Current sense amplifiers, Shunt resistors, TVS diodes

Thermal Evaluation of Current Sensing Circuit Using Shunt Resistor

High-precision current sensing circuits are utilized in various applications for stable operation, improved characteristics, and enhanced safety. In a current sensing circuit using shunt resistor, heat generation from the shunt resistors is a concern. This application note provides evaluation data of heat generation of shunt resistors that used for reference designs of high-precision current sensing circuits using the shunt resistor (REF68011, REF68012, REF68013, REF68014, and REF68015). The data can help you to understand the differences in heat generation for different shunt resistor types with the same board and different board patterns using the same shunt resistor. Refer to the data when selecting the best shunt resistor for the target equipment specifications.

Overview of reference designs and the shunt resistors evaluated

Table 1 shows the reference designs listed in "Design Guide of Current Sensing Circuit Using Shunt Resistor". It is necessary to select shunt resistors while taking the temperature rise into account. Several shunt resistors are selected for each reference design to evaluate the heat generation.

Note: Please contact our sales representative regarding heat generation by shunt resistors or under current conditions that are not covered in this document. You can receive support for thermal measurements and simulations.

Table 1. Current sensing circuit using shunt resistor: overview of reference designs

	REF68011	REF68012	REF68013	REF68014	REF68015
System Voltage	12 V	24 V	48 V	48 V	48 V
Sensing current	20 A	30 A	50 A	100 A	100 A
Sensing direction	Unidirectional	Unidirectional	Unidirectional	Unidirectional	Bidirectional
Current sense amplifier	BD14211G-LA 26 V, 50 V/V	BD14222G-C 40 V, 100 V/V	BD14232FVJ-C 80 V, 100 V/V		BD14231FVJ-C 80 V, 50 V/V
Shunt resistor	PMR100HZPFV2L00 2 mΩ	PMR100HZP7FV1L00 1 mΩ	PMR100HZP7FV1L50 Two in parallel, 1.5 mΩ//2 = 0.75 mΩ	PMR100HZP7FV0L50 Two in parallel, 0.5 mΩ//2 = 0.25 mΩ	
	PSR100KTQFJ2L00 2 mΩ	PMR100HZP7FV1L50 1.5 mΩ	PMR100HZP7FV1L00 1 mΩ	PSR100KTQFF0L50 Two in parallel, 0.5 mΩ//2 = 0.25 mΩ	
TVS diode	VS20VUA1VWM VS20VUA1VWMTF	VS30VUA1VWM VS30VUA1VWMTF	VS64VLNVWM VS64VLNVWMTF		

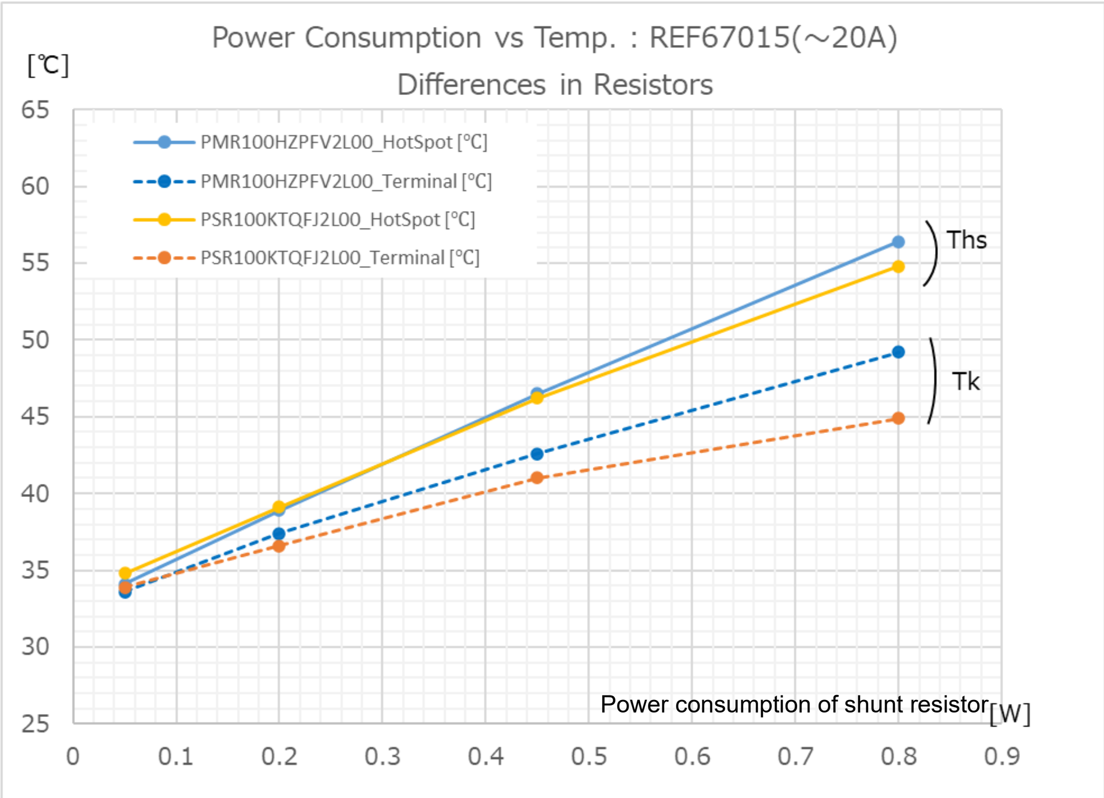
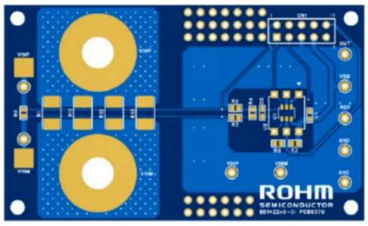
Note: Heat generation by shunt resistors is evaluated with several types of shunt resistors. Make selections according to your design standards.

Evaluation of heat generation by shunt resistors

Tables 2 to 6 show the evaluation results of heat generation by selected shunt resistors.

See Table A-1 in Appendix 1 for the temperature measurement points of Ths (hot spot) and Tk (terminal).

