Thermal Design (Basic)

What Is Thermal Design?

Challenges in designing electronic equipment include downsizing, improvement in efficiency, support for electromagnetic compatibility (EMC), and countermeasures against heat. Heat has been one of the most important considerations because it affects the performance and reliability of the parts and equipment as well as safety. This application note provides the basics of thermal design considering semiconductor parts such as the ICs and transistors used in electronic equipment.

What is thermal design?

For semiconductor parts, the absolute maximum rating of the junction temperature (T_{JMAX}) is specified. This indicates the temperature of a chip inside a package. During the design, it is necessary to consider the heating and the ambient temperature so that the temperature of the parts will not exceed T_{JMAX}. For this purpose, thermal calculations are performed for all semiconductor parts to be used in order to determine whether or not T_{JMAX} can be exceeded. If T_{JMAX} can be exceeded, countermeasures are taken, such as reducing the power loss or reviewing the heat dissipation, so that T_J is maintained within the maximum rating.

Needless to say, various parts, including capacitors, resistors, and motors, are used in electronic equipment in addition to the semiconductor parts, and each part has its absolute maximum rating in relation to the temperature and the power loss. Therefore, it is necessary to design the equipment so that the absolute maximum rating regarding the temperature of every part comprising the equipment will not be exceeded.

Necessity of performing the thermal design during the initial design phase

If the thermal design is not performed and no countermeasures against heat are taken in the initial design phase, issues due to heat may be detected in the trial phase of the product or possibly immediately before the mass production. While this is not limited to countermeasures against heat, any countermeasures require more time and cost as the process approaches mass production. A delay in the product delivery can cause a significant problem, leading to lost opportunities. In the worst case, an issue may occur in the market, developing into a recall or credibility problem. Since the issues due to heat are highly likely to be life threatening, such as causing malfunction, smoking, or ignition of products, or leading to a fire, the thermal design is fundamentally critical. Therefore, it is essential to perform a reliable thermal design from the initial phase.

Increase in the importance of thermal design

It is taken for granted that recent electronic equipment requires downsizing and improvement in the performance, leading to advances in higher integration. Specifically, the number of parts and the mounting density on the board have been increased, while the chassis has been downsized. Therefore, the heating density has been significantly increased.

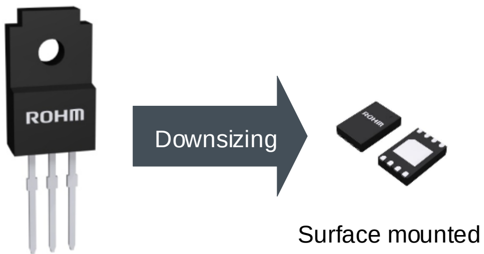
It should be recognized first that the thermal design has now become more difficult due to changes in technological trends. As mentioned above, in addition to “downsizing” and “improvement in functions”, “designability” is required not only for the equipment but also for the parts, making the countermeasures against heat significant challenges. Since the thermal design can provide reliability and safety of the equipment as well as reduction in the total cost, its importance is increasing.

Changes in the technological trends and the thermal design

Recent technological trends have zoomed in on “downsizing”, “improvement in the performance” and “designability”. Let’s think about how these trends affect the heat and the thermal design.

"Downsizing"

An increasing requirement for downsizing of products has led to a similar trend for ICs, mounting boards, capacitors, and other parts. For the downsizing of semiconductor parts, it is now quite common for an IC chip that was previously accommodated in a relatively large through-hole package such as TO220 to be enclosed in a small surface mounted package.

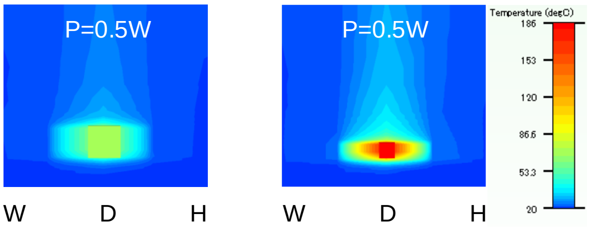


Through-hole package

Surface mounted package

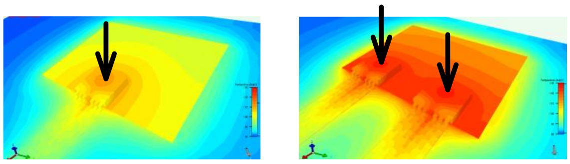
In addition, approaches have been taken to increase the integration. For example, the ratio of functions to area has been increased by installing multiple devices on a single module or highly integrating multiple functions into a single chip. Such downsizing and integration of the parts can increase the heating.

