APPLICATION NOTE

RX21A Group

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Gain Calibration and Compensation with the Temperature Sensor for the ΔΣ A/D Converter

Abstract

The RX21A Group has the function to satisfy the requirements of class 0.2S and 0.5S meters standardized in IEC62052-11 and IEC 62053-22.

The RX21A Group can amplify analog input using the on-chip PGA (programmable gain amplifier) providing the mechanism to reduce errors during amplifying. In the range of current 0.01In ≤ I ≤ Imax, the measurement accuracy after calibration at the reference temperature satisfies the class 0.2S meter requirements standardized in IEC 62053-22.

The measurement values with the 24-bit ΔΣ A/D converter (DSAD) are influenced by temperature. However the temperature characteristics of the RX21A have been clarified. Thus the measured values can be compensated using the powerful calculation ability of the RX21A. Thus even if not using an external reference power supply with high precision, the measurement accuracy after compensation by the RX21A DSAD can satisfy the requirement for the class 0.5S meter standardized by IEC62052-11 and IEC 62053-22 in the temperature range from -25°C to +75°C.

This document describes calibration for DSAD gains in the RX21A Group and the method for compensating the temperature characteristics of the DSAD gain using the built-in temperature sensor.

Products

- RX21A Group 100-pin package with a ROM size between 256 KB and 512 KB
- RX21A Group 80-pin package with a ROM size between 256 KB and 512 KB
- RX21A Group 64-pin package with a ROM size between 256 KB and 512 KB

Note: Only the G version (operating temperature: -40°C to +105°C) of RX21A is the target device in this application note.

Contents

1. Specifications

With 7 channels of independent DSAD, different input voltages can concurrently be measured switching PGA gains. Then some errors will occur due to chip variations or temperature characteristics. When high accuracy is required on a DSAD conversion, the system gain including the external circuit such as sensor may have to be calibrated among channels and the temperature characteristics may have to be compensated. If the application cannot eliminate an offset with the bypass filter such as direct current measurement, an offset will also need to be calibrated.

The G version of the RX21A Group has the I/O registers (ΔΣ A/D input impedance calibration data register and ΔΣ A/D gain calibration data registers) which store the calibration data for input impedance and gains measured on each chip at factory shipping. With these calibration data, the user can calibrate gains for all channels by calibrating only one given gain.

The ΔΣ A/D input impedance calibration data register and the ΔΣ A/D gain calibration data registers are not included in the RX21A Group products other than the G version. In those products, the sample code handles the read value as 1 (no effect on a calculation) when it performs calculations. The sample code cannot be used for calibrating gains for all channels by calibrating one given gain. However, it can be used as a reference when calibrating among channels and compensating the temperature characteristics.

Table 1.1 lists the Peripheral Functions and Their Applications.

Table 1.1 Peripheral Functions and Their Applications

Peripheral Function	Application
24-bit ΔΣ A/D converter (DSAD)	Measures analog input voltage.
Temperature sensor (TEMPSa)	Measures an ambient temperature for the MCU.
10-bit A/D converter (AD)	Measures the temperature sensor output.
Compare match timer (CMT1)	Used as the start trigger source of DSAD conversion and used for start processing of the temperature sensor.
Event link controller (ELC)	Used as the start trigger of DSAD conversion.

2. Operation Confirmation Conditions

The sample code accompanying this application note has been run and confirmed under the conditions below.

Table 2.1 Operation Confirmation Conditions

Item	Contents
MCU used	R5F521A8BGFP (RX21A Group G version)
Operating frequencies	• Main clock: 20 MHz • System clock (ICLK): 50 MHz • Peripheral module clock B (PCLKB): 25 MHz • Peripheral module clock C (PCLKC): 25 MHz • Peripheral module clock D (PCLKD): 12.5 MHz
Operating voltage	3.3 V
Integrated development environment	Renesas Electronics Corporation High-performance Embedded Workshop Version 4.09.01
C compiler	Renesas Electronics Corporation C/C++ Compiler Package for RX Family V.1.02 Release 01
	Compile options -cpu=rx200 -output=obj="$(CONFIGDIR)\$(FILELEAF).obj" -debug -nologo (The default setting in the integrated development environment is used.)
iodefine.h version	Version 1.1B
Endian	Little endian
Operating mode	Single-chip mode
Processor mode	Supervisor mode
Sample code version	Version 1.10

3. Reference Application Note

For additional information associated with this document, refer to the following application notes.

- RX21A Group Initial Setting (R01AN1486EJ)
- RX21A Group Using the Temperature Sensor to Calculate the Ambient Temperature (R01AN1923EJ)
- RX21A Group ΔΣ A/D Converter User’s Guide (R01AN1437EJ)
- RX Family Coding Example of Wait Processing by Software (R01AN1852EJ)

The sample code in this application note uses the initial setting functions and wait processing by the software in the reference application notes. The revision number of the reference application note is current as of when this application note was created. However, the latest version is always recommended. Visit the Renesas Electronics Corporation website to check and download the latest version.

4. Hardware

4.1 Example of the Hardware Configuration

Figure 4.1 shows the block diagram of functions used.

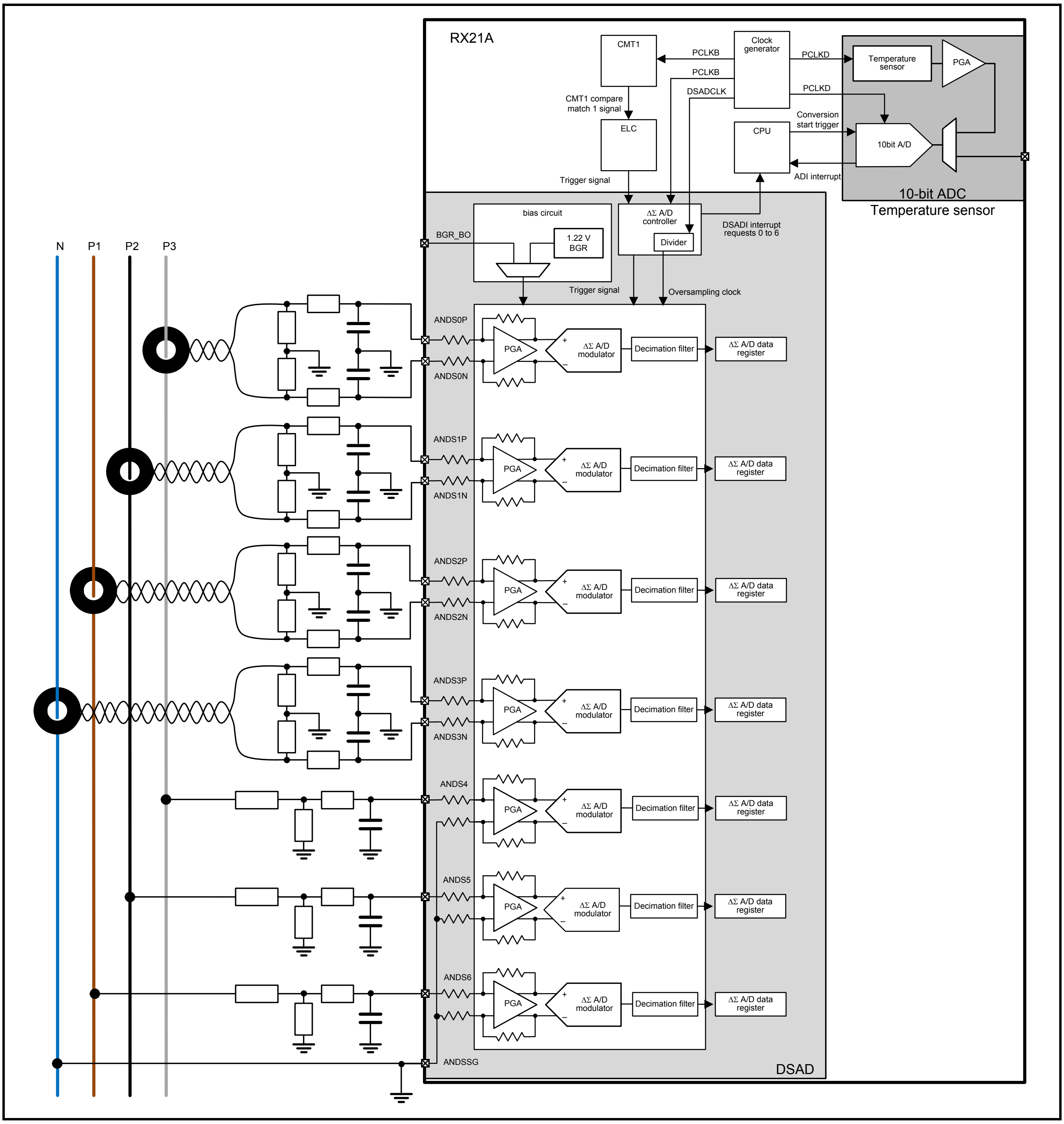


Figure 4.1 Block Diagram

4.2 Pins Used

Table 4.1 lists the Pins Used and Their Functions.

The number of pins in the sample code is set for the 100-pin package. When using products with less than 100 pins, select pins appropriate to the package used.

Table 4.1 Pins Used and Their Functions

Pin Name	I/O	Function
ANDS0P, ANDS0N	Input	Analog differential input pin, channel 0
ANDS1P, ANDS1N	Input	Analog differential input pin, channel 1
ANDS2P, ANDS2N	Input	Analog differential input pin, channel 2
ANDS3P, ANDS3N	Input	Analog differential input pin, channel 3
ANDS4	Input	Analog single-ended input pin, channel 4
ANDS5	Input	Analog single-ended input pin, channel 5
ANDS6	Input	Analog single-ended input pin, channel 6
ANDSSG	Input	Analog single-ended input pin, connected to the common signal ground
BGR_BO	Input	Reference external application terminal, the input is used as the internal reference voltage.

5. Calibration for Gain and Offset Errors

5.1 Errors of the DSAD

Figure 5.1 shows an Example of the DSAD I/O Characteristics.

The values of the ΔΣ A/D data registers are expressed as 32 bits of 2's complement. When the DSAD has the ideal characteristics, the formula becomes as follows:

Formula 5.1

$$\text{(A/D conversion value)} = \text{(analog input voltage} \times \text{gain)} / \text{(VREFDSH pin voltage)} \times 2^{23} \times (t_{TRIG} / (t_{os} \times 256))$$

However, the DSAD actually has gain and offset errors and the DSAD conversion value will be slightly different from the theoretical value. Furthermore, the sensor externally connected to the DSAD normally has gain and offset errors as well. To calculate an analog input voltage value with high accuracy based on the measured digital value, errors of gains and offsets need to be calibrated.

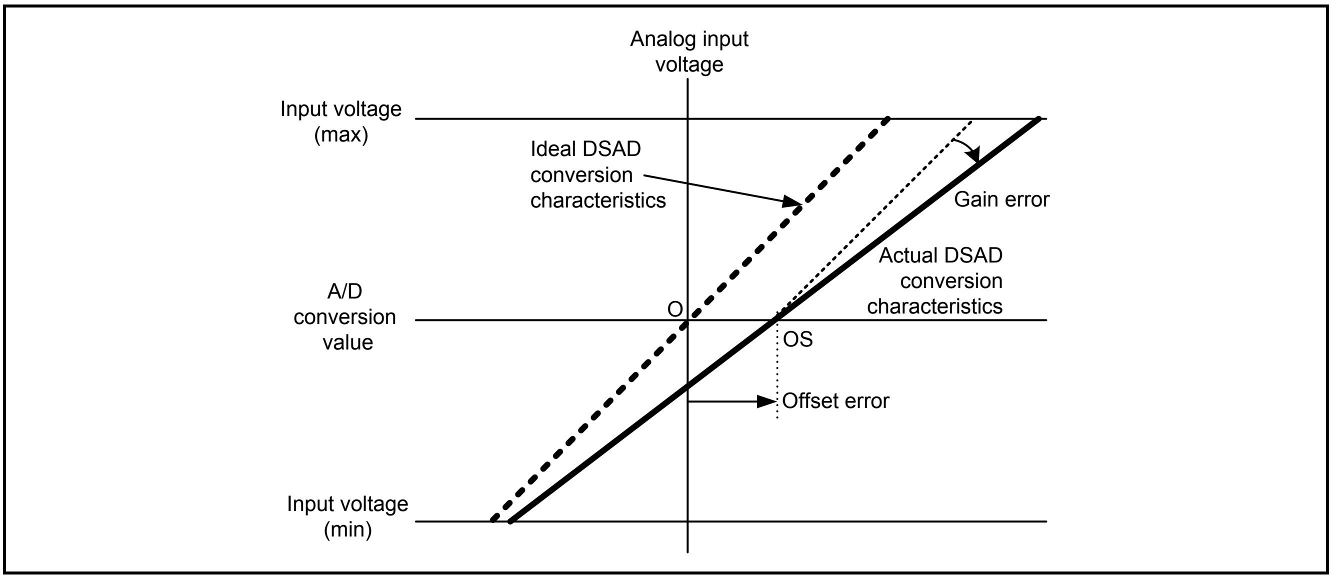


Figure 5.1 Example of the DSAD I/O Characteristics

5.2 Calculating the Calibration Values for Gains and the Offsets

Gain and offset can be calibrated by inputting voltages on two or more reference points to the DSAD input pins and measuring digital output values from each point beforehand.

When the voltage applied to the DSAD input pin is used as the reference voltage, gain and offset of RX21A itself (device gain and device offset) can be calculated. When the voltage or current applied to the sensor input section of the system is used as the reference value, gain and offset of a whole system including the sensor (system gain and system offset) can be calculated.

Calibration value error must be reduced as much as possible by averaging multiple measurement values when measuring the calibration value or by using the least squares method when calculating the calibration value.

DC power supply or sine wave AC power supply can be used for calibration.

5.2.1 Calibration with a DC Power Supply

Figure 5.2 shows the Method to Calculate the Calibration Values for Gain and Offset with DC Power Supply.

Calibration values for gain and offset can be calculated based on the measured values of two different DC voltages applied to the DSAD input pins.

When input voltages are yB and yC, and digital output values at them are xB and xC, the formula to calculate calibration values for gain and offset are as follows:

Formula 5.2

Gain = (xC - xB) / (yC - yB)

Formula 5.3

Offset = xB - (xC - xB) / (yC - yB) × yB

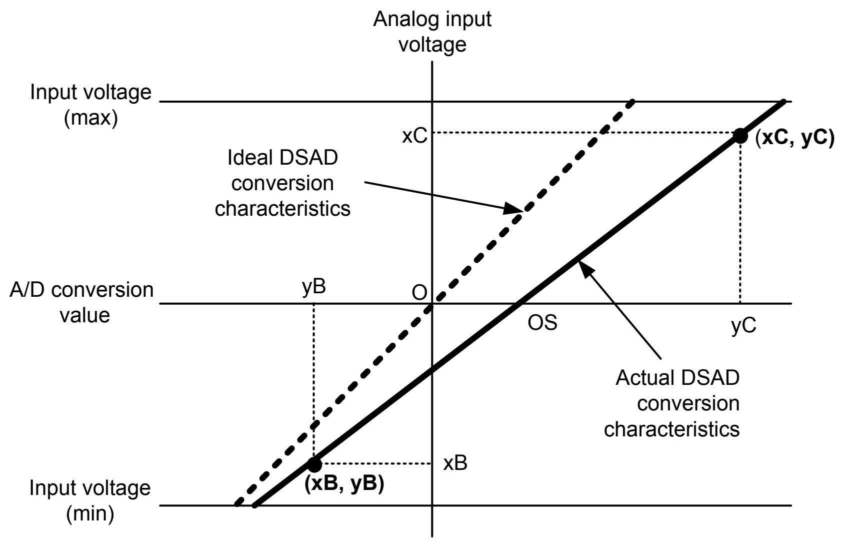


Figure 5.2 Method to Calculate the Calibration Values for Gain and Offset with DC Power Supply

5.2.2 Calibration with Sine Wave AC Power Supply

Figure 5.3 shows the Method to Calculate the Calibration Values for Gain and Offset with Sine Wave AC Power Supply.

When calculating the calibration values for gain and offset with sine wave AC power supply, formulas 5.2 and 5.3 are also used. In formula 5.2, values are assigned to xB and xC assuming that absolute values of positive and negative peak values of sine waves are same, and the minimum and maximum values of sine waves based on the digital values which are oversampled in the DSAD are assigned to yB and yC. And at this time, offset corresponds to the average value of the sine waves based on the digital values.

Calibration values for gain and offset can also be calculated using formula 5.4 instead of formula 5.2.

Formula 5.4

Gain = xRMS / yRMS

xRMS: RMS value of a sine wave based on the digital value

yRMS: RMS value of an input sine wave

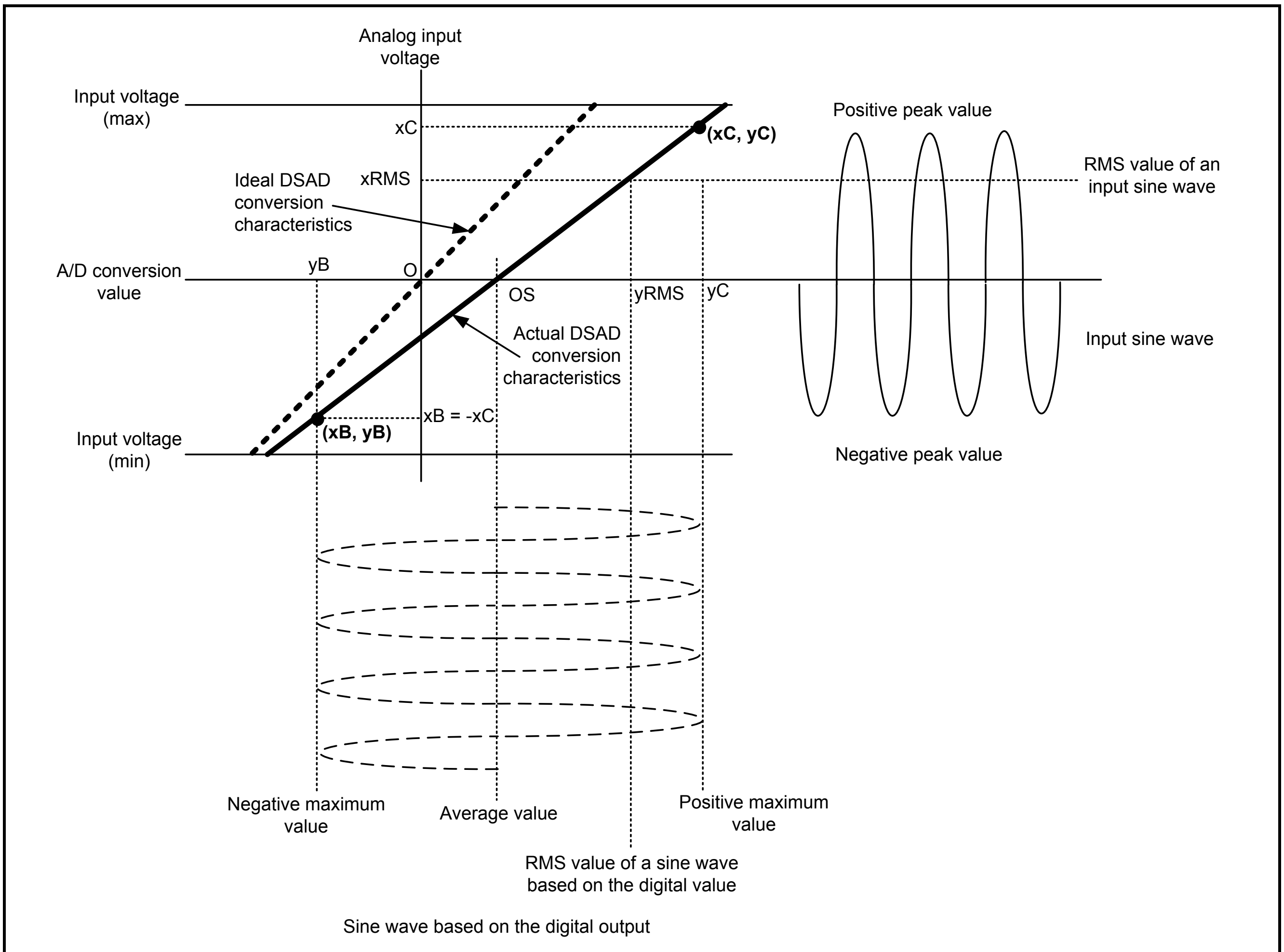


Figure 5.3 Method to Calculate the Calibration Values for Gain and Offset with Sine Wave AC Power Supply

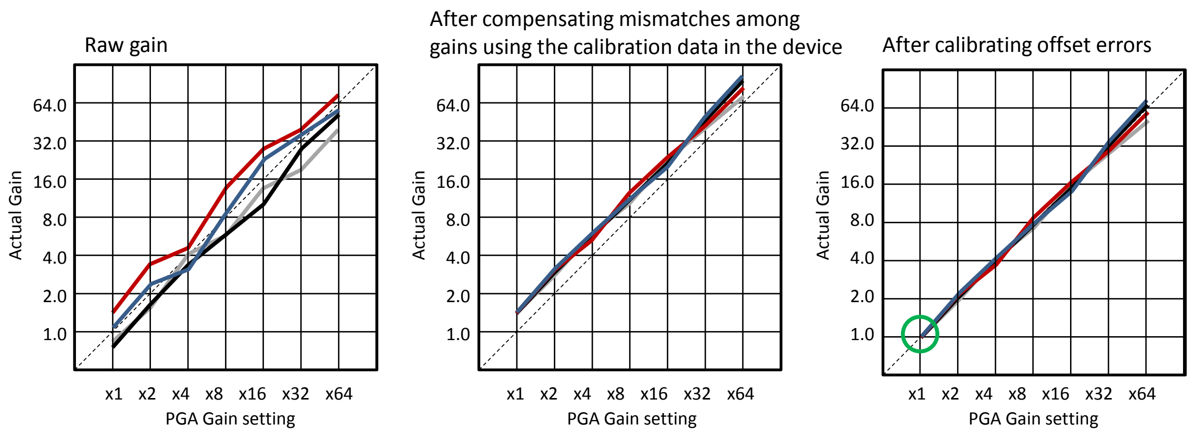
6. System Gain Calibration

6.1 Calibrating the System Gain

System gain error is caused by the DSAD internal circuit for each selectable gain and external sensor input circuits. If related voltages are measured in multiple channels, the system gain error needs to be calibrated to reduce measurement error among channels.

With the finalized product, the system gain must be calibrated at least once for all channels while the external circuit is connected.

Figure 6.1 shows the concept of the gain calibration. The left chart shows raw gains, the center shows gains after compensating linearity mismatches among gains using the calibration data stored in the device, and the right shows gains after calibrating offset errors. Actual gains for channels appear in a variety of positions relative to the PGA gain settings (left chart). The gains are calibrated starting in order from gain x1 to make each gain be closer with fewer mismatches (center chart). Then offset errors are removed shown in the right chart.



Note: This figure shows concept only. Errors in these charts are exaggerated.

