WHITE PAPER

Intel® Enpirion® Power Solutions

Thermal Management Considerations for EM21xx and EM22xx PowerSoCs

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Introduction

Intel® Enpirion® PowerSoCs are fully integrated step-down DC-DC power modules with available output currents ranging from 400 mA to 80 A. They include the controller, inductor, power MOSFETs, and supporting circuitry in a single surface mount package.

With the introduction of the EM2130 (30 A) and the EM2260 (60 A) device parts, power levels have increased to a point where more attention needs to be paid to thermal management. Considering that an EM2260 device with an output voltage of 0.9 V and a load of 50 A will result in heat dissipation of over 6 W due to losses, some attention needs to be paid as to how this heat is managed. These details need to be considered particularly when densely packed enclosures or elevated operating temperatures are encountered.

This white paper discusses some of these considerations and presents experimental findings of various cooling approaches that can be leveraged in real designs.

Mechanisms of Heat Transfer

Thermal energy, or 'heat' always flows from hot to cold and in many ways is analogous to voltage flowing from a higher potential to a lower potential.

There are three ways in which thermal energy can be transferred:

- Conduction
- Convection
- Radiation

Transfer by conduction requires direct contact between two surfaces; an example would be heat flowing from the semiconductor, through the lead frame and eventually to the PCB. In the case of a power transistor, conduction of thermal energy allows heat to flow from the semiconductor die to the heatsink.

Heat transfer by convection requires a fluid such as water or air in liquid or gas form to remove heat. A heatsink is able to remove heat by convection. Fins on the heatsink increase the surface area to allow for better cooling. The amount of heat transferred is proportional to the surface area.

$$\dot{Q} = hA(T_a - T_b)$$

Where $\boldsymbol{Q}$ is the heat transferred per unit time, $\boldsymbol{A}$ is the surface area of the object, $\boldsymbol{h}$ is the heat transfer coefficient, $\boldsymbol{T_a}$ is the object's surface temperature and $\boldsymbol{T_b}$ is the fluid temperature, with the fluid being either water or air in most cases.

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Energy transfer by radiation occurs as a result of the thermal motion of particles emitting electromagnetic waves across the spectrum from visible to infrared. A familiar example would be the warmth of sunlight on your skin.

In electronic systems, all three of these mechanisms are responsible for removing heat from an IC, but conduction and convection will dominate. Heat is transferred from the FETs by conduction to the internal package substrate and then to the PCB. The PCB, and in particular the copper planes help dissipate the heat. Furthermore, the increased surface area aids in convection cooling. Natural convection or forced air using fans can be used to improve the heat removal.

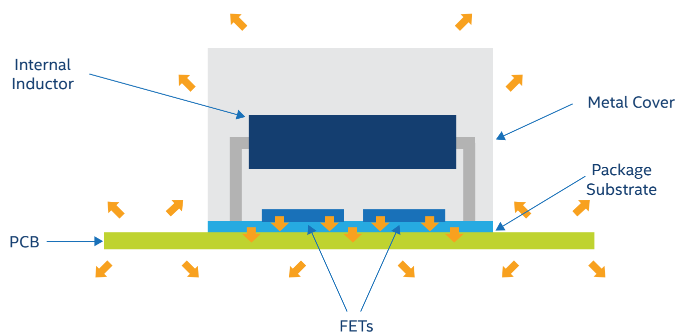

Figure 1. Thermal pathways removing heat from the Intel Enpirion PowerSoC package

As mentioned earlier, a heatsink is an effective way to increase the surface area available for convective cooling. To increase the amount of heat that can be dissipated, air can be forced across the heatsink, thus increasing the cooling efficiency. Some of the drawbacks of this approach are the increased noise caused by the fans and additional space required for the heatsink.

An approach that has seen a growth in popularity in recent years is liquid cooling. Liquid cooling gains an advantage in that liquids typically have a much higher thermal transfer coefficient than air. Commonly, water or glycol/water combinations as well as other fluids are used depending on performance requirements and operating conditions. A cold plate, through which the cooling fluid is passed is attached directly to the component to be cooled or in contact with the PCB to be cooled. With the assistance of a pump, heated fluid is transferred from the cold plate to a radiator where heat energy is dissipated and it returns at a colder temperature to the cold plate. The radiator, which has a very high surface area due to the use of fins, allows for very efficient heat removal.

Heat transfer by conduction to a liquid cooled plate is considered in this white paper. The effects of cooling the device and the PCB together, versus cooling the PCB or the device alone were investigated.

Experimental Setup

The experimental setup consisted of different cooling configurations. The configurations chosen were selected to represent some of the actual situations that designers may consider for cooling their designs, thus allowing them some insight for potential implementations.

