4 Steps
for Successful Thermal Designing of Power Devices

White Paper

Summary

From railways to automobiles, infrastructure and even home appliances, power electronics support our daily lives in many familiar ways. In order to ensure energy saving and low (or net-zero) carbon emissions, ever more advanced and highly efficient power electronics technology is required. We already have next-generation power devices like IGBTs, SiCs and GaNs that can help us attain these goals. However, if used incorrectly, these devices may lead to unexpected problems and reduced reliability. In worst-case scenarios, they may even result in product recalls as a result of problems in the market. Thermal design, which has a direct effect on reliability, is therefore particularly important. Once problems have occurred, man-hours and additional costs required for reworking (eg. re-selecting parts, correcting board patterns, redesigning heat dissipation, etc.) increase enormously. ROHM has prepared several application notes on the thermal design knowledge required to improve set reliability and reduce design rework. In this white paper we introduce some of them.

Introducing application notes

Figure 1 shows the tools and support that ROHM can provide to assist with users' development process.

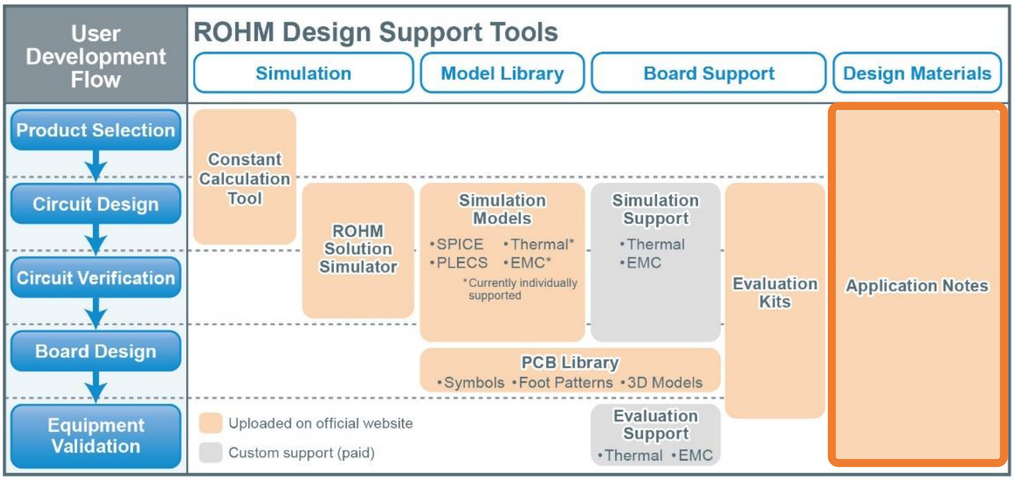


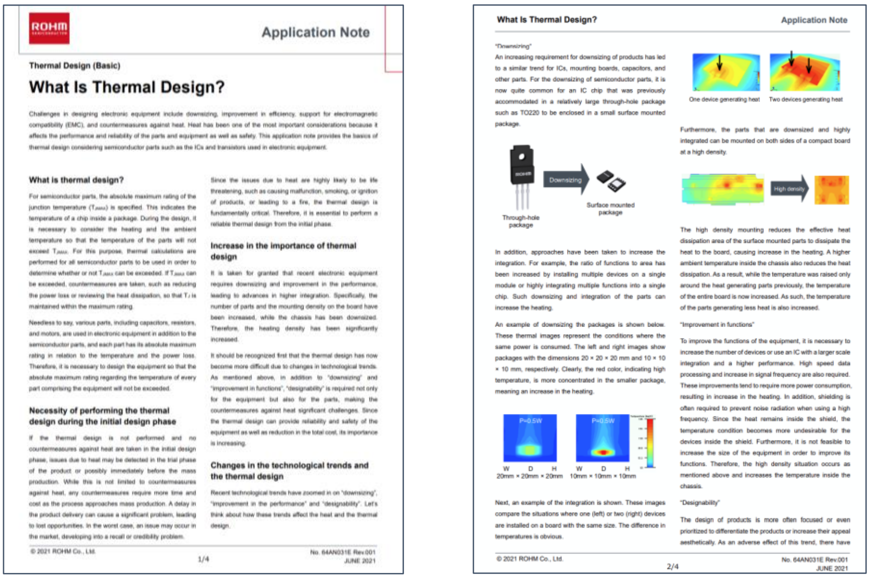
Figure 1. Design and verification support tools provided by ROHM

Application notes are documents presenting the technical information required at each stage of users' development process and offer broad support, from basics to practical matters. In this document we introduce the application notes we have prepared for successful thermal design, divided in four steps.

Step 1 Learning the basics of thermal design
Step 2 Knowing the thermal properties of each component used
Step 3 Making the best use of thermal simulations
Step 4 Performing accurate thermal measurements

Step 1 Learning the basics of thermal design

Knowing the basics of thermal design is extremely important. No matter how expensive a system (measuring instrument or simulator) you may adopt, unless you know the basics, you won't be able to use it effectively because of unsuccessful thermal design. First of all, we would like for you to grasp the importance of thermal design by reading "What Is Thermal Design?" (Fig. 2).


