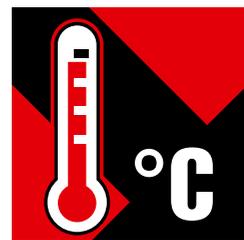


Heat management of circuit boards



This contribution describes heatsink technology as deployed by Würth Elektronik, based on the “maxon compact drive” application example. It also describes how heat dissipation can be improved through design measures.



Heat management of circuit boards

Introduction

The increasing miniaturisation and power of electronic components is not only accompanied by mounting electromagnetic compatibility (EMC) requirements, a heat management concept also needs to be developed. Reliability studies have revealed that 50 % of electronic system failures are caused by elevated temperature demands [1].

This means that critical temperatures should be avoided and components operated within their prescribed temperature range. The PCB becomes of particular importance for effective thermal management. Suitable heat dissipation measures should be considered as early as in the design and development phase, because subsequent modifications are generally more costly and involve an increased engineering effort.

This article describes the heat management option adopted by Würth Elektronik, based on the example of a motor control unit. Our technology is mainly deployed with circuit boards populated with power semiconductors or LEDs. These circuit boards are generally two-layer or multilayer, as the logic cannot be accommodated on single layer circuits.



Figure 2: Example application [1]
Circuit board with cooling element

Application example

A means of heat management through the circuit board itself, based on the example of the maxon compact drive control unit (Fig. 2) from the company maxon motor, is investigated as follows. A way was sought of integrating the control unit within the motor housing so as to arrive at a more compact construction. The control unit is usually placed outside the motor housing, as it is adversely affected by the motor temperature. This influence has to be minimised with a heat management solution, so that the motor functions reliably despite the control unit being integrated in the motor. In this case the control logic circuit board was produced as a heatsink circuit board. A heatsink circuit board is generally defined as a combination of circuit board and cooling element (Fig. 3).

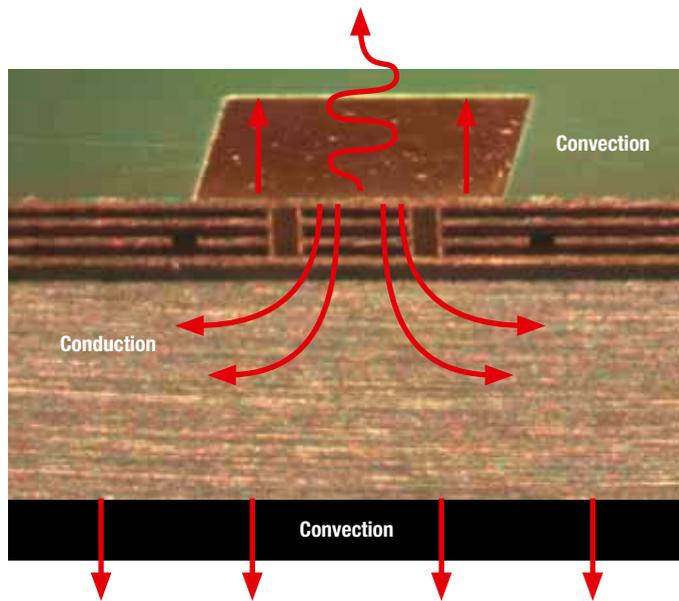


Figure 1: Three types of heat transfer

Basics

There are three ways of transferring heat (Fig. 1). The first means of heat dissipation is convection. Convection is understood as the transfer of heat through gases and liquids (e.g. air and water). The heat is removed with the medium. The second type of heat transfer is the emission of infrared photons (radiation). The circuit board manufacturer has only limited means of influencing these two types of heat transfer. The third type of heat transfer is conduction through solids. The image shown in figure 1 illustrates a 4 layer PCB glued to an aluminium heatsink.

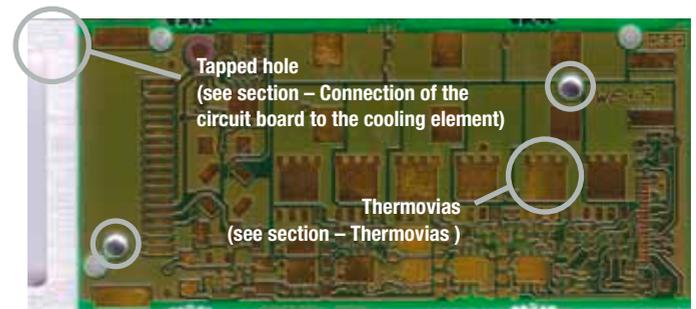


Figure 3: Heatsink circuit board

The heat management concept adopted by Würth Elektronik is a combination of vertical thermal conduction (through thermovias or a combination of microvias and buried vias) and horizontal thermal conduction (through the spread of heat in copper surfaces and/or laminated aluminium cooling element).

