

GigaDevice Semiconductor Inc.

**Methods to improve the accuracy of the
GD32 temperature sensor**

**Application Note
AN095**

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1. Introduction

The GD32 MCU internal temperature sensor generates a voltage that varies linearly with the chip junction temperature and is connected internally to the input channel of the ADC0_IN16 for converting the output voltage into a digital quantity. This application note describes how to improve the accuracy of temperature sensors through factory calibration and user procedures.

1.1. Temperature sensor

Chip integrated temperature sensor has good linear characteristics, the temperature range is equal to the device operating temperature range, uncalibrated temperature sensor is not suitable for high-precision applications. The factory-calibrated offset is measured by the sensor for the ambient temperature, and the corrected offset measured by the ADC is stored in the memory read-only area. Users can obtain the parameters as shown in [Table 1-1. Temperature sensor characteristics](#) in the datasheet of GD32W515xx.

Table 1-1. Temperature sensor characteristics

| Symbol | Parameter | Min | Typ | Max | Unit |
|---------------|--|-----|---------|-----|------------------------|
| T_L | V_{SENSE} linearity with temperature | — | ± 1 | — | $^{\circ}\text{C}$ |
| Avg_Slope | Average slope | — | 4.3 | — | mV/ $^{\circ}\text{C}$ |
| V_{25} | Voltage at 25 $^{\circ}\text{C}$ | — | 1.42 | — | V |
| t_{START} | Startup time | — | 8 | — | μs |
| t_{s_temp} | ADC sampling time when reading the temperature | — | 13.7 | — | μs |

1.2. Theoretical analysis of temperature sensor measurement process

The output of the temperature sensor is connected to the ADC0_IN16 inside the chip. The ADC channel is used to sample and convert the output voltage data of the temperature sensor. The temperature value is obtained by further processing the original data. The error value of temperature value is related to the noise of the output signal of temperature sensor and the sampling error of ADC. ADC sampling error and methods to improve accuracy are in AN059. The error of temperature sensor is related to the change of the supply voltage and the characteristics of the temperature sensor.

If the device is powered directly by the battery, the supply voltage of the microcontroller will change. With the small package low-pin connection (V_{DDA} equals V_{REFP}), the ADC conversion value shifts with the voltage, and the current supply voltage needs to be known to compensate for this temperature drift. In the case of GD32W515, the internal reference voltage (V_{REFINT}) is used to determine the actual power supply (V_{DDA}). ADC0_IN17 internal channel sampling value $V_{VREFINT}$ is represented by the following formula:

$$\text{Val}_{V_{\text{REFINT}}} = V_{\text{REFINT}} * 4095 / V_{\text{REFP}} = V_{\text{REFINT}} * 4095 / V_{\text{DDA}} \quad (1-1)$$

The exact internal chip reference voltage (V_{REFINT}) is sampled separately by the ADC. During manufacturing, its ADC conversion value ($\text{Cal}_{V_{\text{REFINT}}}$) is obtained using the external reference voltage (3.3V) and stored in a protected area whose address is specified in the datasheet. Determine the actual VDDA voltage, as shown below:

$$V_{\text{DDA}} = 3.3 * \text{Cal}_{\text{REFINT}} / \text{Val}_{V_{\text{REFINT}}} \quad (1-2)$$

When sampling the temperature sensor data, follow the above steps to determine the actual VDDA value.

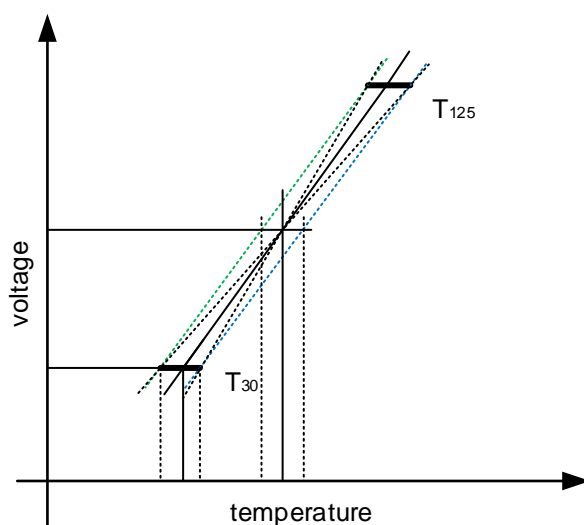
The temperature sensor calibration data is stored in the memory read-only area, which is provided in the data manual. The user reads the service data from this point to improve the accuracy of temperature measurement. Generally, one or two calibration values should be provided in the production process. For specific calibration values, please refer to the datasheet of corresponding MCU:

Room temperature (30°C) : $\text{Cal}_{T_{30}}$

High temperature (125°C) : $\text{Cal}_{T_{125}}$

The temperature calibration data is an unsigned number of 12 bits (stored in 2 bytes). If no calibration value is available, the default value is used (provided by the datasheet). Default values are based on statistics about the characteristics of the temperature sensor, and due to individual differences during the manufacturing process, using default values results in poor accuracy of temperature estimates.

Figure 1-1. Transmission characteristics of the temperature sensor



Linear sampling is performed by the ADC and temperature is calculated by the digital quantity Val_{T_s} . If the coordinates of the two calibration points T_{30} and T_{125} are known, this method can

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be used. The known coordinates of low temperature are expressed as $(T_{30}, CalT_{30})$ and high temperature is expressed as $(T_{125}, CalT_{125})$. The formula is as follows:

$$T_s = (T_{125} - T_{30}) / (CalT_{125} - CalT_{30}) * (Val_{Ts} - CalT_{30}) + T_{30} \quad (1-3)$$

If there is only one calibration value at room temperature, the formula is as follows:

$$T_s = (Val_{Ts} - CalT_{30}) / Avg_Slope + T_{30} \quad (1-4)$$

Avg_Slope: Average slope of temperature and temperature sensor voltage curve. For details, see the datasheet.