Application Note

Thermal Design (Basic)

What Is Thermal Design?

What is thermal design?

Necessity of performing the thermal design during the initial design phase

Increase in the importance of thermal design

Changes in the technological trends and the thermal design

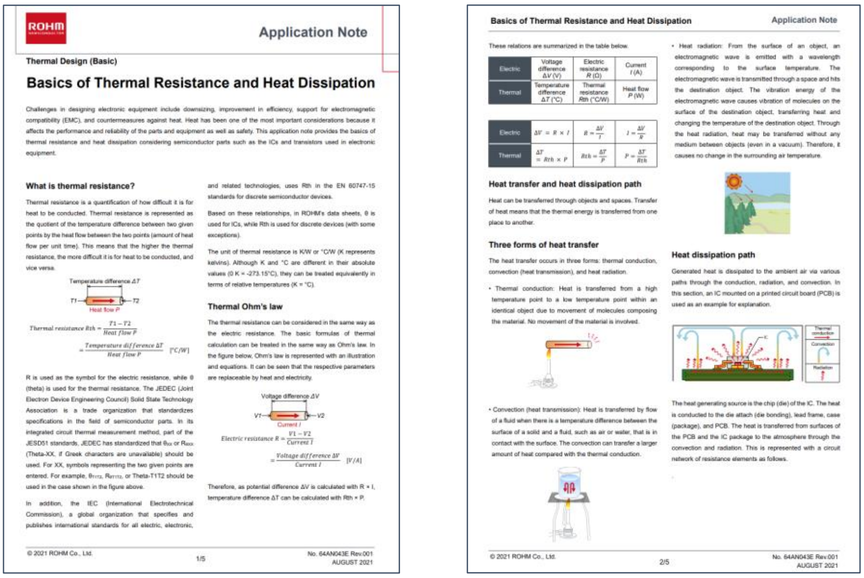
© 2021 ROHM Co., Ltd.

What Is Thermal Design?

Application Note

Figure 2. What Is Thermal Design? (excerpt)

The most important parameter in thermal design is the "thermal resistance" of each component. The proper use of thermal resistance helps us understand complicated heat transfer phenomena in simple terms, and represents a shortcut to successful thermal design ("Basics of Thermal Resistance and Heat Dissipation" Fig. 3).


Application Note

Thermal Design (Basic)

Basics of Thermal Resistance and Heat Dissipation

What is thermal resistance?

Thermal Ohm's law

© 2021 ROHM Co., Ltd.

Basics of Thermal Resistance and Heat Dissipation

Application Note

Heat transfer and heat dissipation path

Three forms of heat transfer

Heat dissipation path

Figure 3. Basics of Thermal Resistance and Heat Dissipation (excerpt)

Step 2 Knowing the thermal properties of each component used

For users of semiconductors to fully achieve the specifications of the sets developed, it is necessary to know certain characteristics of the power devices used. Specifically, these characteristics are "absolute maximum rating for junction temperature", "thermal resistance" and "calorific value (power loss)." The absolute maximum rating for junction temperature varies from device to device, but is always included for reference in the data sheet. For example, in the case of SiC MOSFET, a junction temperature of 175ºC is the absolute maximum rating (Fig. 4).

●**Absolute maximum ratings** (T_a = 25°C)

Parameter		Symbol	Value	Unit
Drain - Source Voltage		V_{DSS}	650	V
Continuous Drain current	T_c = 25°C	I_D *1	70	A
	T_c = 100°C	I_D *1	50	A
Pulsed Drain current		$I_{D,pulse}$ *2	175	A
Gate - Source voltage (DC)		V_{GSS}	-4 to +22	V
Gate - Source surge voltage (t_{surge} < 300ns)		V_{GSS_surge} *3	-4 to +26	V
Recommended drive voltage		V_{GS_op} *4	0 / +18	V
Junction temperature		T_j	175	°C
Range of storage temperature		T_{stg}	-55 to +175	°C

Figure 4. Example of absolute maximum ratings in data sheet (SCT3030AW7)

