# Design and Implementation of High Precision Temperature Measurement Unit

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**Abstract**. Large-scale neutrino detector requires calibration of photomultiplier tubes (PMT) and electronic system in the detector, performed by plotting the calibration source with a group of designated coordinates in the acrylic sphere. Where the calibration source positioning is based on the principle of ultrasonic ranging, the transmission speed of ultrasonic in liquid scintillator of acrylic sphere is related to temperature. This paper presents a temperature measurement unit based on STM32L031 and single-line bus digital temperature sensor TSic506. The measurement data of the temperature measurement unit can help the ultrasonic ranging to be more accurate. The test results show that the temperature measurement error is within ±0.1℃, which satisfies the requirement of calibration source positioning. Take energy-saving measures, with 3.7V/50mAH lithium battery-powered, the temperature measurement unit can work continuously more than 24 hours.

## 1.Introduction

Large-scale neutrino detector require calibration of PMT and electronic system in the detector, performed by plotting the calibration source with a batch of designated coordinates in the acrylic sphere which inside diameter is 30m and thickness is 12cm [1]. Calibration source positioning is performed by the principle of ultrasonic ranging [2], the transmission speed of ultrasonic in liquid scintillator is related to the temperature, so it is necessary to measure the temperature of the liquid scintillator.

## 2. Analysis of System Design Requirements

As shown in Figure1, the calibration source is connected with an ultrasonic transmitter and moves within the acrylic sphere. There are 8 ultrasonic receivers arranged on the inner wall of the acrylic sphere. The ultrasonic transmitter, ultrasonic receiver and electronic system form an ultrasonic positioning system.
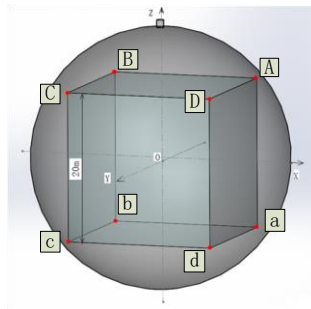
**Figure 1:** The system layout of ultrasonic positioning
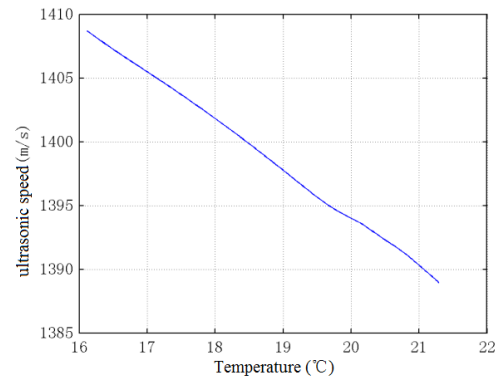


**Figure 2:** The temperature-ultrasonic speed curve

In a wide range of positioning environment, the transmission speed of ultrasonic in liquid scintillator is related to the temperature [3], the temperature-ultrasonic speed curve is shown in Figure2, ultrasonic speed changes 4 m/s for every 1℃.The distance between transmitter and receiver is defined as $s$, the transmission time between transmitter and receiver is defined as $t$, and the transmission speed is defined as $v$, we know that：

$$s = v \cdot t \tag{2.1}$$

The slight variation in distance can be expressed as：

$$ds = dv \cdot t + v \cdot dt \tag{2.2}$$

Divide both ends of the above equation by $s$ and take the absolute value：

$$\left| \frac{ds}{s} \right| = \left| \frac{dv}{v} \right| + \left| \frac{dt}{t} \right| \tag{2.3}$$

The required positioning error is less than 3cm, for the positioning range of 30m, the relative error should be less than 0.1%. The formula (2.3) shows that the positioning error is determined by the error of $v$ and $t$, and mainly caused by the error of $v$, since the error of $t$ can be ignored in electronic system. The relative error of v is less than 0.1%, then the absolute value of $v$ changes less than 1.39m/s since $v$ is about 1390m/s at 21℃. As we know, the temperature changes 1℃ then $v$ changes 4m/s, to meet the error requirements, the temperature measurement error should be less than 0.3475℃. Assuming that the temperature measurement error is less than 0.1℃, then $v$ changes 0.4 m/s for every 0.1℃. At this point the error of $v$ is less than 0.029%, fully meet the positioning system error requirements.

