SNIA
SFF TWG
Technology Affiliate

SFF-TA-1022

Specification for

PCIe® Enclosure Compatible Form Factor Specification (PECFF) Thermal Reporting Specification

Rev 0.8.3 January 6, 2020

SECRETARIAT: SFF TA TWG

This specification is made available for public review at http://www.snia.org/sff/specifications. Comments may be submitted at http://www.snia.org/feedback. Comments received will be considered for inclusion in future revisions of this specification. This specification originates from the Gen Z Consortium and supersedes their prior documents.

Commented [NJ1]: Added origination comment

ABSTRACT: This specification defines thermal performance measurement fixtures, methods, and reporting requirements for the PCIe® Enclosure Compatible Form Factor Specification (PECFF). PECFF AICs are influenced by the temperature and airflow velocity and volume present across these cards. To enable enclosure management to comprehend whether a given AIC without integrated air movers can be adequately cooled based on its dynamic operating conditions.

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Foreword
The development work on this specification was done by the SNIA SFF TWG, an industry group. Since its formation as the SFF Committee in August 1990, 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 TWG, the signup for membership can be found at http://www.snia.org/sff/join.

Revision History

Rev 0.8.1 *December 2, 2019*:
-Initial Draft
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-Initial Draft
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-added origination note

Contents

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1. Scope

This specification defines a PCIe Enclosure Compatible Form Factor (PECFF) that is mechanically compatible with enclosures that support a PCI Express® Card Electromechanical (CEM) add-in card (AIC). The specification defines PECFF with connector interfaces based on SFF-TA-1002 and SFF-TA-1020 connectors.

2. References and Conventions

2.1. Industry Documents

The following documents are relevant to this specification:

- ASME Y14.5 Dimensioning and Tolerancing
- EIA-364-1000 Environmental Test Methodology for Assessing the Performance of Electrical Connectors and Sockets Used in Controlled Environment Applications
- OCP NIC 3.0 Design Specification
- PCI Express Card Electromechanical Specification
- REF-TA-1011 Cross Reference to Select SFF Connectors
- SFF-TA-1002 Protocol Agnostic Multi-Lane High Speed Connector
- SFF-TA-1020 SFF-TA-1002 Cables and Connector Variants
- SFF-TA-1021 PECFF (PCIe Enclosure Compatible Form Factor) Specification

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 found at http://www.snia.org/sff/specifications. Suggestions for improvement of this specification will be welcome, they should be submitted to http://www.snia.org/feedback.

Copies of PCIe standards may be obtained from PCI-SIG (http://pcisig.com).

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 Open Compute Project specifications may be obtained from https://www.opencompute.org/

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 first appear.

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, Geometric Dimensioning and Tolerancing. All dimensions are in millimeters, which are the controlling dimensional units (if inches are supplied, they 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
0.6	0,6	0.6
1,000	1 000	1 000
1,323,462.9	1 323 462,9	1 323 462.9

3. Keywords, Acronyms, and Definitions

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

3.1. Keywords

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 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 reserved bit, byte, word, or field (e.g., a restricted byte uses the same value as defined for a reserved byte).

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

PCB: Printed Circuit Board
AIC: Add in Card

3.3. Definitions

Connector: Each half of an interface that, when joined together, establish electrical contact and mechanical retention between two components. In this specification, the term connector does not apply to any specific gender; it is used to describe the receptacle, the plug or the card edge, or the union of receptacle to plug or card edge. Other common terms include: connector interface, mating interface, and separable interface.

4. Add-in Card (AIC) Thermal Reporting

4.1. Overview

PCIe Enclosure Compatible Form Factor (PECFF) AICs are influenced by the temperature and airflow velocity and volume present across these cards. To enable enclosure management to comprehend whether a given AIC without integrated air movers can be adequately cooled based on its dynamic operating conditions, an AIC may communicate its operating requirements over a range of environmental conditions as specified in PCI Express Base Specification (if the AIC supports PCIe).

Platform software reads this field to determine whether an AIC can be supported based on the AIC's thermal characteristics as well as to determine how to optimize cooling mechanisms to ensure correct operation without expending excessive power.

Thermal Reporting uses three graph sets that each define up to 15 operating curves. Each curve corresponds to one numeric value communicated through the Thermal Attributes field. Values associated with unspecified curves shall be treated as Reserved.

