Chapter 9 Temperature Sensing Function

1. Scope

This section will describe the temperature sensing function. It will also describe the details of applying the temperature sensing function during actual ADI-ADuM4138 usage, as well as provide details on the correction function and correction method for dealing with temperature sensing voltage fluctuation.

2. Function

The temperature sensing function is a function that detects the IGBT junction temperature T_{vj} . The temperature sensor is integrated on the same chip as the IGBT chip and outputs a temperature sensing voltage that corresponds to T_{vj} based on a constant current flow. The temperature sensing voltage is characterized by its linearity with the temperature, and as such, this characteristic makes it easy to achieve a T_{vj} monitoring function.

3. Temperature Sensing Characteristics

Fig. 9-1 shows the T_{vj} dependence for the temperature sensing voltage V_F when a constant current of 1 mA flows to the temperature sensor. Furthermore, Fig. 9-2 shows the dependence under a state in which the constant current fluctuates at 1 mA ±5%. In such a case, the temperature sensing voltage will fluctuate at ±11 mV.

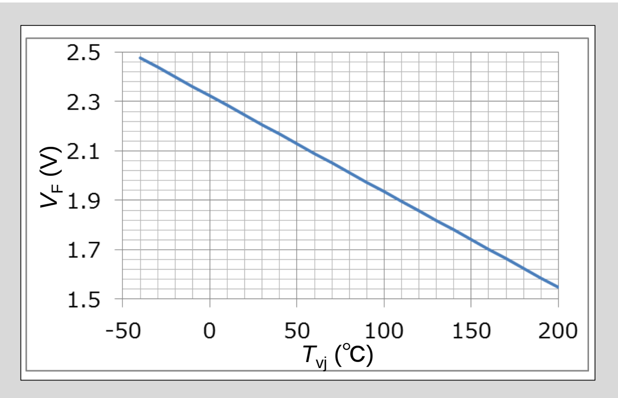

Fig. 9-1 V_F -T_{vj} dependence at I_F = 1 mA

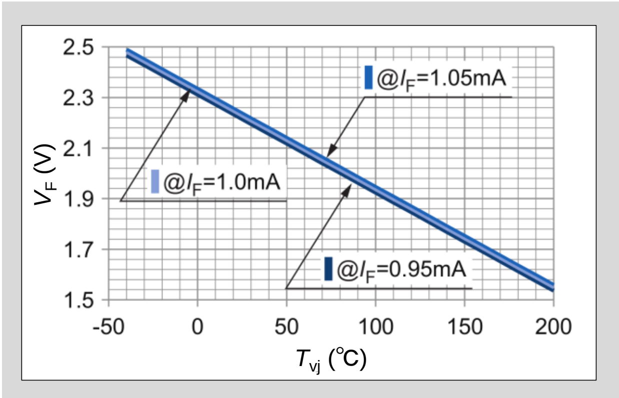

Fig. 9-2 V_F -T_{vj} dependence at I_F = 1±0.05 mA

* Note :

ADuM4138 I_F current specification: ±5% (at I_F = 1 mA)

→ Temperature diode V_F fluctuation at I_F = 1 mA ±5%: ±11 mV

4. Temperature Sensing Function when Using ADI-ADuM4138

The ADuM4138 has a function to supply a constant current to the temperature-voltage conversion sensor built in the IGBT chip and a function to convert the temperature information returned to the voltage into the duty cycle of the PWM signal.

Fig. 9-3 shows an example of the dependence of the duty cycle of the PWM signal on the temperature sense voltage of the ADuM4138.

From the V_F - T_{vj} characteristic shown in Fig. 9-1 and the Duty - V_F characteristic of Fig. 9-3, it is possible to finally obtain the duty cycle of the PWM signal corresponding to the junction temperature: T_{vj} of the IGBT chip.

