

ADVANCED COOLING FOR SMALL FORM FACTOR ELECTRONICS

CONTENTS

1. Problem statement
2. Limitations of fanless cooling
3. Advanced conduction cooling for small form factor electronics
4. Performance evaluation
5. Theoretical analysis
6. Conclusion

WRITTEN BY

Dr.-Ing. Adam Pawlowski

Principal Engineer, Cooling

Michael Joist

Principal Engineer, Design

Amy Escobio

Global Product Manager, EMCA

Pentair Electronics Protection

www.pentairprotect.com

September, 2015

1. PROBLEM STATEMENT

Systems are continuing to get smaller and processors more powerful. Typically as the processing capabilities of a system increase, so does the power consumption, and as a result the amount of heat produced, and sensitive electronics require adequate cooling to ensure consistent operation.

Fanless cooling may be desired for a number of reasons including greater IP protection, the ability to shield sensitive electronics from air contaminants, reduced operating noise, and greater reliability. Unfortunately, the performance of conduction cooling has been limited. Engineers requiring fanless cooling have had two solutions, limit the performance of their boards or opt for expensive liquid cooling or heat pipe solutions.

The purpose of this whitepaper is to explain the factors that limit conduction cooling performance, introduce Schroff's innovative conduction cooling products, and finally to review the performance of the various solutions presented.

2. LIMITATIONS OF FANLESS COOLING

Fanless conduction cooling is achieved by creating a direct thermal path from the processor (figure 1.A) to external environment via a heat sink (figure 1.C), either via conductive materials such as an aluminum block (figure 1.B), heat pipe or liquid.

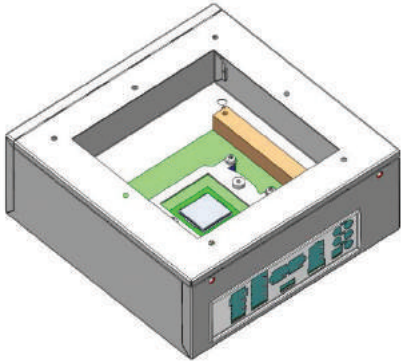


Figure 1.A

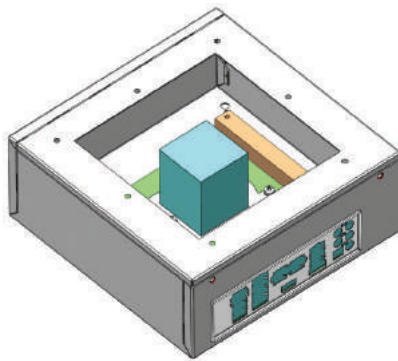


Figure 1.B

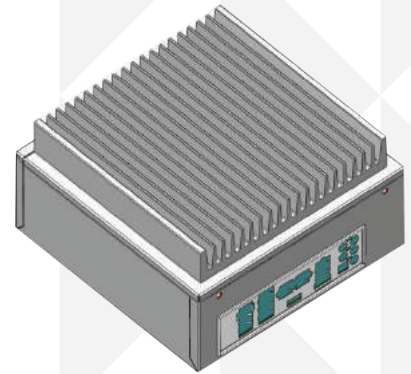


Figure 1.C

Minimizing thermal resistance is critical to maximizing thermal dissipation.

In conduction cooling applications, thermal resistance is caused by a combination of uneven surfaces, even at the microscopic level, due to surface finish, hardness or surface flatness (figure 2). Special attention must be paid to each of the component interfaces along the thermal path, and dimensional tolerances must be accounted for, to ensure proper surface contact.

Unfortunately, within a system, the processor, socket, PCB thickness, stud length and enclosure tolerances can stack up to ± 1.5 mm. These gaps can increase the thermal resistance and prevent heat from efficiently flowing from the processor to the heat sink.