Figure 6.1 Gain Calibration

6.2 Device Gain

The calibration data for gains on each device (device gain) is measured and stored in the GCD[15:0] bits in the ΔΣ A/D gain calibration data registers (DSADGmXn) (m = 0 to 6, n = 1, 2, 4, 8, 16, and 32) before shipping.

The device gain for each channel with each gain setting can be obtained using the formula 6.1.

Note that the calibration data for gain x64 is not stored. Twice the gain x32 for the device gain of gain x64.

Formula 6.1

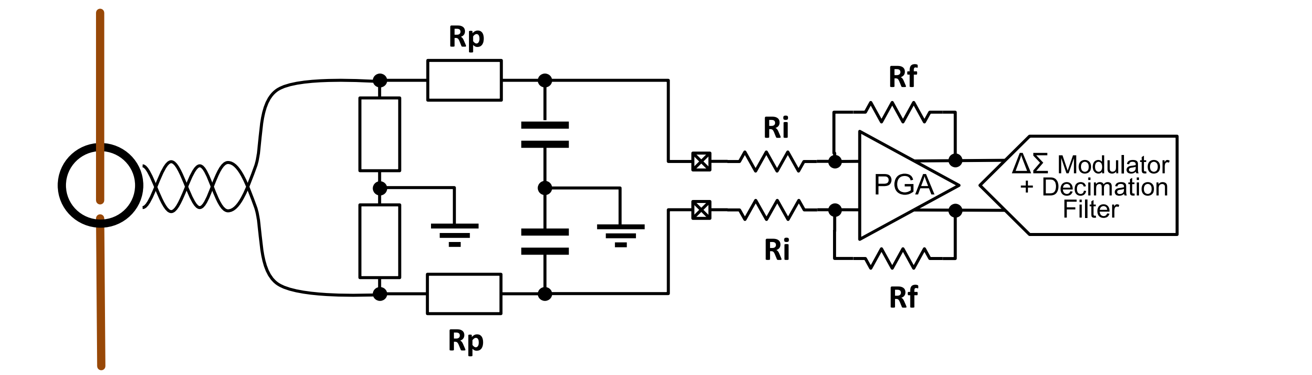
DeviceGain (m, n) = n × DSADGmXn.GCD[15:0] / 47971

DeviceGain (m, 64) = DeviceGain (m, 32) × 2

m: Input channel (0 to 6)
n: Gain (1, 2, 4, 8, 16, and 32) selected with ΔΣ A/D gain select registers 0 to 6 (DSADGSRm)

6.3 Influences of External Input Resistor and Internal Input Resistor

Figure 6.2 shows the Connection Diagram of the Differential Input Channel.



Rp: External input resistor, Ri: Internal input resistor, Rf: Feedback resistor

Figure 6.2 Connection Diagram of the Differential Input Channel

A low-pass filter (anti-aliasing filter) composed of the external input resistor Rp and the capacitor must be connected to the input pins of the DSAD for preventing an aliasing error.

In this connection example, the input resistor is the sum of the internal input resistor Ri within the DSAD and the external input resistor Rp. Then the device gain is proportional to the ratio between the input resistor and the feedback resistor.

Formula 6.2

$$DeviceGain\ (m, n) \propto Rf(n) / \{ Ri(n) + Rp(m) \}$$

m: Input channel (0 to 3)
n: Gain (1, 2, 4, 8, 16, 32 and 64) selected with ΔΣ A/D gain select registers 0 to 3 (DSADGSRm)
Rf(n): Feedback resistor at gain n
Ri(n): Internal input resistor at gain n
Rp(m): External input resistor of channel m

Table 6.1 shows the internal resistor (Ri and Rf) for each gain setting.

Table 6.1 Internal Resistor Values when Setting Each Gain

DSADGSRm. GAIN[2:0]	Gain	Internal Input Resistor Ri(n)	Feedback Resistor Rf(n)	Gain of the ΔΣ Modulator
000b	x1	Ri_0	Rf_0	1
001b	x2	Ri_0	$2Rf_0$	1
010b	x4	Ri_0	$4Rf_0$	1
011b	x8	Ri_0	$8Rf_0$	1
100b	x16	$Ri_0 / 2$	$8Rf_0$	1
101b	x32	$Ri_0 / 2$	$8Rf_0$	2
110b	x64	$Ri_0 / 2$	$8Rf_0$	4

Ri_0 and Rf_0 values in Table 6.1 are designed to 100 kΩ. In practice, these values vary depending on devices. This variation in Ri_0 is proportional to variation in impedance. Ri_0 can be expressed with formula 6.3 using the value of the IICD[15:0] bits in the ΔΣ A/D input impedance calibration data register (DSADIIC), which is measured and stored before shipping.

Formula 6.3

Ri_0 = 100.0 × DSADIIC.IICD[15:0] / 32768 [kΩ]

The system gain is a product of the sensor gain and the device gain. The sensor gain is the gain on the circuit that inputs to the DSAD.

Formula 6.4

SystemGain (m, n) = SensorGain (m) × DeviceGain (m, n)

m: Input channel (0 to 6)
n: Gain selected with ΔΣ A/D gain select registers 0 to 6 (DSADGSRm) (1, 2, 4, 8, 16, and 32)
SystemGain (m, n): Total of the sensor gain and the device gain on channel m with gain setting n
SensorGain (m): Sensor gain on channel m

When the gain setting is for x16, x32, and x64, the input resistor becomes half the value of the input resistor with gain setting for x1, x2, x4 and x8. Therefore the influence of the external input resistor Rp on the system gain varies depending on the gain setting. Formula 6.5 shows the influence ratio.

Formula 6.5

SystemGain (n_H = 16, 32, 64) / SystemGain (n_L = 1, 2, 4, 8)
$\propto \{Ri_0 / 2 + Rp\} / (Ri_0 + Rp)$
$\approx 1 + Rp / Ri_0$

7. Temperature Characteristics and Compensation

7.1 Compensating Temperature Characteristics

If the device temperature varies, the device gain, the VBGR, and the temperature characteristics of input impedance cause DSAD measurement errors. The DSAD measurement errors can be reduced by compensating the system gain, which is calibrated as described in Section 6, using the temperature information for the device.

The device temperature is obtained using the built-in temperature sensor. The accuracy of the temperature measured with the temperature sensor affects the accuracy of gain compensation. Therefore the temperature sensor must be calibrated beforehand.

Figure 7.1 shows the Elements that Have Temperature Characteristics.

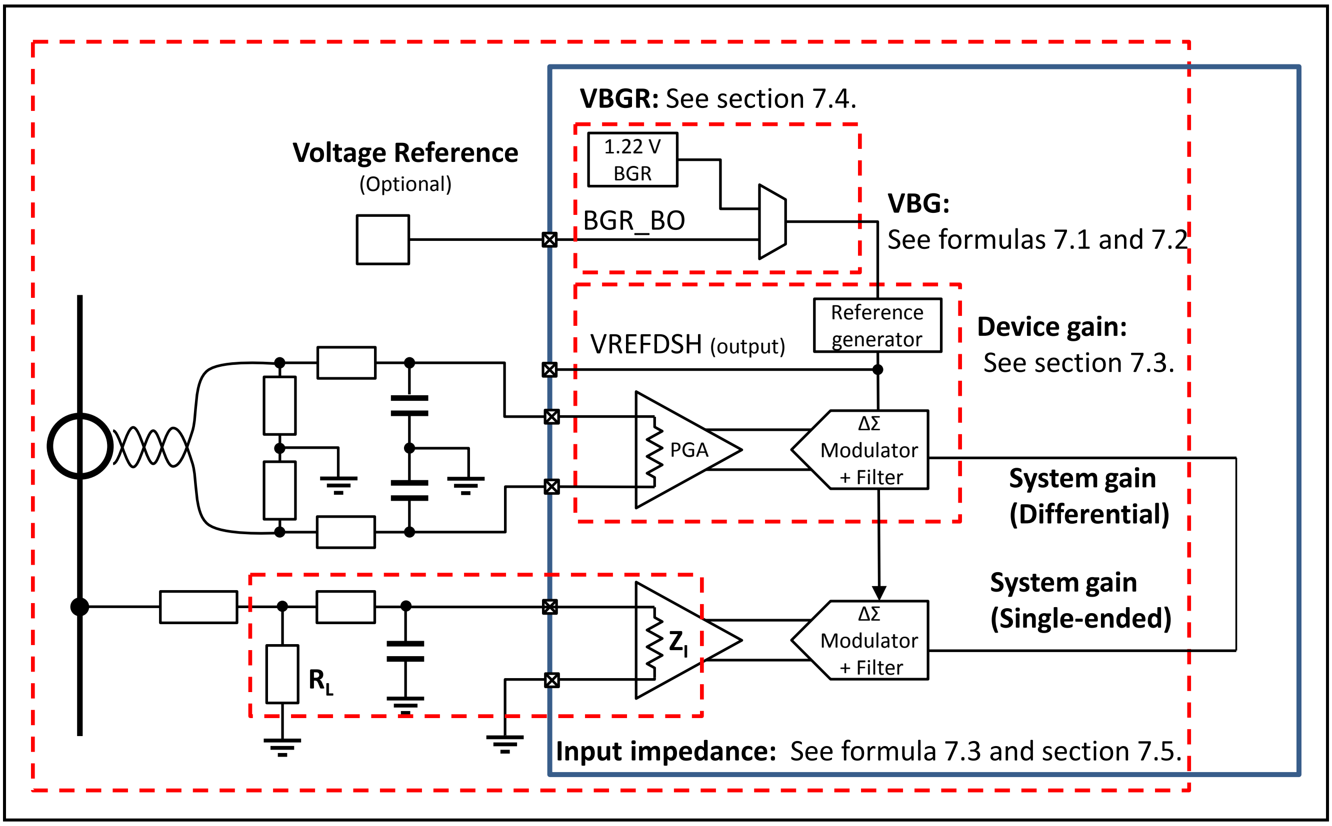


Figure 7.1 Elements that Have Temperature Characteristics

7.2 Coefficients of the Temperature Characteristics

Table 7.1 lists the Coefficients of the Temperature Characteristics in the RX21A Group.

Table 7.1 Coefficients of the Temperature Characteristics in the RX21A Group

Element		Coefficient	Symbol	Value	Unit
BGR		Quadratic slope	C_{BA}	-0.26×10^{-6}	K^{-2}
		Linear slope	C_{BB}	5.5×10^{-6}	K^{-1}
Device Gain	x1	Linear slope	C_{X1}	-5×10^{-6}	K^{-1}
	x2		C_{X2}	-4×10^{-6}	
	x4		C_{X4}	-7×10^{-6}	
	x8		C_{X8}	-2×10^{-6}	
	x16		C_{X16}	-14×10^{-6}	
	x32		C_{X32}	-14×10^{-6}	
	x64		C_{X64}	-14×10^{-6}	
Input impedance		Linear slope	C_Z	-1200×10^{-6}	K^{-1}

7.3 Device Gain

Figure 7.2 shows the theoretical temperature characteristics of the device gain when the reference voltage (VBG) assumes to have no temperature characteristics.

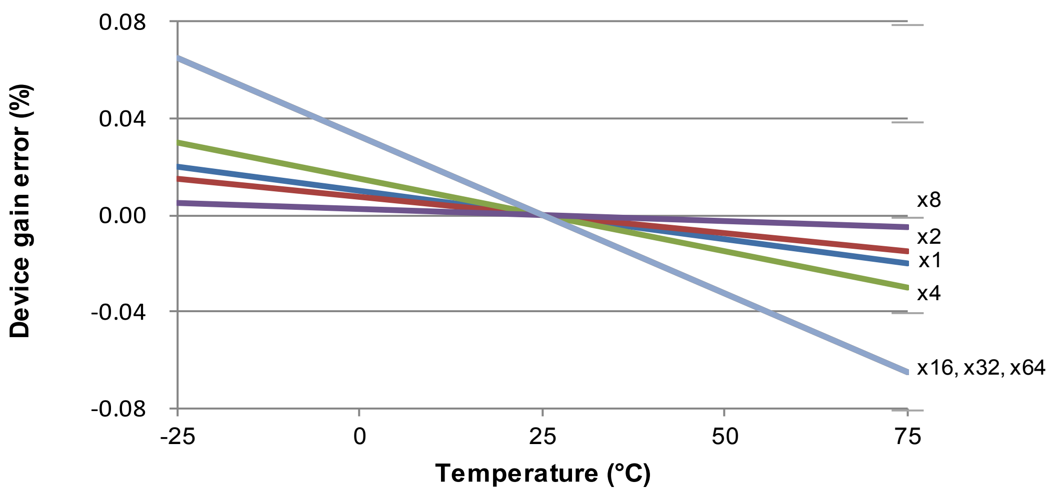


Figure 7.2 Theoretical Temperature Characteristics of the Device Gain When the Reference Voltage (VBG) Assumes to Have No Temperature Characteristics

The temperature characteristics of the device gain can be calculated with formula 7.1.

Formula 7.1

$$\text{Device gain (Tj)} = \text{Device gain(Tj = 25)} \times \{1 + C_{Xn}(Tj - 25)\}$$

Tj: Junction temperature on the chip [°C]

C_{Xn}: (n = 1, 2, 4, 8, 16, 32, and 64): Coefficient of the temperature characteristics.
Refer to Table 7.1 for coefficient values.

7.4 VBGR

The on-chip BGR voltage (VBGR) or the external reference voltage (BGR_BO) can be used as the reference voltage (VBG). When BGR_BO is used, the influence of the VBGR can be excluded. However, the temperature characteristics of BGR_BO need to be taken into account.

Figure 7.3 shows the Temperature Characteristics of the VBGR. The VBGR is adjusted to output 1.22 V at 25°C before shipping, however, it may drop up to 1.2189 V depending on the temperature.

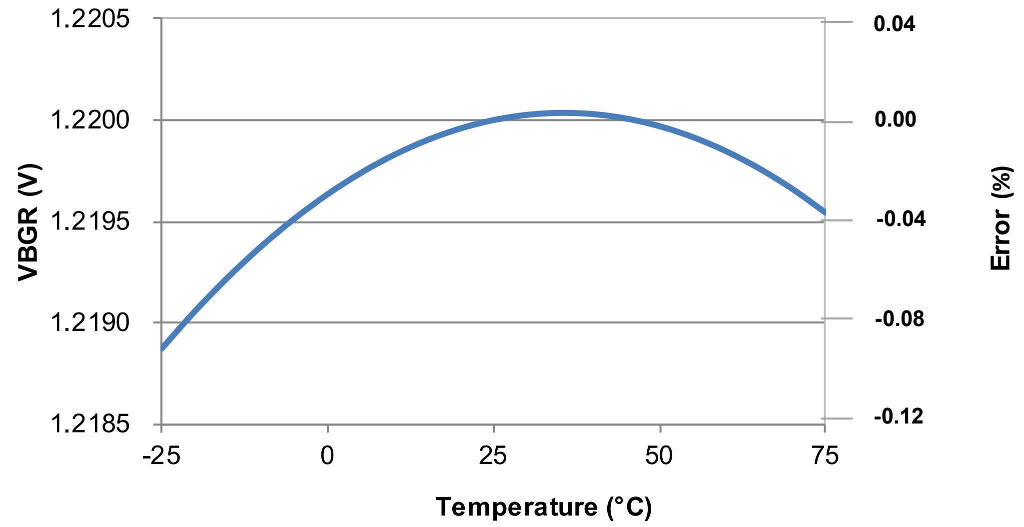


Figure 7.3 Temperature Characteristics of the VBGR

The temperature characteristics of the VBGR is calculated with formula 7.2.

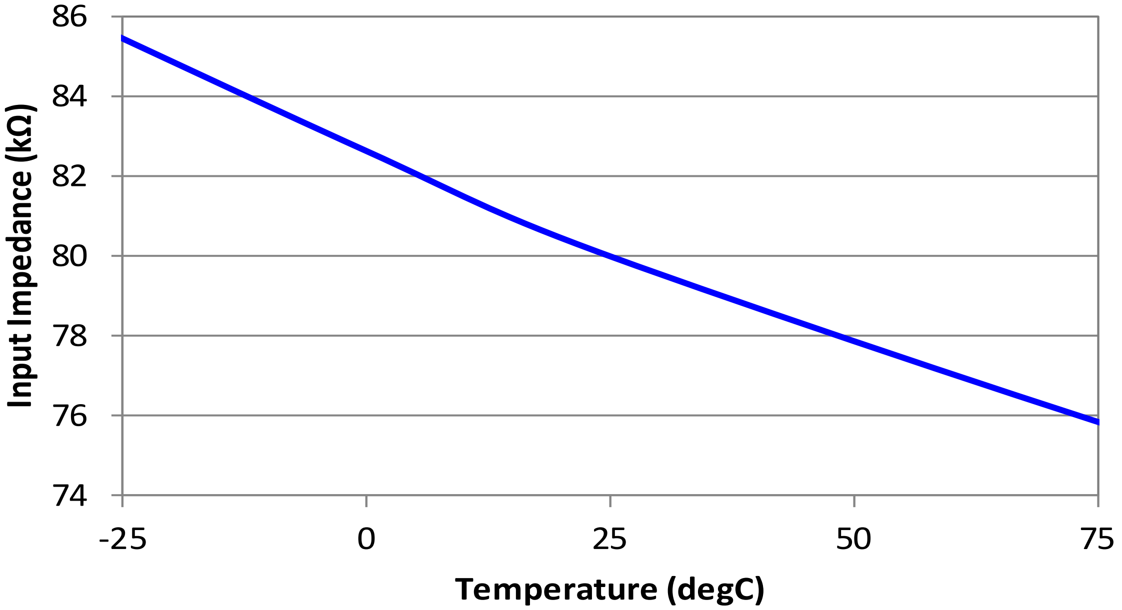
Formula 7.2

$$VBGR(Tj) = VBGR(Tj = 25) \times \{1 + C_{BA}(Tj - 25)^2 + C_{BB}(Tj - 25)\}$$

Tj: Junction temperature on the chip [°C]
C_{BA}: Coefficient of quadratic slope. Refer to Table 7.1 for the coefficient values.
C_{BB}: Coefficient of linear slope. Refer to Table 7.1 for coefficient values.
VBGR(Tj = 25): Typical voltage of BGR: 1.220 [V]

7.5 Input Impedance

Figure 7.4 shows the temperature characteristics of input impedance Z_I for the single-ended input at gain x1.



degC: Degrees Celsius

Figure 7.4 Temperature Characteristics of the Input Impedance for The Single-Ended Input at Gain x1

The temperature characteristic of input impedance Z_I at each gain setting can be calculated with formula 7.3.

Formula 7.3

$Z_I\ (Tj) = Z_I\ (Tj = 25) \times \text{DSADIIC.IICD}[15:0] / 32768 \times \{1 + C_Z \times (Tj - 25)\}$

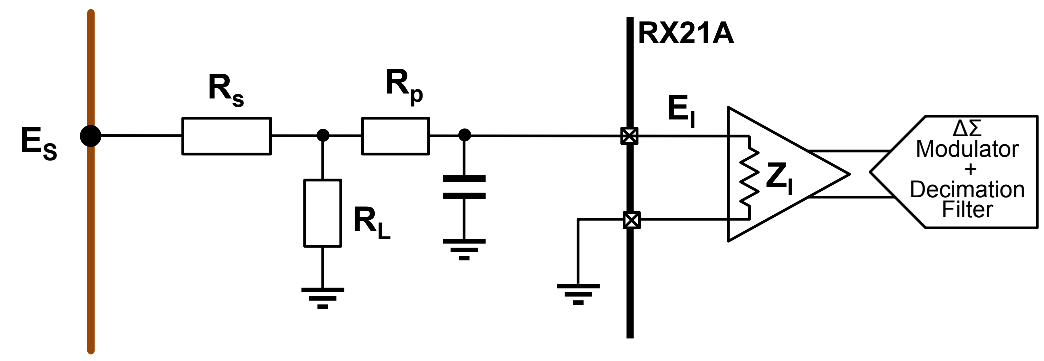
Tj: Junction temperature on the chip [°C]

Z_I (Tj = 25): Typical value of the input impedance. The value differs depending on the gain setting. Refer to “Differential input voltage” and “Single-ended input voltage” in the ΔΣ A/D Conversion Characteristics section in the User’s Manual: Hardware for details.

C_Z: Coefficient. See Table 7.1 for coefficient values.

7.6 Influences of External Load Resistor and Input Impedance

Figure 7.4 shows the Connection Example of Single-Ended Input.



R_S: External input resistor, R_L: External load resistor, R_P: Resistor of the anti-aliasing filter,
Z_I: Input impedance, E_S: Measurement voltage, E_I: Input voltage

Figure 7.5 Connection Example of Single-Ended Input

In this connection example, when the input impedance becomes lower due to rise in temperature, electrical current flows through the external load resistor is reduced. Then the input voltage (Ei) to the DSAD is also reduced and the appearance of the system gain changes. Formula 7.4 shows the relations among the load resistor, the input impedance, and the system gain.

Formula 7.4

$$\text{SystemGain} \propto E_S / E_I = [\{R_S \times (R_P + Z_I) + R_L \times (R_S + R_P + Z_I)\} / (R_L \times Z_I)]$$
$$\approx (1 + R_L / Z_I) \times (R_S / R_L) \propto 1 + R_L / Z_I$$

R_P: Resistor of the anti-aliasing filter
R_L: External load resistor
Z_I: Input impedance
* The approximation formula is when R_P is 100 Ω, R_L is 1.8 kΩ, Z_I is 80 kΩ, and R_S is 1.32 MΩ.

In Figure 6.2 Connection Diagram of the Differential Input Channel, when the output impedance from the sensor is low enough, even if the input impedance to the DSAD changes, the input voltage to the DSAD does not change. Thus influences on the system gain by the temperature characteristics of the input impedance can be ignored.

7.7 Compensation for the Temperature Characteristics of the System Gain

The system gain of the differential input is proportional to the device gain and is inversely proportional to the reference voltage VBG composed of the on-chip BGR or the external reference voltage.

The system gain of the single-ended impedance is influenced by the input impedance shown in formula 7.4.

System gain of the differential input

Formula 7.5

$\text{SystemGain (differential input)} \propto \text{Device gain / VBG}$

$\text{Device gain (Tj)} = \text{Davice gain (Tj = 25)} \times \{1 + C_{Xn}(Tj - 25)\}$ (from formula 7.1)

$\text{VBGR(Tj)} = \text{VBGR(Tj = 25)} \times \{1 + C_{BA}(Tj - 25)^2 + C_{BB}(Tj - 25)\}$ (from formula 7.2)

Formula 7.6

$\text{SystemGain (differential input) (Tj)}$

$\approx \text{SystemGain (differential input)} \times \{1 - C_{BA}(Tj - 25)^2 + (C_{Xn} - C_{BB})(Tj - 25)\}$

System gain of the single-ended input

Formula 7.7

$\text{SystemGain (single-ended input)} \propto \text{Device gain / VBG} \times (1 + R_L/Z_I)$

R_L: External load resistor [Ω]

Z_I: Input impedance [Ω]

$\text{DeviceGain (Tj)} = \text{Davice gain (Tj = 25)} \times \{1 + C_{Xn}(Tj - 25)\}$ (from formula 7.1)

$\text{VBGR (Tj)} = \text{VBGR (Tj = 25)} \times \{1 + C_{BA}(Tj - 25)^2 + C_{BB}(Tj - 25)\}$ (from formula 7.2)

$Z_I \text{ (Tj)} = Z_I \text{ (Tj = 25)} \times \text{DSADIIC.IICD[15:0]} / 32768 \times \{1 + C_Z \times (Tj - 25)\}$ (from formula 7.3)

Formula 7.8

$\text{SystemGain (single-ended input) (Tj)}$

$\approx \text{SystemGain (single-ended input) (Tj = 25)}$

$\times \{1 - C_{BA}(Tj - 25)^2 + (C_{Xn} - C_{BB} + R_L / Z_I \text{ (Tj = 25)} / \text{DSADIIC.IICD[15:0]} \times 32768 \times C_Z) (Tj - 25)\}$

8. Calibration and Compensation Procedures

This chapter describes calibration and compensation for the system gains of differential input channels and single-ended input channels, and calibration for offsets using formulas described in sections 6 and 7.