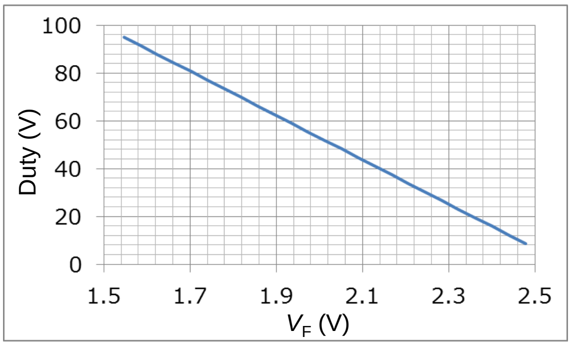

Fig. 9-3 PWM duty - V_F dependence

5. Temperature Sensing Correction Method for ADI-ADuM4138

As shown in Fig. 9-2, the temperature sense voltage output from the IGBT on-chip temperature sensor varies due to variations in the constant current input to the temperature sensor and temperature dependence of the temperature sensor itself. The ADuM4138 has a function to correct the PWM duty cycle output with respect to the temperature sense voltage to realize more accurate temperature sensing. This function corrects the dispersion by adjusting the gain and offset of the operational amplifier for temperature sense voltage detection built into the IC. The correction value can be written to the EEPROM by the SPI communication function.

The correction method will be explained below for your reference. (If you want to correct the PWM duty cycle output in actual product, please contact ADI for detailed correction method.)

5.1 Temperature sensor function correction overview

The correction method is outlined below.

1) Table 9-1 shows the relationship (specification) of junction temperature, temperature sense voltage, and PWM duty cycle.

Table 9-1 Default value of the circuit board parameters

Item	Specification *1)	
Junction temperature T_{vj}	25°C	175°C
Temperature sensing voltage V_F	2.23V	1.65V
PWM duty cycle D_{PWM}	30%	82%

*1) Refer to the specifications of the IGBT module and driver IC for the exact value

2) Get the current uncorrected characteristic data (junction temperature, PWM duty cycle).
3) Calculate the gain and offset value of the operational amplifier for temperature sense voltage detection built into the IC so as to correct the difference of the acquired characteristic data against the specification value. Fig. 9-4 shows the outline of the correction method.
4) Write the calculated gain and offset correction value to the EEPROM using the IC's SPI communication function.