4.1.1. Airflow Impedance (AFI) Level

The intent of Airflow Impedance Level information is to identify AICs which, if in the same airflow path as other platform features to be cooled, may contribute to a total airflow impedance that impacts platform cooling. Also, the installation of higher impedance AICs, especially if multiple such AICs are installed, in a platform may exceed the capabilities for a given platform fan's performance curve. Through testing, developers determine which AIC AFI Levels a platform can support.

Impedance is categorized as one of N levels communicated by the AFI Level field. Each level corresponds to one of the curves illustrated in **Figure 4-1**. The level is assigned based on the highest AFI level number which is still below the measured AIC AFI throughout the range of air flows. The AFI Level field is set to a value of one through nine; all other values shall be Reserved.

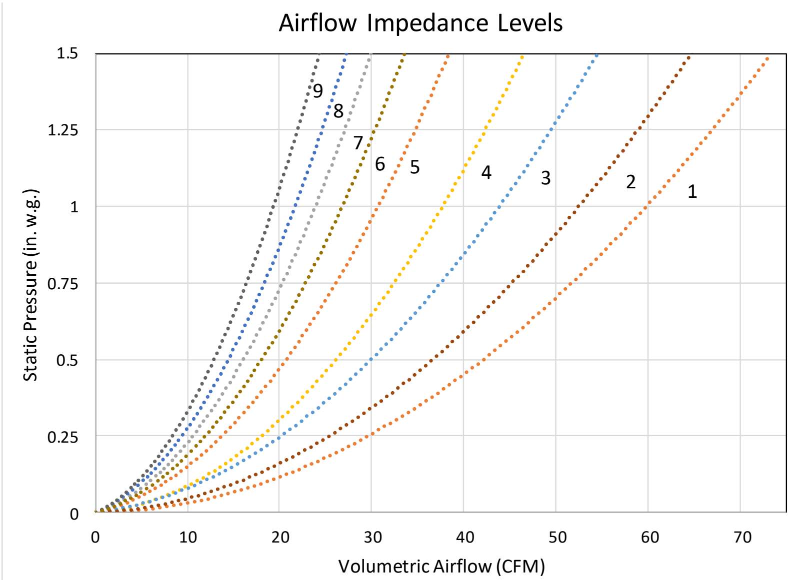

Figure 4-1: AFI Levels

An AIC is rated to an AFI Level by comparing its measured impedance, in 0.25-inch water increments through the static pressure range of 0.25 to 1.25 in.w.g., to the AFI Level equations listed in **Table 4-1**. The lowest AFI Level which always has higher volumetric airflow for a given static pressure relative to the AIC's measured impedance shall be listed as the AIC's AFI Level.

The airflow impedance testing for an AIC shall start at 0.25 in.w.g. to lessen the potential for error at low flowrates.

Table 4-1: AFI Level Equations

AFI Level	Equation (X=volumetric airflow [CFM]; Y=static pressure [in.w.g.])
0	Reserved
1	Y = 0.0003 * X^2 + 0.0003 * X
2	Y = 0.0003 * X^2 + 0.0012 * X
3	Y = 0.0004 * X^2 + 0.0035 * X
4	Y = 0.0006 * X^2 + 0.0023 * X
5	Y = 0.0008 * X^2 + 0.0066 * X
6	Y = 0.0011 * X^2 + 0.078 * X
7	Y = 0.0014 * X^2 + 0.0091 * X
8	Y = 0.0016 * X^2 + 0.0117 * X
9	Y = 0.0020 * X^2 + 0.078 * X
10-15	Reserved

4.2. Maximum Thermal (MaxTherm) Level

The intent of the Maximum Thermal (MaxTherm) Level information is to define the minimum airflow required at a given air temperature for which an AIC, when stressed to its TDP (thermal design power) level limit, will operate within its component's reliability limits and without degraded AIC performance.

Once an AIC's thermal performance profile is established, the MaxTherm Level is determined. MaxTherm is the lowest curve in **Figure 4-2** which is entirely above the AIC's quantified thermal performance curve throughout the range of approach ambient temperatures (also referred to as local ambient temperatures) illustrated on the X-axis ranging from 25 °C up to 65 °C.

Curves in **Figure 4-2** and **Figure 4-3Figure 4-3: Example AIC Thermal Profile**

- **Table 4-2: Thermal Level Equations** are for reference only.
- Compare measured readings against the equations defined in **Table 4-2**.
- Thermal Levels 2, 3, and 4 have a low limit for their approach air speed of 100 LFM, meaning their Thermal Levels do not require an AIC to support less than 100 LFM.

