Heat generation and dissipation of small chip components

§0 Abstract

As electronic devices become smaller and more reliable, the suppression of the local temperature rise is becoming more important for electronic components and printed-circuit-board(PCB). For high-heat generating components, it has become common to estimate the temperature rise and take measures at the initial design phase. On the other hand, for small chip components used in large quantities, because the same method cannot be simply applied, heat related problems due to dense mounting arises after prototyping in some cases. This technical note explains the basic concept of thermal design using the thermal resistance as an index and a simple temperature estimation method for small electronic components using a temperature distribution simulator available for free.

§1 Components that require heat dissipation measures

1.1 Classification of components by cooling method

Heat-generating components used in electronic devices come in a variety of sizes and shapes, and each generates different amount of heat and dissipates heat with different methods. For example, CPUs and power semiconductors that generate large amount of heat must have a dedicated heat dissipation mechanism for cooling. Meanwhile, small semiconductors and chip resistors dissipate heat into the PCB for cooling. Nevertheless, as the heat generation density of components has been increasing with the miniaturization, when mounted in high density, the temperature of the components rises significantly. These components require an attention to avert accidents. Figure 1 shows the classification of components by cooling method using the thermal resistance as an indicator(*). Next section explains how the chart can be used.

* Source: Thermal Design Lab Co., Ltd.

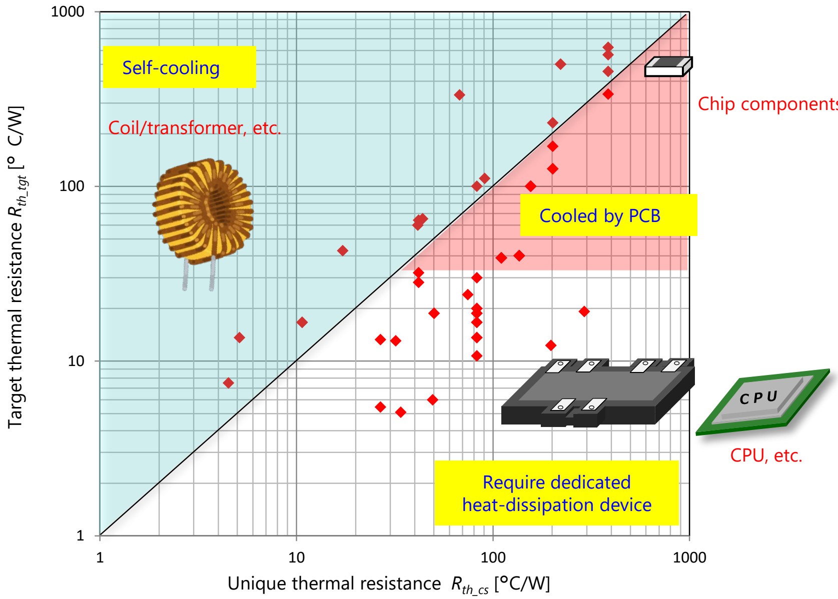

Fig.1 Classification of components by cooling method

1.2 Quantification by thermal resistance

In Fig.1, components are classified based on thermal resistance instead of temperature so that the heat dissipation measure can be quantified. Heat of small chip components is mainly dissipated into PCBs. Therefore, the temperature rise when power is applied to a component depends on the applied power, wiring pattern of PCB, and layout of the component. Figure 2 shows the temperature rise of the chip resistors that are mounted on the respective PCB with different patterns when power is applied. Since the temperature rise with respect to power differs depending on wiring pattern of PCB as mentioned above, the temperature alone cannot be an index for the heat dissipation measure. The thermal resistance, that is, the ratio of temperature rise to the generated heat, is used as an index because its reduction plays an important role in the heat dissipation measure. In this technical note, the thermal resistance is derived from temperature divided by power, and the power is equivalent to the heat to be dissipated.