Table 2. Evaluation of heat generation by shunt resistors for REF68011

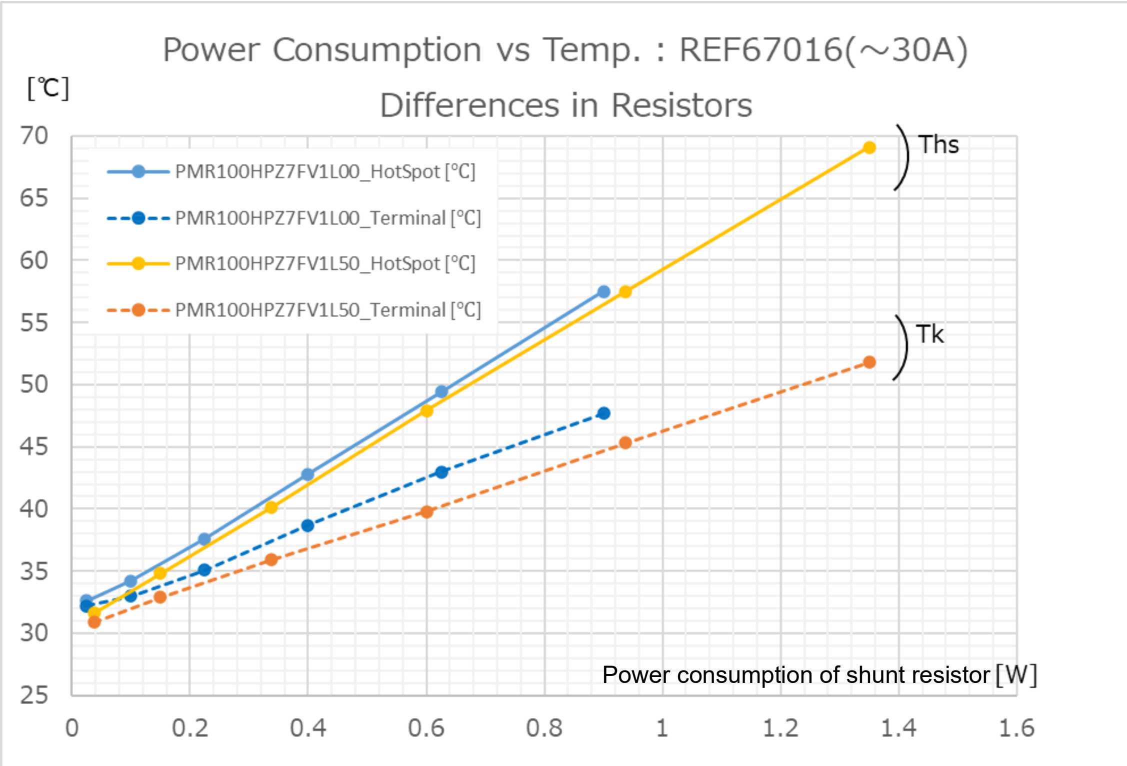
<table>
<tr><th rowspan="2">Reference design No.</th><th rowspan="2">Shunt resistor</th><th rowspan="2">Sensing current [A]</th><th rowspan="2">Shunt resistor [mΩ]</th><th rowspan="2">Power consumption [W]</th><th colspan="2">Temperature rise of shunt resistor</th></tr>
<tr><th>Ths (hot spot)</th><th>Tk (terminal)</th></tr>
<tr><td rowspan="2">REF68011</td><td>PMR100HZPFV2L00</td><td>20</td><td>2.0</td><td>0.8</td><td>56.4°C at 20 A, 0.8 W</td><td>49.2°C at 20 A, 0.8 W</td></tr>
<tr><td>PSR100KTQFJ2L00</td><td>20</td><td>2.0</td><td>0.8</td><td>54.8°C at 20 A, 0.8 W</td><td>44.9°C at 20 A, 0.8 W</td></tr>
<tr><td>Evaluation result</td><td colspan="6">
</td></tr>
<tr><td>Board information</td><td colspan="6">BD1422xG-EVK-001/BD1423xFVJ-EVK-001 (area on which resistors are mounted with the same board pattern)
Pattern size of area with shunt resistors mounted: 25 mm × 20 mm, 2 layers
Thermal via: 0.3Φ, layout as shown in the figure
Parts other than shunt resistors were not mounted for evaluation.
Ta=Room

</td></tr>
</table>

Note: The horizontal axis of the graph is the power consumption calculated from the resistor value (designed value) and the applied current. Resistance variation and temperature characteristics are not taken into account.

Table 3. Evaluation of heat generation by shunt resistors for REF68012

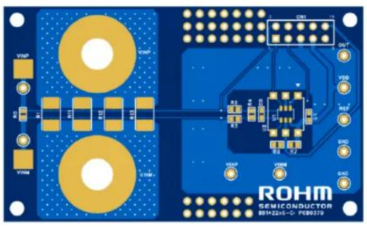
Reference design No.	Shunt resistor	Sensing current [A]	Shunt resistor [mΩ]	Power consumption [W]	Temperature rise of shunt resistor	
					Ths (hot spot)	Tk (terminal)
REF68012	PMR100HZP7FV1L00	30	1.0	0.9	57.5°C at 30 A, 0.9 W	47.7°C at 30 A, 0.9 W
	PMR100HZP7FV1L50	30	1.5	1.35	69.1°C at 30 A,1.35 W	51.8°C at 20 A, 1.35 W