Conditions for calibration and compensation for input channels, and calibration for offsets are as follows:

- Reference temperature = 25°C (when inputting a voltage for a test)
- Voltage yB = 450 mV, yC = -450 mV

8.1 System Gain Calibration and Compensation (Differential Input)

This section describes the procedure for system gain calibration.

1. Calculate the linear coefficient (C_{Xn} - C_{BB}) used for temperature compensation and store the result in the appropriate variable. Then assign the quadratic coefficient to the appropriate variable.
   Refer to Table 7.1 for details on C_{BA}, C_{Xn}, and C_{BB}.
   SystemGain (m, 1) (differential input) (Tj) (from formula 7.6)
   ≈ SystemGain (m, 1) (differential input) (Tj = 25) × {1 - C_{BA}(Tj - 25)^2 + (C_{Xn} - C_{BB})(Tj - 25)}
2. Calculate the sensor gain using the system. First initialize the DSAD and specify gains for all channels (e.g. gain x1).
3. Input the voltage (yB in Figure 5.2) for testing to the input pins for each channel in the system used.
4. Repeat DSAD conversion at a given cycle for an appropriate number of times and obtain the average of the conversion results.
5. Input the voltage (yC in Figure 5.2) for testing to the input pins for each channel.
6. Repeat DSAD conversion at a given cycle for an appropriate number of times and obtain the average of the conversion results.
7. Input 0 V voltage for testing, repeat DSAD conversion at a given cycle for an appropriate number of times and obtain the average of the conversion results, and measure the offset for each gain.
8. Calculate the sensor gain using the DSAD conversion data obtained from the voltages at two points.
   SystemGain (m, 1) (Tj) = (xC - xB) / {T_{TRIG} / (T_{OS} × 256)} / 2^{23} (from formula 5.1)
   × VREFDSH voltage / (yC - yB)
9. To perform temperature compensation for the sensor gain at the temperature when the DSAD conversion data has been obtained, perform temperature compensation for the result of formula 5.1.
   SystemGain (m, n) (Tj) = SensorGain (m) (Tj) × DeviceGain (m, n) (from formula 6.4)
   SystemGain (m, n) (differential input) (Tj) (from formula 7.6)
   ≈ SystemGain (m, n) (differential input) (Tj = 25) × {1 - C_{BA}(Tj - 25)^2 + (C_{Xn} - C_{BB})(Tj - 25)}

   Formula 8.1
   SystemGain (m, 1) (Tj = 25) = SystemGain (m, 1) (Tj) / {1 - C_{BA}(Tj - 25)^2 + (C_{Xn} - C_{BB}) (Tj - 25)}
   SensorGain (m) (Tj) = SystemGain (m, 1) (Tj = 25) / DeviceGain (m, 1)
10. Calculate the system gains for gains x1 to x8 based on the sensor gain obtained with formulas 6.1 and 8.1.
    DeviceGain (m, n) (Tj) = n × DSADGmXn.GCD[15:0] / 47971 (from formula 6.1)
    SystemGain (m, n) (Tj) = SensorGain (m) × DeviceGain (m, n) (from formula 6.4)

    Formula 8.2
    SystemGain (m, n) (Tj) = SensorGain (m) (Tj) × n × DSADGmXn.GCD[15:0] / 47971
11. Compensate the system gains (formula 8.2) for gain x1 to gain x8 with a temperature.
    SystemGain (m, n) (differential input) (Tj) (from formula 7.6)
    ≈ SystemGain (m, n) (differential input) (Tj = 25) × {1 - C_{BA}(Tj - 25)^2 + (C_{Xn} - C_{BB})(Tj - 25)}

    Formula 8.3
    SystemGain (m, n) (differential input) (Tj)
    ≈ SystemGain (m, n) (Tj - 25) × {1 - C_{BA}(Tj - 25)^2 + (C_{Xn} - C_{BB}) (Tj - 25)}

12. Calculate the system gains for gains x16 to x32 based on formulas 6.1, and 6.3 to 6.5.

DeviceGain (m, n) (Tj) = n × DSADGmXn.GCD[15:0] / 47971 (from formula 6.1)

Ri0 = 100.0 × DSADIIC.IICD[15:0] / 32768 [kΩ] (from formula 6.3)

SystemGain (m, n) (Tj) = SensorGain (m) × DeviceGain (m, n) (from formula 6.4)

SystemGain (n = 16, 32, 64) (Tj) / SystemGain (n = 1, 2, 4, 8) (Tj) (from formula 6.5)
$\approx 1 + Rp / Ri_0$

Formula 8.4

∴ SystemGain (m, n) (Tj) = SensorGain (m, 1) (Tj) / 1* /
DSADGmX1.GCD[15:0] × 47971 × DSADGmXn.GCD[15:0] × n / 47971
× (1 + Rp / 100k × 32768 / DSADIIC.IICD[15:0])

* This formula is when the reference gain is set to gain x1.

13. Calculate the system gain for gain x64 based on formula 6.1.

DeviceGain (m, 64) = DeviceGain (m, 32) × 2 (from formula 6.1)

Formula 8.5

SystemGain (m, 64) = SystemGain (m, 32) × 2

14. Compensate the system gain for gains x16 to x64 with a temperature.

SystemGain (m, n) (differential input) (Tj) (from formula 7.6)
≈ SystemGain (m, n) (differential input) (Tj = 25) × $\{1 - C_{BA}(Tj - 25)^2 + (C_{Xn} - C_{BB})(Tj - 25)\}$

Formula 8.6

SystemGain (m, n) = (Differential input) (Tj) ≈ SystemGain (m, n) (differential input) (Tj = 25)
× $\{1 - C_{BA}(Tj - 25)^2 + (C_{Xn} - C_{BB}) (Tj - 25)\}$

Up to here, the calibration and compensation are complete. Step 15 is used when the temperature result is obtained in the main loop.

15. Compensate the measured result using the information of the system gain compensation after the temperature compensation.

Formula 8.7

(DSAD value after compensation) = ((value from any of DSADDR0 to DSADDR 3) -
(gain offset value (result in step 7))) / SystemGain (m, n) (Tj = 25)
× SystemGain (m, n) (differential input) (Tj)

8.2 System Gain Calibration and Compensation (Single-Ended Input)

This section describes the procedure for system gain calibration.

1. Calculate the linear coefficient (C_{Xn} - C_{BB} + R_L / Z_I (Tj = 25) / DSADIIC.IICD[15:0] × 32768 × C_Z) used for temperature compensation and store the result in an appropriate variable. Then assign the quadratic coefficient (CBA) to an appropriate variable.

   Refer to Table 7.1 for details on C_{BA}, C_{Xn}, C_{BB}, and C_Z.

   SystemGain (m, 1) (single-ended input) (Tj) (from formula 7.8)
   ≈ SystemGain (m, 1) (single-ended input) (Tj = 25)
   × {1 - C_{BA}(Tj - 25)^2 + (C_{Xn} - C_{BB} + R_L / Z_I (Tj = 25) / DSADIIC.IICD[15:0] × 32768 × C_Z) (Tj - 25)}

2. Calculate the sensor gain using the system. First initialize the DSAD and specify gains for all channels (e.g. gain x1).
3. Input the voltage (yB in Figure 5.2) for testing to the input pins for each channel in the system used.
4. Repeat DSAD conversion in a given cycle for an appropriate number of times and obtain the average of the conversion results.
5. Input the voltage (yC in Figure 5.2) for testing to the input pins for each channel.
6. Repeat DSAD conversion in a given cycle for an appropriate number of times and obtain the average of the conversion results.
7. Input 0 V voltage for testing, repeat DSAD conversion at a given cycle for an appropriate number of times and obtain the average of the conversion results, and measure the offset for each gain.
8. Calculate the sensor gain using the DSAD conversion data obtained from the voltages at two points.

   SystemGain (m, 1) (Tj) = (xC - xB) / {T_{TRIG} / (T_{OS} × 256)} / 2^{23} (from formula 5.1)
   × VREFDSH voltage / (yC - yB)

9. To perform temperature compensation for the sensor gain at the temperature when the DSAD conversion data has been obtained, perform temperature compensation for the result of formula 5.1.

   SystemGain (m, n) (Tj) = SensorGain (m) (Tj) × DeviceGain (m, n) (from formula 6.4)

   SystemGain (m, n) (single-ended input) (Tj) (from formula 7.8)
   ≈ SystemGain (m, n) (single-ended input) (Tj = 25)
   × {1 - C_{BA}(Tj - 25)^2 + (C_{Xn} - C_{BB} + R_L / Z_I (Tj = 25) / DSADIIC.IICD[15:0] × 32768 × C_Z) (Tj - 25)}

   Formula 8.8
   SystemGain (m, 1) (Tj = 25) = SystemGain (m, 1) (Tj) / {1 - C_{BA}(Tj - 25)^2 + (C_{Xn} - C_{BB} + R_L / Z_I (Tj = 25) / DSADIIC.IICD[15:0] × 32768 × C_Z) (Tj - 25)}
   SensorGain (m) = SystemGain (m, 1) (Tj = 25) / DeviceGain (m, 1)

10. Calculate the system gains for gains x1 to x4 based on the sensor gain obtained with formulas 6.1 and 6.4.

    DeviceGain (m, n) (Tj) = n × DSADGmXn.GCD[15:0] / 47971 (from formula 6.1)

    SystemGain (m, n) (Tj) = SensorGain (m) × DeviceGain (m, n) (from formula 6.4)

    Formula 8.9
    SystemGain (m, n) (Tj) = SensorGain (m) × n × DSADGmXn.GCD[15:0] / 47971

11. Compensate the system gains (formula 8.9) for gains x1 to x4 with a temperature.

    SystemGain (m, n) (single-ended input) (Tj) (from formula 7.8)
    ≈ SystemGain (m, n) (single-ended input) (Tj = 25)
    × {1 - C_{BA}(Tj - 25)^2 + (C_{Xn} - C_{BB} + R_L / Z_I (Tj = 25) / DSADIIC.IICD[15:0] × 32768 × C_Z) (Tj - 25)}

    Formula 8.10
    SystemGain (m, n) (differential input) (Tj)
    ≈ SensorGain (m) (Tj) × DeviceGain (m, n) × {1 - C_{BA}(Tj - 25)^2 + (C_{Xn} - C_{BB} + R_L / Z_I(Tj - 25)
    / DSADIIC.IICD[15:0] × 32768 × C_Z) (Tj - 25)}

12. Compensate the measured result using the information of the system gain compensation after the temperature compensation.

    Formula 8.11
    (DSAD value after compensation) = (value from any of DSADDR0 to DSADDR3) -
    (gain offset value (result in step 7)) / SystemGain (m, n) (Tj = 25) /
    SystemGain (m, n) (single-ended Input) (Tj)

9. Software

9.1 Operation Overview

After a reset, the DSAD values for calibration and compensation are obtained, the system gain is calibrated and compensated, the temperature sensor is calibrated, and then DSAD conversion is performed while the system gain is compensated for the DSAD using the temperature information obtained from the temperature sensor.

The DSAD values for calibration and compensation are measured for gains x2 to x64 at 0 V and at voltages of two points. The voltages at two points are used to calculate the sensor gain. The measurement results at 0 V for gains x2 to x64 are used as offset values. The offset value varies for each gain, thus the offset value needs to be obtained for all gains from x2 to x64.

The temperature sensor is calibrated using the A/D conversion results after a reset and the calibration values at 125°C stored internally. After the temperature sensor has been calibrated, the calibration results are used for calculating the temperature data.

DSAD conversion is triggered by CMT1 every 163.84 µs and ten conversions are treated as one sampling. First two conversion results are discarded and the rest of eight results are used to calculate the sum. Then the sum is divided by 8 to obtain the average.

For A/D conversion used by the temperature sensor, 163.84 ms is counted by CMT1 610 times, A/D conversion is performed every 100 ms, six A/D conversion results are stored in the RAM, the maximum and minimum values are subtracted from the sum of the conversion results, and then the subtraction result is divided by 4 to obtain the average.

Figure 9.1 shows the Operation Timing Diagram.

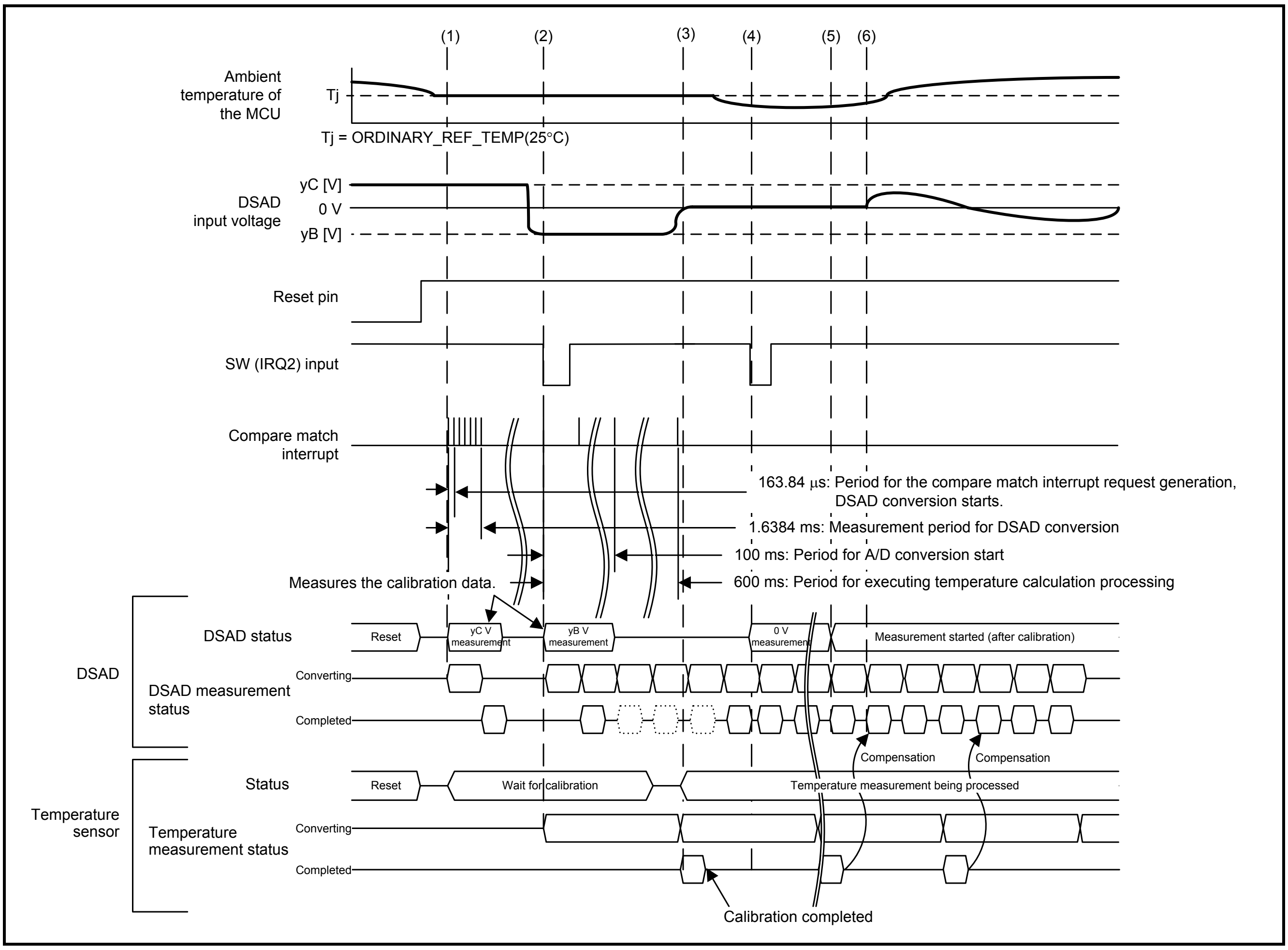


Figure 9.1 Operation Timing Diagram

(1) Reset is released with the voltage of yC [V] and temperature of ORDINARY_REF_TEMP, the initialization is performed, DSAD conversion values are obtained at yC [V] for each channel, and then a wait for the IRQ2 interrupt request is performed.

(2) At an appropriate timing that the conversions can be completed, the voltage is changed to yB [V] and SW is pressed. Then the IRQ2 interrupt request is generated and DSAD conversion values at yB [V] are obtained for each channel. At the same time, the temperature sensor is started and the A/D conversion values at the temperature of ORDINARY_REF_TEMP are obtained.

(3) A/D conversion results are obtained six times and the temperature sensor is calibrated.

(4) At an appropriate timing that the calibration for the temperature sensor can be completed, the voltage is changed to 0 [V] and SW is pressed. Then the IRQ2 interrupt request is generated and DSAD conversion values at 0 [V] are obtained for each channel at all gains.

(5) The DSAD conversion results are calibrated and compensated. At this point, the voltage and temperature held can be released.

(6) The DSAD conversion results are compensated using the ambient temperature information obtained with the temperature sensor. The DSAD conversion result is compensated using the calculated compensation value.

The settings for the DSAD, CMT1, temperature sensor, and A/D converter are as follows:

DSAD

- Reference voltage generation: On-chip BGR circuit
- Gain setting: All gains for offset measurement. Gain x1 for measurements other than offset.
- A/D conversion end interrupt: Used
- Overwrite interrupt (interrupt by data register overwrite): Not used
- Input select: Input from analog input pins used.

CMT1

- Count clock: PCLK divided by 32
- Compare match interrupt period: 163.84 μs

Note: The period must be set with an integral multiple of t_{OS}, so the trigger period will be between $t_{OS} \times 256$ and $t_{OS} \times 768$.

Temperature sensor

- PGA gain [1]: $2.7 V \leq AVCC0 \leq 3.6 V$ [2]

Notes:
1. PGA: Programmable Gain Amplifier
2. Change the parameter setting according to the system used.

A/D converter

- Operating mode: Single scan mode
- A/D conversion start trigger: Synchronous trigger (trigger from the temperature sensor)
- Sampling state count: 180 states (sampling time: 72 μs)
- Analog input disconnection detection assist: Not used.
- A/D-converted value addition mode: Not used.
- Self-diagnosis of 10-bit A/D converter: Not used.

9.2 Required Memory Size

Table 9.1 lists the Required Memory Size.

Table 9.1 Required Memory Size

Memory Used	Size	Remarks
ROM	7311 bytes	
RAM	2046 bytes	
Maximum user stack usage	80 bytes	
Maximum interrupt stack usage	0 bytes	

Note: The required memory sizes vary depending on the C compiler version and compile options.

9.3 File Composition

Table 9.2 lists the Files Used in the Sample Code, Table 9.3 lists the Standard Include Files, and Table 9.4 and Table 9.5 list the Functions and Setting Values in the Reference Application Notes. Files generated by the integrated development environment are not included in this table.

Table 9.2 Files Used in the Sample Code

File Name	Outline
main.c	Main processing
dsad.c	Functions for DSAD gain calibration and temperature compensation
dsad.h	Header file for dsad.c
temps.c	Temperature sensor processing
temps.h	Header file for temps.c

Table 9.3 Standard Include Files

File Name	Outline
stdbool.h	Defines macros associated with Boolean and its value.
stdint.h	Defines macros declaring the integer type with the specified width.
float.h	Defines various limit values relating to the limits of floating-point numbers.
machine.h	Defines types of intrinsic functions for the RX Family.

Table 9.4 Functions and Setting Values in the Reference Application Note (RX21A Group Initial Setting)

File Name	Function	Setting Value
r_init_stop_module.c	R_INIT_StopModule()	—
r_init_stop_module.h	—	—
r_init_non_existent_port.c	R_INIT_NonExistentPort()	—
r_init_non_existent_port.h	—	100-pin version is specified.
r_init_clock.c	R_INIT_Clock()	—
r_init_clock.h	—	Clock selection: No. 1 is specified. The PCLKD division ratio is changed to divide-by-16.

Table 9.5 Functions and Setting Values in the Reference Application Note (RX Family Coding Example of Wait Processing by Software)

File Name	Function	Setting Value
r_delay.c	R_DELAY_Us(unsigned long us, unsigned long khz)	Wait time is specified.
r_delay.h	—	—

9.4 Option-Setting Memory

Table 9.6 lists the Option-Setting Memory Configured in the Sample Code. When necessary, set a value suited to the user system.

Table 9.6 Option-Setting Memory Configured in the Sample Code

Symbol	Address	Setting Value	Contents
OFS0	FFFF FF8Fh to FFFF FF8Ch	FFFF FFFFh	The IWDT is stopped after a reset. The WDT is stopped after a reset.
OFS1	FFFF FF8Bh to FFFF FF88h	FFFF FFFFh	The voltage monitor 0 reset is disabled after a reset. HOCO oscillation is disabled after a reset.
MDES	FFFF FF83h to FFFF FF80h	FFFF FFFFh	Little endian

9.5 Constants

Table 9.7 to Table 9.13 list the Constants Used in the Sample Code.

Table 9.7 Constants Used in the Sample Code (dsad.c)

* The constants listed in the table can be changed by the user.

Constant	Setting Value	Contents
RI0TYP	100e3	Designed value of the internal input resistor [Ω]
CHIP_VER	1	Selection of the device version used.
BGR_CIRCUIT	1	Enable/disable setting of the BGR circuit
VALID_CHANNEL	0x7F	Selection of channels used (1: Used, 0: Not used) * With this, channels are associated with the corresponding bits (ch0 to ch6 correspond to bit 0 to bit 6, respectively).
VREFDSH_VOLT	600	Reference voltage (mV)
TRIG_MS	1 / 25.0f * 32 * 128	Setting value of t_{TRIG} (CMT1 cycle)
TOS_MS	1.0f / (25.0f / 8)	Setting value of t_{OS} (3.125 MHz: DSADCLK divided by 8)
SENSOR_CALC	TRIG_MS / (TOS_MS * 256)	Constant used for calculating the analog input voltage based on the A/D conversion value.

Table 9.8 Constants Used in the Sample Code (dsad.h)

* The constants listed in the table can be changed by the user.

