


# SFF-TA-1023

Specification for

# Thermal Characterization Specification for EDSFF Devices

Rev 1.0.1 ~~October 25, 2021~~November 24, 2026

SECRETARIAT: SFF ~~TA~~ TWG

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ABSTRACT: This specification defines thermal performance measurement fixtures, methods, and reporting requirements for Enterprise and ~~/~~Datacenter ~~Small~~ Standard Form Factor (EDSFF) devices. Air-cooled EDSFF device thermal characteristics are influenced by ~~the~~ air temperature and airflow velocity, enclosure design, workload and power requirements. Direct liquid cooled (DLC) EDSFF device thermal characteristics are influenced by the device interface temperature, workload and power requirements. This specification establishes a common method to characterize the variety of EDSFF devices such that host system integrators are enabled to evaluate whether a given device can be adequately cooled ~~based on the host system's dynamic operating capabilities.~~by their system.

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## FOREWORD

~~Foreword~~

The development work on this specification was done by the SNIA SFF ~~TA~~ TWG, an industry group. Since its formation as the SFF Committee in August 1990, as well as since SFF's transition to SNIA in 2016, the membership has included a mix of companies which are leaders across the industry.

For those who wish to participate in the activities of the SFF ~~TA~~ TWG, the signup for membership ~~can be~~is found at https://www.snia.org/sff/join.

## REVISION HISTORY

~~Revision History~~

**Rev 1.0** *October 25, 2020*

- Initial publication

**Rev 1.0.1** November 24, 2026

- Updated Boiler Plate
- ~~-~~Added an overview Section (Section 4)
-
- Renumbered old Sections 4 and 5 as Sections 5 and 6 and renamed them to specify air cooling
- Added SFF-TA-1042 (E2) test fixture to Section 6 and mentions for air-cooled coverage
- Added Sections 7 and 8 for direct liquid cooling
- Added DLC associated acronyms and definitions
- Updated abstract

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# CONTENTS


1. Scope 8~~5~~

2. References and Conventions 8~~5~~
   - 2.1. Industry Documents 8~~5~~
   - 2.2. Sources 8~~5~~
   - 2.3. Conventions 11~~6~~

3. Keywords, Acronyms, and Definitions 13~~7~~
   - 3.1. Keywords 13~~7~~
   - 3.2. Acronyms and Abbreviations 14~~7~~
   - 3.3. Definitions 15~~8~~
   - 3.4. Units and Unit Conversions 16~~9~~

4. EDSFF Device Thermal Characterization 17~~10~~
   - 4.1. Overview 17~~10~~

5. Air-Cooled Thermal Reporting 18~~11~~
   - 5.1. Overview 18~~11~~
   - 5.2. Airflow Impedance (AFI) Level 18~~11~~
   - 5.3. Maximum Thermal (MaxTherm) Level 21~~14~~
   - 5.4. Designed Thermal (DTherm) Level 24~~17~~
   - 5.5. High Temperature – Low Flow Design Space (HT-LF) 25~~18~~
   - 5.6. MaxAmbient 25~~18~~
   - 5.7. MinAmbient 25~~18~~

6. Air-Cooled Thermal Data Collection and Test Procedure 26~~19~~

7. DLC Thermal Reporting 43~~35~~
   - 7.1. Maximum DLC Interface Temperature (MaxDLCTemp) 43~~35~~
   - 7.2. Designed DLC Interface Temperature (DDLCTemp) 44~~36~~

8. DLC Thermal Data Collection and Test Procedure 46~~37~~
   - 8.1. DLC Reporting Requirements 46~~37~~
   - 8.2. DLC Test Fixture and Setup 46~~38~~


DRAFT


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## Figures

Figure 5-1: AFI Levels for EDSFF Devices 19~~12~~
Figure 5-2: Example Device AFI Level 20~~13~~
Figure 5-3: MaxTherm and DTherm Levels 22~~15~~
Figure 5-4: Example Device Thermal Profile 23~~16~~
Figure 6-1: Airflow Chamber 27~~20~~
Figure 6-2: Example E3 2T Air-Cooled Test Fixture and Device Setup 30~~22~~
Figure 6-3: Example E3 Air-Cooled Test Fixture 31~~23~~
Figure 6-4: Example E1 Air-Cooled Test Fixture 32~~24~~
Figure 6-5: Required Dimensions of E3 Air-Cooled Test Fixture 33~~25~~
Figure 6-6: Required Dimensions of E3 2T Air-Cooled Test Fixture 34~~26~~
Figure 6-7: Required Dimensions of E1.S 9.5mm Air-Cooled Test Fixture 35~~27~~
Figure 6-8: Required Dimensions of E1.S 15mm Air-Cooled Test Fixture 36~~28~~
Figure 6-9: Required Dimensions of E1.S 25mm Air-Cooled Test Fixture 37~~29~~
Figure 6-10: Required Dimensions of E1.L 9.5mm Air-Cooled Test Fixture 38~~30~~
Figure 6-11: Required Dimensions of E1.L 18mm Air-Cooled Test Fixture 39~~31~~
Figure 6-12: Required Dimensions of E2 Air-Cooled Test Fixture 39~~31~~
Figure 6-13: Maximum Test Cabling Keep-in Dimensions for Air-Cooled E3, E2 40~~32~~
Figure 6-14: Maximum Test Cabling Keep-in Dimensions for Air-Cooled E1 41~~33~~
Figure 6-15: Actual Air-Cooled Thermal Test Fixture Set-up 42~~34~~
Figure 8-1: Example Thermoelectric Module 47~~38~~
Figure 8-2: Example DLC Test Fixture and Device Setup 48~~39~~
Figure 8-3: Reference E3.S Test Fixture **Error! Bookmark not defined.**~~41~~

## Tables

Table 3-1: Units and Unit Conversions 16~~9~~
Table 5-1: AFI Level Equations 20~~13~~
Table 5-2: Thermal Level Equations (CFM/Device) 24~~17~~
Table 6-1: Air-Cooled Device Thermal Performance Template 27~~20~~
Table 7-1: Device Thermal Profile for DLC (Template) ~~44~~36
Table 8-1: DLC Device Thermal Performance Template ~~46~~37


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# 1. Scope

This specification defines a methodology for thermal performance characterization of EDSFF devices defined within SFF-TA-1008 (E3), SFF-TA-1006 (E1.S), ~~and~~ SFF-TA-1007 (E1.L), and SFF-TA-1042 (E2), in both air-cooled and direct liquid cooled (DLC) environments.~~.~~ This specification defines the test methodology, simulation methodology, test fixtures, and parameters to be reported for thermal characterization.

# 2. References and Conventions

## 2.1. Industry Documents

The following documents are relevant to this specification:

- ASME Y14.5-2009 Dimensioning and Tolerancing
- ANSI/AMCA210-~~07~~99, ISO 5801:2017 Performance testing using standardized airways
- SFF-TA-1002 Protocol Agnostic Multi-Lane High Speed Connector
- SFF-TA-1006 Enterprise and Datacenter 1U Short SSD Form Factor (E1.S)
- SFF-TA-1007 Enterprise and Datacenter 1U Long SSD Form Factor (E1.L)
- SFF-TA-1008 Enterprise and Datacenter SSD 3" Form Factor (E3)
- SFF-TA-1042 Enterprise and Datacenter 2U Form Factor (E2)
- CAD-TA-1023 3D CAD files for SFF-TA-1023
- ~~-~~ ASTM D5470 Standard Test Method for Thermal Transmission

## 2.2. Sources

The complete list of SFF documents which have been published, are currently being worked on, or that have been expired by the SFF Committee ~~can be~~is found at https://www.snia.org/sff/specifications. Suggestions for ~~improvement~~improvement of this specification ~~will be~~are welcome~~, they~~ and should be submitted to https://www.snia.org/feedback.

Other standards may be obtained from the organizations listed below:

| Standard | Organization | Website |
|---|---|---|
| ASME | American Society of Mechanical Engineers (ASME) | https://www.asme.org |
| Electronic Industries Alliance (EIA) | Electronic Components Industry Association (ECIA) | https://www.ecianow.org/eia-technical-standards |
| ANSI | American National Standards Institute | https://www.ansi.org/ |
| ISO | International Organization for Standards | https://www.iso.org |
| AMCA | Air Movement and Control Association International | https://www.amca.org |
| ASHRAE | ASHRAE | https://www.ashrae.org |
| ASTM | ASTM International | *https://www.astm.org* |


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~~Copies of ASME standards may be obtained from the American Society of Mechanical Engineers (https://www.asme.org).~~

~~Copies of Electronic Industries Alliance (EIA) standards may be obtained from the Electronic Components Industry Association (ECIA) (https://www.ecianow.org).~~

~~Copies of American National Standards Institute Documents may be obtained from the American National Standards Institute (ANSI) at https://www.ansi.org/~~

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## 2.3. Conventions

The following conventions are used throughout this document:

**DEFINITIONS:**

Certain words and terms used in this standard have a specific meaning beyond the normal English meaning. These words and terms are defined either in the definitions or in the text where they~~ text~~ first appears.

**ORDER OF PRECEDENCE:**

If a conflict arises between text, tables, or figures, the order of precedence to resolve the conflicts is text; then tables; and finally figures. Not all tables or figures are fully described in the text. Tables show data format and values.

**LISTS:**

Lists sequenced by lowercase or uppercase letters show no ordering relationship between the listed items.

EXAMPLE 1 - The following list shows no relationship between the named items:

a. red (i.e., one of the following colors):
    A. crimson; or
    B. pink.
b. blue; or
c. green.

Lists sequenced by numbers show an ordering relationship between the listed items.

EXAMPLE 2 -The following list shows an ordered relationship between the named items:

1. top;
2. middle; and
3. bottom.

Lists are associated with an introductory paragraph or phrase and are numbered relative to that paragraph or phrase (i.e., all lists begin with an a. or 1. entry).

**DIMENSIONING CONVENTIONS**

: The dimensioning conventions are described in ASME-Y14.5~~-2009~~, Geometric Dimensioning and Tolerancing. All dimensions are in millimeters, which are the controlling dimensional units (if inches are supplied, ~~they~~ then these dimensions are for guidance only).

**NUMBERING CONVENTIONS:**

The ISO convention of numbering is used (i.e., the thousands and higher multiples are separated by a space and a period is used as the decimal point). This is equivalent to the English/American convention of a comma and a period.

| American | French | ISO |
|---|---|---|
| 0.60010 | 0,600 10 | 0.600 10 |
| 1,000 | 1 000 | 1 000 |
| 1,323,462.90030 | 1 323 462,900 30 | 1 323 462.900 30 |


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# 3. Keywords, Acronyms, and Definitions

For the purposes of this document, the following keywords, acronyms, and definitions apply.

## 3.1. Keywords

**May:** Indicates flexibility of choice with no implied preference.

**May or may not:** Indicates flexibility of choice with no implied preference.

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**Shall:** Indicates a mandatory requirement. Designers are required to implement all such mandatory requirements to ensure interoperability with other products that conform to this specification.

**Should:** Indicates flexibility of choice with a strongly preferred alternative.

**Vendor specific:** Indicates something (e.g., a bit, field, code value) that is not defined by this specification. Specification of the referenced item is determined by the manufacturer and may be used differently in various implementations.

~~**May/ may not:** Indicates flexibility of choice with no implied preference.~~

~~**Obsolete:** Indicates that an item was defined in prior specifications but has been removed from this specification.~~

~~**Optional:** Describes features which are not required by the SFF specification. However, if any feature defined by the SFF specification is implemented, it shall be done in the same way as defined by the specification. Describing a feature as optional in the text is done to assist the reader.~~

~~**Prohibited:** Describes a feature, function, or coded value that is defined in a referenced specification to which this SFF specification makes a reference, where the use of said feature, function, or coded value is not allowed for implementations of this specification.~~

~~**Reserved:** Defines the signal on a connector contact [when] its actual function is set aside for future standardization. It is not available for vendor specific use. Where this term is used for bits, bytes, fields, and code values; the bits, bytes, fields, and code values are set aside for future standardization. The default value shall be~~


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~~zero. The originator is required to define a Reserved field or bit as zero, but the receiver should not check Reserved fields or bits for zero.~~

~~**Restricted:** Refers to features, bits, bytes, words, and fields that are set aside for other standardization purposes. If the context of the specification applies the restricted designation, then the restricted bit, byte, word, or field shall be treated as a value whose definition is not in scope of this document and is not interpreted by this specification.~~

~~**Shall:** Indicates a mandatory requirement. Designers are required to implement all such mandatory requirements to ensure interoperability with other products that conform to this specification.~~

~~**Should:** Indicates flexibility of choice with a strongly preferred alternative.~~

~~**Vendor specific:** Indicates something (e.g., a bit, field, code value) that is not defined by this specification. Specification of the referenced item is determined by the manufacturer and may be used differently in various implementations.~~

## 3.2. Acronyms and Abbreviations

**AFI:** Airflow Impedance
**CAD:** Computer-Aided Design
**CFM:** Cubic Feet per Minute
**DLC:** Direct Liquid Cooled
**E1:** Form factors and devices defined in SFF-TA-1006 and SFF-TA-1007
**E2:** Form factors and devices defined in SFF-TA-1042

**E3:** Form factors and devices defined in SFF-TA-1008
~~**E2:** Form factors and devices defined in SFF-TA-1042~~
**EDSFF:** Enterprise and ~~/~~Datacenter Standard~~Small~~ Form Factor
**HT-LF:** High Temperature – Low Flow
**IOPS:** Input/Output Operations per Second
**LED:** Light-Emitting Diode
**LFM:** Linear Feet per Minute
**NVMe:** NVM Express
**PCB:** Printed Circuit Board
**PEEK:** Polyether Ether Ketone
**PLA:** Polylactic Acid
**QD:** Queue Depth
**TDP:** Thermal Design Power
**TEM:** Thermoelectric Module
**TIM:** Thermal Interface Material
**TTV:** Thermal Test Vehicle
**UUT:** Unit Under Test


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## ~~3.4.~~3.3. Definitions

**AFI Level:** —Air Flow Impedance Level – used to compare airflow impedance between devices of the same form factor

——**Air-Cooled:** Heat transferred from the device ~~to through~~via air moving across or through it

**Approach Air Temperature:** Average temperature of the air before it reaches the EDSFF devices

**Channel Velocity:** Velocity of air when traveling in the gaps between the EDSFF devices. See Section 6.

**Cooling Interface Area:** The area of the device surface through which heat is removed by a cold plate in a DLC system, as defined in the applicable form factor specification. For E3 devices, this is the primary cooling interface area on the top side of the device defined in SFF-TA-1008.

**DDLCTemp**: Maximum interface temperature at which a device operates at a defined reduced-performance state.

**Device:** The component under test

**Direct Liquid Cooled:** Heat transferred from the device ~~to~~ through contact conduction to a liquid-cooled cold plate

**DTherm Level:**– Minimum airflow required at a given approach air temperature for which a device will operate but at a reduced device performance level. More than one Dtherm level can be set for a device under different performance modes. Dtherm levels should coincide with NVMe power states for NVMe EDSFF devices.

