Heat Sink Testing Methods

and Common Oversights

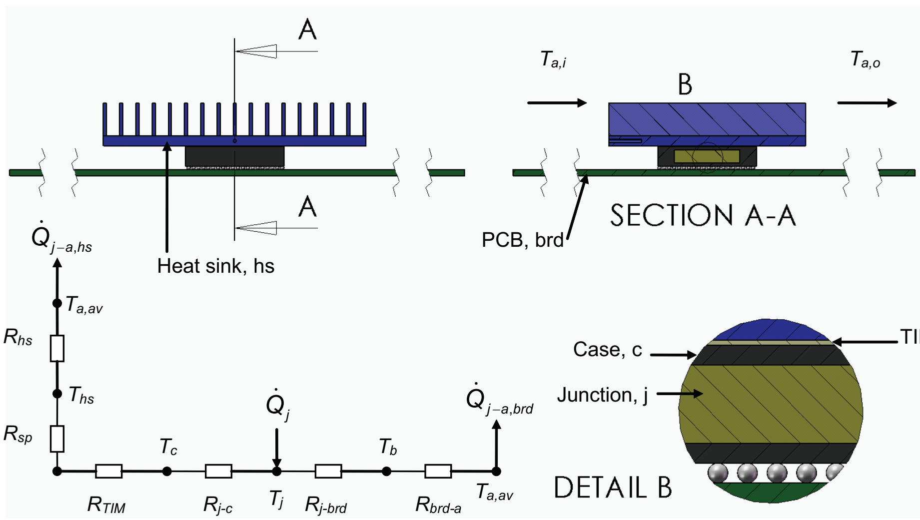

Figure 1. Heat Sink Applied to a Component, Mounted on a Board.

Introduction

The effective use of an electrical component is limited by its maximum operational junction temperature. To achieve a desired component temperature, excess heat dissipated by the device must be transferred to the environment [1]. The most common method for transferring heat from the component to the environment is to use a heat sink.

To estimate a component's junction temperature, a required value is the heat sink's thermal resistance. The thermal resistance of a heat sink can be determined analytically or experimentally. This article looks at three experimental methods of testing heat sinks.

First, it is necessary to understand the heat transfer path from the component to the local ambient, and then to understand the differences between the practical and experimental application of a heat sink.

Heat Sink Mounted On a Component: Practical Use

In a practical application, the heat transferred to the air from multiple junctions of a component follows a complex 3D heat transfer path. Simplified, the heat transferred from the junction of a component, $\dot{Q}_j$, to the air follows two heat transfer paths, as shown in Figure 1. The first heat transfer path is from the junction to the air via the heat sink $\dot{Q}_{j-a,hs}$. The second path is also from the junction to the air, but via the board $\dot{Q}_{j-a,brd}$. The portion of heat transfer via the heat sink depends on the thermal resistance of the two paths.

For BGA components without a heat sink, heat transfer to a board is typically 80% of the total heat transfer rate. When a heat sink is mounted to the BGA, the thermal resistance from the case to the air is decreased. Heat transfer to the board will decrease and more heat will be transferred to the air.

Heat Sink Set Up for Testing

A research quality wind tunnel, air temperature and velocity sensor, thermocouples and a power supply are needed to test heat sinks. A resistor is used to dissipate electrical power in the form of heat energy. The resistor is typically attached to the heat sink using thermally conductive double-sided tape. Such tape also attaches the resistor to a board, which is typically a low thermal conductivity printed circuit board or FR4.

As with a heat sink mounted on a component, the heat dissipated in the resistor is transferred to the environment by two paths. However, the thermal resistance from the resistor to the heat sink and to the board is only the interface resistance, R_{TIM}. Heat transfer to the air via the heat sink, $\dot{Q}_{r-a,hs}$ will not equal the energy dissipated in the resistor. If this value is used, there will be an error in determining the thermal resistance of the heat sink because the energy dissipated, $\dot{Q}_r$, is not the heat transfer to the environment via the heat sink.

