Winning at the slots: Strategies for complying with PICMG ECN Shelf Thermal Requirements 5.4.2

By Jason Leboeuf

The PICMG ECN specification for AdvancedTCA requires shelf manufacturers to provide an abundance of airflow characterization data for board design use. Although the specification clearly states these requirements, it does not detail the methods to be used in obtaining the data. Jason provides elaboration on the pertinent sections of the standard as well as examples of test methods used to analytically and empirically fulfill the PICMG thermal requirements.

Introduction

AdvancedTCA's role as an open industry standard provides significant flexibility to both the manufacturer and consumer of the final system level product. The AdvancedTCA specification provides a versatile solution that allows for a variety of opportunities and functions for shelf and board makers. Manufacturers can then pass this same versatility on to end users, allowing them to satisfy a multitude of needs solely through the AdvancedTCA technology base.

On the other hand, when examining additional aspects of the AdvancedTCA concept, the challenges faced in obtaining this versatility quickly become evident. This rings especially true when looking at the area of thermal management. As is the case in almost all of the electronics industries, managing the ever-increasing heat load of faster and more capable components has become extremely challenging. To manage this against the criteria of a single application from a single manufacturer is an effort in itself, and becomes even more challenging against the metrics of an open industry standard created for countless applications from countless manufacturers. This is why the documentation and interpretation of section 5.4 of the PICMG ECN standard, *Shelf Thermal Requirements*, has become a critical topic.

Due to the previously emphasized wide-ranging audience for the PICMG ECN standard, section 5.4's thermal guidelines for shelf manufacturers are very broad in their requirements. This is an attempt to encompass all shapes, sizes, and most importantly airflow regimes of all the shelf level products that PICMG members may introduce into the AdvancedTCA marketplace. The goal behind this catering to all shelf manufacturers is to supply the corresponding PICMG card manufacturers with an accurate portrayal of each shelf's airflow characteristics, features which can then be used to design and test each new card product.

What follows is a section-by-section breakdown and discussion of how to comply with and obtain the necessary data to fulfill section 5.4.2, *Slot Cooling Capability.*

For purposes of this discussion, the Equipment Under Test (EUT) will be a 22.75-inch (13U) chassis with 14 vertically oriented boards. The air delivery system will be comprised of four horizontal blowers, all located above the boards and exhausting directly out the rear of the chassis. To add realism to the test matrix the blowers will have two operating speeds: nominal (50 percent) and high (100 percent). In addition to the dual fan speeds, the system will be tested with two sets of test boards; 14 boards with no impedance (0 percent blockage) and 14 boards fitted with a thin *lip* near the card's leading edge. The lip will extend the length of the card, front to rear, and the height will be 70 percent of the board pitch (70 percent blockage). Although this impedance is not a true volumetric resistance, it will deter airflow and therefore aid in the cooling of the populated slots. Figure 1 is an example of a test card, or *slot blockers,* outfitted with a number of air velocity sensors.

5.4.2.1: Slot impedance curve

The standard states that "the shelf manufacturer shall determine pressure drop versus volumetric airflow rate curve or the slot impedance curve for each empty front board slot within the shelf over the intended operating range" and shall provide one of the following:

- A single curve for the shelf that accounts for worst-case slot airflow if all slots have impedance curves at a given pressure differing from each other within ±10 percent.
- The slot impedance curve for outlying slots in addition to the (otherwise worst-case) slot airflow.
- The slot impedance curve for each slot.
- The slot impedance curve(s) may be determined by analysis, simulation, or empirical testing.

Interpretation

At first examination, the standard's request for manufacturers to obtain pressure drop seems a bit confusing, considering that the pressure inside a single slot during any system operation is not represented by an entire curve but simply by a single pressure reading. In order for the static pressure readings inside a system to compose, for example, a slot impedance curve, a volume of air that is increasing or decreasing in flow rate must be present. One instance would be an impedance curve taken on a test card utilizing an airflow test chamber where the static pressure can be monitored and the flow rate can be adjusted from zero to some upper

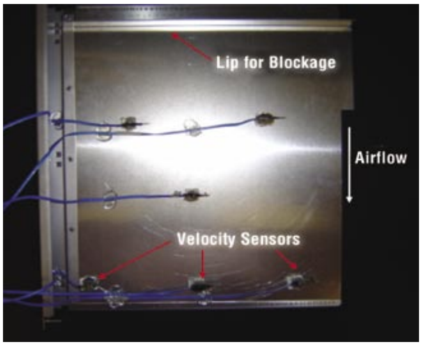

Figure 1

limit such as 100 cubic feet per minute (cfm). As the conditions just described don't exist inside a system running at a set fan speed, the best that can be provided is the location of the operating point on the test card's impedance curve, for each slot, at each fan speed. After examining multiple possible solutions, IQS devised the following test method by utilizing empirically derived data as well as a number of calculations, both of which the standard recognizes as acceptable means of determining the results.