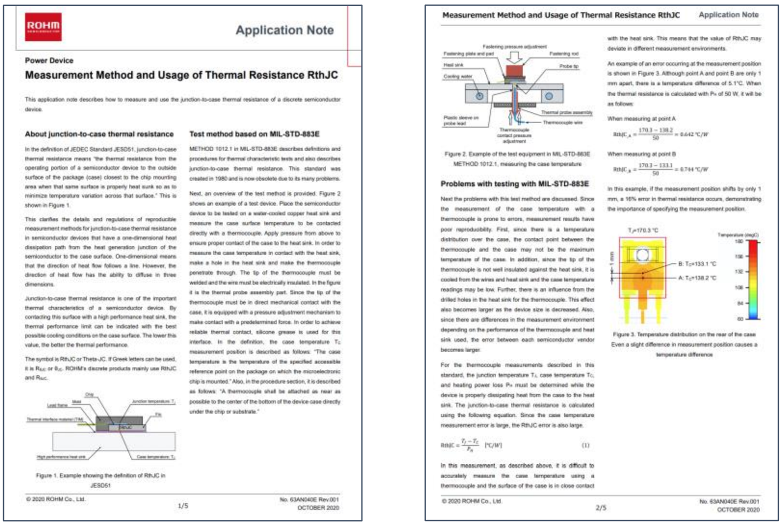
Thermal resistance is another piece of information that is always included in the data sheet (Fig. 5).

●**Thermal resistance**

Parameter	Symbol	Values			Unit
		Min.	Typ.	Max.	
Thermal resistance, junction - case *6	R_{thJC}	-	0.44	0.56	°C/W

Figure 5. Example of Thermal Resistance in Data Sheet (SCT3030AW7)

While there are different thermal resistance parameters, for example RthJA, which indicates the thermal resistance between the junction and the surrounding environment, the one listed in the data sheet of power devices is thermal resistance RthJC. RthJC is the value of thermal resistance between the junction and the case, and it is measured as specified in JEDEC Standard JESD 51-14 [*1]. "Measurement Method and Usage of Thermal Resistance RthJC" (Fig. 6), which describes how to measure RthJC and which points to pay attention to, presents information that any power device user should know.


Application Note

Power Device

Measurement Method and Usage of Thermal Resistance RthJC

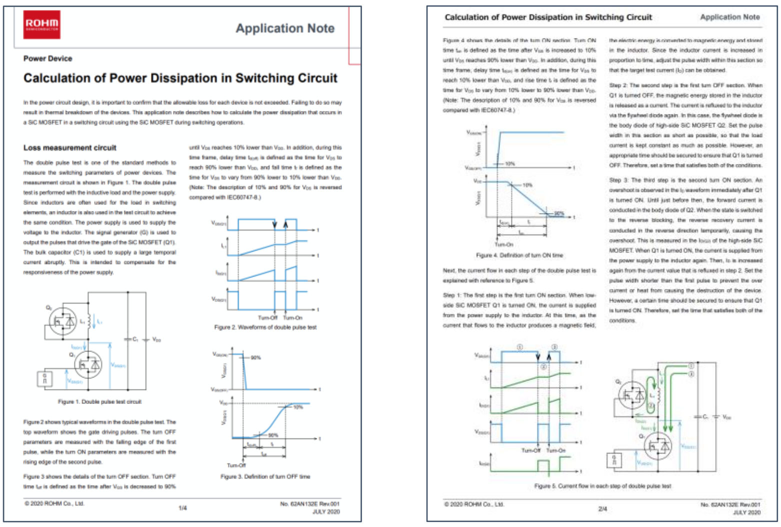
About junction-to-case thermal resistance

Test method based on MIL-STD-883E

Problems with testing with MIL-STD-883E

Figure 6. Measurement Method and Usage of Thermal Resistance RthJC (excerpt)

Just as important as thermal resistance is calorific value (power loss). Since calorific value depends not only on the characteristics of the power device but also on circuit operation, it must be calculated based on the application used. "Calculation of Power Dissipation in Switching Circuit" describes how to calculate calorific value (power loss) in inductance load switching (Fig. 7).


Application Note

Power Device

Calculation of Power Dissipation in Switching Circuit

Loss measurement circuit

Figure 7. Calculation of Power Dissipation in Switching Circuit (excerpt)

If the calorific value (power loss) changes over time, it is necessary to determine junction temperature using the transient thermal resistance listed in the data sheet. "Method for Calculating Junction Temperature from Transient Thermal Resistance Data" (Fig. 8) describes how to determine junction temperature from the transient thermal resistance data.