**Interface Temperature**: Calculated temperature at the device's cooling interface area during DLC testing, determined from the measured thermal plate temperature using Equation 8-1.

**MaxAmbient:**– Approach air temperature upper threshold if required by a device (for example, some devices may not be designed to operate above 60 °C)

**MaxDLCTemp**: Maximum interface temperature at which a device operating at TDP operates without degraded performance.

**MaxTherm Level:**– Minimum airflow required at a given approach air temperature for which a device operating at TDP will operate without degraded performance. TDP ~~refers to 'Thermal Design Power', which~~ is the maximum amount of heat capable of being generated by the device under load.

~~**DTherm Level** – Minimum airflow required at a given approach air temperature for which a device will operate but at a reduced device performance level. More than one Dtherm level can be set for a device under different performance modes. Dtherm levels should coincide with NVMe power states for NVMe EDSFF devices.~~


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~~**MaxAmbient** – Approach air temperature upper threshold if required by a device (for example, some devices may not be designed to operate above 60 °C)~~

**MinAmbient~~–~~:** Approach air temperature lower threshold if required by a device (for example, some devices may not be designed to operate below 0 °C)

**Thermal Plate:** The fixture cooling surface that contacts the device's cooling interface area, through the TIM, during DLC testing.

**Worst-Case Workload:** The single stress workload used to determine MaxDLCTemp and DDLCTemp, as defined in Section 7.1.

~~**Approach Air Temperature** – Average temperature of the air before it reaches the EDSFF devices~~

~~**Channel Velocity** – Velocity of air when traveling in the gaps between the EDSFF devices. See Section 5.~~

## ~~3.5.~~3.4. ~~-~~Units and Unit Conversions

| Parameter | Standard Units | SI | Conversion |
|---|---|---|---|
| **Volumetric Flowrate** | CFM (Cubic Feet per Minute) | M^3/S (Cubic Meters per Second) | 1 CFM = 4.72 E-4 M^3/s |
| **Velocity** | LFM (Linear Feet per Minute) | M/s (Meters per Second) | 1 LFM = 5.08 E-3 M/s |
| **Pressure** | in. $H_2O$~~0~~ (Inches of Water) | Pa (Pascals) | 1 in. $H_2O$~~0~~ = 248.84 Pa |
| **Length** | In (inches), Ft (feet) | mm (millimeter) | 1 foot = 12 inches = 304.8mm |
| **Temperature** | Fahrenheit (°F) | Celsius (°C) | F=(9/5)*C+32 |
| **Pressure (Contact)** | psi (Pounds per Square Inch) | kPa (Kilopascals) | 1 psi = 6.895 kPa |

**Table 3-1~~3-1~~: Units and Unit Conversions**

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# 4. EDSFF Device Thermal Characterization

## 4.1. Overview

This document defines thermal characterization and parameter reporting for EDSFF devices including the ~~and describes the~~ test and model~~l~~ling procedure for the measurement of thermal and airflow impedance of an array of devices and the characterization of a DLC device. Using this framework, specific implementations of EDSFF devices may be characterized and their parameters communicated effectively to enable system integrations.

Air-cooled characterization is a function of approach air temperature and airflow; DLC characterization is a function of interface temperature only.

This specification is organized into the following sections:

- Section 5 covers the thermal reporting of an air-cooled device.
- Section 6 covers the method for thermal data collection and testing for an air-cooled device.
- Section 7 covers thermal reporting of a DLC device.
- Section 0~~8~~ covers the method for thermal data collection and testing for a DLC device.

For thermal characterization in air-cooled environments, this specification covers test fixturing for E3.S, E3.S 2T, E3.L, E3.L 2T, E1.S 9.5mm, E1.S 15mm, E1.S 25mm, E1.L 9.5mm, E1.L 18mm, and E2. Fixturing for other form factors is not defined.~~—~~

For thermal characterization in DLC environments, this specification covers comprehensive test fixturing for E3.S and E3.L with a complete reference fixture defined in CAD-TA-1023. Additionally, guidance on adapting the reference fixture for E1 and E2 devices is provided, but a reference fixture is not defined.

The same device may be characterized for both air-cooled and DLC provided that the device is expected to operate in both environments.

The results of testing of pre-production units may need to be considered as optimistic. Reported results should be based on production-representative devices.


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# ~~4.~~5. ~~EDSFF Device~~ Air-Cooled Thermal Reporting

## ~~4.1.~~5.1. Overview

Air-cooled Thermal Reporting uses three metrics that characterize the device airflow impedance levels and cooling requirements. These metrics are AFI, MaxTherm, and DTherm. The metrics allow devices to be classified into groups so that system designers may select devices that are compatible with their host systems. In addition, system software may retrieve the metrics from the device and utilize that information to set appropriate fan speeds. Device designers are encouraged to utilize the metrics and work with system designers to ensure that the devices being developed, and their associated metrics are aligned with system capabilities.

## ~~4.2.~~5.2. Airflow Impedance (AFI) Level

The intent of AFI~~irflow Impedance~~ Level information is to classify devices into groups based on their impedance to airflow. These groups are referred to as AFI levels for the purpose of this specification. The AFI level is an important parameter for system designers due to the impact to system airflow that a high airflow impedance device may have versus a low airflow impedance device. The AFI level is important for system cooling as well as individual device cooling. The installation of higher airflow impedance devices, especially if multiple such devices are installed, in a platform may exceed the capabilities for a given platform fan performance curve. Through testing, system developers determine which device AFI levels a platform can support. The AFI level may also be used in real time by system fan control algorithms to manipulate fan speeds based on the AFI reported by the devices.

Section ~~6~~5 details the test procedure for determining a device's AFI level and provides the appropriate test fixture geometry for each type of EDSFF device. Device airflow impedance is categorized as one of 8 levels communicated by the AFI level field. Each AFI level corresponds to one of the curves illustrated in Figure 5-1~~Figure 4-1~~. The AFI Level field is reported as a value of one ("A1") through eight ("A8").


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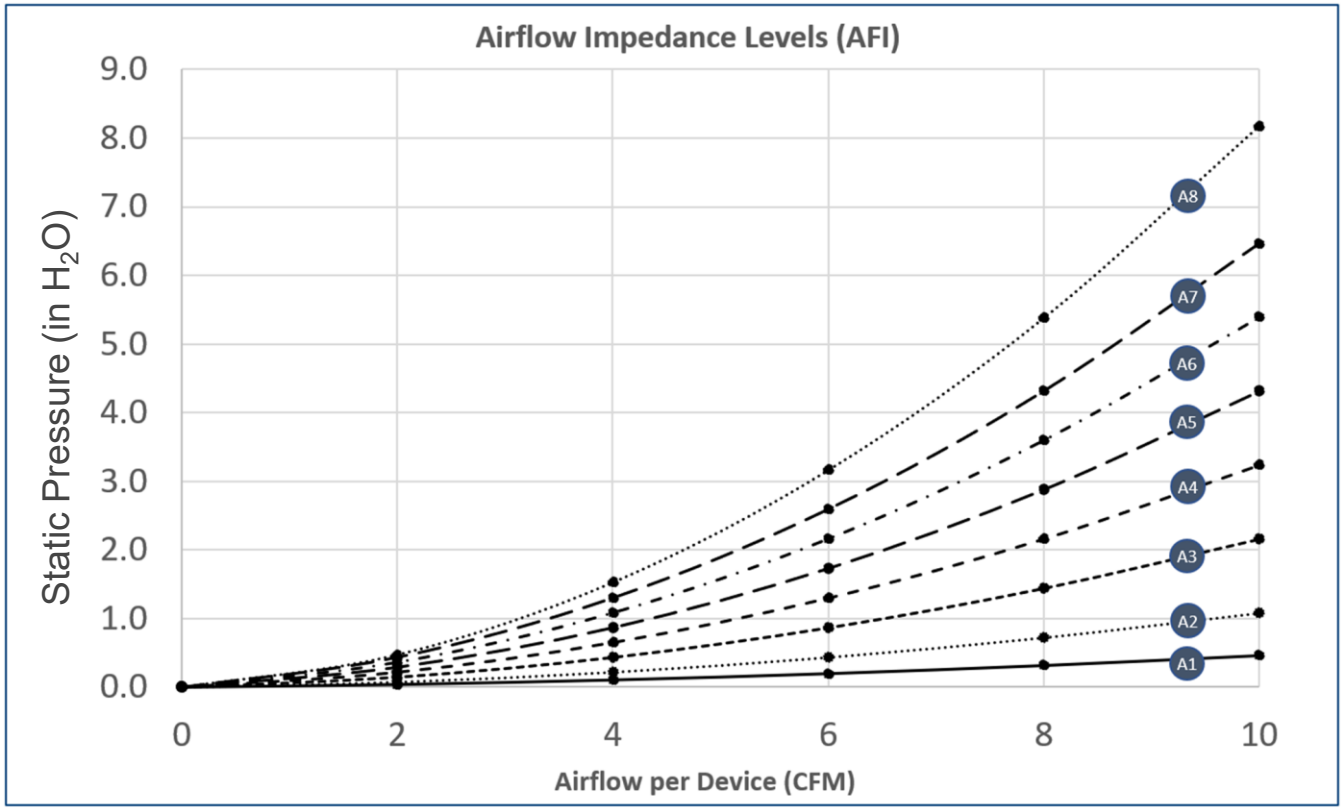



**Figure 5-~~1~~1 ~~5-1~~: AFI Levels for EDSFF Devices**

A device is assigned to an AFI level by comparing its measured airflow impedance in the appropriate test fixture within the range of 2 to 10 CFM per device to the AFI Level equations listed in Table 5-1~~Table 4-1~~. The device is assigned the highest of the AFI levels intersected by the device airflow impedance curve. The airflow vs static pressure measurements used to characterize a devices AFI level should be corrected to equivalent values at sea level and 25 °C if the test is conducted at a different altitude or ambient temperature. An example of proper AFI characterization is displayed below in Figure 5-2~~Figure 4-2~~. Here, the UUT ~~(Unit Under Test)~~ represents a hypothetical device whose airflow impedance is characterized in the appropriate test fixture. In this instance, the UUT would be assigned AFI level 2, as that is the highest AFI level that the device's airflow impedance curve intersects.


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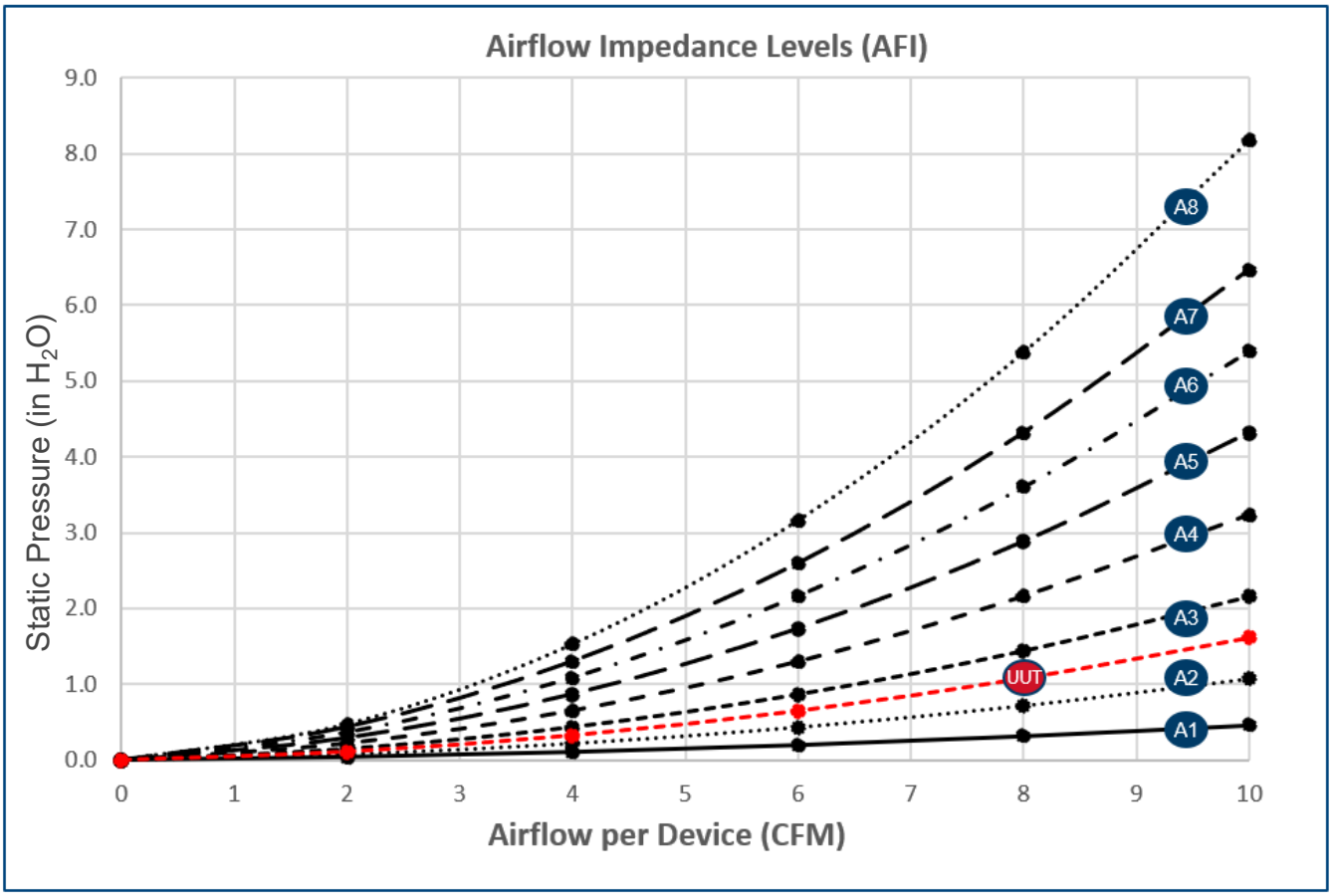



**Figure 5-25-2: Example Device AFI Level**

**Table 5-15-1: AFI Level Equations**

| AFI Level | Equation (X=volumetric airflow [CFM]; Y=static pressure [in. $H_20$]) |
|---|---|
| 0 | Reserved |
| A1 | Y = 0.003 30 * X^2 + 0.013 30 * X |
| A2 | Y = 0.008 93 * X^2 + 0.018 57 * X |
| A3 | Y = 0.017 85 * X^2 + 0.037 13 * X |
| A4 | Y = 0.026 78 * X^2 + 0.055 70 * X |
| A5 | Y = 0.035 70 * X^2 + 0.074 27 * X |
| A6 | Y = 0.044 63 * X^2 + 0.092 83 * X |
| A7 | Y = 0.053 55 * X^2 + 0.111 40 * X |
| A8 | Y = 0.072 60 * X^2 + 0.091 50 * X |

***Developer's Note:*** *It is imperative that the appropriate test fixture ~~(~~as defined in Section 665 is used to determine AFI~~)~~ is used to determine AFI level for a given device. Due to differences in test fixture geometry, it is not accurate to directly compare airflow impedance of different form factors. AFI level is a useful metric for comparing two devices of the same form factor but is not to be used to compare different form factor devices.*


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## ~~4.3.~~5.3. Maximum Thermal (MaxTherm) Level

The intent of the Maximum Thermal (MaxTherm) Level information is to define the minimum airflow rate required at a given air temperature for which a device, when stressed to its TDP ~~(thermal design power)~~ level limit, will operate within its component's reliability limits (as defined by the device/part manufacturer) and without degraded device performance. Once a device's thermal performance profile is established, the MaxTherm Level is determined. MaxTherm is the lowest curve in Figure 5-3 ~~Figure 4-3~~ which is entirely above the device's quantified thermal performance curve throughout the range of approach ambient temperatures (also referred to as approach temperature) illustrated on the X-axis ranging from 25 °C up to 65 °C.

