R-Car Series, 3rd Generation
Thermal Sensor Module (THS)

Introduction
With the aim of application to advanced in-vehicle computing platforms, third-generation R-Car series products provide enhanced performance in computing and graphics processing that surpasses that of products in the previous second-generation R-Car series as well as peripheral functions that support more sophisticated multimedia systems. Being such an advanced platform, the SoC device consumes a substantial amount of power so the importance of controlling its temperature is increased.

Third-generation R-Car series products include an on-chip thermal sensor module to measure the temperature within the SoC device itself. This application note describes how to use the thermal sensor module.

There will be some differences in specification between the thermal sensor modules for the R-Car H3 (Ver.1.0 and Ver.1.1) and the latest hardware user’s manual of the device. When using the R-Car H3 (Ver.1.0 or Ver.1.1), please contact a Renesas Electronics sale office.

Also, note that this document does not cover products (such as the R-Car E3) that incorporate the thermal sensor module designed for the second-generation R-Car series.

Target Device
- R-Car H3,
- R-Car H3-N
- R-Car M3-W/Ver.1.x
- R-Car M3-W+
- R-Car M3-N
- R-Car V3H
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1. **On-Chip Thermal Sensor Modules in Third-Generation R-Car Series Products**

1.1 **Thermal Sensors on Silicon Chips**

Some SoC devices have on-chip thermal sensors or thermal sensor modules that use the temperature-dependent characteristic of the forward voltage ($V_F$) in diodes. This on-chip thermal sensor using thermal diodes is useful to directly sense the temperature at a silicon junction.

On-chip thermal sensors in SoC devices are classified into two types: one provides only diodes in the SoC device and uses an externally connected sensor IC to sense temperature, and the other directly senses temperature through a sensor inside the SoC device. The thermal sensor module in third-generation R-Car series products is of the latter type.

The R-Car H3, H3-N, M3-W/Ver.1.x, and M3-W+ incorporate three thermal sensors (The R-Car V3H incorporate two thermal sensors) that convert the analog values of the sensed results into digital values before output.

As fabrication processes progress to form finer patterns, the characteristics of the elements that compose thermal sensors will have greater variation, resulting in larger errors in measured temperatures. Measures for correcting sensed temperature values to improve their accuracy are thus required. Third-generation R-Car series products (R-Car H3, H3-N, M3-W/Ver.1.x, M3-W+, and R-Car M3-N) are to include a function for correcting sensed temperatures (only in mass-produced devices).
1.2 Block Diagram of the On-Chip Thermal Sensor Modules

Notes:
1. The thermal sensor modules of the R-Car H3 Ver.1.0 and Ver.1.1 also require the USB_EXTAL input as a clock signal, but other devices in the third-generation R-Car series, including the R-Car H3 Ver.2.0, do not require this.
2. The specifications of the thermal sensor module differ between the R-Car H3 (Ver.1.0 and Ver.1.1) and the other third-generation R-Car series product. R-Car V3H does not have TSC3 module.

Figure 1-1  Block Diagram of the On-Chip Thermal Sensor Modules
Table 1-1  Analog Output Pins of the Thermal Sensor Module

<table>
<thead>
<tr>
<th>Pin</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>VTHREF0</td>
<td>Reference voltage pin. Outputs an almost constant voltage. The output voltage varies between individual sensors within the range from 0 V to 1.3V</td>
</tr>
<tr>
<td>VTHSENSE0</td>
<td>Temperature sensor output pin. The output voltage depends on the temperature in the LSI. The output voltage is within the range from 0V to 0.9V. To measure the temperature through analog output, use the difference in voltage between VTHSENSE0 and VTHREF0 Note.</td>
</tr>
</tbody>
</table>

Note:

- The analog output of thermal sensor should be used for easy temperature measurement at evaluation with understanding that it may have a lot of measurement error, and its function should not be used for temperature measurement means for the customer’s mass-production set.

- The analog thermal sensor outputs (VTHREF0 and VTHSENSE0) of R-Car M3-N and V3H are not valid just after reset. In order to validate the analog thermal sensor outputs, some register setting should be needed. For detail, please refer to “2.8 Register configuration for activation of analog thermal sensor outputs of R-Car M3-N and V3H”.

Note:

- The analog output of thermal sensor should be used for easy temperature measurement at evaluation with understanding that it may have a lot of measurement error, and its function should not be used for temperature measurement means for the customer’s mass-production set.

- The analog thermal sensor outputs (VTHREF0 and VTHSENSE0) of R-Car M3-N and V3H are not valid just after reset. In order to validate the analog thermal sensor outputs, some register setting should be needed. For detail, please refer to “2.8 Register configuration for activation of analog thermal sensor outputs of R-Car M3-N and V3H”.

1.3 Overview of the On-Chip Thermal Sensor Modules

1.3.1 On-Chip Thermal Sensor Modules in the Third-Generation R-Car Series Products

R-Car H3, H3-N, M3-W/Ver.1.x, M3-W+, and M3-N have three thermal sensor digital output, and R-Car V3H has two thermal sensor digital output.

The sources of the analog output (one channel) and one of the three digital output channels are the same thermal sensor; that is, the total number of thermal sensors is three or two.

The digital output from each module is generated by using an A/D converter having a resolution of 12 bits to convert the analog output (difference between the sensor output voltage and reference voltage) from the thermal sensor itself into a digital code. Each thermal sensor can generate interrupts in response to comparison of the measured temperature values with up to three digital codes for temperature specified in advance.

1.3.2 Accuracy of the On-Chip Thermal Sensor Modules

Prior to the shipment of Third-Generation R-Car Series Products (R-Car H3, H3-N, M3-W/Ver.1.x, M3-W+, M3-N and V3H SoC devices, individual compensation values for each chip are written to the chip so that the results of measurement by the thermal sensor module can be corrected. Note that only digital output can be corrected and analog output cannot be corrected.

Without correction of the values for the measured temperatures, the accuracy of the on-chip thermal sensor modules is roughly around ±10°C. The target for accuracy after correction is ±2°C. The compensation values for the digital outputs are only written to mass-produced devices; they are not written to working samples or engineering samples. To correct the temperatures measured in a working sample or engineering sample, use additional measures for sensing temperatures such as thermocouples or a thermography system.
1.3.3 Characteristics of the Thermal Sensor Module

Each of the on-chip thermal sensor modules converts the differences between the VTHSENSE0 voltage (sensor voltage) and the VTHREF0 voltage (reference voltage) output from each thermal sensor into values representing temperature. The VTHREF voltage (reference voltage) is used to measure the differential voltages so that offset errors and errors due to noise on the power supply or GND lines can be eliminated.

The change in output from a thermal sensor module is approximately proportional to changes in temperature. As the temperature rises, the voltage difference in analog output becomes smaller and the value of the digital output code becomes larger.

The actual output values from the thermal sensor module have the temperature-dependent characteristics shown in figure 1-2, which are represented by curves which are convex as seen from above around the normal temperatures. To improve the measurement accuracy, the digital outputs should be corrected by software to compensate for this characteristic in each chip.

