MLX91220 Application Note

Module Thermal Management

Contents

1. Scope

The MLX91220 (MLX91221) integrated circuit (IC) is an isolated Hall-effect current sensor that measures the current flowing through the lead frame (primary current) of its SOIC package. Due to the Joule effect, this current generates heat, leading to an increase of the temperature of the IC. This application provides guidelines regarding the thermal management for MLX91220 and MLX91221 to ensure optimal performance of the application.

2. Power dissipation

Heat is mainly generated by 2 components: the silicon chip and the primary lead frame.

2.1. Package internal dissipation mechanisms

To understand how the heat is dissipated in MLX91220/1, it is necessary to investigate the internal thermal resistances of the package, related to the main heat conduction paths. As shown in Figure 1, MLX91220/1 is composed of:

- The primary lead frame, that is the metallic conductor in which the primary current is flowing
- The silicon chip, that is in the middle of the package, isolated and close to the primary lead frame
- The primary pins, connected to the primary lead frame
- The secondary pins, for the read-out of the sensor, connected to the silicon chip
- The plastic material of the package

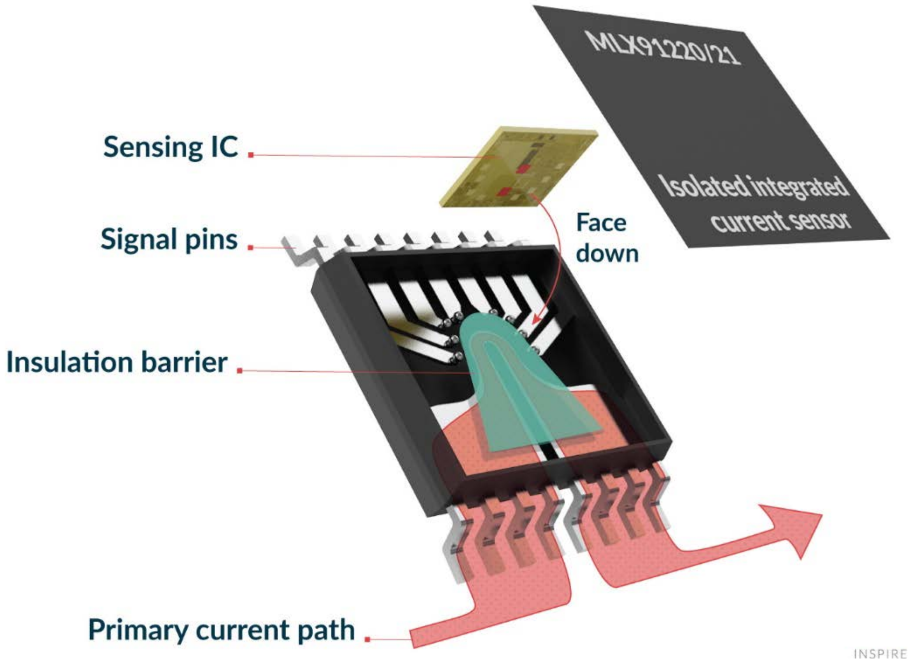


Figure 1: Composition of MLX91220/1

2.1.1. Dissipation from silicon chip

On a first order approximation, the dissipated power of the silicon chip is constant, and depends on the supply voltage and current. Typical values are the following:

- MLX91221: Vdd = 3.3V, Idd = 20mA. Dissipated power: 66mW
- MLX91220: Vdd = 5V, Idd = 20mA. Dissipated power: 100mW

These values introduce a constant junction temperature increase, independent from the primary current. Heat is dissipated from the silicon chip to the external environment through the following paths, as shown in Figure 2:

- Through primary pins
- Through secondary pins
- Through package top surface
- Through package bottom surface

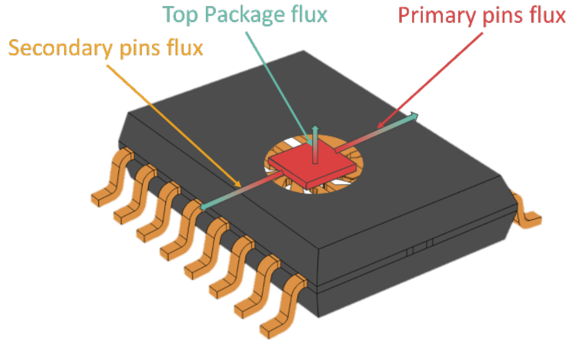


Figure 2: Dissipation paths for heat from silicon IC in SOIC16 package (for SOIC8 package, the same principle is applied). Bottom package surface is hidden.