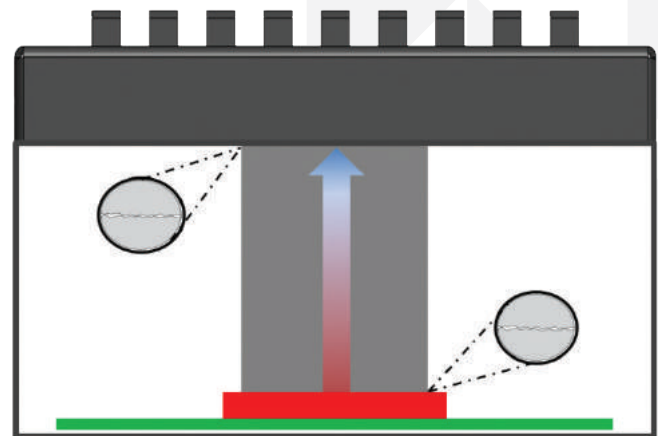


Figure 2

To compensate for these tolerances, a thermal gap pad (figure 3) must be incorporated into the thermal path, typically between the heat exchanger and the heat sink. In order to compensate for a ± 1.5 mm tolerance stack up, a thermal gap pad at least 5 mm thick would be required.



Figure 3

Use of a thermal gap pad results has two negative consequences:

- Non-optimized conduction cooling performance
While the thermal gap pad improves the surface contact throughout the thermal path by compensating for tolerances, because the gap pad is not as thermally conductive as aluminum; the thermal resistance is still not minimized.
- Risk of inconsistent cooling performance over the life of the product
Thermal gap pads often exhibit permanent deformation, as a result of the compression, even after a short period of use and should be replaced each time the case is opened. When replacing the thermal gap pad, special attention must be paid to the thickness, hardness and thermal resistance to ensure consistent conduction cooling performance. If the thermal gap pad is not replaced, or replaced with a pad that has greater thermal resistance, then consistent thermal performance cannot be guaranteed. Additionally, if the gap pad is used that is too thick or too hard there is a risk of creating too much compression force which may damage the processor.

3. ADVANCED CONDUCTION COOLING FOR SMALL FORM FACTOR ELECTRONICS

In order to meet the cooling needs of increasingly powerful processors, and overcome the challenges of current conduction cooling solutions, Pentair is pleased to introduce two new Schroff products: the Flexible Heat Conductor (FHC) and Interscale C cases. Together the Flexible Heat Conduction and Interscale C can provide industry leading conduction cooling performance and reliability over the lifetime of the system.

Flexible Heat Conductor (FHC)

Pentair has developed a Flexible Heat Conductor, which leverages the excellent conductivity of an aluminum block but features an innovative spring.

Technical specifications

Flexible heat conductors are available in two standard sizes, which we will call the "20 mm" and "70 mm" based on their respective heights. The 20 mm FHC (figure 4) is compatible with various Intel, AMD, Via, Freescale, NVidia and Texas Instruments processors that employ a BGA socket.



Figure 4



Figure 5

The 20 mm FHC is capable of expanding/contracting ± 1.5 mm, and requires a maximum force of 60N to install. Due to its small size, weight, and the lack of standardized fixing points, the 20 mm FHC does not require a mounting bracket; the 20 mm FHC can simply be installed directly onto the processor with thermally conductive adhesive tape (figure 5).

The 70 mm FHC (figure 6) is well suited for ATX/ITX/Mini ITX & COM using Intel core-i processors and AMD processors with the following sockets:

- Intel: LGA775, LGA1150, LGA1155, LGA1156, LGA1366, LGA2011
- AMD: AM2, AM2(+), AM3, AM3(+), FM1, FM2, FM2(+)

The 70 mm FHC is capable of expanding/contracting ± 2.5 mm, and requires a maximum force of 120N to install. The installation force is within the range specified for various processors, so there is no risk in the FHC causing damage when installed properly.



Figure 6

ADVANCED COOLING FOR SMALL FORM FACTOR ELECTRONICS

The 70 mm FHC is affixed using a mounting bracket and frame. Pentair currently offers Schroff brackets for ATX/ITX/Mini ITX & COM (Intel and AMD chips) systems; both Intel and AMD brackets utilize standard fixing points to not interfere with other components on the printed circuit board (figure 7.A). Enclosing the 70 mm FHC is an aluminum frame (figure 7.B). This frame allows for easy handling of the FHC during assembly, secures the FHC to the mounting bracket, and provides the internal FHC components with protection against contaminants.

Together the bracket and the frame position the FHC directly above the processor and securely fasten the FHC to the printed circuit board (figure 7.C).