An example of downsizing the packages is shown below. These thermal images represent the conditions where the same power is consumed. The left and right images show packages with the dimensions 20 × 20 × 20 mm and 10 × 10 × 10 mm, respectively. Clearly, the red color, indicating high temperature, is more concentrated in the smaller package, meaning an increase in the heating.



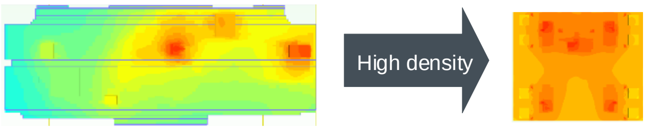
20mm × 20mm × 20mm 10mm × 10mm × 10mm

Next, an example of the integration is shown. These images compare the situations where one (left) or two (right) devices are installed on a board with the same size. The difference in temperatures is obvious.



One device generating heat Two devices generating heat

Furthermore, the parts that are downsized and highly integrated can be mounted on both sides of a compact board at a high density.



The high density mounting reduces the effective heat dissipation area of the surface mounted parts to dissipate the heat to the board, causing increase in the heating. A higher ambient temperature inside the chassis also reduces the heat dissipation. As a result, while the temperature was raised only around the heat generating parts previously, the temperature of the entire board is now increased. As such, the temperature of the parts generating less heat is also increased.

"Improvement in functions"

To improve the functions of the equipment, it is necessary to increase the number of devices or use an IC with a larger scale integration and a higher performance. High speed data processing and increase in signal frequency are also required. These improvements tend to require more power consumption, resulting in increase in the heating. In addition, shielding is often required to prevent noise radiation when using a high frequency. Since the heat remains inside the shield, the temperature condition becomes more undesirable for the devices inside the shield. Furthermore, it is not feasible to increase the size of the equipment in order to improve its functions. Therefore, the high density situation occurs as mentioned above and increases the temperature inside the chassis.

"Designability"

The design of products is more often focused or even prioritized to differentiate the products or increase their appeal aesthetically. As an adverse effect of this trend, there have been cases where the temperature of the chassis is increased, causing issues due to an excessively high density of mounting or inability to adequately exhaust the heat. As mentioned above, the parts are already downsized and have a lower profile to increase the designability, namely the degree of freedom in the external shape. However, the design is often prioritized even further.

Also as explained above, the changes in technological trends, including “downsizing”, “improvement in functions”, and “designability”, have increased the heating while making the heat dissipation more difficult. Therefore, the thermal design is imposed with severe conditions and requirements. Although it is true that this is a significant problem, there is another factor to be considered.

In many cases, evaluation standards should be implemented for the thermal design within the corporate equipment design. If the evaluation standards have been implemented since early times without being reviewed with an additional consideration of the recent technological trends and other factors, the evaluation standards themselves may be a problem. If the evaluation standards are followed without such review or consideration of the current status, it is necessary to accept that a significant problem could occur.

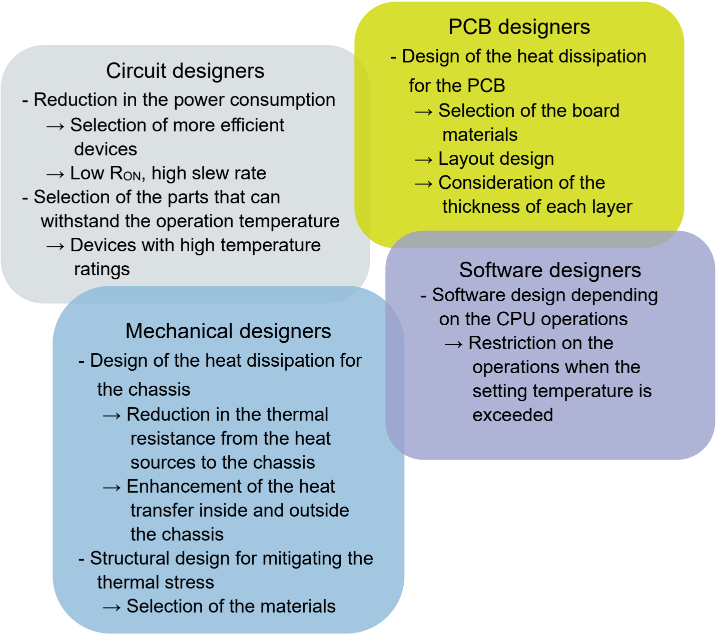
To address the changes in the technological trends, a review of the evaluation standards for the thermal design is also required.

