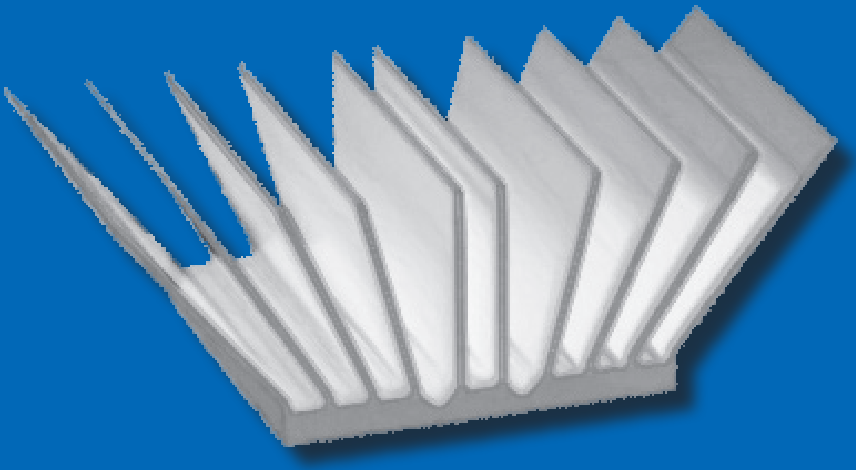

ATS WHITE PAPER

Optimizing PCB Layout for Thermal Management

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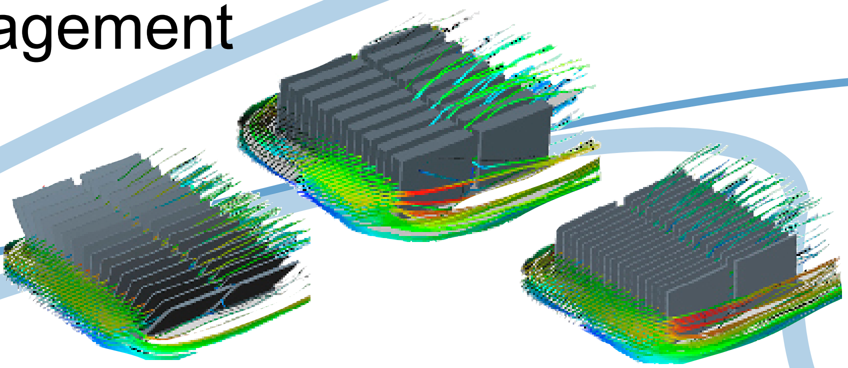
ATS ADVANCED THERMAL SOLUTIONS, INC.
Innovations in Thermal Management®

The Effect of Compact PCB Layout on Themal Management



Many Qpedia articles discuss ways to sustain effective cooling as components get smaller and their power levels rise. Yet, continuing advances in packaging and die technology are increasing the demands for thermal management.

One result is pressure on engineers to replace standard heat sinks with optimized, higher performance designs. Optimized heat sinks offer more performance with less weight, in a smaller spatial volume, than an off the shelf designs. This allows the use of higher frequency components, and ideally leads to higher performing end products. Despite these benefits, because of PCB layout and system configuration, there is no one simple method for optimizing heat sink geometry to guarantee increased performance. One such a way to optimize the heat sink is optimizing the air flow to the heat sink by relaying out the components for optimal flow, and/or optimizing the heat sink design to minimize pressure drop in a PCB.

Effect of Air Velocity in Heat Sink Design

Heat sink optimization starts with the basic equation, Newton's cooling law, for convection heat transfer.

$Q = h\,A\,\Delta T$

Q = Rate of heat transfer

h = Convection heat transfer coefficient

A = Convective heat transfer surface area

ΔT = Temperature differential

The objective, of course, is to increase Q, the rate of heat transfer from the heat sink to the environment. At the same time, the component temperature gradient, junction to case, and case to package edge, must be minimized so it doesn't exceed the manufacturer's recommended temperature. This leaves the heat transfer coefficient and the convective surface area as the two parameters that must be optimized.

Of these two factors, surface area is the most straightforward and the easiest place to begin when designing a heat sink. Unfortunately, surface area and the heat transfer coefficient are intrinsically linked and become more prevalent in electronics cooling situations as they must be optimized simultaneously. A proper optimization must balance the total surface area with a high heat transfer coefficient to provide the best possible thermal performance.

How are the two parameters linked in heat sink design? The answer is pressure drop and its effect on air velocity through the heat sink. The majority of air flow configurations in the electronics industry are not ducted. This means that the heat sink experiences bypass flow conditions, where the flow can go around the heat sink in addition to through the fin field, i.e. path of least resistance. In ducted flows only the fan performance curve is affected by the pressure drop of the heat sink. In unducted flow the heat sink's pressure drop also causes air to bypass the sink, which further reduces the effective flow rate through the fin field. In this article we assume a simplified relationship between air velocity and the average heat transfer coefficient. Advanced methods for increasing the heat transfer coefficient by modifying heat sink design geometry are subjects of future articles.