Figure 7.A

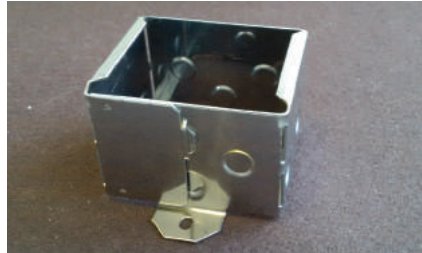


Figure 7.B



Figure 7.C

The specification for both the 20 mm and 70 mm Flexible Heat Conductors are summarized below (figure 8)

	20 mm FHC	70 mm FHC
Size (L x W x H)	22 mm x 22 mm x 19.75 mm	50 mm x 50 mm x 68.5 mm
Covered tolerance range	±1.5 mm	±2.5 mm
Processor compatibility	Intel, AMD, Via, Freescale, NVidia and Texas Instruments processors that employ a BGA socket	ATX/ITX/Mini ITX & COM using Intel core-i processors and AMD processors with the following sockets: <ul style="list-style-type: none"> Intel: LGA775, LGA1150, LGA1155, LGA1156, LGA1366, LGA2011 AMD: AM2, AM2(+), AM3, AM3(+), FM1, FM2, FM2(+)
Recommended mounting method	Thermally conductive adhesive tape	Frame and bracket
Maximum locking force of the lid, including heat sink	60N	120N

Figure 8

Key benefits

- Industry leading conduction cooling performance:
 - The integrated springs within the FHC allow the aluminum block to expand and contract vertically thereby eliminating the need for a thermal gap pad (figure 9).
 - The integrated springs also create vertical force throughout the thermal path; positive force results in better surface contact between mating surfaces and decreased thermal resistance.
 - If components, such as the processor and heat sink, are not perfectly parallel to each other, the thermal performance will be negatively affected. Due to the innovative design, the FHC can flex as necessary to ensure optimal contact between surfaces.
- Consistent performance over the lifetime of the system
 - The FHC conducts heat by purely mechanical means and therefore does not have parts, such as a thermal gap pad, that require replacement.
 - Since a thermal gap pad is not required, there is no need to recall original specifications and installation method to ensure consistent performance; this also eliminates the risk of damage to the processor by using the wrong gap pad.

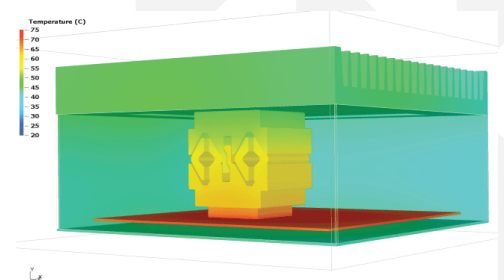


Figure 9

Both the 20 mm and 70 mm FHC's are designed to work in coordination with Pentair range of conduction cooled Schroff Interscale C cases.

Schroff

Interscale C case

Pentair has developed Schroff Interscale C, a line of conduction cooled cases specifically designed for small form factor electronics.

Technical specifications

Schroff Interscale C cases leverage the same proven design as Interscale M cases. Whereas Interscale M cases are available with perforations and optional fan kits, Interscale C cases feature integrated heat sinks and are compatible with the flexible heat conductors for conduction cooling (figure 10).

Interscale C features an interlocking tabbed construction that provides integrated EMC protection of 20 dB at 2 GHz. The three piece design, consisting of the base plate, front panel and top cover are easily secured with two screws and provide ingress protection up to IP 30.

Standard cases are available for common embedded computing modules, such as MiniITX, ATX, embeddedNUC and others. Due to the flexibility of the Interscale platform, custom case sizes to accommodate different modules, riser boards, or internal power supplies can be realized. Each case is available with a choice of heat sink fin heights; customers can choose the heat sink height that best meets their performance and cost requirements.

Key benefits

- Performance centric design
 - All Interscale cases provide EMC protection
 - Choice of heat fin heights to meet application performance / cost requirements
 - Standard cases work with FHCs for industry leading conduction cooling performance
- Ease of use
 - Innovative design requires only two screws for assembly
 - Heat sink is integrated into the case cover; provided assembled
 - Case ships with board mounting studs pre-assembled
- Flexible platform
 - Standard cases available as off-the-shelf solutions for common embedded computing boards
 - Custom sizes available to accommodate riser boards and internal power supplies
 - Options for different cut-out size and locations, powder coating and screen printing colors
 - Variety of accessories including adhesive feet, tip up feet and stacking aids
 - Aesthetic look with the option at add design elements for corporate branding or a unique look



Figure 10

4. PERFORMANCE EVALUATION

Many variables affect the amount of heat dissipated by conduction cooling, among them are:

- Size and shape of the heat sink fins
Increasing fin height of the heat exchanger, the last link in the heat transfer chain, decreases thermal resistance (figure 11).
- Environmental conditions
The ambient temperature, as well as the amount and direction of air flow around the heat sink have a large influence on the thermal behavior of the heat exchanger. Heat sink temperature is linearly dependent from the ambient temperature (figure 12).