Developer Note: *It is strongly recommend that developers strive to offer solutions that can operate within the shaded recommended design space envelope illustrated in* **Figure 4-2** *to maximize the number of systems that can support such conditions.*

The MaxTherm field is defined for a value of 1 through 8 (inclusive); for all other values, MaxTherm shall be ignored. See **Figure 4-2** for encodings.

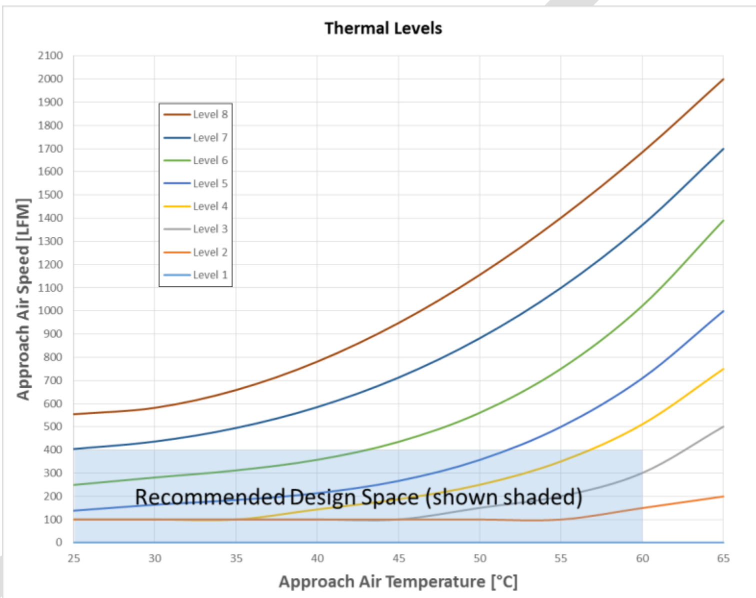

Figure 4-2: MaxTherm and DTherm Levels

No lower air speeds shall be presumed for approach air temperatures below 25 °C.

For example, **Figure 4-3** illustrates the curve of a hypothetical AIC that has been tested. Given this profile, the MaxTherm Level for the unit under test (UUT) AIC would be set to support the entire temperature range up through 65 °C. The highlighted circle illustrates it exceeds MaxTherm Level 5 above an approach air temperature of 52 °C.

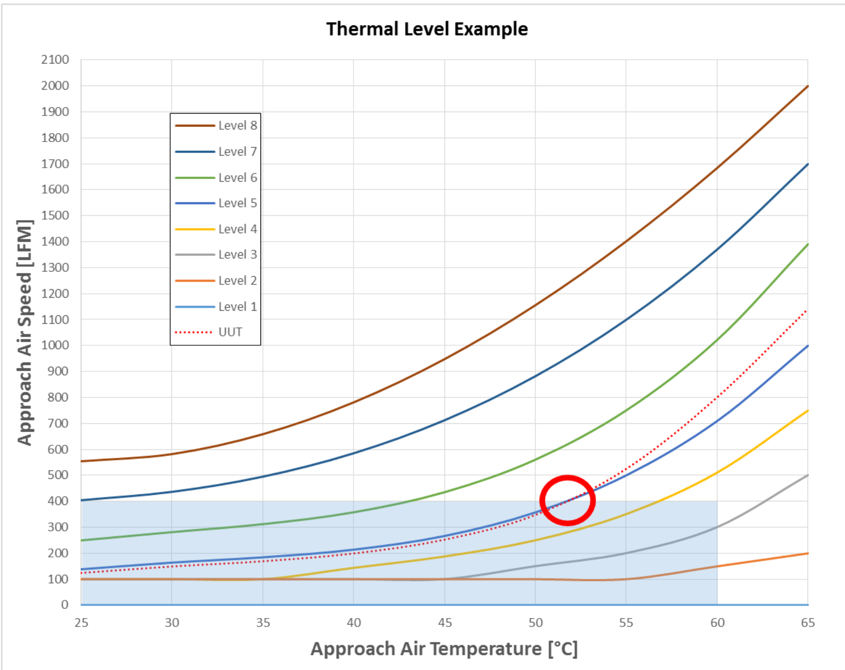

Figure 4-3: Example AIC Thermal Profile

Table 4-2: Thermal Level Equations

Thermal Level	Equation (X=approach air temperature [Celsius]; Y= approach airflow speed [LFM])
0	Reserved
1	Y = 0
2*	Y = -0.00093 * X^3 + 0.16705 * X^2 – 250.92807
3*	Y = 0.06667 * X^3 – 10.0000 * X^2 + 508.33333 * X – 8600.00000
4*	Y = 0.02700 * X^3 – 3.27605 * X^2 + 140.74670 * X – 1972.30735
5	Y = 0.01915 * X^3 – 1.82974 * X^2 + 62.21147 * X – 572.75974
6	Y = 0.02201 * X^3 – 2.00909 * X^2 + 66.82862 * X – 509.54545
7	Y = 0.00717 * X^3 – 0.11926 * X^2 – 3.31674 * X + 449.64286
8	Y = –0.00340 * X^3 + 1.28248 * X^2 – 57.26411 * X + 1237.37229
9-15	Reserved

Note: * Approach air speed values for indicated Thermal Levels shall not be less than 100 LFM.