Test method

The test data necessary for the method came from two different tests. The first was *air catch* data, which can also be defined as the total volumetric flow rate of a system. This consists of a single value measured in either cfm or cubic meters per minute (cmm), and is usually obtained by attaching the system exhaust directly to the inlet of a wind tunnel or airflow test chamber, which then measures the total output of the system. We decided to use this as the foundation of the test method because we preferred to base the necessary calculations on empirical data whenever possible. Therefore, as Table 1 shows, the air catch data for four different cases was used.

A different air catch value was necessary for each of the four scenarios because changing either the fan speed or the amount of blockage on each card can drastically affect the air movers' ability to pass air through the chassis. For each case the air catch value was broken down into an average volumetric flow rate for each slot to be used later in the calculations.

Along with the air catch data, velocity profile data was also necessary. We obtained velocity profile data by using a test card, for both blockage values, outfitted with three velocity probes on the leading edge of the card. Inserting the cards one at a time into each slot of the chassis at the different air mover speeds (low and high) captured the velocity data at each of the probe locations. Once collected, the data was formatted and an average inlet velocity for each card was then calculated by averaging the data from all three probes. For each test case the average inlet velocities for each slot were then averaged again to obtain the average inlet velocity for the chassis. Once we obtained this value we used it to calculate the amount that each card's average inlet velocity deviated from the average inlet velocity of all the slots in the chassis. Applying this deviation value to the average volumetric flow rate previously calculated enabled us to calculate each slot's flow rate. The flow rate data was then combined with the impedance curve for the test card by plotting both pieces of data on the same x/y plane. The resultant data for all 14 slots, with 70 percent blockage under a high fan speed condition is shown in Table 2. Figure 2 also shows the first four slots plotted against the slot impedance curve.

Although it is not displayed in Figure 2, this method allows all slots in the chassis to be plotted on the same graph for each test condition. Each vertical line represents a different slot and the intersection of each vertical line with the test card's impedance curve represents the static pressure measurement (operating point) of the slot, or the *slot impedance.*

This approach makes a number of assumptions by using the average flow rate and average inlet velocity. However, employing empirical data provides the validity needed for future testing by card manufacturers. One benefit to both shelf and board manufacturers utilizing this test method is that the calculations help to very quickly point out the shelf's strengths and weaknesses in regards to the possible card locations. It becomes clear where the board manufacturer should use extra caution in locating products, as well as where the shelf manufacturer can improve on the cooling scheme.

		Blower Speed	
		Low	High
Blockage	0%	X	X
	70%	X	X

Table 1

Slot	Flow Rate (cfm)
1	36.5
2	37.5
3	40.4
4	41.9
5	41.5
6	42.2
7	40.0
8	40.7
9	40.4
10	39.3
11	43.1
12	41.5
13	41.2
14	29.3

Table 2

5.4.2.2: Slot fan flow curve

The second major part of the PICMG standard requiring interpretation as an established test method is 5.4.2.2, Slot Fan Flow Curve. This section of the standard states:

"The shelf manufacturer shall determine the pressure drop versus volumetric airflow

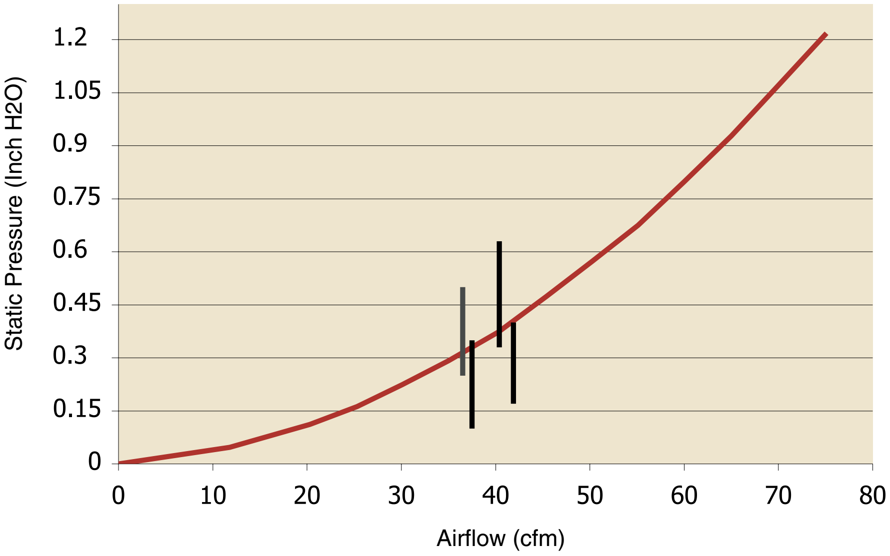

Figure 2

rate curve for the fan behavior of the slot fan flow curve for each empty front board slot within the shelf over the intended operating rage. The slot fan flow curve shall capture the various operating modes supported by the shelf if they apply, such as low-medium-high speed or fan failure."

