Why MuoN SFPs feel hot, but still are the coolest product around

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Introduction

The goal of this white paper is to provide a basic understanding of thermal analysis to broadcast equipment users and to give some insights into the thermal specifications of semiconductor packages. To this end, this paper first presents the basic principles of thermal systems on a high level. Then it explains why you may believe a product is too hot when touching the case. This is a comment that has come up with MuoN SFPs in operation, as they do feel hot indeed. But, while MuoN SFPs do radiate a considerable amount of heat, they are actually running at a very low temperature.

1. Definitions

1.1 T_J : Junction Temperature

This is the temperature of the semiconductor 'silicon die' and it is often assumed that the die temperature is homogenous across the semiconductor surface. CMOS processes can usually reach a maximum junction temperature of 175°C. This maximum junction temperature is not be exceeded, otherwise the silicon die can be damaged or life expectancy can be greatly affected.

1.2 T_C and T_A: Package (or Case) Temperature and Ambient Temperature

The $\mathbf{T_C}$ (package temperature) is measured at the interface between the package and the heat sink. For an optimized engineering design, it should be the hottest spot on the package surface. Note: for SFP+/SFP28s such as the MuoN SFPs, $\mathbf{T_C}$ represents the case temperature, because SFP+/SFP28s go without any molded package (please see figure 3). $\mathbf{T_A}$ (ambient temperature) refers to the air temperature of environment where equipment is used.

1.3 PD: Power Dissipation

Power dissipation is the source of heat flux and is measured in Watts. As you can imagine, the higher the power dissipation, the higher the heat expressed in Watts. Current processing semiconductors, such as CPU, FPGA or GPU can easily dissipate more than 100 Watts of power in an area of just a few cm²!

1.4 $R_{\Theta JC}$: Junction to Case Thermal Resistance

This is one of the most important factors to ensure that the silicon die is running correctly. If the resistance between the junction and the top of the package (or the case for an SFP+/SFP28) is too high, the heat will not be dissipated correctly, the component will overheat, and performance will be affected. The other important parameter is $\mathbf{R_{\Theta JA}}$.

1.5 $R_{\Theta JA}$: Junction to Ambient Thermal Resistance

As you already know, if the $\mathbf{R_{\Theta JC}}$ of a device is too high, the heat dissipation will not be efficient. By design, we want the $\mathbf{R_{\Theta JA}}$ minimized, meaning that the resistance between the junction to the ambient is low and heat is flowing easily from the junction (silicon) to the ambient (air). Usually, the heat sink represents the biggest impact on this resistance[1]. In general, higher heat sink designs are preferable, as they can provide more air contact. In the case of the MuoN SFP, the heat sink is installed on top of the SFP+/SFP28 cage.

$$T_J = T_A + (R_{\Theta JA} \times \text{consumed power})$$

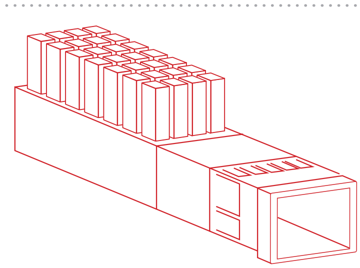

Figure 1. SFP+/SFP28 heat sink

[1] There is a significant amount of literature on heat sinks (forced air or convection), and a detailed account is not within the scope of this paper.

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2. Let's do some math: T_J with different kinds of packages

Now, let's see how these parameters respond to a silicon semiconductor in a heat spreader-equipped flip chip package – one of the best and most common packages – and in our MuoN SFPs.

2.1 The Flip Chip Package (FPGA, CPU, GPU)

The flip chip package is a package consisting of a silicon die with something called "C4 bumps" connected to a substrate. This is the first level of connection. The substrate is then connected to the mainboard (just like a modular processing card installed inside a frame) or the PCB of a 1RU 'pizza box'. This is the second level interconnect. To ensure that the die junction is as close as possible to the ambient, heat spreaders are used, or the bare silicon die is attached directly to the heat sink. When a semiconductor die draws a significant amount of power, this type of package is recommended.