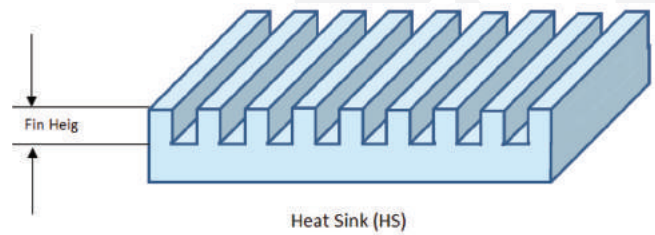


Figure 11

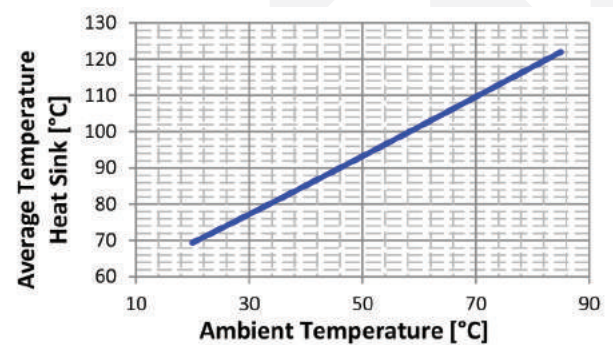


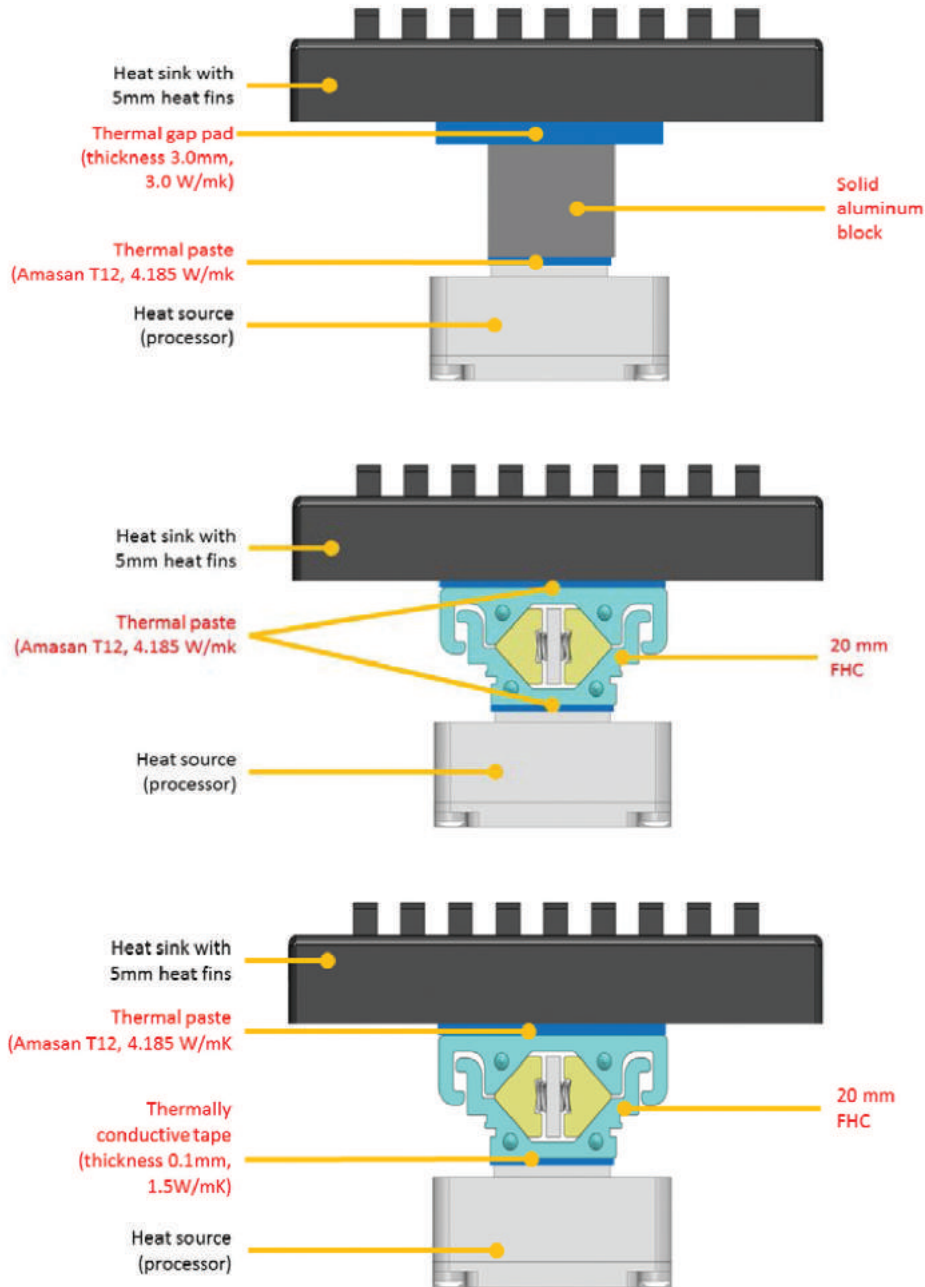
Figure 12

To evaluate the fanless cooling performance of the Flexible Heat Conductor and Interscale C versus current market solutions, the thermal engineers at Pentair have developed a specialized thermal test fixture. The test fixture includes a conductive heat exchanger (aluminum block or FHC), Interscale C chassis with integrated aluminum heat fins, heat source (an Intel i7 processor), and thermocouples for data acquisition. To accurately demonstrate comparative performance, the processor temperature and ambient temperature are held constant in all tests. Each test was repeated four times, for a duration of 1.5 hours, to ensure a steady state.

In real world applications the actual heat dissipation will be dependent on factors specific to the application, therefore the results of these tests are intended to be comparative, not absolute.

20 MM FHC PERFORMANCE

The 20 mm FHC was tested with a processor temperature of 70 °C, ambient temp of 20 °C, and within an Interscale C case with 5 mm heat fins. The test was repeated under three scenarios:



Scenario 1:

Current conduction cooling method with recommended 3 mm thermal gap pad to account for tolerance stack up

Scenario 2:

20 mm FHC theoretical performance (FHC not secured to the processor)