Constant Name	Setting Value	Contents
DSAD_CH_NUM	7	Number of channels of the DSAD
DSAD_DIFFER_CH_NUM	4	Number of channels for the differential input
DSAD_SINGLE_CH_NUM	3	Number of channels for the single-ended input
DSAD_GAIN_NUM	7	Number of gains available in the DSAD
DSAD_DIFFER_GAIN_NUM	7	Number of gains available with the differential input channel
DSAD_SINGLE_GAIN_NUM	3	Number of gains available with the single-ended input channel
DSAD_DISCARD_CNT	2	Number of DSAD conversions to be discarded
DSAD_CNT_MAX	(DSAD_DISCARD_CNT+8)	Number of DSAD conversions (‘2’ for discarding + ‘8’ for calculating the average)

Table 9.9 Constants Used in the Sample Code (dsad.h)

* The constants listed in the table cannot be changed by the user.

Constant Name	Setting Value	Contents
STA_DSAD_IDLE	0	DSAD in preparation
STA_DSAD_PATERN_0	1	DSAD conversion with yC [V]
STA_DSAD_PATERN_1	2	DSAD conversion with yB [V]
STA_DSAD_COMPESETE	3	DSAD conversion with 0 V
DSAD_GAIN_X1 DSAD_GAIN_X2 DSAD_GAIN_X4 DSAD_GAIN_X8 DSAD_GAIN_X16 DSAD_GAIN_X32 DSAD_GAIN_X64	0 1 2 3 4 5 6	Gain number to be selected

Table 9.10 Constant Used in the Sample Code (main.c)

Constant Name	Setting Value	Contents
CMT_CYCLE_MS	610	A/D conversion cycle (163.84 μs × 610 = approx. 100 ms)

Table 9.11 Constants Used in the Sample Code (temps.c)

Constant Name	Setting Value	Contents
HIGH_REF_TEMP	125	High reference temperature [°C]
ADCONV_IN_OPERATION	0xFFFF	A/D conversion value during A/D conversion being performed (invalid value)
SLOPE_COEFFICIENT_ TEMP	(HIGH_REF_TEMP – ORDINARY_REF_TEMP) * TEMP_ACCURACY	Temperature slope
ORDINARY_REF_TEMP_IN_ ACC	ORDINARY_REF_TEMP * TEMP_ACCURACY	Product of normal reference temperature (25°C) and temperature calculation accuracy

Table 9.12 Constants Used in the Sample Code (temps.h)

* The constants listed in the table can be changed by the user.

Constant Name	Setting Value	Contents
SEL_PGAGAIN	GAIN_RANGE1	Selection of the PGA gain (1) GAIN_RANGE0: 1.8 V ≤ AVCC0 < 2.7 V GAIN_RANGE1: 2.7 V ≤ AVCC0 ≤ 3.6 V
AVCC_VOLTAGE	3.3	Voltage [V] applied to the AVCC0 pin (1)
VREF_VOLTAGE	3.3	Voltage [V] applied to the VREFH0 pin
ORDINARY_REF_TEMP	25	Normal reference temperature [°C] * When the setting value is 25, the normal reference temperature is recognized as 25°C.
TEMP_ACCURACY	10	Temperature calculation accuracy * Multiplying factor is specified. When the setting value is 10, the tenth place is included in calculations and when the setting value is 100, the hundredth place is included in calculations. Do not set a value other than multiplier of 10 or a negative value.
CNV_CNT_MAX	6	Number of samplings for calculating the average * When the setting value is 6, A/D conversion results are obtained six times. The minimum and maximum values are discarded from the sum of the conversion results. The average of the remaining four values is used as the A/D conversion value.

Note:

1. The conditions of an applied voltage to the AVCC0 pin and the PGA gain must be consistent. Otherwise the calculation result will not be correct.

Table 9.13 Constants Used in the Sample Code (temps.h)

* The constants listed in the table cannot be changed by the user.

Constant Name	Setting Value	Contents
GAIN_RANGE0 (1)	00h	PGA gain: 1.8 V ≤ AVCC0 < 2.7 V
GAIN_RANGE1 (1)	01h	PGA gain: 2.7 V ≤ AVCC0 ≤ 3.6 V
STA_AD_IDLE	0	A/D conversion status: Not operating
STA_AD_WAIT	1	A/D conversion status: Wait for completion of A/D conversion
STA_AD_FINISH	2	A/D conversion status: A/D conversion completed
TSCDR0_VALUE	(TEMPSCONST.TSCDR0 .BIT.TSCD)	TSCDR0 register value
TSCDR1_VALUE	(TEMPSCONST.TSCDR1 .BIT.TSCD)	TSCDR1 register value
TSCDR3_VALUE	(TEMPSCONST.TSCDR3 .BIT.TSCD)	TSCDR3 register value
HIGH_REF_POTENTIAL _VAL	Note 1	A/D conversion value of the high reference temperature (125°C)

Note:

1. The setting value differs depending on the PGA gain selected. The setting value for each PGA gain is shown below.

   When 'GAIN_RANGE0' is selected:
   (uint16_t) (1.8 / VREF_VOLTAGE * TSCDR0_VALUE)

   When 'GAIN_RANGE1' is selected:
   (uint16_t) ((2.7 / VREF_VOLTAGE * TSCDR1_VALUE) + ((3.3 / VREF_VOLTAGE * TSCDR3_VALUE) - (2.7 / VREF_VOLTAGE * TSCDR1_VALUE)) * (AVCC_VOLTAGE - 2.7) / 0.6)

9.6 Variables

Table 9.14 lists the Global Variables (dsad.c), Table 9.15 to Table 9.17 list the static Variables, and Table 9.18 and Table 9.19 list the const Variables.

Table 9.14 Global Variables (dsad.c)

Type	Variable Name	Contents	Function
int32_t	g_dsad_data[DSAD_CH_NUM]	Areas for ch0 to ch6 to store the DSAD conversion value after calibration and compensation	measure_dsad_calib measure_dsad Excep_DSAD_DSADI0 Excep_DSAD_DSADI1 Excep_DSAD_DSADI2 Excep_DSAD_DSADI3 Excep_DSAD_DSADI4 Excep_DSAD_DSADI5 Excep_DSAD_DSADI6
uint16_t	g_sel_ch_gain[DSAD_CH_NUM]	Area to store the specified gain. The value stored is used as the gain value. When a change is required, rewrite the value.	dsad_init R_DSAD_Calibration measure_dsad_calib measure_dsad
volatile float	g_compensated_gain [DSAD_CH_NUM]	System gain of the whole system after temperature compensation for each DSAD channel and gain setting	R_DSAD_CompensatedGain measure_dsad

Table 9.15 static Variables (main.c)

Type	Variable Name	Contents	Function
static const bool	valid_dsad_channel [DSAD_CH_NUM]	Indicates whether each channel is available or not. Specify an appropriate value according to the user system.	main
static volatile uint16_t	cnt_cycle	Counter for the A/D conversion cycle	Excep_CMT1_CMI1

Table 9.16 static Variables (temps.c)

Type	Variable Name	Contents	Function
static int16_t	high_ref_potential	A/D conversion value (= CAL_{125}) of the high reference temperature (125°C)	temps_init temps_calibration
static volatile uint16_t	slope_potential	A/D conversion slope	temps_calibration temps_calc
static volatile int16_t	ordinary_potential	A/D conversion value (= CAL_{25}) of the normal reference temperature (25°C)	temps_calibration temps_calc
static volatile uint8_t	ad_status	A/D conversion status	main temps_get_ad_status temps_calibration temps_measurement Excep_AD_ADI
static volatile int16_t	now_temp	Current temperature calculated	temps_get_now_temp Excep_AD_ADI
static volatile uint16_t	now_potential	Current A/D conversion value	temps_calibration Excep_AD_ADI
static volatile uint16_t	buf_ad_value[CNT_CNT_MAX]	Buffer for the A/D conversion value	Excep_AD_ADI
static volatile uint8_t	ad_smp_cnt	Pointer for writing the A/D conversion value	Excep_AD_ADI
static volatile uint16_t	ad_max_value	A/D conversion maximum value	Excep_AD_ADI
static volatile uint16_t	ad_min_value	A/D conversion minimum value	Excep_AD_ADI

Table 9.17 static Variables (dsad.c)

Type	Variable Name	Contents	Function
static volatile	uint16_t dsad_smp_cnt[DSAD_CH_NUM]	Number of times for reading the DSAD conversion result	Excep_DSAD_DSADI0 Excep_DSAD_DSADI1 Excep_DSAD_DSADI2 Excep_DSAD_DSADI3 Excep_DSAD_DSADI4 Excep_DSAD_DSADI5 Excep_DSAD_DSADI6
static int32_t	dsad_data_sum [DSAD_CH_NUM]	Area used to sum the DSAD conversion results	
static uint16_t	dsad_comp_fin	Flag to check whether the DSAD value in each register has been read and the average of the values has been obtained.	measure_dsad_calib measure_dsad Excep_DSAD_DSADI0 Excep_DSAD_DSADI1 Excep_DSAD_DSADI2 Excep_DSAD_DSADI3 Excep_DSAD_DSADI4 Excep_DSAD_DSADI5 Excep_DSAD_DSADI6
static uint16_t	dsad_comp_status	Information of the status to check the progress of the calibration and compensation	measure_dsad_calib
static int32_t	dsad_comp_data [DSAD_CH_NUM] [DSAD_GAIN_NUM+2]	Area to store the averaged DSAD conversion result before calibration and compensation [ch][0]: Measurement result at yC [ch][1]: Measurement result at yB [ch][2] to [9]: Measurement result at 0V for each gain	R_DSAD_Calibration measure_dsad_calib measure_dsad
static volatile float	coef_temp_quad	Quadratic coefficient of the temperature characteristics for temperature compensation	R_DSAD_InternalCompensated R_DSAD_Calibration R_DSAD_CompensatedGain
static volatile float	coef_temp_linear [DSAD_CH_NUM] [DASD_GAIN_NUM]	Linear coefficient of the temperature characteristics for temperature compensation	R_DSAD_InternalCompensated R_DSAD_Calibration R_DSAD_CompensatedGain
static volatile float	device_gain [DSAD_CH_NUM] [DSAD_GAIN_NUM]	Device gain for DSAD channels with each gain setting at 25°C	R_DSAD_InternalCalibration R_DSAD_Calibration R_DSAD_CompensatedGain
static volatile float	sensor_gain [DSAD_CH_NUM]	Sensor gain for DSAD channels with each gain setting at 25°C in an external circuit such as a sensor	R_DSAD_Calibration R_DSAD_CompensatedGain
static volatile float	system_gain [DSAD_CH_NUM] [DSAD_GAIN_NUM]	System gain for DSAD channels with each gain setting at 25°C in the whole system gain including the sensor	R_DSAD_Calibration R_DSAD_CompensatedGain measure_dsad

Table 9.18 const Variables (main.c)

Type	Variable Name	Contents	Function
const float	g_dsad_ext_load_res [DSAD_SINGLE_CH_NUM]	Value [Ω] of the external load resistor for single-ended input channels (channels 4 to 6). Specify an appropriate value according to the user system.	main R_DSAD_Internal Compensated

Table 9.19 const Variables (dsad.c)

Type	Variable Name	Contents	Function
static const float	dsad_data_volt[3] [DSAD_CH_NUM]	Voltage [mV] when calibrating, compensating, or measuring an offset	R_DSAD_Calibration
static const float	typ_zi[DSAD_SINGLE_GAIN_NUM]	Typical value [Ω] of the input impedance (x1, x2, and x4) of the single-ended input. Refer to the ΔΣ A/D Conversion Characteristics section in the User's Manual: Hardware for details.	R_DSAD_Internal Compensated
static const float	coef_temp_cba	Quadratic coefficient of the temperature characteristics for the on-chip BGR. The coefficient value is listed in Table 7.1.	R_DSAD_Internal Compensated
static const float	coef_temp_cbb	Linear coefficient of the temperature characteristics for the on-chip BGR. The coefficient value is listed in Table 7.1.	R_DSAD_Internal Compensated
static const float	coef_temp_cxn[DSAD_GAIN_NUM]	Coefficient of the temperature characteristics for the device gain. The coefficient value is listed in Table 7.1.	R_DSAD_Internal Compensated
static const float	coef_temp_cz	Coefficient of the temperature characteristics for the input impedance. The coefficient value is listed in Table 7.1.	R_DSAD_Internal Calibration
static const float	gain_val[DSAD_GAIN_NUM]	Gain amplification	R_DSAD_Internal Calibration

9.7 Functions

Table 9.20 lists the Functions.

Table 9.20 Functions

Function Name	Outline	File
main	Main processing	main.c
peripheral_init	Peripheral function initialization	main.c
cmt_init	CMT1 initialization	main.c
irq_init	IRQ2 initialization	main.c
Excep_CMT1_CMI1	Compare match 1 interrupt handler	main.c
dsad_init	DSAD initialization	dsad.c
dsad_start	DSAD conversion start processing	dsad.c
R_DSAD_InternalCalibration	Coefficient initialization for gain calibration	dsad.c
R_DSAD_InternalCompensated	Coefficient initialization for gain temperature compensation	dsad.c
R_DSAD_Calibration	System gain calibration	dsad.c
R_DSAD_CompensatedGain	Temperature compensation for the system gain	dsad.c
measure_dsad_calib	Obtaining DSAD conversion result at calibration	dsad.c
measure_dsad	Obtaining DSAD conversion result	dsad.c
Excep_DSAD_DSADIm (m = 0 to 6)	DSAD conversion interrupt handler	dsad.c
temps_init	A/D converter and temperature sensor initializations	temps.c
temps_close	A/D converter and temperature sensor stop processing	temps.c
temps_get_ad_status	Obtaining A/D conversion status	temps.c
temps_get_potential	Obtaining temperature sensor measurement result	temps.c
temps_get_now_temp	Obtaining current temperature	temps.c
temps_calibration	Temperature sensor calibration processing	temps.c
temps_measurement	Temperature sensor measurement processing	temps.c
temps_calc	Current temperature calculation	temps.c
Excep_AD_ADI	A/D conversion end interrupt handler	temps.c

9.8 Function Specifications

The following tables list the sample code function specifications.

main	
Outline	Main processing
Header	None
Declaration	void main(void)
Description	After the clock initialization, performs calibration of DSAD conversion, compensation by temperature, and calibration for the temperature sensor. Then performs DSAD conversion every 1.6384 ms and A/D conversion of the temperature sensor output every 100 ms. Compensates the DSAD conversion result by temperature using the temperature sensor output as needed.
Arguments	None
Return Value	None

peripheral_init	
Outline	Peripheral initialization
Header	None
Declaration	static void peripheral_init(void)
Description	Initializes the peripheral functions used.
Arguments	None
Return Value	None

cmt_init	
Outline	CMT1 initialization
Header	None
Declaration	static void cmt_init(void)
Description	Initializes CMT1.
Arguments	None
Return Value	None

irq_init	
Outline	IRQ initialization
Header	None
Declaration	static void irq_init(void)
Description	Initializes IRQ2.
Arguments	None
Return Value	None

Excep_CMT1_CMI1	
Outline	Compare match 1 interrupt handler
Header	None
Declaration	static void Excep_CMT1_CMI1(void)
Description	Executes the interrupt handler every 163.84 µs. The counter is incremented every time an interrupt request is generated. When the counter reaches 610 times (approx. 100 ms), performs a temperature measurement. The compare match interrupt is used as the start trigger for the DSAD channels via the ELC.
Arguments	None
Return Value	None

dsad_init	
Outline	DSAD initialization
Header	dsad.h
Declaration	void dsad_init(void)
Description	Initializes the DSAD converter.
Arguments	None
Return Value	None

dsad_start	
Outline	DSAD conversion start processing
Header	dsad.h
Declaration	void dsad_start(void)
Description	Starts operating the DSAD converter.
Arguments	None
Return Value	None

R_DSAD_InternalCalibration	
Outline	Coefficient initialization for gain calibration
Header	dsad.h
Declaration	void R_DSAD_InternalCalibration(uint16_t channel)
Description	Prepares intermediate calculation results necessary for gain calibration.
Arguments	unit16_t channel: Input channel (0 to 6)
Return Value	None
Remarks	Execute this function before executing the R_DSAD_Calibration and R_DSAD_CompensatedGain functions. Otherwise calibration and compensation cannot be performed correctly. If the constant for the device version is specified as a version other than G, 32768 is used instead of the DSADIIC register value and 47974 is used instead of the DSADGmXn register without reading these registers.

R_DSAD_InternalCompensated	
Outline	Coefficient initialization for gain temperature compensation
Header	dsad.h
Declaration	void R_DSAD_InternalCompensated(uint16_t channel, const float dsad_ext_load_res[DSAD_SINGLE_CH_NUM])
Description	Prepares intermediate calculation results necessary for temperature compensation for gain.
Arguments	unit16_t channel: Input channel (0 to 6) const float dsad_ext_load_res[DSAD_SINGLE_CH_NUM]: External load resistor [Ω] for the single-ended input channels (channels 4 to 6).
Return Value	None
Remarks	Execute this function before executing the R_DSAD_Calibration and R_DSAD_CompensatedGain functions. Otherwise calibration and compensation cannot be performed correctly. If the constant for the device version is specified as a version other than G version, 32768 is used without reading the DSADIIC register.

R_DSAD_Calibration	
Outline	System gain calibration
Header	dsad.h
Declaration	void R_DSAD_Calibration(uint16_t channel)
Description	Calculates the gain for the specified channel before temperature compensation.
Arguments	unit16_t channel: Input channel (0 to 6)
Return Value	None
Remarks	Execute the R_DSAD_InternalCalibration and R_DSAD_InternalCompensated functions before executing this function. Otherwise calibration and compensation cannot be performed correctly.

R_DSAD_CompensatedGain	
Outline	Temperature compensation for the system gain
Header	r_dsad_compensate.h
Declaration	void R_DSAD_CompensatedGain(uint16_t channel, int16_t junction_temp)
Description	Calculates the system gain for the specified channel after temperature compensation.
Arguments	uint16_t channel: Input channel (0 to 6) int16_t junction_temp: The device temperature measured by the temperature sensor. The value should be from -40°C to +105°C.
Return Value	None
Remarks	Execute the R_DSAD_InternalCalibration, R_DSAD_InternalCompensated, and R_DSAD_Calibration functions before executing this function. Otherwise calibration and compensation cannot be performed correctly.

measure_dsad_calib	
Outline	Obtaining DSAD conversion result at calibration
Header	dsad.h
Declaration	void measure_dsad_calib(void)
Description	This function is used for calibration. Obtains measurement results of voltages at 2 points, which are used for calculating the sensor gain, obtains measurement results of voltages at 0 V for gains x2 to x64, and transfers the results to the RAM.
Arguments	None
Return Value	None

measure_dsad	
Outline	Obtaining DSAD conversion result
Header	dsad.h
Declaration	void measure_dsad(void)
Description	Performs calibration and compensation for the DSAD conversion results and transfer the processed result to the RAM.
Arguments	None
Return Value	None

Excep_DSAD_DSADIm (m = 0 to 6)	
Outline	DSAD conversion interrupt handler
Header	dsad.h
Declaration	static void Excep_DSAD_DSADI0(void) static void Excep_DSAD_DSADI1(void) static void Excep_DSAD_DSADI2(void) static void Excep_DSAD_DSADI3(void) static void Excep_DSAD_DSADI4(void) static void Excep_DSAD_DSADI5(void) static void Excep_DSAD_DSADI6(void)
Description	Updates the number of times for obtaining conversion results, stores the DSAD conversion result in the RAM (as described below), and clears the interrupt request. Ten DSAD conversions are treated as one sampling. First two conversion results are discarded and the subsequent results are stored in the RAM. When the DSAD result has been obtained 10 times, the average of the eight results is calculated. The average is treated as the DSAD conversion result.
Arguments	None
Return Value	None

temps_init	
Outline	A/D converter and temperature sensor initializations
Header	temps.h
Declaration	static void temps_init(void)
Description	Initializes the A/D converter and the temperature sensor.
Arguments	None
Return Value	None

temps_close	
Outline	A/D converter and temperature sensor stop processing
Header	temps.h
Declaration	static void temps_close(void)
Description	Stops the A/D converter and the temperature sensor.
Arguments	None
Return Value	None

temps_get_ad_status	
Outline	Obtaining A/D conversion status
Header	temps.h
Declaration	uint8_t temps_get_ad_status(void)
Description	Obtains the current A/D conversion status.
Arguments	None
Return Value	uint8_t: A/D conversion status - STA_AD_IDLE: Not operating - STA_AD_WAIT: Waiting for completion of A/D conversion - STA_AD_FINISH: A/D conversion completed

temps_get_potential	
Outline	Obtaining temperature sensor measurement result
Header	None
Declaration	static uint16_t temps_get_potential (void)
Description	Obtains the measured A/D conversion value.
Arguments	None
Return Value	uint16_t: A/D conversion value of the temperature sensor - ADCONV_IN_OPERATION: A/D conversion in process - Other than above: A/D conversion value

temps_get_now_temp	
Outline	Obtaining current temperature
Header	temps.h
Declaration	int16_t temps_get_now_temp (void)
Description	Obtains the current temperature.
Arguments	None
Return Value	uint16_t: Current temperature

temps_calibration	
Outline	Temperature sensor calibration processing
Header	temps.h
Declaration	void temps_calibration(void)
Description	Obtains the A/D conversion value at the normal reference temperature and stores it in the RAM.
Arguments	None
Return Value	None

temps_measurement	
Outline	Temperature sensor measurement processing
Header	temps.h
Declaration	void temps_measurement(void)
Description	Starts measuring the current temperature.
Arguments	None
Return Value	None

temps_calc	
Outline	Current temperature calculation
Header	None
Declaration	static int16_t temps_calc(uint16_t w_now_potential)
Description	Calculates temperature from the A/D conversion value passed with the argument.
Arguments	uint16_t w_now_potential: A/D conversion value
Return Value	int16_t: Current temperature [°C]

Excep_AD_ADI	
Outline	A/D conversion end interrupt handler
Header	None
Declaration	static void Excep_AD_ADI(void)
Description	Stores the A/D conversion value in the RAM when an A/D conversion has been completed. At the completion of the sixth A/D conversion, subtracts the maximum and minimum values from the sum of six conversion results, divides the subtraction result by 4 to get the average, and calculates the temperature based on the average.
Arguments	None
Return Value	None

9.9 Flowcharts

9.9.1 Main Processing

Figure 9.2 and Figure 9.3 show the Main Processing.