![Figure 1-2 Overview of the Characteristics of the Thermal Sensor Module](image)
1.4 Locations of the Thermal Sensors and Measured Temperatures

The SoC incorporates CPUs and IP modules for various peripheral functions, and each module is placed at a segmented area on the circuit plane in the SoC. The power consumption differs between these modules; CPUs are allocated to relatively small areas but consume a lot of power, and some peripheral modules work at a relatively low speed and consume little power. The value obtained by dividing the power consumed in a module by the area where the module is placed (power density = heat density) indicates the degree of heat generation in that area. A CPU is one of the modules having the largest power density.

When the power density varies between segmented areas on the circuit plane in the SoC, the temperature has a distribution similar to that of the power density; the surface temperature of the SoC is high in some areas and low in other areas. For example, while a CPU is executing an application having a large load, the temperature locally goes high around the CPU.

The thermal sensor module is one of the peripheral modules in the SoC and each sensor in the module is placed at a certain location on the surface of the silicon chip; that is, the thermal sensor module measures the temperature at the location where each sensor is placed. Note that the location where a thermal sensor is placed does not always match the location where the maximum heat is generated in the chip.

In general, the difference between the temperature measured by a thermal sensor and the maximum temperature in the chip is at least several degrees Celsius (°C). In an extreme case, which depends on the use case, the temperature measured by a sensor placed far from the module that generates the maximum heat is lower than the maximum temperature by about 20°C.
1.4.1 Locations of the Thermal Sensors

The R-Car H3, H3-N, M3-W/Ver.1.x, M3-W+, and M3-N have three thermal sensors and R-Car V3H has two thermal sensors: it is located around the Main CPU (CortexA57: R-Car H3, H3-N, M3-W/Ver.1.x, M3-W+, and M3-N, CortexA53: R-Car V3H) which generates a large amount of heat, and one sensor is located at an edge of the silicon chip (near the GPU in the R-Car H3, R-Car M3-W/Ver.1.x, R-Car M3-W+, and R-Car M3-N). The sensor near an edge of the silicon chip has analog output pins. Figures 1-3 to 1-7 and tables 1-2 to 1-6 give detailed information regarding the locations of the thermal sensors in each device of the third-generation R-Car series.

Note:
- The analog output of thermal sensor should be used for easy temperature measurement at evaluation with understanding that it may have a lot of measurement error, and its function should not be used for temperature measurement means for the customer’s mass-production set.

![Diagram of Thermal Sensor Locations](image)

**Figure 1-3 Locations of the Thermal Sensors in the R-Car H3 Ver.1.0 and Ver.1.1**

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>THS1</td>
<td>Placed beside the GPU (GX6650) near an edge of the chip. As the GPU is a large module, the sensor might not be placed near the highest-temperature section of the GPU, but the measured temperature will be relatively high while the GPU is executing large-load processing.</td>
</tr>
<tr>
<td>THS2</td>
<td>Placed beside CA57 #2 near an edge of the chip. The measured temperature will be relatively high while CA57 #2 or CA57 #3 is executing large-load processing.</td>
</tr>
<tr>
<td>THS3</td>
<td>Placed beside CA57 #0. The measured temperature will be relatively high while CA57 #0 or CA57 #1 is executing large-load processing. Because this sensor is not far from CA57 #2 or CA57 #3 and is closer to the center of the chip than THS1 or THS2, the measured temperature will be higher than that measured by THS1 or THS2 when the entire load on the system is large.</td>
</tr>
</tbody>
</table>
Figure 1-4  Locations of the Thermal Sensors in the R-Car H3 Ver.2.0 later and R-Car H3-N

Table 1-3  List of the Thermal Sensors in the R-Car H3 Ver.2.0 later and R-Car H3-N

<table>
<thead>
<tr>
<th>THS</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>THS1</td>
<td>Placed beside the GPU (GX6650) near an edge of the chip. As the GPU is a large module, the sensor might not be placed near the highest-temperature section of the GPU, but the measured temperature will be relatively high while the GPU is executing large-load processing.</td>
</tr>
<tr>
<td>THS2</td>
<td>Placed beside CA57 between #2 and #3 near an edge of the chip. The measured temperature will be relatively high while CA57 #2 or CA57 #3 is executing large-load processing.</td>
</tr>
<tr>
<td>THS3</td>
<td>Placed beside CA57 #0. The measured temperature will be relatively high while CA57 #0 or CA57 #1 is executing large-load processing. Because this sensor is not far from CA57 #2 or CA57 #3 and is closer to the center of the chip than THS1 or THS2, the measured temperature will be higher than that measured by THS1 or THS2 when the entire load on the system is large.</td>
</tr>
</tbody>
</table>
Figure 1-5  Locations of the Thermal Sensors in the R-Car M3-W/Ver.1.x and R-Car M3-W+

Table 1-4  List of the Thermal Sensors in the R-Car M3-W/Ver.1.x and R-Car M3-W+

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Location Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>THS1</td>
<td>Placed beside the GPU (GX6250) near an edge of the chip. As the GPU is a large module, the sensor might not be placed near the highest-temperature section of the GPU, but the measured temperature will be relatively high while the GPU is executing large-load processing.</td>
</tr>
<tr>
<td>THS2</td>
<td>Placed beside CA57 #1 near an edge of the chip. The measured temperature will be relatively high while CA57 #1 is executing large-load processing.</td>
</tr>
<tr>
<td>THS3</td>
<td>Placed beside CA57 #0. The measured temperature will be relatively high while CA57 #0 is executing large-load processing. Because this sensor is not far from CA57 #1 and is closer to the center of the chip than THS1 or THS2, the measured temperature will be higher than that measured by THS1 or THS2 when the entire load on the system is large.</td>
</tr>
</tbody>
</table>
Figure 1-4 Locations of the Thermal Sensors in the R-Car M3-N

Table 1-4 List of the Thermal Sensors in the R-Car M3-N

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>THS1</td>
<td>Placed beside the GPU (GE7800) near an edge of the chip. As the GPU is a large module, the sensor might not be placed near the highest-temperature section of the GPU, but the measured temperature will be relatively high while the GPU is executing large-load processing.</td>
</tr>
<tr>
<td>THS2</td>
<td>Placed beside CA57 #1 near an edge of the chip. The measured temperature will be relatively high while CA57 #1 is executing large-load processing.</td>
</tr>
<tr>
<td>THS3</td>
<td>Placed beside CA57 #0. The measured temperature will be relatively high while CA57 #0 is executing large-load processing. Because this sensor is not far from CA57 #1 and is closer to the center of the chip than THS1 or THS2, the measured temperature will be higher than that measured by THS1 or THS2 when the entire load on the system is large.</td>
</tr>
</tbody>
</table>

Note:
The analog thermal sensor outputs (VTHREF0 and VTHSENSE0) of R-Car M3-N and V3H are not valid just after reset. In order to validate the analog thermal sensor outputs, some register setting should be needed. For detail, please refer to “2.8 Register configuration for activation of analog thermal sensor outputs of R-Car M3-N and V3H”.
Table 1-6 List of the Thermal Sensors in the R-Car V3H

<table>
<thead>
<tr>
<th>THS1</th>
<th>Placed beside the CR7 near an edge of the chip. The measured temperature will be relatively high while the CR7 is executing large-load processing.</th>
</tr>
</thead>
<tbody>
<tr>
<td>THS2</td>
<td>Placed beside CA53 #0. The measured temperature will be relatively high while CA53 are executing large-load processing.</td>
</tr>
</tbody>
</table>

Note:
The analog thermal sensor outputs (VTHREF0 and VTHSENSE0) of R-Car M3-N and V3H are not valid just after reset. In order to validate the analog thermal sensor outputs, some register setting should be needed. For detail, please refer to “2.8 Register configuration for activation of analog thermal sensor outputs of R-Car M3-N and V3H”.