Evaluation result



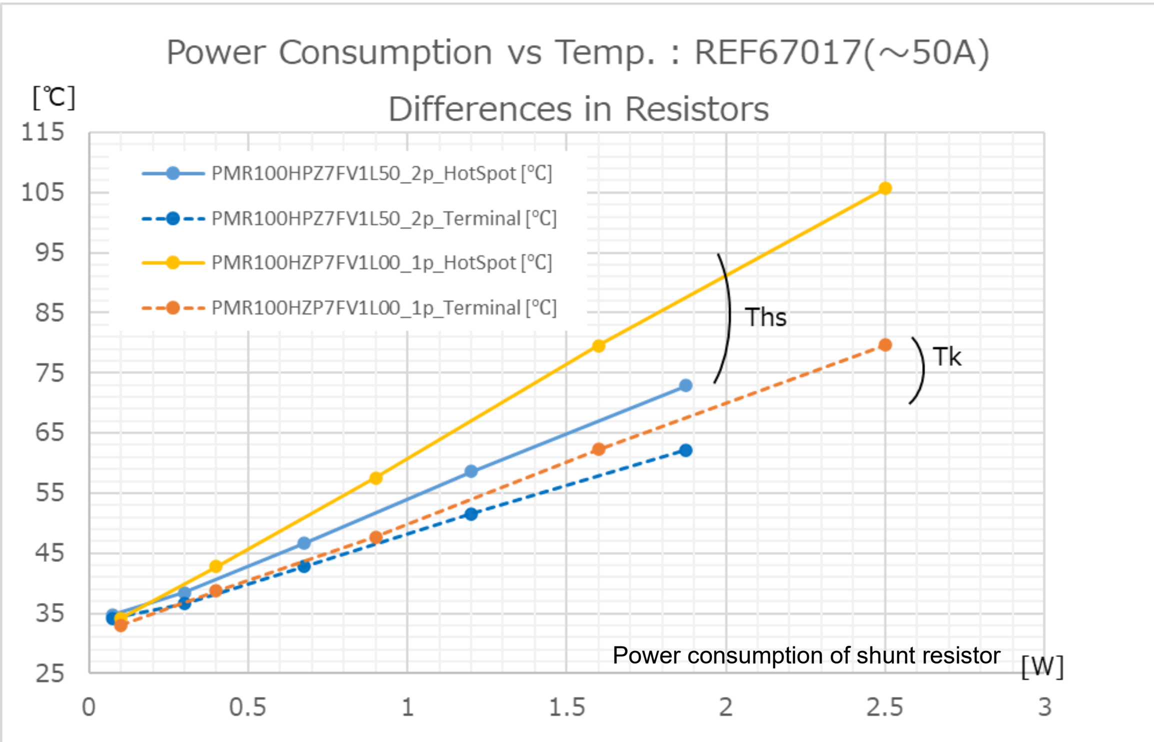
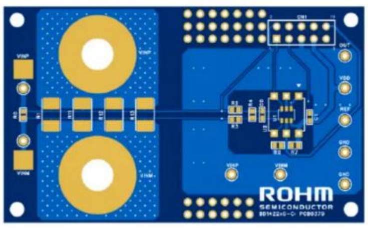
Board information

BD1422xG-EVK-001/BD1423xFVJ-EVK-001 (area on which resistors are mounted with the same board pattern)
Pattern size of area with shunt resistors mounted: 25 mm × 20 mm, 2 layers
Thermal via: 0.3Φ, layout as shown in the figure
Parts other than shunt resistors were not mounted for evaluation.
Ta=Room



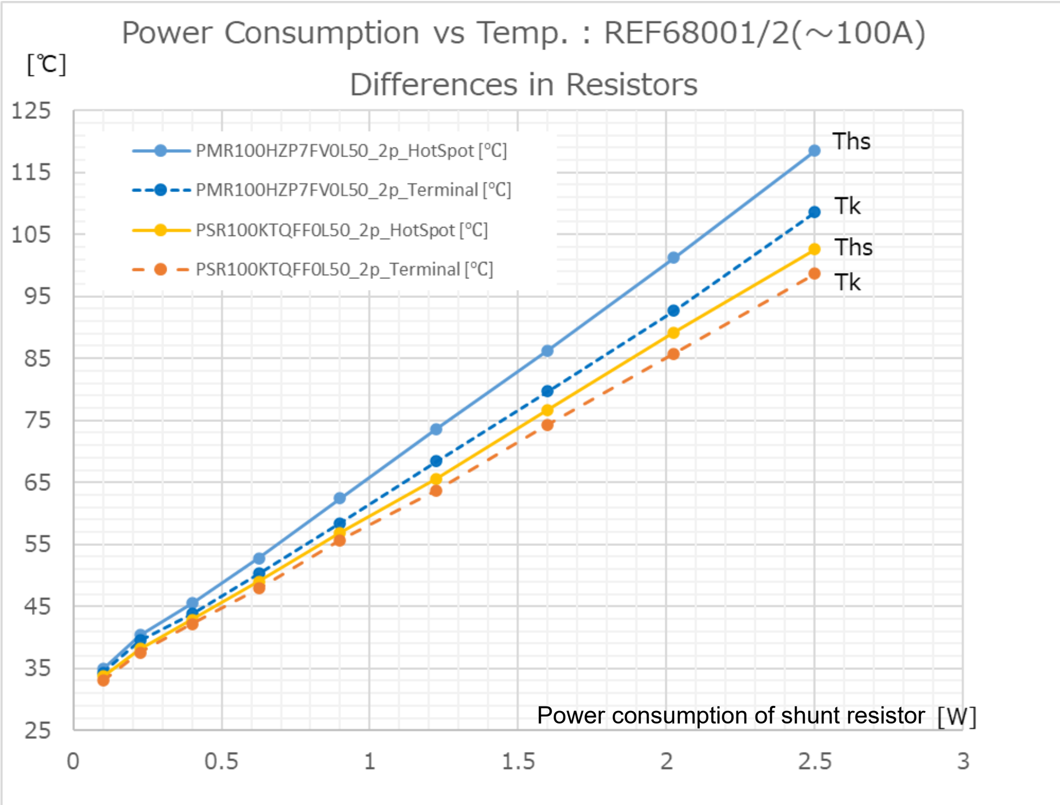
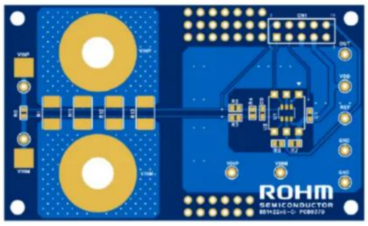
Note: The horizontal axis of the graph is the power consumption calculated from the resistor value (designed value) and the applied current. Resistance variation and temperature characteristics are not taken into account.

