# FS1b Processor Platform Thermal Design Guide


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*Advanced Micro Devices*

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# Revision History

| Date | Revision | Description |
|---|---|---|
| April 2014 | 3.00 | Initial Public release. |

# Chapter 1 Introduction

This document assists thermal and mechanical engineers in the design of thermal solutions for FS1b APU based systems. This document explains the following:

- FS1b APU platform thermal features
- FS1b APU heatsink design and attachment hardware
- Description of the height-restriction zones for FS1b APU motherboards
- System-level considerations:
  - Platform fan-control guidelines
  - VRD cooling guidelines

The thermal solution should maintain the processor temperature within specified limits. Thermal performance, physical attachment, acoustic noise, mass, reliability, and cost should be considered during the design of a thermal solution.

# Chapter 2 FS1b APU Thermal Features and Specifications

This chapter describes processor thermal specifications and features for systems based on FS1b APU.

## 2.1 FS1b APU Thermal Features

This section gives an overview of temperature monitoring and thermal management features of FS1b APU platforms. For details of the processor-related signals, refer to the *BIOS and Kernel Developers Guide (BKDG) for AMD Family 16h Models 00h-0Fh Processors*, order# 48751. For details of the platform-level thermal management using the fusion Control Hub (FCH) Integrated Micro-Controller (IMC), refer to *AMD Fusion Control Hub Fan Control and Temperature Sensing Guidelines with Integrated Micro-Controller (IMC)*, order # 49153.

### 2.1.1 APU Temperature Monitoring

FS1b APU on-die temperature monitoring is supported through the side-band temperature sensor interface (SB-TSI) as well as through reading the Reported Temperature Control Register. SB-TSI is the digital temperature sensor interface fully supported by AMD temperature calculation circuit (TCC) micro-architecture. For details on the TCC architecture, refer to the *BIOS and Kernel Developers Guide (BKDG) for AMD Family 16h Models 00h-0Fh Processors*, order# 48751.

#### 2.1.1.1 SB-TSI

The reported value is referred to as $T_{control}$ ($T_{ctl}$) and should be used by the platform to control the cooling solution. $T_{control}$ does not represent the actual temperature of the die or the processor case. The maximum value of $T_{control}$ ($T_{control,max}$) is normalized to 70 °Cfor all processors regardless of the processor's maximum case temperature.

$T_{ctl}$ - $T_{ctl,max}$ represents how many degrees Celsius a processor is below the maximum temperature. For example when $T_{ctl}$ = 65 the processor is 5 °C below its maximum temperature (70 – 65 = 5 °C). Tcontrol should be used for fan speed control to keep the processor within its functional temperature specification and can also be used by the system to initiate processor throttling.

The SB-TSI largely follows SMBus v2.0 specification, which allows use with embedded controllers. The register interface is the same as that for many common thermal diode monitor devices. The processor also has an ALERT_L pin to facilitate an interrupt-driven model instead of polling. Refer to the *SB Temperature Sensor Interface (SB-TSI) Specification*, order #40821, for details.

#### 2.1.1.2 Reported Temperature Control Register

The processor $T_{control}$ reading can also be read through the Reported Temperature Control Register of the processor located at D18F3xA4. This temperature reading is from the same temperature sensor that is read through SB-TSI and provides a way for software to directly read the temperature from the processor. Refer to the *BIOS and Kernel Developers Guide (BKDG) for AMD Family 16h Models 00h-0Fh Processors*, order# 48751, for the register encoding.

#### 2.1.1.3 Temperature Slew Controls

The Reported Temperature Control Register also contains settings for slew rate controls that affect how fast the reported $T_{control}$ value changes relative to the measured $T_{control}$ values. This feature helps avoid changes in the heatsink fan speed in response to unfiltered temperature measurements. A threshold setting is defined to ensure cooling system response when the measured temperature is significantly greater that the reported temperature. Refer to the *BIOS and Kernel Developers Guide (BKDG) for AMD Family 16h Models 00h-0Fh Processors*, order# 48751, for the encoding and range of values for the slew settings.

### 2.1.2 APU Thermal Management

Several thermal-related features are enabled on the FS1b APU. The main features—Hardware Thermal Control (HTC), PROCHOT, and ThermTrip—are described in this section.

#### 2.1.2.1 Hardware Thermal Control (HTC)

HTC is a power-reduction mechanism activated internally by the processor. HTC activates when the processor temperature exceeds a pre-set functional limit. The default temperature limit for HTC activation (Temp Limit) is programmed by AMD. Upon activation of HTC the processor enters the HTC-active state and initiates a performance state (P-state) transition to lower the frequency and voltage. HTC stays active until the temperature drops below Temp Limit minus Hysteresis. For setting the hysteresis value, refer to the *BIOS and Kernel Developers Guide (BKDG) for AMD Family 16h Models 00h-0Fh Processors*, order# 48751.

The FS1b APU may have up to eight P-states in the P-state model-specific registers (MSRs). Each P-state defines different voltage and frequency combinations of the processor. The HTC register (F3x64) specifies the P-state limit when HTC is active. For example, in a processor capable of 2.5-GHz operation, the P-state limit register may only allow operation to 1.8 GHz while HTC is active. AMD will program a default P-state limit, Temp Limit, and Hysteresis but the BIOS can adjust the register values if necessary.

#### 2.1.2.2 PROCHOT_L Pin

PROCHOT_L is a bi-directional pin, which can be initiated by the system to place the processor in the HTC-active state. Example situations for this use include limiting current in case of voltage regulator overheating or reducing power in case of fan failure.

PROCHOT_L is also used as an output to indicate when the processor has entered and left the HTC-active state.

#### 2.1.2.3 Thermtrip_L Pin

The Thermtrip_L pin is activated by the processor when the processor temperature exceeds a preset limit. The processor clocks are gated off and a low-voltage VID code is sent to the voltage regulator. In such an event, the system should enter the system shutdown state (S5) within 500 ms.

Thermtrip_L is used as a protection to help prevent permanent hardware damage and only activates when the processor temperature is much greater than the specified maximum temperature.

The same on-die temperature-sensing mechanism is used for SB-TSI, HTC, and ThermTrip.

### 2.1.3 Application Power Management

On previous-generation processors, maximum frequency was limited by the thermal solution and the voltage regulator performance limits. Additionally, a single, high-power application, such as a Thermal Design Power (TDP) application, was used to measure power against TDP specification, even though many typical applications consume far less power. The bi-directional application power management (BAPM) feature on the FS1b APU platform exploits this power headroom to increase performance within the same sustained power and current limits. Performance boost with BAPM only occurs when an operating system requests the highest P-state (typically P0 state). BAPM can be disabled using software.

When BAPM is enabled, many multi-threaded applications that used to consume lower power than the TDP application (on previous-generation processors) can now potentially consume power approaching TDP. Additionally, when some cores are inactive, BAPM can leverage the inactive cores' power budget to dynamically increase the power budget of the active cores. While reallocating the power from inactive cores to active cores, BAPM ensures that thermal equivalence is maintained.

Thermal equivalence is used to account for the inefficiency in heat transfer caused by increased power density when some cores are inactive. If the thermal solution is designed to specification, BAPM ensures that $T_{control,max}$ is not exceeded under any scenario. To realize the maximum performance benefit of BAPM, customers should not under-design their thermal solutions. Additionally, since BAPM can potentially increase the power consumption of typical applications, system designers should optimize the fan policy to meet the acoustic specifications while running these typical applications.

