Thermal Design

Judgment Criteria of Thermal Evaluation

In the thermal design of semiconductor devices, the junction temperature must be lower than the absolute maximum rating. Since no method can measure the junction temperature directly, it is necessary to estimate the junction temperature by some methods. There are various methods to enable such estimation depending on device shapes and application structures. Companies may also have their own methods based on their experience and know-how. There is no correct solution applicable to all cases. This application note introduces several methods to estimate the junction temperature and provides their verification as a reference for the judgment criteria of thermal evaluation.

Methods of estimating the junction temperature

During the circuit design, the junction temperature (hereafter referred to as T_J) is theoretically estimated because no PCB exists. After the PCB is completed in a trial, T_J is estimated using the actual equipment. To estimate T_J more accurately, it is desirable to perform the estimation with the actual equipment under the final operation conditions (for example, sealing the equipment for a structure with sealed chassis, operating any other heat sources to generate heat, and setting the outside air temperature to the maximum expected temperature).

Three methods of estimating T_J are shown below.

1. Measure the temperature inside the chassis and use the result as ambient temperature T_A. Use θ_{JA} listed in the data sheet to estimate T_J.

2. Measure the temperature in the solder area of the device pins to estimate T_J.

3. Measure the temperature at the center of the package surface (T_T). Use Ψ_{JT} listed in the data sheet to estimate T_J.

The verification results are shown below. The verification is performed with the thermal fluid simulation of a specific application structure as follows.

Figure 1 shows the board layout. DC-DC converters of three systems are placed on the left half of the board. These converters generate heat. There is no heat generating part on the right half of the board.

The specifications of the board are shown below.

Thickness: 1.6 mm
Outline dimensions: 100 mm × 80 mm
Material: FR-4
Copper foil thickness: Top 70 μm, Middle-1 35 μm, Middle-2 35 μm, Bottom 70 μm
Thermal via: None

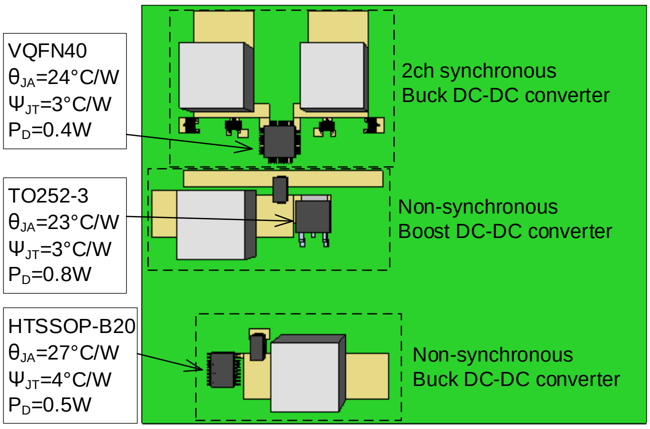

Figure 1. Board layout

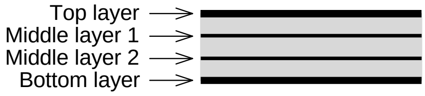

Figure 2. 4-layer board sectional view

The board is contained in a sealed resin chassis as shown in Figure 3.

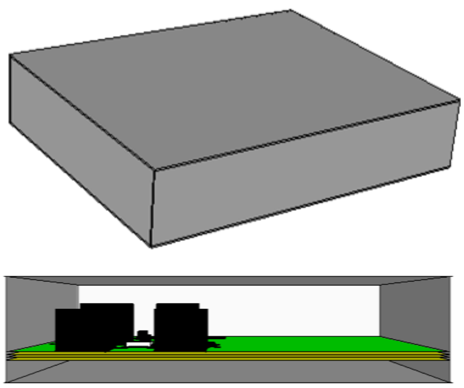

Figure 3. Chassis appearance and sectional view

101 mm × 81 mm × 21 mm

Figure 4 shows the external view of the DC-DC converter ICs.

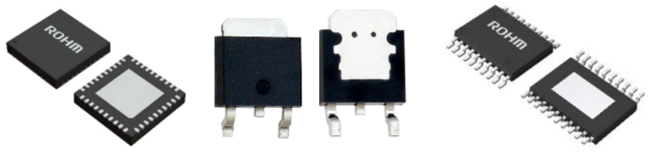

Figure 4. External view of the DC-DC converter ICs

Figure 5 shows the simulation results of T_J under the conditions above. We will compare these results with the values obtained below with the three methods of estimating T_J.