Table 4. Evaluation of heat generation by shunt resistors for REF68013

<table>
<tr><td rowspan="2">Reference design No.</td><td rowspan="2">Shunt resistor</td><td rowspan="2">Sensing current [A]</td><td rowspan="2">Shunt resistor [mΩ]</td><td rowspan="2">Power consumption [W]</td><td colspan="2">Temperature rise of shunt resistor</td></tr>
<tr><td>Ths (hot spot)</td><td>Tk (terminal)</td></tr>
<tr><td rowspan="2">REF68013</td><td>PMR100HZP7FV1L50</td><td>50</td><td>0.75 (Two in parallel)</td><td>1.88</td><td>72.9°C at 50A, 0.88 W</td><td>62.2°C at 50 A, 0.88 W</td></tr>
<tr><td>PMR100HZP7FV1L00</td><td>50</td><td>1.0</td><td>2.5</td><td>105.7°C at 50A,2.5 W</td><td>79.6°C at 50 A, 2.5 W</td></tr>
<tr><td>Evaluation result</td><td colspan="6">
</td></tr>
<tr><td>Board information</td><td colspan="6">BD1422xG-EVK-001/BD1423xFVJ-EVK-001 (area on which resistors are mounted with the same board pattern)
Pattern size of area with shunt resistors mounted: 25 mm × 20 mm, 2 layers
Thermal via: 0.3Φ, layout as shown in the figure
Parts other than shunt resistors were not mounted for evaluation.
Ta=Room

</td></tr>
</table>

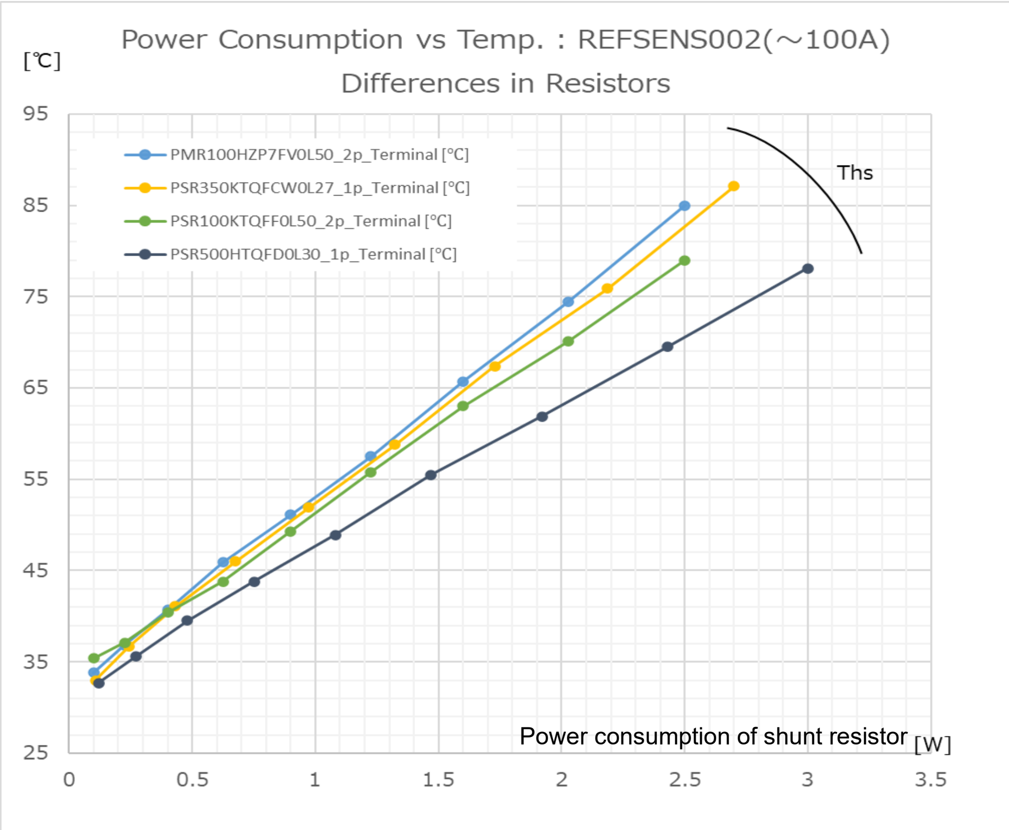
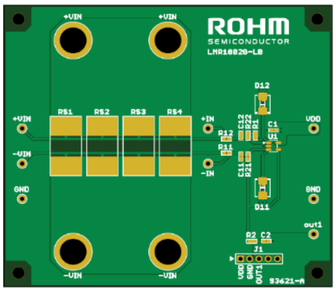
Note: The horizontal axis of the graph is the power consumption calculated from the resistor value (designed value) and the applied current. Resistance variation and temperature characteristics are not taken into account.

Table 5. Evaluation of heat generation by shunt resistors for REF68014/REF68015

Reference design No.	Shunt resistor	Sensing current [A]	Shunt resistor [mΩ]	Power consumption [W]	Temperature rise of shunt resistor	
					Ths (hot spot)	Tk (terminal)
REF68014 REF68015	PMR100HZP7FV0L50	100	0.25 (Two in parallel)	2.5	118.5°C at 100A, 2.5 W	108.6°C at 100A, 2.5 W
	PSR100KTQFF0L50	100	0.25 (Two in parallel)	2.5	102.6°C at 100A, 2.5 W	96.7°C at 100A, 2.5 W
Evaluation result						
Board information	BD1422xG-EVK-001/BD1423xFVJ-EVK-001 (area on which resistors are mounted with the same board pattern) Pattern size of area with shunt resistors mounted: 25 mm × 20 mm, 2 layers Thermal via: 0.3Φ, layout as shown in the figure Parts other than shunt resistors were not mounted for evaluation. Ta=Room 					

Note: The horizontal axis of the graph is the power consumption calculated from the resistor value (designed value) and the applied current. Resistance variation and temperature characteristics are not taken into account.