For more information on application power management, refer to *BIOS and Kernel Developers Guide (BKDG) for AMD Family 16h Models 00h-0Fh Processors*, order# 48751, Section 2.5.4.1.1.

## 2.2 FS1b APU Thermal Solution Design

In order to maintain the APU case temperature within specification and to help ensure compatibility with standard heatsink-attachment hardware on the motherboard, the design parameters defined in this document should be met. Table 1 lists the FS1b APU heatsink design requirements. The thermal resistance requirement in this document are for reference only. Always refer to the *Socket FS1b Infrastructure Roadmap*, order# 52171, for more updated details on the thermal resistance requirements of the FS1b APU. For cooling FS1b APU, orthogonal-flow heatsinks are used. These heatsinks exhaust airflow in four directions to better cool the surrounding components.

**Table 1. FS1b Processor Heatsink Design Requirements/Parameters**

| Symbol | Description | Processor TDP (W) 4 Cores | Units |
|---|---|---|---|
| Heatsink Class | Thermal performance classification scale | HS44 | |
| $T_{case,max}$ | Maximum case temperature[1] | 76 | °C |
| $\theta_{CA}$ | Case-to-ambient thermal resistance [1, 3] | 1.24 | °C/W |
| $T_A$ | Local air temperature upstream of the processor heatsink[1] | 45 | °C |
| Flow Exhaust | Airflow exhaust from processor heatsink | Orthogonal | |
| L | Maximum Length of heatsink | Please refer to Figure 2, on page 14, Figure 3, on page 15, and Figure 9 through Figure 13, beginning on page 23. | |
| W | Maximum width of heatsink | Please refer to Figure 2, on page 14, Figure 3, on page 15, and Figure 9 through Figure 13, beginning on page 23. | |
| H (inclusive of fan) | Maximum height of heatsink | Please refer to Figure 2, on page 14, Figure 3, on page 15, and Figure 9 through Figure 13, beginning on page 23. | |

***Notes:***

1. *Only some specification values are given here for illustration. For details and upto date information , refer to the Socket FS1b Infrastructure Roadmap, order # 51271.*
2. *Heatsinks of mass ≤450 g can be attached to the motherboard. It is recommended that a heatsink with mass >450 g be mounted directly to the chassis for reliable shock-and-vibration performance.*
3. *Refer to the Flotherm Thermal Model of the Socket FS1b Processor's Users Guide, order # 52122, to use the processor thermal model for design and verification purposes.*
4. *For details on heatsink class definitions for FS1b processor heatsinks, refer to Section 2.2.1.1, on page 13.*

### 2.2.1 Enablement of Orthogonal-Flow Heatsinks

The AMD Processor-In-a-Box (PIB) heatsinks for FS1b processors exhaust airflow in four orthogonal directions—along and perpendicular to the clip axis. Figure 1 shows the airflow exhaust of the orthogonal-flow heatsink. The FS1b processor heatsink airflow-exhaust pattern provides airflow to additional components on the motherboard, enabling the use of lower-cost passive heatsinks for the surrounding components such as the discrete GPU.

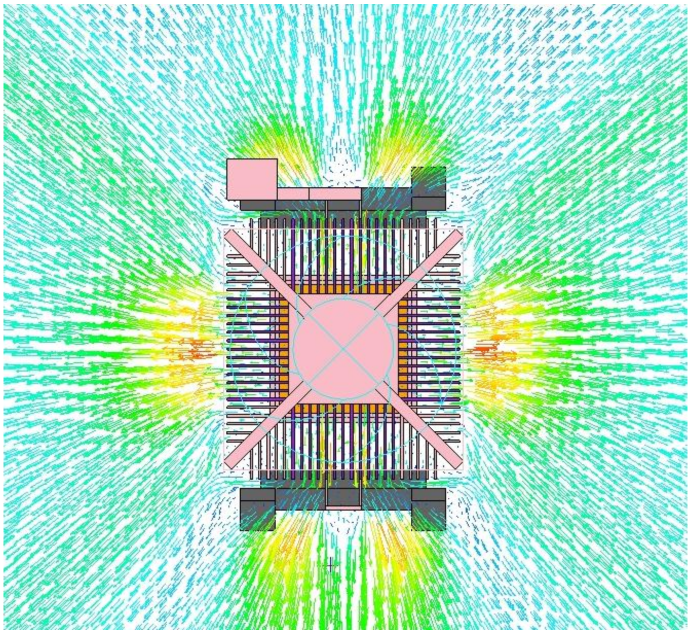
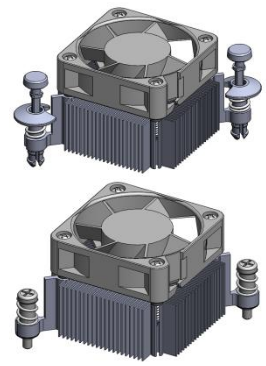


**Figure 1. Airflow Exhaust of the Orthogonal-Flow Heatsink**

#### 2.2.1.1 Orthogonal-Flow Heatsinks

The orthogonal-flow heatsink recommended for the processor are described in Table 2, on page 13.

**Table 2. FS1b Processor Heatsink Classes**

| **Infrastructure Roadmap Class** | **Power Range** | **Thermal Resistance Target (°C/W)** | **Total Mass** | **Maximum Acoustic Noise Emission** | **FS1b Platform Orthogonal-Flow Heatsinks** |
|---|---|---|---|---|---|
| HS44 | ≤25 W | 1.24°C/W | <200 g | ≤ 28dBA (25°C)<br>≤ 28dBA (35°C) |  |

#### 2.2.1.2 Orthogonal-Flow Heatsink Thermal and Mechanical Design

There are two heatsinks specified for FS1b processors. Both options have equivalent thermal performance. Table 2 and Figure 2, on page 14, and Figure 3, on page 15, show several views of FS1b platform heatsinks. (***Note:*** *All dimensions shown in Figure 2, on page 14, and Figure 3, on page 15, are in millimeters.*)