Figure 1-7 Locations of the Thermal Sensors in the R-Car V3H
2. Using the Thermal Sensor Module

2.1 Measuring Temperatures through the Thermal Sensors

The digital code output from a thermal sensor is the result of A/D conversion of the difference between the VTHSENSE and VTHREF voltages in the SoC. The code should be converted to a value representing temperature by software. To compensate for the variation in characteristics between individual thermal sensors, the codes for two known temperatures and the code for obtaining the normal (intermediate) temperature shown in table 2-1 are stored in each thermal sensor. Use these values and obtain the characteristic equations for each thermal sensor to convert the output code to a value representing temperature.

Note that these compensation codes are stored only in mass-produced devices; they are not available in working samples or engineering samples.

![Figure 2-1 Operation of the On-Chip Thermal Sensor](image)

Table 2-1 Codes to be Referenced in Conversion to Temperatures (Read-Only Registers)

<table>
<thead>
<tr>
<th>Register</th>
<th>Abbreviation</th>
<th>TSC1</th>
<th>TSC2</th>
<th>TSC3</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>THCODE parameter 1</td>
<td>THCODE1</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>TEMP_CODE[11:0] in the thermal sensor at 116°C or 126°C <strong>1</strong> <strong>3</strong></td>
</tr>
<tr>
<td>THCODE parameter 2</td>
<td>THCODE2</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>TEMP_CODE[11:0] in the thermal sensor at the normal temperature</td>
</tr>
<tr>
<td>THCODE parameter 3</td>
<td>THCODE3</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>TEMP_CODE[11:0] in the thermal sensor at -41°C <strong>1</strong></td>
</tr>
<tr>
<td>PTAT parameter 1</td>
<td>PTAT1</td>
<td>✓</td>
<td></td>
<td></td>
<td>Digital value of VTHSENSE in the thermal sensor at 116°C or 126°C <strong>1</strong> <strong>3</strong></td>
</tr>
<tr>
<td>PTAT parameter 2</td>
<td>PTAT2</td>
<td></td>
<td>✓</td>
<td></td>
<td>Digital value of VTHSENSE in the thermal sensor at the normal temperature <strong>2</strong></td>
</tr>
<tr>
<td>PTAT parameter 3</td>
<td>PTAT3</td>
<td></td>
<td></td>
<td>✓</td>
<td>Digital value of VTHSENSE in the thermal sensor at -41°C <strong>1</strong> <strong>2</strong></td>
</tr>
</tbody>
</table>

✓: Available

Notes:
1. The temperatures for the compensation code values may be changed in a future device.
2. The digital output code has good linearity with respect to temperature changes but includes an offset error.
3. For R-Car M3-W/Ver.1.x and M3-W+ : 116°C, for R-Car H3, H3-N, M3-N, and V3H : 126°C
2.2 Converting a Digital Code to a Value Representing Temperature

The simplest way to convert an output digital code to a value representing temperature is to obtain a linear approximation equation from the codes for two known temperatures and use this equation to convert the current output code to a value representing temperature.

From THCODE1 (for a high temperature) and THCODE3 (for a low temperature), obtain the change of code value per 1°C and convert the current output code to a value representing temperature.

Change of code value per 1°C: \( \Delta D = (\text{THCODE1} - \text{THCODE3}) / 167 \) (*

Current temperature (°C) \( f() = -41 + \frac{\text{current code} - \text{THCODE3}}{\Delta D} \)

(*) For R-Car M3-W/Ver.1.x and M3-W+, replace ‘167’ to ‘157’

This conversion assumes that a thermal sensor has a completely linear characteristic with respect to the temperature change, but the actual characteristic of the thermal sensor is represented by a convex curve (the red curve in figure 2-2).

Accordingly, the temperature converted with the above equation has a substantial error around the normal temperature, which is far from the temperatures for THCODE1 and THCODE3.

To reduce this error, the code for the third known temperature is used (figure 2-3).

In third-generation R-Car series products, the code for a temperature around the middle point between the temperatures for THCODE1 and THCODE3 — that is, THCODE2 for the normal temperature — is stored in the thermal sensor.

The value (°C) of this normal temperature should be calculated first.

Note (*) The temperatures may be changed in a future device.

For R-Car H3, H3-N, M3-N, V3H: T1=126, T2=167 For R-Car M3-W/Ver.1.x, M3-W+: T1=116, T2=157

Figure 2-2 Relationship between the Characteristic of the Thermal Sensor and THCODE (1)

Figure 2-3 Relationship between the Characteristic of the Thermal Sensor and THCODE (2)
To calculate the temperature around the middle point (normal temperature), use the PTAT1, PTAT2, and PTAT3 codes, which are digital code values obtained by converting the $V_{THSENSE}$ voltage when THCODE1, THCODE2, and THCODE3 temperatures are measured, respectively. They have unknown offset errors due to variation in characteristics between circuit elements, but they exhibit good linearity with respect to the temperature change. From PTAT1 and PTAT3, obtain the change of code value per 1°C and convert the PTAT2 code to a value representing temperature.

$$\Delta D_{PTAT} = \frac{(PTAT1 - PTAT3)}{167}$$ (*)

Temperature measured for PTAT2: $T \ (°C) = -41 + \frac{(PTAT2 - PTAT3)}{\Delta D_{PTAT}}$

(*) For R-Car M3-W/Ver.1.x and M3-W+, replace ‘167’ to ‘157’

This temperature, $T \ (°C)$, is the temperature measured when THCODE2 is written to the device.

Here, three codes for known measured temperatures are ready. Make two pairs of codes, THCODE3 and THCODE2, and THCODE2 and THCODE1, and obtain a linear approximation equation similar to that shown in the previous page for each pair. Divide the temperature range into two at THCODE2 and use each approximation equation in the corresponding temperature range. This calculation is relatively easy and has small errors with respect to the actual characteristic of the thermal sensor, which can be approximated by a quadratic equation.

\[ \text{Note (*) The temperatures may be changed in a future device.} \]

For R-Car H3, H3-N, M3-N, V3H: $T_1=126$, $T_2=167$
For R-Car M3-W/Ver.1.x, M3-W+: $T_1=116$, $T_2=157$

**Figure 2-4  Calculating the Normal Temperature from PTAT (1)**

\[ \text{Note (*) The temperatures may be changed in a future device.} \]

For R-Car H3, H3-N, M3-N, V3H: $T_1=126$
For R-Car M3-W/Ver.1.x, M3-W+: $T_1=116$

**Figure 2-5  Calculating the Normal Temperature from PTAT (2)**
When the current code is smaller than THCODE2:

Change of code value per 1°C: $\Delta D_1 = \frac{(\text{THCODE2} - \text{THCODE3})}{(T - (-41))}$
Current temperature (°C) = $-41 + \frac{\text{(current code} - \text{THCODE3})}{\Delta D_1}$

When the current code is equal to or greater than THCODE2:

Change of code value per 1°C: $\Delta D_2 = \frac{(\text{THCODE1} - \text{THCODE2})}{(126 - T)}$ (*)
Current temperature (°C) = $T + \frac{(\text{current code} - \text{THCODE2})}{\Delta D_2}$

(*) For R-Car M3-W/Ver.1.x and M3-W+, replace ‘126’ to ‘116’

There are also other ways to obtain approximation equations from three known values, but in any case take special care regarding the fact that the point where THCODE2 is measured is not the most convex point on the characteristic curve. For details, refer to section 2.4, Discussion Regarding Errors in Measured Temperatures (Errors in Approximation).