Table 6. Evaluation of heat generation by shunt resistors for REFSENS002 board

<table>
<tr><th rowspan="2">Reference design No.</th><th rowspan="2">Shunt resistor</th><th rowspan="2">Sensing current [A]</th><th rowspan="2">Shunt resistor [mΩ]</th><th rowspan="2">Power consumption [W]</th><th colspan="2">Temperature rise of shunt resistor</th></tr>
<tr><th>Ths (hot spot)</th><th>Tk (terminal)</th></tr>
<tr><td rowspan="4">REFSENS002</td><td>PMR100HZP7FV0L50</td><td>100</td><td>0.25 (Two in parallel)</td><td>2.5</td><td>95.5°C at 100A,2.5 W</td><td>85.0°C at 100 A, 2.5 W</td></tr>
<tr><td>PSR100KTQFF0L50</td><td>100</td><td>0.25 (Two in parallel)</td><td>2.5</td><td>84.3°C at 100A, 2.5 W</td><td>79.0°C at 100 A, 2.5 W</td></tr>
<tr><td>PSR350KTQFCW0L27</td><td>100</td><td>0.27</td><td>2.7</td><td>94.9°C at 100A,2.7 W</td><td>87.1°C at 100 A, 2.7 W</td></tr>
<tr><td>PSR500HTQFD0L30</td><td>100</td><td>0.3</td><td>3.0</td><td>87.1°C at 100A,3.0 W</td><td>78.1°C at 100 A, 3.0 W</td></tr>
<tr><td>Evaluation result</td><td colspan="6">
</td></tr>
<tr><td>Board information</td><td colspan="6">REFSENS002-EVK-001
Pattern size of area with shunt resistors mounted: 40 mm × 35 mm, 4 layers
Thermal via: 0.3Φ, layout as shown in the figure
Parts other than shunt resistors were not mounted for evaluation.
Ta=Room

</td></tr>
</table>

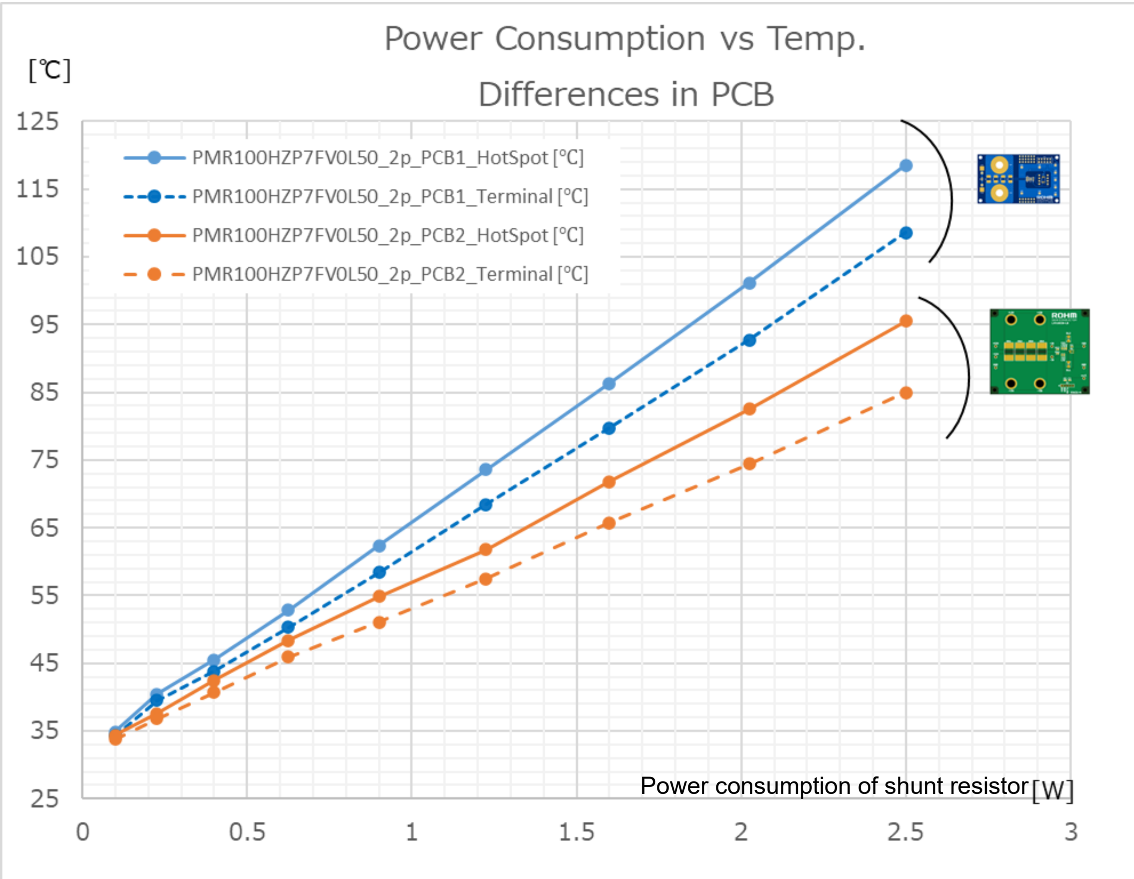
Note: The horizontal axis of the graph is the power consumption calculated from the resistor value (designed value) and the applied current. Resistance variation and temperature characteristics are not taken into account.

Comparison of heat generation with different board patterns

The following is a comparison of heat generation by shunt resistors for two board types with the same shunt resistor and different patterns of the area with shunt resistors mounted.

For details of the boards, see “Boards used for evaluation of heat generation by shunt resistors” in Appendix 1.