4.3. Degraded Thermal (DTherm) Level

The intent of the Degraded Thermal (DTherm) Level information is to determine the minimum airflow required at a given air temperature for which an AIC, when provided the same stress application as it was for MaxTherm, will operate within its component's reliability limits but at a degraded AIC performance level. Typically, this is accomplished by the AIC'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 adapter's MaxTherm Level.

If an AIC can operate at a reduced performance level to protect itself thermally and this translates into a reduced adapter thermal profile than that established for MaxTherm, then DTherm is not equal to MaxTherm. DTherm is calculated using the same curves and process as MaxTherm, however, the AIC's profile is created using the AIC's most reduced performance operating level at which it is still operating and providing useful work that is not less than 10% of its maximum sustained performance noted in MaxTherm testing. The DTherm field is defined for a value of one through eight (inclusive); for all other values, platform software shall ignore DTherm and shall use only the MaxTherm value.

4.4. MaxAmbient

Some AICs may not be thermally viable up to an approach air temperature of 65 °C, regardless of the air speed involved. Or, even if the AIC could be thermally viable at high temperature extremes, the airflow requirements to do so may require it to operate at a higher thermal challenge level, potentially reducing the number of systems able to supply the needed airflow. In either circumstance, the AIC 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. MaxAmbient shall be an integer value between 50 °C and 65 °C inclusive. Max Ambient applies to the full operating potential MaxTherm condition.

For the example as illustrated in **Figure 4-2** when establishing a MaxTherm Level for an AIC, if the AIC reports less than a MaxTherm Level of 6, then a MaxAmbient 52 °C can be used by the instead of 65 °C. In such a case, declaring a MaxTherm Level of 5 with a MaxAmbient of 52 °C would have been acceptable. If MaxAmbient is unsupported, then these bits shall be set to 0x0. Platform software shall treat a Reserved MaxAmbient value as if MaxAmbient reporting was not supported (i.e., MaxTherm value applies up to 65 °C).

5. Thermal Data Collection and Test Procedure

The following specifies the thermal test set-up and procedure to evaluate a PECFF AIC's thermal performance. Thermal performance is partitioned into four sub-fields:

- AFI Level
- MaxTherm Level
- DTherm Level
- MaxAmbient

The values of these fields are determined using a custom test fixture. Details regarding the dimensions and construction of the test fixture are provided in the associated CAD files (contained in the SFF-TA-1022.zip file from SNIA) for the thermal challenge and airflow impedance tester.

The test fixture is intended to be attached to an AMCA 210-99/ASHRAE 51-1999 compliant airflow chamber, which can quantify both static pressure as well as volumetric airflow. The tester is attached to the airflow chamber such that air blows toward the AIC and exits the tester at the AIC's I/O bracket.

For MaxTherm and DTherm level testing, the airflow impedance plates (illustrated as orange in color in **Figure 5-1**) shall be removed. For AFI Level testing, where the desire is to understand the relative airflow impedance of the AIC, the use of the airflow impedance plates (two when testing Single-slot AIC; one when testing Dual-slot AIC) is required.

The AIC to be tested is installed in the test fixture, which is positioned above an operational platform IO board's SFF-TA-1002 4C or 4C+ or SFF-TA-1020 4C-HP connector. Any cables needed to fully exercise the AIC are attached to the AIC to be tested. The test fixture's lid is then attached, and the test fixture is checked to ensure air flow is not leaking through its joints.

The AIC is operated to its rated TDP level using a vendor-specific exercise procedure. The AIC's manufacturer is responsible for providing sufficient detail including full descriptions of all software, firmware, and hardware needed such that others could recreate the same results if provided the same AIC.

Figure 5-1 illustrates an exploded view of the tester, with the lid, its mounting screws, the AFI blocks (illustrated in orange for illustration purposes only), and AIC under test (in green) illustrated suspended above the tester housing. See the associated CAD file information for details of the tester's construction and size.

