

Decreasing Thermal Contact

Resistance by Using Interface Materials

Introduction

Heat dissipation is an unavoidable by-product of every electronic device and circuit [1]. Generalized, the temperature of the device or component will depend on the thermal resistance from the component to the environment, and the heat dissipated by the component. To ensure that the component temperature does not exceed its maximum operational temperature, a thermal engineer seeks to find an efficient heat transfer path from the device to the environment. This heat transfer path maybe from the component to a printed circuit board (PCB), to heat sink, to air flow provided by a fan, and eventually to the environment. For heat transfer between two objects in contact with each other, i.e. conduction, a temperature drop across the interface between these objects will occur. For such composite systems, the temperature drop across the interface between materials may be appreciable [2]. This temperature change may be attributed to what is known as the thermal contact resistance [2].

Thermal contact resistance occurs due to the voids created by surface roughness effects, defects and misalignment of the interface. The voids present in the interface are filled with air. Heat transfer is therefore due to conduction across the actual contact

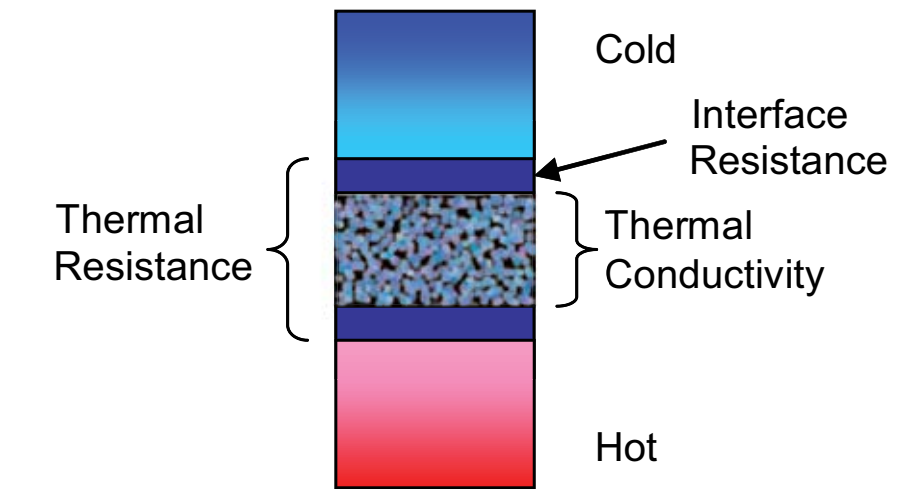


Figure 1. Illustration of the Difference between the Thermal Conductivity and the Thermal Resistance of a Thermal Interface Material

area and to conduction (or natural convection) and radiation across the gaps [2]. If the contact area is small, as it is for rough surfaces, the major contribution to the resistance is made by the gaps [2]. To decrease the thermal contact resistance, the surface roughness can be decreased while the interface pressure is increased. However, these improving methods are not always practical or possible for electronic equipment. To overcome these limitations, thermal interface materials are commonly used.

Properly applied Thermal Interface Materials (TIM) displaces the air, present in the gaps between the two objects, with a material that has a higher

thermal conductivity. Air has a thermal conductivity of $0.0022 \text{ W/m}\cdot\text{K}$ [3] while TIMs have conductivities of $0.3 \text{ W/m}\cdot\text{K}$ [4] and higher. This article will discuss available materials to decrease the thermal contact resistance.

Selection of TIM

When selecting a TIM, care must be taken with the values supplied by the manufacturer. Most manufacturers give a value for the thermal conductivity of a material. However, the thermal conductivity does not take into account the interfaces resistances, as show in Figure 1. Therefore, if a TIM has a high thermal conductivity, it does not mean that the interface resistance will be low.

Selection of a TIM is based on three parameters: the interface gap which the TIM must fill, the contact pressure and the electrical resistance of the TIM. The contact pressure is the pressure applied to the interface between the two materials. Tables 1, 2 and 3 show which TIM may be used for the three previously mentioned parameters, respectively [4]. The selection does not include the cost of the material.

Table 1. Selection Based on Interface Gap.

