

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.

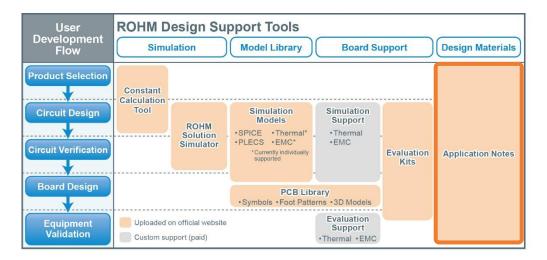


Figure 1. Design and verification support tools provided by ROHM

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 designStep 2 Knowing the thermal properties of each component usedStep 3 Making the best use of thermal simulationsStep 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 "<u>What Is Thermal Design?</u>" (Fig. 2).

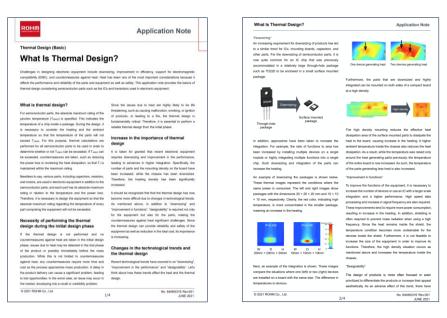


Figure 2. What Is Thermal Design? (excerpt)

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 ("<u>Basics of Thermal Resistance and Heat Dissipation</u>" Fig. 3).