To be able to calculate the junction temperature of the sensor (temperature of the silicon IC), it is necessary to evaluate the equivalent thermal resistance for each path and to know the environment temperature (the temperature of the environment in which the sensor is used).

2.1.1.1. Thermal resistance evaluation

Thermal resistance is calculated by using a Finite Element (FE) model, previously validated with thermal conduction measurements. Table 1 resumes the thermal resistances calculated with the FE model for the four conduction paths shown in Figure 2 from silicon IC ($R_{th_{Si}}$). Figure 3 shows the thermal resistances on a cross section of the sensor.

	SOIC16 $R_{th_{Si}}$ [K/W]	SOIC8 $R_{th_{Si}}$ [K/W]
Primary pins	110.8	80.5
Secondary pins	39.6	23.7
Package top	28.6	37.2
Package bottom	32.9	59.9

Table 1: Values of thermal resistances for silicon IC heat dissipation.

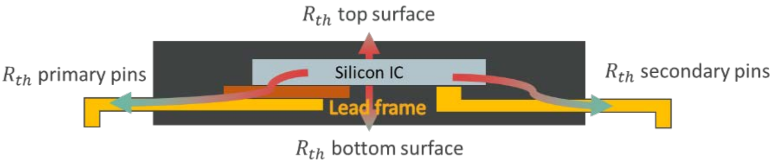


Figure 3: Thermal resistance for dissipation from silicon IC

2.1.2. Dissipation from primary lead frame

Primary current I_{prim}, flowing inside the primary lead frame of the sensor, dissipates the power P following the equation $P = R_{el} I_{prim}^2$. The typical electrical resistance of the primary lead frame is $R_{el} = R_{el_0}(1 + \alpha \Delta T)$, where ΔT is the temperature difference with the reference temperature $T_0 = 0℃$. $\alpha = 3.9 \times 10^{-3}$ is the thermal coefficient of the primary lead frame material. R_{el_0} is 0.99mΩ for SOIC8 package and 0.81mΩ for SOIC16 package.

Dissipated power increases with both the current and the primary lead frame temperature. To evaluate the internal thermal resistances for primary lead frame dissipation, an approach similar to the one used for the silicon IC can be used (see 2.1.1). In this case, we can consider the primary lead frame as uniformly heating, and therefore the dissipation will be from it to the package boundaries. Therefore, the heat conduction paths are from the primary lead frame to:

- The secondary pins
- The package top surface
- The bottom top surface

Table 2 resumes the values for thermal resistance for heat dissipation from the primary lead frame. Figure 4 shows the thermal resistances in this case, on a cross section of the sensor.

	SOIC16 $R_{th_{LF}}$ [K/W]	SOIC8 $R_{th_{LF}}$ [K/W]
Secondary pins	117.8	96.8
Package top	29.4	73.3
Package bottom	28.1	62.5

Table 2: Values of thermal resistances for primary current conduction heat dissipation.

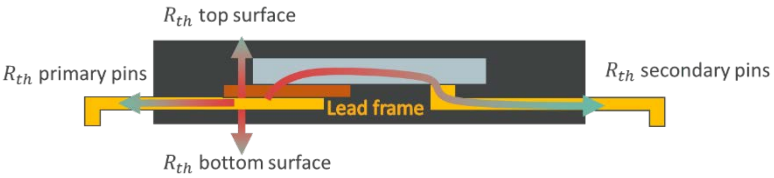


Figure 4: Thermal resistance for dissipation from primary lead frame

2.1.3. Thermal resistance between silicon IC and primary lead frame

The isolation layer between the silicon IC and primary lead frame is introducing a thermal resistance that would generate a temperature difference between the 2 components when heat is flowing through it. This section presents a simple method to estimate this temperature difference. The first step is to calculate the thermal resistance between the silicon IC and the primary lead frame by means of the FE model.

SOIC16 $R_{th_{Si-LF}}$ [K/W]	SOIC8 $R_{th_{Si-LF}}$ [K/W]
102.4	109.4

Table 3: Thermal resistance between primary lead frame and silicon IC.