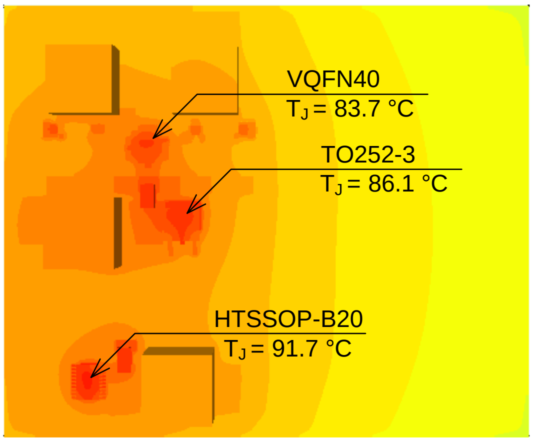

Figure 5. Simulation results of T_J

1. Measure the temperature inside the chassis and use the result as ambient temperature T_A. Use θ_{JA} listed in the data sheet to estimate T_J

Figure 6 shows the result of T_A reading at two points inside the chassis. Point A is positioned 5 mm above the VQFN40 and is influenced by the heat sources. Point B is positioned at the edge of the chassis and is distant from the heat sources.

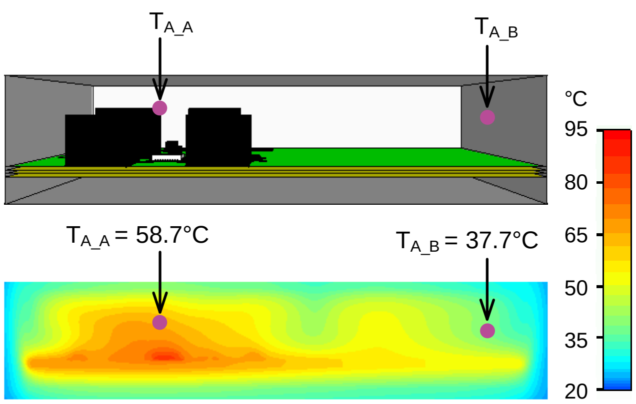

Figure 6. Result of T_A reading at two points inside the chassis

Use Equation 1 to calculate T_J for each IC.

$$T_J = \theta_{JA} \times P_D + T_A \quad [°C] \tag{1}$$

θ_{JA}: Thermal resistance from junction to the surrounding [°C/W]

P_D: Power loss [W]

T_A: Ambient temperature [°C]

VQFN40

Point A: $T_J = 24[°C/W] \times 0.4[W] + 58.7[°C] = 68.3\ °C$

Deviation from the true value: −15.4 °C (−18.4 %)

Point B: $T_J = 24[°C/W] \times 0.4[W] + 37.7[°C] = 47.3\ °C$

Deviation from the true value: −36.4 °C (−43.5 %)

TO252-3

Point A: $T_J = 23[°C/W] \times 0.8[W] + 58.7[°C] = 77.1\ °C$

Deviation from the true value: −9.0 °C (−10.5 %)

Point B: $T_J = 23[°C/W] \times 0.8[W] + 37.7[°C] = 56.1\ °C$

Deviation from the true value: −30.0 °C (−34.8 %)

HTSSOP-B20

Point A: $T_J = 27[°C/W] \times 0.5[W] + 58.7[°C] = 72.2\ °C$

Deviation from the true value: −19.5 °C (−21.3 %)

Point B: $T_J = 27[°C/W] \times 0.5[W] + 37.7[°C] = 51.2\ °C$

Deviation from the true value: −40.5 °C (−44.2 %)

T_J is underestimated compared with the true values in Figure 5. This method has the following problems.

1. Since T_A depends on the monitoring positions, it is difficult to determine T_A as a constant value.
2. Since θ_{JA} depends on the board conditions, θ_{JA} in the data sheet cannot be applied to the board of the actual equipment.

Therefore, this method cannot be used to estimate T_J.

2. Measure the temperature in the solder area of the device pins to estimate T_J

In this method, the temperature is measured in the solder area of the device pins. T_J is judged as not exceeding 150°C if the measured temperature is below 140°C, for example.

Figure 7 shows the pin temperature of each IC.

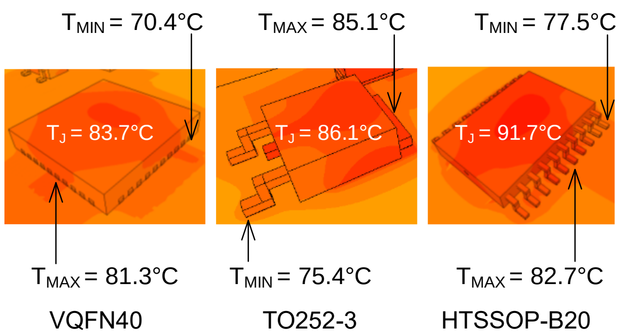

Figure 7. Pin temperature of each IC

The difference between T_J and the pin temperature is calculated for each package as follows.