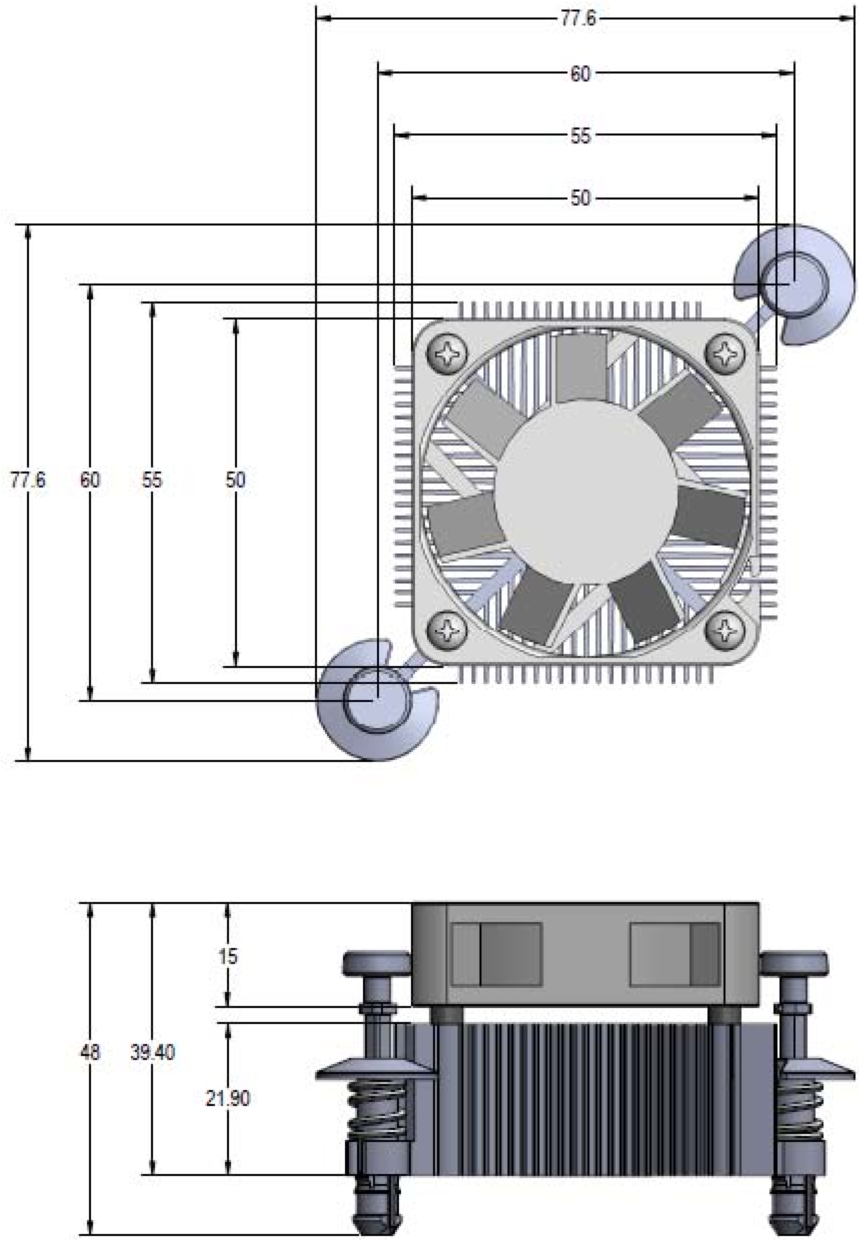
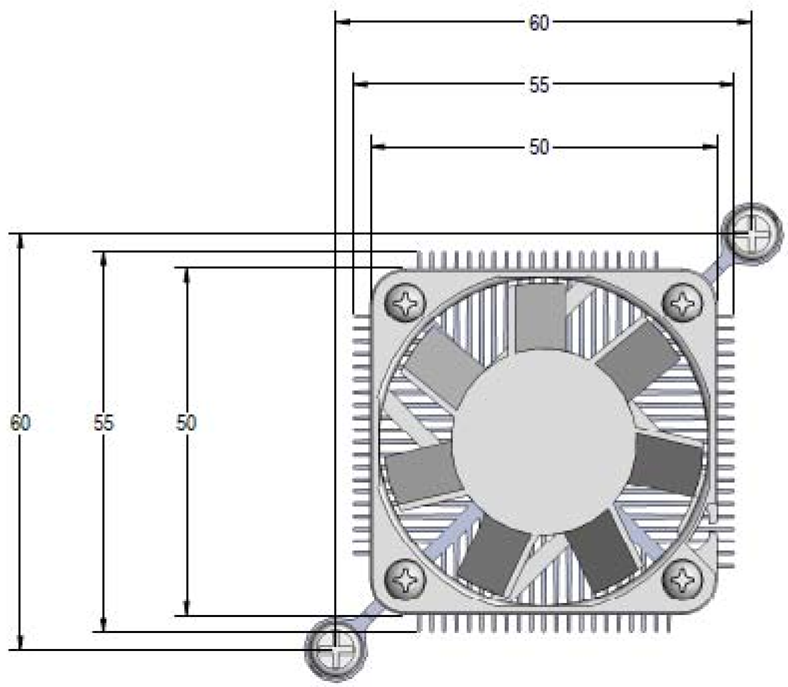



**Figure 2. Reference Design HS44 Orthogonal-Flow Heatsink (Option 1)**



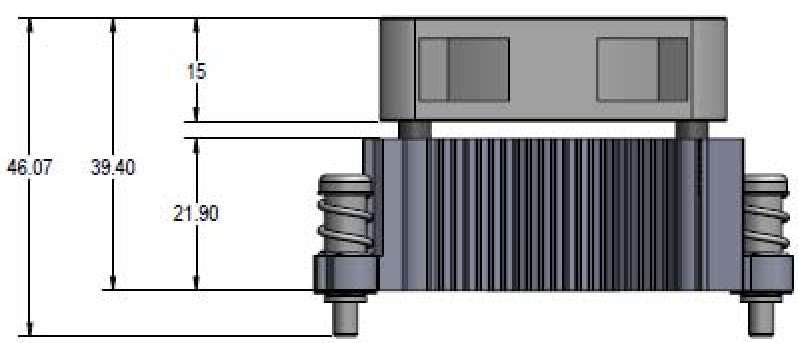




**Figure 3. Reference Design HS44 Orthogonal-Flow Heatsink (Option 2)**

### 2.2.2 Space-Optimized Mounting Hardware

AMD has also enabled space-optimized heatsink mounting hardware in order to give PCBA designers more flexibility in the design of FS1b processor motherboards.

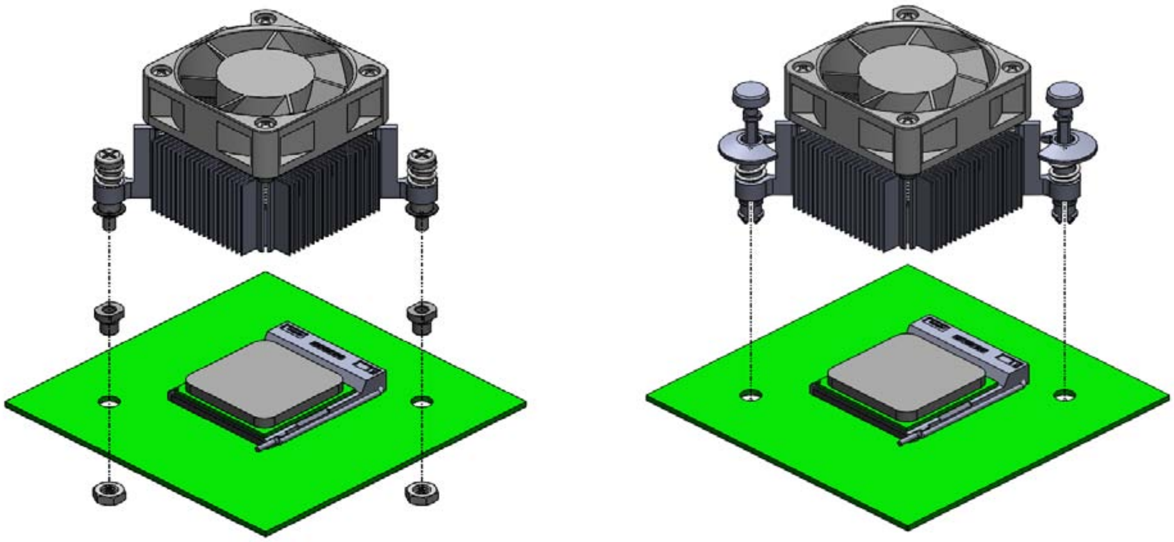


**Figure 4. Space-Optimized FS1b Processor Heatsink Mounting Hardware**

The space optimized heatsink mounting hardware for the FS1b processor motherboards. The height-restriction definitions for motherboards utilizing this heatsink are shown in Appendix A on page 23.