If there is no calibration point, then according to the typical voltage value of the temperature sensor under normal temperature, refer to the relevant model datasheet.

1.3. User calibration

In addition to determining the formula and calculating the temperature according to the factory calibration value, users can also perform user calibration according to the data collected by themselves. There is a linear relationship between temperature "f(x)" and ADC sampling value "x", which is assumed to be:

$$f(x) = ax + b \quad (1-5)$$

Users can perform user calibration based on the acquired known ADC sampling values and corresponding temperature values:

Table 1-2. Data collected by users

| ADC code value | Actual temperature |
|----------------|--------------------|
| x_0 | y_0 |
| x_1 | y_1 |
| x_2 | y_2 |
| | |
| x_n | y_n |

According to the least square method. The minimum sum the squares of the errors $\epsilon = \sum (f(x_i) - y_i)^2 = \sum (ax_i + b - y_i)^2$ as an "optimization criterion". Based on the knowledge of multivariable calculus, When ϵ to a or b partial derivatives equal to 0, ϵ to minimum value:

$$\begin{cases} \frac{\partial}{\partial a} \epsilon = 2 \sum (ax_i + b - y_i)x_i = 0 \\ \frac{\partial}{\partial b} \epsilon = 2 \sum (ax_i + b - y_i) = 0 \end{cases} \quad (1-6)$$

Obtained:

$$\begin{cases} a = \frac{n \sum (x_i y_i) - \sum x_i \sum y_i}{n \sum x_i^2 - (\sum x_i)^2} \\ b = \frac{\sum y_i - \sum x_i a}{n} \end{cases} \quad (1-7)$$

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When $n=2$, The above formula is converted into a two-point calibration formula:

$$\begin{cases} a = \frac{y_1 - y_0}{x_1 - x_0} \\ b = \frac{y_1 + y_0 - (x_1 + x_0)a}{2} \end{cases} \quad (1-8)$$

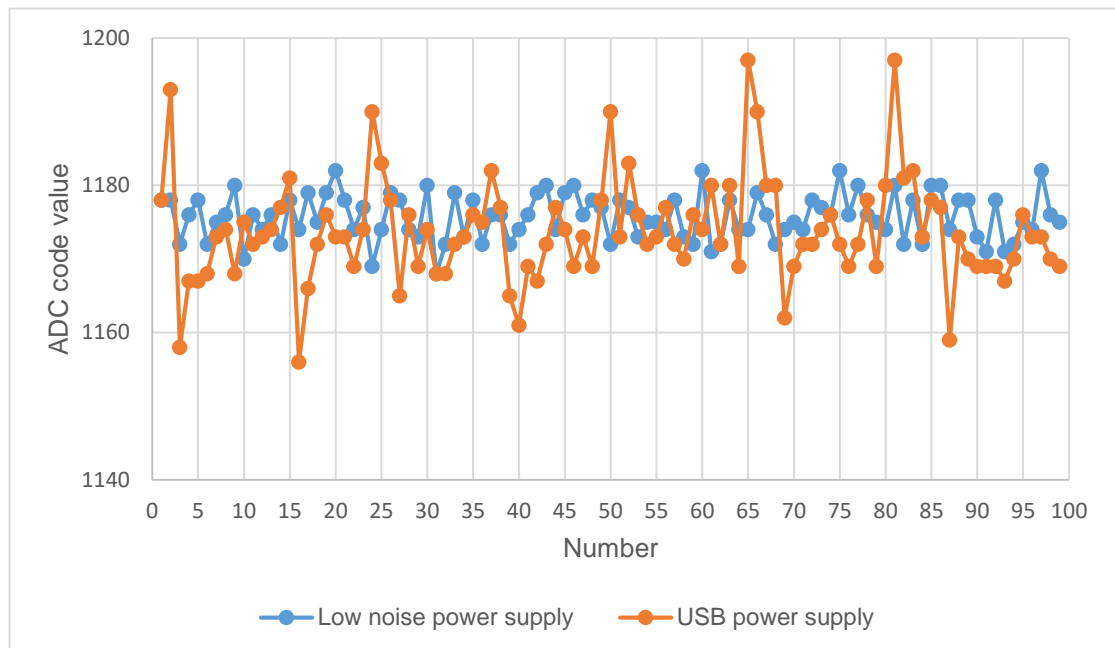
Users can collect more sets of data and calculate the best fitting line according to formula (1-7).

2. Several methods to improve sampling accuracy

2.1. MCU adopts high-precision power supply

The influence of voltage source input with different qualities on ADC sampling results is shown in the figure below. When sampling 100 times, compared with low noise power supply ($\pm 2\text{mV}$) and USB power supply ($\pm 20\text{mV}$), the latter fluctuates widely. Low noise power supply can improve the stability and accuracy of sampling.

Figure 2-1. Influence of power supply on ADC sampling



2.2. Improve accuracy through data processing

Since the temperature sensor is a weak voltage source inside the chip, ADC needs enough time to make the sampling circuit reach the charging-discharge balance and stabilize. The operator needs to determine the appropriate sampling period and ADC frequency according to the relevant model manual. In the code, every two seconds, get 100 sample values from the temperature sensor voltage, the 100 values from the largest to the smallest order, remove the largest 5 values and the smallest 5 values, get the average value of 90 values. The ADC sampling value of the current temperature is obtained according to this average value, and the current temperature is calculated according to the formula.

3. Revision history

Table 1-3. Revision history

| Revision No. | Description | Date |
|--------------|-----------------|-------------|
| 1.0 | Initial Release | Jan.1, 2023 |

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