Each code may be converted to a value representing temperature every time the necessity arises, or alternatively all codes may be converted at one time in advance to create a lookup table to be referenced. In either case, note that the characteristics differ between thermal sensors and calculation should be done separately for each sensor.

Note (*) The temperatures may be changed in a future device.

For R-Car H3, H3-N, M3-N, V3H: $T_1=126$ 
For R-Car M3-W/Ver.1.x, M3-W+: $T_1=116$

Figure 2-6 Equations for Approximating the Thermal Sensor Characteristics
### 2.3 Converting a Digital Code to a Value Representing Temperature in a Working Sample or Engineering Sample

The digital codes for the known temperatures required to convert a digital code to a value representing temperature are not available in working samples or engineering samples. If necessary, use the values shown in table 2-2 as provisional values.

Note: These values do not reflect the characteristics of each individual sensor, and the accuracy of the converted results is roughly around ±10°C.

#### Table 2-2 Provisional Values for THCODE and PTAT in Working Samples and Engineering Samples

<table>
<thead>
<tr>
<th>Register</th>
<th>Abbreviation</th>
<th>TSC1</th>
<th>TSC2</th>
<th>TSC3</th>
</tr>
</thead>
<tbody>
<tr>
<td>THCODE Parameter 1</td>
<td>THCODE1</td>
<td>110101000101</td>
<td>110101000001</td>
<td>110100111101</td>
</tr>
<tr>
<td>(high temperature)</td>
<td></td>
<td>(3397)</td>
<td>(3393)</td>
<td>(3389)</td>
</tr>
<tr>
<td>THCODE Parameter 2</td>
<td>THCODE2</td>
<td>101011110000</td>
<td>101011101011</td>
<td>10101110101</td>
</tr>
<tr>
<td>(normal temperature)</td>
<td></td>
<td>(2800)</td>
<td>(2795)</td>
<td>(2805)</td>
</tr>
<tr>
<td>THCODE Parameter 3</td>
<td>THCODE3</td>
<td>100010101101</td>
<td>100010101000</td>
<td>100010111101</td>
</tr>
<tr>
<td>(low temperature)</td>
<td></td>
<td>(2221)</td>
<td>(2216)</td>
<td>(2237)</td>
</tr>
<tr>
<td>PTAT Parameter 1</td>
<td>PTAT1</td>
<td>101001000111</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(high temperature)</td>
<td></td>
<td>(2631)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PTAT Parameter 2</td>
<td>PTAT2</td>
<td>010111100101</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(normal temperature)</td>
<td></td>
<td>(1509)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PTAT Parameter 3</td>
<td>PTAT3</td>
<td>000110110011</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(low temperature)</td>
<td></td>
<td>(435)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Remark:**

Above provisional values are for 116°C. For R-Car H3, H3-N, M3-N, and V3H, same value should be used. In this case, each formula for current temperature should be same as R-Car M3-W/Ver.1.x, and R-Car M3-W+.

R-Car V3H does not have TSC3.

Table 2-3 shows the characteristic approximation equations for each thermal sensor (TSC1 to TSC3) obtained from the values shown in table 2-2.

#### Table 2-3 Characteristic Approximation Equations Obtained from the Provisional Values for THCODE and PTAT in Working Samples and Engineering Samples

<table>
<thead>
<tr>
<th>TSC1</th>
<th>TSC2</th>
<th>TSC3</th>
</tr>
</thead>
<tbody>
<tr>
<td>ΔD1 = 7.541, ΔD2 = 7.442</td>
<td>ΔD1 = 7.541, ΔD2 = 7.455</td>
<td>ΔD1 = 7.397, ΔD2 = 7.280</td>
</tr>
</tbody>
</table>

- **Current code < 2800**
  - Measured temperature = –41 + (current code – 2221) / 7.541
  - = 0.1326 × current code – 335.54

- **Current code ≥ 2800**
  - Measured temperature = 35.784 + (current code – 2800) / 7.442
  - = 0.1342 × current code – 340.44

**Remark:**

R-Car V3H does not have TSC3.

Table 2-4 is an example of a lookup table for TSC1 to TSC3 obtained from the values shown in table 2-2.
### Table 2-4: Lookup Table for Temperatures Obtained from the Provisional Values for THCODE and PTAT in Working Samples and Engineering Samples

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>TSC1 Code</th>
<th>TSC2 Code</th>
<th>TSC3 Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2530</td>
<td>2525</td>
<td>2540</td>
</tr>
<tr>
<td>25</td>
<td>2719</td>
<td>2714</td>
<td>2725</td>
</tr>
<tr>
<td>50</td>
<td>2906</td>
<td>2901</td>
<td>2908</td>
</tr>
<tr>
<td>55</td>
<td>2943</td>
<td>2938</td>
<td>2945</td>
</tr>
<tr>
<td>60</td>
<td>2980</td>
<td>2976</td>
<td>2981</td>
</tr>
<tr>
<td>65</td>
<td>3017</td>
<td>3013</td>
<td>3018</td>
</tr>
<tr>
<td>70</td>
<td>3055</td>
<td>3050</td>
<td>3054</td>
</tr>
<tr>
<td>75</td>
<td>3092</td>
<td>3087</td>
<td>3091</td>
</tr>
<tr>
<td>80</td>
<td>3129</td>
<td>3125</td>
<td>3127</td>
</tr>
<tr>
<td>82</td>
<td>3144</td>
<td>3140</td>
<td>3141</td>
</tr>
<tr>
<td>84</td>
<td>3159</td>
<td>3154</td>
<td>3156</td>
</tr>
<tr>
<td>86</td>
<td>3174</td>
<td>3169</td>
<td>3171</td>
</tr>
<tr>
<td>88</td>
<td>3189</td>
<td>3184</td>
<td>3185</td>
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<tr>
<td>90</td>
<td>3203</td>
<td>3199</td>
<td>3200</td>
</tr>
<tr>
<td>92</td>
<td>3218</td>
<td>3214</td>
<td>3214</td>
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<tr>
<td>94</td>
<td>3233</td>
<td>3229</td>
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<tr>
<td>96</td>
<td>3248</td>
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<tr>
<td>98</td>
<td>3263</td>
<td>3259</td>
<td>3258</td>
</tr>
<tr>
<td>100</td>
<td>3278</td>
<td>3274</td>
<td>3273</td>
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<tr>
<td>102</td>
<td>3293</td>
<td>3289</td>
<td>3287</td>
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<td>104</td>
<td>3308</td>
<td>3304</td>
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<tr>
<td>106</td>
<td>3323</td>
<td>3318</td>
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<td>108</td>
<td>3337</td>
<td>3333</td>
<td>3331</td>
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<tr>
<td>110</td>
<td>3352</td>
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<td>118</td>
<td>3412</td>
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<td>3404</td>
</tr>
<tr>
<td>120</td>
<td>3427</td>
<td>3423</td>
<td>3418</td>
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<tr>
<td>122</td>
<td>3442</td>
<td>3438</td>
<td>3433</td>
</tr>
<tr>
<td>124</td>
<td>3457</td>
<td>3453</td>
<td>3447</td>
</tr>
<tr>
<td>125</td>
<td>3464</td>
<td>3460</td>
<td>3455</td>
</tr>
</tbody>
</table>

