Application Note

NOVOSENSE

Application of Calibration Based on NSA3300

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ABSTRACT

Human body temperature measurement is roughly divided into contact temperature measurement and non-contact temperature measurement. Mercury and pressure thermometers are often used for contact temperature measurement. Contact temperature measurement equipment features high measurement accuracy and good stability, is not easily affected by environmental factors, and is easy to carry. Mercury thermometers, in particular, are often used as gold standards for high-precision measurement and as standard instruments. However, contact temperature measurement equipment has the disadvantages of long measurement time, repeated disinfection, inability to store measurement data in real time, and high risk of contact transmission, not suitable for simultaneous temperature measurement of large groups of people.

Infrared thermometers provides non-contact temperature measurement. Non-contact temperature measurement equipment features fast response, high sensitivity, dynamic measurement, safe use, and long life, and reduces the chance of contact between people. Its disadvantages include that the accuracy is susceptible to environmental factors, the temperature measurement range is large, the resolution is relatively low, and it needs to be calibrated against a standard blackbody on a regular basis.

This application note is based on the application in human body temperature measurement. It describes in detail the chip's packaging with sensor, configuration, calibration and specific application in human body temperature measurement.

AN-12-0046

NOVOSENSE

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INDEX

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1.Principle Introduction

A thermocouple is a thermoelectric element that works based on the thermoelectric effect and is constructed by welding two ports of two different materials. When a temperature difference occurs between one port and the other, an electromotive force is generated at the open end of the thermocouple due to the Seebeck effect. The temperature difference is proportional to the electromotive force generated. Based on this principle, as long as the temperature of one end is kept constant, the temperature of the other end can be obtained according to the magnitude of the thermoelectric electromotive force.

The figure below shows the connection of a thermocouple tested at room temperature: the solid and dashed lines are two different thermocouple materials that generate Vs electromotive force at room temperature as the reference temperature.

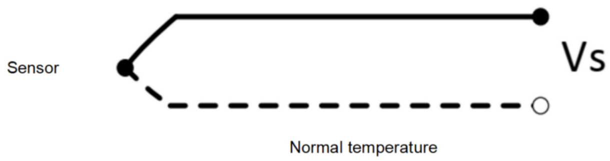

Figure 1.1 Schematic diagram of thermocouple

In order to improve thermocouple sensitivity, a plurality of thermocouples can be connected in series to form a thermopile, and the output of the thermopile is the sum of the voltage outputs of the plurality of thermocouples. Conventional thermopile manufacturers test manufactured thermopiles for the 25°C VT curve as shown in the figure below, i.e., the electromotive force output voltage of the thermopile at room temperature of 25°C for different target temperatures. If the output voltage of the thermopile is measured at room temperature of 25°C, the target temperature value at that time can be inferred through the difference table plus linear fitting method. The thermopile output voltage is 0V at a target temperature of 25°C, positive at a target temperature above 25°C, and negative at a target temperature below 25°C.

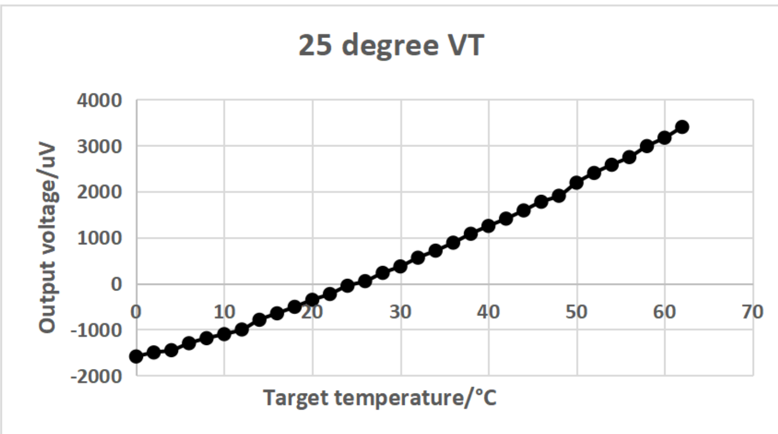

Figure 1.2 VT curve of thermopile at 25°C

At the same target temperature, different ambient temperatures (reference temperatures) will result in different output electromotive forces, as shown in the figure below. (T_{Sens}: ambient temperature; T_{obj}: target temperature; V_{TP}: thermopile output electromotive force) VT curves at different ambient temperatures are similar to parallel.