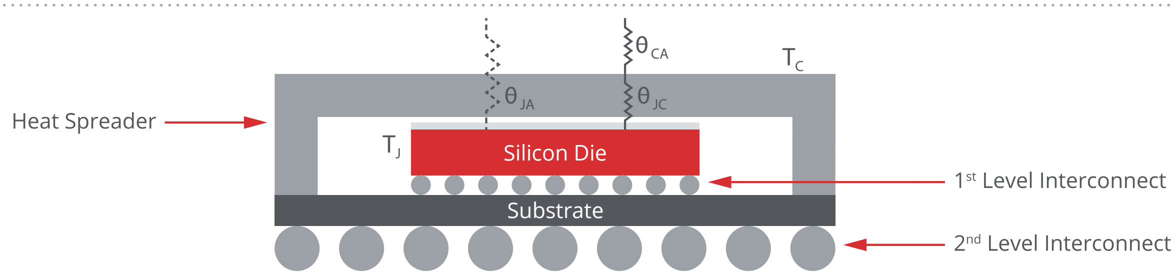

Figure 2. Flip chip package thermal specifications

As a reference, a flip chip package (FC-PBGA in literature) has a $\mathbf{R_{\Theta JA}}$ of between **12-17 °C/W**. Our reference here is a flip chip on substrate without exposed die or spreader, and without airflow. Please note that this figure can change based on the manufacturer. It represents a 23mmx23mm package, which corresponds to the MuoN package top area. The FC-PGBA with heat spreader has an impressive $\mathbf{R_{\Theta JC}}$ of **0.2 °C/W**, therefore we consider this package as one of the best.

FC-PBGA T_J without heat sink

$$T_J = 25°C + (12\ °C / W \times 8W)$$

$$\mathbf{T_J = 121°C}$$

Which is close to the maximum limit of the $\mathbf{T_J}$.

If we add heat sink[2] and air flow, then:

FC-PBGA T_J with heat sink + air flow

$$T_J = 25°C + (6.9\ °C / W \times 8W)$$

$$\mathbf{T_J = 80.2°C}$$

Which is far from the maximum limit of the $\mathbf{T_J}$.

To improve the thermal transfer, a heat spreader can be added, which results in a $\mathbf{R_{\Theta JC}}$ of 0.2 °C/W instead of 3.9°C/W. If we add heat spreader, heat sink and air flow, then:

FC-PBGA T_J with heat spreader + heat sink + air flow

$$T_J = 25°C + (3.2\ °C / W \times 8W)$$

$$\mathbf{T_J = 50.6°C}$$

Which is even further from the maximum limit of the $\mathbf{T_J}$.

[2] We used the same heat sink specs for the MuoN heat sink inside a VirtU 32.

2.2 The MuoN Package

The MuoN package is a custom SFP+/SFP28 package designed to support HD-BNC connectors. Reflecting the evolving needs of IP to IP functionalities, the new MuoN SFPs are also offered without connectors. To protect Riedel's intellectual proprerty and competitive advantages in terms of this crucial thermal management design, we will not disclose the information in this white paper, but we will provide the specifications of the package.

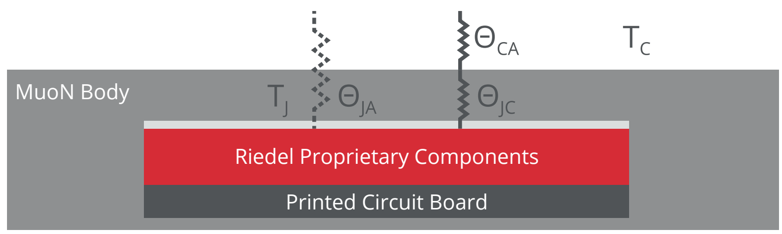

Figure 3. MuoN package thermal specifications

Let's compare the $\mathbf{R_{\Theta JC}}$ of our MuoN (0.5°C/W) with the measurement we did on the FC-PBGA with heat spreader (0.2 °C/W). Assuming a theorical 8W load for both, we get a difference of **2.4 °C**, which is almost neglectable.