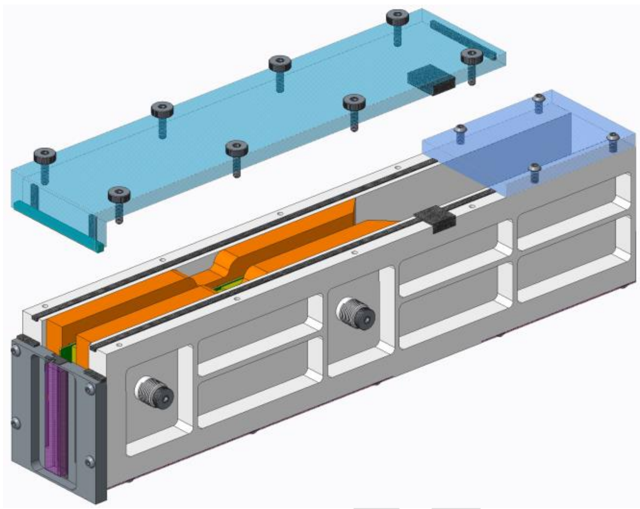

Figure 5-1: Tester Isometric View: {Lid, AFI Block, AIC, AFI Block}

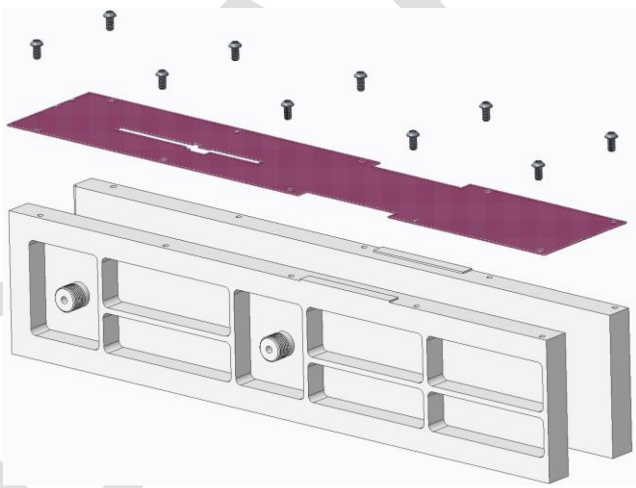

Figure 5-2: Tester Bottom Permanent Floor

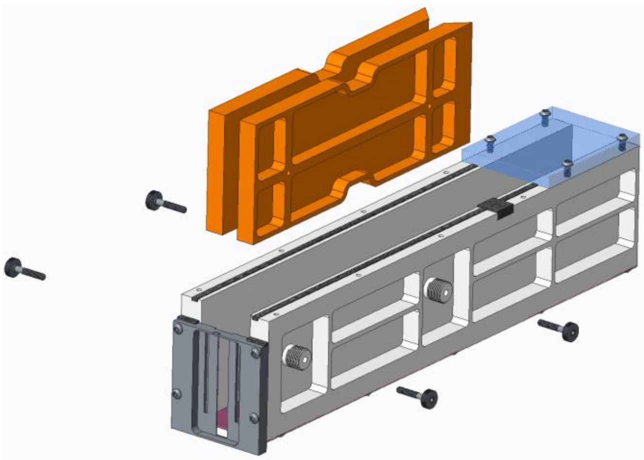

Figure 5-3: Tester with AFI Blocks Removed

During Thermal Level testing for MaxTherm and DTherm data, the AFI blocks (illustrated in orange in **Figure 5-3**) are not used in the tester as illustrated in **Figure 5-4** or **Figure 5-5**. The tester is connected to a flow bench which provides quantifiable volumetric airflow and static pressure.

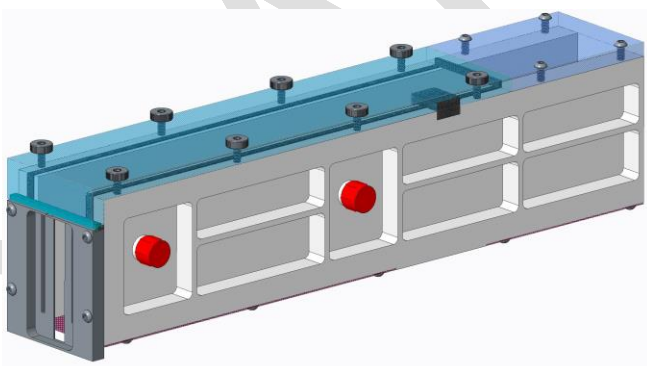

Figure 5-4: Single-slot Isometric View in MaxTherm and DTherm Testing Configuration