# Chapter 3 System-Level Considerations

Each motherboard design can be unique; however, the guidelines provided in this chapter will be useful to both the motherboard layout engineer and the system-level thermal design engineer for properly designing for appropriate component cooling. At the system level, a properly selected thermal solution should be coupled with appropriate fan policy for optimal performance.

## 3.1 Platform Fan Speed Control

In order for the processor to stay within its temperature limits, adequate airflow must be provided to the heatsink, while minimizing the acoustic noise emissions of the system. This can be achieved by implementing an appropriate fan policy using the FCH as discussed in the *AMD Hudson Fusion Control Hub Fan Control and Temperature Sensing Guidelines with Integrated Micro-Controller*, order #49153.

The CPU temperature should be sensed using SB-TSI. The FCH reads SB-TSI through the SMBus protocol. Fan control is accomplished using the integrated micro-controller (IMC).

### 3.1.1 Single-Sensor Fan-Control Scheme

Under the single-sensor fan-control scheme, the processor fan speed is controlled based only on the processor temperature. This can be achieved by programming the BIOS to ensure that the processor fan spins at the required speed at all times. For design choices an appropriate baseline fan speed may need to be determined by the motherboard designer and/or system integrator.

As shown in Figure 5, on page 18, the FCH IMC reads the SB-TSI temperature information from the SMBus and sets the fan speed based on the fan-control algorithm programmed by the IMC firmware. A detailed description of the software settings is discussed in the *AMD Hudson Fusion Control Hub Fan Control and Temperature Sensing Guidelines with Integrated Micro-Controller*, order #49153.

### 3.1.2 Fan Specification

Both heatsink options defined for the FS1b processor use a three-wire fan. The maximum fan speed is 4000 rpm. Fan speed can be varied by voltage control. Please refer to section 3.1.3 for the recommended fan control policy.

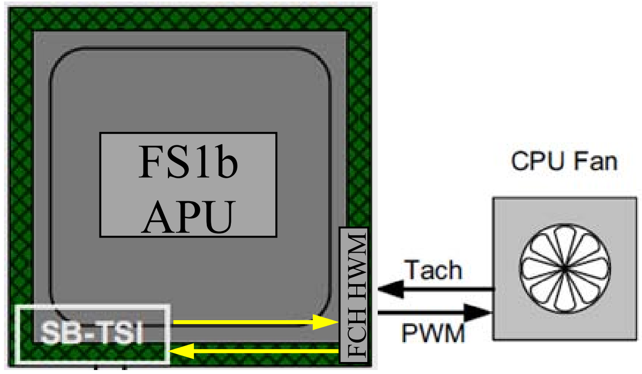



**Figure 5. Fan-Control Options with FCH IMC**

### 3.1.3 Platform Fan Policy

Platform fan policy defines the relationship between the processor fan speed and the processor temperature. It is needed to control and optimize the system acoustics. AMD recommends a fan policy that makes use of linearly increasing fan speed with the SB-TSI temperature. Figure 6 shows the recommended fan-control policy. The processor fan speed is at its minimum when $T_{control}$ is < 60. With increasing $T_{control}$, beginning at 60, the fan speed is linearly increased up to its maximum speed coinciding with $T_{control} = T_{control,max}$ (i.e., SB-TSI reading 70). The fan speed is driven by varying the duty cycle of a PWM signal input to the fan.

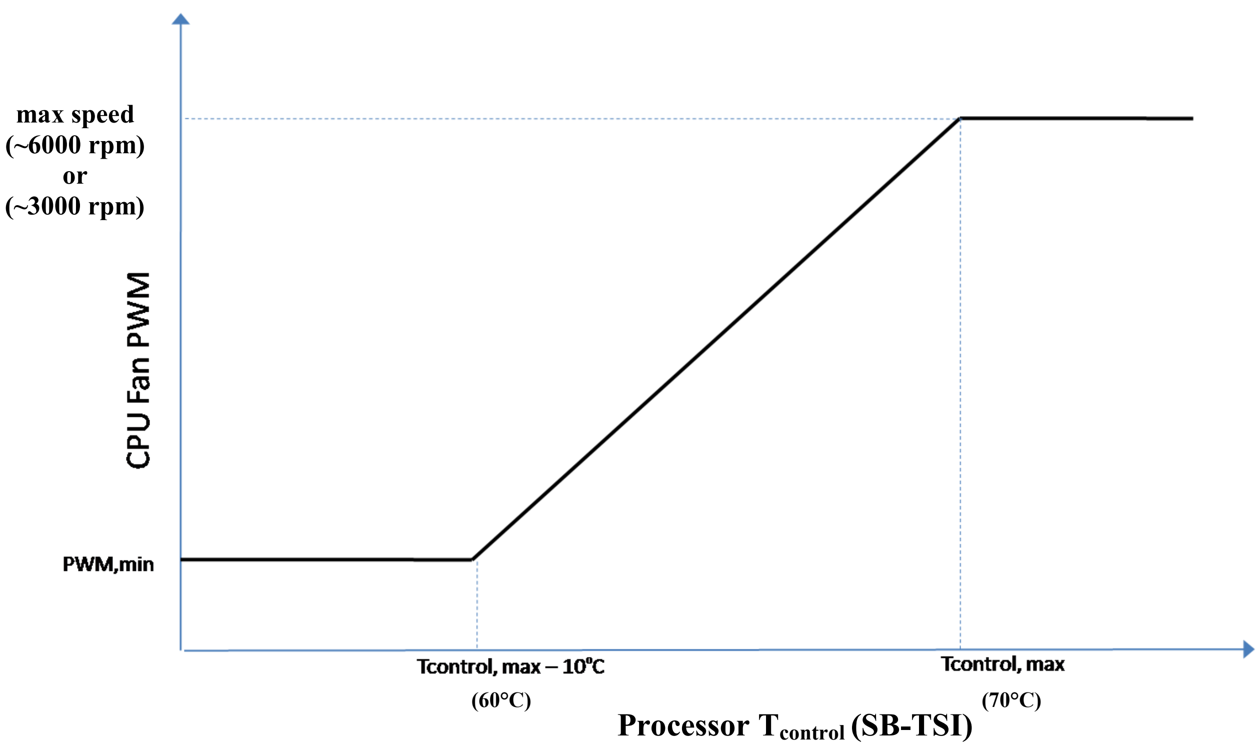



**Figure 6. Fan-Control Policy Diagram**

### 3.1.3.1 Enhanced Acoustic-Control Parameters

System acoustics can be enhanced by controlling the way the fan responds to temperature. The objective of using the enhanced acoustic-control parameters is to achieve a smooth fan operation that is least noticeable to the end-user. This can be done in two ways: one is to enable fan micro-stepping function by dampening the fan response to temperature spikes and noise, and the other is to prevent the fan from responding to temperature changes within a pre-defined temperature range, i.e., set up a hysteresis.

Another method for achieving a smooth fan-output signal is to modify the temperature signal. An averaging algorithm can be applied to a transient signal by the FCH IMC so that the noise in the sensor data can be reduced. For the digital SB-TSI signal, a slew setting (applied by the processor) that modifies the rate of change of SB-TSI can be used.