Then, the heat flux from the primary lead frame to the silicon IC should be evaluated. To do this, it is possible to compute with the FE the ratio of the heat flux from the primary lead frame to the silicon IC and the total heat flux from the primary lead frame to the package top surface (see Figure 5). The heat flux will be then this ratio times the heat flux from the package top surface, that can be calculated according to the dissipation system used (for instance forced convection, or metallic thermal dissipators) and the thermal resistance between the primary lead frame and the package top surface in Table 2.

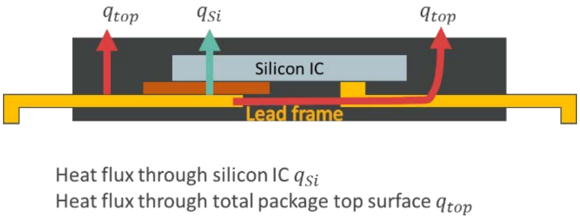


Figure 5: Heat flux from the primary lead frame to silicon and package top surface.

SOIC16 $\frac{q_{Si}}{q_{top}}$	SOIC8 $\frac{q_{Si}}{q_{top}}$
0.27	0.67

Table 4: Ratio between heat flux through silicon IC and total heat flux through package top surface.

To estimate the temperature difference during operation, Equation 1 can finally be used.

$$\Delta T = q_{top} \times \frac{q_{Si}}{q_{top}} \times R_{th_{Si-LF}} \qquad \text{Equation 1}$$

2.2. External dissipation mechanism

In applications, the sensor is soldered on PCB boards. The main dissipation path for power generated by the primary current and the silicon chip is the primary lead frame and pins, passing through the PCB current traces. To analyze the dissipation due to the primary current, it is possible to make 2 assumptions:

- In absence of forced convection or dissipators, natural convection in air has a negligible contribution.
- If cables connection with PCB are massive enough (i.e., their electrical resistance is negligible with respect to the electrical resistance of PCB and sensor), one can assume that the connections on the PCB are always at the environment temperature.

Based on these assumptions, one can calculate the junction temperature to be equal to the primary lead frame temperature (no heat is flowing inside the sensor). A simple thermal model can be built, as in the schematic in Figure 6).

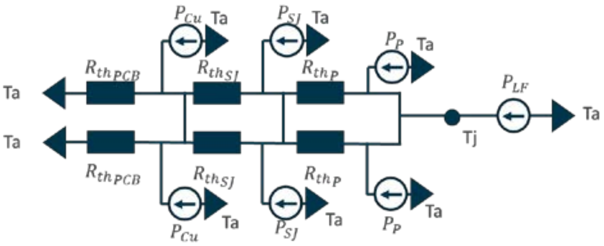
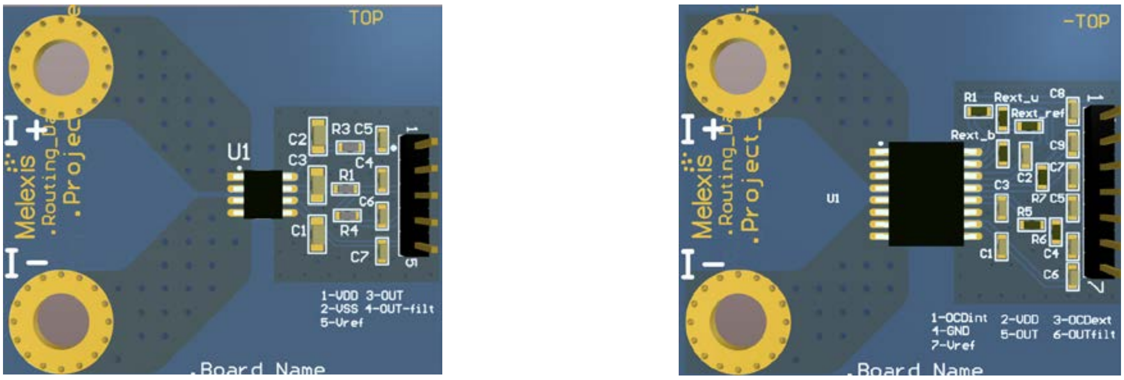


Figure 6: Schematic for a simple thermal model of dissipation in MLX91220/1

In Figure 6, $R_{th_{PCB}}$ is the thermal resistance of PCB traces, $R_{th_{SJ}}$ is the thermal resistance of soldering junctions, R_{th_P} is the thermal resistance of package pins (can be approximated with 26 K/W for SOIC8 package and 15.7 K/W for SOIC16 package), P_{LF} is the power dissipated by the primary lead frame internal at the package, P_P is the power dissipated by pins, P_{SJ} is the power dissipated by the soldering junction, P_{Cu} is the power dissipated by the PCB traces, T_a is the environment temperature.

