GigaDevice Semiconductor Inc.

Methods to Improve the Accuracy of the GD32 Temperature Sensor

Application Note
AN095

Revision 1.2

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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 to the ADC's internal input channel to convert the output voltage into a digital quantity. This application note describes how to improve the accuracy of temperature sensors through calibration and user procedures.

1.1. Theoretical analysis of temperature sensor measurement process

The chip integrated temperature sensor has good linear characteristics, and the temperature range is equal to the operating temperature range of the device. The uncalibrated temperature sensor is not suitable for applications requiring high precision. The output of the temperature sensor is connected to the ADC input channel 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 raw data. Generally, the typical voltage value at room temperature (V_{room}) in the datasheet and the mean slope of the temperature and temperature sensor voltage curve (Avg_Slope) can be calculated:

$$\text{temperature}(°C)=\{V_{temperture} – V_{room}\} / Avg\_Slope+T_{room} \quad (1\text{-}1)$$

$V_{temperature}$: Temperature sensor voltage data obtained and calculated from the ADC data register.

T_{room}: Normal temperature Indicates the temperature corresponding to the typical voltage.

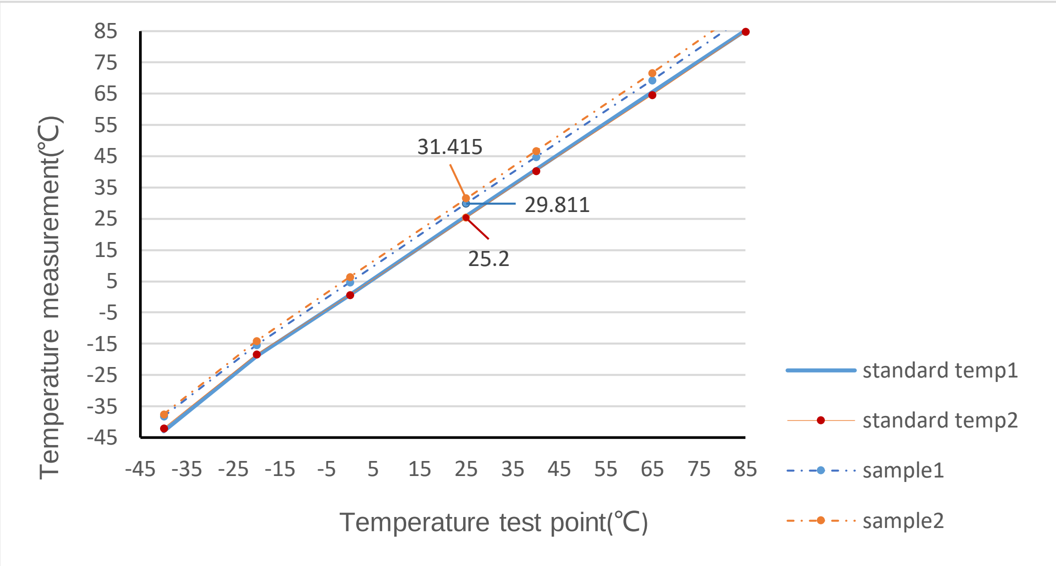
Note:

1. Different series of calculation formulas may be slightly different, please refer to the relevant model user manual;
2. The use of high-precision temperature sensors has requirements for ADC clock frequency, which should not be greater than 5MHz. The high precision temperature sensor series includes GD32L23x, GD32A503xx, GD32H759xx, etc.
3. When using ADC to collect temperature, sufficient sampling time should be ensured. The recommended minimum sampling time is shown in the data manual t_{s_temp};
4. After the temperature sensor is enabled, wait for at least 3 sampling cycles before the ADC conversion code value is considered valid, and the first 3 conversion data should be discarded;
5. The sampling accuracy of the temperature sensor can be improved by means of hardware oversampling or software averaging.

V_{room} is a statistical data based on the characteristics of the temperature sensor. Due to individual differences in the manufacturing process, the voltage sampling value at the same temperature varies greatly from chip to chip (up to 45°C), so the use of this typical voltage value will result in poor accuracy. In order to visually see the difference between the uncalibrated internal temperature sensor and the standard high-precision temperature sensor, two GD32F103VET6 samples were selected, the VREFP was internally connected to the

VDDA, the system frequency was 72MHz, and the operating voltage was 3.3V. Several temperature measuring points given in the sample were randomly measured. After the temperature of each temperature measuring point was stable, the sample waited for 5 minutes, ADC sampled the voltage value of the internal temperature sensor, and measured the average temperature value for 100 consecutive times. The standard high precision temperature sensor used for testing has an accuracy of ±0.5°C. From the curve trend in the ***Figure 1-1. Test results of GD32F103VET6 sample temperature sensor***, it can be seen that the change trend of the internal temperature sensor is basically consistent with that of the standard high-precision temperature sensor, but there is a certain offset, so the uncalibrated temperature sensor is only suitable for measuring the relative temperature change. It is not suitable for measuring absolute temperature.

Figure 1-1. Test results of GD32F103VET6 sample temperature sensor



The error value of temperature value is related to the noise of the output signal of temperature sensor and the sampling error of ADC. The ADC sampling error and methods to improve the accuracy are shown in AN059. The error of the temperature sensor is related to the change of the supply voltage and the characteristics of the temperature sensor.