Mutual understanding of the thermal design

Product development involves electronic circuit designers, mounting board (PCB) designers, mechanical designers, software designers, and so on. Conventionally, the products are developed separately by dedicated designers and the responsible departments. For example, the electronic circuit designers select the parts that meet the product specifications and design the circuit. The software designers develop the software to operate the hardware. The mounting board designers design the boards by considering the appropriate parts configuration, layout, board size, and so on. Then, the mechanical designers design the chassis and the structures. This has been the way the product development is divided.

Under such circumstances, considering the thermal design required currently, it is difficult to deliver a product with an optimized thermal design unless there is a system where the respective designers incorporate the thermal design into the design they are in charge of and then their designs are shared to be integrated with each other into a single design.

As an example, consider a fan-less specification to address downsizing, noise reduction, and cost reduction, which are the trends in the equipment. If the product is equipped with a fan, the mechanical designers are normally responsible for the cooling inside the chassis. However, which designers should address the cooling without a fan? The figure below shows examples of what could be done as the thermal design by the respective designers.



Circuit designers
- Reduction in the power consumption
  → Selection of more efficient devices
  → Low R_{ON}, high slew rate
- Selection of the parts that can withstand the operation temperature
  → Devices with high temperature ratings

PCB designers
- Design of the heat dissipation for the PCB
  → Selection of the board materials
  → Layout design
  → Consideration of the thickness of each layer

Mechanical designers
- Design of the heat dissipation for the chassis
  → Reduction in the thermal resistance from the heat sources to the chassis
  → Enhancement of the heat transfer inside and outside the chassis
- Structural design for mitigating the thermal stress
  → Selection of the materials

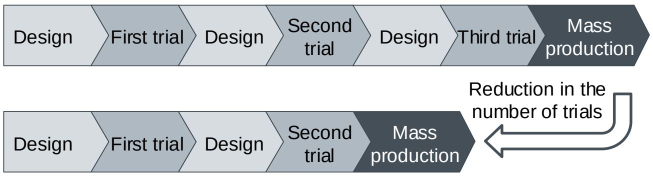
Software designers
- Software design depending on the CPU operations
  → Restriction on the operations when the setting temperature is exceeded

As can be quickly recognized from the descriptions, the fan-less product will be realized through interplay between countermeasures taken by the respective designers within their duties to reduce the heating or enhance the heat dissipation. Mutual communications are often required to advance this process, and the expectations of each department could lead to no result without mutual understanding. In addition, the designers may find something they would not have noticed only within their duties, expanding the possibility of finding a more efficient solution.

What can be done by optimizing the thermal design through mutual understanding

There is a term called “design quality”. Simply put, the design quality is considered high if the trial production is performed as designed, the mass production is reached in a short period without issues, and no problem occurs in the market. Not limited to the thermal design, this is what everyone wishes for. Therefore, it is important to improve the design quality. To do so, it is essential to “seriously address” the requirement for thermal design, as well as create thermal designs that meet the current demands, establish the evaluation standards, and ensure the mutual understanding of thermal design concepts, as mentioned above.

In reality, there may be issues such as a lack of personnel or prioritization of costs. However, improving the design quality will eventually lead to the resolution of these issues. By improving the design quality, the number of trial productions can be reduced as illustrated in the figure below. This leads to a significant cost reduction. In addition, it also allows the saving of personnel resources because the number of reworks will be reduced.



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