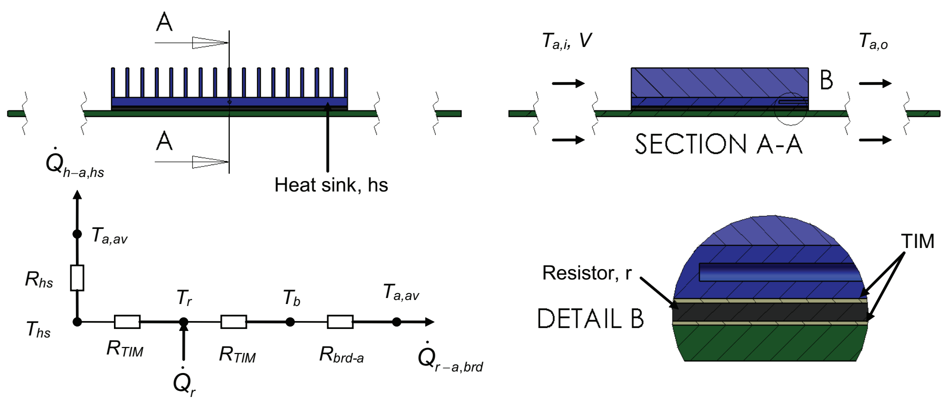

Figure 2. Heat Sink Experimental Set Up.

Thermal resistance from the board to the air increases with decreasing board thickness. Resistance decreases with increasing board thermal conductivity and increased air flow velocity across the board. Though, as previously stated, a low thermal conductivity printed circuit board is used to minimize the loss through the board.

Heat Sink Experimental Set Ups

The first method of heat sink testing is set up in an unducted environment. This is similar to the flow experienced in typical applications. The airflow through the heat sink is affected by its fin density. The higher the fin density, the more airflow bypasses the heat sink. This provides realistic data for the thermal performance of the heat sink. The test is easy to set up, but requires a higher quality testing facility. One