ROHM	Application Note	Basics of Thermal R			Heat radiation: From the surface of an object, and
Thermal Design (Basic)			Fiectric		 Heat radiation: From the surface of an object, an electromagnetic wave is emitted with a wavelengt
Thermal Design (Basic)		Dectric Voltage	resistance	Current (A)	corresponding to the surface temperature. The
Basics of Thormal Resist	ance and Heat Dissipation	ΔV(V) Temperature	R(D)		electromagnetic wave is transmitted through a space and hit
busics of filefillar resist	ance and near Dissipation	Thermal difference	resistance	P (N)	the destination object. The vibration energy of the
An effective the Antonio state and the Antonio state and the Antonio State	sizing, improvement in efficiency, support for electromegnetic	Δ7 (°C)	Rth (*C/W)	. ()	electromagnetic wave causes vibration of molecules on th
	has been one of the most important considerations because it	22			surface of the destination object, transferring heat an
	nt as well as safety. This application note provides the basics of	Eachie Mark and	ΔV		changing the temperature of the destination object. Throug
	suctor parts such as the ICs and transitions used in electronic	Decide The Risk	$B = \frac{\Delta V}{I}$	$l = \frac{m}{R}$	the heat radiation, heat may be transferred without an
ovipment.		Thermal AT	$R_{\rm TR} = \frac{\Delta T}{n}$	$P = \frac{\delta T}{\delta T}$	medium between objects (even in a vacuum). Therefore, causes no change in the surrounding air temperature.
		$= Rth \times P$	$BEB = \frac{1}{p}$	P = Rth	causes no change in the surrounding air temperature.
What is thermal resistance?	and related technologies, uses Rth in the EN 60747-15	Heat transfer and he	at dissipatio	on path	Ö
Permai resistance is a quartification of how difficult it is for	standards for discrete semiconductor devices.	Heat can be transferred through	ch chiects and s	maren Transfer	A DAY
Thermal resistance is a guart/fication of how difficult it is for wat to be conducted. Thermal resistance is represented as	Based on these relationships, in ROHM's data sheets, 0 is	of heat means that the therm			
eat to be conducted. Thermal resistance is represented as the quotient of the temperature difference between two given	Based on these relationships, in RDFW's data sheets, 0 is used for ICs, while Rth is used for discrete devices (with some	place to another.	a energy is using	served adars one	
cents by the heat flow between the two points (amount of heat	used for ruls, while hth is used for discrete devices (with some exceptions).	press of an entering			
forms by the near now between the neo points (amount or near low per unit time). This means that the higher the thermal	exceptions).	Three forms of heat	transfer		
esistance, the more difficult it is for heat to be conducted, and	The unit of thermal resistance is K/W or *C/W (K represents				Heat dissipation path
Ice verse.	kelvins). Although K and "C are different in their absolute	The heat transfer occurs in t			
Temperature difference 47	values (0 K = -273.15°C), they can be treated equivalently in	convection (heat transmission	 and heat radio 	ation.	Generated heat is dissipated to the ambient air via vario
Temperature citerence A7	terms of relative temperatures (K = "C).	Thermal conduction: Here	it is transferred	t from a high	paths through the conduction, radiation, and convection.
71-4-72	122 Million and Million and Million	temperature point to a lo	w temperature	point within an	this section, an IC mounted on a printed circuit board (PCB)
Heat flow P	Thermal Ohm's law	identical object due to mov	ement of moleci	ules composing	used as an example for explanation.
71-72	The thermal resistance can be considered in the same way as	the material. No movement	of the material is	involved.	
Thermal resistance $Rth = \frac{71 - 72}{Heat flaw P}$	the electric resistance. The basic formulas of thermal		14.		
= Temperature difference bT PC/W	calculation can be treated in the same way as Ohm's law. In	(+ 0		- 2 3 2 - Convesto
Heat flow P	the figure below. Ohm's law is represented with an illustration	(L)			
	and equations. It can be seen that the respective parameters				3 3 6 molection 3 8 3 Marketon
is used as the symbol for the electric resistance, while $\boldsymbol{\theta}$	are replaceable by heat and electricity.				1
reta) is used for the thermal resistance. The JEDEC (Joint		24(565)			
ectron Device Engineering Council) Solid State Technology	Voltage difference ΔV				The heat generating source is the chip (die) of the IC. The he
ssociation is a trade organization that standardizes	V7	Convection (heat transmiss			is conducted to the die attach (die bonding), lead frame, ca
eofications in the field of semiconductor parts. In its	Current /	of a fluid when there is a ten			(package), and PCB. The heat is transferred from surfaces
legrated circuit thermal measurement method, part of the	Electric resistance $R = \frac{V1 - V2}{V1 - V2}$	surface of a solid and a flue			the PCB and the IC package to the atmosphere through I
SD51 standards, JEDEC has standardized that $\theta_{\rm N2}$ or $R_{\rm B03}$	Electric resistance R = Current F	contact with the surface. The			convection and radiation. This is represented with a circ
heta-XX, if Greek characters are unavailable) should be	= Voltage difference AV [V/A]	amount of heat compared w	th the thermal co	anduction.	network of resistance elements as follows.
sed. For XX, symbols representing the two given points are	Current / [V/A]				
stered. For example, Bring, Rarrito, or Theta-T1T2 should be					
ed in the case shown in the figure above.	Therefore, as potential difference ΔV is calculated with R + I, temperature difference ΔT can be calculated with Rth + P.	_ +	H		
addition, the IEC (International Electrotechnical	temperature dimenence (a) can be calculated with Rth + P.				
ommission), a global organization that specifies and					
ublishes international standards for all electric, electronic,			1		
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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 175°C is the absolute maximum rating (Fig. 4).

Parameter		Symbol	Value	Unit	
Drain - Source Voltage		V _{DSS}	650	V	
Continuous Drain current	$T_c = 25^{\circ}C$	I _D *1	70	Α	
Continuous Drain current	$T_c = 100^{\circ}C$	I _D *1	50	Α	
Pulsed Drain current		I _{D,pulse} *2	175	Α	
Gate - Source voltage (DC)		V _{GSS}	-4 to +22	V	
Gate - Source surge voltage (t _{surg}	_e < 300ns)	V _{GSS_surge} *3	-4 to +26	V	
Recommended drive voltage		V _{GS_op} *4	0 / +18	V	
Junction temperature		Tj	175	°C	
Range of storage temperature		T _{stg}	-55 to +175	°C	

•Absolute maximum ratings (T_a = 25°C)

Figure 4. Example of absolute maximum ratings in data sheet (<u>SCT3030AW7</u>)

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

•Thermal resistance

Parameter	Symbol		Values		Unit
Falameter	Symbol	Min.	Тур.	Max.	Unit
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}. "<u>Measurement Method and Usage of Thermal Resistance RthJC</u>" (Fig. 6), which describes how to measure RthJC and which points to pay attention to, presents information that any power device user should know.