The temperature measurement unit is powered by a 3.7V/50mAH lithium battery. Before the calibration system works, the drive mechanism first drives the temperature measurement unit in the acrylic sphere to measure the temperature and store the temperature information. After the measurement is completed, the drive mechanism retracts the measurement unit, then the measurement unit is charged by the charger circuit and transmits temperature information to the charger circuit.

The requirements of the temperature measurement unit include working continuously for more than 24 hours, the overall average operating current should be less than 2 mA; temperature measurement error should be less than 0.1℃.

## 3. System Design

### 3.1 The overall structure of the system
The overall structure of the system is shown in Figure3, it consists of the power bulk-boost circuit, microcontroller, temperature sensor, charger circuit and other components.
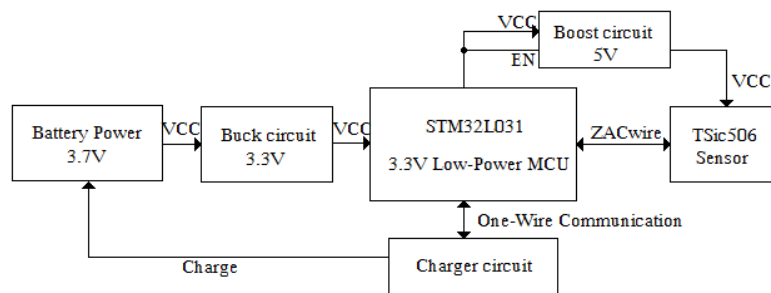
**Figure 3:** The overall structure of the system

The working principle of the system is: the voltage range of lithium battery is 3.0～4.2V, lithium battery is connected to the REG710-3.3 as input, and REG710-3.3 output is 3.3V, as the power supply to the microcontroller, the microcontroller is STM32L031 with low power consumption in STM32 series [4-5]. Temperature sensor requires 5V power to ensure measurement accuracy, so we use REG710-5 boost voltage to 5V, as the power supply of temperature sensor. In order to reduce power consumption, the input and enable pin of REG710-5 are controled by the microcontroller. The microcontroller and temperature sensor communicate via the single-line bus protocol, as well as with the charger circuit through a custom single-line bus protocol.

*3.2 Temperature sensor selection*

There are many kinds of temperature sensor, for example thermal resistance, thermocouple, integrated sensor and digital temperature sensor and others, taking into account the temperature measurement unit miniaturization requirements, choose the digital temperature sensor [6].

Currently widely used digital temperature sensor is the DS18B20 with 0.5℃ accuracy, which cannot meet the 0.1℃ accuracy requirements [7]. According to the accuracy requirements and low power consumption point of view, TSic506 temperature sensor was used [8]. The TSic506 consists of an integrated chip and a calibrated temperature sensor, internally integrated with a signal converter for analog or digital signal output. Which digital signal resolution is 0.034℃, measurement accuracy is ±0.1℃, and low power consumption (typically 30μA), meets the measurement requirements. The interface is single-line bus, which is easily used.
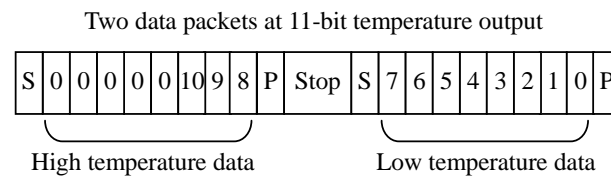
**4. Implementation of System Functions**

*4.1 Implementation of temperature measurement function*

*4.1.1 The communication interface and protocol of TSic506*
The microcontroller communicates with TSic506 through ZACwire protocol, which is a single-line bidirectional communication protocol [9]. Its bit encoding is similar to the Manchester encoding, which embeds data signal with clock signal (the falling edge of the signal is generated at a fixed period). Such a protocol is insensitive to differences in baud rates when communicating between two devices [10].