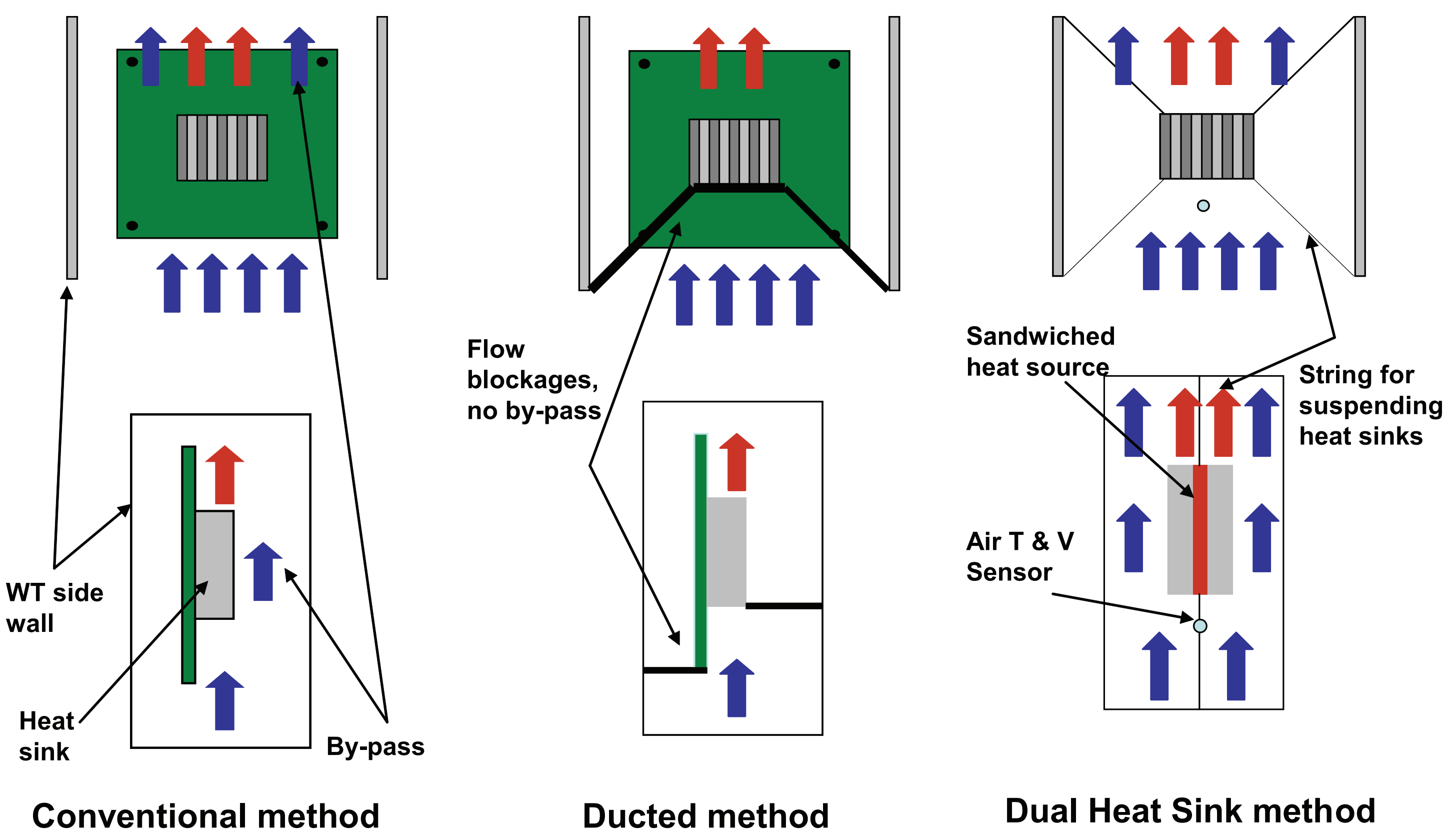

Figure 3. Heat Sink Experimental Set Ups: Unducted (a), Ducted (b) and Dual Heat Sink Testing Methods [3].

prominent issue is that the heat loss to the board must be taken into account.

The second method of heat sink testing is set up in a duct. This forces all of the airflow to go through the heat sink. There is no air flow around the heat sink or bypass airflow. It is moderately easy to set up. Vendor supplied thermal resistance data is commonly provided for ducted test results. However, the results are optimistic and can give misleading data when heat sinks are used in an unducted application.

The third method is dual heat sink testing, which uses two identical heat sinks with a heater sandwiched between them. The assembly is suspended on the centerline of a research quality wind tunnel. Dual heat sink testing is a good approach because there are no heat transfer losses to the air, e.g. via a board. But this method is rarely used in industry because it is time consuming to set up and because the approach velocity is difficult to measure without using a quality testing facility.

Example of a Heat Sink Testing Results

To show the differences in thermal resistances, as determined by each testing method, we can compare the resistances of a maxiFLOW™ and a straight fin heat sink. The maxiFLOW heat sink has a base size of 42.5 x 42.5 mm, and is 17.5 mm high. However, the straight fin heat sink has a base size of 80 x 76 mm and is 20 mm high. Due to these size differences, the thermal resistance of the smaller maxiFLOW sink will be higher than that of the straight fin heat sink. The straight fin sink is 284% bigger in volume than the maxiFLOW heat sink.

As shown in Table 1, the maxiFLOW heat sink has a thermal resistance of 1.5 K/W when ducted, and 1.9 K/W when unducted at 1 m/s,. This results in a 21% difference between the testing methods. The dense straight fin heat sink was simulated using CFD. It has a ducted thermal resistance of 0.38 K/

Table 1. Ducted and Unducted Thermal Resistance of an ATS-52425P-C2-R0 at ~1 m/s (200 LFM) (42.5 x 42.5 x 17.5 mm) [2].

Test Environment	Thermal resistance [K/W]	Difference between thermal resistances [%]
Ducted	1.5	-21%
Unducted	1.9	Datum

Table 2. Ducted, Unducted and Dual Thermal Resistance of a Straight Fin Heat Sink at 1 m/s (~200 LFM) (80 x 76 x 20 mm).

Testing Method	Base Temperature [ºC]	Thermal Resistance [K/W]	Difference Between Thermal Resistances [%]	Pressure Drop [Pa]
Ducted	23.8	0.38	-71%	40
Unducted	33.1	1.31	Datum	2.0
Dual	34.7	1.47	12%	2.4

W, and resistance of 1.31 K/W when unducted as shown in Table 2. This results in a difference of 71%. The large difference in thermal resistance between testing methods is due to the dense fins. Airflow goes around the heat sink in an unducted test, as shown by the particle tracks in Figure 5. All of the particle tracks go through the heat sink in the ducted simulation, as shown in Figure 4.

Simulated as a dual heat sink, the thermal resistance differs by 12%. This is due to the heat loss to the environment via the FR4 board.

Summary

Heat sink manufacturers often report ducted test data, but most practical applications involve an unducted heat sink. Unducted thermal resistance data can be 20% higher or more than ducted data. It is essential that the design engineer makes sure what test data to use. Failure to do so can have serious implications for the reliability of the hot components. Table 3 provides a summary of the heat sink testing methods.