The MuoN package has delta of 0.3 °C/W on $\mathbf{R_{\Theta JA}}$ compared to a FC-PBGA with a heat sink with the same area as that of an SFP28[3]. This translates to a 6 °C/W in VirtU 48-S and a 3.5 °C/W in VirtU 32. This means the dual UHD JPEG-XS to ST2110 code (8W) would create a difference of **48°C** between the junction and the ambient in a VirtU 48-S or 25GE switch and **28°C** between the junction and the ambient in a VirtU 32.

VirtU 48-S

$$T_J = 25°C + (6\ °C / W \times 8W)$$

$$\mathbf{T_J = 73°C}$$

Which is far from the maximum limit of the $\mathbf{T_J}$ and better than the FC-PBGA without heat spreader.

VirtU 32

$$T_J = 25°C + (3.5\ °C / W \times 8W)$$

$$\mathbf{T_J = 53°C}$$

Which is far from the maximum limit of the $\mathbf{T_J}$ and on par with the FC-PBGA with heat spreader.

So we can establish that the thermal performance of the MuoN package is comparable to that of an FC-PBGA package.

The difference between the junction temperature in an FC-PBGA and a MuoN running with the same load is about 2.4 °C.
Please note that **the MuoN thermal transfer and the $\mathbf{R_{\Theta JC}}$ figures contain all semiconductors** (other semiconductors, memories, or power supplies) **inside the MuoN**. It is impossible to accurately calculate the added heat generated by individual MuoN components, but we can estimate that **without other sources of heat, the MuoN die $\mathbf{R_{\Theta JC}}$ will be even closer to the die $\mathbf{R_{\Theta JC}}$ of the FC-PBGA with heat sink.**

[3] Because the average 1W SFP+ cage without heat sink is not efficient enough to manage the thermal dissipation of SFP28s, SFP28 cages feature heat sinks as shown in Figure 1.

3. CONCLUSION

Our study of different heat dissipation and package methods (FC-PGBA and MuoN) demonstrated that MuoN's thermal specifications are pretty much on par with the most advanced package on the market. MuoN's thermal design might create the impression that the device is running hot or overheating, but, as this white paper aimed to demonstrate, this is far from the truth:

With a Junction Temperature (T_J) of 53°C, the temperature of MuoN's silicon die is nearly the same as that of the best FC-PBGA on the market (50.6°C)

So why is it that measuring the temperature of the MuoN SFP head may lead to the assumption that the MuoN is running hot, when in fact, it is operating at a very low temperature? In a nutshell, the main reason is that the Riedel design team perfectly optimized the device's thermal resistance, creating an extremely low resistance between the junction and the ambient. Therefore, the heat is flowing easily from the silicon to the outer body of the MuoN.

When comparing MuoN's heat generation to that of other CMOS processors, you should keep in mind that with MuoN, you are almost holding the device's **silicon die** in your bare hand! This would be comparable to directly touching the silicon chip installed on normal modular cards.

To take a simple, real-world example, consider a powerful motorcycle and an equally powerful car. You know that both vehicles generate extreme heat within their engine blocks to create propulsion. But, while it would be no problem at all to touch the hood of the car, you would deeply regret getting too close to the actual engine of the motorcycle. But does that mean that the motorcycle engine itself is hotter? No!

And this is just the same with MuoN. Here, just like with an open motorcycle engine, the hottest part of the construction is practically exposed. While Muon's core operates at a lower temperature that comparable processors, the heat it generates is directly transported outwards, without heat spreaders or additional protective layers. So you can rest assured that your MuoNs are not overheating.

Because MuoN SFPs feel hot, but are, in fact, the coolest product around.