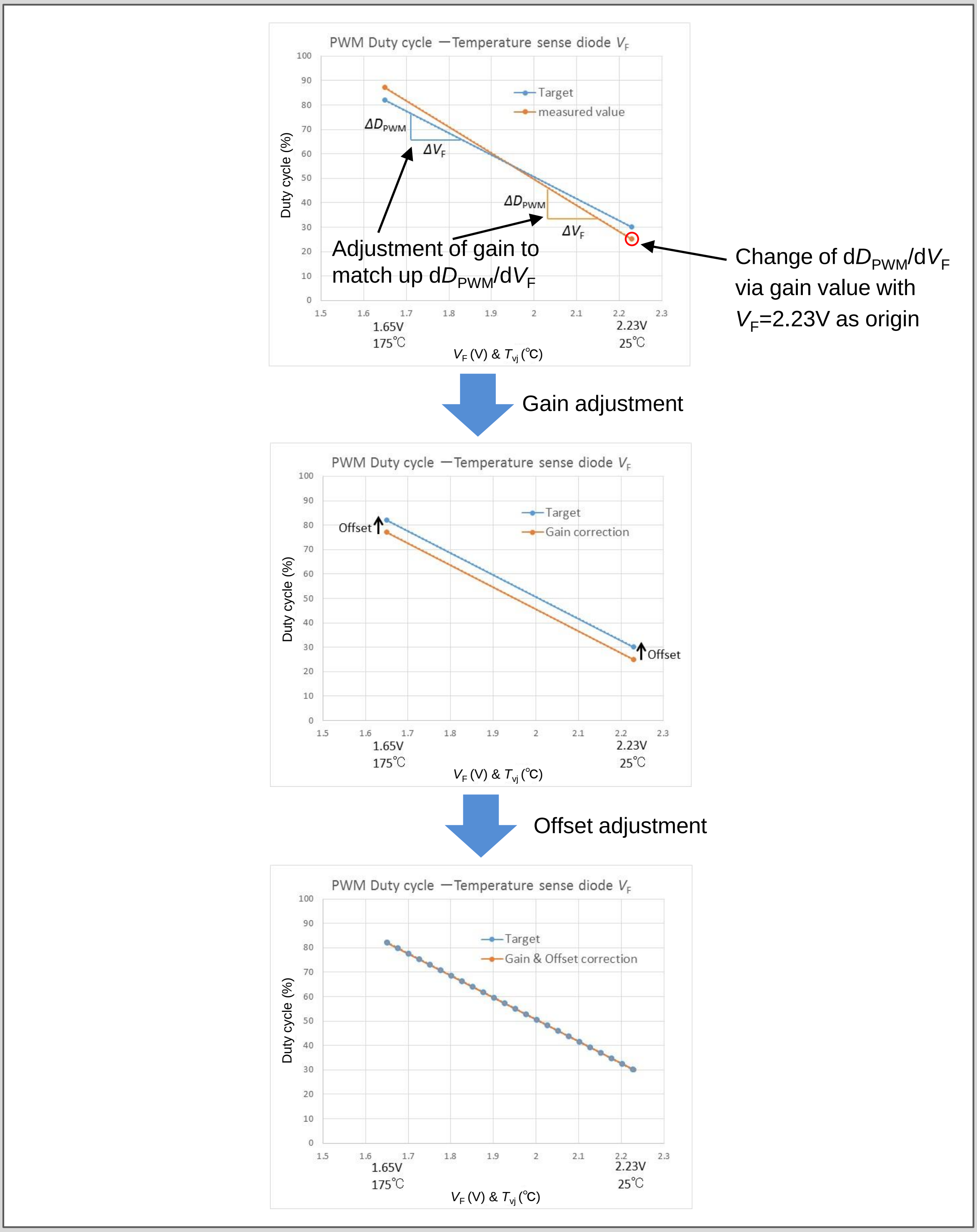

Fig. 9-4 Overview of correction method

5.2 Acquisition of characteristic data

In order to make corrections, it is necessary to acquire current characteristic data.

1) Measurement conditions

Please flow cooling water of a given temperature to the water jacket so that T_{vj} of the IGBT module is at the target temperature. For actual measurement, measurement is recommended after sufficient time has elapsed since the coolant flowed into the water jacket.

2) Measurement items

We recommend data measurement on the low temperature side and measurement at as high a temperature as possible up to 175℃ on the high temperature side. The more accurate the data acquisition in a wide range, the better the accuracy of correction.

Table 9-2 Measurement item

Measurement item	Measurement location	Measurement value	
Junction temperature T_{vj}	Temperature of cooling water and water jacket	Measurement value $T_{vj\ LOW}$	Measurement value $T_{vj\ HIGH}$
PWM duty cycle D_{PWM}	TEMP-U~W TEMP-X~Z	Measurement value D_{LOW}	Measurement value D_{HIGH}

5.3 Calculation of offset correction value

1) From the temperature sense related specification in Table 9-1, find the change amount of V_F with respect to the change of T_{vj} and the change amount of D_{PWM} with respect to the change of V_F.

- $dV_F/dT_{vj\ spec}$ = (1.65V - 2.23V) / (175°C - 25°C) = -0.003867 [V / °C]
- $dD_{PWM}/dV_{F\ spec}$ = (82% - 30%) / (1.65V - 2.23V) = -89.655 [% / V]

2) Calculate the change amount of D_{PWM} with respect to the change of T_{vj} before correction the measured values for temperature-PWM duty cycle in Table 9-2.