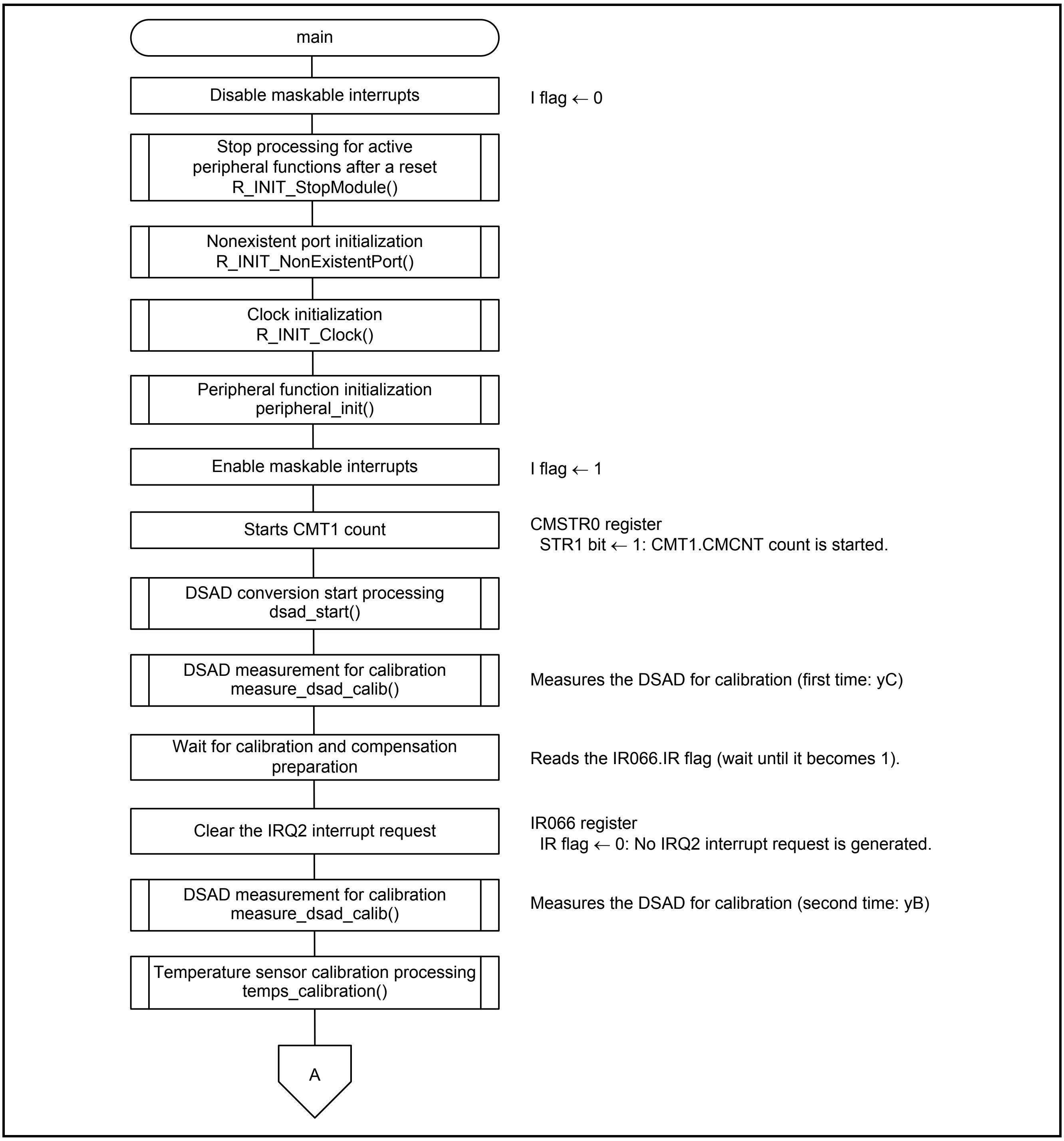


Figure 9.2 Main Processing (1/2)

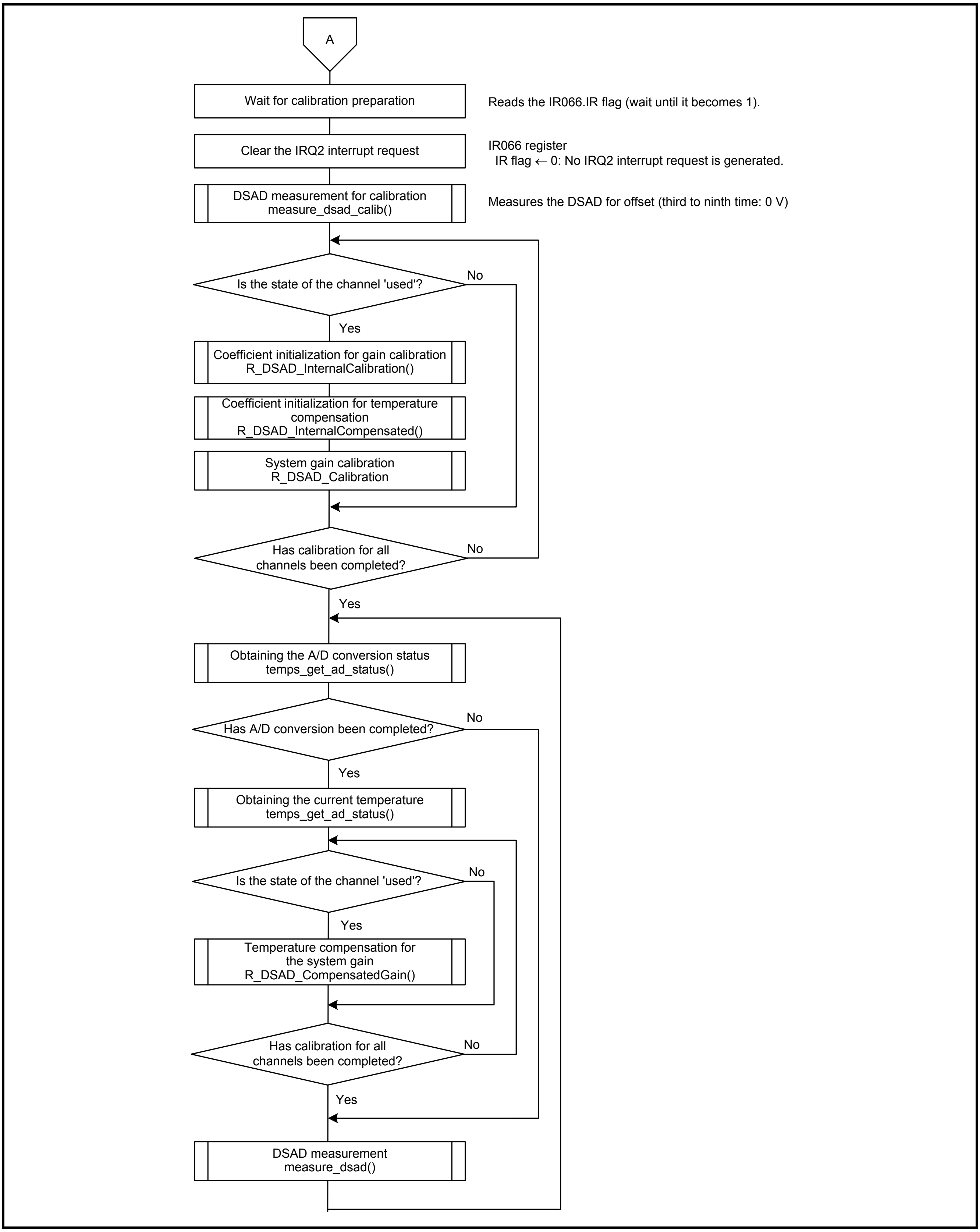


Figure 9.3 Main Processing (2/2)

9.9.2 Peripheral Function Initialization

Figure 9.4 shows the Peripheral Function Initialization.

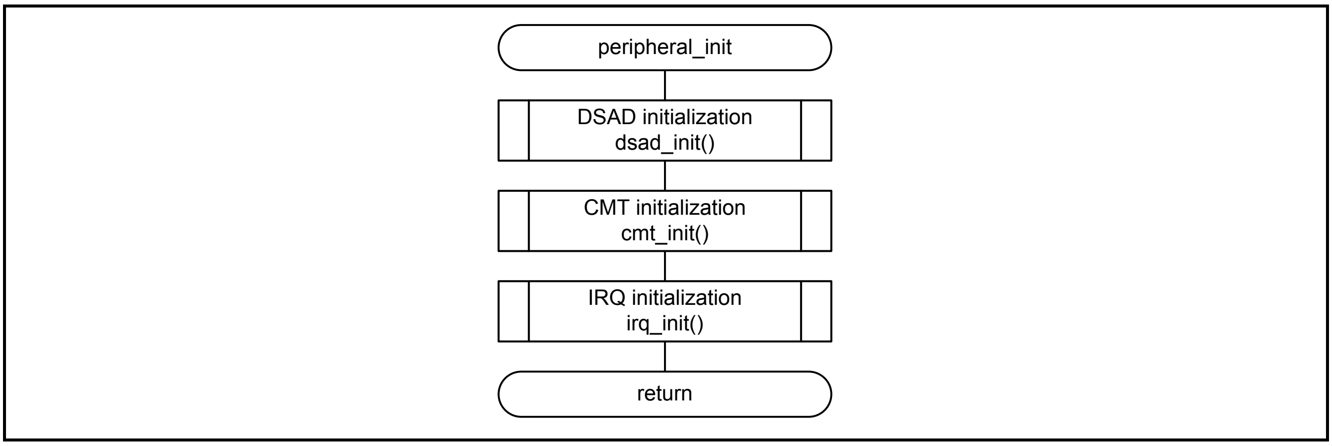


Figure 9.4 Peripheral Function Initialization

9.9.3 CMT1 Initialization

Figure 9.5 shows the CMT1 Initialization.

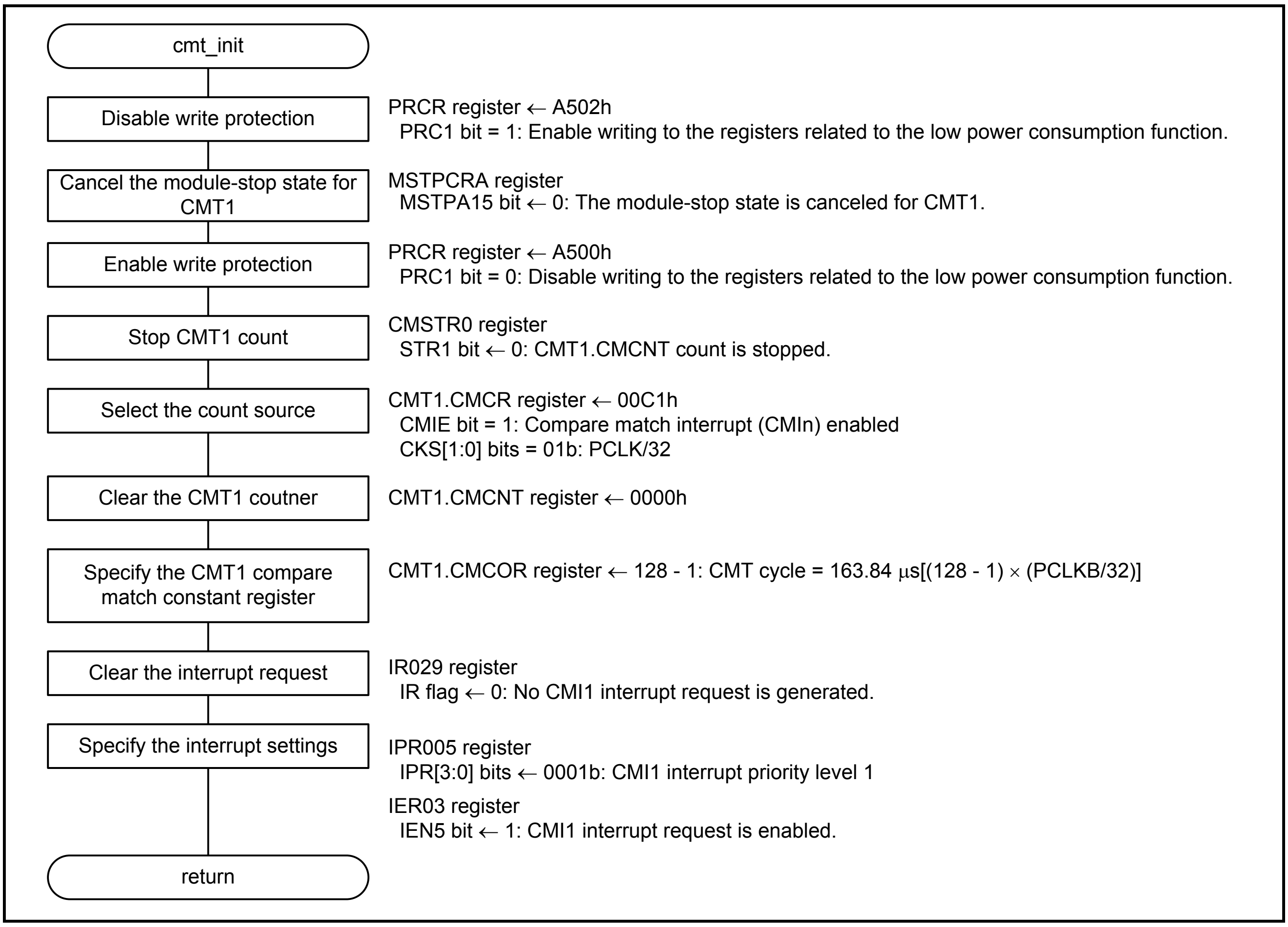


Figure 9.5 CMT1 Initialization

9.9.4 IRQ2 Initialization

Figure 9.6 shows the IRQ2 Initialization.

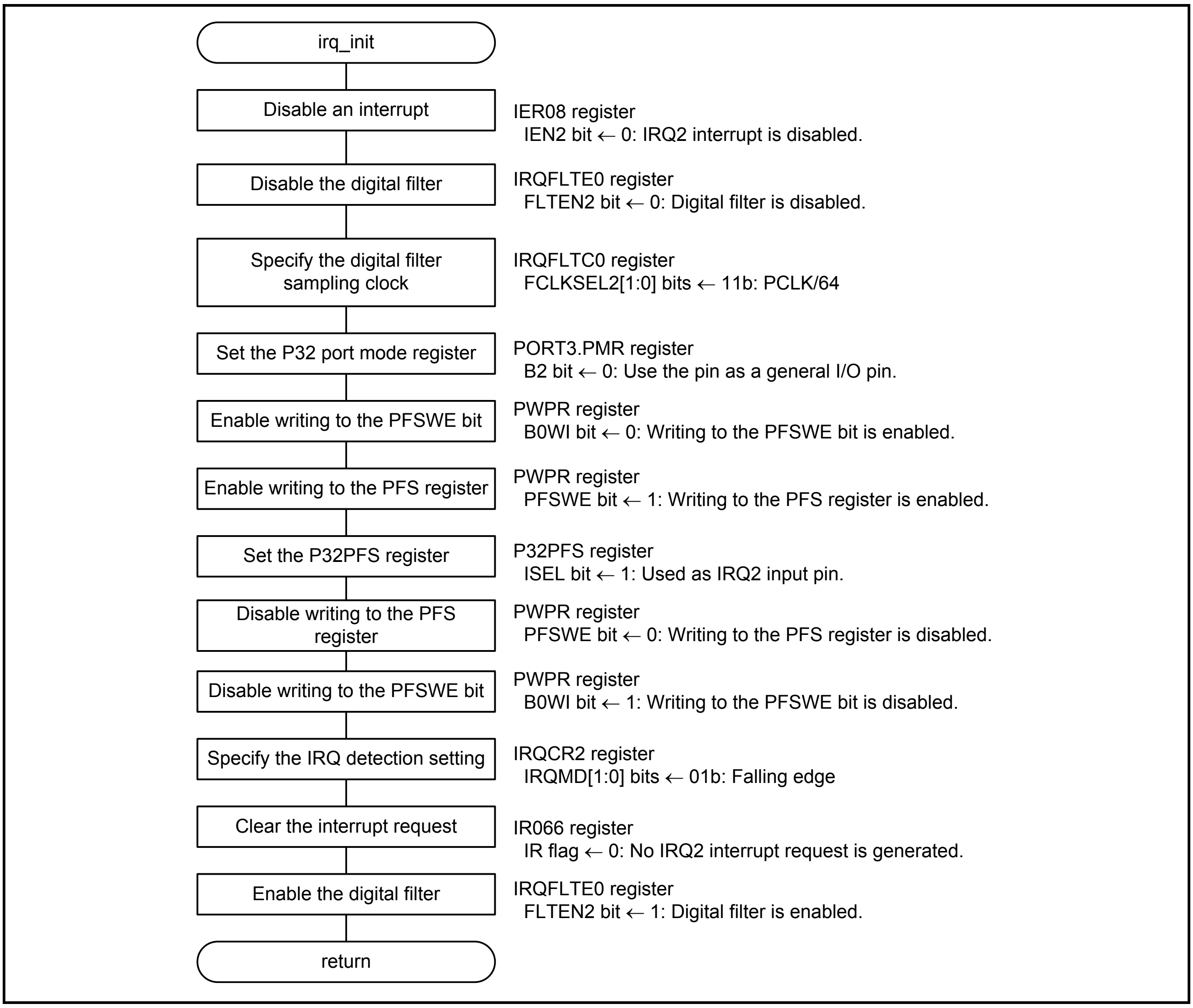


Figure 9.6 IRQ2 Initialization

9.9.5 Compare Match 1 Interrupt Handler

Figure 9.7 shows the Compare Match 1 Interrupt Handler.

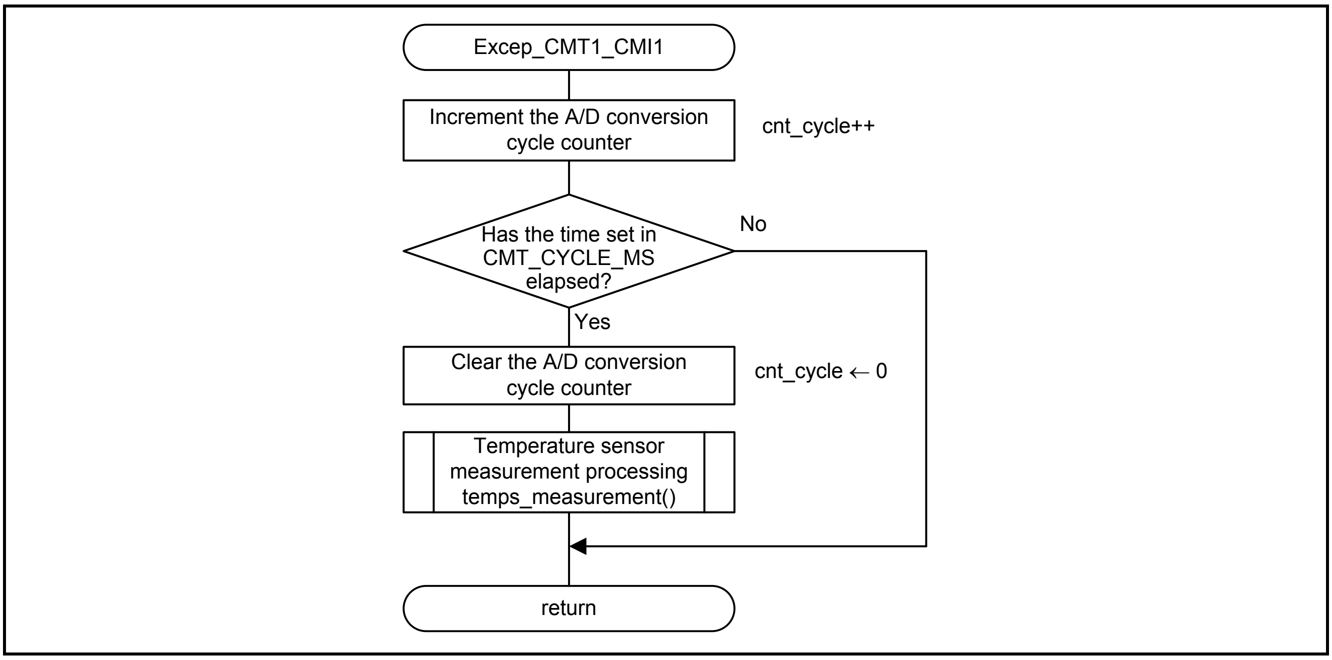


Figure 9.7 Compare Match 1 Interrupt Handler

9.9.6 DSAD Initialization

Figure 9.8 shows the DSAD Initialization for system gain calibration.

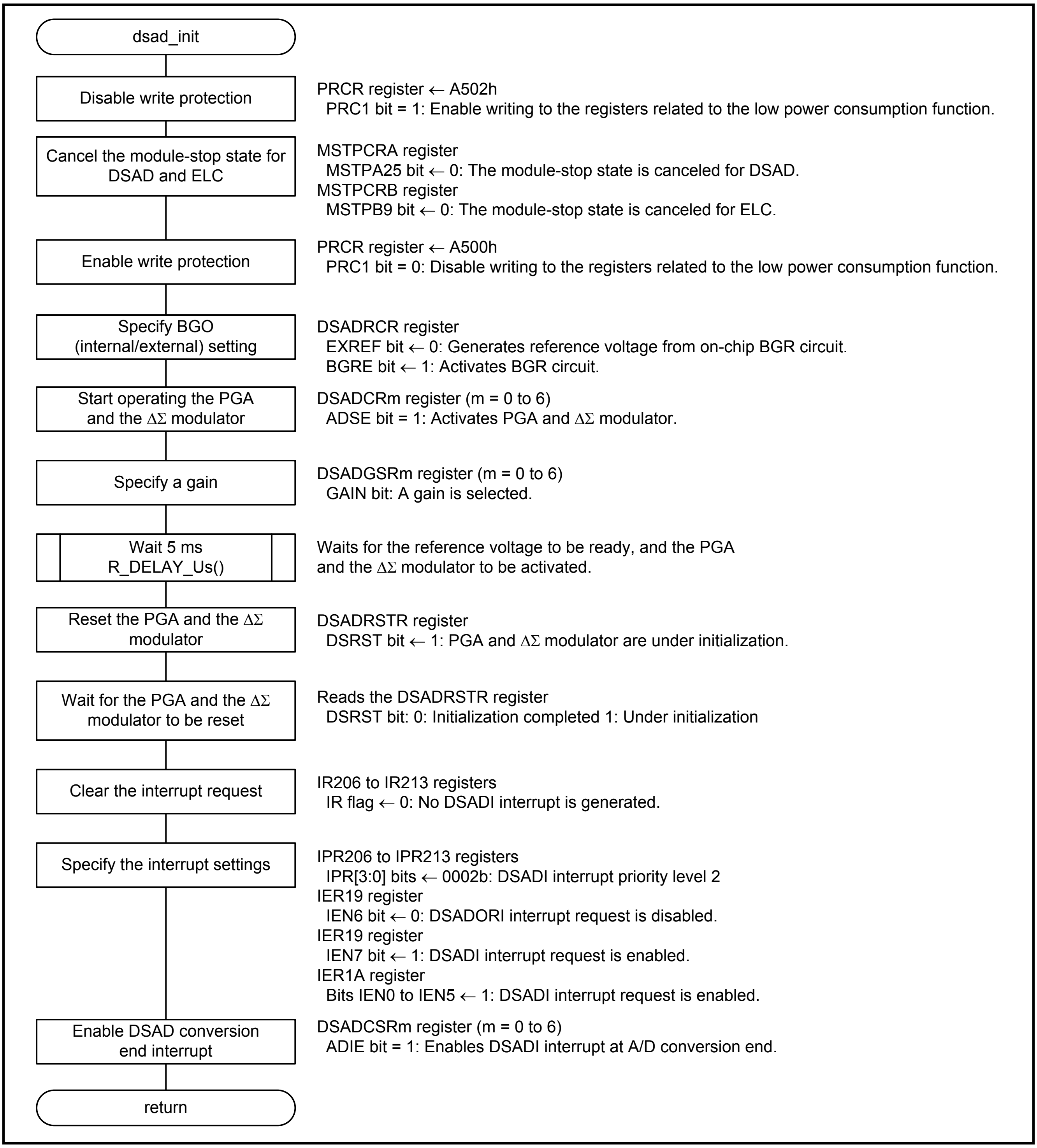


Figure 9.8 DSAD Initialization

9.9.7 DSAD Conversion Start Processing

Figure 9.9 shows the DSAD Conversion Start Processing.

