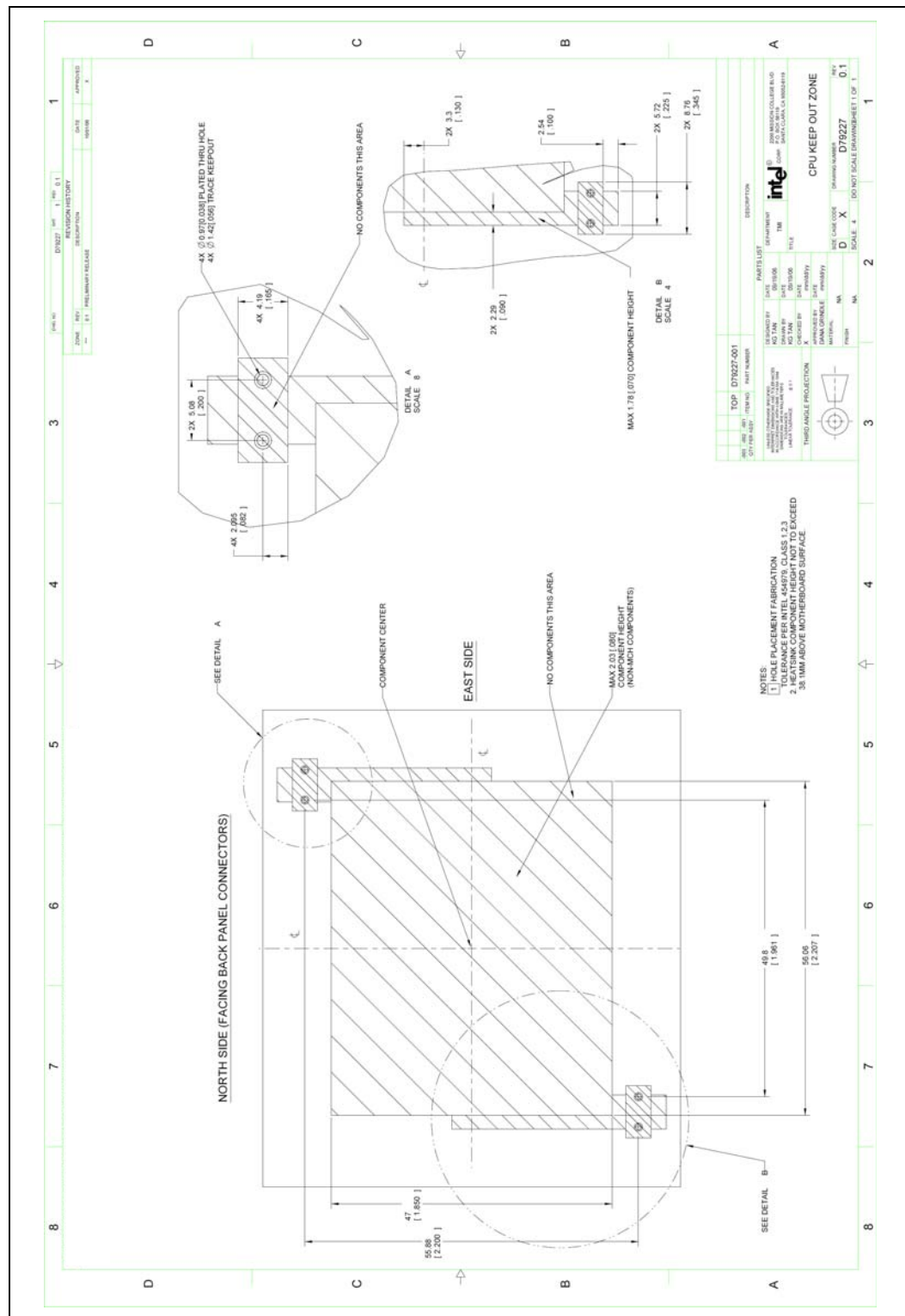
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Thermal and Mechanical Design Guidelines

Appendix C Mechanical Drawings

The following table lists the mechanical drawings included in this appendix. These drawings refer to the reference thermal mechanical enabling components for the processor.

Note: Intel reserves the right to make changes and modifications to the design as necessary.

49. Drawing Description	50. Page Number
51. Motherboard Keep-out Footprint Definition and Height Restrictions for Enabling Components	52. 50
53. Reference Clip E21952-001	54. 51
55. Reference Heatsink D96271-001	56. 52
57. Intel® Boxed Processor Thermal Solution E21953-001	58. 53

Figure 21. Motherboard Keep-out Footprint Definition and Height Restrictions for Enabling Components

Figure 22. Reference Clip E21952-001

Figure 23. Reference Heatsink D96271-001

Figure 24. Intel® Boxed Processor Thermal Solution E21953-001

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