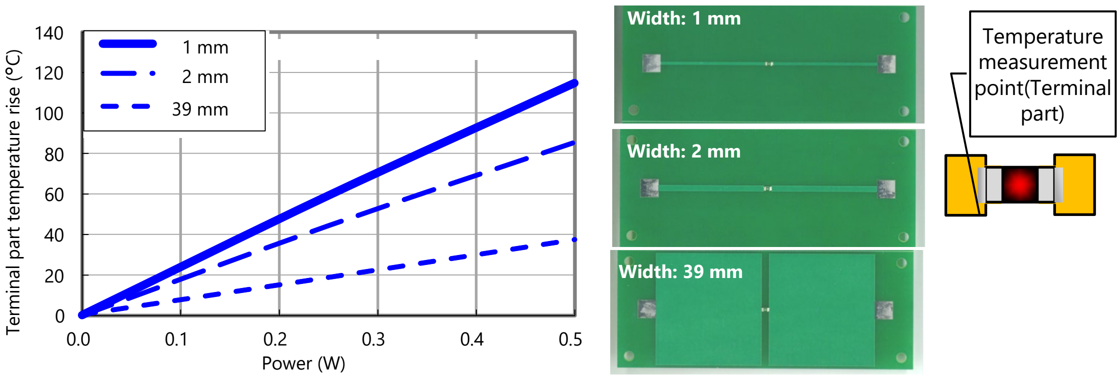

Fig.2 Difference in temperature rise of chip resistors by pattern

1.3 Calculation of target thermal resistance

The first step in considering the heat dissipation measure for a component is to set a target and understand the basic condition. The target thermal resistance R_{th_tgt} should be determined first. This is the thermal resistance when the temperature of the component needs to be kept below T_{tgt} (°C) when the heat generation is Q_c(W) and the operating environment temperature is T_a (°C), which is expressed by Equation 1. The target thermal resistance is the heat dissipation capability required to meet the above-mentioned conditions. Low target thermal resistance indicates that the temperature rise of the component must be small even when electric power is applied, and the heat dissipation capability required is high.

$$R_{th\_tgt} = (T_{tgt} - T_a)/Q_c \text{ (°C/W)} \qquad (1)$$

Next, the heat dissipation capability of the component itself should be identified to understand the basic condition. Assuming that the surface area of the component is S_c (m^2, Sum of 6 surfaces), the heat transfer coefficient from the component surface to ambient is h ($W/m^2 \cdot K$*), the ambient temperature is T_a (°C), and the heat dissipation at the component surface temperature of T_{tgt} (°C) is Q_{cs}. The Q_{cs} is expressed by Equation (2) based on Newton's law of cooling.

$$Q_{cs} = S_c \cdot h\,(T_{tgt} - T_a) \qquad (2)$$

*The heat transfer coefficient is h≦20 for natural convection and h≦90 for forced convection.

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Equation (3) is deformed from equation (2) and gives the difficulty of heat dissipation from the component in thermal resistance R_{th_cs}, which is called unique thermal resistance in this technical note. When the unique thermal resistance is low, the temperature rise will be kept small even when power is applied, which means that the component has high heat dissipation capability.

$$R_{th\_sc} = (T_{tgt} - Ta)/Q_{cs} = 1/(S_c h)\ (°C/W) \qquad (3)$$

Figure 1 (re-shown below) plots the components used in a certain device with the unique thermal resistance on the horizontal axis and the target thermal resistance on the vertical axis. Components in the blue area have unique thermal resistance that is lower than the target thermal resistance, which means that the component itself has a sufficient heat dissipation capability. There are two categories for when the unique thermal resistance of the component is higher than the target thermal resistance. Components in the white area require high heat dissipation capability through heat-dissipation devices such as a heatsink. Components in the red area which include chip resistors and small semiconductors have capability to dissipate heat through the PCB. Table 1 shows an example of the unique thermal resistance of a chip resistor. The smaller size gives the higher unique thermal resistance, so all the chip resistors belong to the red area. The border between the red and the white areas empirically represent the limit of heat dissipation capability through typical resin PCBs, which is between 30 and 40 °C/W. Next section forward explains the heat dissipation measure for the components in the red area.

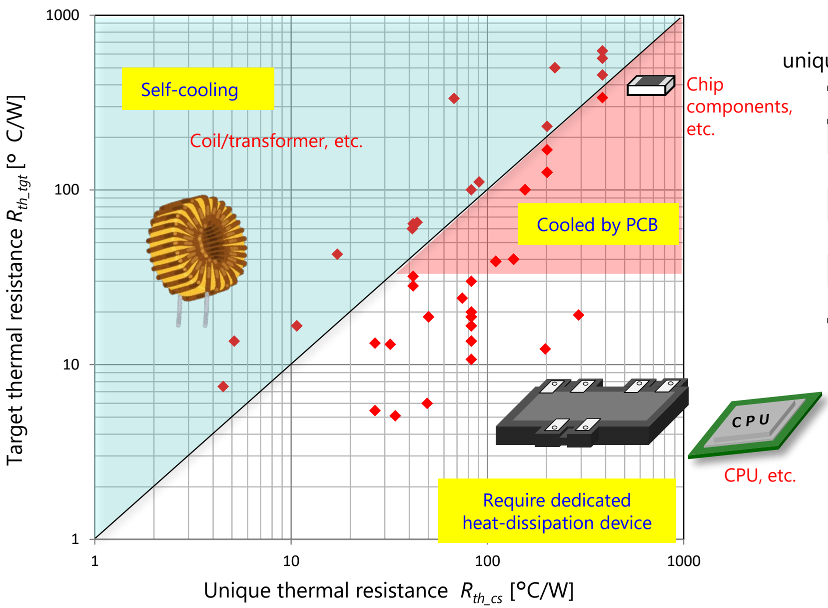


Fig.1 Classification of components by cooling method

Table 1
Chip resistor
unique thermal resistance (°C/W)

Size	R_{th_cs}
0402	24390
0603	10593
0805	6250
1206	3125
2010	1471
2512	993

Inch size code

Source: Thermal Design Lab Co., Ltd.