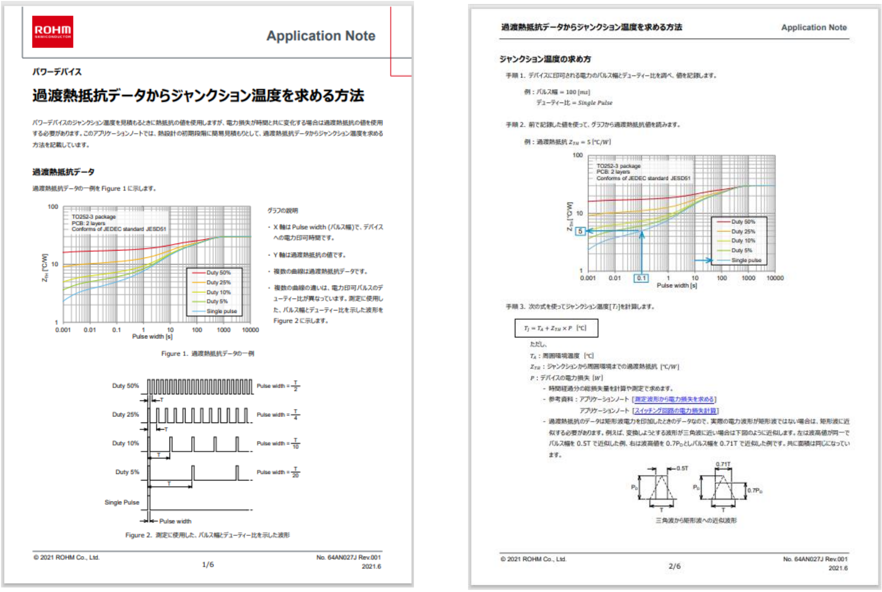


Figure 8. Method for Calculating Junction Temperature from Transient Thermal Resistance Data (excerpt)

Step 3 Making the best use of thermal simulations

When it comes to simulations in thermal design, many users will no doubt immediately think of 3D CFD (Computational Fluid Dynamics) simulations. Broadly speaking, simulations using CFD require specialized knowledge, which is why many circuit designers may not be familiar with it. In order to help such circuit designers to easily perform thermal simulations, ROHM has released online a thermal model to be used in SPICE-based simulators, which are often used for electric circuit simulations. "What is a Thermal Model?" (Fig. 9) explains what thermal models are, while "How to Use Thermal Models" (Fig. 10) explains how to download the thermal model and how to use it for thermal simulations.

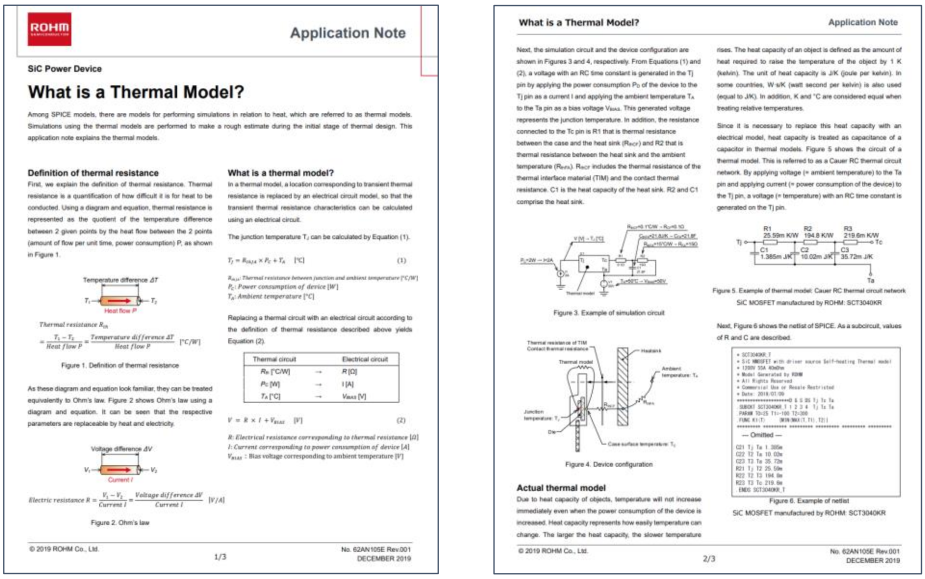


Figure 9. What is a Thermal Model? (excerpt)