For details on how to set up these parameters, refer to the *AMD Hudson Fusion Control Hub Fan Control and Temperature Sensing Guidelines with Integrated Micro-Controller*, order #49153.

## 3.2 Voltage Regulator Cooling Guidelines

Cooling the voltage regulator FETs depends on the airflow available for these components. It is important to provide adequate airflow to the FETs to ensure that the junction temperatures remain below specification at all times.

- Since a large percentage of the heat dissipated in the FETs is conducted to the motherboard (up to 90% or more depending on package and motherboard properties), the FET packages thermally interact when placed close to each other. This thermal interaction decreases when the package center-to-center distance increases. Thus the FETs should be placed as far away from each other as is possible.
- The flow exhaust from the processor heatsink is non-uniform. Figure 7, on page 20, shows the exhaust airflow speed contour of an orthogonal-flow heatsink at 3000-rpm fan speed at a 5mm height above the motherboard. There is a region where exhaust airflow to the motherboard is adequate for cooling the FETs. FETs should be placed inside the region as shown by the dashed lines in Figure 7, on page 20.
- Airflow provided to the FETs can be significantly impeded by capacitors and inductors that are located between the processor socket and the FETs. Inductors should be placed such that they do not block airflow to the FET packages. Figure 8, on page 21, shows a good example of the placement of capacitors (white) and FETs (black). The inductors are not shown. The large arrow in Figure 8 shows the general airflow direction. To maximize the airflow provided to the FETs, the distance between the capacitors should be maximized. A good rule of thumb is to ensure that the distance between the capacitors, $L_{gap}$, is greater than or equal to half of the diameter of the capacitor, $D_{cap}$:

$$\mathbf{L_{gap} \geq D_{cap}/2}$$

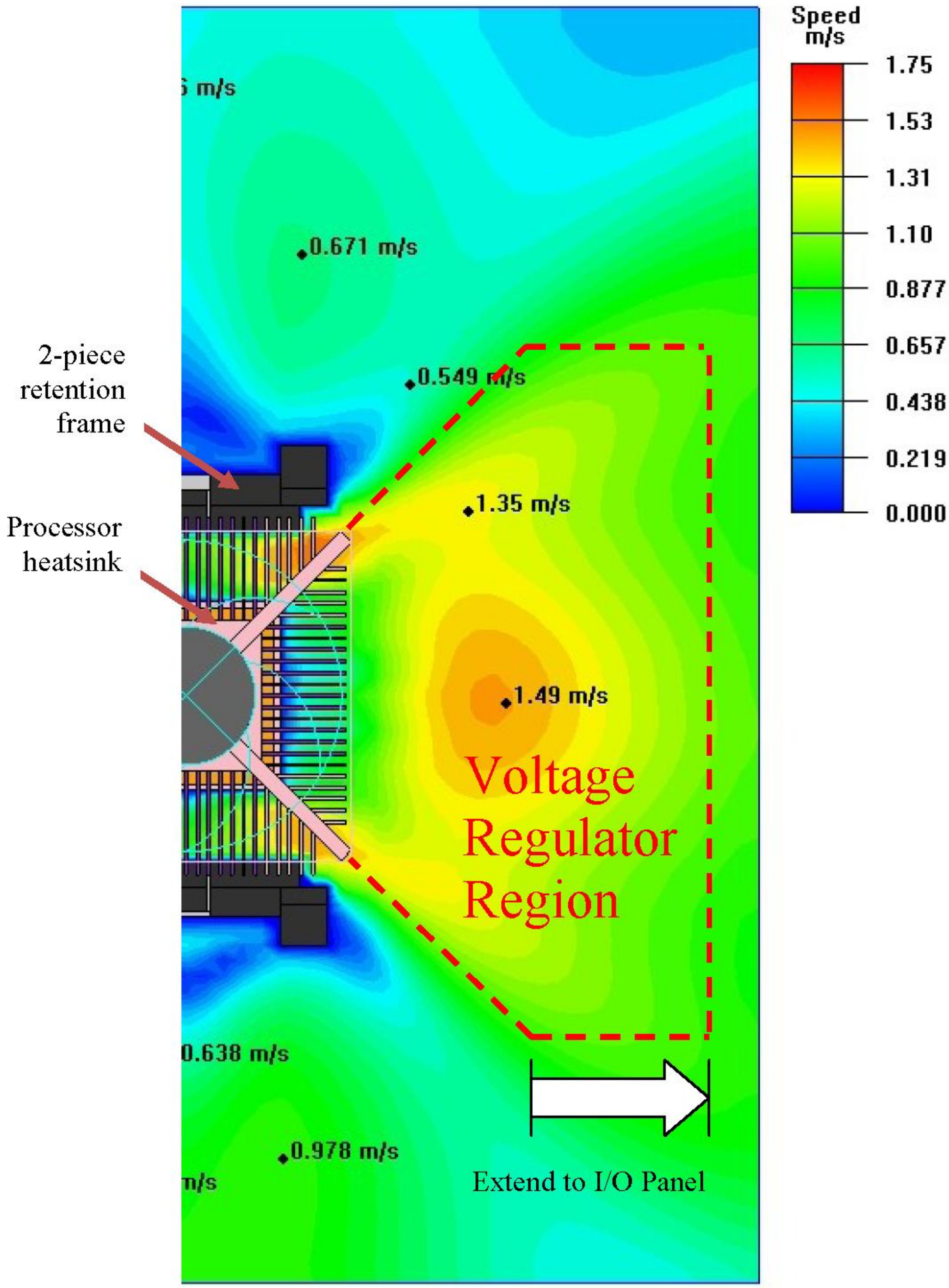



**Figure 7. Exhaust Airflow Speed Contour—Orthogonal-flow Heatsink**

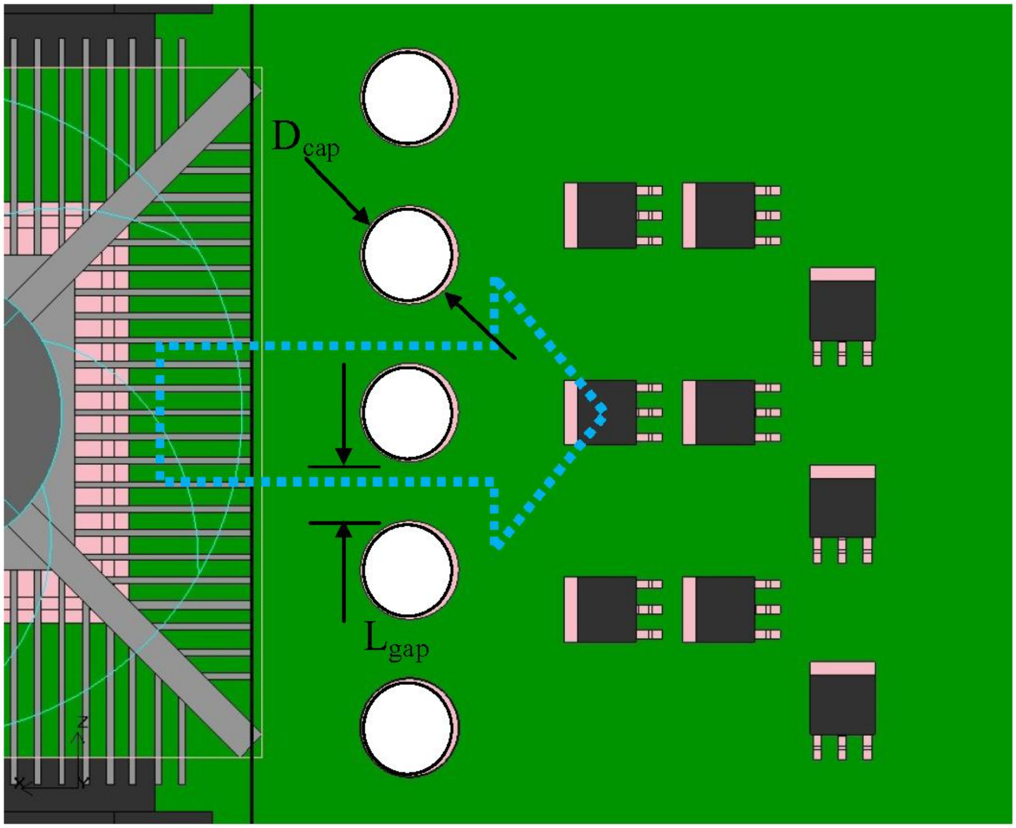



**Figure 8. Capacitor and FET Placement in Relation to Air Flow**

# Chapter 4 FS1b Processor Platform Solution Options

Thermal reference design solutions for the FS1b Processor have been presented in this document. The document is mostly focused on the material developed together with the FS1b processor hardware. Table 3 shows recommended solutions for the motherboard designers. Alternative solutions may have their unique advantages and disadvantages, which depend on the motherboard vendor's cost and acoustics assessment.

**Table 3. FS1b Processor Platform Solution Options**

| Component | Platform Solution Details |
|---|---|
| Processor TDP | 25 W |
| Processor Heatsink | Orthogonal flow, HS44 |
| Motherboard height restrictions | As documented in Chapter 4 |
| Retention frame | - |
| VRD placement | As per Section 3.2 |
| Fan policy | As per Section 3.1.3 |