A thermovia is a hole located in the circuit board specifically for heat transfer. These holes should usually be located beneath the heat source to ensure direct dissipation of heat. Figure 4 shows the thermovias from the example. These thermovias are completely filled with resin and capped with copper so that they can be soldered upon without solder flowing away.

Air entrapment in the thermovias – which could have a negative effect on the soldering process – is avoided.

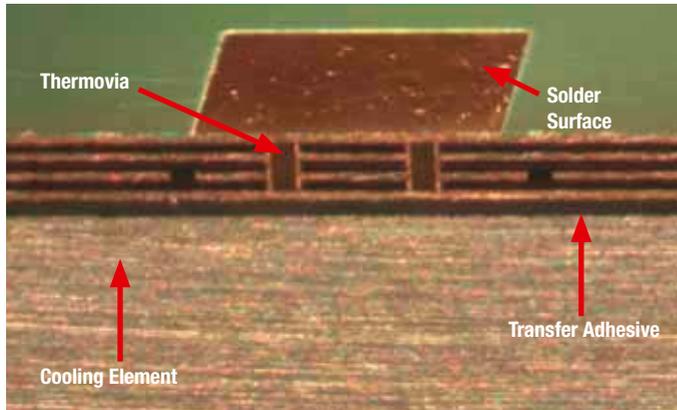


Figure 4: Section through the thermovia region

To illustrate the advantage of these thermovias, the thermal resistance of the solder surface shown in figure 4 is calculated, both with and without thermovias. In a further comparison, the thermal resistance of the thermovia region of buried vias and of laser microvias is calculated (Fig. 6 and 7). The calculation of thermal resistance is analogous to the calculation of electrical resistances connected in series and parallel (Equation 1 and 2).

Equation 1

$$R_{th} \text{ (seriesconnected)} = \sum_i R_i$$

Equation 2

$$\frac{1}{R_{th} \text{ (parallelconnected)}} = \sum_i \frac{1}{R_i}$$

Please note that this is only an estimate of the thermal resistance. The spread of heat outside of the solder area is not taken into consideration. A more precise calculation can be achieved by simulation or by generating an FEM model, however. The total thermal resistance of the control unit results as the sum of the individual thermal resistances (Fig. 5).

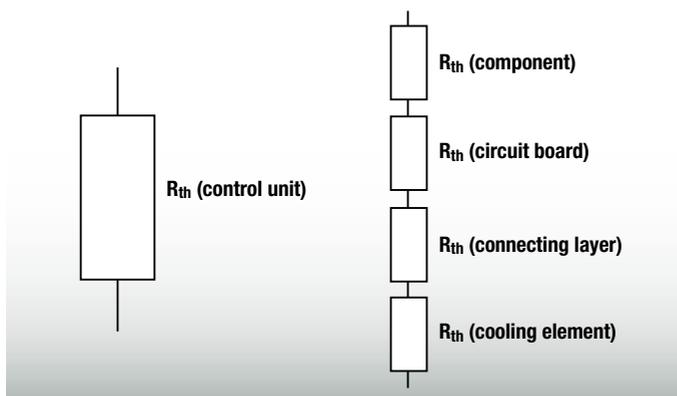


Figure 5: Total resistance of the heatsink circuit board

Without thermovias, the thermal resistance of the solder area is given by:
Equation 3

$$R_{th} \text{ (LP)} = \frac{d}{\lambda \cdot A} = 118 \frac{K}{W}$$

d (copper) = 280 μm, λ (copper) = 360 W/mK;
d (FR4) = 370 μm, λ (FR4) = 0,30 W/mK;
A (solder area) = 10.50 mm².

The thermal resistance of the solder area with 9 thermovias for the maxon compact drive is calculated as:

$$R_{th} \text{ (9 Vias)} = 7.4 \frac{K}{W}$$

End Ø (thermovia) = 0.30 mm, Thickness (copper sleeve) = 25 μm,

In comparison, the thermal resistance of the region with microvias and buried vias (Fig. 6 and 7).

$$R_{th} \text{ (40 Microvias \& 9 Buried Vias)} = 3.7 \frac{K}{W}$$

End Ø (microvia) = 0.100 mm
copper sleeve: Wall thickness = 25 μm
End Ø (buried Via) = 0.25 mm
Copper sleeve: Wall thickness = 25 μm