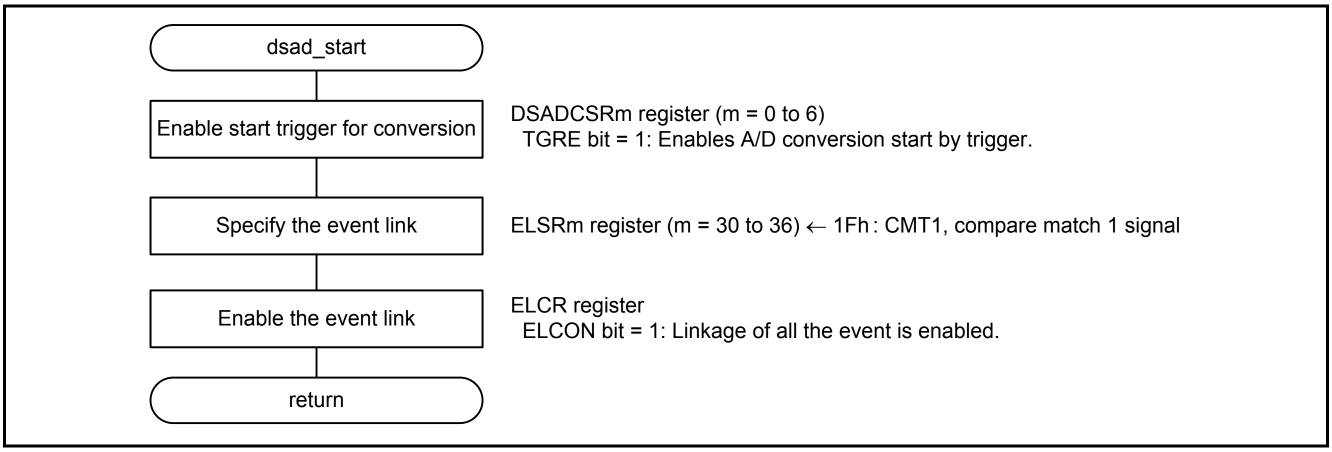


Figure 9.9 DSAD Conversion Start Processing

9.9.8 Coefficient Initialization for Gain Calibration

Figure 9.10 shows the Coefficient Initialization for Gain Calibration.

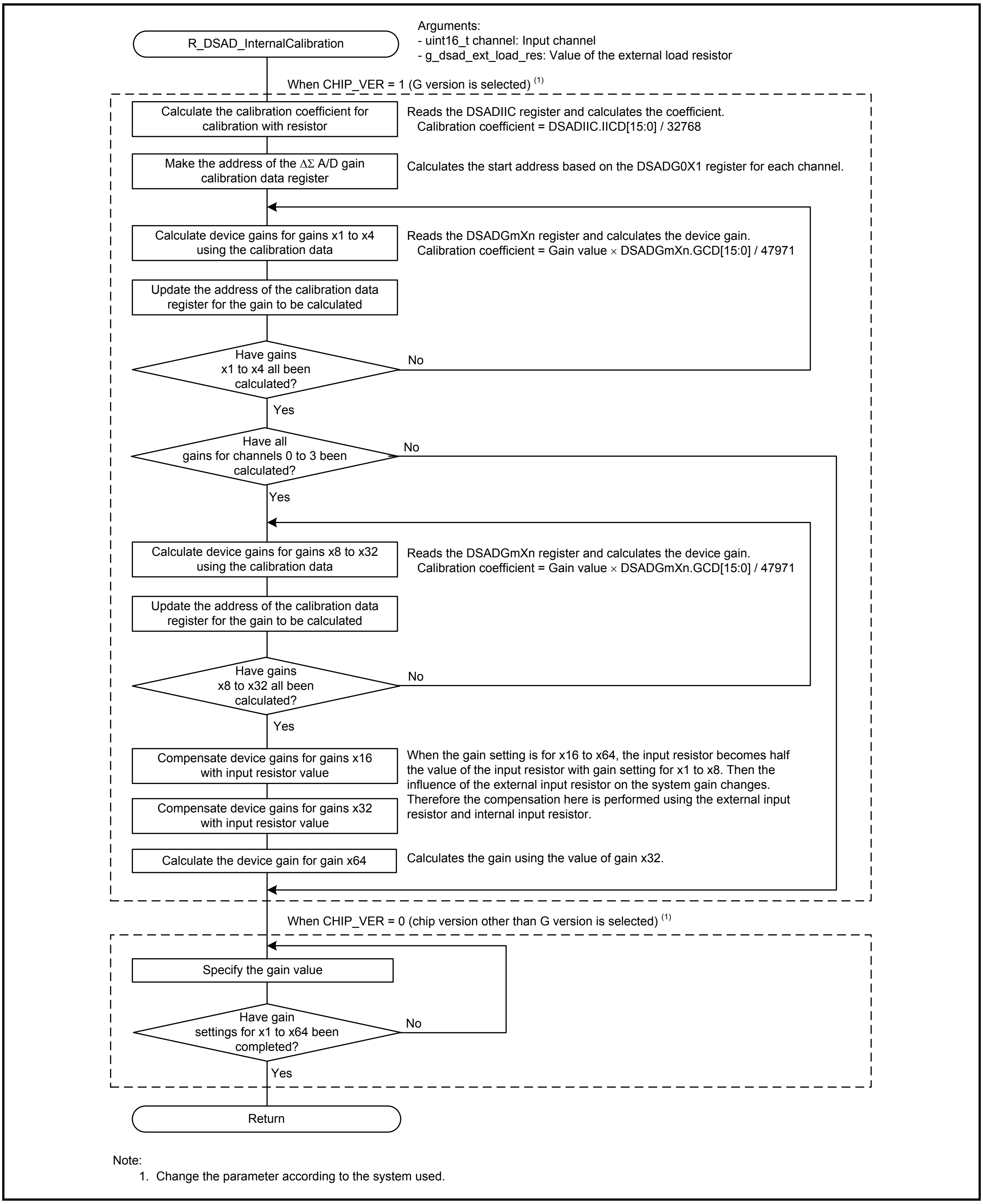
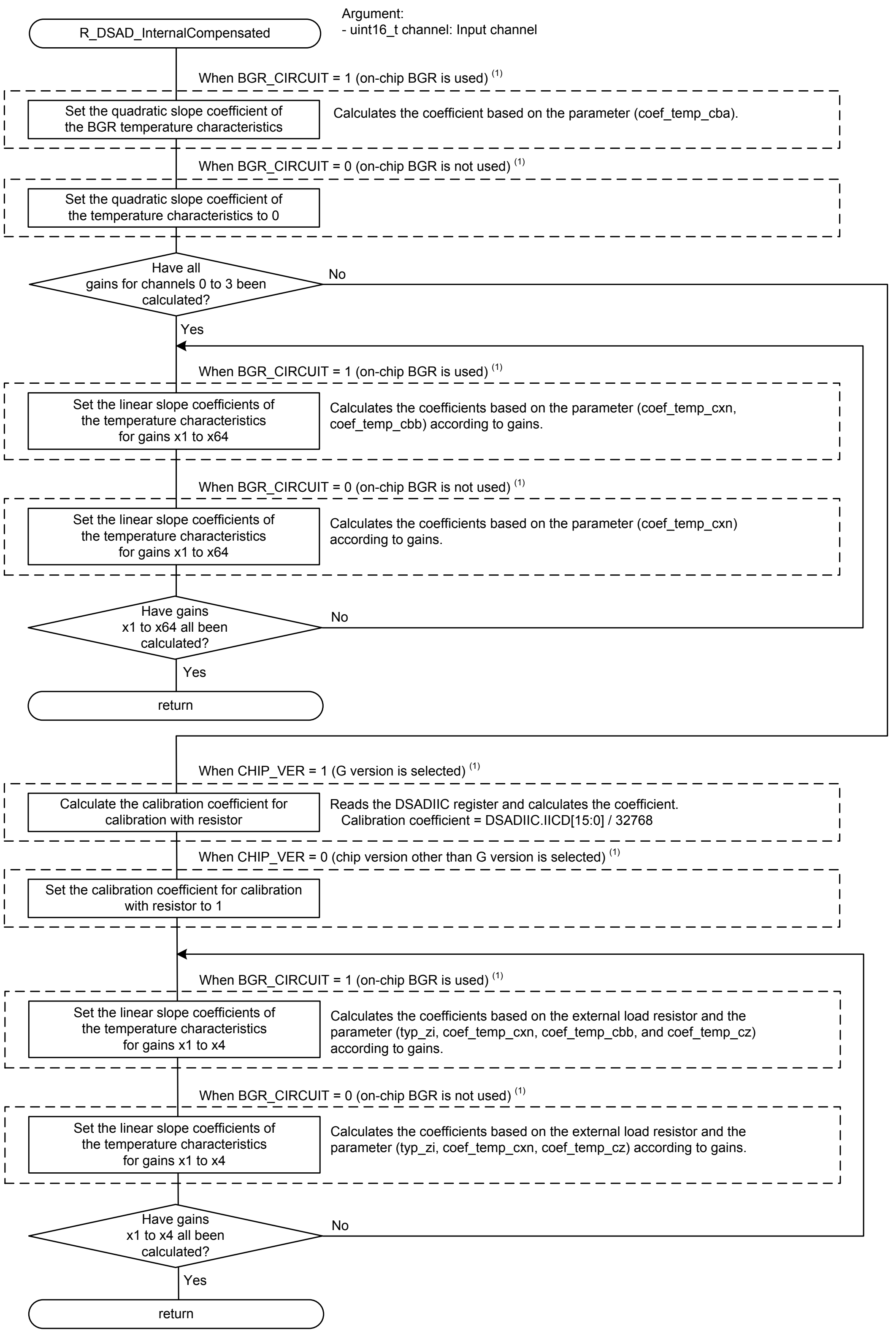


Figure 9.10 Coefficient Initialization for Gain Calibration

9.9.9 Coefficient Initialization for Gain Temperature Compensation

Figure 9.11 shows the Coefficient Initialization for Gain Temperature Compensation.



Note:
1. Change the parameter according to the system used.

Figure 9.11 Coefficient Initialization for Gain Temperature Compensation

9.9.10 System Gain Calibration

Figure 9.12 shows the System Gain Calibration.

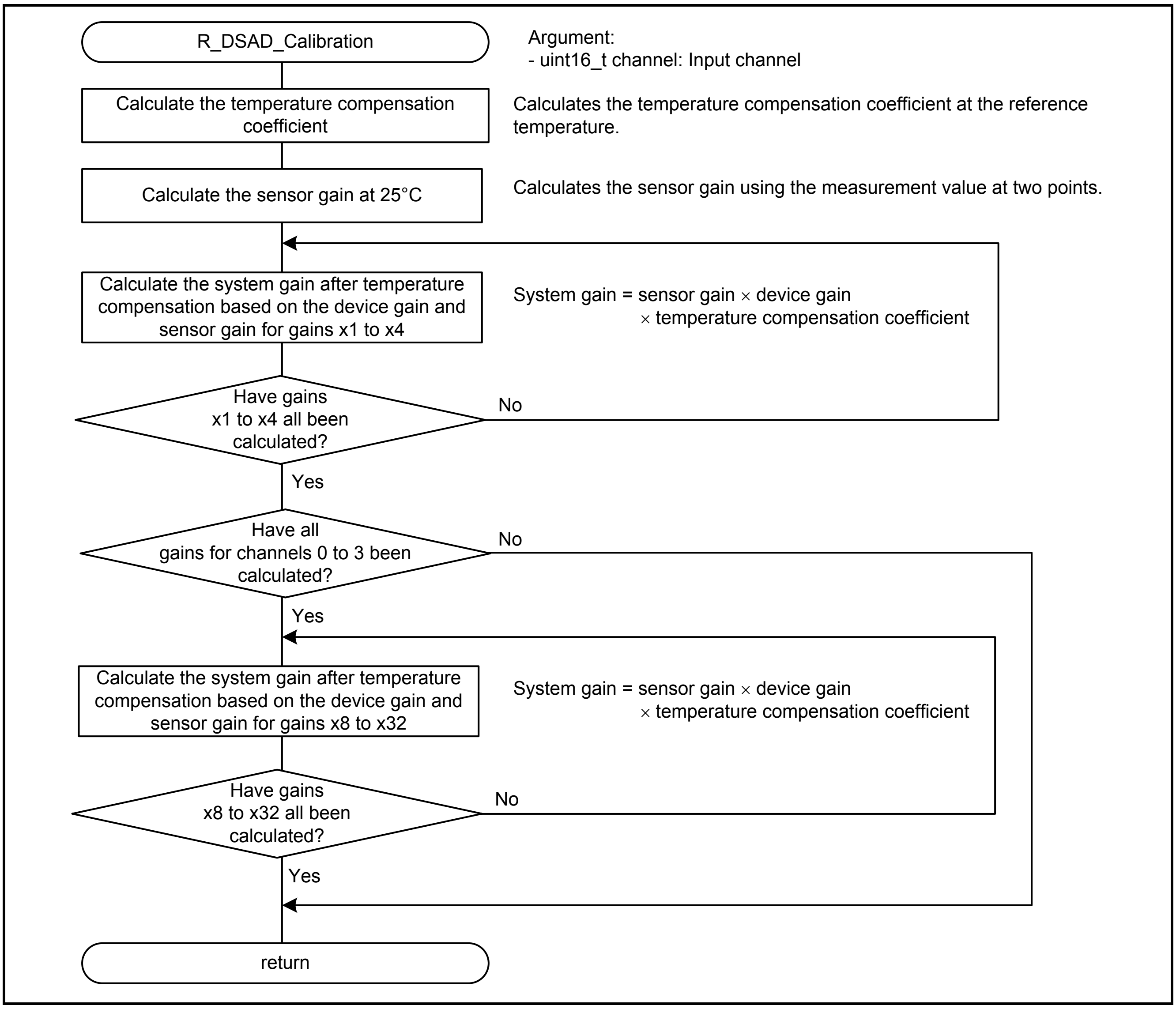


Figure 9.12 System Gain Calibration

9.9.11 Temperature Compensation for the System Gain

Figure 9.13 shows the Temperature Compensation for the System Gain.

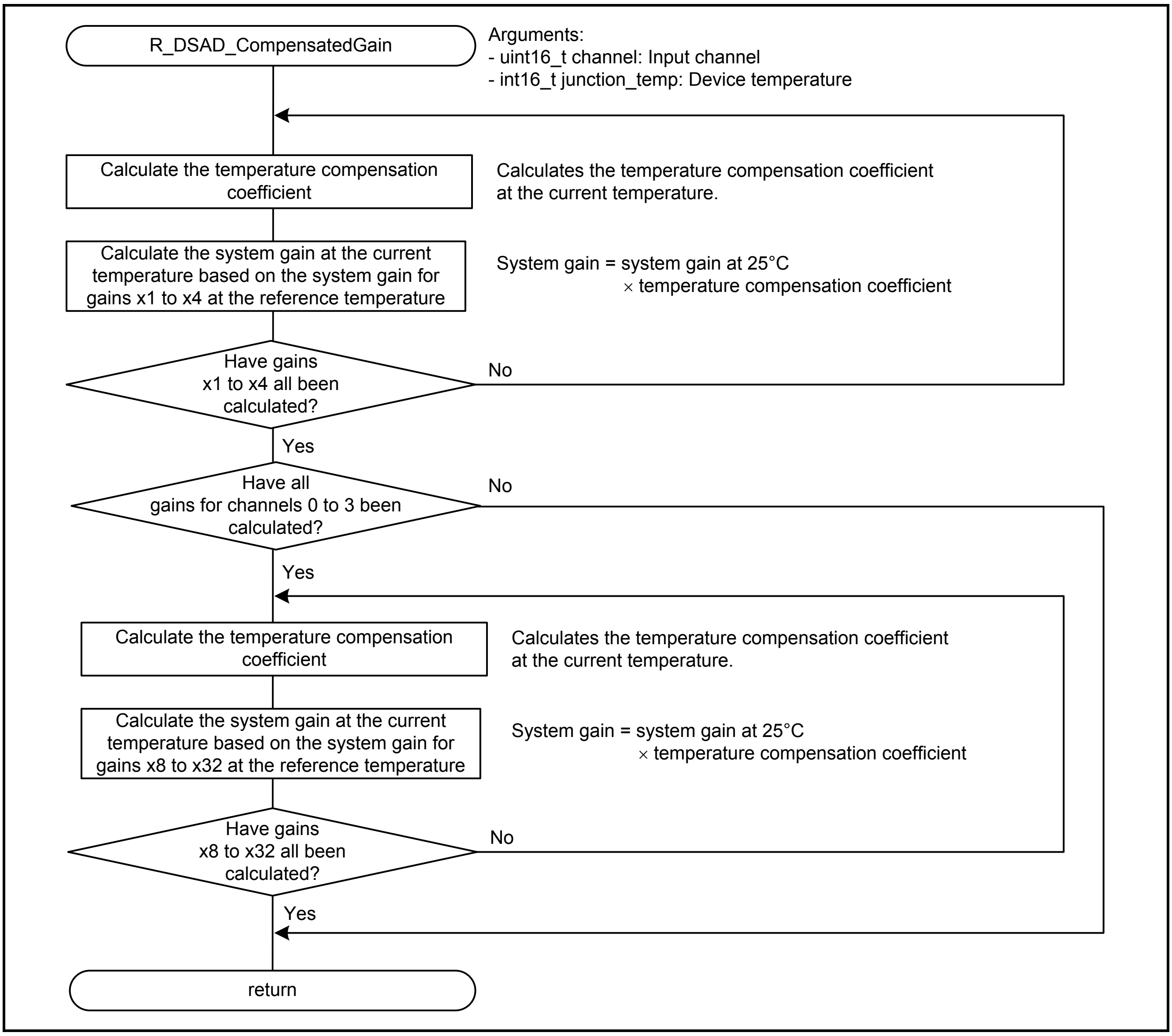


Figure 9.13 Temperature Compensation for the System Gain

9.9.12 Obtaining DSAD Conversion Result at Calibration

Figure 9.14 shows the Obtaining DSAD Conversion Result at Calibration.

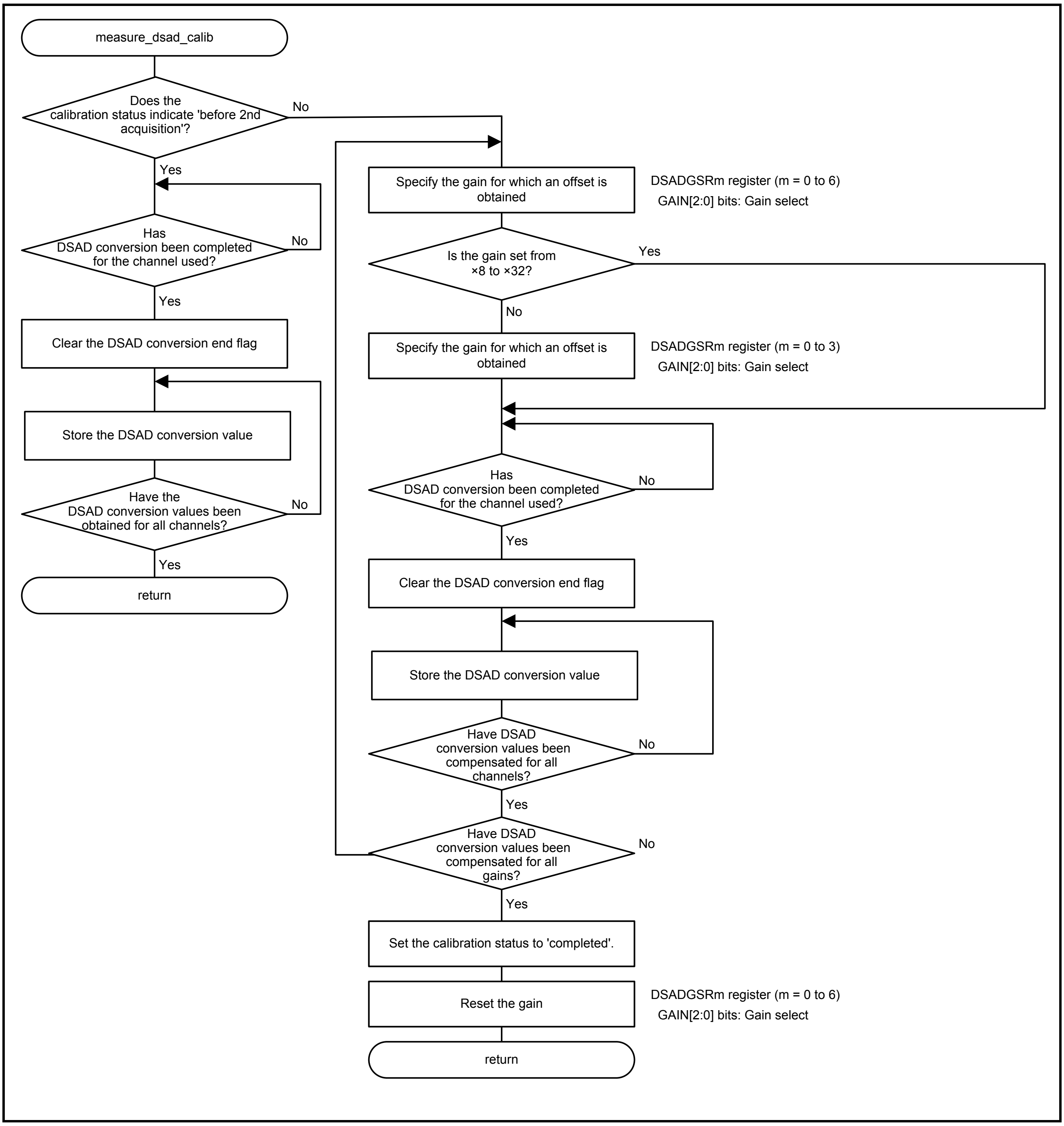


Figure 9.14 Obtaining DSAD Conversion Result at Calibration

9.9.13 Obtaining DSAD Conversion Result

Figure 9.15 shows the Obtaining DSAD Conversion Result.