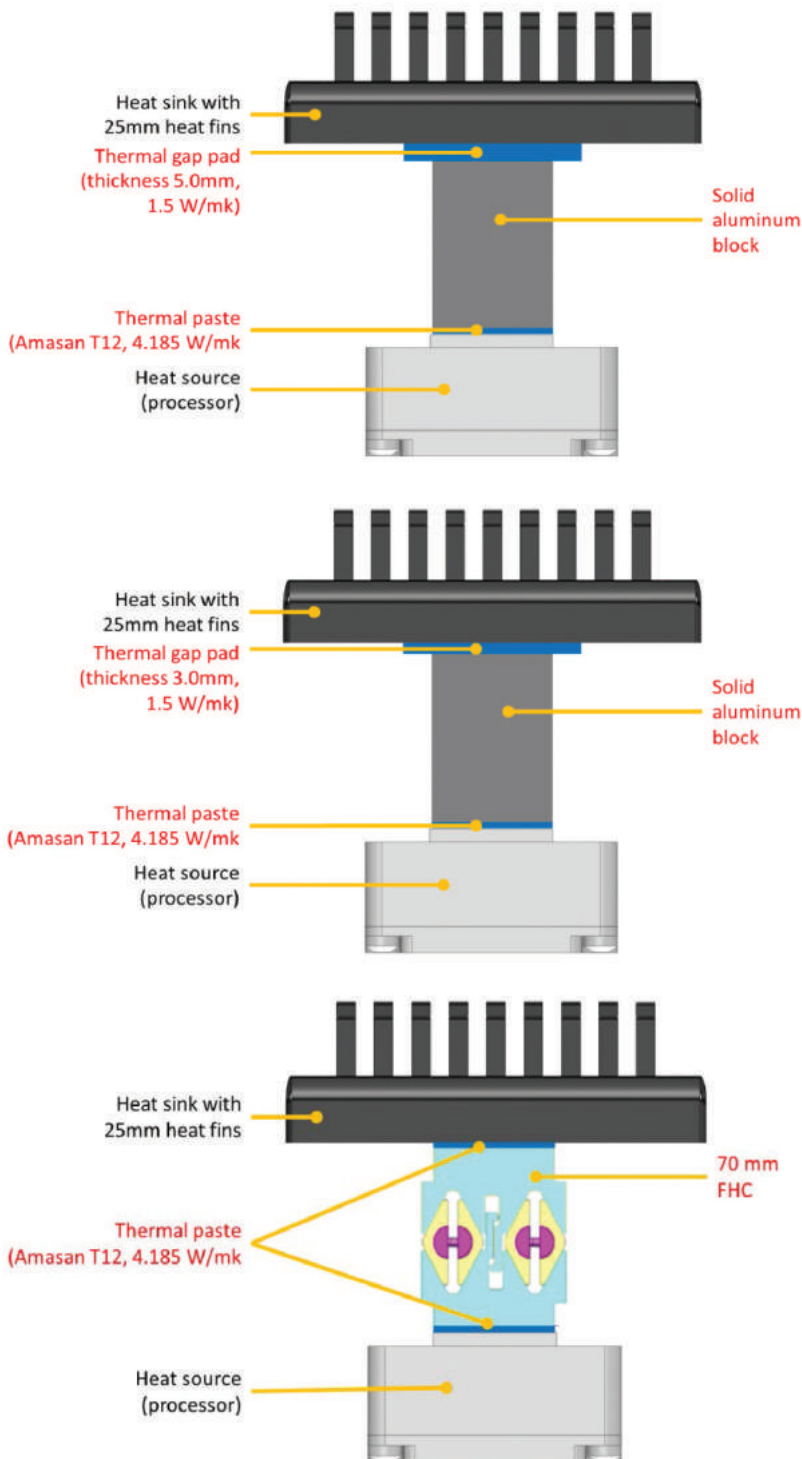
Scenario 3:

20 mm FHC recommended use (FHC secured to the processor)

Under the given conditions, the current conduction cooling method was able to dissipate 10 watts, whereas the FHC could theoretically dissipate 12 watts. Fixing the 20 mm FHC to the processor using thermally conductive tape resulted in a heat dissipation of 11 watts, a 10% improvement over the current conduction cooling method.

70 MM FHC PERFORMANCE

The 70 mm FHC was tested with a processor temperature of 75 °C, ambient temp of 20 °C, and within an Interscale C case with 25 mm heat fins. Again, the test was repeated under three scenarios:



Scenario 1:

Current conduction cooling method with recommended 5 mm thermal gap pad to account for tolerance stack up

Scenario 2:

Current conduction cooling method with 3 mm thermal gap pad to account for tolerance stack up

Scenario 3:

70 mm FHC

Under the given conditions, the current conduction cooling method with a 5 mm gap pad was able to dissipate 32 watts with a total thermal resistance of 2.45 K/W. Using a thinner gap pad, 3 mm, the current conduction cooling method was limited to 34 watts. The 70 mm FHC dissipated 55 watts with a total thermal resistance of 1.444 K/W, a 72% improvement in conduction cooling performance.

5. THEORETICAL ANALYSIS

Within conduction cooling applications, performance is dependent on how efficiently heat flows along the thermal path. Anything that impedes the flow of heat is summarized as "Thermal Resistance". To compare both the individual and the total thermal resistances to each other, the thermal resistance has been defined as the ratio of temperature difference and expended heat dissipation:

$$[1] \quad R_{th} = \frac{dT}{Q} \text{ [K/W]}$$

Heat flows in a similar behavior as the flow of electrical current; the individual thermal resistances are added in a similar manner, as the sum of the individual thermal resistances in series and in accordance with the reciprocals rule in parallel. This results in the total thermal resistance.