# Appendix A Height Restriction Drawings for Socket FS1b

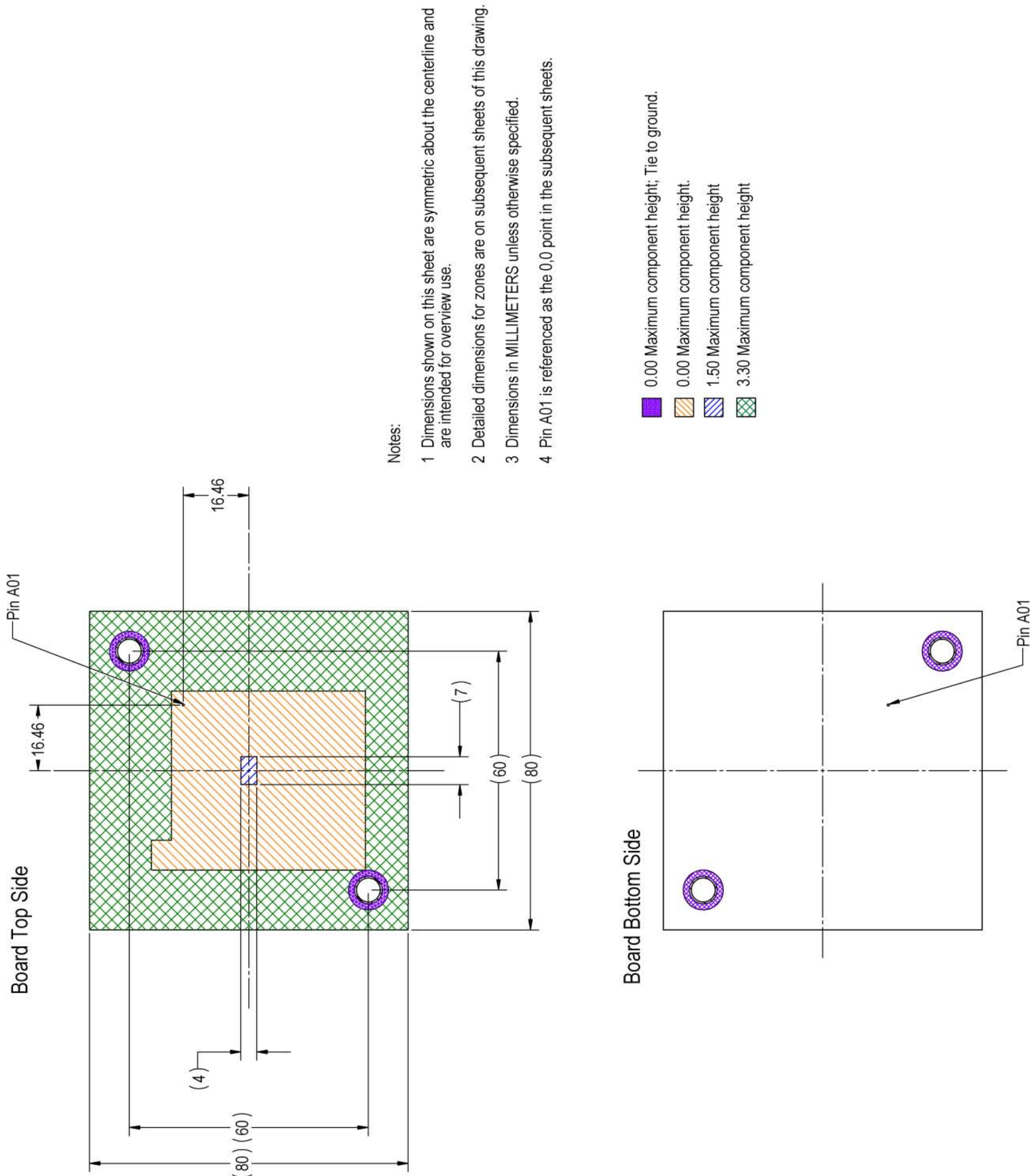



**Figure 9. Socket FS1b Height Restrictions**

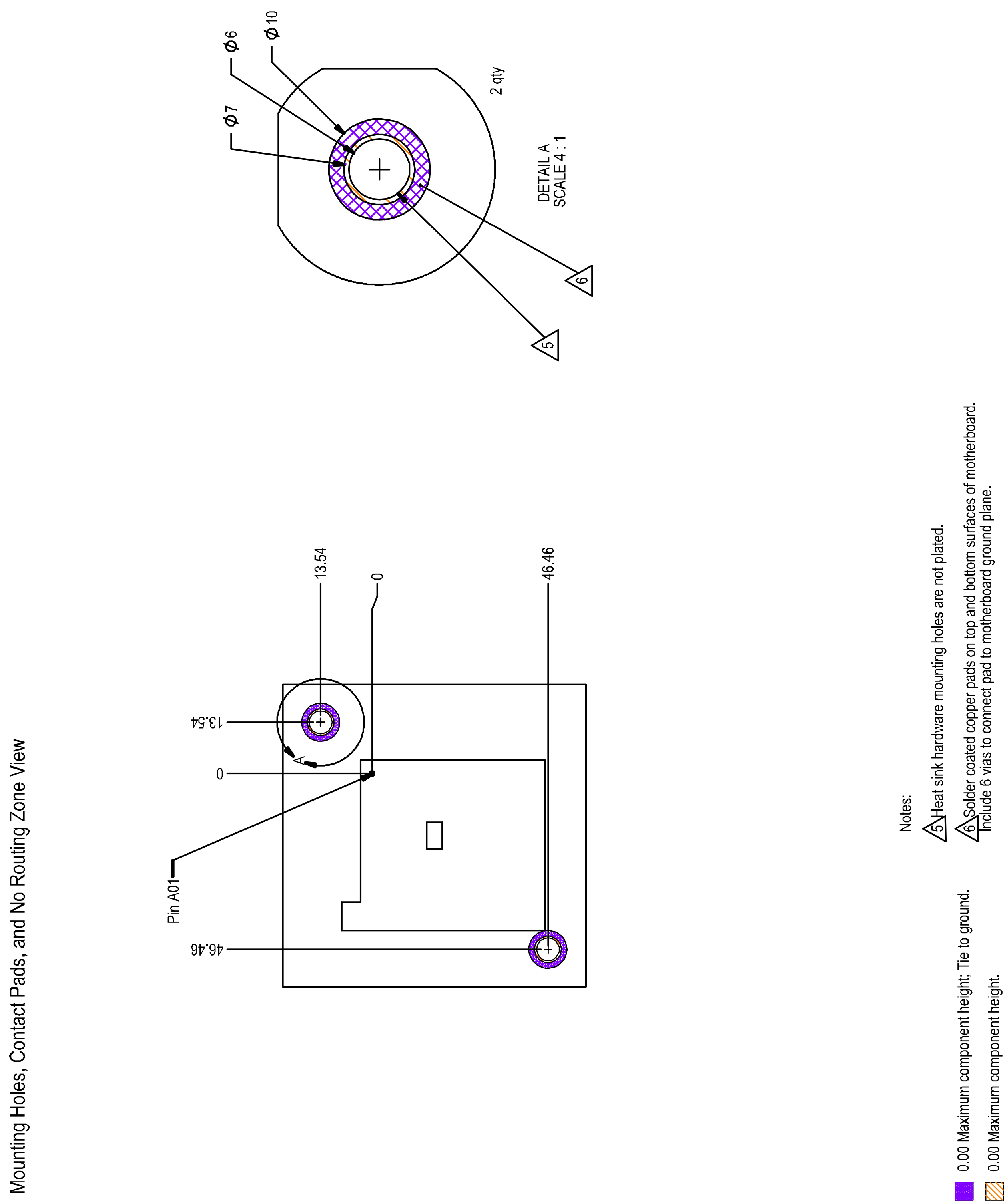



**Figure 10. Mounting Holes, Contact Pads, and No Routing Zone View**

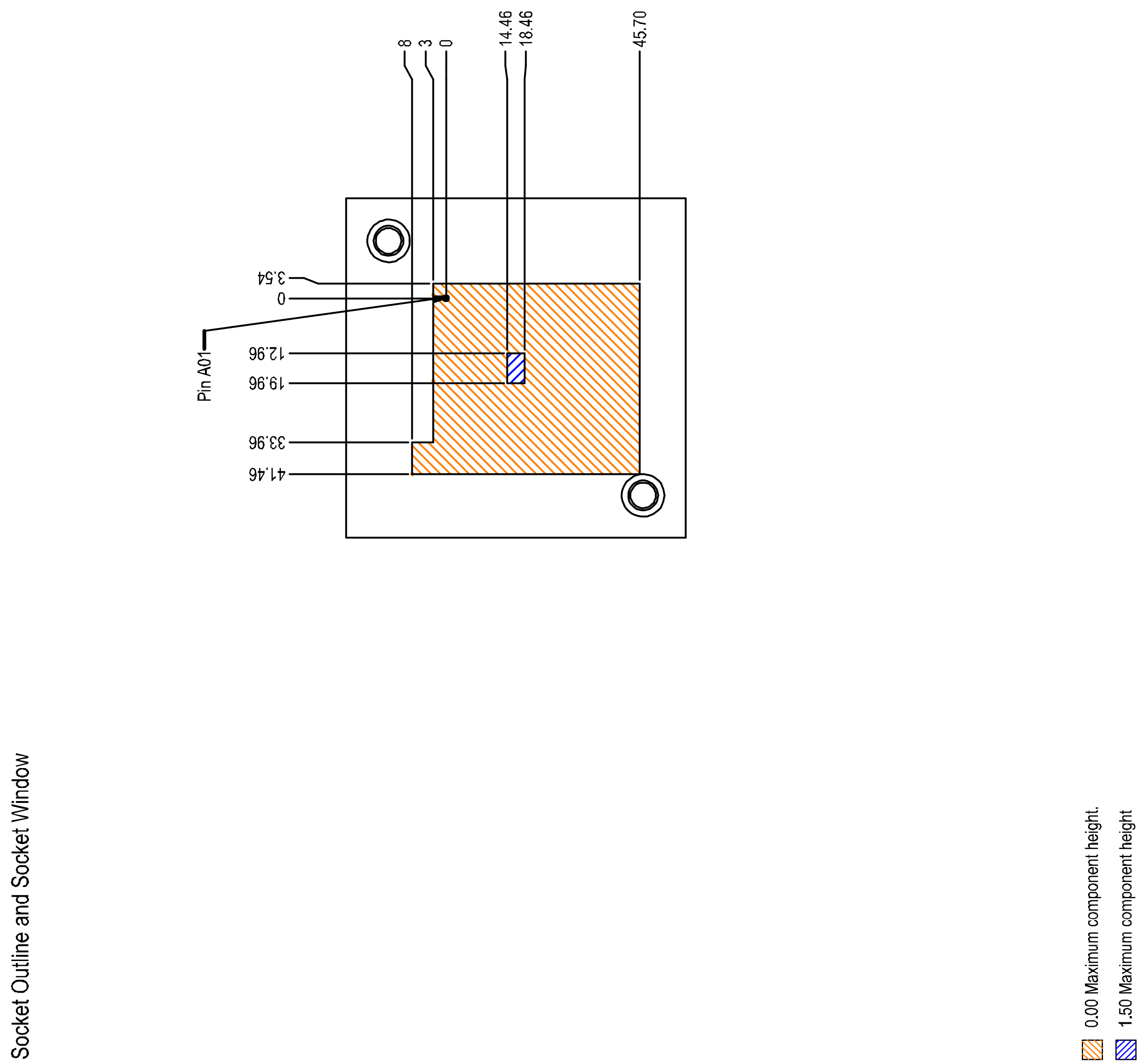



**Figure 11. Socket Outline View**

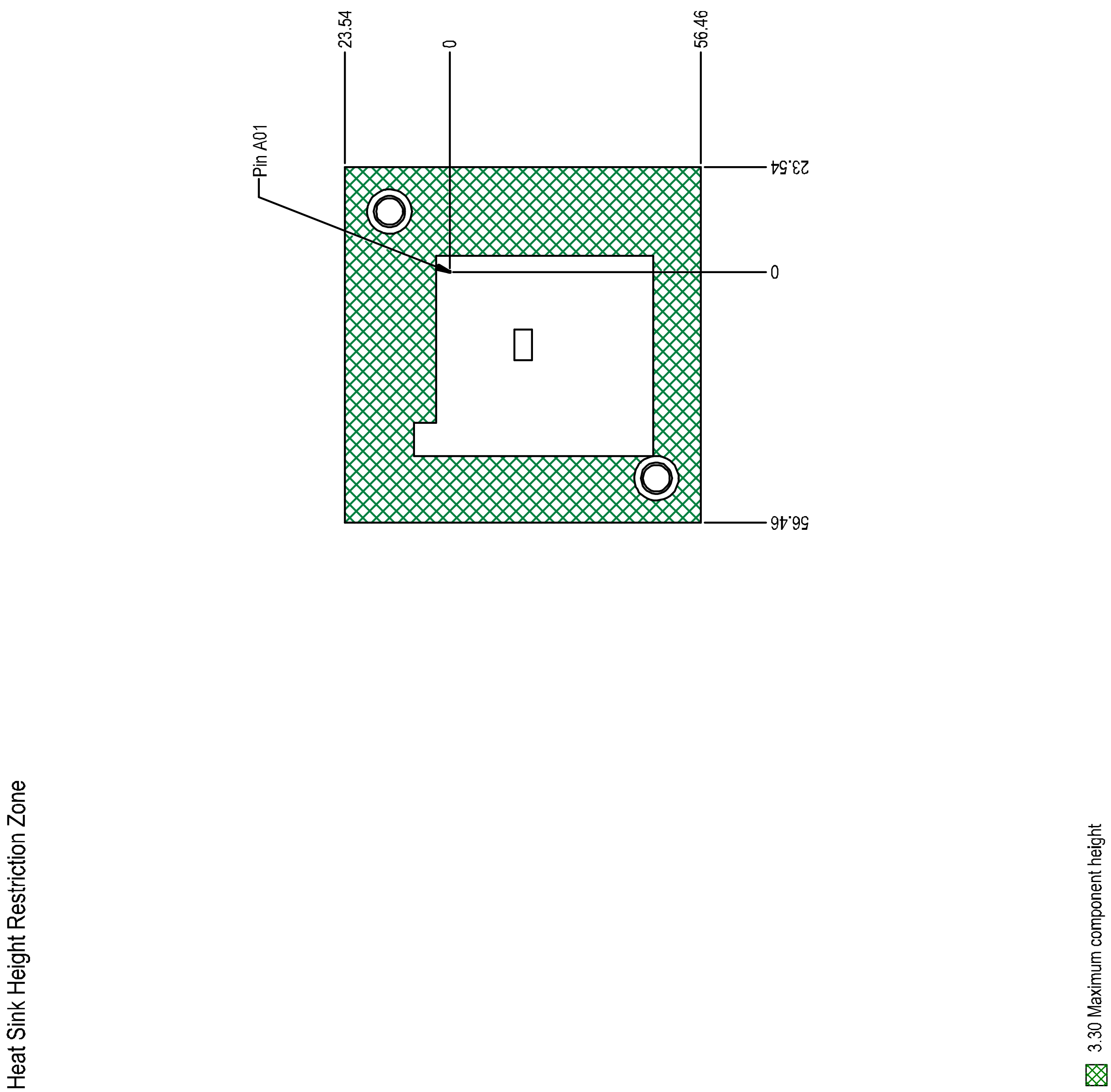