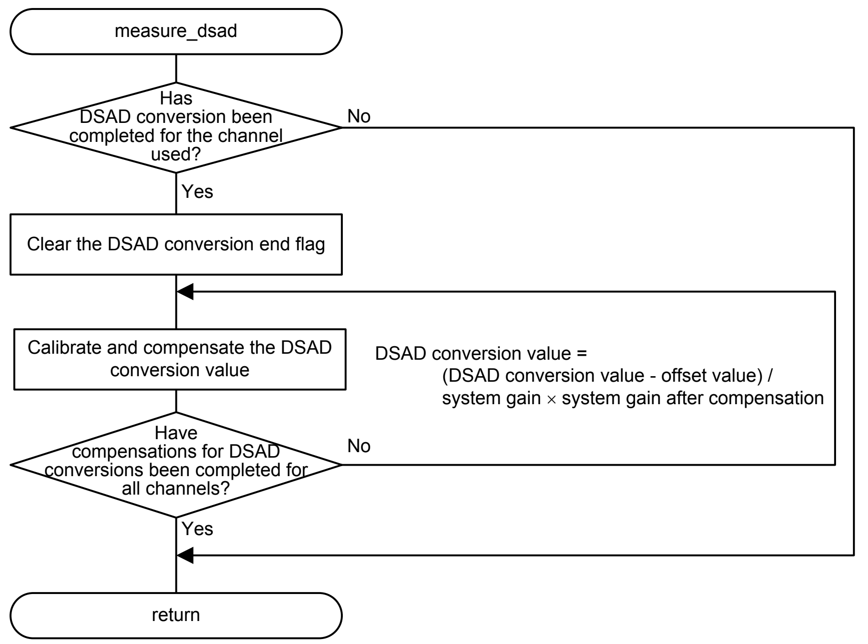


Figure 9.15 Obtaining DSAD Conversion Result

9.9.14 DSAD Conversion Interrupt Handler

Figure 9.16 shows the DSAD Conversion Interrupt Handler.

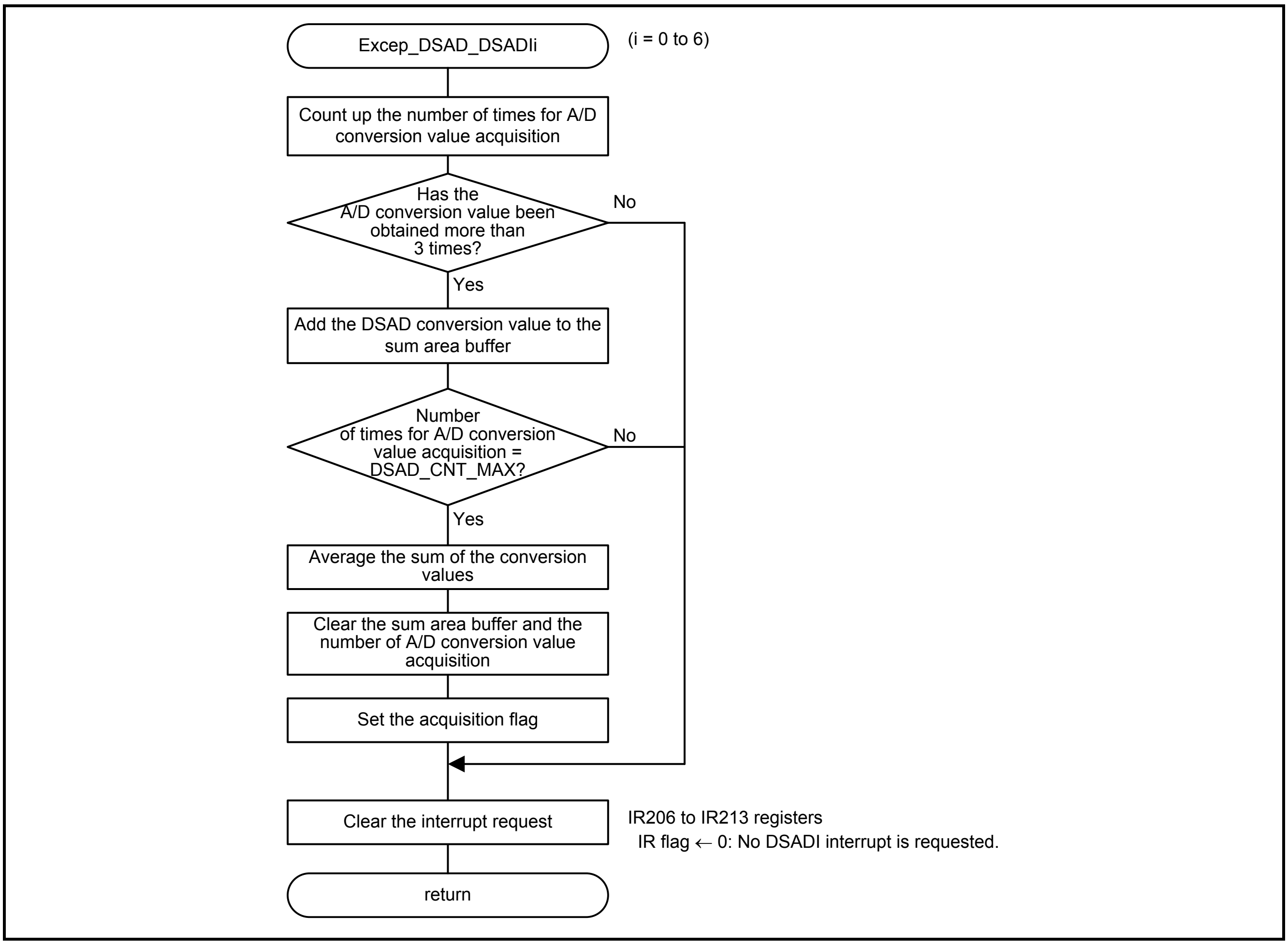
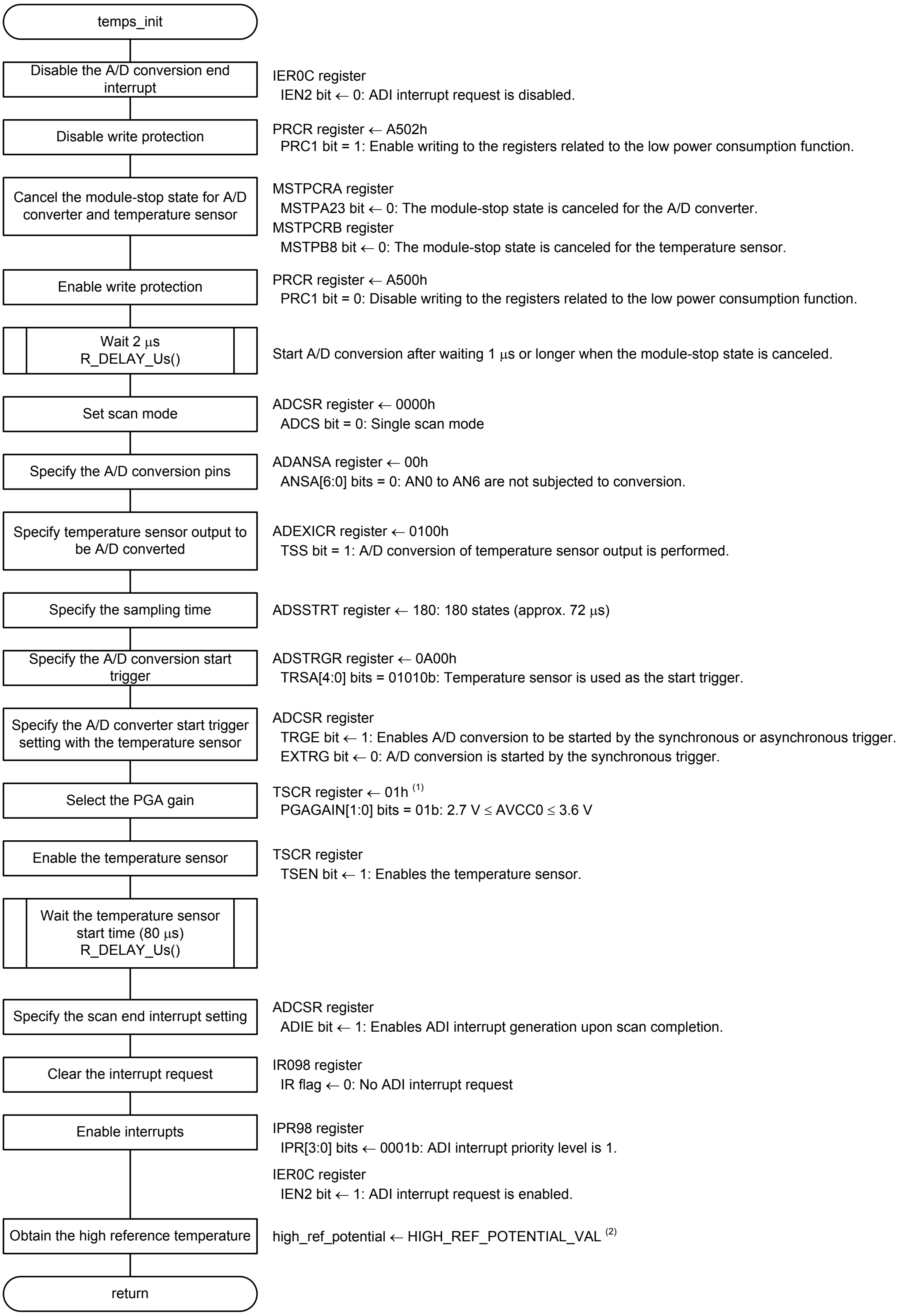


Figure 9.16 DSAD Conversion Interrupt Handler

9.9.15 A/D Converter and Temperature Sensor Initializations

Figure 9.17 shows the A/D Converter and Temperature Sensor Initializations.



Notes:
1. Change the parameter according to the system used.
2. A value set here varies depending on the PGA gain selected with the constant.

Figure 9.17 A/D Converter and Temperature Sensor Initializations

9.9.16 A/D Converter and Temperature Sensor Stop Processing

Figure 9.18 shows the A/D Converter and Temperature Sensor Stop Processing.

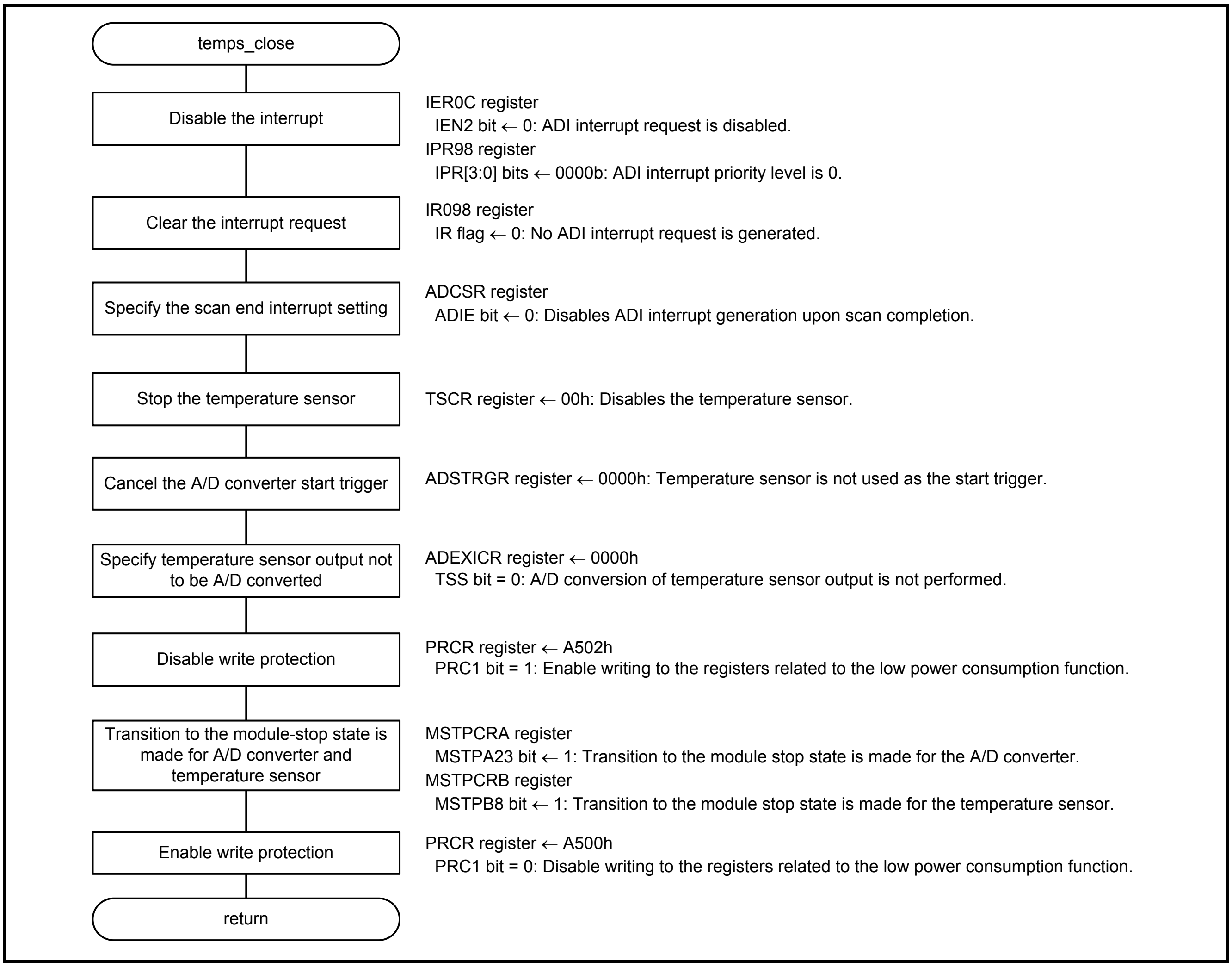


Figure 9.18 A/D Converter and Temperature Sensor Stop Processing

9.9.17 Obtaining A/D Conversion Status

Figure 9.19 shows the Obtaining A/D Conversion Status.

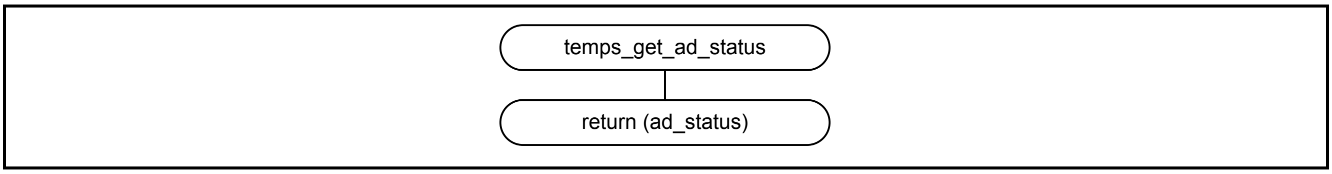


Figure 9.19 Obtaining A/D Conversion Status

9.9.18 Obtaining Temperature Sensor Measurement Result

Figure 9.20 shows the Obtaining Temperature Sensor Measurement Result.

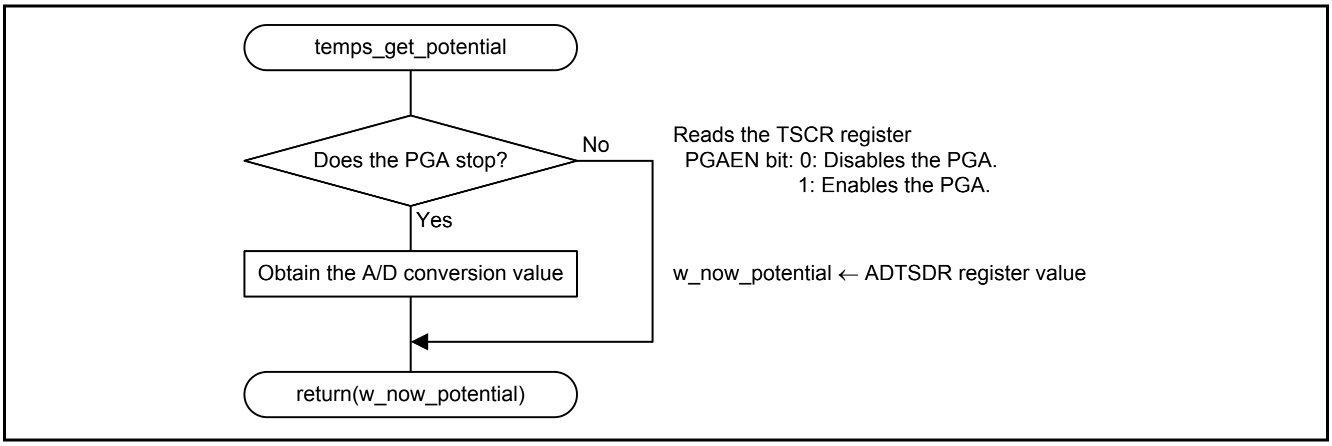


Figure 9.20 Obtaining Temperature Sensor Measurement Result

9.9.19 Obtaining Current Temperature

Figure 9.21 shows the Obtaining Current Temperature.

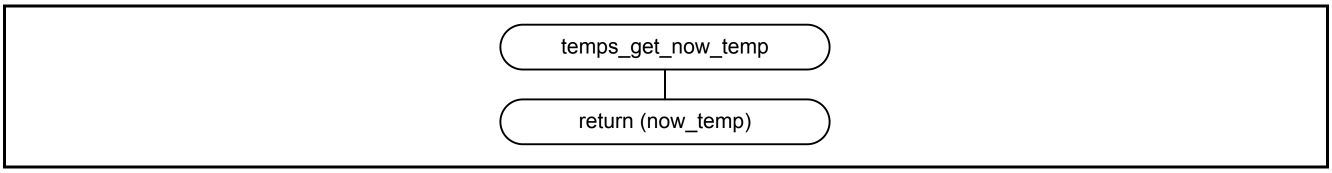


Figure 9.21 Obtaining Current Temperature

9.9.20 Temperature Sensor Calibration Processing

Figure 9.22 shows the Temperature Sensor Calibration Processing.

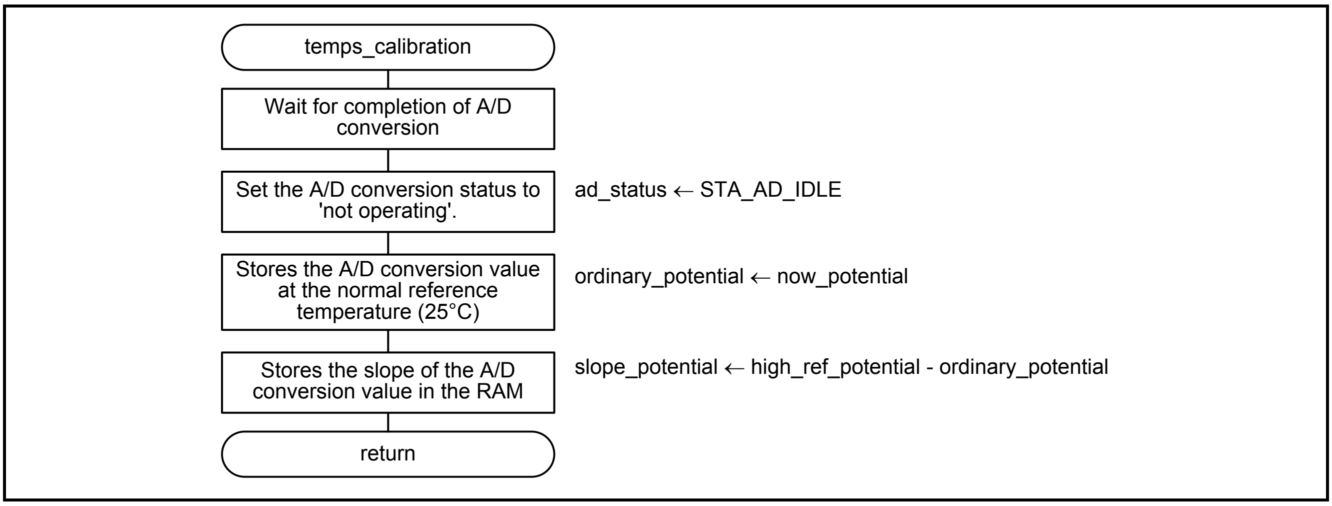


Figure 9.22 Temperature Sensor Calibration Processing

9.9.21 Temperature Sensor Measurement Processing

Figure 9.23 shows the Temperature Sensor Measurement Processing.

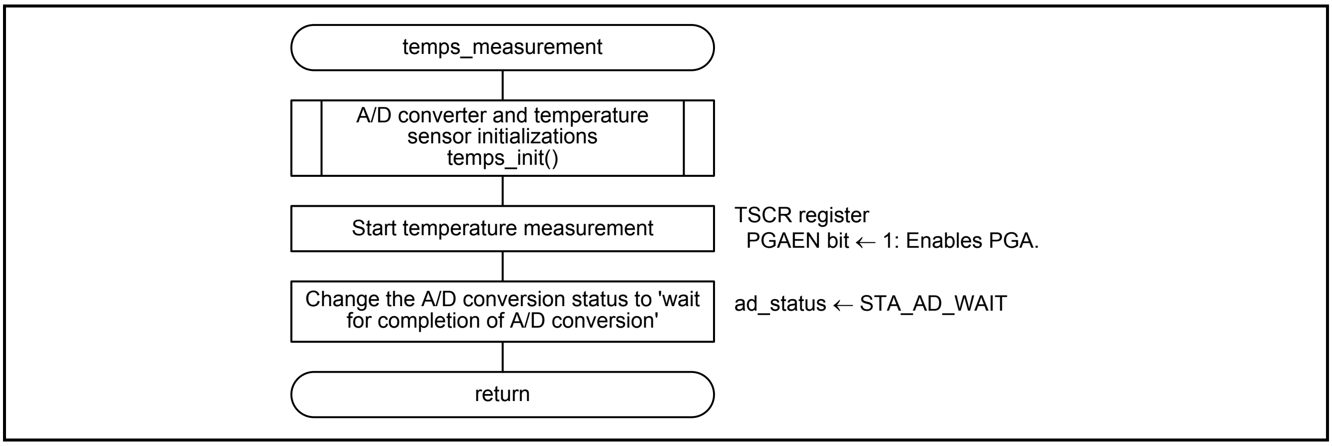


Figure 9.23 Temperature Sensor Measurement Processing

9.9.22 Current Temperature Calculation

Figure 9.24 shows the Current Temperature Calculation.

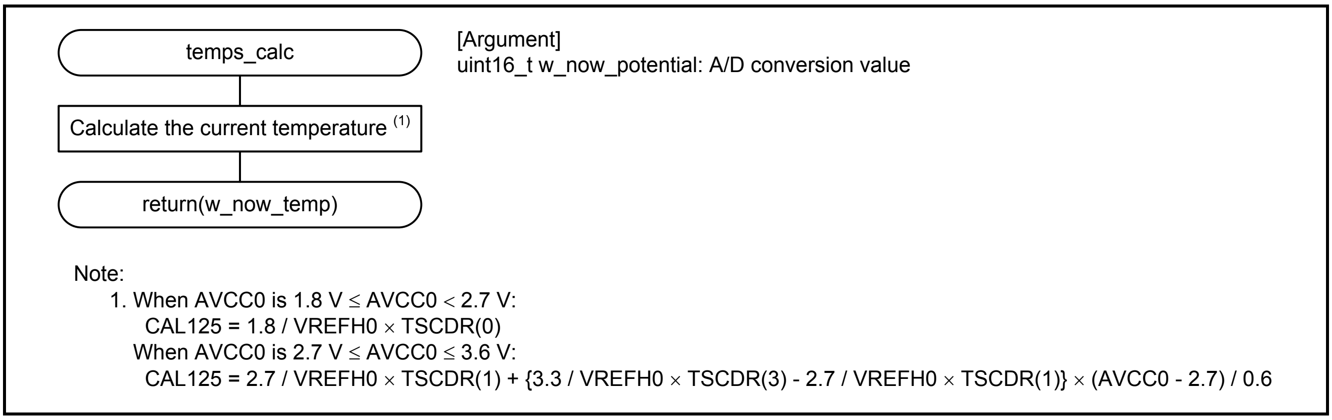


Figure 9.24 Current Temperature Calculation

9.9.23 A/D Conversion End Interrupt Handler

Figure 9.25 shows the A/D Conversion End Interrupt Handler.