- $dD_{PWM}/dT_{vj\ measured}$ = (D_{HIGH} - D_{LOW}) / ($T_{vj\ HIGH}$ - $T_{vj\ LOW}$) = -○.○[% / °C]

3) Calculate the estimated value of V_F at 25℃ and 175℃ input to the driver IC from the temperature - PWM duty cycle measurement value.

- $V_{F\ 25C}$ = 1 / ($dD_{PWM}/dV_{F\ spec}$) × ($dD_{PWM}/dT_{vj\ measured}$ × (25°C - $T_{vj\ HIGH}$) + D_{HIGH} - 30%) + 2.23V
- $V_{F\ 175C}$ = 1 / ($dD_{PWM}/dV_{F\ spec}$) × ($dD_{PWM}/dT_{vj\ measured}$ × (175°C - $T_{vj\ HIGH}$) + D_{HIGH} - 30%) + 2.23V

4) Calculate the offset correction value. Calculate the correction amount so as to correct the difference between the estimated value $V_{F\ 25C}$ of the temperature sensor voltage at 25℃ and the reference value of 2.23V.

- ± offset correction value = **(**$V_{F\ 25C}$ - 2.23V**)** / dV_{OFFSET}/bit
  ★dV_{OFFSET}/bit : Offset correction coefficient = 0.0015

- Process the calculated offset correction value as an integer.
  ★However, since this driver IC has a 6-bit correction bit for offset correction, the range of + offset correction value is 0 to 31, and the range of offset correction value is -1 to -32. Correction is not possible when exceeding this range.

5) Calculate the write value to the EEPROM from the offset correction value.

Table 9-3 Calculation of the offset value to write to the EEPROM

Content	Conversion to binary number
When the integerization offset correction value is positive (+)	Directly convert the positive integerization offset correction value (decimal) to a binary number
When the integerization offset correction value is negative (-)	First calculate 64 + (the negative integerization offset correction value (decimal)), and then convert it to a binary number