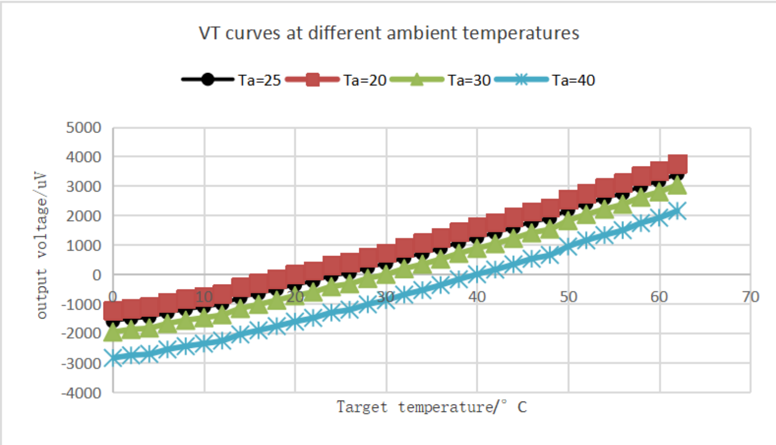

Figure 1.3 VT curves at different ambient temperatures

The signal conditioning chip for the thermopile sensor performs processing based on the thermoelectric electromotive force of the thermopile. Typically, the chip stores a VT curve, which is converted using the intermediate temperature theorem when the ambient temperature changes. When the sensor manufacturer provides a V_{TP}-T_o (target temperature) with T_{A0} (ambient temperature) = 25°C, the ambient temperature is T_A and the object under test is T_o, the following can be obtained according to the intermediate temperature theorem:

$$\mathbf{V}(T_O, T_A) + \mathbf{V}(T_A, T_{A0}) = \mathbf{V}(T_O, T_{A0})$$

That is, the thermoelectric electromotive force of T_o measured at T_A ambient temperature plus the thermoelectric electromotive force of T_A measured at T_{A0} ambient temperature equals the thermoelectric electromotive force of T_O measured at T_{A0} ambient temperature. Therefore, by measuring the thermopile output voltage V(T_o,T_A) and ambient temperature and combining with V_{TP}-T_o at T_{A0}, the measured temperature T_o can be deduced.

Due to the nonlinearity of the thermopile and based on the correction factor, the VT curves at different ambient temperatures can be calculated from a single VT curve. The internal EEPROM (electrically erasable programmable read-only memory) of NSA3300 can store 32 points of a single VT curve. Based on this principle, NSA3300 burns the 25°C sensor VT table, performs table lookup and reverse table lookup through the internal DSP algorithm, and finally calculates the correct temperature value for output.

The chip integrates a NTC (Negative Temperature Coefficient) thermistor inside, which can be used to measure the ambient temperature. It also supports the input of two thermopile sensors: T_{o1} (channel one) and T_{o2} (channel two). The two channels multiplex one ADC, and different channel modes can be selected through configuration. In the body temperature application, we recommend using the T_aT_{o1} mode, that is, the internal ADC will only collect the ambient temperature T_a and the thermopile voltage of channel 1. The collected T_a will be used as the reference temperature of the thermopile. After it is input into the DSP as a parameter with the collected T_{o1} voltage, the current target temperature will be output after processing. The specific schematic diagram is as follows:

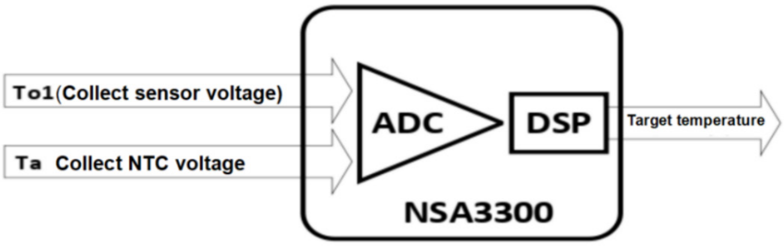

Figure 1.4 Schematic diagram of operation in T_aT_{o1} mode

2.Packaged Finished Product

This chip is shipped in the form of wafers, and customers need to use it together with the front-end thermopile sensor. The specific PAD distribution of the wafer is shown below. For human body temperature measurement, channel 2 does not need to be used, while the remaining channels need to be wired and packaged by themselves. At the same time, the packaging stress will have a certain impact on the NTC temperature measurement. The error can be resolved by recalibrating T_a later.

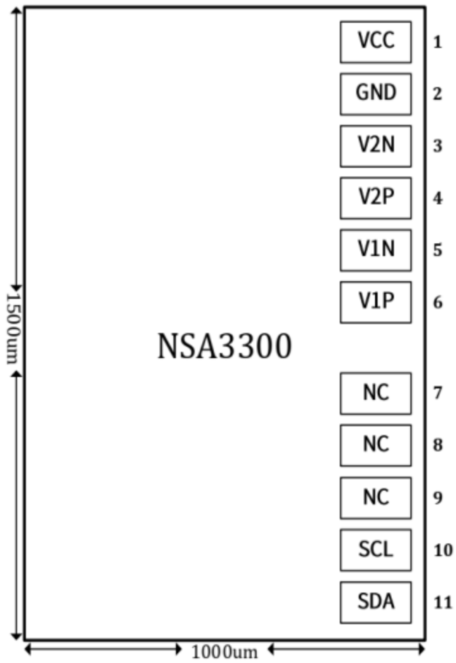

Figure 2.1 PAD distribution diagram of wafer

For

Regular packages include TO46 and DFN chip packages. The wiring diagram of TO46 package is shown below: For single-channel human body temperature measurement application, you only need to wire the chip's channel 1 pad to the sensor and lead out VCC and GND, SCL and SDA.(Wiring needs to avoid crossing chips).

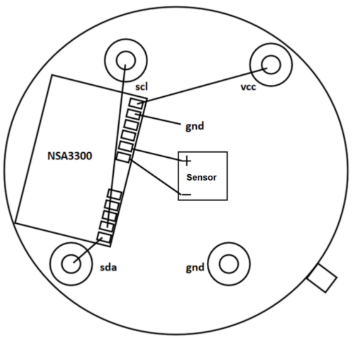

Figure 2.2 Schematic diagram of single-channel TO46 package

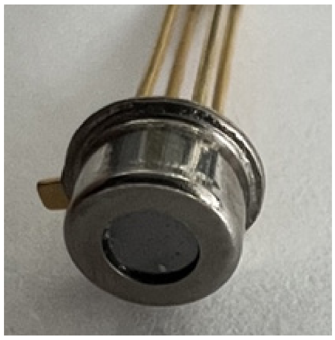

Figure 2.3 Schematic diagram of finished product TO46 after packaging

3.Hardware DEMO Board

For the human body temperature measurement application, only one set of IIC interface and 3.3V power supply are needed. The system hardware connection diagram is as follows:

Figure 3.1 Hardware connection diagram

4.Working Mode Register Configuration

NSA3300 has two types of registers: general register and EEPROM register. The general register can set data status, update data flag bits, and update data, etc. EEPROM can configure different working modes of the chip and solidify them.

The specific recommended register configuration for single-channel human body temperature measurement in this application is as follows:

Register SYS_CONFIG_1 (0X93) is configured to 0x07 (OSR for ambient temperature measurement. OSR is configured to 16384X).