**Remark:**

R-Car V3H does not have TSC3.
2.4 Discussion Regarding Errors in Measured Temperatures (Errors in Approximation)

This section takes the codes shown in table 2-3 as an example to discuss the errors in least-squares approximations (linear and quadratic), linear approximation using two points (high and low temperatures), and the linear approximation described in this document that uses the normal temperature $T$ as the boundary between two temperature ranges.

The equation for TSC1 in each approximation method is shown below.

- Linear approximation (least squares): $f(x) = 7.4536x + 2515.6$
- Quadratic approximation (least squares): $f(x) = 0.0095x^2 + 6.9764x + 2491.1$
- Linear approximation (two points: high and low temperatures): $f(x) = 7.49635x + 2528.35$
- Approximation described in this document: $f(x) = 8.2800x + 2453.116 \ (x > \text{normal temperature})$
  $f(x) = 6.9848x + 2507.358 \ (x \leq \text{normal temperature})$

![Figure 2-7 Example of Each Approximation Line (Using the Codes for TSC1)](image-url)
The temperature-dependent characteristic of a thermal sensor can be represented by a quadratic curve. Assuming that the quadratic curve (least-squares approximation) based on the codes for TSC1 gives an exact approximation to the true characteristic of the thermal sensor, the errors in measured temperatures in other approximation methods are shown in figure 2-8.

![Figure 2-8: Examples of Errors in Measured Temperatures in Other Approximation Methods when Assuming that the Quadratic Curve Gives an Exact Approximation to True Values (Using the Provisional TSC1 Codes)](image)

This figure shows that the simple linear approximations include large errors in measured temperatures but the approximation method used in this document reduces them. Every approximation includes errors in a negative direction (the approximated temperature is lower than the actual temperature) in the temperature range over the THCODE1 temperature (96 °C).
The normal temperature stored in each device does not always match the temperature at the peak (around 40°C to 50°C) of the characteristic curve of the thermal sensor because the characteristic varies between devices. Therefore, the difference between the normal temperature and the peak temperature affects the errors in measured temperatures. Assuming that the quadratic curve (least-squares approximation) based on the codes for TSC1 gives an exact approximation to the true characteristic of the thermal sensor, the variations of errors in measured temperatures depending on –10°C to 10°C differences (in 2.5°C steps) between the normal and peak temperatures are shown in figure 2-9.

Figure 2-9  Examples of Errors in the Approximation Method Used in This Document due to the Difference between the Normal and Characteristic Peak Temperatures (Using the Provisional TSC1 Codes When Assuming that the Quadratic Curve Gives an Exact Approximation to True Values)
2.5 Correcting the Thermal Sensor Module in Working Samples or Engineering Samples

2.5.1 Procedure for Correcting the Thermal Sensor Module

![Diagram of the procedure for correcting the Thermal Sensor Module]

---

**Figure 2-10** Procedure for Correcting the Thermal Sensor Module in Working Samples or Engineering Samples
2.5.2 Detailed Procedure for Correcting the Thermal Sensor Module

1. Preparation
   - Prepare a thermostatic chamber.
   - Remove heat radiators such as a heat sink from the device, and attach the finest possible thermocouples at the left (TSC1), right (TSC2), and center (TSC3) on the silicon chip with reference to the locations of the thermal sensors shown in this document. If the chip is covered with a lid, do not remove it; refer to the external dimensions diagram of the device to determine the location of the silicon chip under the lid and attach thermocouples on the lid directly above the left (TSC1), right (TSC2), and center (TSC3) locations of the chip.
   - After attaching thermocouples, cover the upper surface of the device to insulate heat from the device and the board (solder surface and component surface) so that heat radiation from the device can be reduced as much as possible.

2. Measuring the analog output from THS1
   - Turn on all power supplies to the SoC.
   - Set up the thermal sensor module to output thermal sensor voltages from the analog output pins (VTHSENSE0 and VTHREF0) of the module.
   - Turn off the power supplies to the SoC except for the VCCQ18 power.
   - Note: The temperature sensor module operates while VCCQ18 is supplied. The other power supplies should be turned off to reduce noise generated during SoC logic operation or errors in heat generation due to current leakage to the maximum possible extent.
   - Place the device in the thermostatic chamber and cool it until the temperature measured by the thermocouple near TSC1 reaches about –20°C.
   - Wait until the temperature measured by the thermocouple stabilizes, and record the analog output value (difference between VTHSENSE0 and VTHREF0) from the thermal sensor module and the temperature measured by the thermocouple near TSC1.
   - Change the temperature in the thermostatic chamber to 20°C, 45°C, 65°C, 85°C, and 105°C in that order and perform the measurement at each temperature in the same way as the measurement at –20°C.
   - From the measurement results at each temperature, plot the characteristic curve of the analog thermal sensor TSC1 and obtain the quadratic approximation equation for the relationship between the analog output from the thermal sensor module and the temperature measured by the thermocouple.

3. Correcting the digital output from TSC1
   - Measuring the temperature differences in TSC1 to TSC3
     - Turn off and then turn on all power supplies to the SoC.
     - Turn on the internal power supply domain only for CortexA53 #0 and stop the power supplies to other on-chip modules that can be turned off without problems. Stop all unnecessary clocks to the on-chip modules.
     - Note: The power supplies and clocks should be stopped to reduce errors due to noise generated during SoC logic operation to the maximum possible extent.
     - Cool the device until the temperature measured by the thermocouple near TSC1 reaches about –20°C and wait until the analog output value (difference between VTHSENSE0 and VTHREF0) from the thermal sensor module stabilizes.
     - After the analog output from the thermal sensor module stabilizes, measure temperatures using the thermocouples attached near TSC1 to TSC3.
     - Measure the analog voltage output from the thermal sensor module and obtain the current digital codes in TSC1 to TSC3 by CortexA53.
     - Note: When using a program in CortexA53 to obtain these values, place the program in the on-chip SRAM.
     - Change the temperature in the thermostatic chamber to 20°C and then to 105°C and perform the measurement at each temperature in the same way as the measurement at –20°C.
     - Use the approximation curve obtained in step 2 to convert the analog output from the thermal sensor module measured at each temperature into a value representing temperature.
     - From the digital code in the thermal sensor obtained at each temperature and the temperature converted from the analog output, calculate the characteristic equation for TSC1.
     - Subtract the difference between the temperatures measured by the thermocouples for TSC1 and TSC2 from the temperature obtained from the analog output from the thermal sensor module, and use the result as the temperature measured at TSC2 to calculate the characteristic equation for TSC2.
     - Subtract the difference between the temperatures measured by the thermocouples for TSC1 and TSC3 from the temperature obtained from the analog output from the thermal sensor module, and use the result as the temperature measured at TSC3 to calculate the characteristic equation for TSC3.
2.6 Correcting the Analog Output from the Thermal Sensor Module in Mass-Produced Devices

Correction method 1:
Use the same procedure as for correcting the analog output from the thermal sensor module in working samples or engineering samples.