Airflow and thermal measurement shall be performed in the appropriate thermal test fixture for the device being tested, as defined in Section 6~~5~~. The general process to determine the MaxTherm Level is as follows:

1. Setup devices in the appropriate test fixture with cables or backplane connecting devices to host system or controller. Keep-in ~~(keep-in~~ volumes for cables in the test fixtures are defined in Section 6~~5~~~~)~~.
2. Set flow bench or wind tunnel to appropriate airflow setting for desired measurement point.
3. Initiate device stress required to achieve the maximum device TDP.
4. Allow device temperatures to reach steady state.
5. Collect device temperatures in addition to local approach temperature and airflow measurements.
6. Approach temperature and measured device temperatures are scaled up until the UUT ~~(Unit Under Test)~~ reaches its maximum component temperature. This approach temperature and air flow rate (per device) pair is one point on the device cooling curve. This temperature scaling can be performed experimentally via heating the approach air, or analytically by holding approach air temperature constant and using remaining thermal margin to determine the maximum allowable approach temperature for a given flowrate. For a detailed explanation of the analytical approach for air temperature scaling, see Section 6~~5~~.
7. Repeat for other airflow rates as defined by Figure 5-3 ~~Figure 4-3~~ to develop the complete device cooling curve.
8. The device cooling curve (required CFM/device vs. local approach temperature) is plotted against the predefined MaxTherm levels shown in Figure 5-3~~Figure 4-3~~. The device MaxTherm level is the lowest curve in the figure which is entirely above the device cooling curve throughout the range of approach temperatures illustrated on the X-axis ranging from 25 °C up to 65 °C. An example of this is illustrated in Figure 5-4~~Figure 4-4~~, where the thermal performance of a hypothetical UUT ~~(Unit Under Test)~~ is displayed. In this instance, the UUT would be classified as being a thermal level 2 device in the tested operating state.

The thermal levels defined in Figure 5-3 ~~Figure 4-3~~ display CFM/dev on the Y-axis, and approach air temperature on the X-axis.

- *Curves in Figure 5-3 ~~Figure 4-3~~ are shown along with the recommended design space.*
- *Compare measured readings against the equations defined in Table 5-2 ~~Table 4-2~~.*
- *Thermal Levels 3-8 do not require a device to support less than 1.5 CFM.*
- *Not every device is expected to perform within the HT-LF design space – this area is for targeted device designs or reduced performance applications as defined in Section 5.5~~5~~.4~~.5~~.*

***Developer's Note:*** *Airflow is recorded as CFM/device, but channel velocity can be calculated easily for uniformly shaped devices using Equation 6-1~~Equation 6-1~~~~Equation 5-1~~ as defined in Section 6~~65~~. An example of this is shown in Figure 5-3~~Figure 4-3~~. Note that the recommended design space for EDSFF devices is shown in the blue shaded region on the chart. For EDSFF devices, the recommended design space is below Level 3, up to 60 °C approach ~~velocity~~temperature. A high-temperature, low airflow design space is specified as well, and detailed in Section 5.5~~5~~.4~~.5~~.*


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***Developer's Note:*** *It is strongly recommended that device developers strive to offer solutions that can operate within the shaded recommended design space envelope illustrated in* Figure 5-3 *~~Figure 4-3~~ to maximize the number of systems that can support such conditions. Some devices may not meet the recommended design space, e.g., devices consuming 70 W. Systems intended to incorporate such devices have practical implications to implement thermal mitigations.*

The MaxTherm field is defined for a value of 1 through 8.

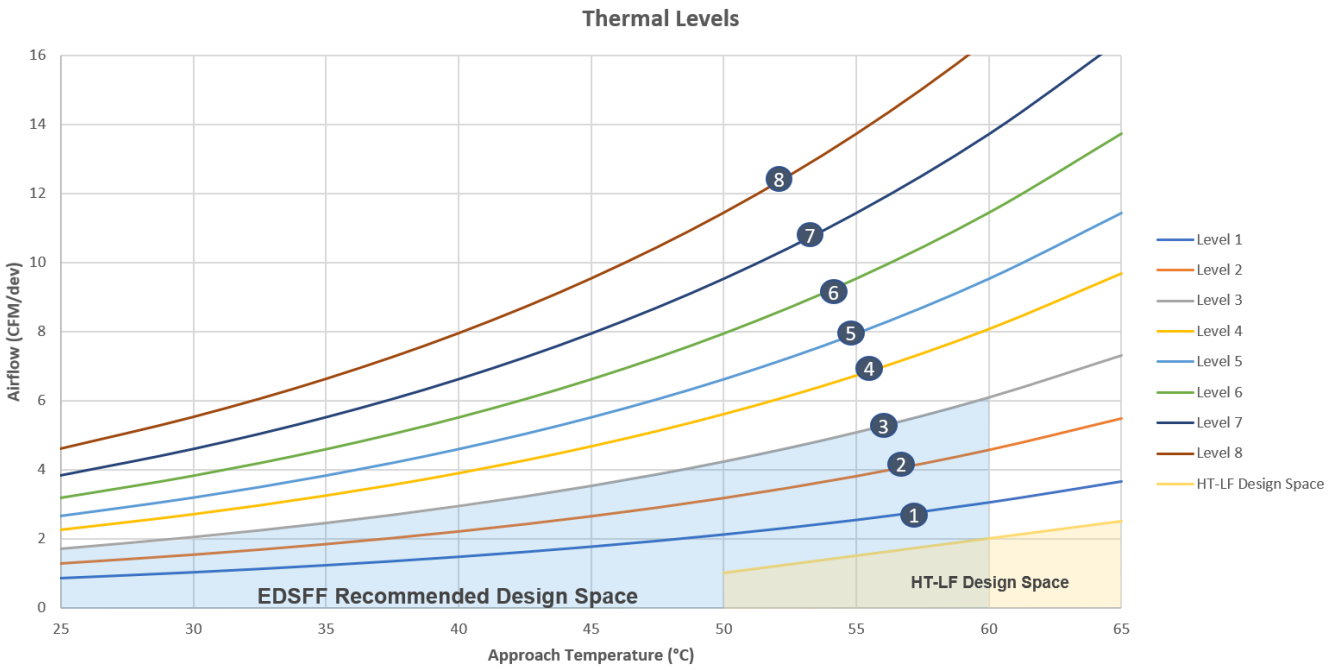



**Figure 5-~~3~~5 ~~3~~: MaxTherm and DTherm Levels**

No lower flow rates shall be defined for approach air temperatures below 25 °C.


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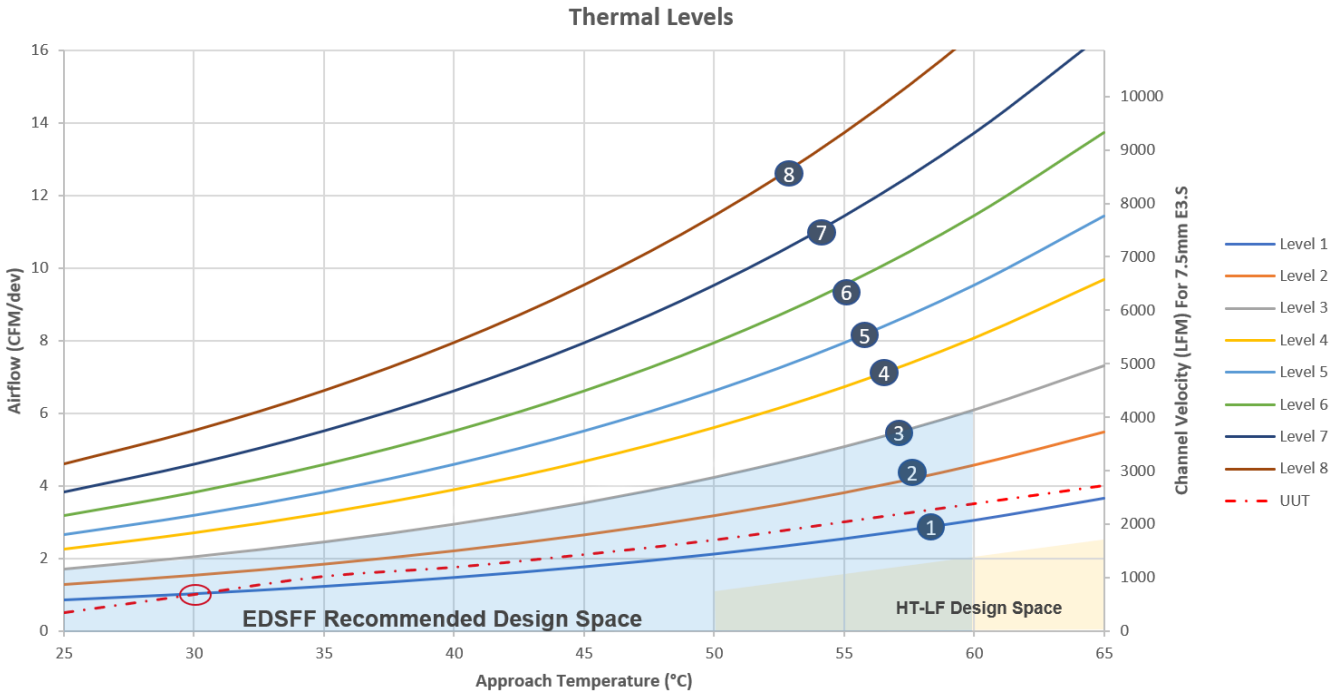



**Figure 5-~~45-~~4: Example Device Thermal Profile**


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As an example of proper EDSFF test fixture usage, Figure 5-4 ~~Figure 4-4~~ includes the curve of a hypothetical device that has been tested. The highlighted circle illustrates that the UUT ~~(Unit Under Test)~~ exceeds MaxTherm Level 1 above an approach air temperature of 30 °C. Given this example device cooling curve, MaxTherm Level 2 would be selected for this device when running at its maximum TDP. The UUT in this instance is assumed to be a 7.5mm E3 ~~1T~~ device, and channel velocity has been calculated using Equation 6-1~~Equation 6-1~~~~Equation 5-1~~ and is displayed on the right-hand Y-axis. Table 5-2 ~~Table 4-2~~ provides the Thermal Level equations as displayed in Figure 5-3~~Figure 4-3~~.

**Table 5-2~~5-2~~: Thermal Level Equations (CFM/Device)**

| Thermal Level | X = Approach Temperature; Y = Airflow Required (CFM/Device) |
|---|---|
| 0 | Reserved |
| 1 | Y = 0.341 6 * e^(0.036 5 * X) |
| 2 | Y = 0.521 4 * e^(0.036 5 * X) |
| **3*** | Y = 0.683 2 * e^(0.036 5 * X) |
| 4 | Y = 0.904 2 * e^(0.036 5 * X) |
| 5 | Y = 1.068 9 * e^(0.036 5 * X) |
| 6 | Y = 1.282 8 * e^(0.036 5 * X) |
| 7 | Y = 1.539 4 * e^(0.036 5 * X) |
| 8 | Y = 1.847 2 * e^(0.036 5 * X) |
| HT-LF** | Y = 0.1 * X - 4 |

***Note**** *Level 3 is the recommended design space limit for EDSFF devices.*

***Note**** *HT-LF ~~(High Temp, Low Flow)~~ is a specific design space not expected to be targeted for every device.*

## ~~4.4.~~5.4. Designed Thermal (DTherm) Level

The intent of the Designed Thermal (DTherm) Level information is to determine the minimum airflow required at a given air temperature for which a device will operate within its component's reliability limits but at a reduced device performance level. The stress application that was used for MaxTherm is also used for DTherm. Typically, the reduced performance is induced by the device's self-initiated thermal protection schemes, such as throttling. This is of interest for platforms unable to provide sufficient cooling, such as due to the loss of a cooling fan which reduces the platform's cooling capacity. The reduced cooling capacity in such a case may be below the device's MaxTherm Level.

If a device supports multiple designed power performance levels and these translate into reduced thermal profiles than established for MaxTherm, then DTherm is not equal to MaxTherm. DTherm is calculated using the same process as MaxTherm, however, the device's minimum Dtherm profile is created using the device's most reduced performance operating level at which it is still operating and providing useful work as defined by the device implementer. The number of reported DTherm levels are up to the device implementer based on software definition and numbers of operating states. DTherm reporting is strongly recommended as this information allows system integrators to understand performance throttling options to balance performance with available system cooling. Devices may be set to run continuously in a DTherm level or be allowed to self-regulate Dtherm levels based on available cooling. DTherm levels should be used to represent a device in different power states as defined by the appropriate industry standard for that device type (e.g.~~i.e.~~, NVMe devices would utilize the NVMe Power States). Additionally, DTherm levels can be used to enable a device to perform within the recommended EDSFF design space or the HT-LF design space.

***Developer's Note:*** *It is strongly recommended that device developers strive to achieve better thermal performance by establishing multiple DTherm levels. Not all slots in all systems will be optimally located for EDSFF device cooling; creating a means for a device to function (even in a reduced performance state) in a wide variety of boundary conditions ensures that the device can be used broadly across a system portfolio. For instance, a device will have a MaxTherm level representing thermal performance at TDP and maximum bandwidth but should also have multiple DTherm levels beneath this showing improved thermal performance at reduced bandwidth and device*


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*power. The device should be able to switch to a DTherm level of performance automatically in the event of a thermal excursion but should also contain a means by which the controller can initiate a DTherm level limit for the device. An example of proper Dtherm usage would be as follows: MaxTherm represents 100% bandwidth, DTherm 1 represents 75%, DTherm 2 represents 50%, DTherm 3 represents 25%, DTherm 4 represents maximum throttled condition while still providing useful performance. Additional DTherm levels may be used to add further granularity as needed.*

## ~~4.5.~~5.5. High Temperature – Low Flow Design Space (HT-LF)

In addition to the recommended design space, some applications will require High Temperature, Low Flowrate (HT-LF) operating conditions. It is not expected that a device will have to achieve maximum performance within the HT-LF design space, but reliability and performance capability should be understood and reported for devices designed to operate within this space. The HT-LF design space is defined by the yellow shaded region in Figure 5-3~~Figure 4-3~~. Typical use cases for HT-LF devices might include rear storage slots, or for environments where system inlet temperature is expected to be 50˚C or greater during normal operation.