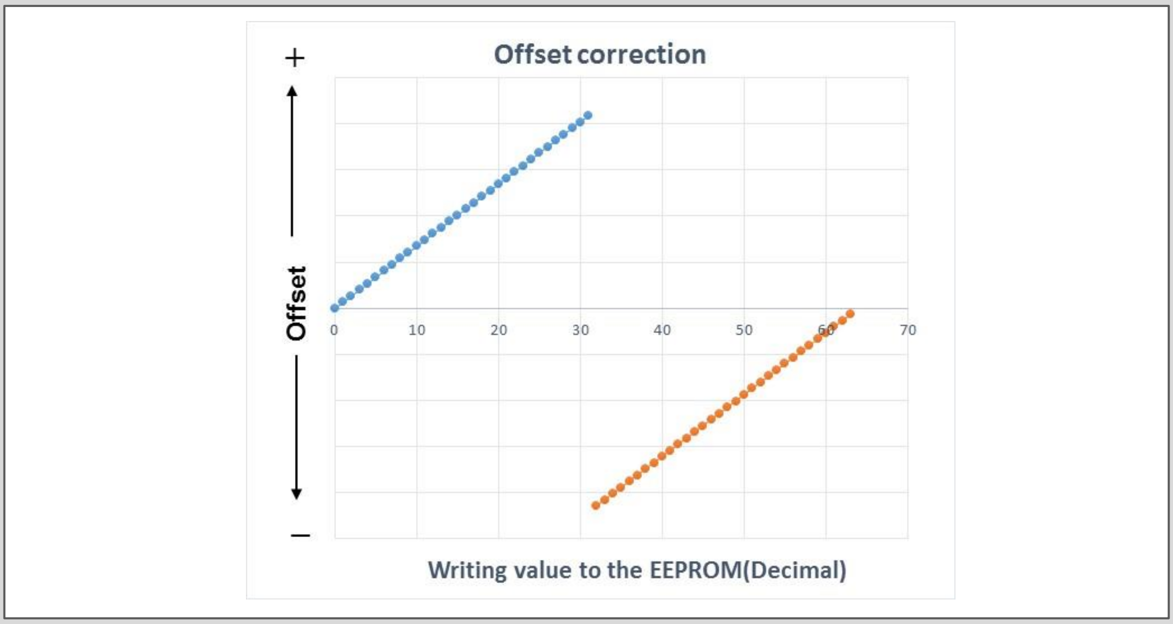

Fig. 9-5 EEPROM write value and offset correction

5.4 Calculation of gain correction value

1) Calculate the gain correction value. Calculate the correction amount so as to correct the difference between the estimated value of the V_F change amount and the specification value with respect to the change of T_{vj} (25℃ to 175℃) calculated from the temperature-PWM duty cycle measurement value.

- ± gain correction value = **(**1 - **(**$V_{F\ 175C}$ - $V_{F\ 25C}$**)** / **(**175°C - 25°C **)** / dV_F/d$T_{vj\ spec}$**)** / dV_{GAIN}/bit
  ★ dV_{GAIN}/bit : Gain correction coefficient = 0.00618

- Calculate the gain correction value as an integer.
  ★ However, since this driver IC has a 6-bit correction bit for gain correction, the range of + gain correction value is 0 to 31, and the range of gain correction value is -1 to -32. Correction is not possible when exceeding this range.

2) Calculate the write value to the EEPROM from the gain correction value.

Table 9-4 Calculation of the gain value to write to the EEPROM

Content	Conversion to binary number
When the integerization gain correction value is positive (+)	Directly convert the positive integerization gain correction value (decimal) to a binary number
When the integerization gain correction value is negative (-)	First calculate 64 + (the negative integerization gain correction value (decimal)), and then convert it to a binary number

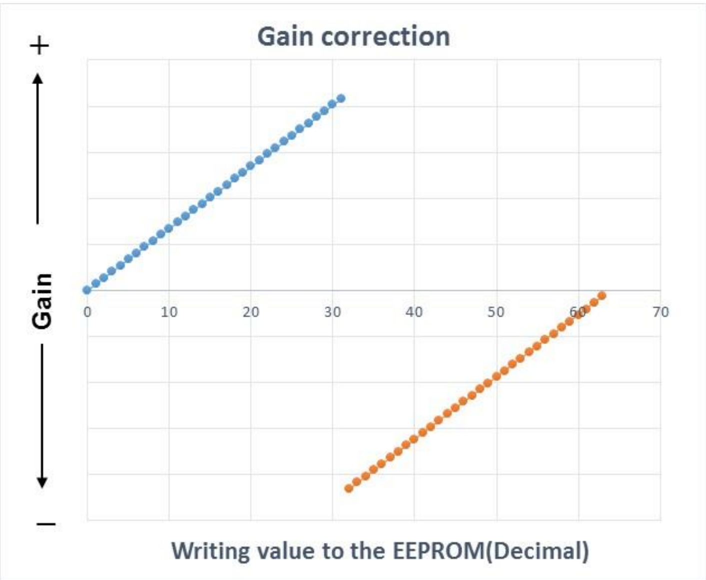

Fig. 9-6 EEPROM write value and gain correction

5.5 Writing data to EEPROM of ADuM4138

In fact, in order to actually write data to the EEPROM in the IC using the SPI communication function of the ADuM4138, it is necessary to have SPI communication module and writing software to connect between PC and IC terminals.

For more information, please contact Analog Devices.

5.6 Example of actual calculation

1) From the temperature sense related specifications in Table 9-1, find the change amount of V_F with respect to the change of T_{vj} and the change amount of D_{PWM} with respect to the change of V_F.
   - $dV_F/dT_{vj\ spec}$ = **(**1.65V - 2.23V**)** / **(**175°C - 25°C **)** = -0.003867 [V / °C]
   - $dD_{PWM}/dV_{F\ spec}$ = **(**82% - 30%**)** / **(**1.65V - 2.23V**)** = -89.655 [% / V]

2) Calculate the amount of change in D_{PWM} relative to the change in T_{vj} before correction from the measured temperature-PWM duty cycle in Table 9-5.