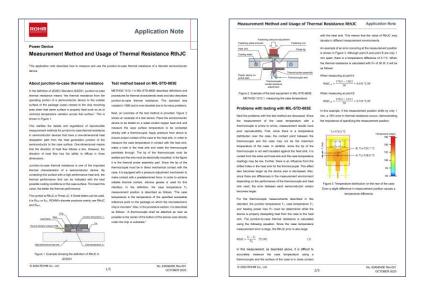


Figure 6. Measurement Method and Usage of Thermal Resistance RthJC (excerpt)

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. "<u>Calculation of Power Dissipation in</u> <u>Switching Circuit</u>" describes how to calculate calorific value (power loss) in inductance load switching (Fig. 7).

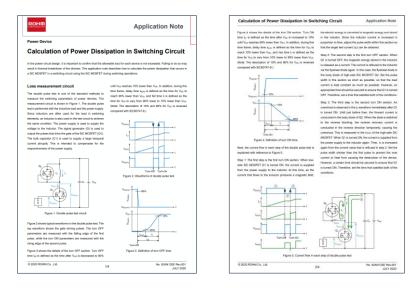
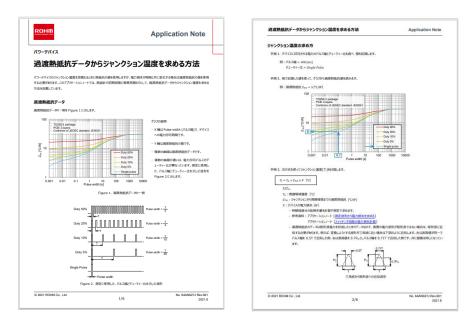
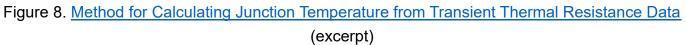


Figure 7. Calculation of Power Dissipation in Switching Circuit (excerpt)



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. "<u>Method for</u> <u>Calculating Junction Temperature from Transient Thermal Resistance Data</u>" (Fig. 8) describes how to determine junction temperature from the transient thermal resistance data.







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.