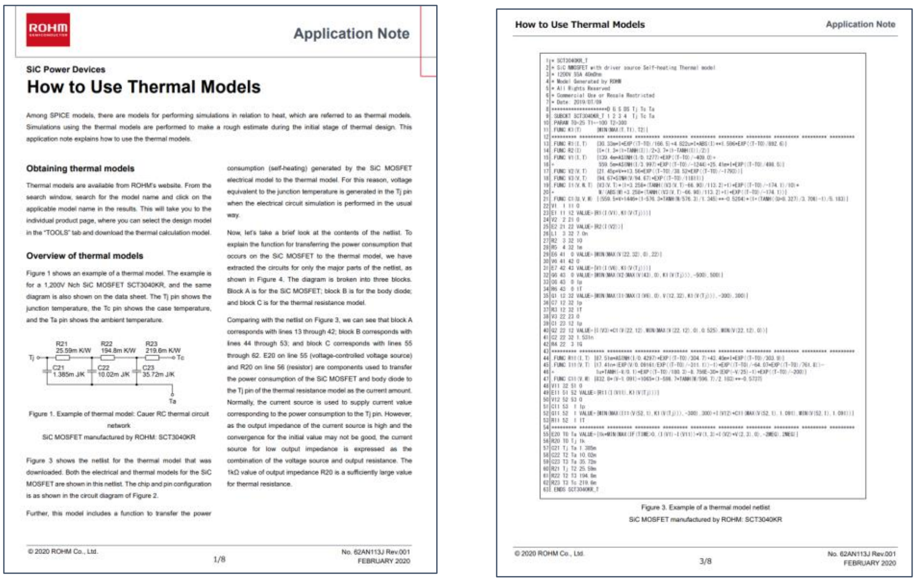
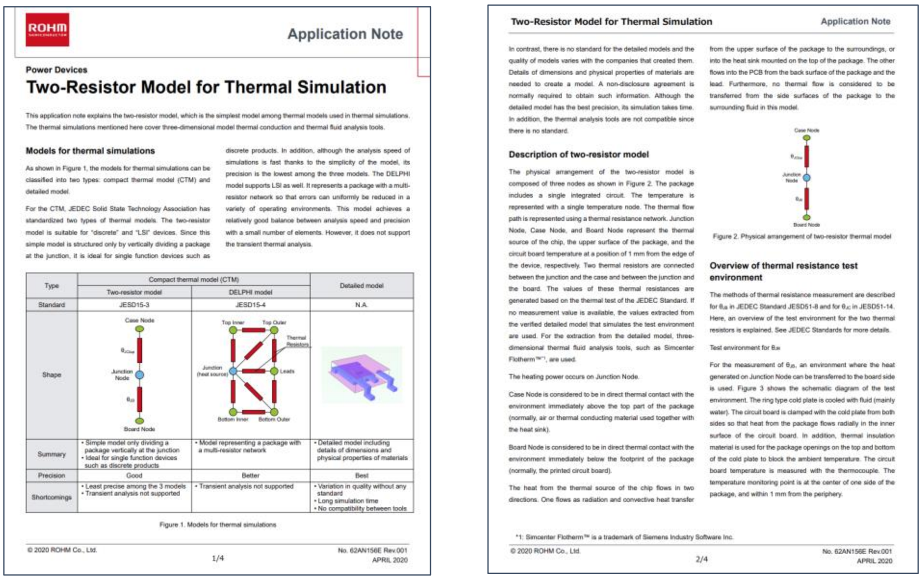


Figure 10. How to Use Thermal Models (excerpt)

While SPICE simulations using thermal models are suitable for estimating junction temperature at the initial stage of design, they cannot be used to calculate the thermal resistance of the entire set, including insulating sheet and heat sink. In order to find out the heat dissipation performance of a set, it is recommended to use 3D CFD simulations. The models used for 3D CFD simulation are described in "Two-Resistor Model for Thermal Simulation" (Fig. 11). Besides describing the simplest model, the two-resistor model, it also describes other models like the DELPHI model and the detailed model. Should it be required, individual support is also available for models used in 3D CFD simulations. In the end, however, it is necessary to formulate a judgment by measuring the actual device.



Application Note

Power Devices

Two-Resistor Model for Thermal Simulation

This application note explains the two-resistor model, which is the simplest model among thermal models used in thermal simulations. The thermal simulations mentioned here cover three-dimensional model thermal conduction and thermal fluid analysis tools.

Models for thermal simulations

As shown in Figure 1, the models for thermal simulations can be classified into two types: compact thermal model (CTM) and detailed model.

For the CTM, JEDEC Solid State Technology Association has standardized two types of thermal models. The two-resistor model is suitable for "discrete" and "LSI" devices. Since this simple model is structured only by vertically dividing a package at the junction, it is ideal for single function devices such as discrete products. In addition, although the analysis speed of simulations is fast thanks to the simplicity of the model, its precision is the lowest among the three models. The DELPHI model supports LSI as well. It represents a package with a multi-resistor network so that errors can uniformly be reduced in a variety of operating environments. This model achieves a relatively good balance between analysis speed and precision with a small number of elements. However, it does not support the transient thermal analysis.

Type	Compact thermal model (CTM)		Detailed model
	Two-resistor model	DELPHI model	
Standard	JESD15-3	JESD15-4	N.A.
Shape	Case Node, θ_{JCtop}, Junction Node, θ_{JB}, Board Node	Top Inner, Top Outer, Thermal Resistors, Junction (heat source), Leads, Bottom Inner, Bottom Outer	
Summary	• Simple model only dividing a package vertically at the junction • Ideal for single function devices such as discrete products	• Model representing a package with a multi-resistor network	• Detailed model including details of dimensions and physical properties of materials
Precision	Good	Better	Best
Shortcomings	• Least precise among the 3 models • Transient analysis not supported	• Transient analysis not supported	• Variation in quality without any standard • Long simulation time • No compatibility between tools

Figure 1. Models for thermal simulations

© 2020 ROHM Co., Ltd. 1/4 No. 62AN156E Rev.001 APRIL 2020

Two-Resistor Model for Thermal Simulation Application Note

In contrast, there is no standard for the detailed models and the quality of models varies with the companies that created them. Details of dimensions and physical properties of materials are needed to create a model. A non-disclosure agreement is normally required to obtain such information. Although the detailed model has the best precision, its simulation takes time. In addition, the thermal analysis tools are not compatible since there is no standard.