In order to improve the accuracy of the GD32 MCU temperature sensor use, temperature calibration values are provided in some GD32 MCU series, and factory calibration offsets are stored in the memory read-only area, which is provided in the datasheet. For example, GD32F527xx, GD32L23x, GD32H759xx (high precision temperature sensor), provides a normal temperature calibration point, the normal temperature calibration point is a 12-bit unsigned number (stored in 2 bytes), which can be substituted for the typical value V_{room} into the formula (1-1) calculation. In GD32A503xx, GD32H759xx (general temperature sensor), two calibration points are provided. Refer to the datasheet, as shown in ***Table 1-1. GD32xx Temperature sensor calibration value*** **example**, the current MCU temperature and temperature sensor voltage curve slope can be calculated according to the two calibration points, then:

$$\text{Avg\_Slope}=\frac{(\text{TS\_CAL2-TS\_CAL1})*3.3}{4095*(105-30)} \quad (1\text{-}1)$$

$$\{V_{room},T_{room}\}=\left\{\frac{\text{TS\_CAL1}*3.3}{4095},30\right\} \quad (1\text{-}2)$$

Take (1-2) and (1-3) into the formula (1-1) for calculation.

Table 1-1. GD32xx Temperature sensor calibration value example

Symbol	Parameter	Memory address
TS_CAL1	Temperature sensor raw data acquired value at 30 °C (± 3 °C), V_{DD} = V_{DDA} = V_{REFP} = 3.3V (± 1.5 mV)	0x1FFF F7F8 - 0x1FFF F7F9
TS_CAL1	Temperature sensor raw data acquired value at 105 °C (± 3 °C), V_{DD} = V_{DDA} = V_{REFP} = 3.3V (± 1.5 mV)	0x1FFF F7FA - 0x1FFF F7FB

1.2. 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:

$$f(x)=ax+b \quad (1\text{-}4)$$

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:

$$\begin{cases}\frac{\partial}{\partial a}\epsilon=2\sum(ax_i+b-y_i)x_i=0\\ \frac{\partial}{\partial b}\epsilon=2\sum(ax_i+b-y_i)=0\end{cases} \quad (1\text{-}5)$$

Obtained:

$$\begin{cases} a=\frac{n\sum(x_i y_i)-\sum x_i \sum y_i}{n\sum x_i^2-(\sum x_i)^2} \\ b=\frac{\sum y_i-\sum x_i a}{n} \end{cases} \tag{1-6}$$

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

$$\begin{cases} a=\frac{y_1-y_0}{x_1-x_0} \\ b=\frac{y_1+y_0-(x_1+x_0)a}{2} \end{cases} \tag{1-7}$$

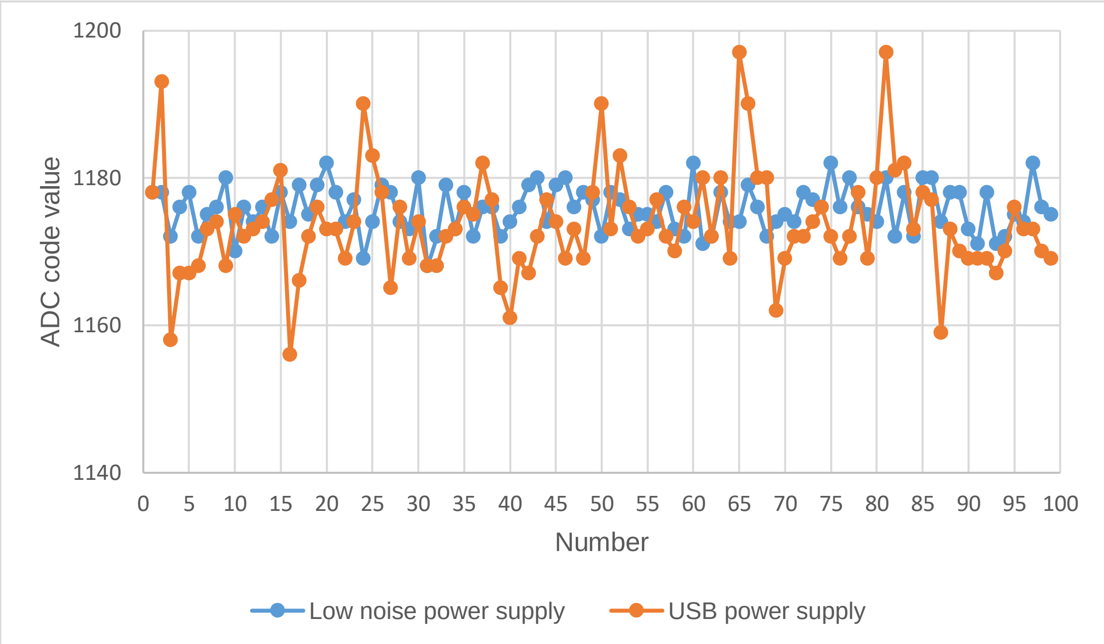
Users can collect more sets of data and calculate the best fitting line according to formula (1-6).

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 (±2mV) and USB power supply (±20mV), 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. For example, 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 3-1. Revision history

Revision No.	**Description**	**Date**
1.0	Initial Release	Jan.1, 2023
1.1	Update Partial Description	Apr.11,2023
1.2	Add the content specification of the first chapter	Jun.1, 2024