The slot fan flow curve may be determined through analysis, simulation, or empirical testing.

Interpretation

Again the standard is requesting data that upon first look seems to be somewhat intimidating to capture. The term *slot fan flow curve* can also be defined as a fan performance curve in relation to each individual slot in the chassis. To further simplify, the standard is requesting data showing how the volumetric flow rate of each slot is affected by a blockage, typically ranging from wide open to fully impeded. This information, as in section 5.4.2.1, is not simply collected through a typical laboratory test due to it being physically impossible to take pressure and flow rate measurements for a single slot inside an operating chassis. However, this problem can be solved by obtaining a small amount of empirical data and utilizing a simple fan law. The result will be a representative curve for each slot at each of the system's fan speeds and as for a fan failure scenario, one that will account for one less fan with the remaining fans operating at high speed. The following test method provides an example of this performed on the 13U chassis previously chosen as the EUT.

Test method

The single piece of empirical data used for this portion of the system analysis is the previously mentioned *fan performance* curve. This is gathered by again utilizing an airflow test chamber, or a wind tunnel, to characterize an air mover's ability to overcome a static pressure situation. In the case of the sample EUT the exhaust of a single blower, operating at high speed, was affixed to the airflow test chamber. Static pressure was then incrementally decreased from the maximum achievable to zero. At each increment we measured the differential pressure across the internal nozzle of the test chamber and calculated the volumetric flow rate. Table 3 and Figure 3 illustrate the results:

Static Pressure (in. H2O)	Flow Rate (cfm)
3.14	0.0
2.59	55.1
2.25	75.3
1.98	93.3
1.65	114.6
1.33	131.3
1.11	143.0
0.93	150.3
0.79	157.2
0.46	173.2
0.30	178.5
0.00	184.2

Table 3

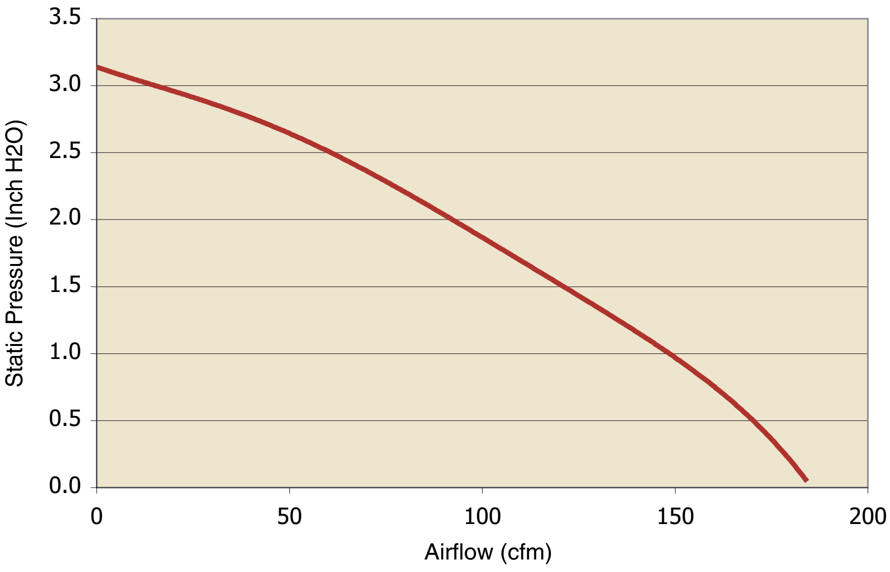

Figure 3

From this information the performance curve for the entire blower system (all four blowers working in conjunction) was derived. Since the EUT has four radial blowers working side by side, the fan law pertaining to fans in parallel operation was applicable. According to Gordon Ellison in *Thermal Computations for Electronic Equipment,* this fan law states:

> The single fan performance curve may be used to indicate the effects of using two identical fans in parallel or series (push-pull)…The parallel combination is constructed by following several horizontal constant pressure lines from zero airflow out to the fan curve. The corresponding point on the two-fan curve is at this constant pressure, but twice the airflow. If this is done for several points, a complete, two-parallel-fan curve is established.[1]

To apply this law each of the volumetric flow rate values was multiplied by a factor of four, the number of air movers in the EUT. With static pressure points for the curve all staying the same, performing this calculation yielded the adjusted system performance curve. Uniform flow through each of the EUT's 14 slots was assumed, allowing the system performance curve to be evenly divided by the number of slots to obtain the fan performance curve for a single slot, or in other words, the slot fan flow curve.