This model has been validated through measurements, and found valid for PCBs similar to the one from the DVK (Figure 7).



(a) (b)

Figure 7: PCBs from DVK of (a) SOIC8 and (b) SOIC16

3. Measurements

This section shows a typical measurement of the junction temperature of MLX91220/1, for both SOIC8 and SOIC16 packages. Moreover, an analysis of the effect of current cables and thickness of PCB copper traces on the junction temperature is performed.

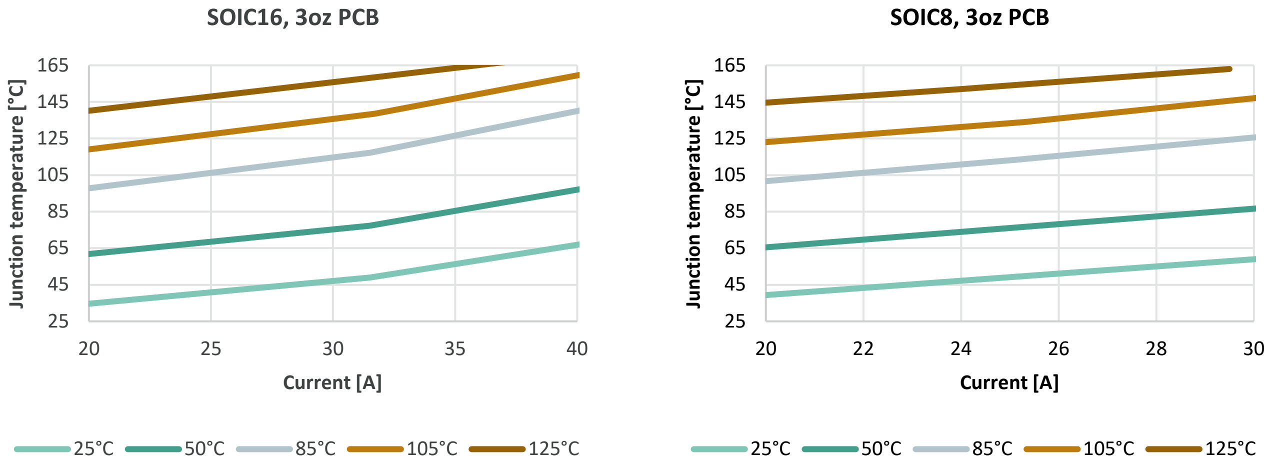
3.1. Junction temperature versus primary current

3.1.1. Setup

Environment temperature control is achieved by means of a climatic chamber. Current is applied by using cables with a diameter of 8mm. Measurements were performed on both SOIC16 and SOIC8 packages, on PCBs with 3oz copper traces.

3.1.2. Results

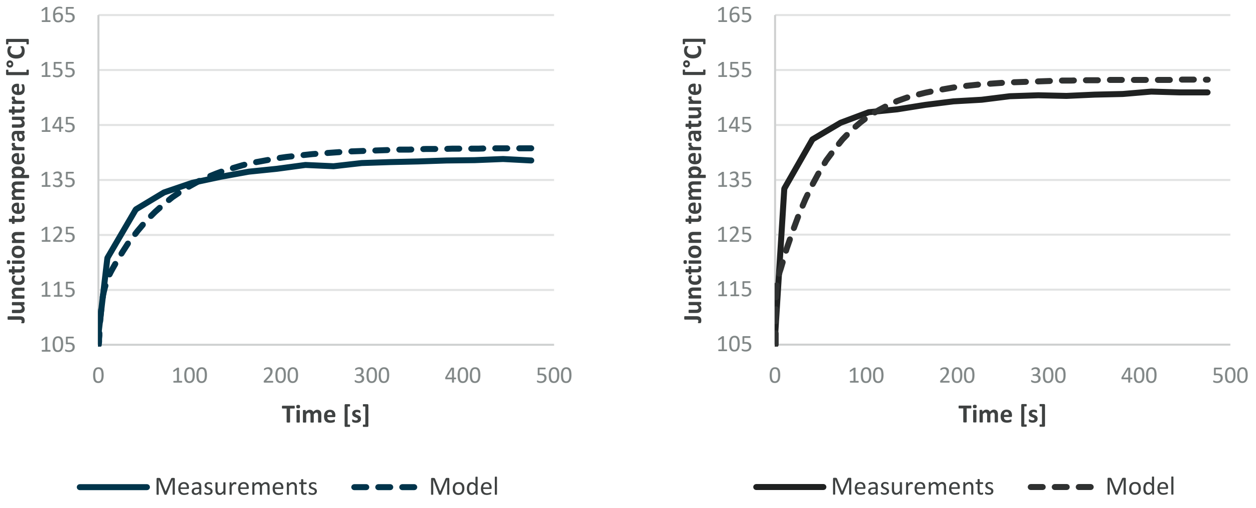
Figure 8 shows the measurement results for SOIC16 and SOIC8 packages of the junction temperature versus current at different environment temperatures.