Description of two-resistor model

The physical arrangement of the two-resistor model is composed of three nodes as shown in Figure 2. The package includes a single integrated circuit. The temperature is represented with a single temperature node. The thermal flow path is represented using a thermal resistance network. Junction Node, Case Node, and Board Node represent the thermal source of the chip, the upper surface of the package, and the circuit board temperature at a position of 1 mm from the edge of the device, respectively. Two thermal resistors are connected between the junction and the case and between the junction and the board. The values of these thermal resistances are generated based on the thermal test of the JEDEC Standard. If no measurement value is available, the values extracted from the verified detailed model that simulates the test environment are used. For the extraction from the detailed model, three-dimensional thermal fluid analysis tools, such as Simcenter Flotherm™*1, are used.

The heating power occurs on Junction Node.

Case Node is considered to be in direct thermal contact with the environment immediately above the top part of the package (normally, air or thermal conducting material used together with the heat sink).

Board Node is considered to be in direct thermal contact with the environment immediately below the footprint of the package (normally, the printed circuit board).

The heat from the thermal source of the chip flows in two directions. One flows as radiation and convective heat transfer from the upper surface of the package to the surroundings, or into the heat sink mounted on the top of the package. The other flows into the PCB from the back surface of the package and the lead. Furthermore, no thermal flow is considered to be transferred from the side surfaces of the package to the surrounding fluid in this model.

Figure 2. Physical arrangement of two-resistor thermal model

Overview of thermal resistance test environment

The methods of thermal resistance measurement are described for θ_{JB} in JEDEC Standard JESD51-8 and for θ_{JC} in JESD51-14. Here, an overview of the test environment for the two thermal resistors is explained. See JEDEC Standards for more details.

Test environment for θ_{JB}

For the measurement of θ_{JB}, an environment where the heat generated on Junction Node can be transferred to the board side is used. Figure 3 shows the schematic diagram of the test environment. The ring type cold plate is cooled with fluid (mainly water). The circuit board is clamped with the cold plate from both sides so that heat from the package flows radially in the inner surface of the circuit board. In addition, thermal insulation material is used for the package openings on the top and bottom of the cold plate to block the ambient temperature. The circuit board temperature is measured with the thermocouple. The temperature monitoring point is at the center of one side of the package, and within 1 mm from the periphery.

*1: Simcenter Flotherm™ is a trademark of Siemens Industry Software Inc.

© 2020 ROHM Co., Ltd. 2/4 No. 62AN156E Rev.001 APRIL 2020

Figure 11. Two-Resistor Model for Thermal Simulation (excerpt)

Step 4 Performing accurate thermal measurements

When a prototype is completed, it is necessary to verify that it performs as designed by taking actual measurements. The first element of thermal design to check is "calorific value (power loss)". For the measurement of calorific value, see "Calculating Power Loss from Measured Waveforms" (Fig. 12).

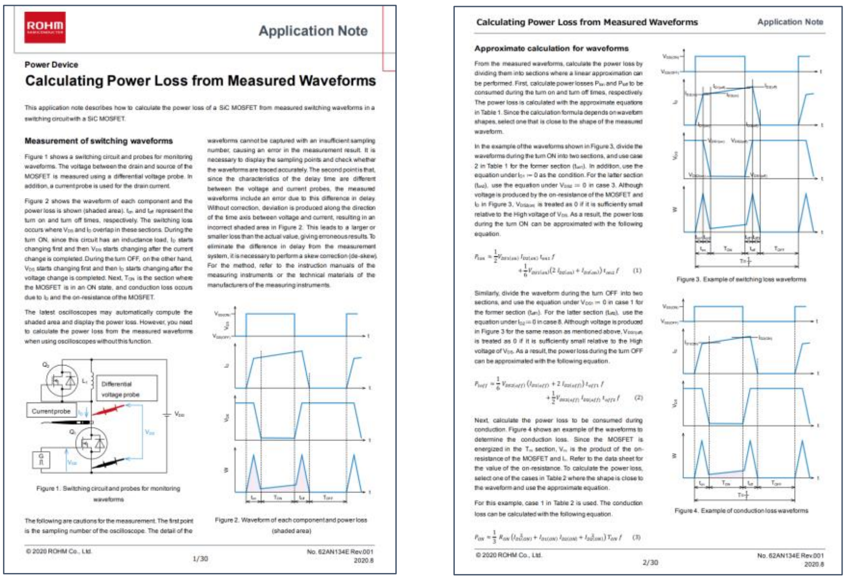

ROHM
Application Note
Power Device
Calculating Power Loss from Measured Waveforms
Measurement of switching waveforms
© 2020 ROHM Co., Ltd. 1/30 No. 62AN134E Rev.001 2020.8
Calculating Power Loss from Measured Waveforms Application Note
Approximate calculation for waveforms
© 2020 ROHM Co., Ltd. 2/30 No. 62AN134E Rev.001 2020.8

Figure 12. Calculating Power Loss from Measured Waveforms (excerpt)

For skew errors, which can be problematic when acquiring waveforms, refer also to "Importance of Probe Calibration When Measuring Power: Deskew" (Fig. 13), which describes the importance of probe deskew.