- Register SYS_CONFIG_2 (0x94) is configured to 0x80 (enable ADC internal dither).
- Register SENSOR_CHAN1_CONFIG (0x95) is configured to 0x2F (GAIN=64; 0SR=16384X).
- Register BPS_CONFIG (0x97) is configured to 0x0D (5/16*AVDD).

After completing the register configuration of the working mode, burn the VT table data. The chip allows 32 VT curve points to be stored inside. The 16mV range is recommended for human body temperature measurement. The formula for storing values is as follows: The data obtained at each temperature point is divided into the upper eight bits and the lower eight bits, and registers VT_DATA1_MSB (0xC0) to VT_DATA32_LSB (0xFF) are configured in sequence.

$$\pm 16\text{mV}: \quad \text{DEC2HEX}(\text{FIXED}(V_{TP}(\text{mV})*256*8))$$

Table 4.1 VT conversion table

To	Ta 25°C	EEPROM
0	-1668.15	F2A8
2	-1557.468	F38B
4	-1442.826	F476
6	-1324.224	F568
8	-1201.662	F663
10	-1075.14	F767
12	-944.658	F872
14	-810.216	F985
16	-671.814	FAA1
18	-529.452	FBC4
20	-383.13	FCF0
22	-232.848	FE24
24	-78.606	FF60
26	79.596	00A3
28	241.758	01EF
30	407.88	0343
32	577.962	049F
34	752.004	0604
36	930.006	0770
38	1111.968	08E5

40	1297.89	0A62
42	1487.772	0BE6
44	1681.614	0D73
46	1879.416	0F09
48	2081.178	10A6
50	2286.9	124B
52	2496.582	13F9
54	2710.224	15AE
56	2927.826	176C
58	3149.388	1931
60	3374.91	1AFF
62	3604.392	1CD5

- According to this VT table, the highest temperature point is 62°C, the corresponding DEC2HEX (62*64) = 0x0F80, register Tomax_1 (0x9F) is configured to 0x0F, and register Tomax_2 (0xA0) is configured to 0x80.
- According to this VT table, the lowest temperature point is 0°C, the corresponding DEC2HEX (0*64) = 0x000, register Tomin_1 (0xA1) is configured to 0x00, and register Tomin_2 (0xA2) is configured to 0x00.
- Registers Emissivity_1 (0xA4) and Emissivity_2 (0xA5) are recommended to be configured to 0x7F and 0xFF, i.e. the maximum radiation coefficient.
- After completing the above working mode configuration of EEPROM, you can choose power-down save, that is, burn the general register BLOW_start (0x40) to 0x68.

5.Data Reading

In the human body temperature measurement application, the single-channel To1Ta mode is used. In terms of data collection, there are a total of five data, namely TaRaw (raw data collected by the ADC of internal ambient temperature), TaCal (data after a linear calibration of TaRaw internally); To1Raw (data of the thermopile sensor collected by the internal ADC), To1Cal (data after a linear calibration of To1Raw internally), To (the target temperature value finally output by the internal DSP through TaCal and To1Cal). The overall data flow is shown in the figure below:

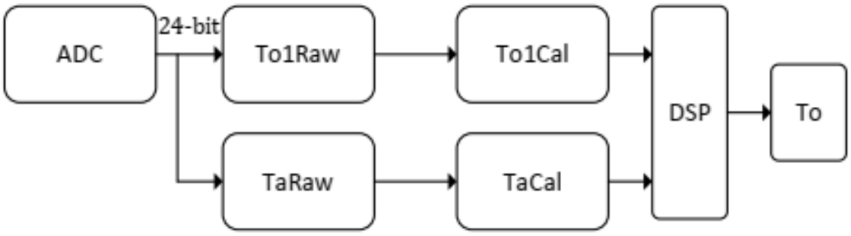

Figure 5.1 Data flow diagram for single-channel application

The register addresses of the five groups of data are as follows: (all data are stored in the form of complement)

- TaRaw: (0x28, 0x29, 0x2A)
- TaCal: (0x16, 0x17, 0x18)