(a) (b)

Figure 8: Junction temperature measurements on (a) SOIC16 package and (b) SOIC8 package

From these measurements, it is possible to notice that, with the same primary current, SOIC8 reaches a higher junction temperature of SOIC16 (due to higher electrical resistance and lower number of pins for heat dissipation). Figure 9 shows the junction temperature versus time for 32A at 105C for both packages. This can be fit according to the exponential fitting shown in Equation 2, where T_j is the junction temperature at equilibrium, $T_{j,t=0}$ is the initial junction temperature, $\Delta T_j = T_j - T_{j,t=0}$, t is the time and τ is the the time constant, equal to 49s for both SOIC16 and SOIC8 packages. The same time constant is explained by the fact that the PCB has a thermal mass much larger than the sensors.



(a) (b)

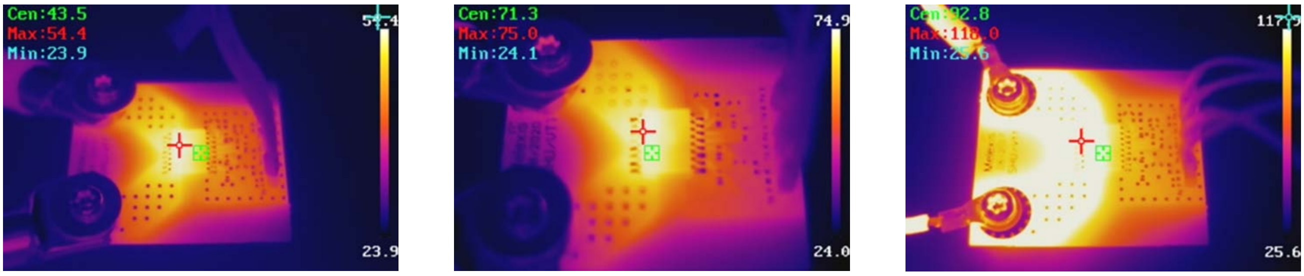
Figure 9: Time measurements and fitting of (a) SOIC16 and (b) SOIC8, for 32A at 105°C

$$T_j = T_{j,t=0} + \Delta T_j \left(1 - e^{-\frac{t}{\tau}}\right) \qquad \textit{Equation 2}$$

This is valid for a sensor soldered on the PCB from DVK, as shown in Figure 7.

3.2. Effect of cables and PCB on junction temperature

Cables and PCB traces design have a large influence on the junction temperature. This can be explained by looking at the schematic of Figure 6. Here, it is possible to observe that all the dissipation contributions are related to components external to the package. Figure 10 shows the thermal image of SOIC16 package soldered on 2 and 3oz PCBs, and with 8mm and 1.5mm cables.



(a) (b) (c)

Figure 10: Thermal images of SOIC16 sensors on (a) 3oz PCB, 8mm cables, (b) 2oz PCB, 1.5mm cable, (c) 3oz PCB, 8mm cable

By reducing the PCB traces thickness and the cables section, the junction temperature increases, due to an increase of their thermal resistance, that reduces the dissipation through conduction. A smaller cables section would have the same effect. Moreover, cables power dissipation becomes not negligible, therefore cables are also heating up the sensor, and contribute to the temperature increase. In general, the effect of thinner cables is the same as the effect of thinner or smaller copper traces.