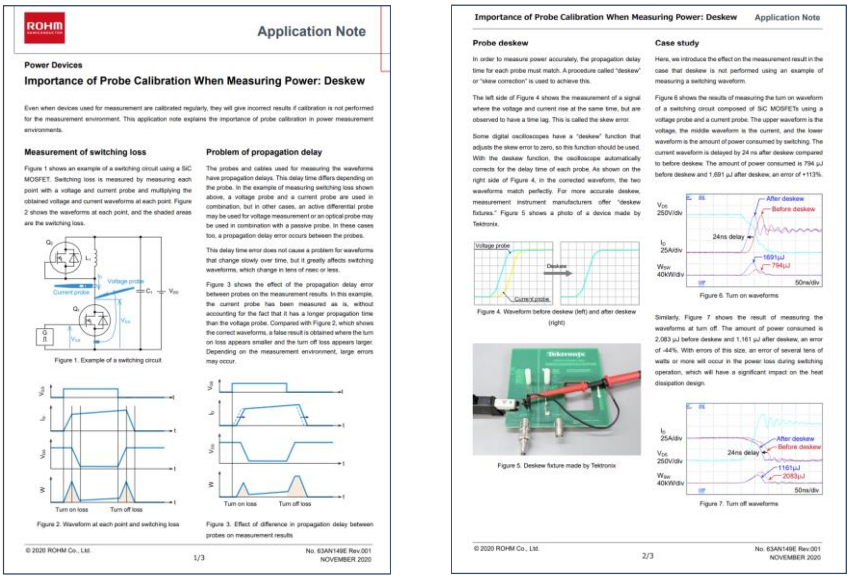

ROHM
Application Note
Power Devices
Importance of Probe Calibration When Measuring Power: Deskew
Measurement of switching loss
Problem of propagation delay
© 2020 ROHM Co., Ltd. 1/3 No. 63AN149E Rev.001 NOVEMBER 2020
Importance of Probe Calibration When Measuring Power: Deskew Application Note
Probe deskew
Case study
© 2020 ROHM Co., Ltd. 2/3 No. 63AN149E Rev.001 NOVEMBER 2020

Figure 13. Importance of Probe Calibration When Measuring Power: Deskew (excerpt)

The last important element is temperature measurement. "Notes for Temperature Measurement Using Thermocouples" (Fig. 14) focuses on the points that may prove problematic when measuring temperature with a thermocouple and presents them together with actual measurement results. "Precautions When Measuring the Rear of the Package with a Thermocouple" (Fig. 15) describes the precautions required when measuring temperature by digging a groove in the rear of the package, something which is rarely done by users. While this method is not recommended for semiconductor vendors, if implementing it, great care must be taken when measuring.

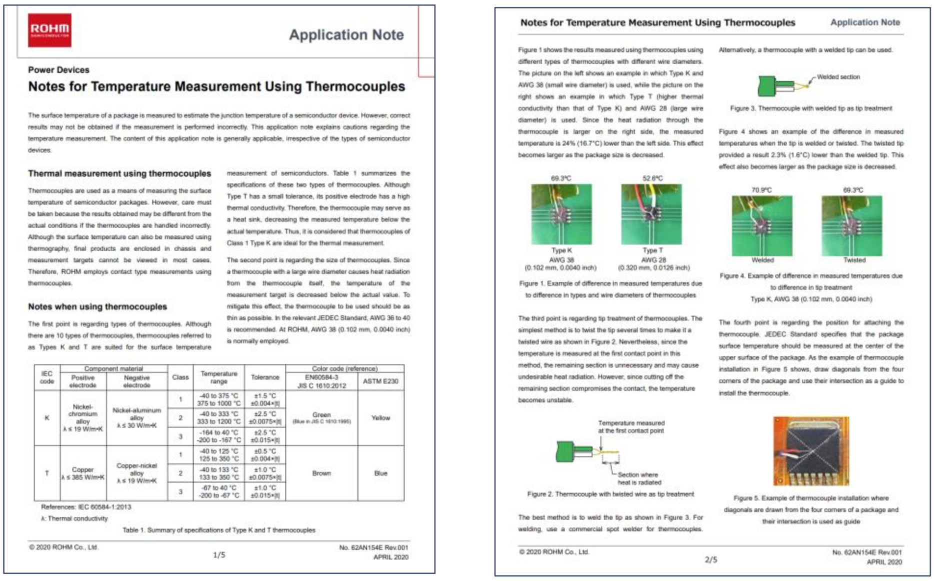


Figure 14. Notes for Temperature Measurement Using Thermocouples (excerpt)