The knowledge of the total thermal resistance in a heat chain allows us to approximate the final temperature for a given power dissipation. Starting from the equation [2], which describes the heat transport Q by a solid and at a temperature difference of dT :

$$[2] \quad Q = \frac{\lambda}{L} * A * dT \text{ [W]}$$

in which $L \Rightarrow$ length of the solid in [m],
 $A \Rightarrow$ Cross section / bearing surface of the solid in [m²],
 $\lambda \Rightarrow$ Thermal conductivity coefficient of solid in [W/(mK)]

The thermal resistance R_{th} can be calculated according to [1] as follows:

$$[3] \quad R_{th} = \frac{L}{\lambda * A} \text{ [K/W]}$$

Thus, the heat transport is

$$[4] \quad Q = \frac{1}{R_{th}} dT$$

The R_{th} for some materials can only be determined empirically. These include the thermal resistance between two metallic bright and smooth surfaces with 0.05 K/W to 0.2 K/W depending on the contact pressure and surface roughness of these surfaces but also the thermal resistance of the thermal paste. Thermal resistance is applicable to both solids and liquids, such as water. Based on the well-known equation which describes the transfer of heat Q_{Lq} by means of a liquid medium and at a temperature difference dT :

$$[5] \quad Q_{Lq} = \rho_{H_2O} * \dot{V}_{H_2O} * C_P^{H_2O} * dT \quad \text{[W]}$$

in which $\rho_{H_2O} \Rightarrow$ Specific density of the fluid in [kg/m³],
 $C_P^{H_2O} \Rightarrow$ Specific head of the fluid in [kJ/(kgK)],
 $\dot{V}_{H_2O} \Rightarrow$ Volume flow of the liquid in [m³/s]

The thermal resistance analogous to the solid and in accordance with [1] calculated as follows:

$$[6] \quad R_{th}^{H_2O} = \frac{1}{\rho_{H_2O} * \dot{V}_{H_2O} * C_P^{H_2O}} \text{ [K/W]}$$

So also here the equation [4] remains valid.

Figure 13 demonstrates the flow of heat, and the typical series of thermal resistances, in a conduction cooled solution. In this example, the heat originates in the CPU (Pos 1). To ensure proper surface contact, thermal paste can be used between the processor and the solid block (Pos 2). The heat continues to travel through two solid aluminum blocks (Pos 3 and Pos 5), with intermediate heating pad (Pos 4), a second heating pad (Pos 6) to the aluminum heat sink (Pos 7) where it is dissipated to the outside air.

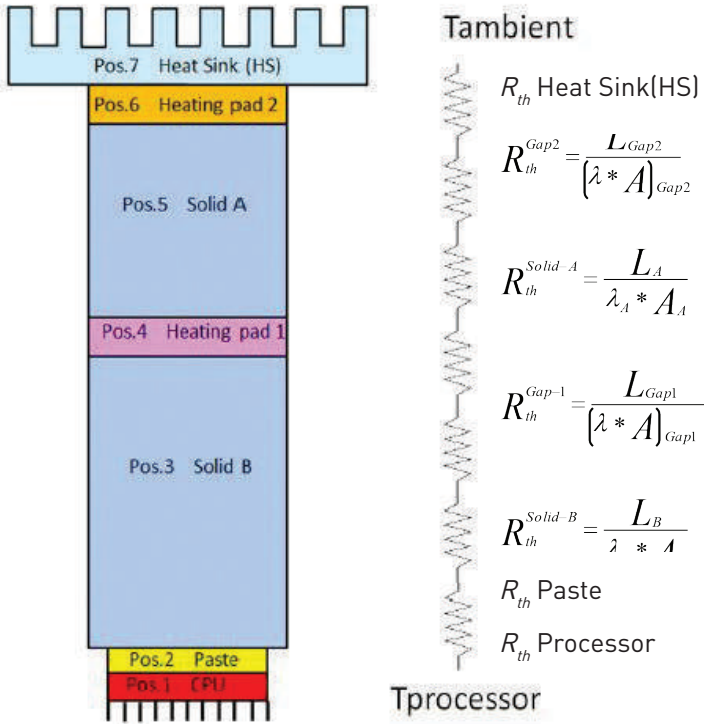


Figure 13

The whole, in the following calculations, referred to as “total” thermal resistance, is the sum of individual thermal resistances:

$$[7] \quad R_{th}^{total} = \sum_{i=1}^n R_{th}^i = R_{th}^{CPU} + R_{th}^{Paste} + R_{th}^{Solid-B} + R_{th}^{Gap-2} + R_{th}^{Solid-A} + R_{th}^{Gap-1} + R_{th}^{HS}$$

in which the individual thermal resistances can be determined empirically or calculated by:

$$[8] \quad R_{th}^{Solid} = \frac{L_{Solid}}{\lambda_{Solid} * A_{Solid}} \quad R_{th}^{Gap} = \frac{L_{Gap}}{\lambda_{Gap} * A_{Gap}}$$

They have to be specified by the manufacturer, such as for thermal paste R_{th}^{Paste} or for CPU R_{th}^{CPU}

In the case of parallel heat flows Q1 and Q2 (figure 14) applies to the entire heat flow:

$$[9] \quad Q^{total} = Q_1 + Q_2$$

The Flexible Heat Conductor within Interscale C has two thermal paths from the processor to the heat sink.