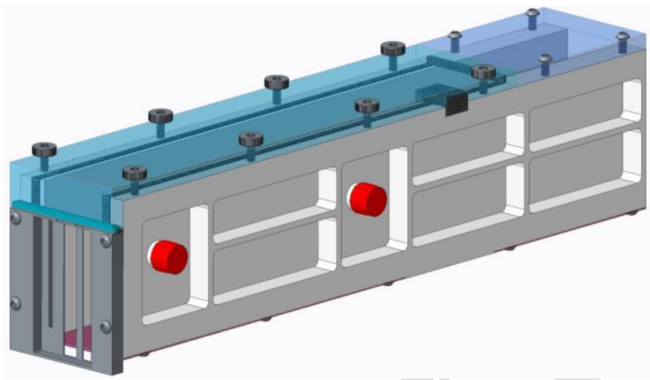

Figure 5-5: Double-slot Isometric View in MaxTherm and DTherm Testing Configuration

During Thermal Level testing for AFI Level data, the AFI blocks (illustrated in orange in **Figure 5-1**) are used in the tester (two AFI blocks when testing Single-slot AICs as illustrated in **Figure 5-6**; one AFI block when testing Dual-slot AICs as illustrated in **Figure 5-7**.

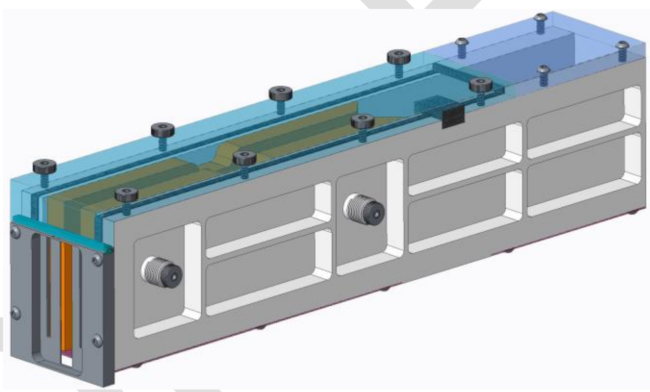

Figure 5-6: Tester Isometric View in Single-Slot AIC AFI Testing Configuration

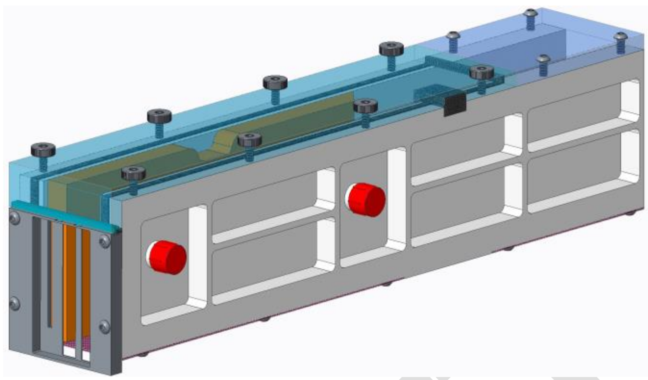

Figure 5-7: Tester Isometric View in Dual-Slot AIC AFI Testing Configuration

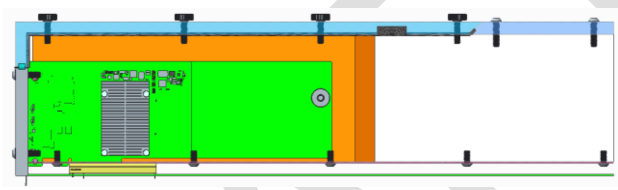

Figure 5-8: Side view in Dual-Slot AIC AFI Testing Configuration
(Side wall Removed for viewing illustration only)

A system board with at least one SFF-TA-1002 4C or 4C+ or SFF-TA-1020 4C-HP slot capable of operating at the AIC's maximum link width and maximum link speed is needed for the testing. The AIC 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 AIC to run at their highest performance levels.

For MaxTherm and DTherm testing, the quantified volumetric airflow is divided by the cross-sectional area of the duct to establish the average velocity of air entering the test fixture:

Velocity (FT/min) = volume flow (ft^3/min) / tester's inner area (ft^2) perpendicular to airflow.