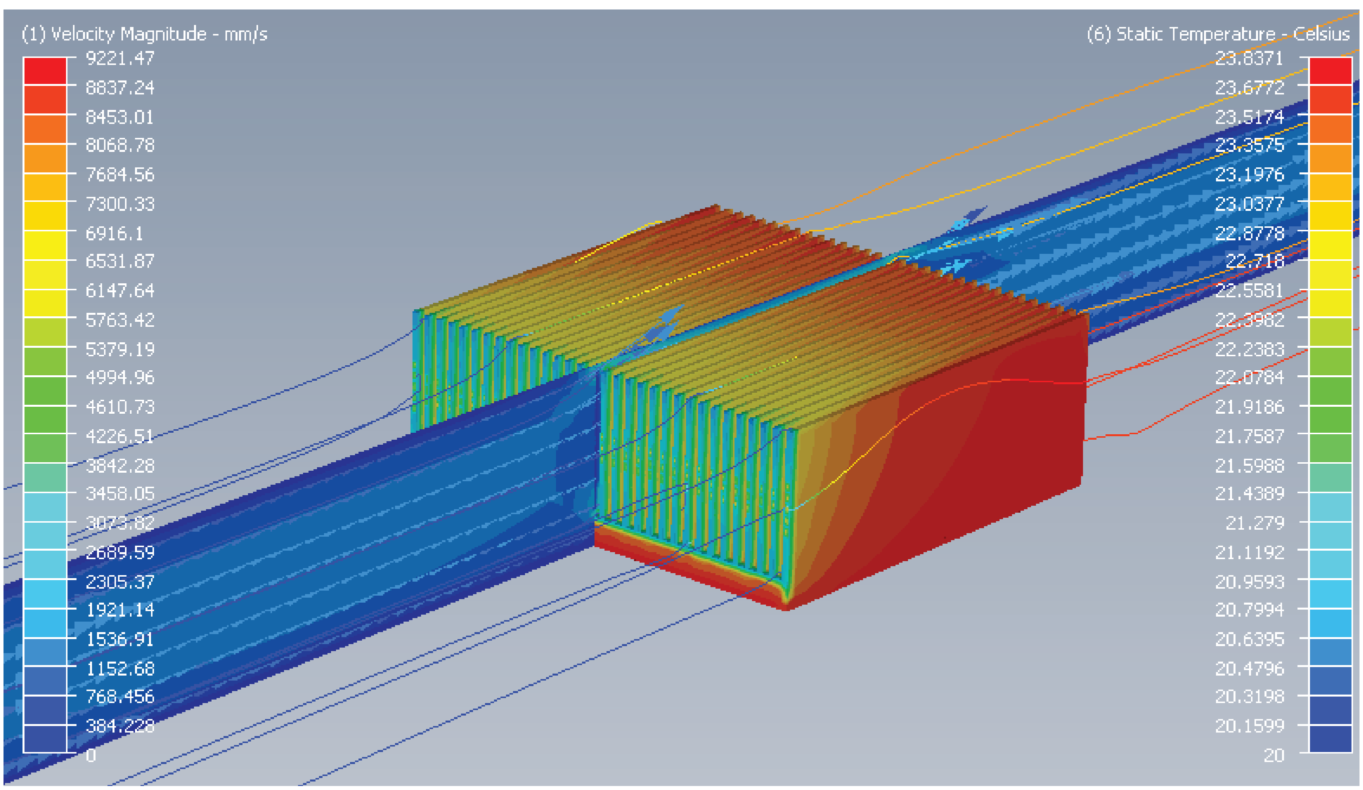

Figure 4. CFD Image of a Straight Fin Heat Sink in a Ducted Environment, Dissipating 10 W at an Inlet Air Flow Velocity of 1 m/s (~200 LFM).