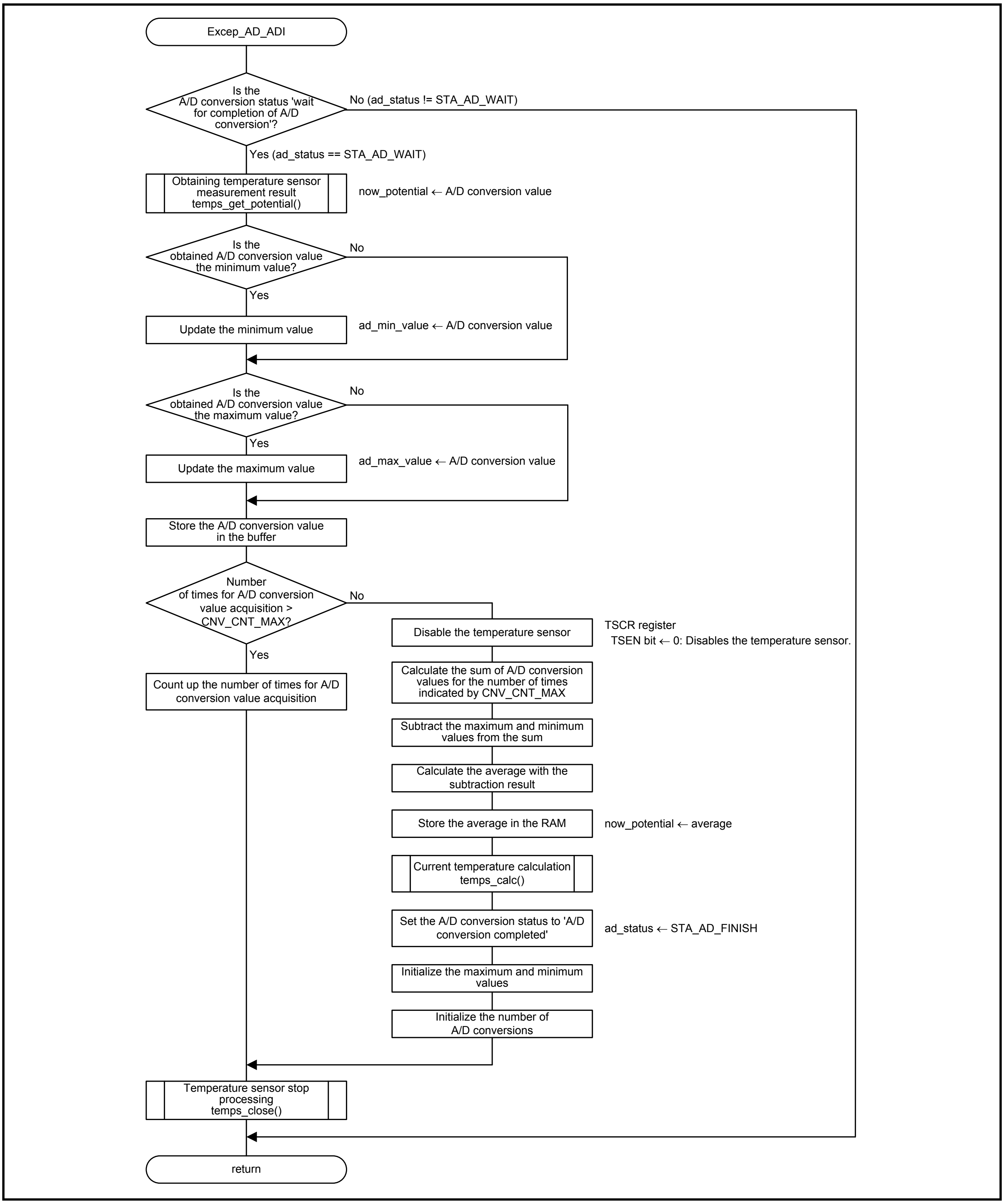


Figure 9.25 A/D Conversion End Interrupt Handler

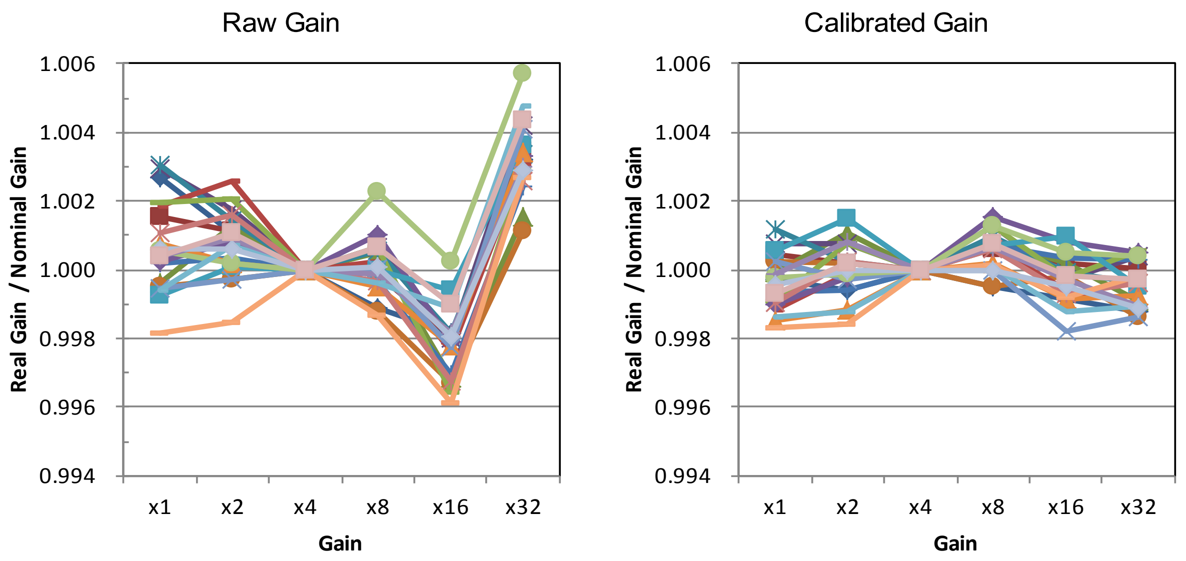
10. Appendices (Calibration and Compensation Results)

This chapter analyzes the results of the system gain calibration and the temperature characteristic compensation.

10.1 Result of the System Gain Calibration

Figure 10.1 shows an example of the result for the system gain calibration. In the example, the gain is calibrated for each channel with each gain setting based on the gain with channel 0 and gain x4 using formulas 8.3 and 8.5 (for differential input, formula 8.11 for single-ended input). In the result, the gain errors have been reduced from 6 ppm to 2 ppm.

To make the gain measurement conditions consistent, in this example, 14.06 mV of voltage is input taking into account the limit of gain x32 (14.4 mV). To raise the precision of the calibration, use the test voltage and current appropriate to the reference gain selected.



Measurement conditions:
- Number of samples: 5
- Channels: 0 to 3
- Gains: x1 to x32,
- Input: AC 50.664 Hz ± 14.06 mV (peak-to-peak: 28.12 mV) for all gains
- External input resistor: 0 Ω

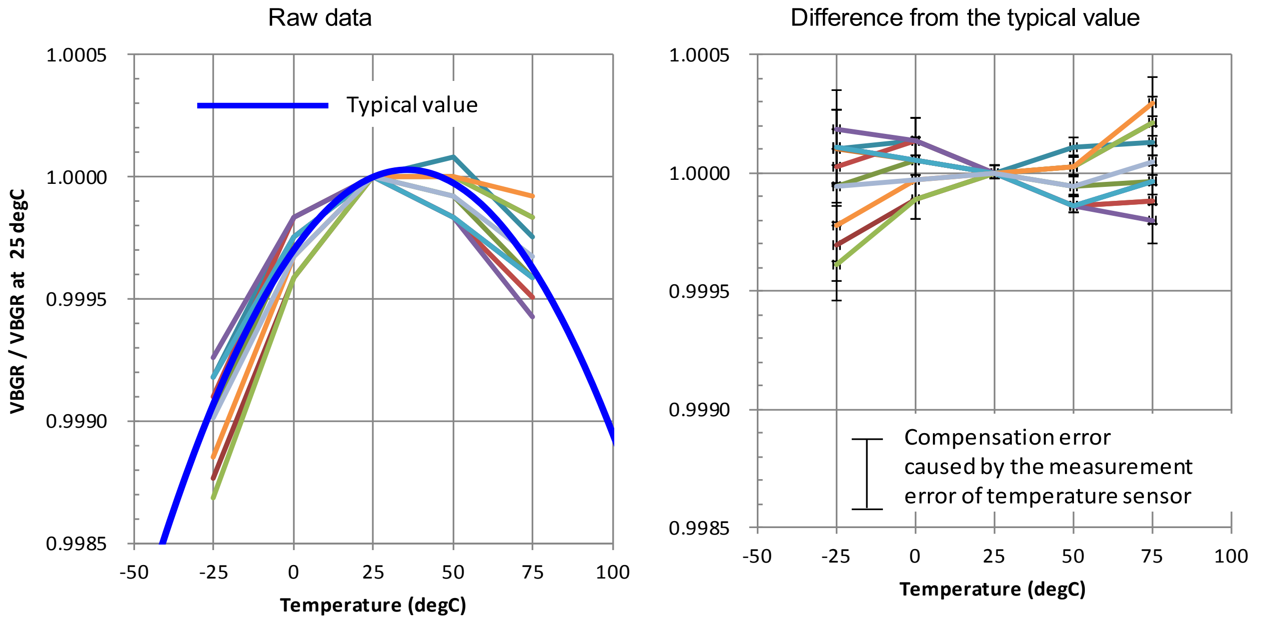
Figure 10.1 Result of the System Gain Calibration

10.2 Result of Temperature Compensations

10.2.1 Temperature Characteristics of the VBGR

The Figure 10.2 shows the Temperature Characteristics of the VBGR (Difference Between the Measured Values and Typical Values).

The typical VBGR voltage can be calculated by assigning the coefficients shown in Table 7.1 and the temperature measured by the temperature sensor to formula 7.2. If errors exist in temperatures, calculations for the typical VBGR also have errors.



degC: Degrees Celsius

Figure 10.2 Temperature Characteristics of the VBGR (Difference Between the Measured Values and Typical Values)

The temperature characteristics of the VBGR can be decreased from 30 ppm/°C to 10 ppm/°C by compensating with formula 7.2.

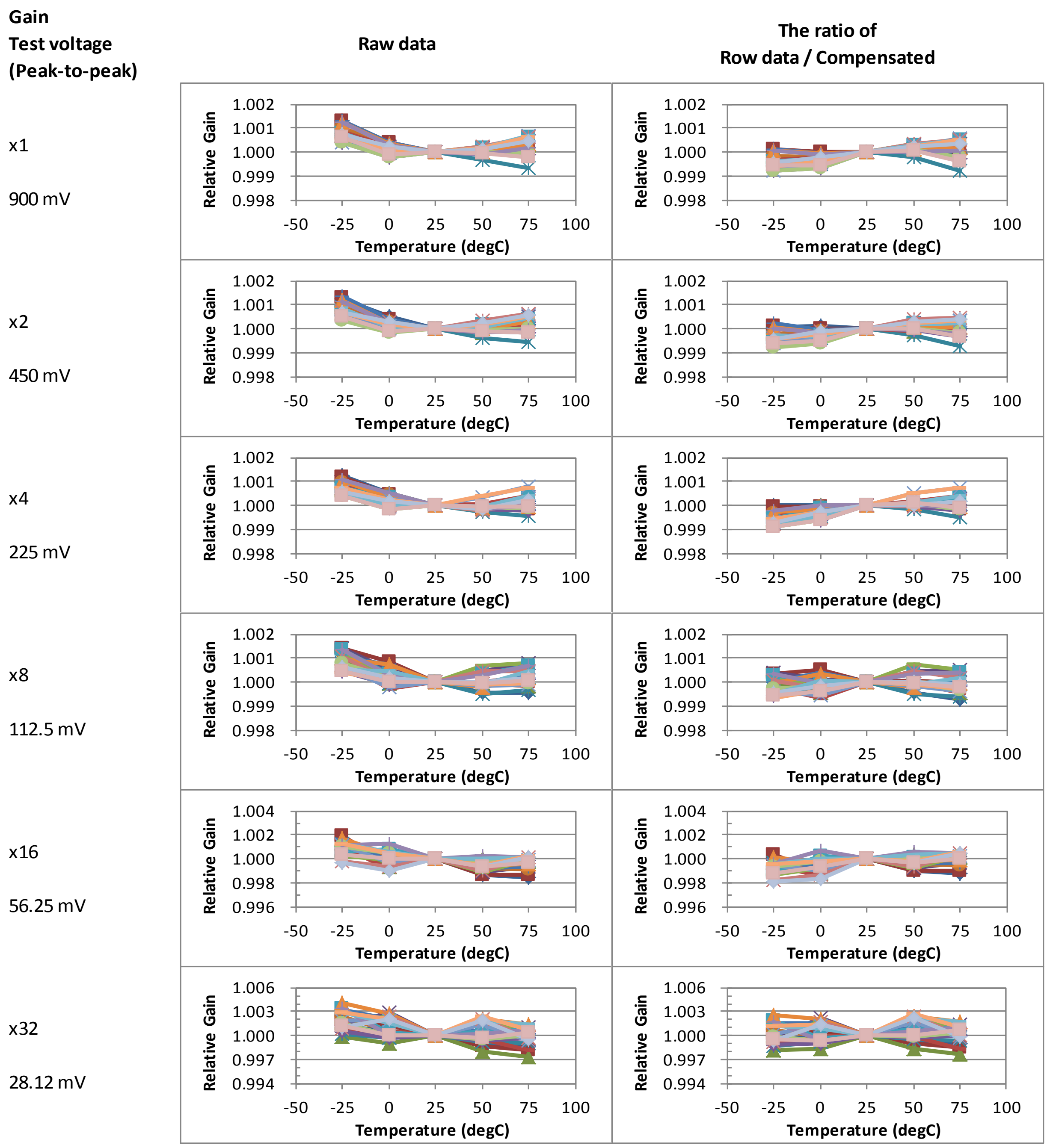
Table 10.1 Results of the VBGR Compensation

Reference Voltage Temperature Coefficient	-40 to +105 °C	
Electrical characteristics in the User's Manual: Hardware	±30 ppm/°C	
Maximum value of the raw data	+30 ppm/°C (-40°C to +25°C)	-24 ppm/°C (+25°C to +105°C)
Residual error after compensation	±10 ppm/°C	

10.2.2 System Gain of the Differential Input Pins

Figure 10.3 shows the System Gain of the Differential Input Pins.

The temperature characteristics are compensated to appear around 1.000 whereas they appear as parabola before compensation.



degC: Degrees Celsius

Measurement condition:
- Test input: AC 50.664 Hz

Figure 10.3 System Gain of the Differential Input Pins

Compensating the temperature characteristics of the system gains on the differential input pins can reduce differences in the temperature characteristics among devices and then the temperature characteristics appear as flat.
Table 10.2 lists the Results of the Compensation for Temperature Characteristics of the System Gain on the Differential Input Pins.

Table 10.2 Results of the Compensation for Temperature Characteristics of the System Gain on the Differential Input Pins

Gain Setting	Temperature Compensation Coefficient [ppm/K]			
	Raw data		Data after compensation	
	Every 25 K [1]	-25°C to +75°C [2]	Every 25 K [1]	-25°C to +75°C [2]
x1	-38 +21	16	-24 +25	14
x2	-39 +17	14	-17 +23	10
x4	-31 +21	15	-13 +24	14
x8	-48 +29	18	-21 +30	10
x16	-96 +45	33	-57 +64	23
x32	-136 +94	41	-97 +111	31

Notes:

1. The range between -25°C and +75°C is divided every 25 K, the temperature characteristic coefficients are calculated for all divided ranges, and the minimum and maximum values are picked up and shown in the table.
2. Value calculated with the box method.
   Temperature compensation coefficient = Gain range (maximum value - minimum value) / Temperature range (75 - (-25))

10.2.3 System Gain of Single-Ended Input Pin

Figure 10.4 shows the System Gain of the Single-Ended Input Pins.
System gains are inversely proportional to temperatures in the temperature characteristics before compensation. After compensation, system gains are compensated to appear around 1.000.

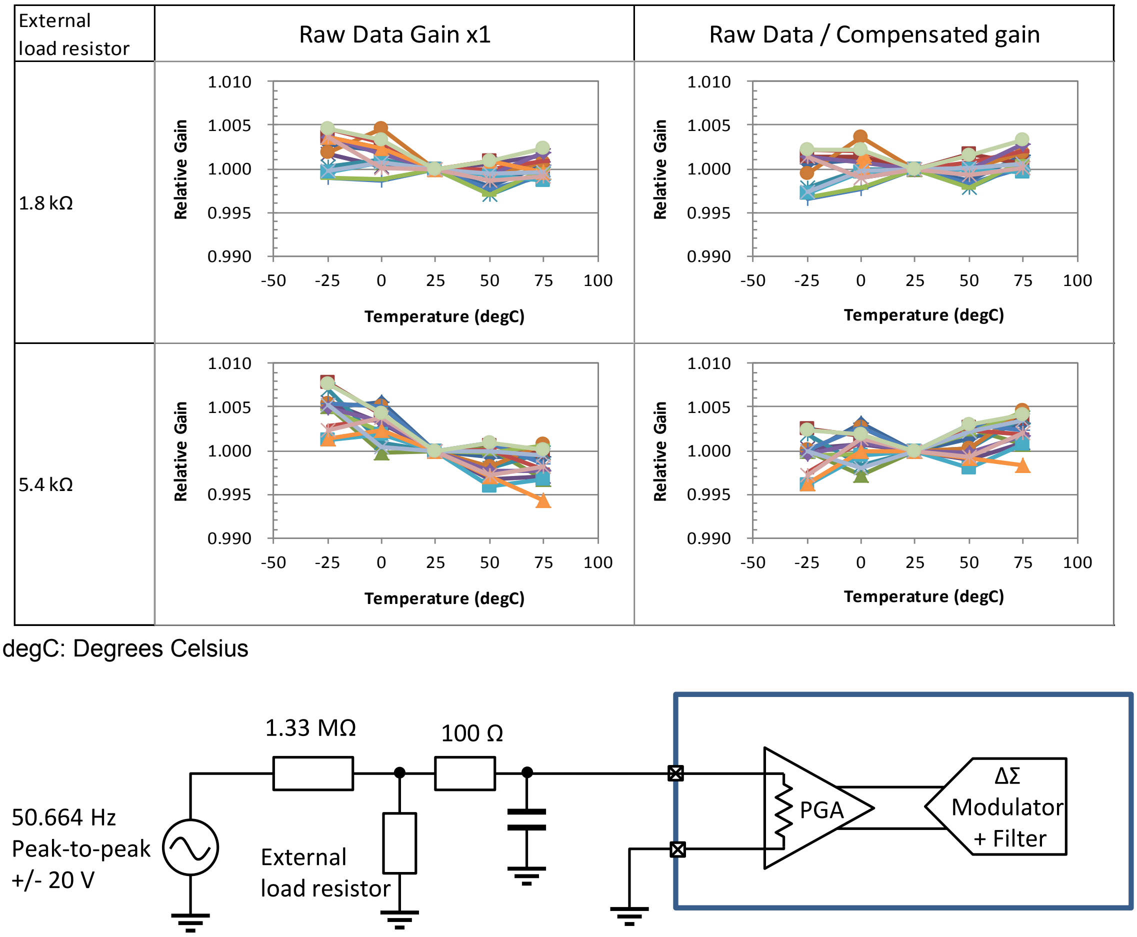


Figure 10.4 System Gain of the Single-Ended Input Pins

Compensating the temperature characteristics of the system gains on the single-ended input pins can reduce differences in temperature characteristics among devices and then the temperature characteristics appear as flat.
Table 10.3 lists the Results of the Compensation for Temperature Characteristics of the System Gain on the Single-Ended Input Pins.

Table 10.3 Results of the Compensation for Temperature Characteristics of the System Gain on the Single-Ended Input Pins

External Load Resistor [kΩ]	Temperature Characteristic Coefficient [ppm/K]			
	Raw data		Data after compensation	
	Every 25 K (1)	-25°C to +75°C (2)	Every 25 K (1)	-25°C to +75°C (2)
1.8	-186 +114	54	-145 +167	43
5.4	-249 +104	90	-136 +176	55

Notes:

1. The range between -25°C and +75°C is divided every 25 K, the temperature characteristic coefficients are calculated for all divided ranges, and the minimum and maximum values are picked up and shown in the table.
2. Value calculated with the box method.
   Temperature compensation coefficient = Gain range (maximum value - minimum value) / Temperature range (75 - (-25))

11. Sample Code

Sample code can be downloaded from the Renesas Electronics website.

12. Reference Documents

User's Manual: Hardware
RX21A Group User's Manual: Hardware Rev.1.10 (R01UH0251EJ)
The latest version can be downloaded from the Renesas Electronics website.

Technical Update/Technical News
The latest information can be downloaded from the Renesas Electronics website.

User's Manual: Development Tools
RX Family C/C++ Compiler Package V.1.01 User's Manual Rev.1.00 (R20UT0570EJ)
The latest version can be downloaded from the Renesas Electronics website.

Website and Support

Renesas Electronics website
http://www.renesas.com

Inquiries
http://www.renesas.com/contact/

REVISION HISTORY	RX21A Group Application Note Gain Calibration and Compensation with the Temperature Sensor for the ΔΣ A/D Converter

Rev.	Date	Description	
		Page	Summary
1.00	Oct. 1, 2014	—	First edition issued
1.10	Mar. 2, 2015	—	Revised the structure and contents of the document.

General Precautions in the Handling of MPU/MCU Products

The following usage notes are applicable to all MPU/MCU 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. 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 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. Unused pins should be handled as described under Handling of Unused Pins in the manual.
2. Processing at Power-on
   The state of the product is undefined at the moment 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 moment 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 moment 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 moment when power is supplied until the power reaches the level at which resetting has been specified.
3. Prohibition of Access to Reserved Addresses
   Access to reserved addresses is prohibited.
   — The reserved addresses are provided for the possible future expansion of functions. Do not access these addresses; the correct operation of LSI is not guaranteed if they are accessed.
4. Clock Signals
   After applying a reset, only release the reset line after the operating clock signal has become stable. When switching the clock signal during program execution, wait until the target clock signal has 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. Moreover, 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.
5. Differences between Products
   Before changing from one product to another, i.e. to a product with a different part number, confirm that the change will not lead to problems.
   — The characteristics of an MPU or MCU in the same group but having a different part number may differ in terms of the 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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