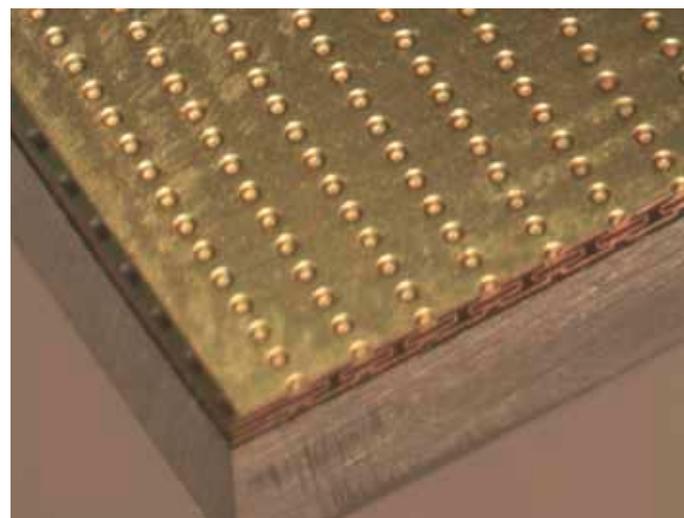


Figure 6: Microvia region

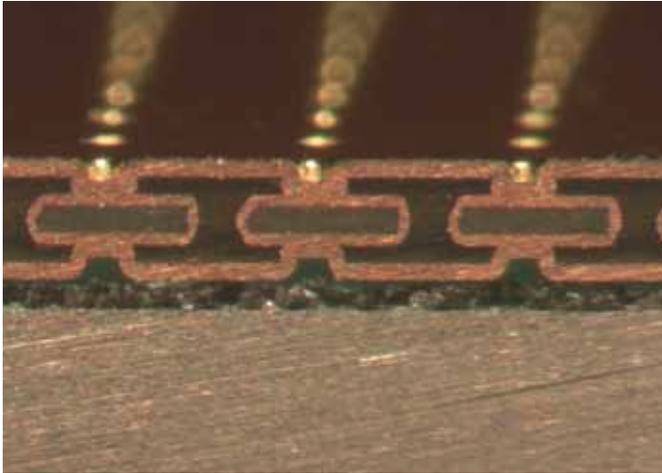


Figure 7: Section through the thermovias

This example shows that an increase in the copper cross-section considerably lowers the thermal resistance.

Table 1 summarises the thermal resistances calculated. The poorest thermal conductivity is found on the version without thermovias. The best thermal conductivity is achieved with the use of microvias and buried vias.

Thermal conductivity	Thermal resistance R_{th}
Without thermovias	118 K/W
9 thermovias	7.4 K/W
microvias and buried vias	3.7 K/W

Table 2 presents an overview of the alternative via regions and their thermal resistances.

Pitch Array 10 x 10 mm	Number of vias End Ø 0.35 mm	R_{th} in K/W	Proportion of copper	Thermal conductivity W/mK
	20	8.25	0.51 %	1.94
1.50 mm	49	3.39	1.18 %	4.15
1.10 mm	81	2.04	2.07 %	7.86
1.00 mm	100	1.65	2.55 %	9.70
0.90 mm	121	1.36	3.09 %	11.74
0.80 mm	169	0.98	4.29 %	16.57
0.60 mm	289	0.57	7.38 %	28.03
0.52 mm	400	0.41	10.21 %	38.30

To be in a position to lower the thermal resistance even further, as many vias as possible should be located near the heat source. The aim is also to minimise the circuit board thickness and maximise the surfaces involved in the transfer of heat.

Connection of the circuit board to the cooling element

Connecting the circuit board with a cooling element is a common method of cooling. In our example, this bond is achieved with transfer adhesive (Fig. 4). Table 3 shows an overview of thermal conductivity values for different materials.

Material	Thermal conductivity [W/mK]
Silver	429
Cooper	360
Aluminium	204
Iron	73
Transfer adhesive	0.20 - 0.90
FR4	0.30
Air	0.026

Aluminium has become established as a cooling element material in circuit board practice. A common method is pressing with prepreg FR4 or the use of transfer adhesive. The advantage of using an adhesive rather than a prepreg lies in the dynamics during soldering. Permanently elastic adhesive can compensate for the difference in the expansion coefficients of aluminium and the circuit board by up to 300 % of its thickness. In the application example, the cooling element was bonded with the circuit board under vacuum.

The thermal resistance of the transfer adhesive for the solder surface in the maxon compact drive example is given by

$$R_{th} \text{ transfer adhesive} = 20.1 \frac{K}{W}$$

($A = 10.50 \text{ mm}^2$; $\lambda = 0.9 \text{ W/mK}$; $d = 0.19 \text{ mm}$)

Ideally, the reverse side of the circuit board is produced with a continuous copper layer, i.e. the heat is distributed over this plane and then passes to the cooling element via the transfer adhesive.

The thermal resistance is reduced to

$$R_{th} \text{ transfer adhesive} = 0.12 \frac{K}{W}$$

($A = 1740 \text{ mm}^2$; $\lambda = 0.9 \text{ W/mK}$; $d = 0.19 \text{ mm}$)

Comparing with Equation 3; an increase in the surface area reduces the thermal resistance.