## ~~4.6.~~5.6. MaxAmbient

Some devices may not be thermally viable up to an approach air temperature of 65 °C, regardless of the air speed involved. Even if the device could be thermally viable at high temperature extremes, the airflow requirements to do so may require it to operate at an airflow that is impractical to deliver. In either circumstance, the device may opt to have its upper approach air temperature limit be less than 65 °C. This approach air temperature upper threshold is referred to as MaxAmbient and is defined as the temperature just below or at a throttling condition. MaxAmbient shall be an integer value between 50 °C and 65 °C inclusive. Max-Ambient applies to the full operating potential MaxTherm condition.

## ~~4.7.~~5.7. MinAmbient

Like MaxAmbient, some devices may not be thermally viable below a given air temperature. The thermal levels defined in Figure 5-3 ~~Figure 4-3~~ do not assume any ambient temperatures lower than 25 °C. In some operating environments, ambient temperature may fall below 25 °C, and therefore a lower threshold for ambient temperature should be established by the device manufacturer. The MaxTherm level of a device at a temperature below 25 °C can be determined based on that device's performance from 25 °C to MaxAmbient.


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## ~~5.~~6. ~~Thermal Data Collection~~ Air-Cooled Thermal Data Collection and Test Procedure

The following specifies the thermal test set-up and procedure to evaluate an EDSFF device's thermal performance in an air-cooled environment. As previously discussed, thermal performance is partitioned into five sub-fields:

- AFI Level – airflow impedance c~~Air Flow Impedance C~~urve
- MaxTherm Level - Minimum airflow required at a given air temperature for which a device at TDP level limit will operate and without degraded performance
- DTherm Level - Minimum airflow required at a given air temperature for which a device, when provided the same stress application as it was for MaxTherm, will operate but at a reduced device performance level
- MaxAmbient - Approach air temperature upper threshold between 50 °C and 65 °C if required by a device
- MinAmbient – Approach air temperature lower threshold at some value below 25 °C if required by a device.

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These five sub fields should be used to populate Table 6-1 ~~Table 5-1~~ for the ~~UTT~~ UUT(~~Unit Under Test~~):

**Table 6-~~16-1~~: Air-Cooled Device Thermal Performance Template**

| | | | | |
|---|---|---|---|---|
| **Device Form Factor:** | | | | |
| **Device AFI Level** | | | | |
| **Device Max Ambient** | | | | |
| **Device Min Ambient** | | | | |
| **HT-LF Capable (Y/N)** | | | | |
| | **Device Power (W)** | **Thermal Level** | **Seq Read~~RD~~ (MB/s)** | **Seq ~~Wr~~ Write (MB/s)** |
| **MaxTherm** | | | | |
| **DTherm 1** | | | | |
| **DTherm 2** | | | | |
| **DTherm 3** | | | | |
| **DTherm 4** | | | | |
| **DTherm 5 (as needed)** | | | | |

In the above table, performance should be specified in Megabytes per second (MB/s). The values of these fields are determined using the test fixture. Details regarding the dimensions and construction of the test fixture are provided in this specification. Reference 3D CAD models of several types of test fixtures are available as STEP files contained in CAD-TA-1023. ~~Example 3D CAD models of several types of test fixtures are available as STEP files (contained in the SFF-TA-1023.zip file from SNIA SFF TA TWGCAD-TA-1023).~~ The test fixture is intended to be attached to an AMCA 210-99/ASHRAE 51-1999/ISO 5~~8008~~1:2017 compliant airflow chamber, an example of which is shown in ~~Figure 5-1~~, which can quantify both static pressure as well as volumetric airflow.



**~~Figure 6-6-1: Airflow Chamber~~**

The tester is attached to the airflow chamber such that ambient air is pulled into the fixture from the LED facing side of the device. When performing airflow impedance tests to determine the AFI level only the devices should be installed into the fixture. No backplane or cables should be included. Airflow set points for AFI levels are 2, 4, 6, 8, and 10 CFM per device. Thus, for an example of a 3 device fixture the airflow points are 6, 12, 18, 24, and 30 CFM. An example of a fixture with 6 devices will have airflow points of 12, 24, 36, 48, and 60 CFM. At each airflow point the static pressure at the flow bench is collected in units of inches of water (in. $H_20$.).


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**Figure 6-1: Airflow Chamber**

Additionally, Channel Velocity or Approach Velocity can be calculated to aid in system design. As device pitch and thickness can vary from system to system, channel velocity can be used in place of CFM/device for regularly shaped devices without extended fin surfaces. Channel velocity can be calculated easily as follows using Equation 6-1~~Equation 6-1~~~~Equation 5-1~~ (which contains the unit conversions necessary to input CFM/dev and device thickness/pitch in millimeters):

**Equation 6-1:** $$Channel\ Velocity\ (LFM) = \frac{\frac{CFM}{Dev} * 92\ 903}{(Drive\ Pitch\ (mm) - Drive\ Thickness\ (mm)) * Drive\ Width\ (mm)}$$

For example, channel velocity in the test fixture for a 7.5mm E3 ~~1T~~ device at 2.5 CFM/dev would be found as follows:

**Example:** $$Channel\ Velocity\ (LFM) = \frac{2.5\ CFM/dev * 92\ 903}{(9.3mm - 7.5mm) * 76mm} = 1\ 697\ LFM$$

Here, channel velocity is defined as the gap between two uniformly shaped EDSFF devices. The thermal levels defined in Figure 5-3~~Figure 5-3~~~~Figure 4-3~~ display CFM/dev on the left-hand Y-axis, and channel velocity (in the test fixture) on the right-hand Y-axis. Calculating channel velocity may allow more accurate predictions of device performance in system slots, as device pitch and device thickness can vary. Additionally, approach velocity can also be derived from CFM/dev, using Equation 6-2~~Equation 5-2~~ below:

**Equation 6-2:** $$Approach\ Velocity\ (LFM) = \frac{\frac{CFM}{Dev} * 92\ 903}{(Drive\ Pitch\ (mm)) * Drive\ Width\ (mm)}$$

Both Channel Velocity and Approach Velocity are derived from CFM/dev, which is the recommended unit for evaluating device thermal performance in a test fixture. Channel Velocity and Approach Velocity may be used by system designers as needed, but only CFM/dev should be reported by the device designer.

When testing to determine the MaxTherm or DTherm levels the test fixture and device to be tested ~~must~~ shall be set up according to this specification. As with the AFI level testing, the tester is attached to the airflow chamber such that ambient air is pulled into the fixture from the LED facing side of the device. Identical devices ~~must~~ shall be installed in the slots adjacent to the device under test. All cables needed to fully exercise the three devices are attached to the devices and routed outside the system to minimize the blockage of airflow. While the E3 ~~1T~~ test fixture can hold up to 6 devices, only 3 adjacent devices need to be stressed for each measurement. The 3 devices not stressed need to share the same geometry with those being stressed so that airflow is uniform through the devices. For example, in Figure 6-3~~Figure 6-3~~~~Figure 5-3~~ only UUT, Device 1 and Device 2 need to be functioning devices; the other devices can be nonfunctioning representations of the UUT. The test fixture's lid is attached, and the test fixture is checked to ensure air flow is not leaking through its joints, cable egress locations, or at interface with the flow chamber.


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The device under test and each adjacent identical device is operated to its rated maximum TDP level using an appropriate device stress test procedure. The device manufacturer should provide sufficient detail including software, firmware, and hardware required such that system integrators could recreate the same results if provided the same device. The following figures beginning with Figure 6-2~~Figure 6-2~~ ~~Figure 5-2~~ illustrate the test fixtures for E3 devices.

This specification is intended to provide consistent measurements, but care should be exercised when using airflow impedance data for platform integration. Latches, backplanes, carriers, and cables will have a profound effect on both thermal and airflow impedance measurements and are not accounted for in this specification, as they will vary from implementation to implementation. Latches, backplanes, carriers, and cables are not included in the AFI test methodology, and only necessary cables are allowed in the designated keep-in areas for MaxTherm and DTherm measurements.~~The current spec guarantees consistency in measurements but care should be exercised when using airflow impedance data for platform integration. Latches, backplanes, carriers, and cables will have a profound effect on both thermal and airflow impedance measurements and are not accounted for in this specification {and latches, backplanes, carriers and cables are not included in the AFI test methodology and only necessary cables are allowed in designated keep-in areas for MaxTherm and DTherm measurements} as they will vary from implementation to implementation.~~ In addition, comparisons of airflow impedance across form factors should not be done as the test fixtures vary greatly.

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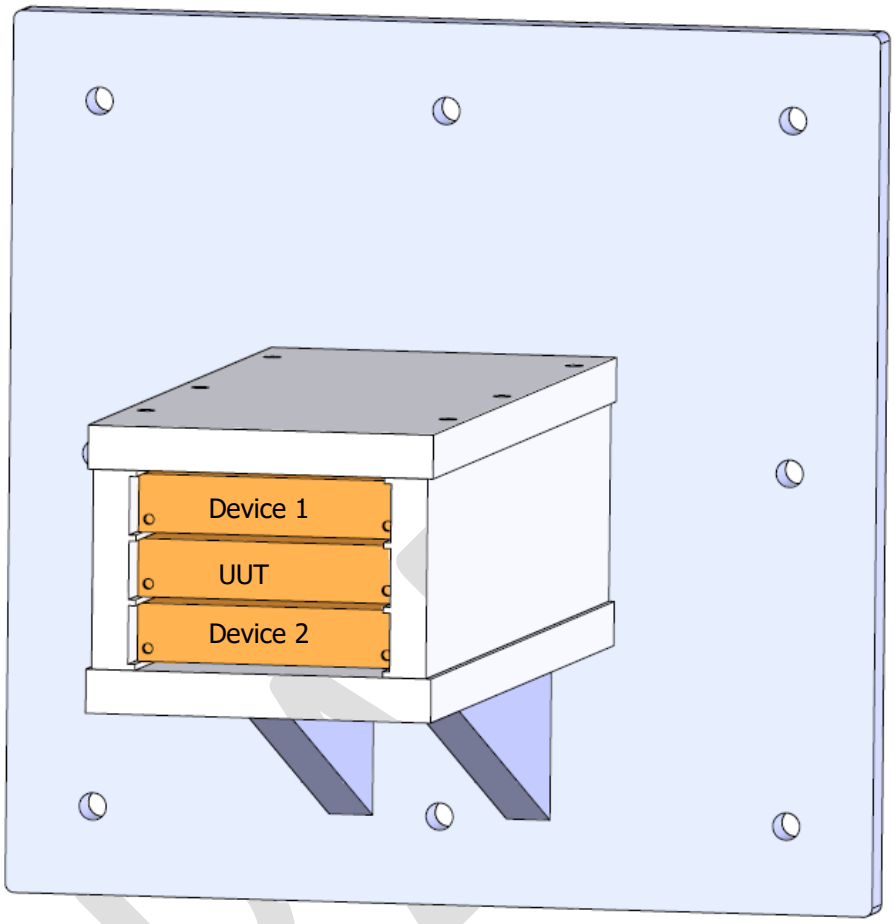



**Figure 6-2~~6-2~~: Example E3 2T Air-Cooled Test Fixture and Device Setup**

***Developer's Note:*** *It is recommended that test fixtures be fabricated using materials with a low thermal conductivity less than 1.0$Wm^{-1}K^{-1}$. This and the following examples show the devices in a horizontal orientation. The orientation of the devices may be horizontal or vertical.*


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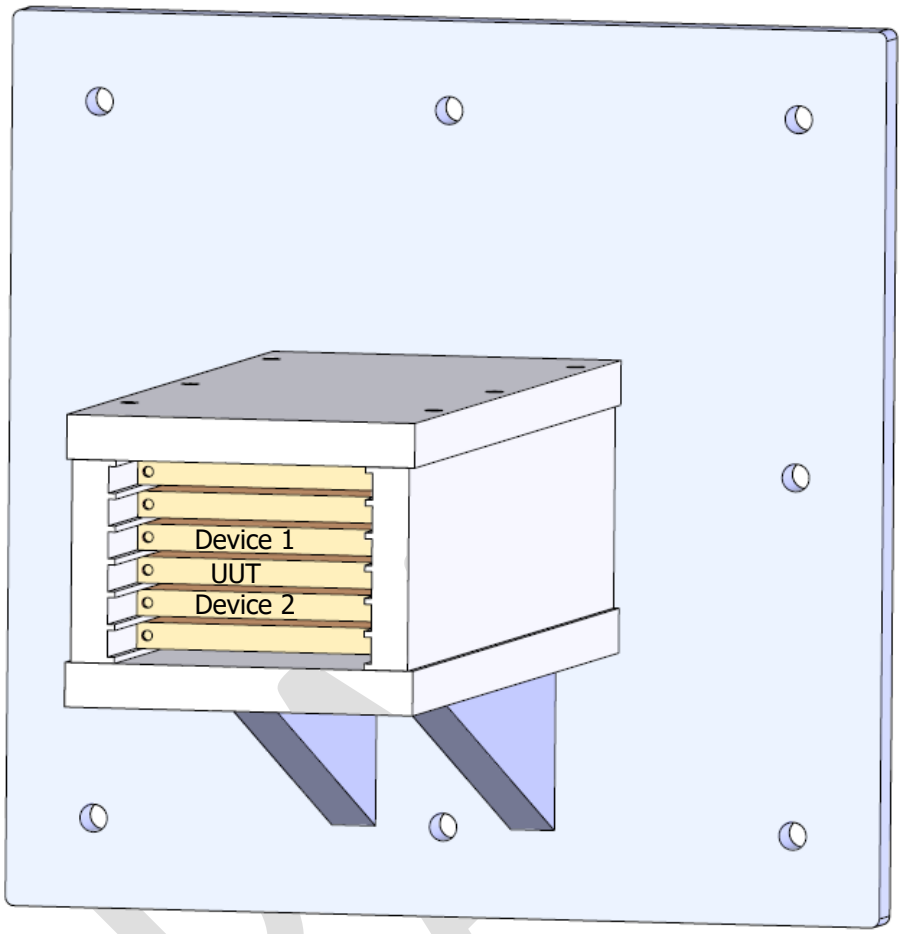