§ 2 Heat dissipation from PCB

To secure the heat dissipation capability of the PCB, the copper pattern is specified for some chip components. However, the temperature rise is also influenced by the surrounding heat-generating components and the clearance from the edge of the copper pattern. Figure 3 shows the simulation result of the temperature rise by clearance with the same component type and copper pattern.

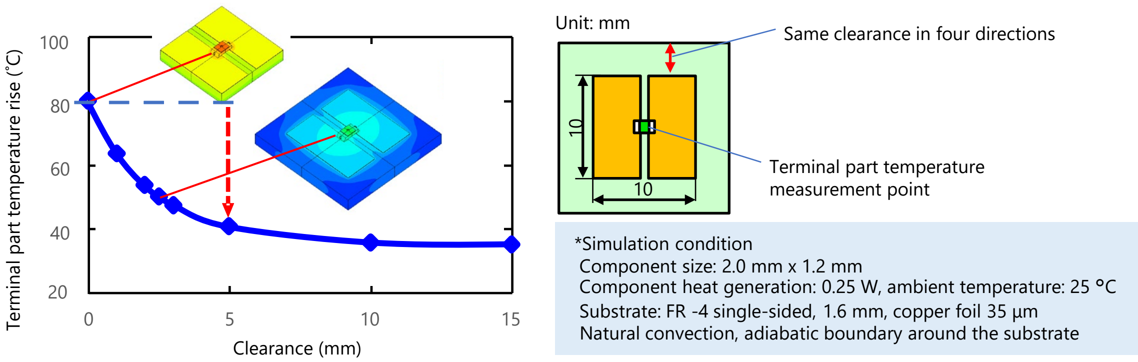


Fig.3 Variation in temperature rise by the clearance

With a clearance of 0 mm, the temperature rises approximately 80 °C, and with a clearance of 5 mm, the temperature rises approximately 40 °C, which indicates that even with the same copper pattern, variation in the clearance exceedingly changes the temperature. Accordingly, the clearance in addition to the copper pattern carries weight on the heat dissipation of the PCB where components are mounted in high density. Figure 4 shows the simulated relationship among the size of copper pattern, clearance, and thermal resistance.

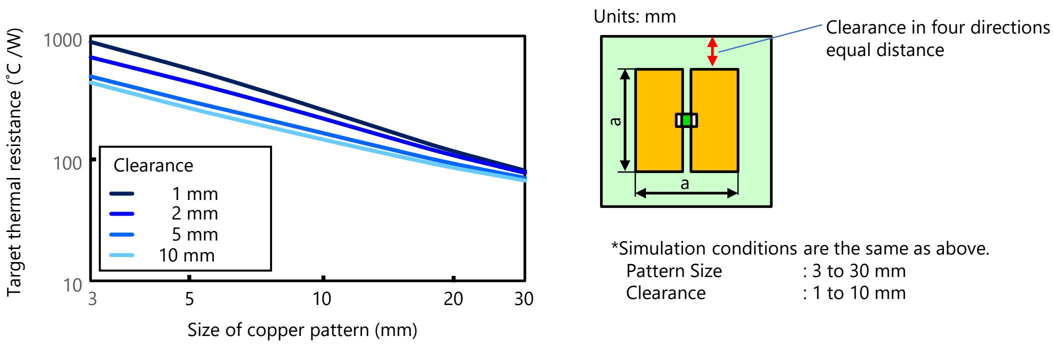


Fig.4 Relationship among copper pattern size, clearance, and thermal resistance

This chart shows the size of copper pattern and clearance required for the target thermal resistance. Although reflecting the simulated result on a design helps avert accidents, it is not realistic to apply this procedure to every small heat-generating chip components. Next section explains a simpler approach to determine the pattern size and the clearance based on the target thermal resistance.