As shown in Figure 1, the lowest thermal resistance is found when the heat sink surface area and the pressure drop are correctly balanced. For example, in the 1 m/s case, a heat sink with 8 fins does not provide enough surface area for optimal cooling, while a 20 fin heat sink is very dense and has a large pressure drop across its length. Neither of these heat sinks is well suited for a 1 m/s bypass flow condition. For this case, the optimal heat sink has 14 fins, as shown in Figure 1.

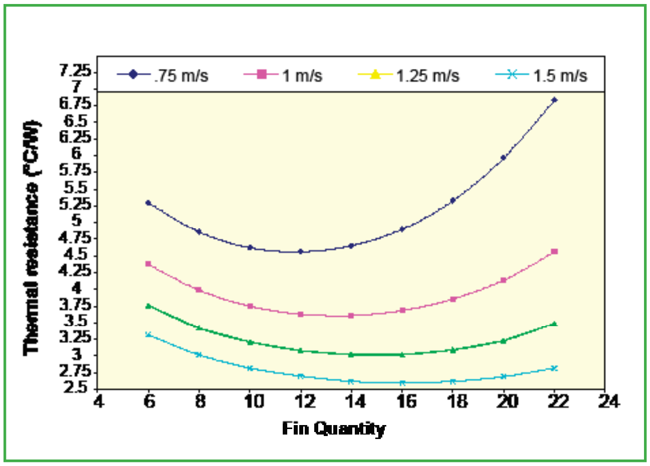


Figure 1. Optimal Fin Quantity as a Function of Velocity.

Measuring Airflow in a Telecom Chassis

An optimized heat sink was needed to cool a high powered processor in a seven slot blade server. Initial air velocity estimates were not available. The chassis manufacturer only specified volume flow rate per slot using the free flow capacity of the fan tray. For a more realistic measurement, nine ATVS Candlestick Sensors (Figure 2) were used to determine air velocity in each slot. For comparison, velocity data was taken for both a blank and a fully-populated board. In Figure 3 the nine sensors are arranged on a blank PCB. Figure 4 shows the velocity distribution recorded during the test.

Figure 2. ATVS Hot Wire Anemometer Candlestick Sensor (Advanced Thermal Solutions, Inc.)

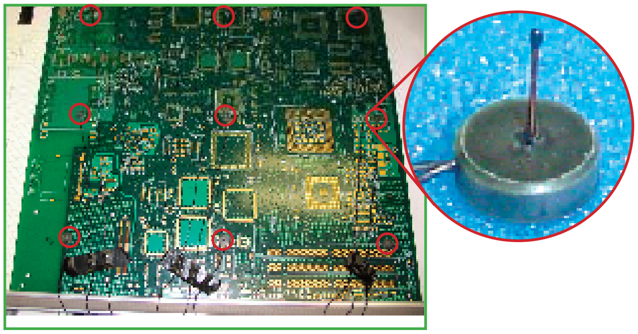


Figure 3. Blank Card with ATVS Sensors (Circled in Red).

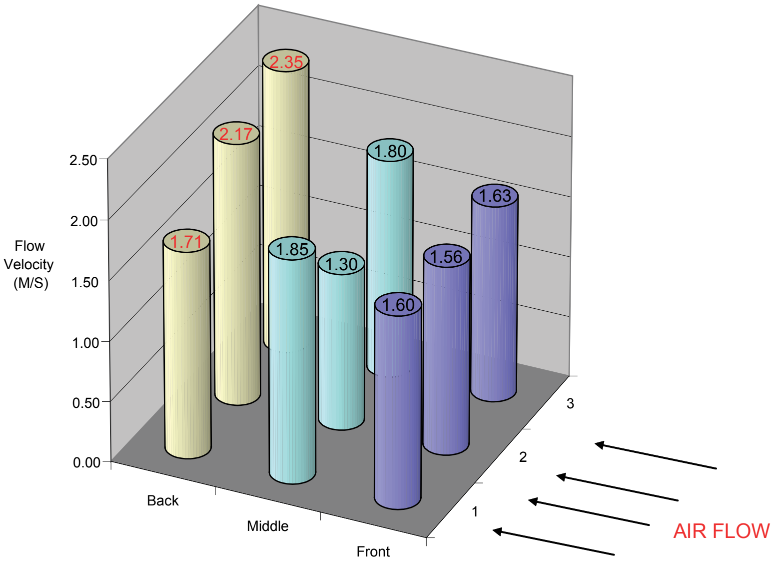


Figure 4. Velocity Distribution in a Seven Slot Chassis, Blank Card.

The flow distribution with the blank test card averaged 1.8 m/s, with a maximum flow rate of 2.4 m/s and a minimum flow of 1.3 m/s. The overall flow quantity helps to characterize the restrictions on air flow from the inlet filter and EMI screens. It also helps reveal the effectiveness of the plenum. However, these blank card tests are not an ideal evaluation, and should only be used if the final populated PCB is not available. These tests are only helpful to determine bulk air flow, as the air flow pattern will change due to component placement on the final PCB.