Interface Gap Values	Products Types Available
< 2 mil	Thermal grease
	Epoxy
	Phase change materials
2 – 5 mil	Kapton, graphite or aluminum tapes
5 – 18 mil	Silicone coated fabrics
> 18 mil	Gap fillers



Figure 2. Various Types of Thermal Interface Materials from Laird Technologies are Shown Including Thermal Grease, Phase Change Materials, Gap Fillers and Tapes [5].

Table 2. Selection Based on Contact Pressure.

Contact Pressure Scale	Typical Pressure Ranges	Products Types Available
Very low	< 70 kPa	Gap fillers
Low	< 140 kPa	Thermal grease
		Epoxy
		Kapton, graphite or aluminium tapes
High	2 MPa	Silicone coated fabrics

Table 3. Selection Based on Dielectric Strength.

Electrical Insulation	Dielectric Strength	Typical Values	Products Types Available
Not required	N/A	N/A	Thermal grease
			Epoxy
			Graphite or aluminium tapes
Required	Low	< 300 V/mil	Silicone coated fabrics
			Gap fillers
Required	High	> 1500 V/mil	Kapton tape

The selection of possible TIM types will have been narrowed after going through Tables 1, 2 and 3. Table 4 details additional application notes for the TIM in the previously mentioned tables.

Table 4. TIM Application Notes Based on Product Type.

Product Type	Application Notes	Thermal Performance
Thermal Paste	- Messy - Labour intensive - Relatively Slow	++++
Epoxy	Create 'permanent' interface bond	++++
Phase Change	- Allows for pre-attachment - Softens and conforms to interface defects at operational temperatures - Can be repositioned in field	++++
Thermal Tapes ¹	- Easy to apply - Some mechanical strength	+++
Silicone Coated Fabrics	Provide cushioning and sealing while still allowing heat transfer	+
Gap Filler	- Can be used to thermally couple varying height components to a heat spreader or heat sink - Naturally tacky	++

¹ Thermal tapes include graphite, kapton and aluminium tapes

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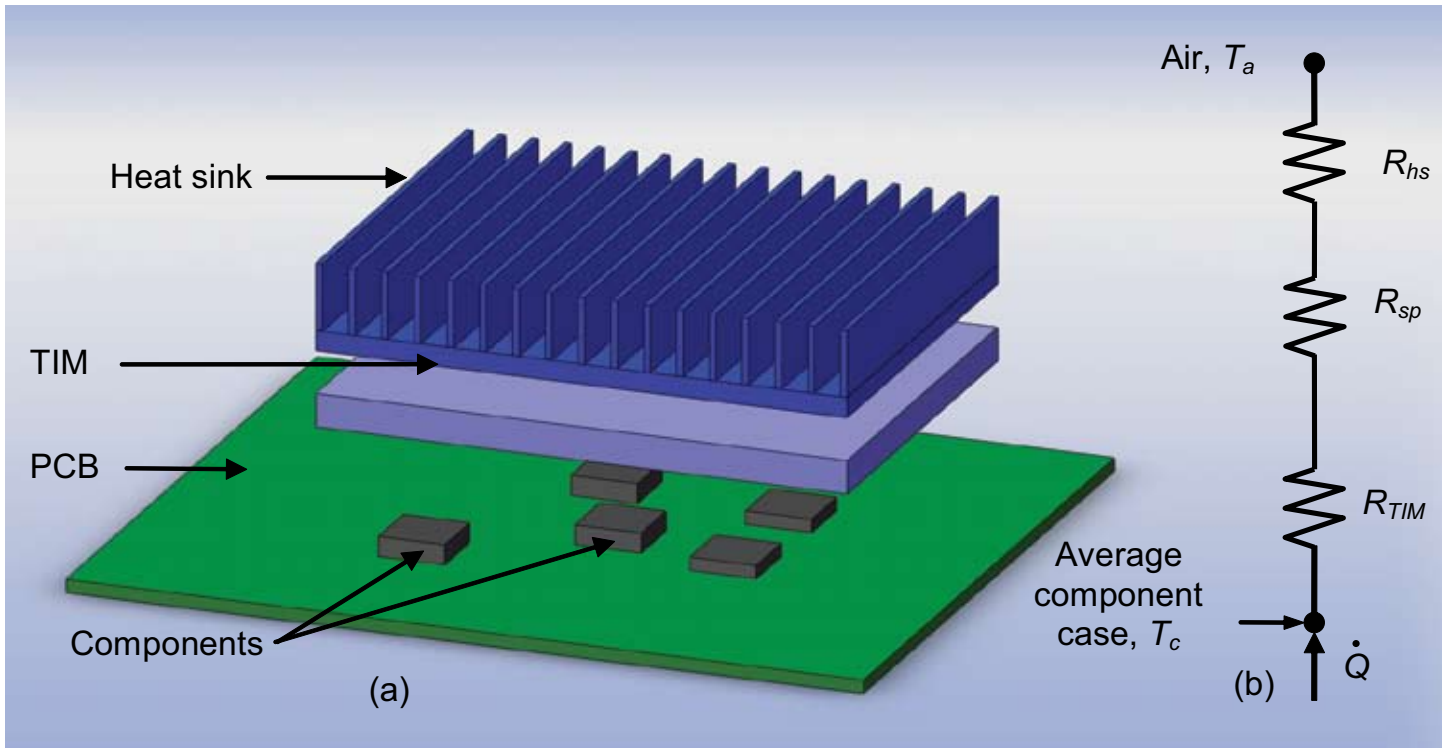