ROHM	Application Note	What is a Thermal Model?	Application Not
SiC Power Device		Next, the simulation circuit and the device configuration are shown in Figures 3 and 4, respectively. From Equations (1) and (2), a voltage with an RC time constant is generated in the T	rises. The heat capacity of an object is defined as the amoun heat required to raise the temperature of the object by ' (selvin). The unit of heat capacity is JK (joule per kelvin)
What is a Thermal Mod	el?	pin by applying the power consumption P_0 of the device to the T) pin as a current I and applying the ambient temperature $T_{\rm A}$	some countries, W s/K (walt second per kelvin) is also un (equal to J/K). In addition, K and *C are considered equal wh
Among SPICE models, there are models for performing simulations Simulations using the thermal models are performed to make a application note explains the thermal models.		to the Ta pin as a bits voltage Vaue. This generated voltage represents the junction temporature. In addition, the resistance connected to the To pin is R1 that is thermal resistance between the case and the heat simil, (Ra _C) and R2 that is thermal resistance between the heat similar and the unitient	beating relative temperatures. Since it is necessary to replace this heat capacity with electrical model, heat capacity is tratated as capacitance or capacitor in thermal models. Figure 5 shows the circuit or thermal model. This is referent to as a Caure FC temmat or
Definition of thermal resistance Fint, we explain the definition of thermal resistance. Thermal resistance is a quartification of how difficult it is for heat to be	What is a thermal model? In a thermal model, a location corresponding to transient thermal resistance is replaced by an electrical circuit model, so that the	temperature (Rena). Recr includes the thermal resistance of the thermal interface material (TIM) and the contact thermal resistance. C1 is the heat capacity of the heat sink. R2 and C1 comorise the heat air/k.	network. By applying voltage (= arritient temperature) to the pin and applying current (= power consumption of the device the Tj pin, a voltage (= temperature) with an RC time constant
conducted. Using a diagram and equation, thermal resistance is represented as the quotient of the temperature difference	transient thermal resistance characteristics can be calculated using an electrical circuit.	Harrish PCAV - Roadt NO	generated on the T) pin.
between 2 given points by the heat flow between the 2 points (amount of flow per unit time, power consumption) P, as shown in Figure 1.	The junction temperature T_i can be calculated by Equation (1). $T_i = R_{IRM} \times R_i + T_A [9]$ (1)	V(M - 1.(C) V(M - 1.(C) Prove 1004 - 0.0010 Prove 1004 - 0.0010 Prov	R1 R24 BKW 213 BKW 213 BKW 71 C C C C C C C C C C C C C C C C C C
Temperature difference ΔT $T_1 \longrightarrow T_p$	$\label{eq:response} The matrix of the term investion and ankiest superstance [C/W] \\ R_{max}(Thermal residues between junction and ankiest superstance [C/W] \\ R_{pl}(Power consumption of derive [W] \\ T_{pl}(Archivent temperature ['C]) \\$		Figure 5. Example of thermal model: Cauer RC thermal orcoit ne SIC MOSFET manufactured by ROHM: SCT3040KR
Heat flow P Thermal resistance R_{ijk} $= \frac{T_1 - T_2}{Rest flow P} = \frac{Temperature difference dT}{Rest flow P} [°C/W]$	Replacing a thermal circuit with an electrical circuit according to the definition of thermal resistance described above yields Equation (2).	Figure 3. Example of simulation circuit	Next, Figure 6 shows the netlist of SPICE. As a subcircuit, va of R and C are described.
Figure 1. Definition of thermal resistance	Thermal circuit Electrical circuit R _B ("CW) -> R (Ω)	Correct human rold dates	SCIDADD.1 Sci MADDET with driver surrow Self-heating Thermal made TOPY 554 Abodh Model Generated by FEMM Add B Mathematical
As these diagram and equation look familiar, they can be treated equivalently to Ohm's law. Figure 2 shows Ohm's law using a diagram and equation. It can be seen that the respective	$P \subseteq \{M\}$ $\rightarrow I[A]$ $T_A ["C] \rightarrow V_{BALL}[M]$	Junter January Stran	 Commercial Unit of Resalt Restricted Date: 2011/02109 Date: 2012/02109 Dat
parameters are replaceable by heat and electricity.	$V = R \times l + V_{HAI}$ [V] (2) R: Electrical resistance corresponding to thermal resistance [Ω] 1: Current corresponding to power consumption of device [Λ]	Interpretation T ₀	PARC K1(T) 009(00(1,11),12)) Omitted C21 Ta 1,355e
	$V_{\rm MAR}$: Bias voltage corresponding to ambient temperature $[V]$	Figure 4. Device configuration	022 12 Ta 10 00w 023 13 h 05 72m R21 12 17 10 5 72m R22 12 12 10 10 00 R22 12 12 10 100
$Electric \ resistance \ R = \frac{V_1 - V_2}{Current \ I} = \frac{Voltage \ difference \ \Delta V}{Current \ I} V .$	u .	Actual thermal model Due to heat capacity of objects, temperature will not increase immediately even when the power consumption of the device is	R22 12 To 219.86 BBS S013040R.1 Figure 6. Example of netlist SiC MOSFET manufactured by ROHM SCT3040KR
Figure 2. Ohm's law		increased. Hest capacity represents how easily temperature can change. The larger the heat capacity, the slower temperature	
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Figure 9. What is a Thermal Model? (excerpt)