3.3. Conclusions

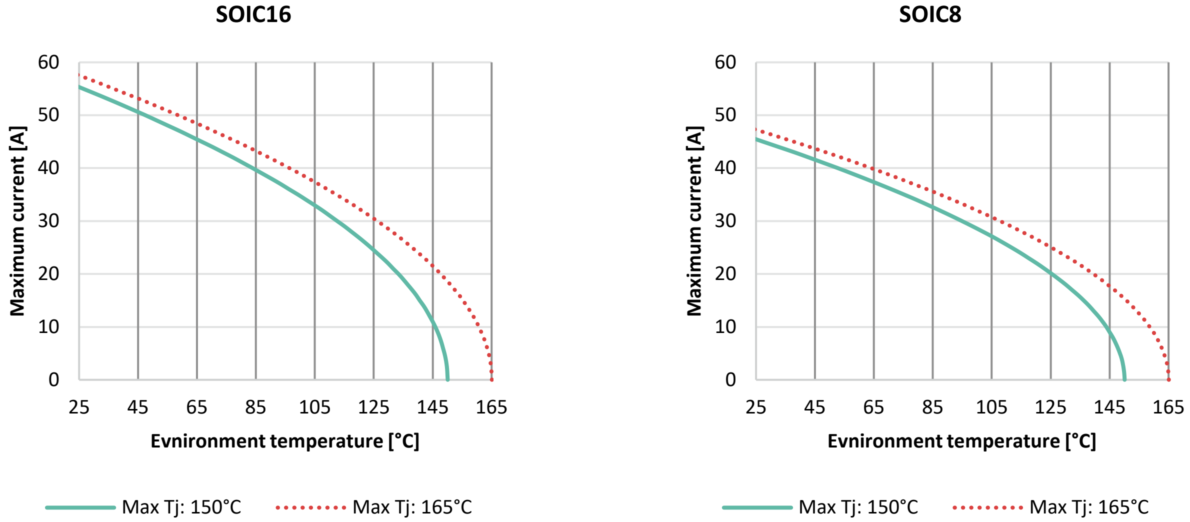
Measurements show that the most important contribution to junction temperature are the primary current connections:

- Current cables
- Current path on PCB
- Soldering connections

Guidelines are listed in section 5.

4. Current capability versus environment temperature

Using the model validated with measurements (section 2.2), it is possible to extrapolate the maximum current for each environment temperature (Figure 11). These results are obtained for DVK PCBs (Figure 7) with 3oz copper thickness, with 8mm section cables connected to the current traces. The current capability is calculated for 2 maximum junction temperatures: 150°C (the maximum temperature for datasheet performances) and 165°C (the maximum temperature to avoid permanent damage to the sensor).



(a) (b)

Figure 11: Current capability in function of environment temperature for 2 different maximum junction temperatures for (a) SOIC16 package and (b) SOIC8 package.

5. Conclusions and design recommendations

From this guide, it is possible to conclude that the most important dissipation path for heat in MLX91220/1 is the one passing through the primary pins, the PCB and the current cables or bus bars. The following recommendations can be applied to different components of a current sensing design:

- PCB traces:
  - PCB traces for primary current measurements should be similar to the ones used in the development kit. A resistance smaller than 0.18mΩ between the sensor primary pins and the cables contact with PCB would ensure to have performances similar or better than what we shown in this guide. The geometry of the PCB from DVK can be found at www.melexis.com/DVK91220. The traces thickness is 105µm, for 2 copper layers.
  - Copper layers should be connected by means of filled vias, uniformly distributed. Tracks must be aligned on top of each other.
  - 35 µm plating thickness are recommended.
- Soldering: It is important to have good thermal conduction between the package pins and the PCB pads. Results shown in this guide are obtained by using standard SMD soldering process with an Sn based solder paste.
- Cables: We performed our characterizations with 8mm diameter copper cables connected to PCBs. Similar connections will allow a similar dissipation to what presented in this guide
- Convection: Forced convection would improve the heat dissipation from the package surfaces.

- Liquid cooling on PCB: Liquid cooling on PCB close to the sensors would improve the heat dissipation through conduction.

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7. Revision history table

Revision	Date	Description/comments
1.0	June 2022	Initial release