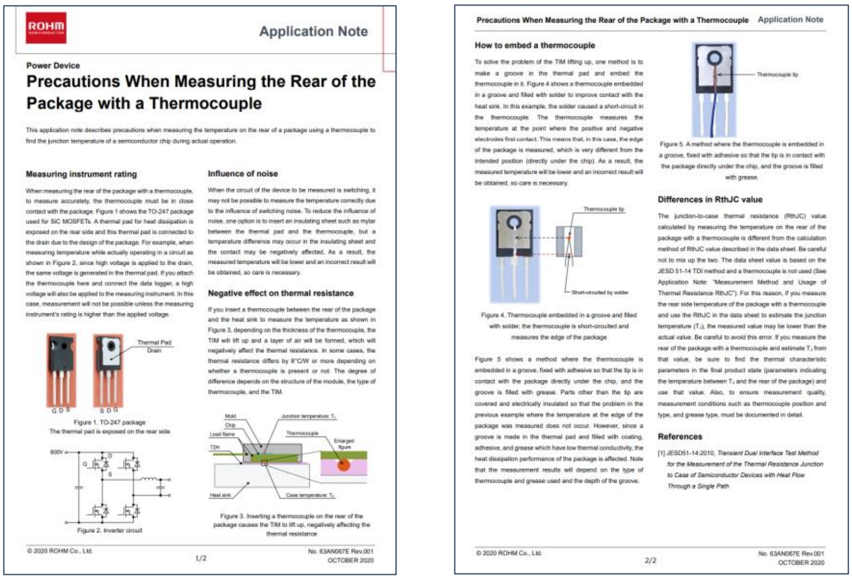


Figure 15. Precautions When Measuring the Rear of the Package with a Thermocouple (excerpt)

Conclusion

In this paper we have provided step-by-step application notes on the thermal design knowledge required to improve set reliability and reduce design rework. ROHM also offers a wide range of other solutions and materials that are optimized for each process, from component selection to simulation, evaluation and board creation, to solve problems encountered by users. We believe that these materials can contribute to speeding up application development by users as well as prevent problems and defects.

Introduced application notes

"What Is Thermal Design?"
https://fscdn.rohm.com/en/products/databook/applinote/common/what_is_thermal_design_an-e.pdf

"Basics of Thermal Resistance and Heat Dissipation"
https://fscdn.rohm.com/en/products/databook/applinote/common/basics_of_thermal_resistance_and_heat_dissipation_an-e.pdf

"Measurement Method and Usage of Thermal Resistance RthJC"
https://fscdn.rohm.com/en/products/databook/applinote/discrete/common/rthjc_measurement_and_usage_an-e.pdf

"Calculation of Power Dissipation in Switching Circuit"
https://fscdn.rohm.com/en/products/databook/applinote/common/pd_calc_power_dissipation_switching_cir_an-e.pdf

"Method for Calculating Junction Temperature from Transient Thermal Resistance Data"
https://fscdn.rohm.com/en/products/databook/applinote/common/tj_from_transient_rth_data_an-e.pdf

"What is a Thermal Model?"
https://fscdn.rohm.com/en/products/databook/applinote/discrete/sic/common/what_is_a_thermal_model_sic_an-e.pdf

"How to Use Thermal Models"
https://fscdn.rohm.com/en/products/databook/applinote/discrete/sic/common/how_to_use_thermal_models_an-e.pdf

"Two-Resistor Model for Thermal Simulation"
https://fscdn.rohm.com/en/products/databook/applinote/common/two_resistor_model_for_thermal_simulation-e.pdf

"Calculating Power Loss from Measured Waveforms"
https://fscdn.rohm.com/en/products/databook/applinote/discrete/sic/common/pd_calc_power_loss_measured_waveform_an-e.pdf

"Importance of Probe Calibration When Measuring Power: Deskew"
https://fscdn.rohm.com/en/products/databook/applinote/common/Importance_probe_calibration_descue_an-e.pdf

"Notes for Temperature Measurement Using Thermocouples"
https://fscdn.rohm.com/en/products/databook/applinote/common/notes_on_temperature_measurement_using_thermocouples_an-e.pdf

"Precautions When Measuring the Rear of the Package with a Thermocouple"
https://fscdn.rohm.com/en/products/databook/applinote/common/precautions_when_measuring_the_rear_of_the_package_with_a_thermocouple_an-e.pdf

References

*1. JESD51-14:2010, Transient Dual Interface Test Method for the Measurement of the Thermal Resistance Junction to Case of Semiconductor Devices with Heat Flow Through a Single Path

ROHM Co., Ltd.
2323 Owen Street,
Santa Clara, CA 95054 U.S.A
TEL : +1-408-720-1900
www.rohm.com

Catalog No. 64WP010E Rev.002