Figure 3. Evaluating the Effect of Different TIM based on The Thermal Resistance Diagram of a Single Component to a Heat Sink.

Example Application Calculation

Suppliers will generally have a number of products for any given type of TIM. In most cases, these products will vary in thermal resistance. And generally, with increasing thermal resistance, the price of the material will go up. But how critical is a change in resistance from 1 to 3 K/W for an application? The thermal engineer will have to look at the overall thermal resistance diagram of the application and evaluate from there.

Consider the application shown in Figure 3 (a). Components of varying height transfer their heat to the environment via a heat sink and TIM. Gap filler material was selected for this example. The thermal diagram, shown in Figure 3 (b), shows that the thermal resistance from the component case to the air or environment is the sum of the thermal resistances of the TIM, R_{TIM} , heat sink base spreading resistance, R_{sp} , and

the heat sink, R_{hs} .

$$\dot{Q}_t = \frac{T_{hot} - T_{cold}}{R_t} = \frac{T_c - T_a}{R_{hs} + R_{sp} + R_{TIM}} \quad (1)$$

$$T_c = T_a + \dot{Q}_t / (R_{hs} + R_{sp} + R_{TIM}) \quad (2)$$

The heat transfer rate from the component to the air can be calculated using equation (1). The temperature of the component, equation (2), can be calculated by rearranging equation (1). Table 5 shows the results of the calculation of the component temperatures for TIM thermal resistance of 1 or 3 K/W and a heat sink thermal resistance of 1.5 and 10 K/W. A heat sink with a thermal resistance of 10 K/W can be a natural convection cooled heat sink while 1.5 K/W for forced convection.

Table 5 shows that using the natural convection cooled heat sink, case 1 and 2, results in an increase of 16°C in the component temperature for different TIM materials, a 12.4% increase in the component temperature. Although the temperature rise for the forced convection heat sink, option 3 and 4, is the same as the natural convection cooled heat sink, however it results in a 26.2% increase in the temperature for different TIM. Table 5 also shows that the percentage resistance of the TIM differs depending on the thermal resistance of the total thermal resistance.

In conclusion, when selecting a TIM, in order to have an effective design, the benefit of a TIM must be evaluated against the total thermal resistance of the design. An improvement of 300%, thermal resistance from 3 K/W to 1 K/W, did not result in a 300% decrease in the component temperature. If the design uses natural convection, it might be more economical to optimise heat sink rather than to spend more money on a TIM.

Summary

Although there are many different TIM types available on the market, each has its own application area, advantages and disadvantages. Eight TIMs have been discussed in this article. The article has also provided tables for the selection of TIMs based on the interface gap which the TIM must fill, the contact pressure and the electrical resistance of the TIM. When selecting between two or more TIM products of the same TIM type, the designer has to

Table 5. The Impact of Cooling Options and TIM Selection on Component Temperature.

Value	Design Options			
	Natural Convection		Forced Convection	
	Case 1	Case 2	Case 3	Case 4
T_c [°C]	113	129	45	61
R_{TIM} [K/W]	1	3	1	3
$R_{hs} + R_{sp}$ [K/W]	10	10	1.5	1.5
R_t [K/W]	11	13	2.5	4.5
R_{TIM}/R_t [%]	9.1	23.1	40.0	66.7
ΔT_c [%]	12.4		26.2	

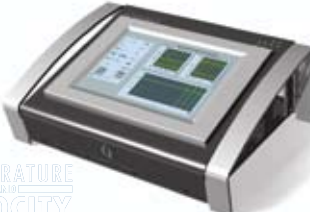
look at the entire design's thermal resistance in order to make an effective design decision on the selection of the appropriate TIM.