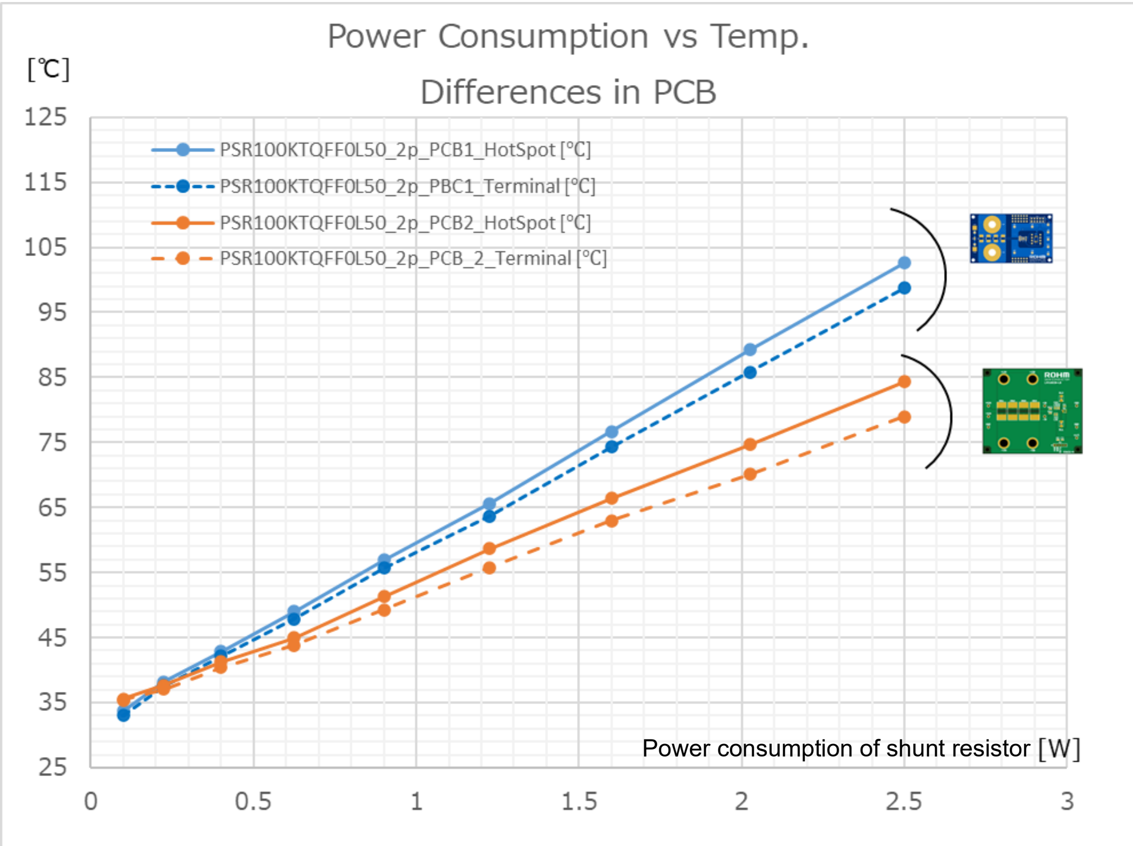
Table 7. Comparison of heat generation by shunt resistors: difference in heat generation with different board patterns (1)

<table>
<tr><td rowspan="2">Reference design No.</td><td rowspan="2">Shunt resistor</td><td rowspan="2">Sensing current [A]</td><td rowspan="2">Shunt resistor [mΩ]</td><td rowspan="2">Power consumption [W]</td><td colspan="2">Temperature rise of shunt resistor</td></tr>
<tr><td>Ths (hot spot)</td><td>Tk (terminal)</td></tr>
<tr><td>REF68014
REF68015</td><td rowspan="2">PMR100HZP7FV0L50</td><td>100</td><td>0.25 (Two in parallel)</td><td>2.5</td><td>118.5°C at 100A, 2.5 W</td><td>108.6°C at 100A, 2.5 W</td></tr>
<tr><td>REFSENS002</td><td>100</td><td>0.25 (Two in parallel)</td><td>2.5</td><td>95.5°C at 100A, 2.5 W</td><td>85.0°C at 100A, 2.5 W</td></tr>
<tr><td>Evaluation result</td><td colspan="6">The temperature rise varies significantly depending on the board pattern (if the same current is passed through the same resistor).
Ta=Room

</td></tr>
</table>

Note: The horizontal axis of the graph is the power consumption calculated from the resistor value (designed value) and the applied current. Resistance variation and temperature characteristics are not taken into account.

Table 8. Comparison of heat generation by shunt resistors: difference in heat generation with different board patterns (2)

Reference design No.	Shunt resistor	Sensing current [A]	Shunt resistor [mΩ]	Power consumption [W]	Temperature rise of shunt resistor	
					Ths (hot spot)	Tk (terminal)
REF68014 REF68015	PSR100KTQFF0L50	100	0.25 (Two in parallel)	2.5	102.6°C at 100A, 2.5 W	96.7°C at 100A, 2.5 W
REFSENS002		100	0.25 (Two in parallel)	2.5	84.3°C at 100A, 2.5 W	79.0°C at 100A, 2.5 W
Evaluation result	The temperature rise varies significantly depending on the board pattern (if the same current is passed through the same resistor). Ta=Room					



Note: The horizontal axis of the graph is the power consumption calculated from the resistor value (designed value) and the applied current. Resistance variation and temperature characteristics are not taken into account.

Summary

Heat generation by shunt resistors is evaluated with the published reference designs of current sensing circuits. Differences in heat generation with different shunt resistors and different board patterns are shown. It can be seen that the heat generation temperature varies depending on the shunt resistor type and the board pattern. The results can be utilized to avoid problems with the thermal design by selecting the best shunt resistor and designing the best board pattern according to the target device specifications.

Thermal simulations are effective for estimating heat generation more precisely. The thermal simulations can calculate heat generation with an error level of a few percent by modeling the boards and the heat dissipation conditions more closely to actual equipment. Please contact our sales representative for support regarding detailed thermal simulations.

References

Low-Side Current Sensing Circuit Design (Application Note)

REFSENS002 – Reference Design: Low Side, 100A, Current Sensing with Op-Amp

REFSENS003 – Reference Design: Low Side, 30A, Current Sensing with Current Sense Amplifire

AEC-Q100 Qualified Automotive Current Sense Amps (Brochure)

Method of Suppressing Increase in Surface Temperature of Shunt Resistors

Effect of PCB Design on Temperature Coefficient of Resistance

PCB Layout Guideline for Current Sensing Circuit using Shunt Resistor

Authored by

Kunihiro Komiya, Application Engineer

Takuya Hashimoto, Application Engineer

Appendix1
Evaluation environment

The evaluation environment is summarized as follows. The evaluation equipment was shielded inside a paper box of 36 cm × 24 cm × 22cm to prevent any influences by air convection, etc. in the surroundings. The thermal camera was installed inside the box. The current was passed through the shunt resistor while monitoring the temperature rise.