  Ambient temperature value conversion: $T(℃) = T_a Cal/2^{14}$
- To1Raw: (0x22, 0x23, 0x24)

  Equivalent input voltage calculation formula: $V_{tp}(mv) = 1.1 * \frac{\frac{To1Raw}{GainPGA}}{2^{23}} * 1000$ GainPGA depends on EE configuration)
- To1Cal: (0x19, 0x1A, 0x1B)

  Equivalent input voltage calculation formula: $V_{tp}(mv) = T_{O1}Cal/2^{19}$ configured to ±16mV)
- To: (0x10, 0x11, 0x12)

  Target temperature value conversion: $T(℃) = T_O/2^{14}$

6.Calibration

After completion of mode configuration, calibration is required:

The NTC resistor integrated in the chip is used to measure the ambient temperature. When the ADC switches to the NTC sensor, it will use the reference voltage generated by itself. The NTC sensor will complete the calibration in the chip CP (Circuit Probing) stage to ensure the accuracy of the ambient temperature test. Therefore, the ambient temperature Ta is generally not calibrated.

However, after the chip is packaged with the sensor, the OFFSET and GAIN of the whole system link will change, and a systematic calibration of the finished product is required. The calibration is divided into two parts: OFFSET calibration and GAIN calibration. The calibration scheme is recommended as follows:

It requires stable and accurate control of ambient temperature and an accurate blackbody radiation source.

After the platform is built, the whole system needs to be calibrated, which is divided into OFFSET calibration and GAIN calibration. The relationship between the raw data Raw and Cal is shown in the following formula:

$$V_{TPcal} = (V_{TP} - offset) * \left(\frac{V_{theoretical}}{V_{measured}} - 1 + 1\right)$$

The offset is stored in registers 0xAE and 0xAF, and ($V_{theoretical}/V_{—measured-1}$) is stored in registers 0xB0 and 0xB1. When calibration is not performed, $V_{TPcal}=V_{TP}$ can be equivalent to the input voltage through To1Raw and To1Cal according to their respective equivalent formulas for comparison and confirmation.

6.1.Offset Calibration:

- Configure registers CH1_OFF_MSB (0xAE), CH1_OFF_LSB (0xAF), CH1_GAIN_MSB (0xB0), and CH1_GAIN_LSB (0xB1) to 0x00 first.
- Set the ambient temperature and the blackbody temperature to 25°C. At this time, the chip's Ta output is 25°C. The schematic diagram is shown below:

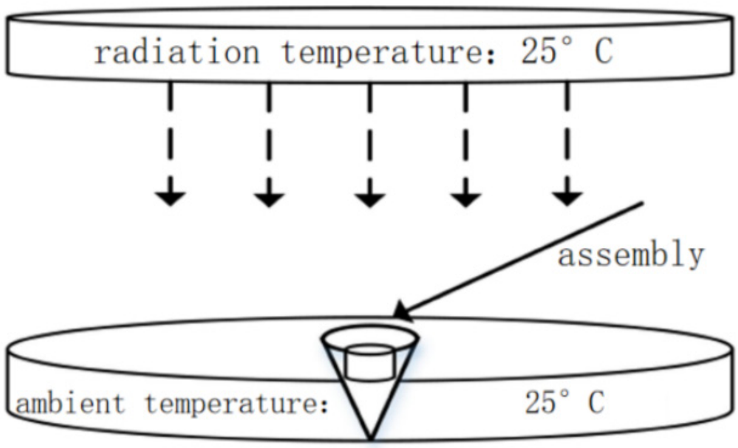

Figure 6.1 Schematic diagram of the placement of OFFSET calibration products

- At this time, collect ADC_rawdata of channel 1. That is, read register DATA1_RAW_MSB (0x22), register DATA1_RAW_CSB (0x23) and register DATA1_RAW_LSB (0x24). The data is stored in the form of complement.
- When the data is stable, collect ADC_rawdata for 100 consecutive times and average to get ADC_new_raw:
- 1. If ADC_new_raw is negative, 0x1000000-ADC_raw (converted to complement), then right shift 7 bits, write the lower 8 bits to CH1_OFF_LSB (0xAF), and write the upper 8 bits to CH1_OFF_MSB (0xAE).
- 2. If ADC_new_raw is positive, right shift 7 bits to ADC_raw_new, 0x10000-ADC_raw_new (converted to complement), write the lower 8 bits to CH1_OFF_LSB (0xAF), and write the upper 8 bits to CH1_OFF_MSB (0xAE).