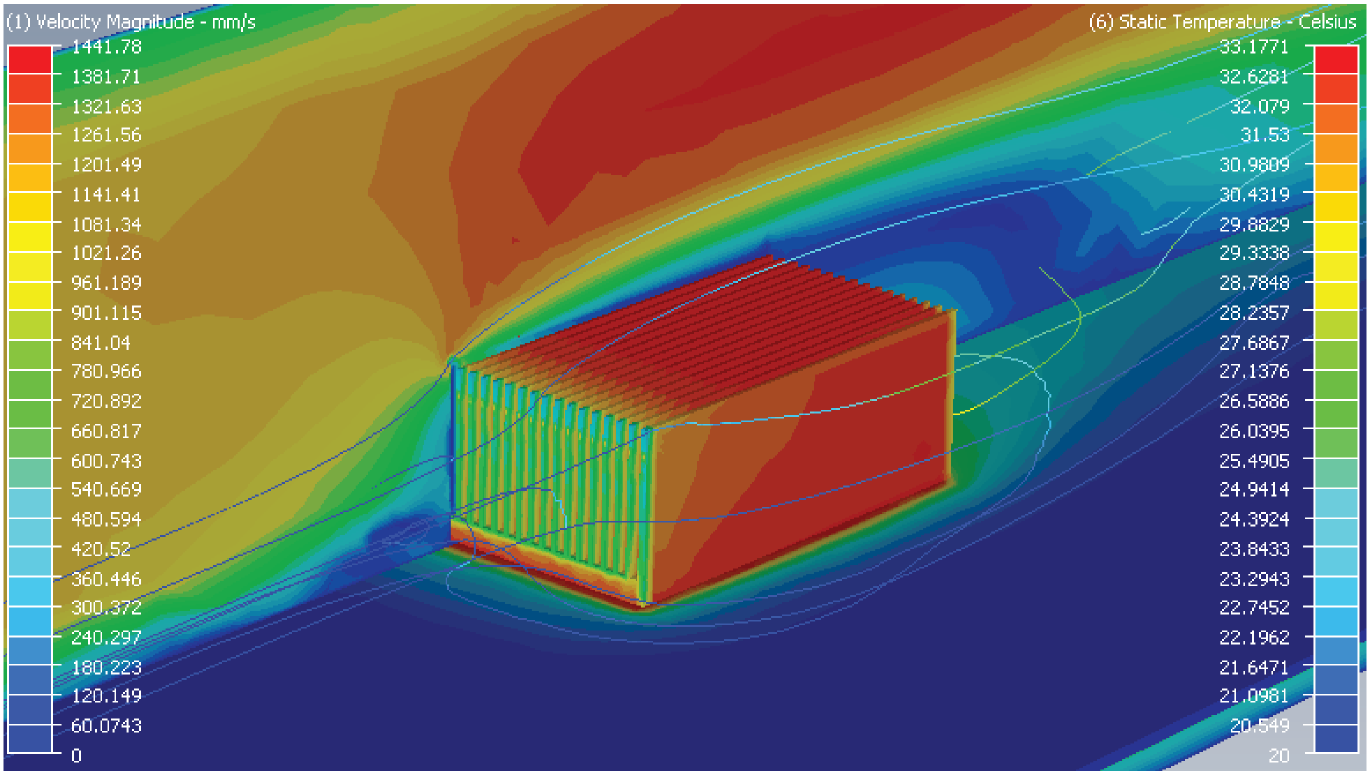

Figure 5. CFD Image of a Straight Fin Heat Sink in an Unducted Environment, Dissipating 10 W at an Inlet Air Flow Velocity of 1 m/s (~200 LFM).

Table 3. Summary of Heat Sink Testing Methods

Method	Description	Pros	Cons
Unducted	Place heat sink on a heat source on a board and suspend assembly in the middle of a wind tunnel.	A better method for thermal characterization. Relatively easy to setup. Provides realistic data that corresponds to application.	Must accurately account for the heat coming through the heat sink. Requires a quality testing facility.
Ducted	Force the entire flow through the heat sink and provide no room for bypass flow.	Most commonly practiced by heat sink vendors because it shows superior data. Moderately easy to setup.	It provides far too optimistic thermal resistance that is misleading for unducted applications.
Dual Heat Sink	Use two identical heat sinks with a heater sandwiched in between; suspend the assembly in the wind tunnel.	No heat losses due to a board. Rarely practiced in the industry.	Time consuming to set up. Requires care for measuring the approach air velocity and temperature. Requires a quality testing facility.

References

1. Sergent, J. and Krum, A., Thermal Management Handbook for Electronic Assemblies, First Edition, McGraw-Hill, 1998.
2. Advanced Thermal Solutions, Inc., Data Sheet for maxiFLOW ATS-52425P-C2-R0
3. Advanced Thermal Solutions, Inc. Heat Sink Design and Characterization, Tutorial.