Considering the two heat paths (figure 14) from the CPU to the heat Sink, Q1 and Q2, the total thermal resistance is calculated as:

$$[10] \quad R_{th}^{Q_1+Q_2} = \frac{1}{\frac{1}{R_{th}^1} + \frac{1}{R_{th}^2}}$$

The two separate thermal resistances R_{th}^1 for Q1 and R_{th}^2 for Q2 they are calculated according to equation [7].

The total thermal resistance, including CPU and heat sink is then:

$$[11] \quad R_{th}^{total} = \sum_{i=1}^n R_{th}^i = R_{th}^{CPU} + R_{th}^{Q_1+Q_2} + R_{th}^{HS}$$

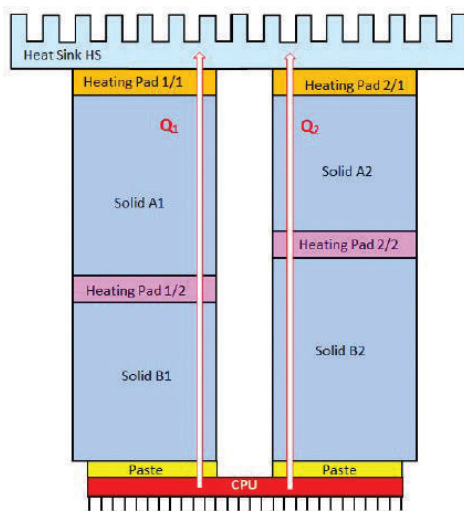


Figure 14

6. CONCLUSION

As electronics continue to get smaller and more powerful, and the trend towards decentralized solutions continues, the demand for reliable high-performance fanless cooling solutions will only increase.

With the introduction of Schroff's new conduction cooling products for small form factor electronics, the Flexible Heat Conductor and Interscale C, it is now possible realize the benefits of conduction cooling for high powered processors.

Compared to the current conduction cooling methods, the 20 mm FHC provides 10%-20% improvement in thermal dissipation, depending on the mounting method used, and the 70 mm FHC provides greater than 70% improvement in thermal dissipation. In addition to industry leading performance, Schroff's FHC technology also provides consistent thermal dissipation over the lifetime of the system.

Flexible Heat Conductors have been designed to work seamlessly with Interscale C cases to provide customers with high performance, easy to assemble, and fully customizable, conduction cooling solutions for small form factor electronics.

ADVANCED COOLING FOR SMALL FORM FACTOR ELECTRONICS

ABOUT PENTAIR TECHNICAL SOLUTIONS

Pentair Technical Solutions is a leading global supplier of systems and solutions that safeguard industrial controls, electrical components, communications hardware, electronic devices, and electrical heat management systems.

Its premier brands Hoffman, Raychem, Schroff, and Tracer provide a comprehensive range of standard, modified, and custom-engineered solutions for the energy, industrial, infrastructure, commercial, communications, medical, security, and defense industries.

The Schroff brand contains a broad portfolio of accessories for electronic assemblies – from card retainers, conduction-cooled frames, front panels, and handles to subracks, cases, backplanes, power supplies, cabinets, and pre-assembled chassis for embedded computing systems.

ABOUT PENTAIR PLC

Pentair plc (www.pentair.com) provides leading products, services, and solutions industry-wide for the many different requirements of its customers in the fields of water and other fluids, thermal management, and equipment protection. With 2014 revenues of \$7 billion, Pentair employs more than 30,000 people worldwide.

For further information visit: WWW.PENTAIRPROTECT.COM



CONTACT: Mark Sichler

PENTAIR TECHNICAL SOLUTIONS ANZ

Mb +61 439 710 527 Email mark.sichler@pentair.com

Pentair and Schroff are owned by Pentair or its global affiliates. All other trademarks are the property of their respective owners.

© 2015 Pentair.

H82038