Correction method 2:
Use the digital value output from TSC1.
1. Place the user board in a thermostatic chamber and cool it until the temperature reaches about –20°C.
2. Read the digital code in TSC1 by the CPU and wait until the read value stabilizes.
3. After the read value stabilizes, obtain the analog output value and digital code from the thermal sensor module.
4. Convert the digital code into a value representing temperature and record it as the temperature corresponding to the analog output voltage.
5. Change the temperature in the thermostatic chamber to about 45°C and then to 95°C and perform the same measurement as in step 4 at each temperature.
6. From the three temperatures measured, obtain the equation for converting the analog output voltage to a value representing temperature.

Note:
• The analog output of thermal sensor should be used for easy temperature measurement at evaluation with understanding that it may have a lot of measurement error, and its function should not be used for temperature measurement means for the customer’s mass-production set.

Remarks: When the temperature for PTAT2 is closer to 45°C, the temperature indicated by the digital code in TSC1 becomes closer to the temperature converted from the analog output. To correct only the high-temperature region, set the temperature in the thermostatic chamber to 60°C and then to 95°C and obtain the conversion equation from these two points. (In this case, errors become large in the low-temperature region.) In an engineering sample or a working sample, if a digital code is converted using the provisional codes shown in this document and the analog output is corrected using correction method 2 above, the accuracy of temperature measurement using the analog output may be worse than ±10°C.
2.7 Interrupts from the Thermal Sensor Module

Each thermal sensor in the module can generate up to three interrupts by comparing the current code with three prespecified digital codes (temperatures). The interrupt generation condition can be when the current code becomes greater than the prespecified comparison code, when it becomes smaller than the comparison code, or when it becomes greater or smaller than the comparison code.

The user can apply these three interrupts for any purpose. For example, with a separate fixed comparison code (temperature) assigned to each of the three interrupts, one interrupt can be used for an emergency stop when the temperature exceeds an upper limit, another used for an alarm for a temperature rise to reduce power consumption, and the last one used to clear the alarm when the temperature falls. As another example, with two interrupts dynamically set for temperatures (codes) over and under the current temperature (code), a system thermometer can be configured so that the system temperature is updated every time an interrupt is generated.
2.7.1 Examples of Interrupt Usage

![Diagram of Interrupt Usage]

- **System temperature**
  - Upper limit of temperature
  - Temperature for activating alarm
  - Temperature for clearing alarm

- **IRQ TEMP**
  - When this limit is exceeded, the shutdown process begins.
  - When this temperature is exceeded, an alarm is given and heat generation is reduced by power management software.
  - When the temperature falls below this value, the alarm is cleared.

- **TEMP CODE**
  - The current temperature is polled using a timer interrupt.

**Figure 2-12 Example of Generating Interrupts with Fixed Comparison Codes**

- **Current temperature = XY°C**
  - **IRQ TEMP1**
    - Code for the current temperature
    - +1°C
    - Code for the current temperature + 1°C
    - Update the comparison value in the interrupt processing.
  - **IRQ TEMP2**
    - Code for the current temperature - 1°C
    - -1°C
    - Code for the current temperature
    - Update the comparison value in the interrupt processing.

**Figure 2-13 Example of System Thermometer Implemented through Interrupts**
2.7.2 Notes on Using Thermal Sensor Module Interrupts

- For interrupt generation, use the codes after correction with respect to the characteristic of each thermal sensor (the specific codes for each device and each thermal sensor).
- An interrupt occurs when the specified condition is satisfied even for a single value sampled by the A/D converter (about 1-ms intervals). When the response to an interrupt or interrupt processing takes a long time, the current temperature may change from the temperature specified as an interrupt condition in some cases. Reading the current code from the TEMP_CODE register within the interrupt processing is recommended before continuing the processing.
- When a code value for generating interrupts needs to be modified while the thermal sensor module is operating, disable the comparator for the target interrupt through the EN bit before modifying the value.
- When a code value for generating interrupts is modified while the thermal sensor module is operating, no interrupt may be generated if the temperature rapidly changes.

2.8 Register configuration for activation of analog thermal sensor outputs of R-Car M3-N and V3H

The analog thermal sensor outputs (VTHREF0 and VTHSENSE0) of R-Car M3-N and V3H are not valid just after reset. In order to validate the analog thermal sensor outputs, following register setting should be needed after reset note.

1. Write data 0x0000_0000 to address 0xE619_811C
2. Write data 0x0000_0000 to address 0xE619_810C
3. Write data 0x0100_0033 to address 0xE619_8104
4. Write data 0x0000_0001 to address 0xE619_8100
5. Write data 0x0000_0000 to address 0xE619_8100

Note:
- The analog output of thermal sensor should be used for easy temperature measurement at evaluation with understanding that it may have a lot of measurement error, and its function should not be used for temperature measurement means for the customer’s mass-production set.
3. Discussion of Thermal Management in a System

3.1 Locations of Thermal Sensors and Measured Temperatures

3.1.1 Locations of Thermal Sensors and Measured Temperatures (Examples)

This section discusses the differences between the maximum temperature in the chip and the temperatures measured at the thermal sensor locations, based on the results of thermal fluid dynamics simulation for the R-Car H3 (Ver.1.0) and R-Car M3-W/Ver.1.0 as examples. The environment specified in the JEDEC standards is used for this simulation; although this standard environment differs from the actual casing or heat radiation environment, the simulation results can be considered to show a similar tendency of temperature distribution in a chip. As the operating conditions for third-generation R-Car series products, (1) high-load operation of CA57 (100% occupancy) and (2) operation of an assumed application were simulated.