A hot-wire anemometer shall be placed at the center of tester's air channel, within 50 mm downstream of the tester's air entrance opening. The anemometer data shall be collected for reference only. Unless using the anemometer's local ambient temperature reading, at least one thermocouple sensor shall be placed at this same location to collect inlet air temperature data, **Figure 5-9** illustrates an example test setup connected to a flow bench.

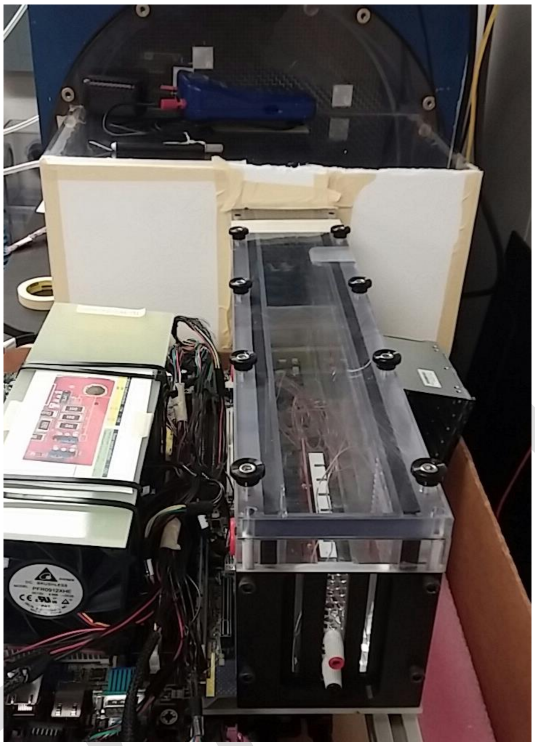

Figure 5-9: Actual Thermal Level Test Fixture Set-up

The target output is the air speed (LFM, or FT / min) required to cool the AIC under test at projected (or actual) air temperatures while the AIC is being stressed to its TDP level. The AIC component's minimum temperature margin at various air speeds are collected, while also noting the air temperature entering the test fixture. The AIC's minimum temperature margin is added to the tester's air inlet temperature to arrive at a projection as to what would be the zero-temperature margin ambient for given air speeds. With the exception of AICs meeting the requirements of Thermal Level 1, no less than six data points, regularly spaced from a project approach ambient of 25 °C to at least 50 °C (65 °C preferred), are to be collected. The projected approach ambients and approach air speeds are compared against the Thermal Levels illustrated in **Figure 5-11.**

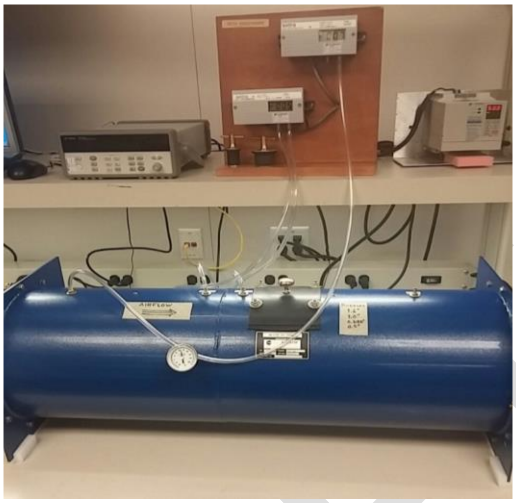

Figure 5-10: An Example of an Airflow Chamber

A hypothetical AIC was profiled for its thermal levels using an airflow chamber, such as the one Figure 5-10**, at various air speeds. Several measurement points were made to enable a good curve the range of interest. The components with the least temperature margin were monitored using sensors that are part of the AIC's design or added thermocouples. An optical transceiver plug, part of the AIC, but being integral for its intended usage, was included in this AIC's for this example AIC are given in Table** 5-1Table 5-1: Hypothetical AIC Thermal Level Measurements

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Table 5-1: Hypothetical AIC Thermal Level Measurements

	Test Run								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Approach Ambient Temperature (°C)	26	26	26	26	25	25	25	25	25
Measured CFM	49	41	32	27	23	18.5	15	12	7.5
VR Temperature (thermocouple reading: 100C max allowed) (°C)	39.3	40	41	42	44	47	56	65	76
QSFP Temperature (AIC sensor reading: 70C max allowed) (°C)	31	34	38	41	43	47	52	56	68
ASIC Temperature (AIC sensor reading: 105C max allowed) (°C)	54.5	55	56	58	60	64	78	92	105

From these measurements the average air speed in LFM (linear feet per minute) can be calculated by dividing the volumetric airflow in CFM (cubic feet per minute) by the tester's inner channel area. The tester's inner dimensions are 4.724 inches in height by 2.337 inches in width. **Table 5-2** illustrates the results of the calculated LFM.