Table 9-5 Example measurements

Measurement item	Measurement value	
Junction temperature T_{vj}	28°C ($T_{vj\ LOW}$)	65°C ($T_{vj\ HIGH}$)
PWM duty cycle D_{PWM}	29.37% (D_{LOW})	43.75% (D_{HIGH})

- $dD_{PWM}/dT_{vj\ measured}$ = **(**D_{HIGH} - D_{LOW}**)** / **(**$T_{vj\ HIGH}$ - $T_{vj\ LOW}$**)**
  = **(**43.75% - 29.37%**)** / **(**65°C - 28°C**)**
  = 0.3886 [% / °C]

3) Calculate the estimated value of V_F at 25℃ and 175℃ input to the driver IC from the temperature - PWM duty cycle measurement value.
   - $V_{F\ 25C}$ = 1 / **(**$dD_{PWM}/dV_{F\ spec}$ **)** × **(**$dD_{PWM}/dT_{vj\ measured}$ × **(**25°C - $T_{vj\ HIGH}$**)** + D_{HIGH} - 30%**)** + 2.23V
     = 1 / **(**-89.655 [% / V]**)** × **(**0.3886 [% / °C] × **(**25°C - 65°C**)** + 43.75% - 30%**)** + 2.23V
     = 2.250V
   - $V_{F\ 175C}$ = 1 / **(**$dD_{PWM}/dV_{F\ spec}$ **)** × **(**$dD_{PWM}/dT_{vj\ measured}$ × **(**175°C - $T_{vj\ HIGH}$**)** + D_{HIGH} - 30%**)** + 2.23V
     = 1 / **(**-89.655 [% / V]**)** × **(**0.3886 [% / °C] × **(**175°C - 65°C**)** + 43.75% - 30%**)** + 2.23V
     = 1.600V

4) Calculate the offset correction value. Calculate the correction amount so as to correct the difference between the estimated value $V_{F\ 25C}$ of the temperature sensor voltage at 25℃ and the reference value of 2.23V.
   - ± offset correction value = **(**$V_{F\ 25C}$ - 2.23V**)** / dV_{OFFSET}/bit
     = **(**2.250V - 2.23V**)** / 0.0015
     = 13.33

   ★dV_{OFFSET}/bit : Offset correction coefficient = 0.0015

   - Calculate the offset correction value as an integer.
     Integerized offset correction value = 13

5) Calculate the write value to the EEPROM from the offset correction value.
   - \+ Integerization offset correction value (decimal number) = + 13
     ⇒ EEPROM write value = 13(DEC) = 001101(BIN)

6) Calculate the gain correction value. Calculate the correction amount so as to correct the difference between the estimated value of the V_F change amount and the specification value with respect to the change of T_{vj} (25℃ to 175℃) calculated from the temperature-PWM duty cycle measurement value.

- ± gain correction value = **(**1 - **(**$V_{F\ 175C}$ - $V_{F\ 25C}$**)** / **(**175°C - 25°C**)** / dV_F/d$T_{vj\ spec}$**)** / dV_{GAIN}/bit
  = **(**1 - **(**1.600V - 2.250V**)** / **(**175°C - 25°C**)** / - 0.003867 [V / °C]**)** / 0.00618
  = -19.51

  ★ dV_{GAIN}/bit : Gain correction coefficient = 0.00618

- Calculate the gain correction value as an integer.
  Integerized gain correction value = -20

7) Calculate the write value to the EEPROM from the gain correction value.

- **-** Integerization gain correction value (decimal number) = **-** 20
  ⇒ EEPROM write value = 64 + (-20) = 44(DEC) = 101100(BIN)