Results of thermal fluid dynamics simulation for R-Car H3 Ver.1.0

![Thermal Sensor Locations Diagram]

- **THS1 = 123.6°C**
- **THS2 = 133.7°C**
- **THS3 = 134.9°C**

Maximum temperature location: CortexA57 #3

**= 137.3°C**

**Figure 3-1** Temperature Distribution Example: R-Car H3 (Ver.1.0) (1)

High-Load CA57x4 Operation without Using the GPU

![Thermal Sensor Locations Diagram]

- **THS1 = 153.4°C**
- **THS2 = 154.0°C**
- **THS3 = 155.6°C**

Maximum temperature location: CortexA57 #0

**= 156.0°C**

**Figure 3-2** Temperature Distribution Example: R-Car H3 (Ver.1.0) (2)

Assumed Application Operation

**Note:** To clearly show the temperature distribution in a chip, the upper limit on the guaranteed operating temperature of the device is exceeded in this thermal fluid dynamics simulation. In the actual environment and conditions used, correct operation of THS1, THS2, and THS3 is not guaranteed at a temperature over 125°C.
Results of thermal fluid dynamics simulation for R-Car M3-W/Ver.1.0

Figure 3-3  Temperature Distribution Example: R-Car M3-W/Ver.1.0 (1)  
High-Load CA57x2 Operation without Using the GPU

Maximum temperature location: CortexA57 #1  
THS1 = 106.1°C  
THS2 = 113.7°C  
THS3 = 112.8°C  
= 117.3°C

Figure 3-4  Temperature Distribution Example: R-Car M3-W/Ver.1.0 (2)  
Assumed Application Operation

Maximum temperature location: CortexA57 #0, near the L2C = 127.7°C

THS1 = 125.9°C  
THS2 = 125.8°C  
THS3 = 126.5°C

Note: To clearly show the temperature distribution in a chip, the upper limit on the guaranteed operating temperature of the device is exceeded in this thermal fluid dynamics simulation. In the actual environment and conditions used, correct operation of THS1, THS2, and THS3 is not guaranteed at a temperature over 125°C.
3.1.2 Discussion of Simulation Results

The simulation results show the following regarding the temperatures measured at the locations of thermal sensors.

- The temperatures differ between the three thermal sensor locations.
- The location of the maximum temperature on the chip varies depending on the SoC operating conditions.
- None of the temperatures measured at the thermal sensor locations matches the maximum temperature on the chip; the measured temperatures are always lower than the maximum temperature.
- The difference between the temperature at each thermal sensor location and the maximum temperature varies depending on the operating conditions.

The operating temperature defined in the electrical characteristics of third-generation R-Car series products is specified for the maximum temperature of the circuit surface (junction surface) of a chip. Therefore, to use the thermal sensors for thermal management of a chip, temperatures should be controlled with an adequate margin for the difference between the temperature measured by each thermal sensor and the maximum temperature.

As an adequate margin for the temperatures measured by the thermal sensors, no single value that can be applied to all cases can be determined. As the difference between the temperatures at the thermal sensor locations and the maximum temperature varies depending on the operating conditions even in simulation, the temperature distribution and temperature difference should be examined through further simulation of actual application operation or evaluation on the actual user board and then the adequate margin should be determined according to the examination. In addition, as described in the discussion of the errors in the approximation equation for conversion from a digital code in a thermal sensor to a value representing temperature in section 2.4, the temperature measured (approximated) at a thermal sensor tends to be lower than the actual temperature when the temperature exceeds the THCODE1 temperature; be sure to consider this tendency when determining a margin.

When monitoring the analog output from the thermal sensor module through an external device or an external circuit, note that the temperature obtained from the analog output may be lower than the maximum temperature in the chip by 10°C or more in some cases.
3.1.3 Results of Measurement by Multiple Thermal Sensors

Among the temperatures measured by the multiple thermal sensors in a third-generation R-Car series device, the highest temperature measured is supposed to be the closest to the maximum temperature in the chip, but in many use cases, the sensor located near CPU #0 in the center of the chip may read the closest temperature to the maximum temperature.

According to the simulation results, when differences in the measured temperatures between the three thermal sensors are large, there is a tendency for the temperature distribution in the chip to become less uniform and for the difference between the measured temperatures and the maximum temperature in the chip to become larger. This tendency is observed in the two simulation cases but may not be applicable to some actual use cases. However, this tendency might be used to determine an adequate margin for the difference between the measured temperatures and the maximum temperature in the chip; that is, a larger margin should be selected when differences in the measured temperatures between the three thermal sensors are large.

![Figure 3-5 Prediction of Maximum Temperature Using Multiple Thermal Sensors](image)

As the nonuniform temperature distribution in the chip reflects the nonuniform operating ratios of the on-chip modules, the total power consumption (heat generation) in the chip may be less and the maximum temperature may be lower compared with the case where all on-chip modules are operating equally; there might be enough margin for the upper-limit temperature for thermal management in such cases.
3.2 Transient Temperature Changes in a Chip

In the calculation of steady temperatures of semiconductor devices and systems, the concept of "thermal resistance" is often used because the thermal conduction can be considered analogous to the electrical conduction.

To calculate device temperatures or indicate the heat radiation performance, the voltage and the temperature difference, the current and the heat flow, and the electrical resistance and the thermal resistance can be considered analogous.

\[
\text{Voltage} = \text{Electrical resistance} \times \text{Current}
\]

\[
\text{Temperature difference} = \text{Thermal resistance} \times \text{Heat flow (heat generation)}
\]

Likewise, to describe the transient temperature changes due to heat generation, the concept of “heat capacity” is often used in an analogy between temperature characteristics and an electric resistor-capacitor (RC) circuit. In the same way as the voltage generated on an electric RC circuit does not immediately jump up to the final steady voltage, the temperature in a silicon chip does not immediately change to the steady temperature.

![Figure 3-6 Analogy between Temperature Characteristics and an Electric Circuit](image)

Correct modeling and prediction of transient temperature changes through a thermal fluid dynamics simulator is difficult, but it is important to be aware that reaching the steady temperature takes a certain period of time when using thermal sensors for thermal management by software or temperature measurement. The user should also pay attention to the fact that the power consumption decreases during transient temperature changes and even when the temperature falls, reaching the steady temperature takes a certain period of time.

![Figure 3-7 Voltage Changes at a Capacitor in a Simple RC Circuit](image)
Figure 3-8  Example of Temperature Changes in a Chip during a CPU Benchmark Test  
(Monitored in an Actual Chip)

Figure 3-9  Example of Temperature Changes in a Chip during a GPU Benchmark Test  
(Monitored in an Actual Chip)

Note: Figures 3-8 and 3-9 show examples of measurement results from a working sample on an evaluation board from Renesas. The results will differ from the behavior in the sample device on the user system depending on the heat radiation environment or use case.
3.2.1 Management of Chip Temperature

With the transient temperature changes in a chip in mind, close attention should also be paid to the temperature changes in a chip over time to enable efficient thermal management.