ROHM	Application Note	How to Use Thermal Models	Application
SIC Power Devices		1+ SCID0400L1 2+ SUC MMCFEI with driver source Self-feating Thermal model	
How to Use Thermal Me	odels	1 = 12000 354 Aladoms 4 = Model Generated by H2000 5 = All Eights Reserved 6 = Commercial Div or Possis Restricted 7 = Done 2010 All 00	
	ons in relation to healt, which are inflored to as thermal models. I rough estimate during the initial stage of thermal design. This	3 4	
Obtaining thermal models	consumption (self-heating) generated by the SiC MOSFET	16 + 559.5e+4520H(1/3.097)+E3P(17-10)/-1246(+25.41e+1+E3P(17-1 17)_PUNC V2 (V_1) 121.45e+0+43.56403P(17-10)/a0.53+E3P(17-10)/-126031	dl./498.573
Thermal models are available from ROHM's website. From the search window, search for the model name and click on the applicable model name in the results. This will take you to the induktail product ongo, where you can select the design model in the "TOOLS" tab and download the thermal calculation model.	electrical model to the thermal model. For this reason, voltage equivalent to the junction temperature is generated in the Tj pin when the electrical circuit simulation is performed in the usual way. Now, left table a brief look at the contents of the netlist. To	 (a) (MR 107.0): B) (C) (C) (C) (C) (C) (C) (C) (C) (C) (C	0/-174 1000
Overview of thermal models	explain the function for transferring the power consumption that occurs on the SiC MOSFET to the thermal model, we have	22 (82 - 5 32 10 28 (85 - 4 32 10 29 (85 - 41 - 0 VALUE - (80 N SMA (9 (22, 32), 6), 22)) 29 (85 - 41 - 0 VALUE - (80 N SMA (9 (22, 32), 6), 22))	
Figure 1 shows an example of a thermal model. The example is or a 1,200V Noh SiC MOSFET SCT3040KR, and the same diagram is also shown on the data sheet. The Tj pin shows the unclose temperature, the Tc pin shows the case temperature,	extracted the circuits for only the major parts of the netled, as shown in Figure 4. The dagram is breaken into three blocks. Block A is for the SCI MOSFET; block B is for the body diode; and block C is for the thermal nesistance model.	5 (a) 22 - 42 - 42 - 52 - 52 - 52 - 52 - 52 -	
and the Ta pin shows the ambient temperature.	Comparing with the netlist on Figure 3, we can see that block A	38 V3 22 23 0 39 C1 23 12 10	
$\begin{array}{c} \begin{array}{c} R23 \\ R23 \\ T_{j} \rightarrow \end{array} \\ \begin{array}{c} R23 \\ R$	corresponds with lines 13 through 42; block 8 corresponds with lines 44 through 35, and block. Corresponds with lines 55 through 42, 128 on line 55 (training-controlled vidage source) and R20 on line 56 (training) are component used to trainifier the power communication of the BIC MOSFET and body diale to the Tip and the training lines model as the current annount.	64/2 21/2 64/2 21/2 64/2 21/2 64/2 <td< td=""><td>01/203.001 4.05-029 ((1-10)/261.01)- </td></td<>	01/203.001 4.05-029 ((1-10)/261.01)-
Figure 1. Example of thermal model: Cauer RC thermal circuit network	corresponding to the power consumption to the Tj pin. However, as the output impedance of the current source is high and the	10 (41.52) 1 (42.16) 400 (101 (V 32.10) K1 (V (1.01)), -3461, 3000 +1 (V12+C11 3440) 52 (81.152) 1 (17 53	
SIC MOSFET manufactured by ROHM: SCT3040KR	convergence for the initial value may not be good, the current source for low output impediance is expressed as the	55 E20 TE Ta VALME (N+RHOMMER(F/TEM)-0, (TVT)-1(V(T))+V(T, 2)+CV2+V(2, 2), 0 56 R(0) TE 5 (K, 10 5) (K, 10 5) 57 Z(2) T 5 TA 1 2006	/,-2MEQ), 2MEB()
igure 3 shows the netlist for the thermal model that was townloaded. Both the electrical and thermal models for the SiC ACSFET are shown in this netlist. The chip and pin configuration as shown in the cricit diagram of Figure 2.	combination of the voltage source and output resistance. The NAQ value of output impedance R20 is a sufficiently large value for thermal resistance.	14 (22) 21 21 10 (0.0m) 19 (27) 21 15 .05 .72m 40 (27) 17 12 25 .54m 41 (27) 17 12 25 .54m 41 (27) 17 13 .104 .4m 42 (27) 17 15 .210 .4m 43 (27) 17 15 .210 .4m	
as shown in the origin dugate of Pigule 2.		Figure 3. Example of a thermal model n SIC MOSFET manufactured by ROHM: SC1	
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Figure 10. How to Use Thermal Models (excerpt)



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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 "<u>Two-Resistor Model for Thermal Simulation</u>" (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.