Offset Calibration Verification:

- In this environment, read ADC_caldata of channel 1, that is, read register DATA1_CAL_MSB (0x19), register DATA1_-CAL_CSB (0x1A) and register DATA1_CAL_LSB (0x1B). The data is stored in the form of complement.
- Use the formula Vtp(uV)=(ADC_caldata/2^19)*1000 to calculate the data equivalent to the input voltage after only offset calibration. The data should be stable and close to 0.
- Read the To output of channel 1, that is, read register DATA1_MSB (0x10), register DATA1_CSB (0x11) and register DATA1_LSB (0x12), and divide the converted data by 2^14 to get the final output temperature value. If the stable output is 25°C, it means that the offset calibration is successful.

6.2.Gain Calibration

- Set the blackbody temperature to 40°C. At this time, the blackbody will affect the ambient temperature of the chip. Reduce the ambient temperature so that the Ta output of the chip is stable at 25°C and maintain the original position, as shown below:

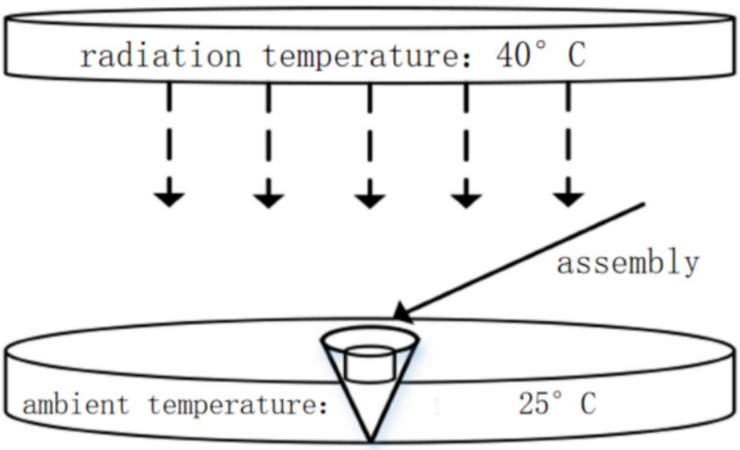

Figure 6.2 Placement position of finished product for GAIN calibration

- Re-collect ADC_caldata of channel 1.
- Collect ADC_caldata for 100 consecutive times and average to get ADC_new_cal:
- 1. Vtp measured (mV) = ADC_new_cal/2^19.
- 2. Read the VT table to get the sensor output V_{tp} value at a target temperature of 40°C under an ambient temperature of 25°C, and record it as V_{tp} theoretical.
- 3. Write value = GAIN*2^16 = (V_{tp} theoretic - V_{tp} measured) / V_{tp} measured * 2^16, convert to hexadecimal, write the upper 8 bits to CH1_GAIN_MSB (0xB0), and the lower 8 bits to CH1_GAIN_LSB (0xB1).
- Gain calibration verification:
- In this environment, read ADC_caldata of channel 1, which should be stable and close to V_{tp} theoretic.
- To should stabilize the output at 40°C, indicating that gain calibration is complete.

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7.Conclusion

This article mainly introduces the application of NSA3300 in human body temperature measurement. And a detailed explanation of the calibration method was provided. We can choose our own suitable hardware and software platform for debugging based on the calibration method.

8.Revision History

Revision	Description	Author	Date
1.0	Initial version	Feifei Sun	2024/12/1