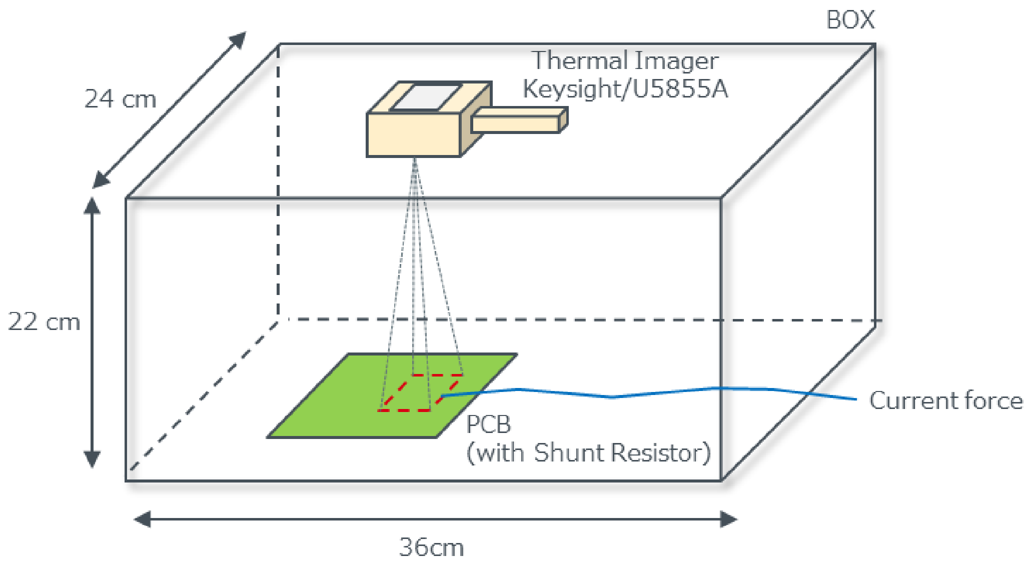


Figure A-1. Summary of evaluation environment for heat generation by shunt resistor

Example of evaluation data

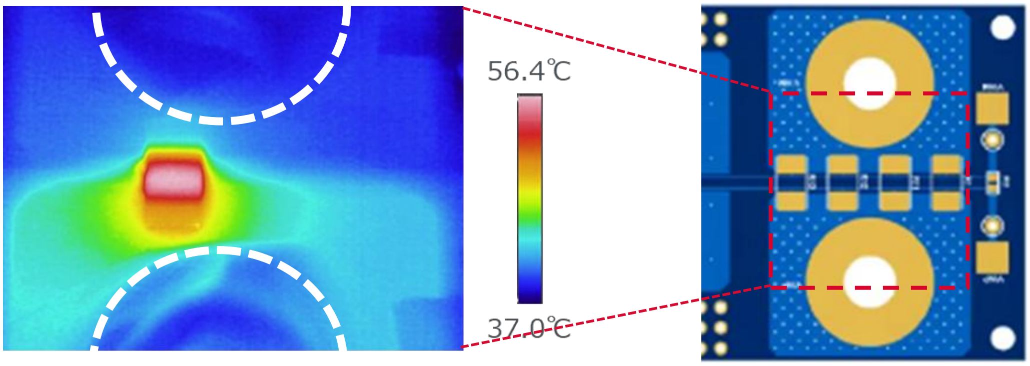


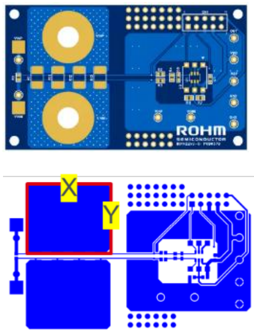
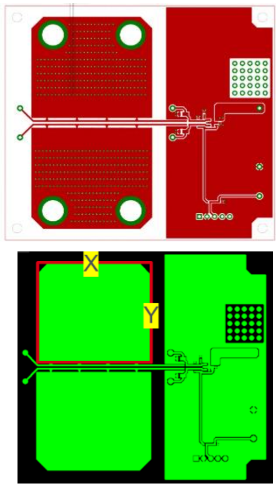
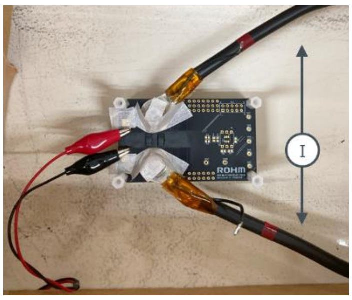
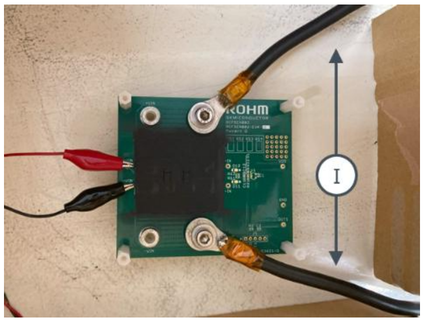
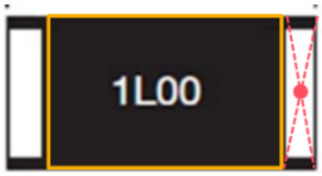
Figure A-2. Example for REF68011:

Temperature contour diagram with 20 A passed through PMR100HZPFV2L00 (2 mΩ, terminal rating of 3 W)

Boards used for evaluation of heat generation by shunt resistors

The two board types shown in Table A-1 were used for the evaluation of heat generation. Heat generation by different shunt resistors with the same power consumption as well as heat generation with different board patterns under the same conditions are compared. Refer to these comparisons when selecting the parts and designing the board patterns.