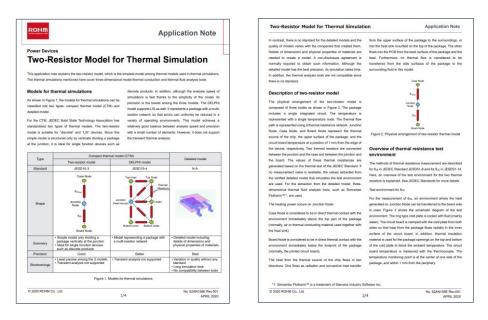


Figure 11. Two-Resistor Model for Thermal Simulation (excerpt)



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 "<u>Calculating Power Loss from Measured</u> <u>Waveforms</u>" (Fig. 12).

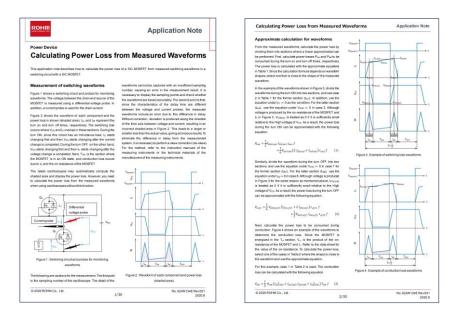


Figure 12. Calculating Power Loss from Measured Waveforms (excerpt)

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

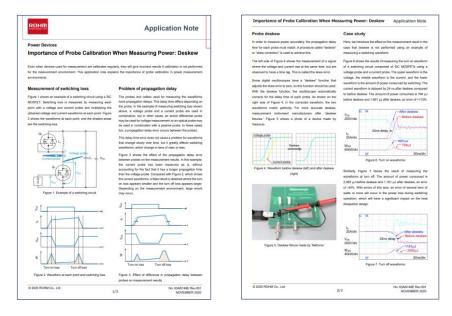


Figure 13. Importance of Probe Calibration When Measuring Power: Deskew (excerpt)



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The last important element is temperature measurement. "<u>Notes for Temperature</u> <u>Measurement Using Thermocouples</u>" (Fig. 14) focuses on the points that may prove problematic when measuring temperature with a thermocouple and presents them together with actual measurement results. "<u>Precautions When Measuring the Rear of the Package</u> <u>with a Thermocouple</u>" (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.

	I					Applicatio	n Note	Notes to	r tempera	ature Meas	arement Us	ing Thermoco	ouples	Applicat	ion Noti
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hermogra	aphy, final produ ment targets car	erature can also be cts are enclosed nnot be viewed is contact type meas	in chass n most	s and Class cases. The s	econd point is	deal for the thermal mean regarding the size of the a large wire diameter car	mocouples. Since	AU	pe K /G 38 (0.0040 inch)	Typ AWI (0.329 mm		Weld		Twisted	
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Figure 14. Notes for Temperature Measurement Using Thermocouples (excerpt)

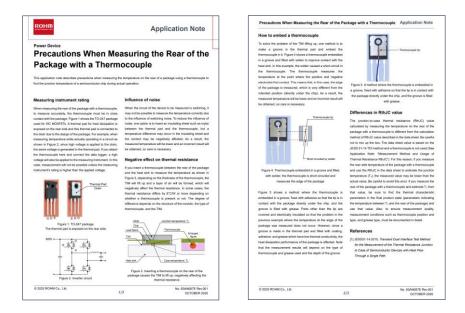


Figure 15. <u>Precautions When Measuring the Rear of the Package with a Thermocouple</u> (excerpt)



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



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