As required in the standard, this was also performed for the blowers operating at low speed and for a blower failure situation. The low speed analysis was accomplished using the airflow test chamber to capture a second blower performance curve, this time with the blower running at low speed. Again, a factor of four was used to extrapolate the flow rate data to obtain the system blower performance curve. Next, that result was then divided evenly among each of the 14 slots in the EUT. To calculate the effect of a fan failure on the system performance curve, the single blower performance curve was multiplied by a factor of three instead of four to account for the missing blower. The EUT fan controller intelligence instructs the remaining functioning blowers to elevate to high speed in the event of an air mover failure, so for this process the curve for a single blower operating at high speed was used.

Table 4 and Figure 4 show the calculations and slot fan flow curve for the EUT operating at high speed.

Again, this test method utilizes an assumption, the uniformity of the chassis' airflow distribution. However the analysis surrounding this assumption is performed on the empirically derived air catch data, making the test method acceptable for the PICMG standard. The validity of the method aside, it would be seemingly difficult to take laboratory measurements capturing the airflow performance of a single slot with varying impedance levels without an elaborate test setup. Another possibility for obtaining this type of focused data would be to default to the usage of Computational Fluid Dynamics (CFD) to measure only a cross section of the chassis. However even through CFD, empirical bulk airflow data would still be necessary as the basis of the analysis. Not to mention that the analysis and the assumptions used in the previously described test method would be exchanged for the multiple assumptions that accompany CFD studies.

Conclusion

The methodologies discussed here cover only a portion of the thermal requirements of the PICMG standard. The complement is the requirements placed on the AdvancedTCA board manufacturers. From the perspective of the board manufacturers the goal is to create boards with a successful layout that allows for proper functionality under all operating conditions. This challenge is managed, as previously stated, through layout and by utilizing other cooling solutions such as heatsinks. It is the goal of this open format standard to bridge these two technical entities to create an environment of totally interchangeable components and ultimately complete technological interoperability between chassis and shelf vendors.

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References

[1] G. Ellison, "Thermal Computations for Electronic Equipment" Van Nostrand Reinhold Company, 1984

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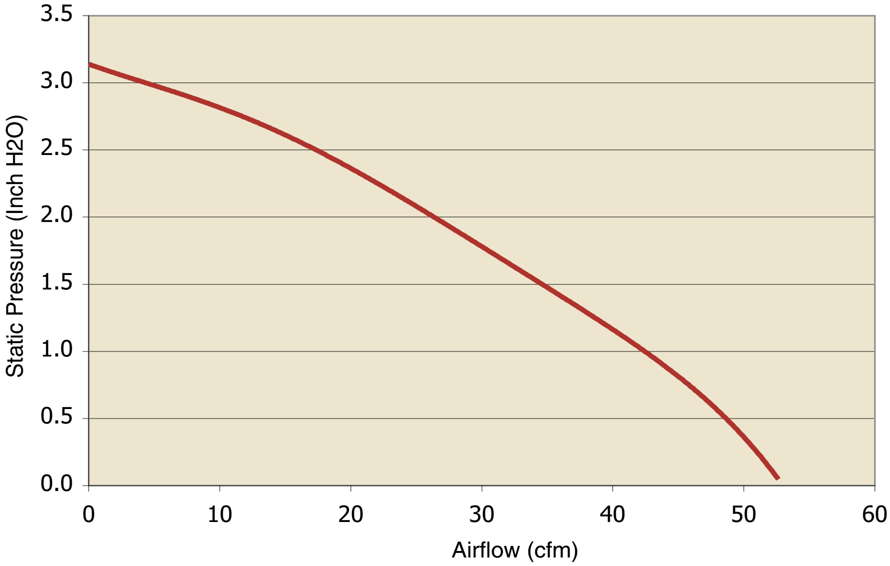

Figure 4

Single Blower Static Pressure (in. H2O)	Single Blower Flow Rate (cfm)	All Blowers Flow Rate (cfm) x 4	Per Slot Flow Rate (cfm) ÷ 14
3.14	0.0	0.0	0.0
2.59	55.1	220.2	15.7
2.25	75.3	301.3	21.5
1.98	93.3	373.4	26.7
1.65	114.6	458.2	32.7
1.33	131.3	525.1	37.5
1.11	143.0	571.8	40.8
0.93	150.3	601.4	43.0
0.79	157.2	628.7	44.9
0.46	173.2	693.0	49.5
0.30	178.5	714.1	51.0
0.00	184.2	736.9	52.6

Table 4