Table A-1. Information on boards used for evaluation of heat generation by shunt resistors

Board No.	BD1422xG-EVK-001 (*1) BD1423xFVJ-EVK-001 (*1)	REFSENS002-EVK-001
Pattern diagram		
Pattern size of area with shunt resistors mounted	X × Y = 25 mm × 20 mm, 2 layers	X × Y = 40 mm × 35 mm, 4 layers
Measurement scene		
Measurement points	Resistor temperature (Ths): Maximum temperature in the resistor body (Hot Spot) Terminal temperature (Tk): Center of the resistor terminal 	
Main reference designs using this board	REF68011, REF68012, REF68013, REF68014, REF68015	REFSENS002

* The layout of the area with shunt resistors mounted.

Appendix2
Estimation of heat generation by shunt resistor
if Rth_{ja} [°C/W] (thermal resistance) is not specified

If the thermal resistance (Rth_{ja} [°C/W]) of an electronic device is not specified, heat generation can be estimated based on the specified values of the power dissipation (Pd) and the load reduction curve. However, since the ideal conditions are assumed to specify these values, it is necessary to provide a large margin when designing actual boards.

• Example of shunt resistor selection and evaluation result for REF68011

The rated power is 3 [W], which is the terminal temperature rating. The load reduction curve is specified as follows.

3. RATING

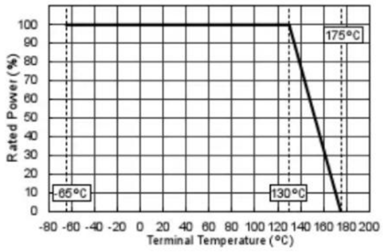
ITEMS	CONDITIONS	SPECIFICATIONS
RATED POWER	For resistors operated at the terminal temperature in excess of 130°C, the load shall be derated in accordance with Fig.1. Fig.1  Tk is the temperature of the terminal on the input side.	3W at 130°C *Tk : Terminal temperature

Figure A-3. Load reduction curve of shunt resistor (PMR100HZPFV2L00) taken from data sheet

The heat generated by a shunt resistor (temperature rise ΔT [°C]) can be expressed as follows.

$$Rth_{jk}[°C/W] = \frac{T_{max.} - T_k}{P_c}$$

$$\Delta T[°C] = Rth_{jk} * P_{LOSS}$$

Rthjk: Thermal resistance calculated from the load reduction curve [°C/W]

Tmax.: Maximum temperature specified with the load reduction curve [°C]

Tk: Terminal temperature [°C]

Pc: Rated power of the resistor [W]

PLOSS: Power consumption of the shunt resistor [W]

As an example, PMR100HZPFV2L00 (2 mΩ, terminal rating 3 W) is selected for 20 A current sensing with reference design REF68011. The temperature rise is then calculated to be 12 [°C] from the calculation formulas below. However, the temperature rise during the actual measurement was 49.2 [°C] - 25 [°C] = 24.2 [°C] (Table 2). Therefore, it can be seen that the calculation does not agree with the actual measurement.

$$Rth_{jk}[°C/W] = \frac{T_{max.} - T_k}{P_c} = \frac{175[°C] - 130[°C]}{3[W]} = 15[°C/W]$$

$$\Delta T[°C] = Rth_{jk} * P_{LOSS} = 15[°C/W] * 20^2[A^2] * 2[m\Omega] = 12[°C]$$

Note: During designing, please be aware that the heat generation values determined with theoretical calculations can be significantly deviated due to reasons including the following.

Heat dissipation mechanism: Ideal environment (infinite heat dissipation capacity)
→ The board heat dissipation and air flow are limited.
Ambient temperature: Fixed at Ta = 70°C
→ Ambient temperature also rises in an enclosed space.
Shunt resistor characteristics: Variation in shunt resistors and the temperature dependence are not taken into account
→ Actual resistors have variations and temperature characteristics.

Important Notes on the Use of Reference Designs

1) The contents of this document are subject to change without notice for the purpose of improvement.
2) ROHM provides reference designs (including, but not limited to, circuit diagrams, layout data, parts lists, reference boards and their evaluation results, etc.) and all materials related to evaluation boards (hereinafter collectively referred to as "Reference Designs, etc.") to customers for the purpose of referencing them in the development of devices, equipment, software, etc. incorporating ROHM products (hereinafter collectively referred to as "Customer Products"). The design, verification, etc. required for the development of the Customer's Product shall be done at the customer's responsibility and expense. In no event shall the customer use the Reference Designs, etc. for any purpose other than the purpose mentioned above.
3) Reference Designs, etc. are provided on an "as is" basis. ROHM disclaims all warranties, express or implied, including, but not limited to, warranties of usefulness, functionality, accuracy, merchantability, and fitness for a particular purpose. In no event shall ROHM be liable for any damages (including, but not limited to, lost profits or other incidental, consequential, or punitive damages) arising out of, related to or in connection with the use of or application of the Reference Designs, etc. whether in contract or tort. For the avoidance of doubt, ROHM does not warrant that the Reference Designs, etc. will work with the Customer’s Product.
4) When using Reference Designs, etc. be sure to request and verify the latest specifications (including the specifications of the products that compose the Reference Design, etc.) separately.
5) The customer shall be responsible for implementing safety measures such as derating, redundant design, fire prevention, backup, and fail-safe measures, etc., to prevent personal injury, fire damage, etc., caused by the Customer's Product developed with Reference Designs, etc. ROHM assumes no liability whatsoever for any use in excess of the ratings or in case of failure to observe the instructions for use.
6) The application circuit examples, constants, and other information provided in Reference Designs, etc. are intended to illustrate standard operation and usage. Therefore, when designing for mass production, please take into account various external conditions.
7) Reference Designs, etc. are intended to show typical operations and examples of application circuits, etc., and do not constitute a license, express or implied, to implement or use any intellectual property rights or any other rights of ROHM or any other company. ROHM shall not be liable for any disputes arising from, related to or in connection with the use of the Reference Designs, etc.
8) Please make sure to contact ROHM and obtain ROHM’s consent before using the Reference Designs, etc. for the following Customer's Product that requires particularly high reliability. Transportation equipment (in-vehicle, ship, railroad, etc.), trunk line communication equipment, traffic signal equipment, disaster and security equipment, safety equipment, medical equipment, servers, solar cells, power transmission systems, etc.
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