**Figure 6-36 ~~-3~~: Example E3~~-1T~~ Air-Cooled Test Fixture**


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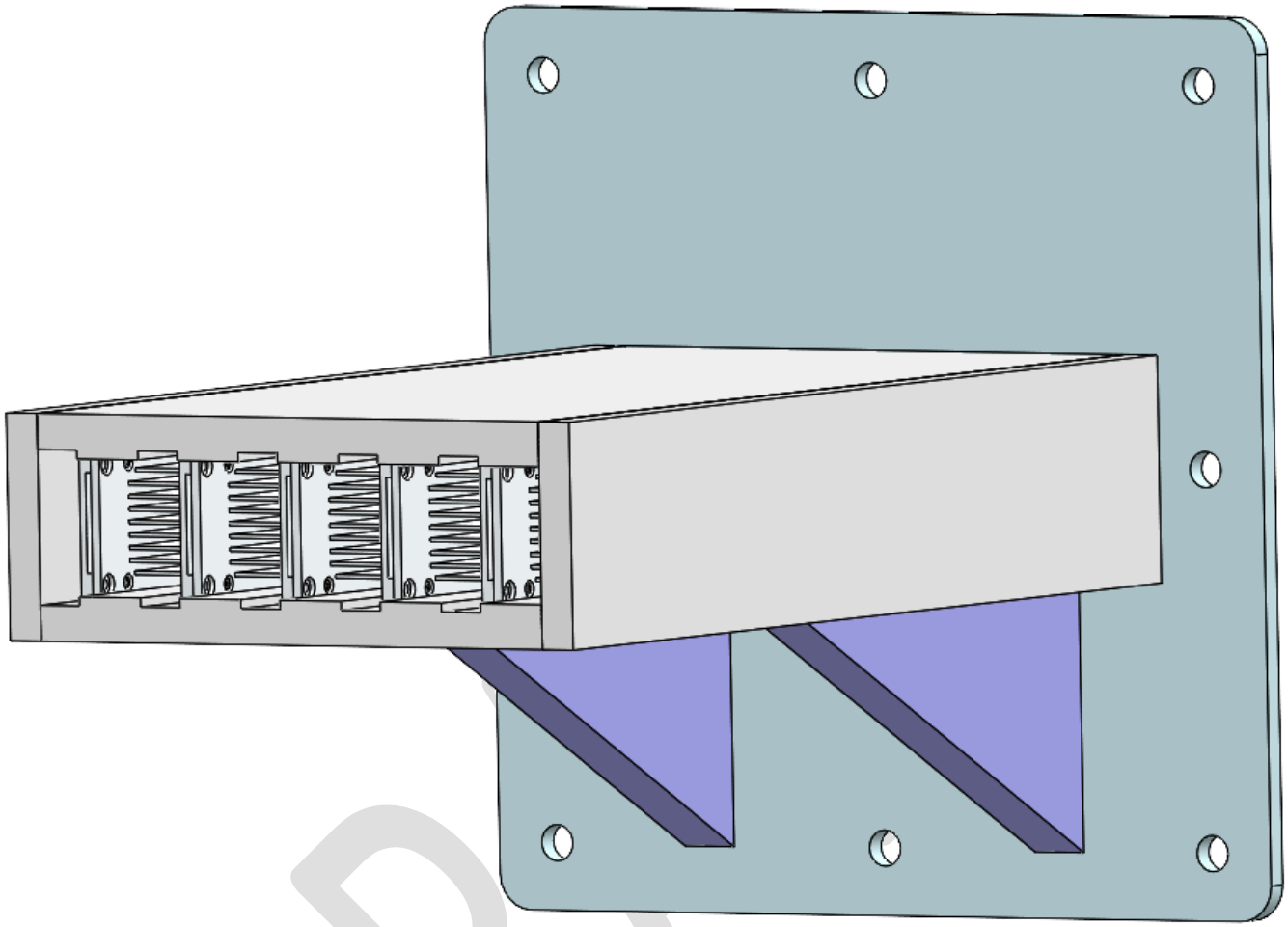


**Figure 6-~~4~~6-~~4~~: Example E1 Air-Cooled Test Fixture**

The test fixture design features are specified to ensure interoperability with E1 devices and consistent measurement. The following figures illustrate these interoperability points.


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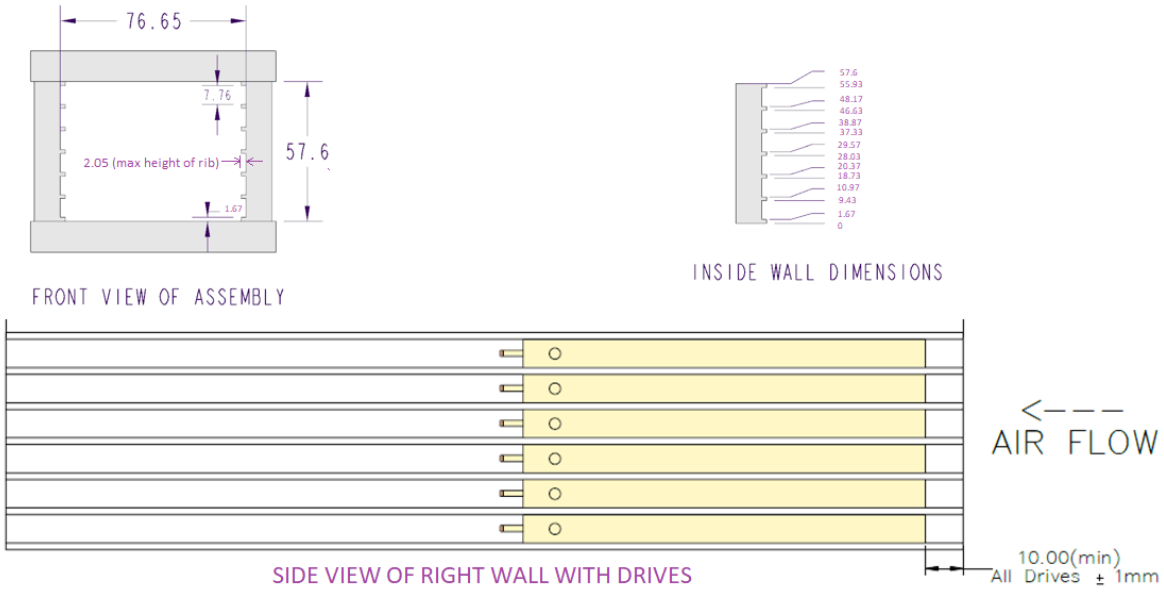



**Figure 6-~~5~~6-~~5~~: Required Dimensions of E3-~~1T~~ Air-Cooled Test Fixture**

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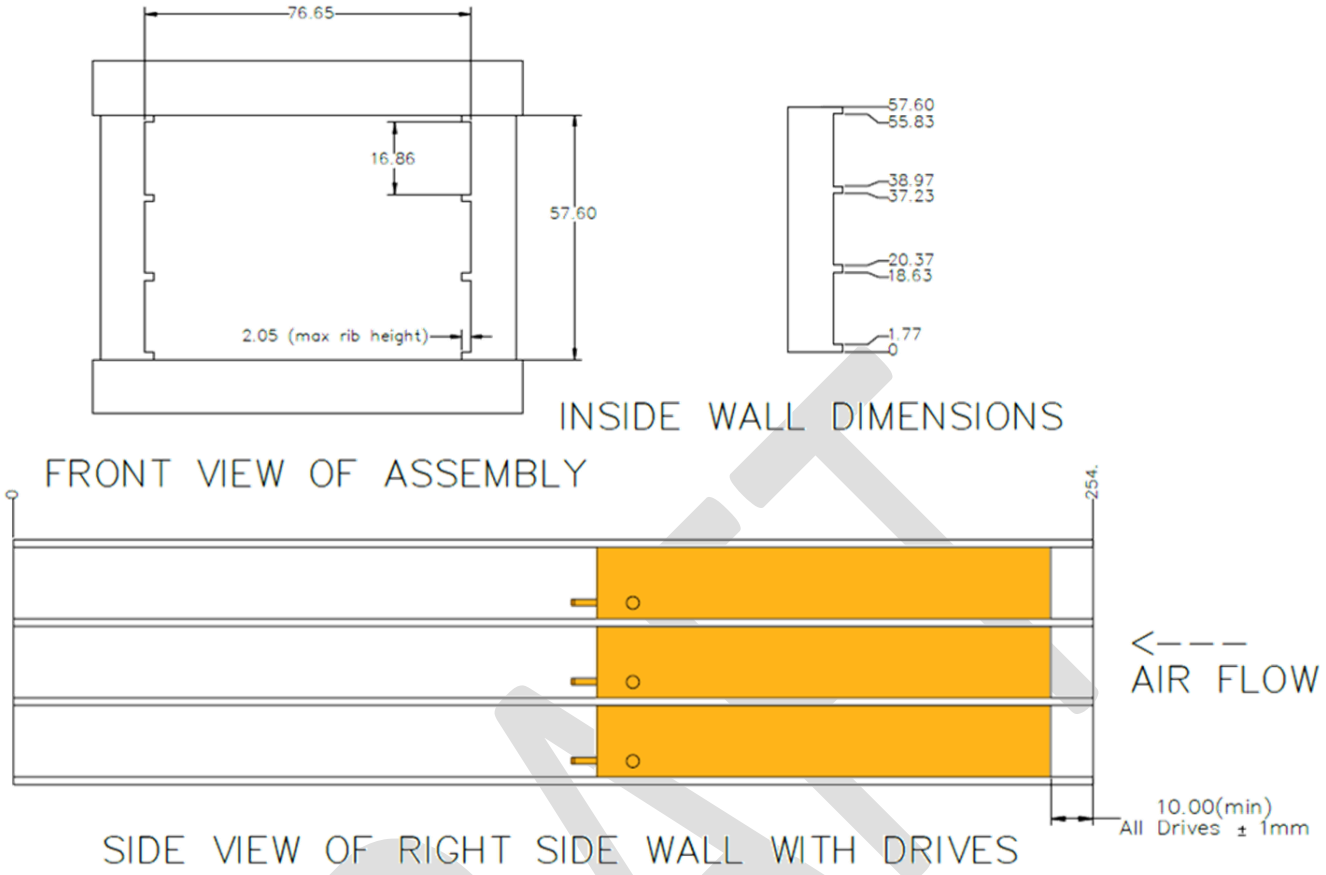



**Figure 6-~~6~~6: Required Dimensions of E3 2T Air-Cooled Test Fixture**

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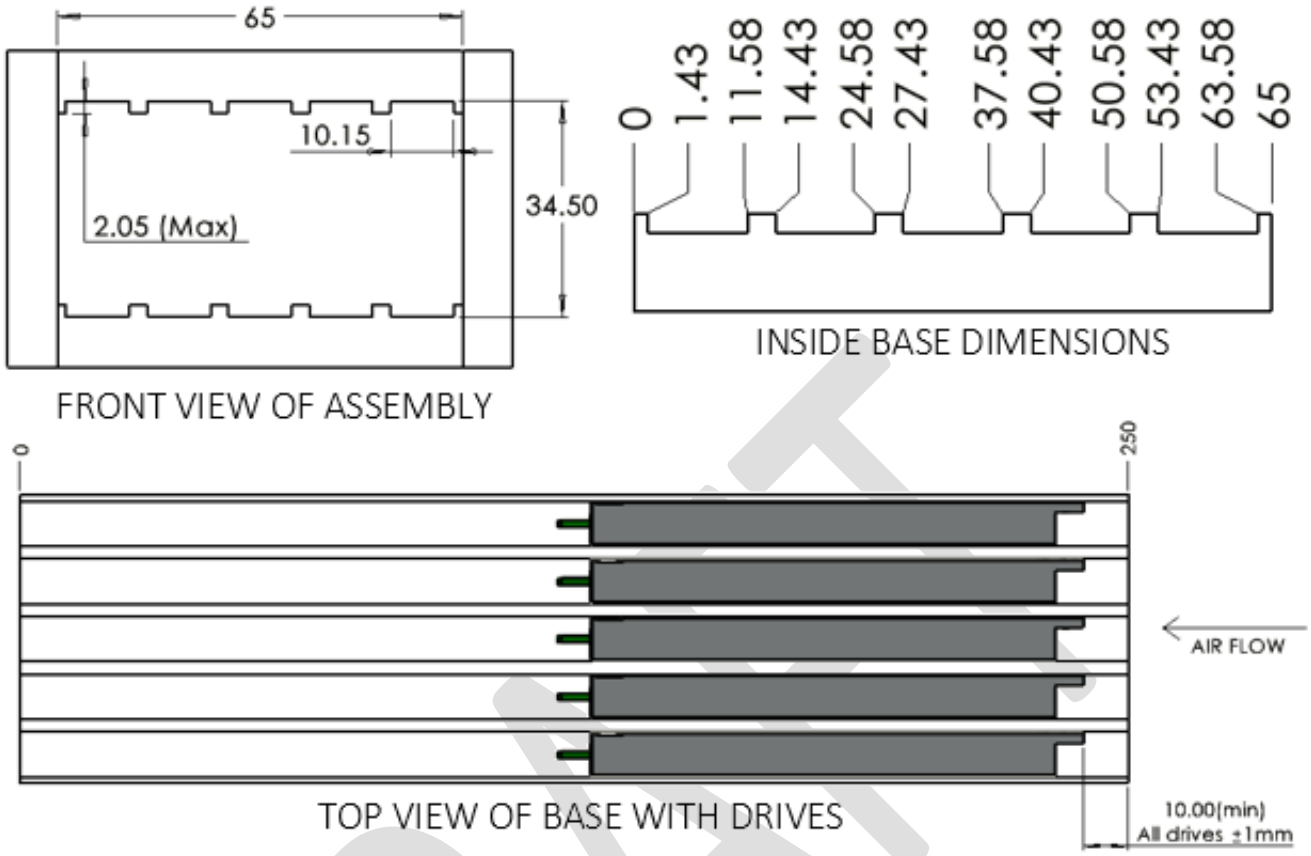



**Figure 6-~~7~~6-~~7~~: Required Dimensions of E1.S 9.5mm Air-Cooled Test Fixture**

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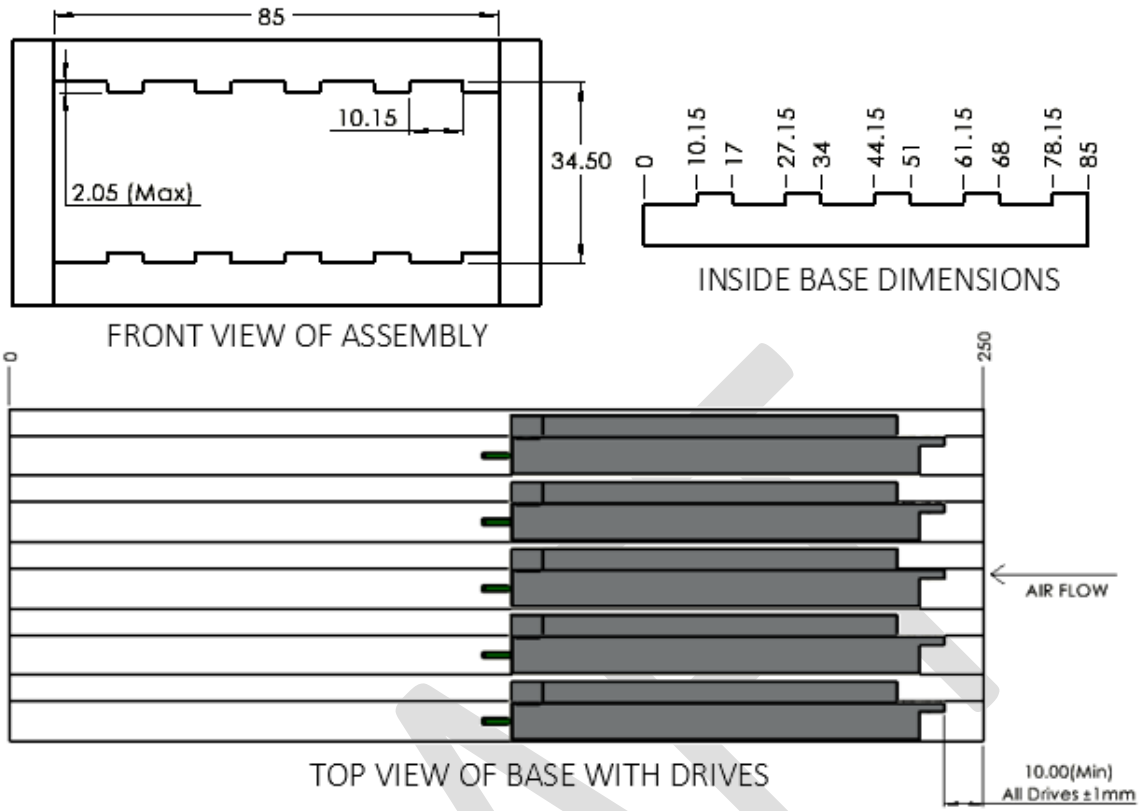