Figure 5 shows the effect of the populated board on air flow behavior. During this test the nine ATVS sensors were placed in similar positions on the final PCB, including temporary heat sinks. The overall average flow rate dropped slightly to 1.6 m/s due to the added pressure drop across the production card. The initial bulk air flow measurements were shown to be a fairly valid estimation, varying only 12% from the final numbers. However, the localized air flow varied greatly according to position on the PCB. The minimum air flow dropped to 0.8 m/s, while the air flow in certain regions jumped to over 3.0 m/s. This highly location-dependant flow is a result of the flow blockages and bypass regions produced by components and heat sinks on the board. While the bulk air flow did not change immensely, this test shows the great importance of localized velocity testing on populated cards in order to optimize or determine the appropriate cooling solution; whether a heat sink or other option.

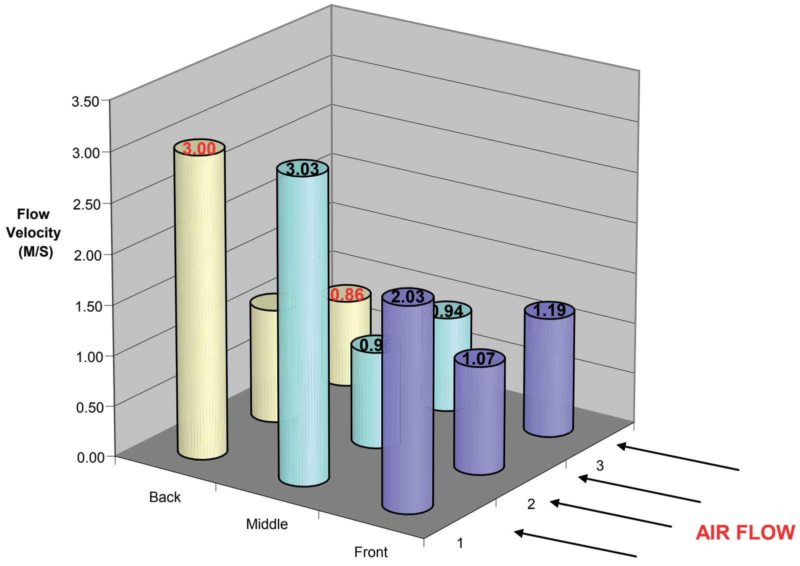
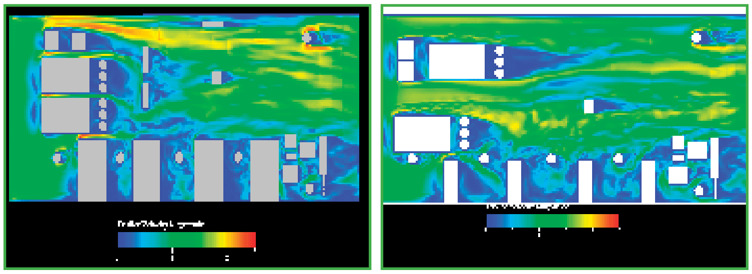


Figure 5. Velocity distribution in a seven Slot Chassis, Populated Card.

Component Placement Effect on Air Flow

As shown in the previous section, component placement can profoundly affect air flow. For instance, the air flow in section "Back-3" dropped from 2.3 m/s to just 0.87 m/s. If the actual PCB velocity test had not been run, the heat sink would be exposed to nearly a third of the projected air flow. This would lead to overheating problems and possible device failure. With a heat sink properly optimized for this flow rate the risks could be minimized, while enhancing component electrical performance and system's expected life.

If a case exists were the available air flow cannot cool a specified component, even with an optimal heat sink, the board layout itself can be changed. Using suitable Computational Fluid Dynamics (CFD) during the board design can lead to major air flow improvements in critical areas. As shown in Figure 6, the results of CFD based on DNS (Direct Numerical Simulation- the highest CFD solution technique). Careful attention must be paid to component location and orientation to ensure the best possible air flow to critical components. By relaying the PCB, compound flow expanse has changed magnificently. The impact of thermally poor board layout has major impact in system performance and expected life. As shown in Figure 6, the slight change in the component layout resulted in an increase in air flow rate a factor of three, in the areas where the original design showed near stagnation.



Original **Optimized**

Figure 6. Original and Optimized Board Layout Using CFD Tool Based on Direct Numerical Simulation.

Conclusion

In modern electronics design, the luxury of cooling a device by an oversized, inefficient heat sink is a thing of the past. There are many factors pushing the need for better engineered cooling solutions including increased board density, heat flux, shock/vibration and shrinking budgets. The most successful thermal solutions will be those designed for their operating environments. These conditions need to be precisely quantified, and in some cases enhanced, before the ideal cooling solutions can be designed. Furthermore, combination of PCB level flow measurement and board layout optimization has shown to be a highly effective technique for low cost cooling of high power devices.

Reference:

Kraus, A., and Bar-Cohen, A., Thermal Analysis and Control of Electronic Equipment, A. Kraus and A. Bar-Cohen, McGraw-Hill Co., 1983.