References:

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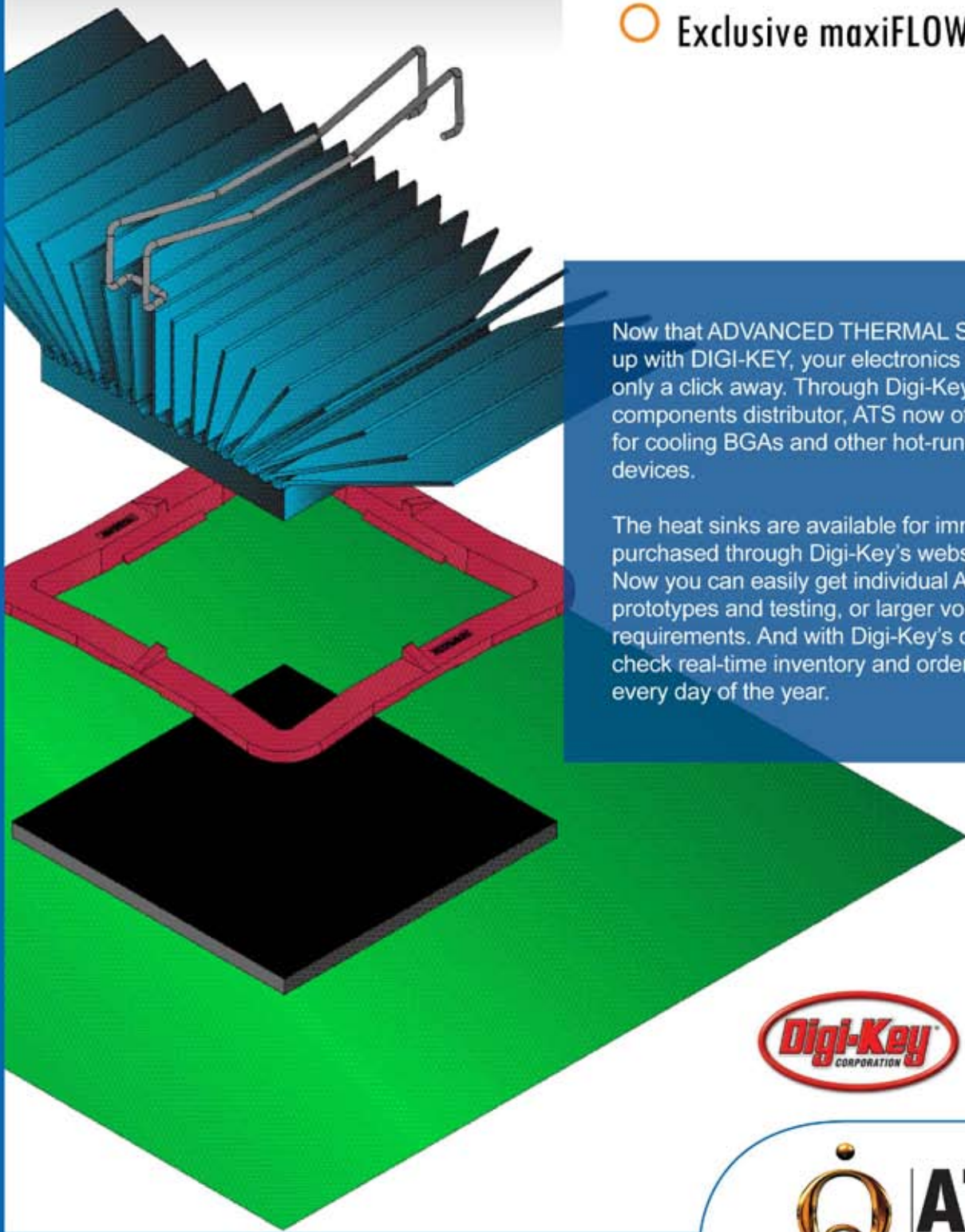




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