The release of heat from the cooling element to the housing takes place via the screw connections. These connections are facilitated by tapping threads in the cooling element. This produces an ideal means of heat transfer from the cooling element to the housing. This tapped hole is marked red in figure 3.

A detailed view of the tapped hole may be seen in figure 9.

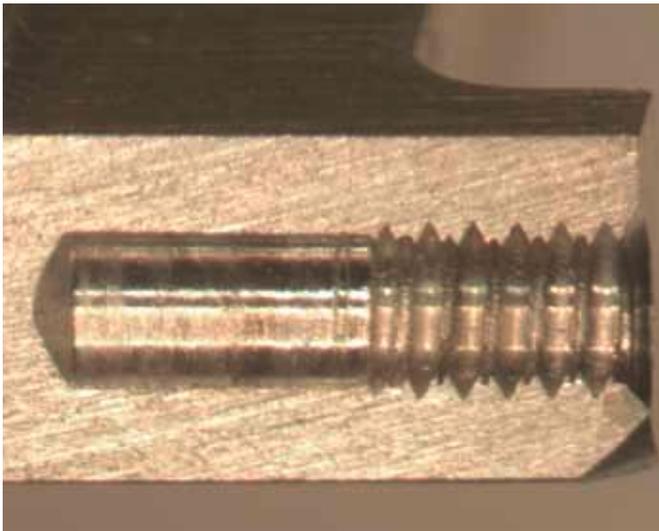


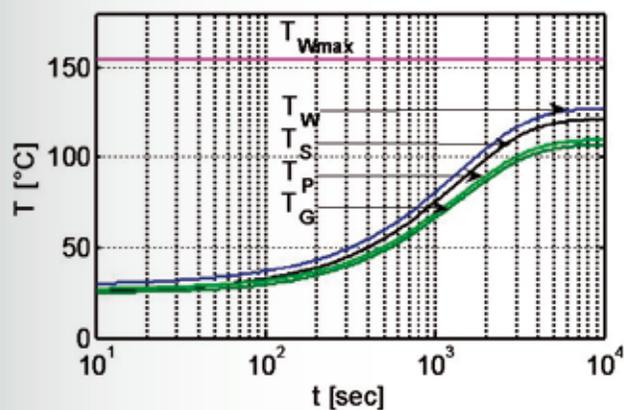
Figure 8: Tapped hole

As described, the calculations performed here are not precise, but they are still sufficient as an estimate. This theoretical estimate with the calculations is a good way of determining the dimensioning of the circuit board layout. Graph 1 confirms this assumption.

In graph 1 you can see the temperature measurement curve for the example application. The measurement is performed using thermistors (**N**egative **T**emperature **C**oefficient resistors).

The test conditions for the measurement are:

- Motor current: $I = 2.6 \text{ A}$
- Speed: $n = 5000 \text{ rpm}$
- Power loss of the motor: $P = 4.7 \text{ W}$
- Ambient temperature: $T = 25^\circ\text{C}$



Graph 1: Temperature curve for the maxon compact drive

The curves represent the temperature of the electromotor windings (TW), the stator (TS), the board (TB) and of the housing (TH). The temperature TWmax is the maximum permissible temperature of the windings. The temperature difference between the circuit board (115°C) and the housing (105°C) is approx. 10°C.

This very good result underlines the good thermal conductivity properties of heatsink technology as presented here.

Discussion

In the selection of soldering method (e.g. reflow, wave soldering) for the heatsink solution described, the limitation applies that the reverse side cannot be used for SMD population. Population of the non-aluminium side with wired components does not present a problem if the cooling element used and the transfer adhesive are omitted from around the through-contacts of the components. Perfect heat dissipation hampers the soldering process! As a result of the very good heat dissipation, temperature management in the soldering process has to be adapted accordingly. Normally this means a longer preheating time and possibly higher temperatures, which means increased stress for the component and the circuit board. The precise soldering parameters have to be verified with solder tests for each application.



Literature

[1] US Air Force Avionics Integrity Program, ieeexplore.ieee.org/iel3/62/3013/00090949.pdf

[2] Presse release of maxon compact drive. Intelligenz und hohe Leistungsdichte auf kleinstem Raum, maxon motor, 24 July 2006, www.maxonmotor.com

Author

Bert Heinz

You will find more information on our website www.we-online.com/heatsink

Würth Elektronik GmbH & Co. KG

Circuit Board Technology

Salzstr. 21 · 74676 Niedernhall · Germany

Tel. +49 (0) 7940 946-0

Fax +49 (0) 7940 946-550000

info@we-online.com