Figure 2. Details of the Different Experiment Configurations

For this experiment, the EM2260 device “Drop-In” board was used. This board is readily available and designed to “drop-in” to an existing circuit to evaluate the EM2260 device within an existing design.

Thermal grease was used to ensure optimal heat transfer between contact surfaces. Alternatively, thermal pads or sheet can be used.

Temperature measurements were taken at 1 minute intervals for 5 minutes, providing enough measurement data to establish a good thermal profile. After 5 minutes, the rate of change of temperature decreases significantly, particularly for the active cooling experiments. This approach avoids lengthy data collection times waiting for the system to reach equilibrium while still allowing for a comparison between cooling approaches.

Results

The results of the experiment are shown in Figure 3. The graph shows the temperature of the EM2260 device, measured using the internal temperature sensor of the device, read back through the PMBUS interface.

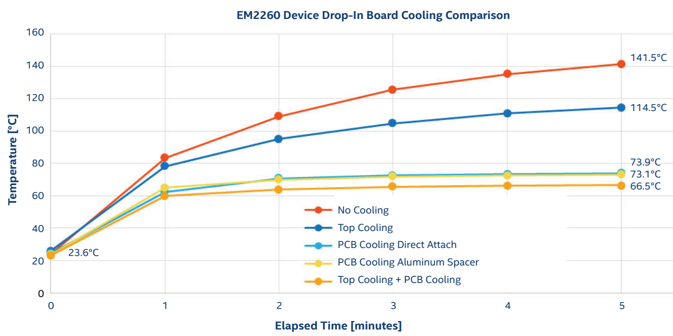

Figure 3. Experimental Results of Thermal Testing

Top Side Cooling Only

The results of the experiment are shown in Figure 3. The graph shows the temperature of the EM2260 device, measured using the internal temperature sensor of the device, read back through the PMBUS interface.

Cooling the PCB

Cooling by touching the PCB either directly or through the aluminum spacer reduced the temperature by approximately 40°C, showing that this was an effective means of removing heat from the system.

Top Side Cooling Plus PCB Cooling

Cooling from the top of the case plus the PCB proved to be most effective, reducing the overall temperature by 47.5°C. It can also be noted that the curve at 5 minutes is nearly flat, indicating that the system has nearly reached thermal equilibrium.

Recommendations

The thermal pathways of the optimal cooling configuration, using top side cooling plus PCB cooling can be seen in Figure 4. The dominant heat flow path is from the EM2260 device into the PCB, while a small amount of heat is conducted away through the top of the package.

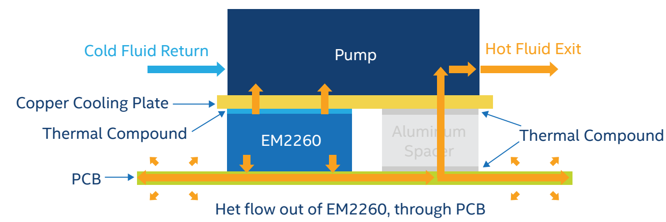

Figure 4. Themal Conduction Pathways of the PowerSoC Package

From the observed thermal pathways, the following recommendations are provided:

1. A larger PCB size and layer count increases the amount of surface area available to dissipate heat. Use a PCB size as large as practical to maximize heat dissipation.
2. Copper planes in the PCB help to move heat away from devices and provide increased surface area. Keep copper planes continuous and as large and thick as possible to assist in dissipating heat.
3. Thermal grease or compound helps with heat transfer and should be used between contact surfaces to allow maximum heat removal. Thermal insulating pads of varying thickness are also available and can be used to fill the gap of machining tolerances.
4. Contacting both the PCB and the top of the EM2260 device provides additional cooling. Where possible, the contact area between heat sources and dissipative elements should be maximized.

Conclusion

From experience with other packaged electronic components, engineers will instinctively want to use a heatsink contacting the top of the EM21xx or EM22xx package. However, the more efficient way to remove heat from the device is to remove heat directly from the PCB, in close proximity to the module. The reason for this is that the EM21xx and EM22xx devices are designed to conduct heat through the bottom of the package directly to the PCB, effectively using the entire PCB to dissipate heat. While some cooling effects were observed by touching the top of the case and the PCB simultaneously, the majority of the heat was lost though the PCB. The thermal resistance (θ_{JA}) taken from the EM2260 device datasheet is 8 °C/W, as compared to cooling from the top surface which is on the order of 50 °C/W. This results in over six times better cooling from the PCB over cooling from the top of the package alone.

The results of this experiment show that the EM2260 device effectively conducts heat to the PCB, where the large surface area of the PCB can assist in cooling the package. Furthermore, providing additional cooling using a fan or an active cooling element is an effective means of thermal management and can further reduce the operating temperature of the devices.