Table 5-2: Hypothetical AIC's Calculated Approach LFM

	Test Run								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Approach Ambient Temperature (°C)	26	26	26	26	25	25	25	25	25
Measured CFM	49	41	32	27	23	18.5	15	12	7.5
Tester's inner channel height (IN)	4.724	4.724	4.724	4.724	4.724	4.724	4.724	4.724	4.724
Tester's inner channel width (IN)	2.337	2.337	2.337	2.337	2.337	2.337	2.337	2.337	2.337
Calculated LFM (CFM/tester's channel area)	**639.1**	**534.8**	**417.4**	**352.2**	**300.0**	**241.3**	**195.7**	**156.6**	**97.8**

The temperature margins at the different air speeds measured were calculated by subtracting the measured temperature for each component from its maximum allowed temperature for reliability and data integrity, sometimes referred to as the component's maximum continuous operating temperature, or MCOT. No additional temperature margin or safety factor were used in these calculations.

By adding the test run's actual measured approach ambient to the least temperature margin for the AIC's components, the result was the maximum approach ambient supportable for that air speed. Note in this example how under different air speeds different components have the least temperature margin for the AIC.

Following the above described steps, the approach temperature to plot against the calculated LFM for this example AIC was determined as illustrated in **Table 5-3**.

Table 5-3: Example AIC's Calculated Approach Air Temperature

	Test Run								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Approach Ambient Temperature (°C)	26	26	26	26	25	25	25	25	25
VR margin to 100 °C (°C)	50.7	50	49	48	46	43	34	25	14
QSFP margin to 70 °C (°C)	**39**	**36**	**32**	**29**	**27**	**23**	**18**	14	2
ASIC margin to 105 °C (°C)	50.5	50	49	47	45	41	27	**13**	**0**
Max Approach Temperature at Calculated LFM [Approach Ambient + Least Margin Component] (°C)	**65**	**62**	**58**	**55**	**52**	**48**	**43**	**38**	**25**

Plotting the resulting max approach level against the calculated LFM graphically illustrates how the AIC compares to the various Thermal Levels as illustrated in **Figure 5-11**.

Note that this AIC's plot never exceeds Thermal Level 5. Even though it is under Thermal Level 4 when above approach air temperatures of approximately 57 °C, its MaxTherm Level would be 5 (to cover the mandatory range below 50 °C. Since it could operate up through an approach air temperature of 65 °C, it would specify a MaxAmbient value of 0x41. Using a lower MaxAmbient value would not allow this AIC the advantage of using a lower Thermal Level, so it shall declare the maximum ambient it could support, up to the limit of 65 °C.

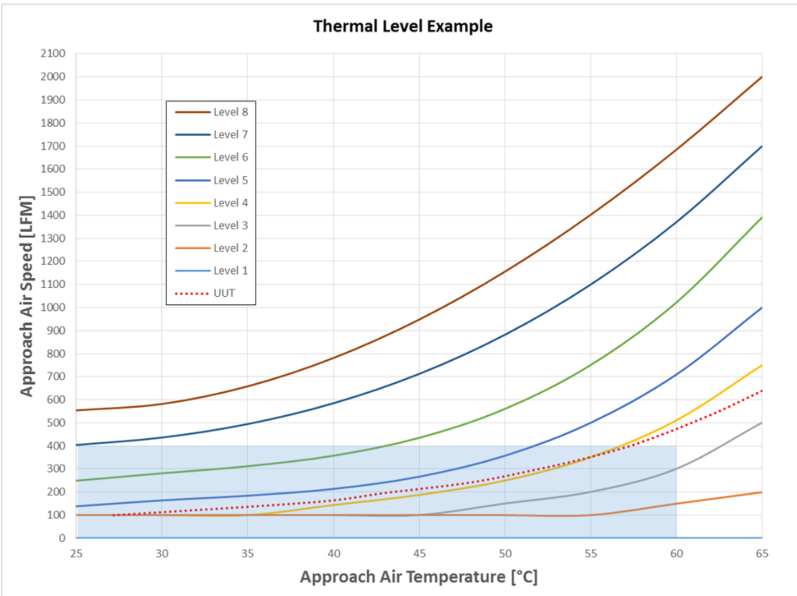

Figure 5-11: Example AIC's Thermal Level

Since this example AIC does not support lowered power levels/lowered performance when under adverse environments, its DTherm Level is the same as its MaxTherm Level.