§ 3 Temperature estimation by simulator

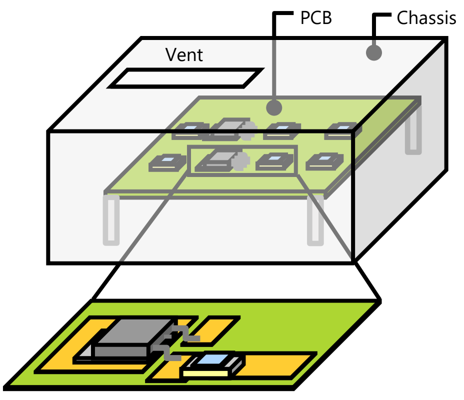
3.1 Temperature estimation of component alone

JEITA's Thermal Management Standardization Group of Technical Standardization Committee on Surface Mounting Technology has published multiple technical reports on the thermal design that dissipates heat mainly through the PCB. The thermal calculation tool is provided in "ETR-7034: Thermal design guidelines for printed circuit boards with mounted components that dissipate heat through the board". This tool is based on the modified Lee's equation (*) and calculates the required clearance from the component dimensions and the target thermal resistance value.
This tool should be utilized when selecting the components and determining the rough arrangement since it gives the required clearance for the target thermal resistance and the land pattern. This tool does not take account of the thermal effect from the surrounding components.

*Modified Lee's equation: Lee's equation that gives heat resistance of the heat sink is modified to calculate the thermal resistance of the dissipation pattern and the PCB.

3.2 Temperature simulation of target components and surroundings

KOA offers a temperature distribution simulator developed in collaboration with Thermal Design Lab Co., Ltd. for free. The temperature distribution over the mounted chip components, the surrounding components and the PCB can be analyzed with the simulator based on the thermal network simulation methodology. The terminal part temperature of the chip resistor can be easily predicted in pattern designing phase. Since it runs on Microsoft® Excel®, installation is not required. Figure 5 shows the functions and the simulation range.
※Currently, the temperature distribution simulator is available only in Japanese. An international version is in preparation.



Functions

- Analyze the steady heat conduction.
- Analyze a portion of a PCB embedded on a chassis.
- Consider the natural/forced convection.
- Analyze assuming the gel/sealant is filled.
  (Thermal conductivity of the gel is fixed at 0.2 $W \cdot m^{-1} \cdot K^{-1}$)
- Design the arrangement of thermal vias.
- Data of often-used materials and components can be registered and referred.
- Data of chip resistors can be imported from the library.

Fig.5 Functions and simulation range of temperature distribution simulator

Figure 6 shows the simulation result. The numerical display and the contour plot of the temperature of the target component and its surroundings give the better understanding of the temperature distribution. This simulator is useful to design the component arrangement and wiring on the PCB.

Copper pattern and component arrangement input

Temperature distribution (contour plot)

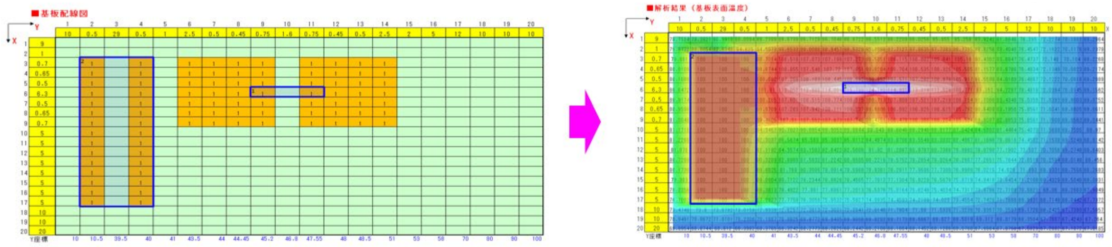


Fig.6 Simulator calculation results of temperature distribution

For analyzing the temperature distribution of the entire PCB or considering the specific influence of a cooling-fan, use of another simulator is recommended. KOA provides a simulation model of KOA's resistors that can be used in the thermal fluid simulator, Simcenter™ Flotherm™. The models can be downloaded from KOA's website and used for thermal analysis of electronic equipment. Table 2 provides an overview of the mentioned tools.

Table 2 Overview of tools

Tool	Feature	Phase to be used in
Thermal calculator	Calculate necessary pattern size and clearance to obtain required thermal resistance.	Component selection Arrangement designing
Temperature distribution simulator	Determine necessary dissipation measures based on simulated temperature distribution of components and surroundings where temperature rise is expected.	Pattern designing
Thermal fluid analyzing simulator	Simulate temperature of a resistor with 3D thermal fluid simulation model.	Completion/verification of design

Make sure to check with the actual PCB since the temperature estimated by the simulation is only an approximate value.

§4 Summary

Although the temperature rise of small chip components is controlled by the heat dissipation through the PCB, accidents due to unexpected temperature rise may occur if inappropriate component arrangement or inadequate wiring pattern is implemented. In order to take heat dissipation measures, it is important to determine the target thermal resistance and calculate the unique thermal resistance which is the heat dissipation capacity of a component alone. Understanding the capability of component alone and the influence of the surrounding components by the simulation prior to designing prevents necessity of taking urgent actions after the PCB is completely assembled.
KOA offers various supports. Feel free to contact us.