## Chapter 9  Temperature Sensing Function

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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 compensation function and compensation 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. Characteristics of the temperature sensor

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.

*Note:

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

$T_{vj}$ dependence 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 $V_F - T_{j}$ 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: $T_{j}$ of the IGBT chip.

![Fig. 9-3 PWM Duty - $V_F$ dependence](image)

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 actual correction method will be explained below.

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

<table>
<thead>
<tr>
<th>Item</th>
<th>Specification *1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Junction temperature $T_{j}$</td>
<td>25°C</td>
</tr>
<tr>
<td>Temperature sensing voltage $V_F$</td>
<td>2.23V</td>
</tr>
<tr>
<td>PWM duty cycle $D_{PWM}$</td>
<td>30%</td>
</tr>
</tbody>
</table>

*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°C on the high temperature side. The more accurate the data acquisition in a wide range, the better the accuracy of correction.

Table 9-2 Default value of the circuit board parameters

<table>
<thead>
<tr>
<th>Measurement item</th>
<th>Measurement location</th>
<th>Measurement value</th>
<th>Measurement value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Junction temperature $T_{vj}$</td>
<td>Temperature of cooling water and water jacket</td>
<td>Measurement value $T_{vj \ LOW}$</td>
<td>Measurement value $T_{vj \ HIGH}$</td>
</tr>
<tr>
<td>PWM duty cycle $D_{PWM}$</td>
<td>TEMP-U<del>W TEMP-X</del>Z</td>
<td>Measurement value $D_{LOW}$</td>
<td>Measurement value $D_{HIGH}$</td>
</tr>
</tbody>
</table>

5.3 Calculation of offset correction value

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 change amount of $D_{PWM}$ with respect to the change of $T_{vj}$ before correction from the measured value of temperature-PWM duty cycle in Table 9-2.
   - $dD_{PWM}/dT_{vj \ measured} = (D_{HIGH} - D_{LOW}) / (T_{vj \ HIGH} - T_{vj \ LOW}) = -0.0101 [% / °C]$

3) Calculate the estimated value of $V_F$ at 25°C and 175°C input to the driver IC from the temperature-PWM duty cycle measurement value.
   - $V_{F \ 25°C} = 1 / (dD_{PWM}/dV_{F \ spec}) \times (dD_{PWM}/dT_{vj \ measured}) \times (25°C - T_{vj \ HIGH}) + D_{HIGH} - 30\%) + 2.23V$
   - $V_{F \ 175°C} = 1 / (dD_{PWM}/dV_{F \ spec}) \times (dD_{PWM}/dT_{vj \ measured}) \times (175°C - T_{vj \ HIGH}) + D_{HIGH} - 30\%) + 2.23V$
4) Calculate the offset correction value. Calculate the correction amount so as to correct the difference between the estimated value $V_{F,25^\circ C}$ of the temperature sensor voltage at 25°C and the reference value of 2.23V.

- $\pm$ offset correction value = $(V_{F,25^\circ C} - 2.23V) / dV_{OFFSET}$/bit
- $dV_{OFFSET}$/bit : Offset correction coefficient = 0.0015

- Calculate the 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 Offset write value calculation to EEPROM

<table>
<thead>
<tr>
<th>Content</th>
<th>Conversion to binary number</th>
</tr>
</thead>
<tbody>
<tr>
<td>When the integerization offset correction</td>
<td>Directly convert the positive integerization offset correction</td>
</tr>
<tr>
<td>value is positive (+)</td>
<td>value (decimal) to a binary number</td>
</tr>
<tr>
<td>When the integerization offset correction</td>
<td>First calculate $64 + (the negative integerization offset</td>
</tr>
<tr>
<td>value is negative (-)</td>
<td>correction value (decimal)), and then convert it to a binary</td>
</tr>
<tr>
<td></td>
<td>number</td>
</tr>
</tbody>
</table>

![Offset correction](image)

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°C to 175°C) calculated from the temperature-PWM duty cycle measurement value.

- $\pm$ gain correction value = $(1 - (V_{F_{175C}} - V_{F_{25C}}) / (175°C - 25°C)) / dV_F / dT_{vj}$

- $dV_{GAIN}$/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>
<thead>
<tr>
<th>Table 9-4 Gain write value calculation to EEPROM</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Content</strong></td>
</tr>
<tr>
<td>When the integerization gain correction value is positive (+)</td>
</tr>
<tr>
<td>When the integerization gain correction value is negative (-)</td>
</tr>
</tbody>
</table>

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 $V_F$.
   - $\frac{dV_F}{dT_{vj\ spec}} = \frac{(1.65V - 2.23V)}{(175^\circ C - 25^\circ C)} = -0.003867 \ [V / ^\circ C]$
   - $\frac{dD_{PWM}}{dV_F\ spec} = \frac{(82\% - 30\%)}{(1.65V - 2.23V)} = -89.655 \ [% / V]$

2) Calculate the amount of change in DPWM relative to the change in $T_{vj}$ before correction from the measured temperature-PWM duty cycle in Table 9-5.
   - $\frac{dD_{PWM}}{dT_{vj\ measured}} = \frac{(D_{HIGH} - D_{LOW})}{(T_{vj\ HIGH} - T_{vj\ LOW})}$
   - $= \frac{(43.75\% - 29.37\%)}{(65^\circ C - 28^\circ C)} = 0.3886 \ [% / ^\circ C]$

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

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°C and the reference value of 2.23V.
   - $\pm \ offset\ compensation\ value = \frac{(V_{F\ 25C} - 2.23V)}{dV_{OFFSET}/bit}$
   - $= (2.250V - 2.23V) / 0.0015$
   - $= 13.33$
   - $\star dV_{OFFSET}/bit: \ Offset\ compensation\ coefficient = 0.0015$

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

5) Calculate the write value to the EEPROM from the offset correction value.
   - $\star \ Integerization\ offset\ correction\ value\ (decimal\ number) = +13 \Rightarrow \ 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°C to 175°C) calculated from the temperature-PWM duty cycle measurement value.

- $\pm$ gain correction value = 
  \[
  \left( 1 - \frac{V_{F_{175C}} - V_{F_{25C}}}{175°C - 25°C} \right) \cdot \frac{dV_F/dT_{vj \text{spec}}}{dV_{\text{GAIN}}/\text{bit}}
  \]
  \[
  = (1 - \frac{1.600V - 2.250V}{175°C - 25°C}) / 0.003867 \frac{[V/°C]}{0.00618}
  \]
  \[
  = -19.51
  \]

  $dV_{\text{GAIN}}/\text{bit}$ : Gain correction coefficient = 0.00618

- Calculate the gain correction value as an integer.
  Integerization 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 =
  \[
  64 + (-20) = 44(\text{DEC}) = 101100(\text{BIN})
  \]