**Figure 6-~~8~~6-~~8~~: Required Dimensions of E1.S 15mm Air-Cooled Test Fixture**

***Note**: The enclosure for this device is asymmetric about the PCB. The intent of this fixture is to prevent air from passing by the left most wall and the device. This can be accomplished by using a gasket to seal the channel that would be between the left-most device and the fixture wall. This is done to simplify the CFM/Device Channel calculation and promote balanced airflow impedance across the row of devices.*


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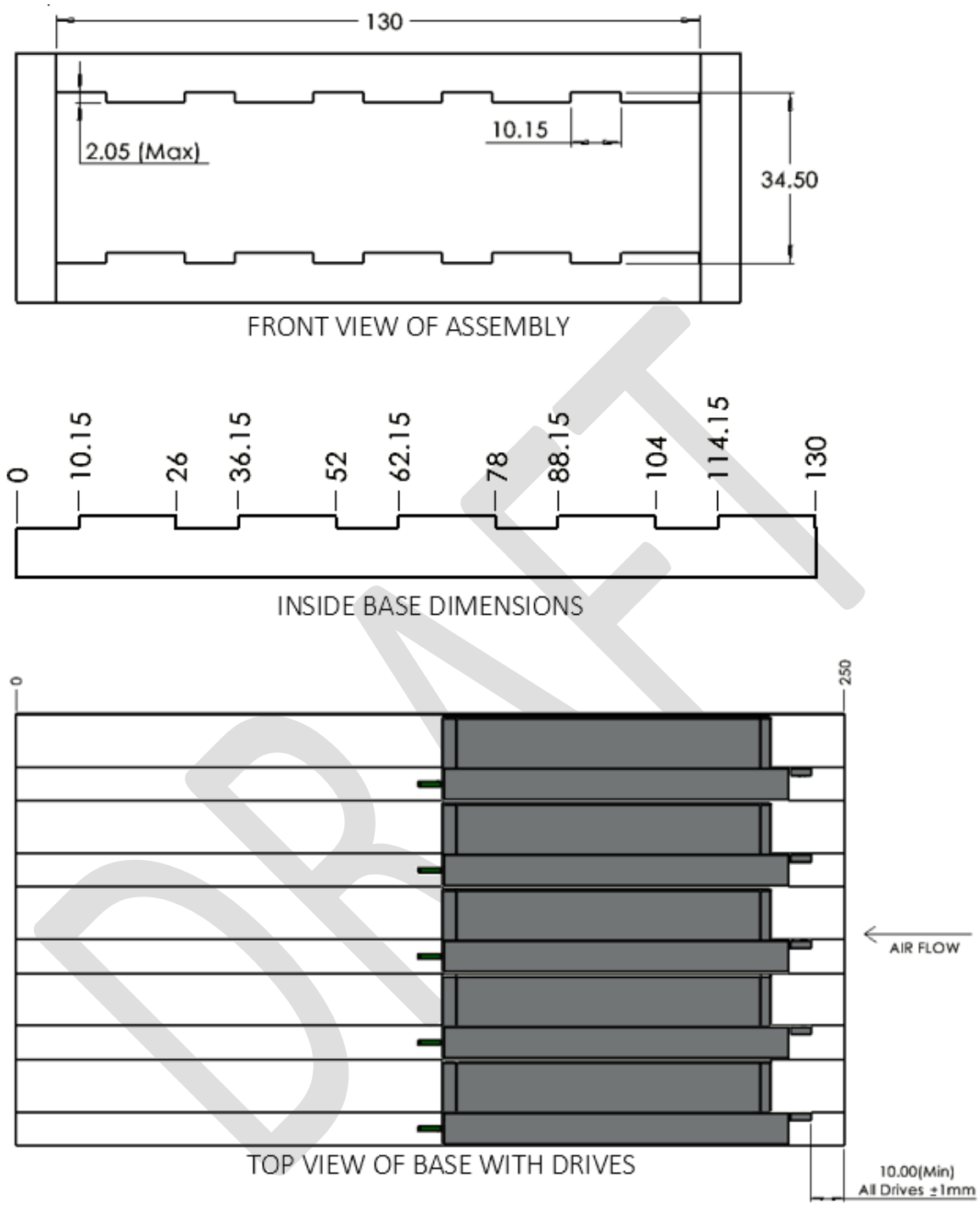



**Figure 6-~~9~~6-~~9~~: Required Dimensions of E1.S 25mm Air-Cooled Test Fixture**

***Note**: The enclosure for this device is asymmetric about the PCB. The intent of this fixture is to prevent air from passing by the left most wall and the device. This can be accomplished by using a gasket to seal the channel that would be between the left-most device and the fixture wall. This is done to simplify the CFM/Device Channel calculation and promote balanced airflow impedance across the row of devices.*


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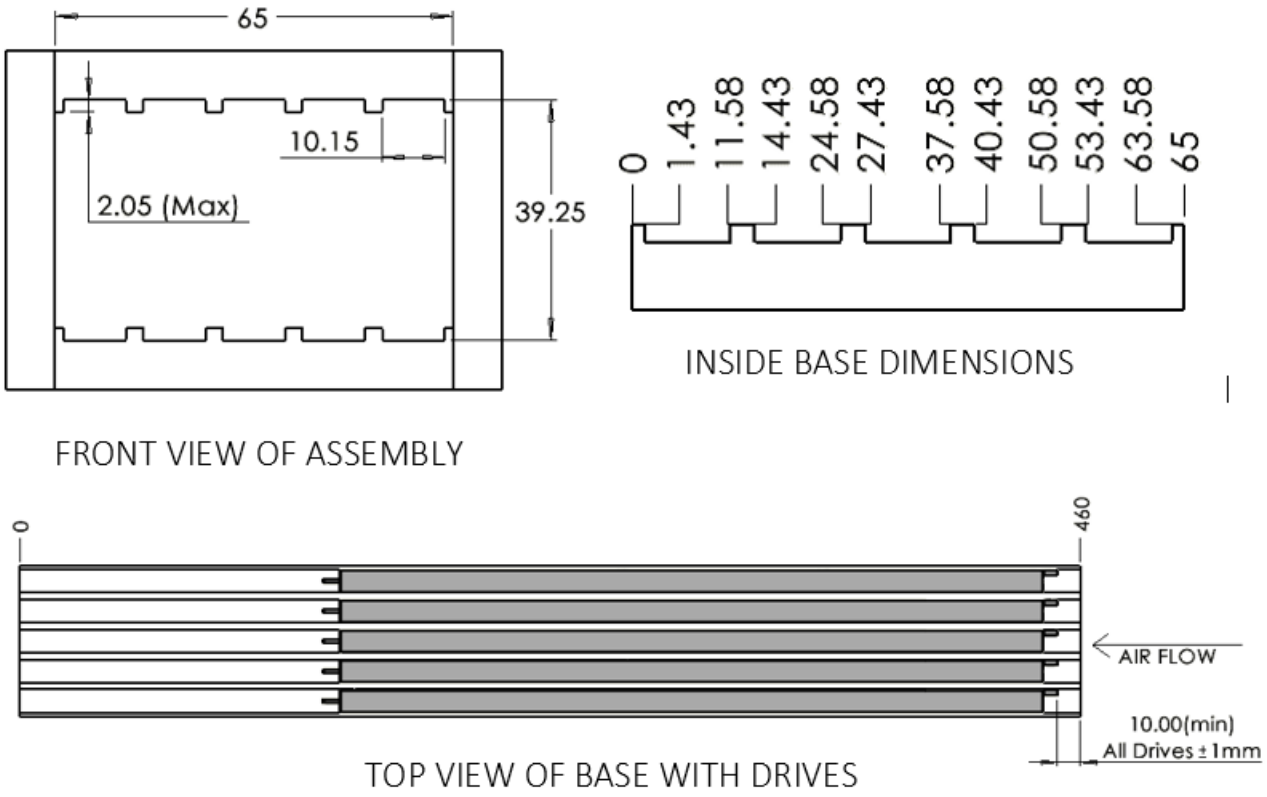



**Figure 6-~~10~~6-~~10~~: Required Dimensions of E1.L 9.5mm Air-Cooled Test Fixture**


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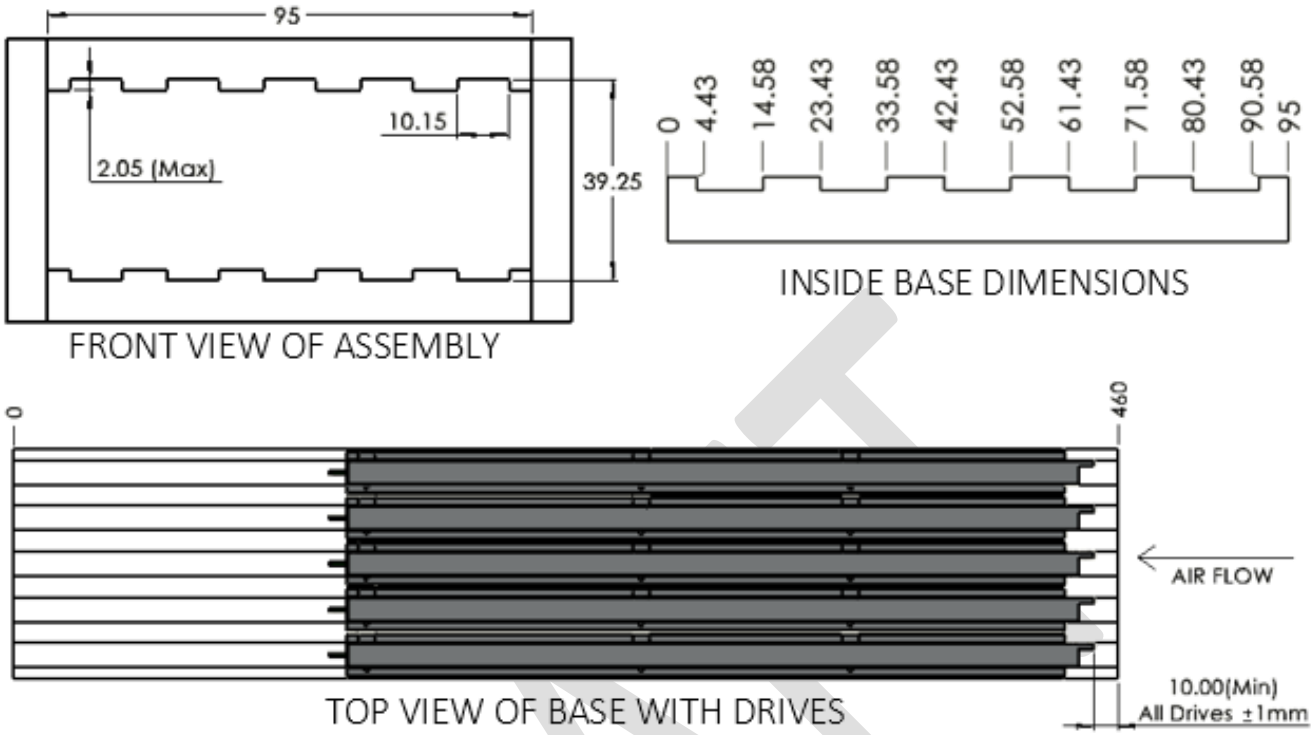



**Figure 6-~~11~~6 ~~11~~: Required Dimensions of E1.L 18mm Air-Cooled Test Fixture**

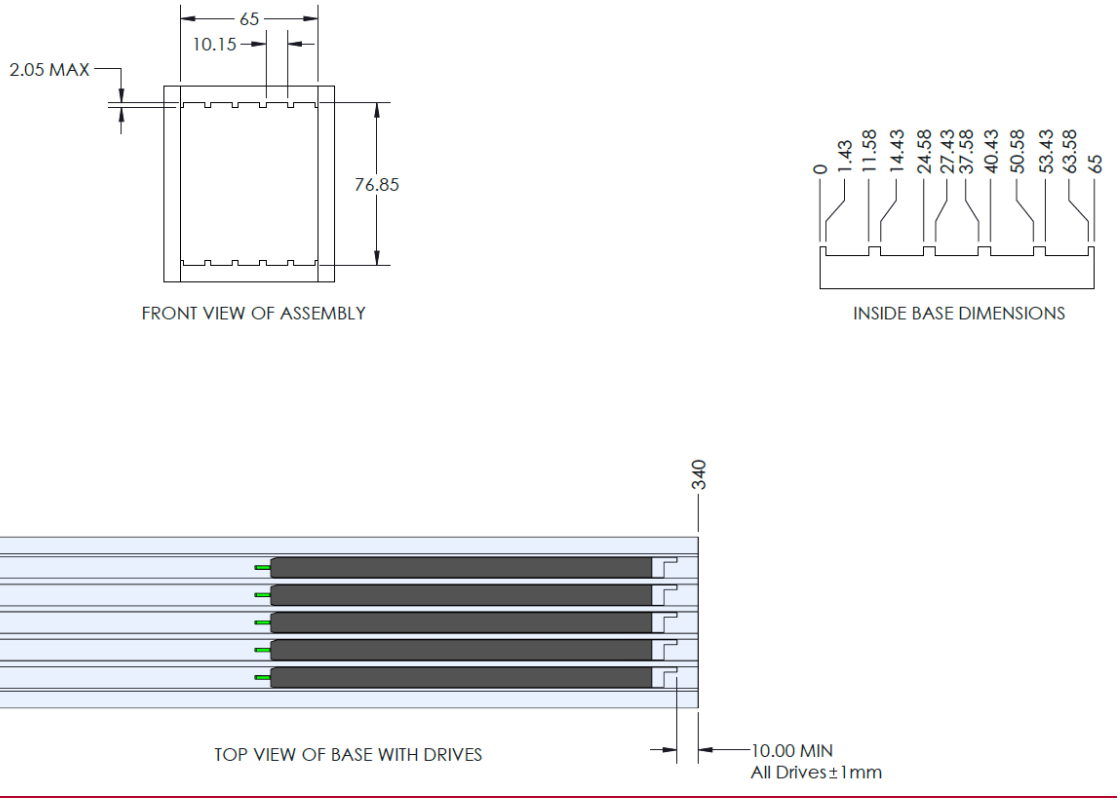



**Figure 6-12: Required Dimensions of E2 Air-Cooled Test Fixture**


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A system board with enough slots to operate each device in the fixture at maximum link width and maximum link speed is needed for the testing. The device and system board shall be configured to operate at their maximum performance level. The platform power supply shall be capable of supplying the power required for the system board and the device to run at their highest performance levels. The following figures illustrate a cabling keep in for connector to devices.