**Figure 12. Heat Sink Height Restrictions**

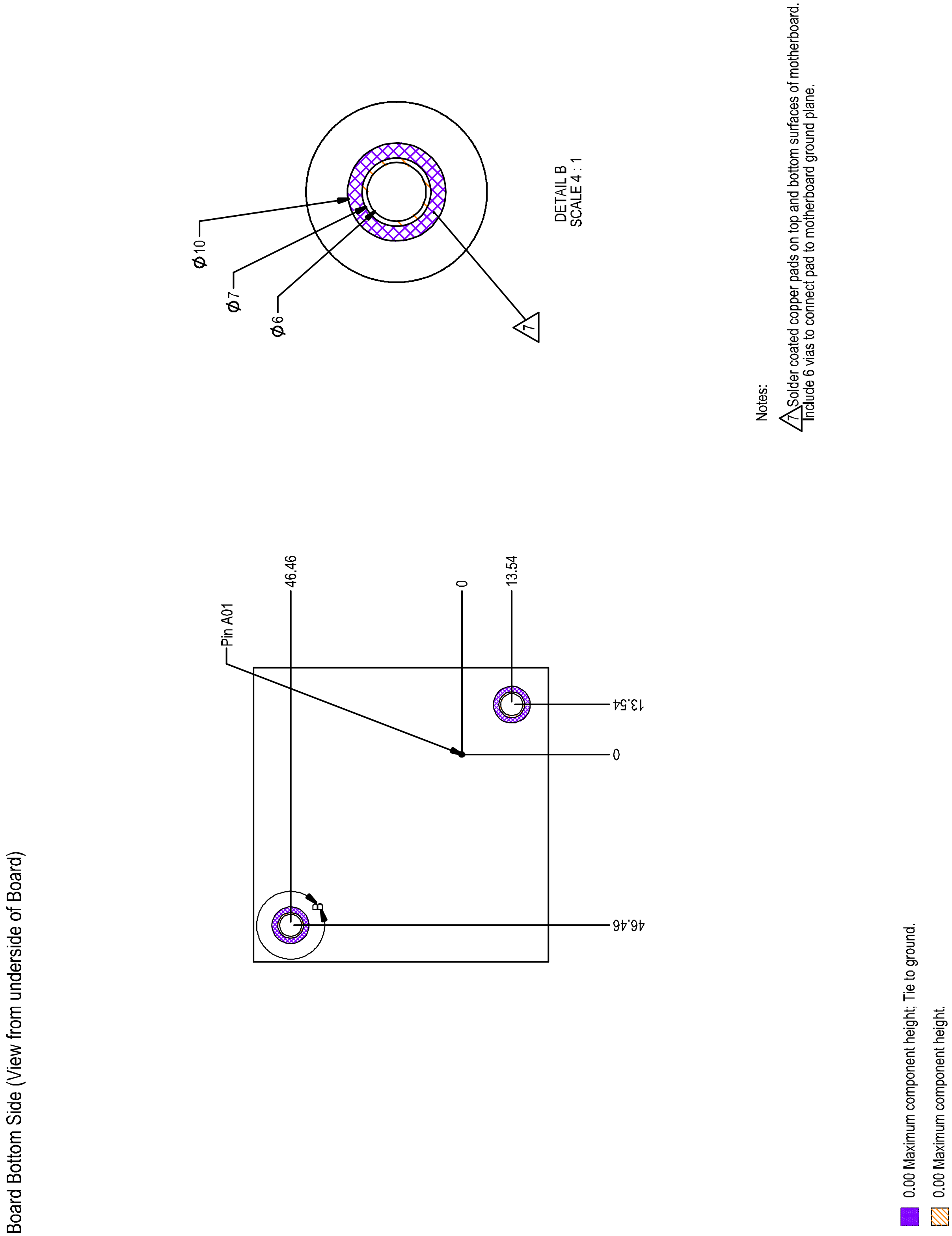



**Figure 13. Board Bottom Side View**

# Appendix B 3rd Party Heat Sink Part Numbers

| Supplier | Supplier Part Number | Contact |
|---|---|---|
| Coolermaster | DKM-00004-A1-GP | Aveline_Chen@coolermaster.com |
| Foxconn | 1A215Q300 | wendy.wang@foxconn.com |
| AVC | Z5LH021001 | apple_chen@avc.com.cn |