VQFN40

$T_J - T_{MAX} = 83.7[°C] - 81.3[°C] = 2.4\ °C$

$T_J - T_{MIN} = 83.7[°C] - 70.4[°C] = 13.3\ °C$

TO252-3

$T_J - T_{MAX} = 86.1[°C] - 85.1[°C] = 1.0\ °C$

$T_J - T_{MIN} = 86.1[°C] - 75.4[°C] = 10.7\ °C$

HTSSOP-B20

$T_J - T_{MAX} = 91.7[°C] - 82.7[°C] = 9.0\ °C$

$T_J - T_{MIN} = 91.7[°C] - 77.5[°C] = 14.2\ °C$

Different results are obtained depending on the packages. The following should be considered for this method.

1. The temperature difference between T_J and the pin temperature depends on the packages.
2. The pin temperature depends on the measurement points.

This method can be used only if the difference between T_J and the specified pin temperature is correctly understood under a specific application.

3. Measure the temperature at the center of the package surface (T_T). Use Ψ_{JT} listed in the data sheet to estimate T_J

Figure 8 shows the result of temperature reading at the center of the package surface for each IC.

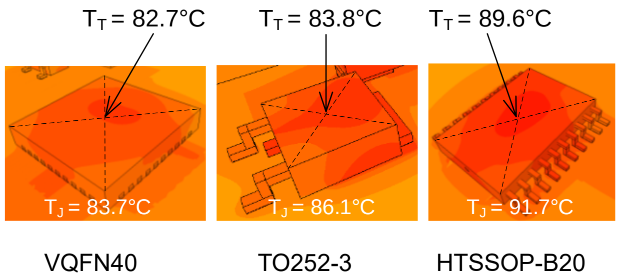

Figure 8. T_T of each IC

Use Equation 2 to calculate T_J for each IC.

$$T_J = \Psi_{JT} \times P_D + T_T \quad [°C] \qquad (2)$$

Ψ_{JT}: Thermal characteristics parameter from the junction to the package surface [°C/W]

P_D: Power loss [W]

T_T: Temperature at the center of the package surface [°C]

VQFN40

$T_J = 3[°C/W] \times 0.4[W] + 82.7[°C] = 83.9\ °C$

Deviation from the true value: 0.2 °C (0.24 %)

TO252-3

$T_J = 3[°C/W] \times 0.8[W] + 83.8[°C] = 86.2\ °C$

Deviation from the true value: 0.1 °C (0.12 %)

HTSSOP-B20

$T_J = 4[°C/W] \times 0.5[W] + 89.6[°C] = 91.6\ °C$

Deviation from the true value: −0.1 °C (−0.11 %)

By measuring T_T and using Ψ_{JT}, T_J can be estimated highly precisely. However, there may be a significant error in T_J even with this method if T_T is not measured accurately. T_T is measured using a thermocouple. For precautions when measuring temperature using thermocouples, refer to the following application note.

Application Note "Notes for Temperature Measurement Using Thermocouples"

Summary

	Method 1 Measure the temperature inside the chassis and use the result as ambient temperature T_A. Use θ_{JA} listed in the data sheet to estimate T_J.	Method 2 Measure the temperature in the solder area of the device pins to estimate T_J.	Method 3 Measure the temperature at the center of the package surface (T_T). Use Ψ_{JT} listed in the data sheet to estimate T_J.
Problems or considerations	Problems - Since T_A depends on the monitoring positions, it is difficult to determine T_A as a constant value. - Since θ_{JA} depends on the board conditions, θ_{JA} in the data sheet cannot be applied to the board of the actual equipment.	Considerations - The temperature difference between T_J and the pin temperature depends on the packages. - The pin temperature depends on the measurement points.	Considerations - Skill is required to accurately measure T_T using a thermocouple. - To estimate T_J more accurately, it is necessary to obtain Ψ_{JT} in a specific application board.
Precision of T_J estimation	Cannot estimate T_J.	Can be used only if the difference between T_J and the specified pin temperature is correctly understood under a specific application.	By accurately measuring T_T with a thermocouple and using Ψ_{JT}, T_J can be estimated highly precisely.

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