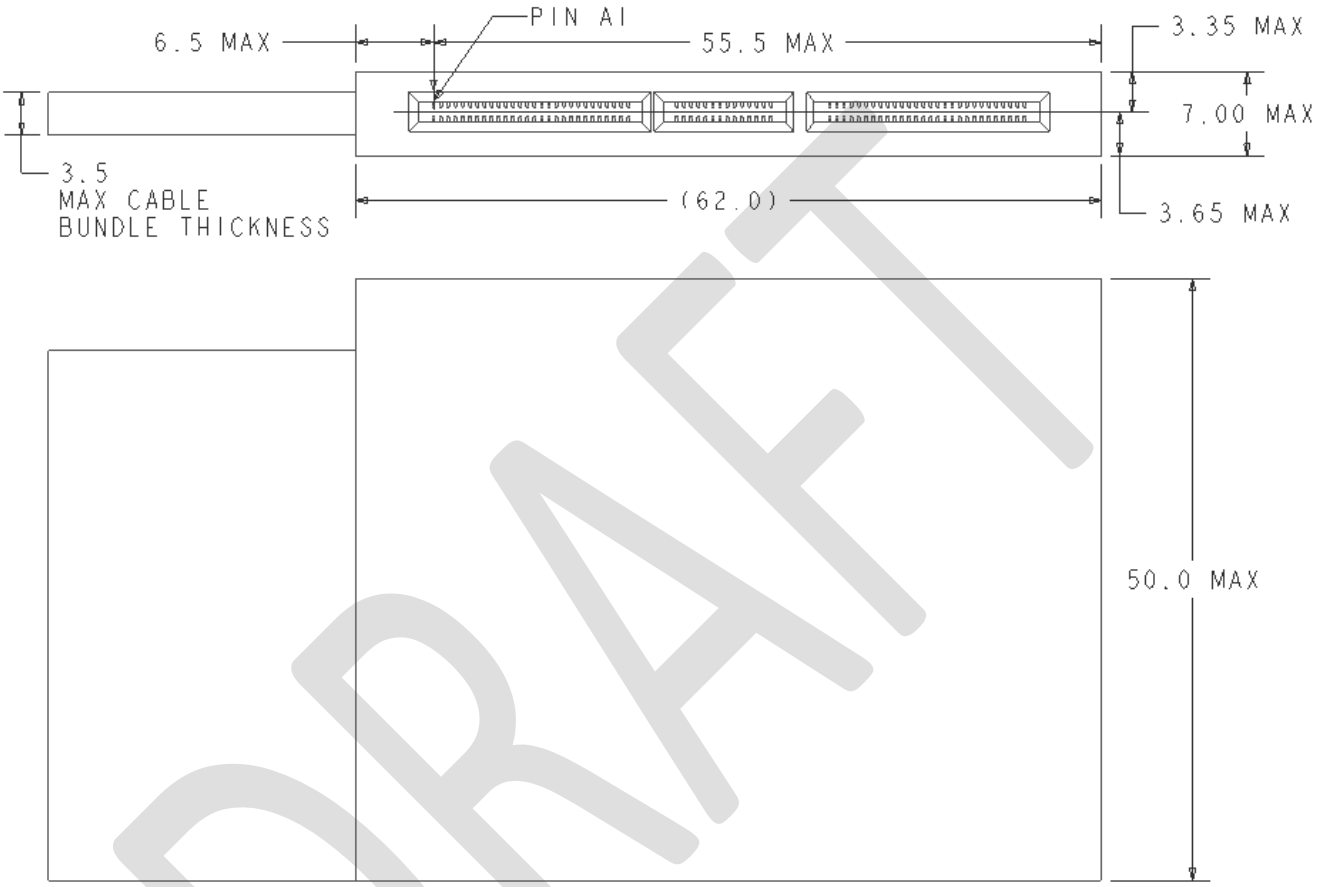



**Figure 6-136-12: Maximum Test Cabling Keep-in Dimensions for Air-Cooled E3, E2**

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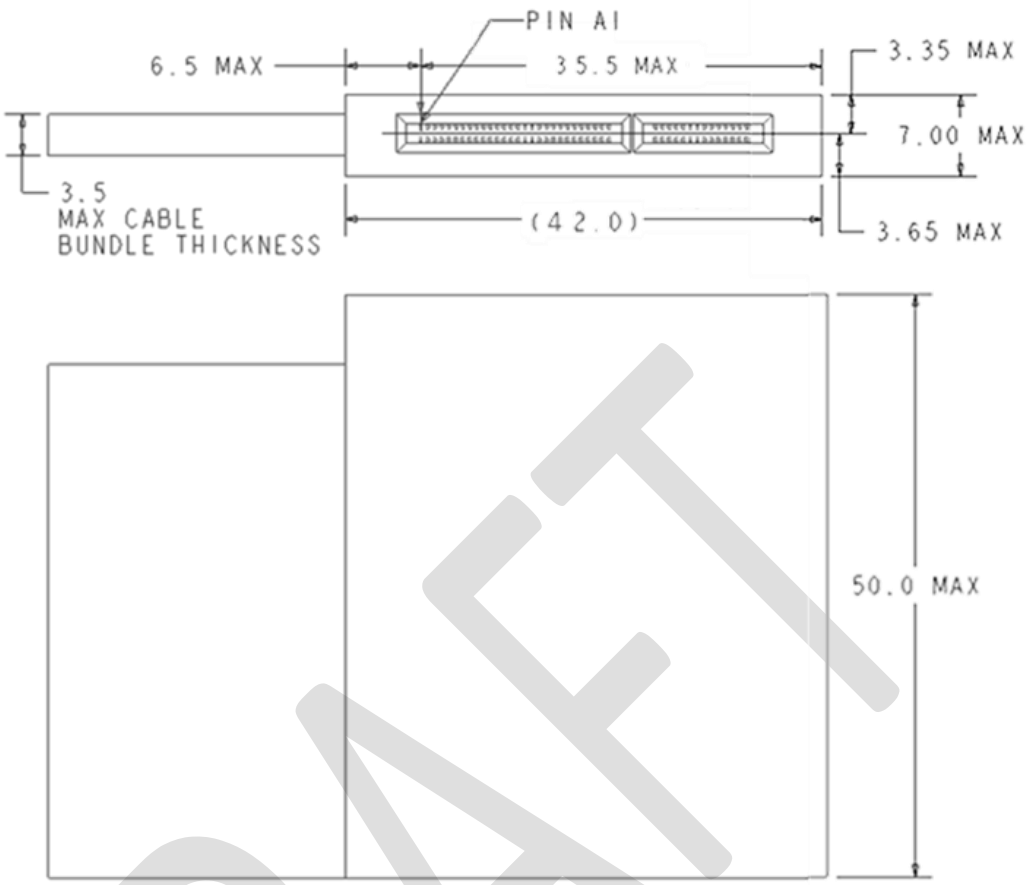



**Figure 6-~~14~~6-~~13~~: Maximum Test Cabling Keep-in Dimensions for Air-Cooled E1**

For MaxTherm and DTherm testing, the quantified volumetric airflow per device is reported.

At least one thermocouple sensor shall be placed to collect inlet air temperature data no less than 5mm from the inlet and no more than 4mm from the front of the device under test. Another thermocouple sensor shall be placed on the device under test to monitor critical local temperature. The location of local temperature measurement is defined by the implementer and should be reported in addition to thermal parameters. Figure 6-15 ~~Figure 5-13~~ illustrates an example test setup connected to a flow bench.


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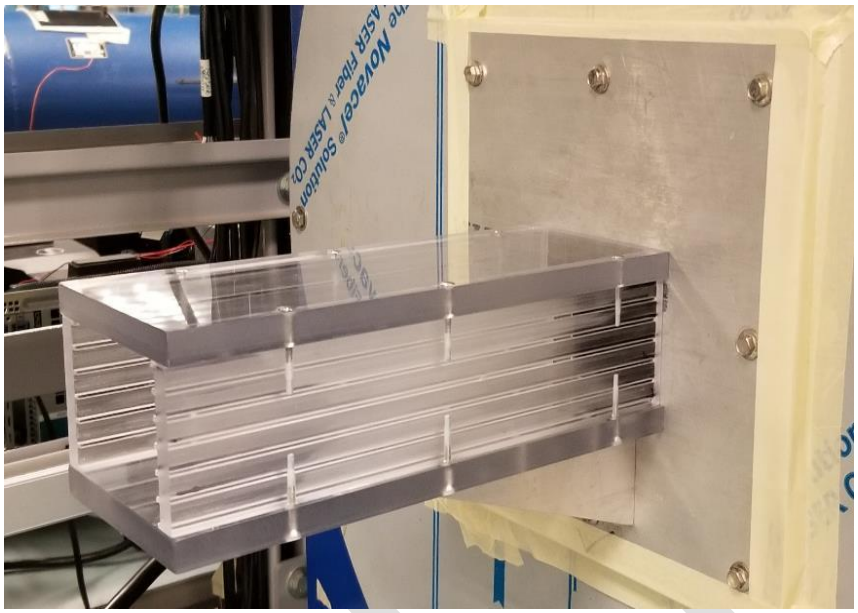


**Figure 6-15~~6-14~~: Actual Air-Cooled Thermal Test Fixture Set-up**

*Note: Device connectors downstream. Data cables not installed.*

To evaluate the air-cooled device's cooling parameters (MaxTherm and DTherm), the approach air temperature can be scaled experimentally or analytically. Experimental air temperature scaling requires a heated flowbench, but analytical temperature scaling can be performed at room temperature. To perform analytical temperature scaling, use the equation as follows:

**Equation 6-3:** $$\boldsymbol{Scaled\ Device\ Temperature = (Desired\ Scaled\ Approach\ Temperature - Approach\ Air\ Temperature) + Device\ Temperature}$$

For ~~e~~Example, if the thermal limiting component on the UUT ~~(Unit Under Test)~~ is at 48 °C when flowrate is held constant at 2 CFM/dev, and the approach air temperature is 24 °C, we could scale the device temperature up as if the approach air temperature was 40 °C (or any other value chosen)

**Example:** $\boldsymbol{64\ °C = (40\ °C - 24\ °C) + 48\ °C}$

The device temperature at 2 CFM/dev and 40 °C approach would be 64 °C in this instance. Using this method, and the thermal temperature limit for the limiting component, the theoretical maximum approach temperature can be calculated at each flowrate for the different workloads associated with MaxTherm and DTherm.


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# 7. DLC Thermal Reporting

DLC thermal reporting differs from the air-cooled thermal reporting defined in Section 5 in the number of variables involved. Air-cooled characterization is a function of two variables, approach air temperature and airflow, so air-cooled devices are classified using predefined levels. DLC characterization is a function of a single variable: the interface temperature at the device's cooling interface area, as defined in Section 8.2. DLC metrics are therefore reported directly as temperatures (°C) rather than as levels.

DLC thermal reporting uses two metrics, MaxDLCTemp and DDLCTemp, and defines a recommended interface temperature that devices should strive to meet. System designers may compare these values directly against the interface temperature their cooling solution can maintain at each device location. Device designers should utilize the metrics and work with system designers to ensure that the devices being developed, and their associated metrics, are aligned with system capabilities.

The air-cooled metrics AFI Level, HT-LF, MaxAmbient, and MinAmbient have no DLC equivalent and are not reported for DLC devices. Liquid cooling considerations other than thermal performance, such as coolant pressure, flatness and roughness of the cooling interface area, and mechanical compliance, are not in scope of this specification.

## 7.1. Maximum DLC Interface Temperature (MaxDLCTemp)

The intent of the Maximum DLC Interface Temperature (MaxDLCTemp) is to define the maximum interface temperature at which a device, when stressed to its TDP limit, operates within its components' reliability limits (as defined by the device/part manufacturer) and without degraded device performance.

MaxDLCTemp and DDLCTemp shall be determined using a single stress workload, referred to as the worst-case workload. The worst-case workload is the workload, from among sequential read, sequential write, random read, and random write, that produces the highest composite temperature (reported by the UUT) at a thermal plate temperature of 25 °C. The device manufacturer may select a different workload if that workload is known to reach the device's thermal limit at a lower interface temperature. The same worst-case workload shall be used for all reported device states (MaxDLCTemp and each DDLCTemp). Characterization using additional workloads is optional, as described in Section 8.1.

The analytical temperature scaling method defined for air-cooled devices in Section 6 shall not be used for DLC characterization. The process to determine MaxDLCTemp is as follows:

1. Set up the device in the appropriate DLC test fixture, as defined in Section 8.2, with cables connecting the device to the host system or controller.
2. Set the TEM to control the thermal plate temperature to the first setpoint of 25 °C.
3. Run the worst-case workload to achieve the maximum device TDP.
4. Allow the test to reach steady state; the device composite temperature, workload performance and power draw should be stable.
5. Record the thermal plate temperature measured by the central thermistor, measured contact pressure, device power, device composite temperature (as reported by the device), and device performance, as shown in Table 7-1. The interface temperature is then calculated from the recorded thermal plate temperature using Equation 8-1.
6. Increase the thermal plate temperature setpoint in increments of 5 °C, repeat steps 4 and 5 until the thermal plate temperature reaches 65 °C.
7. MaxDLCTemp is the calculated interface temperature at the highest thermal plate setpoint at which the device operated at TDP without degraded performance. If performance is not degraded at any setpoint up to and including 65 °C, MaxDLCTemp is reported as the calculated interface temperature at the 65 °C setpoint.


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**Table 7-1: Device Thermal Profile for DLC (Template)**

| **Device State:** | | *(MaxDLCTemp, DDLCTemp 1, DDLCTemp 2, …)* | | |
|---|---|---|---|---|
| **Workload and Parameters:** | | *(e.g., Random Write, 4 KiB, QD 128, 4 jobs)* | | |
| **Measured Contact Pressure (psi):** | | | | |
| **Plate Setpoint (°C)** | **Device Power (W)** | **Interface Temp, calculated (°C)** | **Composite Temp (°C)** | **Performance (MB/s or IOPS)** |
| **25** | | | | |
| **30** | | | | |
| **35** | | | | |
| **40** | | | | |
| **45** | | | | |
| **50** | | | | |
| **55** | | | | |
| **60** | | | | |
| **65** | | | | |

Reporting requirements for Table 7-1 are defined in Section 8.1.

To maximize the number of systems that can support a device, this specification defines a recommended DLC interface temperature of [TBD] °C. Devices should achieve a MaxDLCTemp equal to or greater than the recommended DLC interface temperature.

***Developer's Note:*** *It is strongly recommended that device developers strive to offer solutions with a MaxDLCTemp at or above the recommended DLC interface temperature. Higher allowable interface temperatures allow warmer coolant supply temperatures, which reduce facility cooling energy and increase the number of systems and facilities in which a device can be deployed. Systems intended to incorporate devices that do not meet the recommended DLC interface temperature may require mitigations such as reduced coolant supply temperature or increased coolant flow.*

## 7.2. Designed DLC Interface Temperature (DDLCTemp)

The intent of the Designed DLC Interface Temperature (DDLCTemp) is to determine the maximum interface temperature at which a device operates within its components' reliability limits but at a reduced device performance level. The reduced performance may be induced by the device's self-initiated thermal protection schemes, such as throttling, or by a host-selected power state. This is of interest for platforms that cannot maintain an interface temperature at or below the device's MaxDLCTemp, and for platforms that cannot supply the device's TDP and instead use power state control to reduce device power consumption.