Based on the deviation of the current temperature from the upper temperature limit in a chip and the slope (derivative) of temperature changes in the chip, provide feedback data to enable adjustment of power consumption (through control of the CPU operating frequency and the number of operating CPUs) or adjustment of the fan rotation speed so that the upper temperature limit is not exceeded. In addition, evaluate in advance the temperature response to a change in the CPU operating frequency or the execution of each application on the actual user system and create a temperature response database to provide feedforward data for the management processing. Such feedback and feedforward data makes thermal management more stable.
3.3 Management of Peripheral Device Temperatures

Some peripheral devices connected to a third-generation R-Car series product require a low operating temperature condition; especially for DRAM and eMMC (NAND flash memory). Although there are devices designed for high-temperature operation to support in-vehicle applications, such devices are costly. Peripheral devices sometimes need a fast interface and are located as close as possible to the SoC in many cases. In such cases, when the heat generated in the SoC increases, more heat flows to the board and the temperatures rise on the board around these peripheral devices located close to the SoC. This necessitates thermal management also for the peripheral devices.
## Revision History

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<th>Page</th>
<th>Description</th>
<th>Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.02</td>
<td>July, 2017</td>
<td>—</td>
<td>First edition issued</td>
<td></td>
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<td>1.03</td>
<td>January, 2018</td>
<td>1</td>
<td>Description of Introduction updated.</td>
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<td></td>
<td></td>
<td>ALL</td>
<td>Device version symbol updated from “WS” to “Ver.”.</td>
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<td>1.04</td>
<td>January, 2019</td>
<td>ALL</td>
<td>R-Car H3-N, R-Car M3-W+, R-Car V3H were added as target device of this document</td>
<td>The version information for R-Car M3-W were added</td>
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<tr>
<td></td>
<td></td>
<td>5</td>
<td>Table 1-1 “Note” was added</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>6</td>
<td>1.3.1 Description was modified to support R-Car V3H</td>
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<td></td>
<td></td>
<td></td>
<td>1.3.2 Value of thermal sensor accuracy were modified</td>
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<td></td>
<td></td>
<td>9-13</td>
<td>Figure 1-4 to 1-6 and Table 1-3 to 1-5</td>
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<td></td>
<td>Target product name were modified. “Remark” about thermal sensor analog output of R-Car M3-N and V3H was added</td>
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<td></td>
<td>Figure 1-7 and Table 1-6</td>
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<td></td>
<td>Added for R-Car V3H support</td>
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<td></td>
<td></td>
<td>18, 19</td>
<td>Table 2-2 to 2-4</td>
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<td></td>
<td>Remark about R-Car V3H were added</td>
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<td></td>
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<td>28</td>
<td>Information how to validate of the thermal sensor analog output of R-Car M3-N and R-Car V3H was added</td>
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<td></td>
<td></td>
<td>37</td>
<td>Figure 3-10</td>
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<td>Description of “Note” were updated.</td>
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<td>1.05</td>
<td>April, 2019</td>
<td>ALL</td>
<td>According to actual thermal sensor trimming temperature (high temperature side, 116°C for R-Car M3-W/Ver.1.x and M3-W+, 126°C for R-Car H3, H3-N, and V3H), concerned descriptions were changed, for example from 96°C to 116°C or 126°C, from 137°C to 157°C or 167°C.</td>
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<tr>
<td></td>
<td></td>
<td>5</td>
<td>Table 1-1</td>
<td></td>
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<td></td>
<td>Output voltage range of the thermal sensor analog output pins were modified.</td>
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<tr>
<td>1.06</td>
<td>August, 2019</td>
<td>5, 6, 9, 24, 25, 28, 36</td>
<td>The descriptions regarding for the analog output of thermal sensor were deleted or added ‘note’</td>
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<td></td>
<td></td>
<td></td>
<td>- The descriptions that analog output of thermal sensor is used for customer’s mass-production set were deleted.</td>
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<tr>
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<td></td>
<td>- The following ‘note’ was added for the descriptions that analog output of thermal sensor is used for evaluation.</td>
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<td></td>
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<td></td>
<td>“The analog output of thermal sensor should be used for easy temperature measurement at evaluation with understanding that it may have a lot of measurement error, and its function should not be used for temperature measurement means for the customer’s mass-production set.”</td>
<td></td>
</tr>
<tr>
<td>1.07</td>
<td>June, 2020</td>
<td>ALL</td>
<td>Description which was not included R-Car M3-N as target device were modified.</td>
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</table>
General Precautions in the Handling of Microprocessing Unit and Microcontroller Unit Products

The following usage notes are applicable to all Microprocessing unit and Microcontroller unit products from Renesas. For detailed usage notes on the products covered by this document, refer to the relevant sections of the document as well as any technical updates that have been issued for the products.

1. Precaution against Electrostatic Discharge (ESD)
   A strong electrical field, when exposed to a CMOS device, can cause destruction of the gate oxide and ultimately degrade the device operation. Steps must be taken to stop the generation of static electricity as much as possible, and quickly dissipate it when it occurs. Environmental control must be adequate. When it is dry, a humidifier should be used. This is recommended to avoid using insulators that can easily build up static electricity. Semiconductor devices must be stored and transported in an anti-static container, static shielding bag or conductive material. All test and measurement tools including work benches and floors must be grounded. The operator must also be grounded using a wrist strap. Semiconductor devices must not be touched with bare hands. Similar precautions must be taken for printed circuit boards with mounted semiconductor devices.

2. Processing at power-on
   The state of the product is undefined at the time when power is supplied. The states of internal circuits in the LSI are indeterminate and the states of register settings and pins are undefined at the time when power is supplied. In a finished product where the reset signal is applied to the external reset pin, the states of pins are not guaranteed from the time when power is supplied until the reset process is completed. In a similar way, the states of pins in a product that is reset by an on-chip power-on reset function are not guaranteed from the time when power is supplied until the power reaches the level at which resetting is specified.

3. Input of signal during power-off state
   Do not input signals or an I/O pull-up power supply while the device is powered off. The current injection that results from input of such a signal or I/O pull-up power supply may cause malfunction and the abnormal current that passes in the device at this time may cause degradation of internal elements. Follow the guideline for input signal during power-off state as described in your product documentation.

4. Handling of unused pins
   Handle unused pins in accordance with the directions given under handling of unused pins in the manual. The input pins of CMOS products are generally in the high-impedance state. In operation with an unused pin in the open-circuit state, extra electromagnetic noise is induced in the vicinity of the LSI, an associated shoot-through current flows internally, and malfunctions occur due to the false recognition of the pin state as an input signal become possible.

5. Clock signals
   After applying a reset, only release the reset line after the operating clock signal becomes stable. When switching the clock signal during program execution, wait until the target clock signal is stabilized. When the clock signal is generated with an external resonator or from an external oscillator during a reset, ensure that the reset line is only released after full stabilization of the clock signal. Additionally, when switching to a clock signal produced with an external resonator or by an external oscillator while program execution is in progress, wait until the target clock signal is stable.

6. Voltage application waveform at input pin
   Waveform distortion due to input noise or a reflected wave may cause malfunction. If the input of the CMOS device stays in the area between V_{IL}(Max.) and V_{IH}(Min.) due to noise, for example, the device may malfunction. Take care to prevent chattering noise from entering the device when the input level is fixed, and also in the transition period when the input level passes through the area between V_{IL}(Max.) and V_{IH}(Min.).

7. Prohibition of access to reserved addresses
   Access to reserved addresses is prohibited. The reserved addresses are provided for possible future expansion of functions. Do not access these addresses as the correct operation of the LSI is not guaranteed.

8. Differences between products
   Before changing from one product to another, for example to a product with a different part number, confirm that the change will not lead to problems. The characteristics of a microprocessing unit or microcontroller unit products in the same group but having a different part number might differ in terms of internal memory capacity, layout pattern, and other factors, which can affect the ranges of electrical characteristics, such as characteristic values, operating margins, immunity to noise, and amount of radiated noise. When changing to a product with a different part number, implement a system-evaluation test for the given product.
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