Each DDLCTemp value is determined using the same process used to determine MaxDLCTemp in Section 7.1, with the device operating in the corresponding reduced-performance state rather than at TDP. Because device power is reduced, each DDLCTemp value is expected to be equal to or greater than MaxDLCTemp. The lowest-performance DDLCTemp is determined using the device's most reduced performance operating state at which it is still operating and providing useful work, as defined by the device implementer. Because the thermal plate temperature sweep ends at 65 °C, DDLCTemp values are limited by the highest setpoint. If MaxDLCTemp is determined at the highest setpoint, DDLCTemp values need not be reported.

The number of reported DDLCTemp values is up to the device implementer, based on software definition and the number of operating states. DDLCTemp reporting is strongly recommended, as this information allows system integrators to understand performance throttling options to balance performance with available system cooling.


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Devices may be set to run continuously in a DDLCTemp performance state or be allowed to self-regulate based on interface temperature. DDLCTemp values should be used to represent a device in different power states as defined by the appropriate industry standard for that device type (e.g., NVMe devices would utilize the NVMe Power States).

***Developer's Note:*** *It is strongly recommended that device developers establish multiple DDLCTemp values. Interface temperature varies by device location within a system. For example, devices located downstream in a serial coolant loop receive warmer coolant than upstream devices. Creating a means for a device to function (even in a reduced performance state) across a range of interface temperatures ensures that the device can be used broadly across a system portfolio. For instance, a device will have a MaxDLCTemp representing thermal performance at TDP and maximum bandwidth but should also have multiple DDLCTemp values showing operation at higher interface temperatures with reduced bandwidth and device power. The device should be able to transition to a DDLCTemp performance state automatically in the event of a thermal excursion but should also contain a means by which the host can limit the device to a DDLCTemp performance state. An example of DDLCTemp usage is as follows: MaxDLCTemp represents 100% bandwidth, DDLCTemp 1 represents 75%, DDLCTemp 2 represents 50%, DDLCTemp 3 represents 25%, and DDLCTemp 4 represents the maximum throttled condition while still providing useful performance. Additional DDLCTemp values may be used to add further granularity as needed.*

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# 8. DLC Thermal Data Collection and Test Procedure

The following specifies the thermal test set-up and procedure to evaluate an EDSFF device's thermal performance in a DLC environment.

## 8.1. DLC Reporting Requirements

As defined in Section 7, DLC thermal performance is reported using the following fields:

- MaxDLCTemp – Maximum interface temperature at which a device operating at its TDP limit will operate without degraded performance
- DDLCTemp – Maximum interface temperature at which a device, when provided the same worst-case workload as for MaxDLCTemp, will operate at a reduced device performance level
- Meets Recommended DLC Interface Temperature (Y/N) – Whether the device's MaxDLCTemp is equal to or greater than the recommended DLC interface temperature defined in Section 7.1
- Worst-case workload – The workload and workload parameters (e.g., transfer size, queue depth, and number of jobs) used for all reported device states, as defined in Section 7.1

These fields should be used to populate Table 8-1 for the UUT:

**Table 8-1: DLC Device Thermal Performance Template**

| | | | | |
|---|---|---|---|---|
| **Device Form Factor:** | | | | |
| **Meets Recommended DLC Interface Temperature (Y/N):** | | | | |
| **Worst-Case Workload and Parameters:** | *(e.g., Random Write, 4 KiB, QD 128, 4 jobs)* | | | |
| **Measured Contact Pressure (psi):** | | | | |
| **TIM R_TIM (°C·mm²/W):** | | | | |
| **Device State** | **Workload** | **Device Power (W)** | **Max Interface Temperature (°C)** | **Performance (MB/s or IOPS)** |
| **MaxDLCTemp** | | | | |
| **DDLCTemp 1** | | | | |
| **DDLCTemp 2** | | | | |
| **DDLCTemp 3** | | | | |
| **DDLCTemp 4** | | | | |
| **… As Needed** | | | | |

In Table 7-1 and Table 8-1, sequential workload performance shall be specified in megabytes per second (MB/s) and random workload performance in IOPS. Manufacturers are encouraged to report results for additional workloads by adding rows to Table 8-1, with each workload identified in the Workload column and the worst-case workload identified as such.

In addition to Table 8-1, the data measured at each thermal plate setpoint shall be reported using Table 7-1 for the MaxDLCTemp state and should be reported using Table 7-1 for each DDLCTemp state. Where performance varies at a setpoint, it should be reported as the average over 10 minutes after the device reaches steady state.

## 8.2. DLC Test Fixture and Setup

The values reported in Section 8.1 are determined using the test fixture defined in this section. Reference 3D CAD models of the DLC test fixtures are available as STEP files contained in CAD-TA-1023. Requirements that affect test results (e.g. TEM performance, contact pressure and TIM) are defined in this section. If the CAD models conflict with this specification, this specification takes precedence.


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The reference test fixture defined in CAD-TA-1023 is for E3.S and E3.L devices. A reference fixture is not defined for E1 or E2 devices at this time; however, the E3 reference fixture may be adapted for these form factors by modifying the thermal plate, pressure plate and or TEM module.

The test fixture shall be attached to a TEM that controls the thermal plate temperature. An example is shown in Figure 8-1. The TEM shall meet the following requirements:

- Ability to hold the thermal plate at a uniform temperature from 25 °C to 65 °C while removing 40 W from the cooling interface area.
- Temperature uniformity is such that all five thermal plate temperature sensors read within ±1.0 °C of each other when tested with a TTV that applies a uniform heat load over at least 80% of the cooling interface area.
- Control of the thermal plate temperature to within ± 1 °C of the setpoint, as measured by the central thermistor.
- Thermal plate flatness of better than or equivalent to the defined flatness of the cooling interface area in the device form factor specification (e.g. E3.S is defined as requiring 0.2mm flatness in SFF-TA-1008)

An example of a suitable TEM is the TE Technology CP-110 (https://tetech.com/product/cp-110/).



**Figure 8-1: Example Thermoelectric Module**

The TEM has a thermal plate that contacts the UUT. SFF-TA-1008 permits cooling of both sides of the device; the DLC test fixture defined in this specification cools only the top side of the UUT. The UUT is placed between this thermal plate and a pressure plate. The pressure plate shall apply a contact pressure of 10 ± 1 psi (68.9 ± 6.89 kPa), distributed uniformly across the cooling interface area of the UUT. SFF-TA-1008 requires devices to support contact pressures of up to 15 psi; testing is performed at 10 psi to represent typical system implementations rather than the maximum. The contact pressure shall be applied by a screw-driven compression assembly and measured by a load cell in the load path. For E3.S, 10 psi across 6 208 mm² corresponds to a force of approximately 428 N (96 lbf).

The interface between the UUT and the thermal plate shall use a TIM that covers the cooling interface area of the UUT. At the test contact pressure, the TIM shall have an area-specific thermal resistance (R_TIM) of less than 387 °C·mm²/W (0.6 °C·in²/W). A ±10% variation in contact pressure shall result in no more than a ±10% variation in R_TIM. R_TIM shall be characterized at the test contact pressure, for example using ASTM D5470, and shall be reported with the test results. An example of a suitable TIM is Parker Chomerics THERM-A-GAP PAD 30 with woven glass carrier (PAD30G) at a thickness of 1.0 mm, cut to 95 mm × 65 mm for E3.S devices.

The test operator is responsible for ensuring that the TIM performs at its characterized R_TIM and has not


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degraded. An example setup is shown in Figure 8-2.

Because a TIM is used between the thermal plate and the UUT, the temperature at the UUT's cooling interface area is higher than the thermal plate temperature. The interface temperature reported by this specification is the temperature at the UUT's cooling interface area and shall be calculated using Equation 8-1:

$$T_{interface} = T_{plate} + \frac{R_{TIM} \times Q_{device}}{A_{TIM}}$$ **Equation 8-1:**

where $T_{interface}$ is the interface temperature (°C); $T_{plate}$ is the thermal plate temperature measured by the central thermistor (°C); $R_{TIM}$ is the area-specific thermal resistance of the TIM at the test contact pressure (°C·mm²/W); $Q_{device}$ is the measured device input power (W); and $A_{TIM}$ is the cooling interface area of the UUT (mm²); for example, approximately 6 208 mm² for E3.S, based on the primary cooling interface area defined in SFF-TA-1008. Equation 8-1 assumes that all device heat leaves through the thermal plate. No temperature sensor is placed on the UUT.

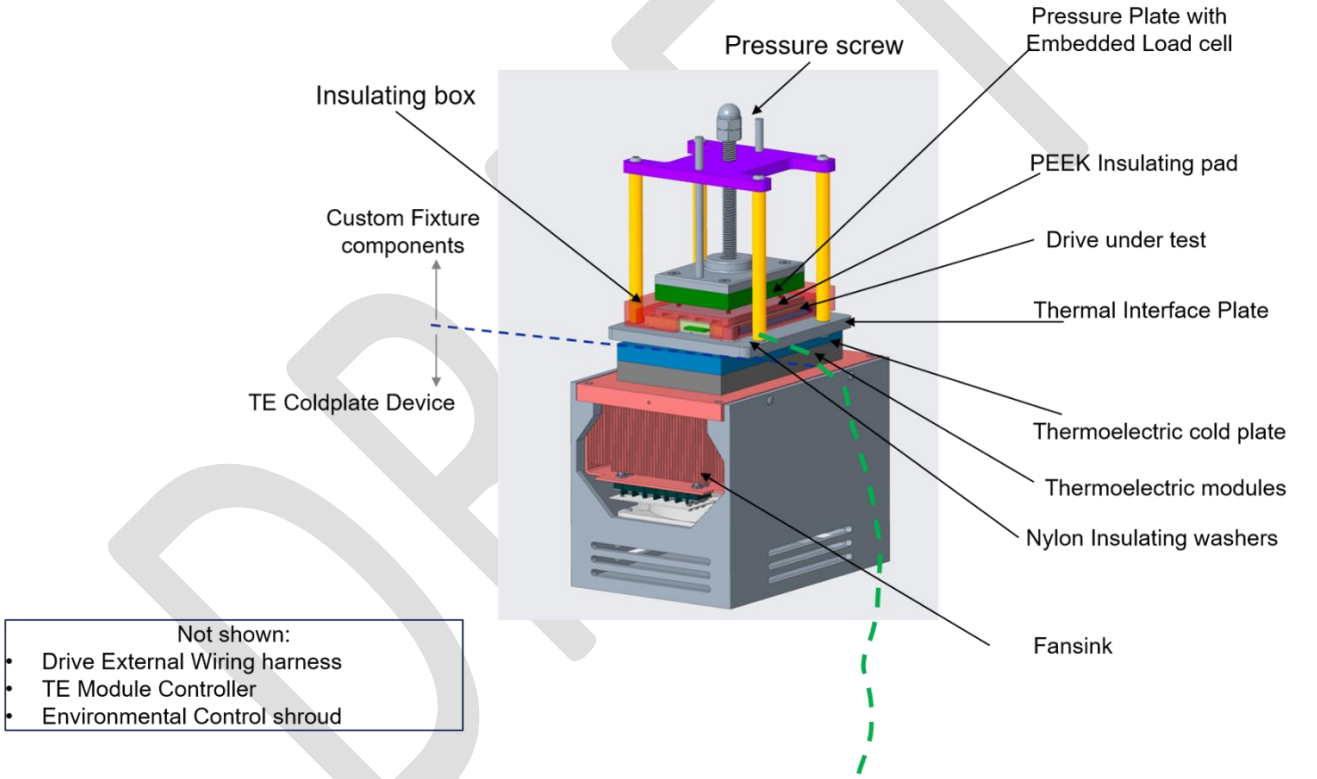



**Figure 8-2: Example DLC Test Fixture and Device Setup**

To minimize heat transfer from the UUT to the surrounding air, all surfaces of the UUT other than the cooling interface area shall be insulated. The UUT shall be separated from the metal pressure plate by a PEEK insulating pad, and the UUT and pressure assembly shall be enclosed by a PLA housing covered with a fiberglass thermal blanket as defined by CAD-TA-1023. Heat transferred from the UUT through paths other than the thermal plate should not exceed 5% of device power.

A single UUT is tested in the DLC test fixture. The thermal plate shall contain five temperature sensors: one at the center of the cooling interface area, which is used for TEM control and as $T_{plate}$ in Equation 8-1, and four additional measurement sensors used to verify temperature uniformity, at the locations shown in CAD-TA-1023. The center


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sensor shall be a thermistor embedded in the thermal plate.

The test fixture should be qualified using a uniform-heat-load TTV with embedded temperature sensors to confirm that the temperature uniformity requirement is met before device testing.

A system board capable of operating the device at maximum link width and maximum link speed is needed for the testing. The device and system board shall be configured to operate at their maximum performance level. The device manufacturer should provide sufficient detail, including the software, firmware, and hardware required, such that system integrators could recreate the same results if provided the same device.

This specification is intended to provide consistent measurements, but care should be exercised when using interface temperature data for platform integration. The TEM provides an idealized, uniform cooling surface; from the device's perspective, heat transfer is equivalent to a liquid cold plate held at the same interface temperature. Cold plate design and shape, TIM, and the contact pressure used in a system (which may differ from the 10 psi test condition) affect the cooling capability of the device and are not accounted for in this specification, as they vary from implementation to implementation. The interface temperature calculated using Equation 8-1 represents an average across the cooling interface area. Because the test fixture cools only one side of the UUT, results may be conservative for systems that cool both sides of the device.

Figure 8-3 illustrates the reference E3.S test fixture. Complete fixture geometry, including the thermal plate temperature sensor locations, is provided in CAD-TA-1023.

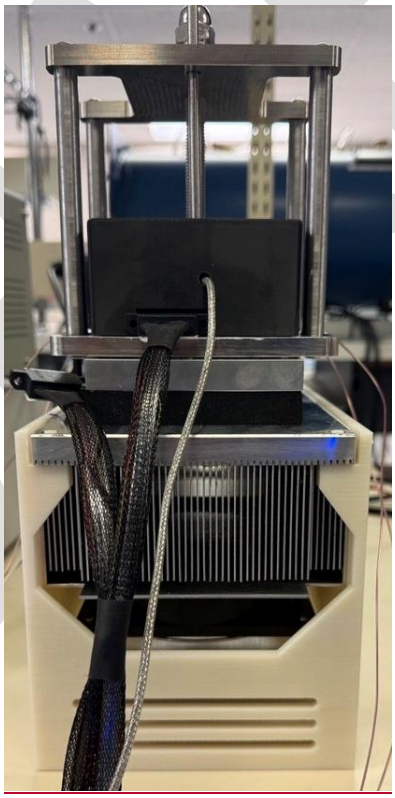


**Figure 8-3: Reference E3.S Test Fixture**


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