TSic506 provides 11-bit resolution temperature data, which cannot be passed in a single data packet. A complete packet from TSic506 consists of two packets. The first packet transfers the upper 3 bits of temperature information and the second packet transfers the lower 8 bits of temperature data. Between the end of the first packet and the beginning of the second packet there is a high signal (stop bit) of half the signal width. The temperature sensor sends two packets every 100ms or so, each packet consists of a start bit, eight data bits and a parity bit. The commonly used baud rate is about 8KHz (125μs bit width). The normal state of the signal is high, when the transmission starts, the start signal occurs, followed by the data bits (first high after low), the end of each packet is the parity bit. The data packet format of TSic506 is shown in Figure4.

Two data packets at 11-bit temperature output

| S | 0 | 0 | 0 | 0 | 0 | 10 | 9 | 8 | P | Stop | S | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 | P |

High temperature data                          Low temperature data

**Figure 4:** The data packet format of TSic506

The bit encoding format of ZACwire is duty cycle encoding. Start bit: 50% duty cycle, used to set the gate time. Logic 1 is 75% duty cycle and logic 0 is 25% duty cycle. Stop bit: High-level signal lasting half a bit of bit width. The timing of ZACwire bit encoding is shown in Figure5.
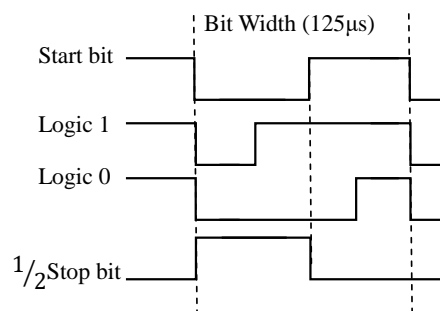


**Figure 5:** The timing of ZACwire bit encoding

*4.1.2 Program design of temperature measurement*

The temperature measurement program starts with detect the start bit. If the time between falling and rising edge is half of the bit width, which means the start bit occurs. Waiting half a bit widh of high level, the next falling edge ZACwire signal can be sampled. Since each bit starts with a falling edge, and ends with high level, which means that there will be no error in the bit sample procedure.

To ensure the correct sampling, the sampling rate of the ZACwire signal is at least 16 times of the normal baud rate. Since the normal baud rate is 8KHz, then a minimum sampling rate of 128 KHz is required. After the start bit is detected, it is followed by nine data bits (eight for data and one for parity). According to the definition of ZACwire bit encoding timing, the signal pin is read at half-width. If it is high, the data bit of the first data packet is 1, otherwise it is 0, and wait for the signal pin level to return to high level. After completing the data reading of the first data packet, the second data packet is started to be read immediately in the same way as the first data packet.

After the two data packets are read, the data verification is performed next. For data accuracy, each of the two data packets to be parity, if the verification fails, the function returns 0 and the end. If the verification is passed, then the temperature data is extracted. The actual temperature value is calculated according to the temperature conversion formula provided in the TSic506 technical document, the function returns 1 and ends. The main program can determine the validity of the data based on the return value of the temperature measurement subroutine. The flow chart of temperature measurement is shown in Figure6.
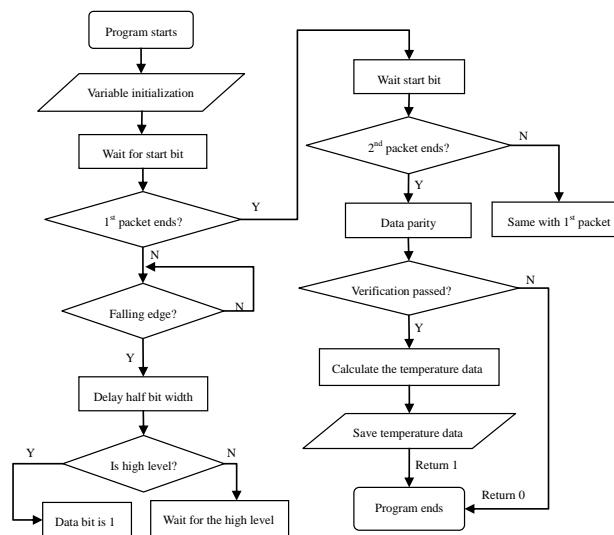
**Figure 6:** The flow chart of temperature measurement

*4.2 Implementation of power-saving function*

The operating current of measurement unit is about 4mA, which includes the power consuming from microcontroller, TSic506 and voltage regulator circuit. Limited by the size of the installation space, the battery capacity is relatively small. The battery can only work a few hours when continuous operation with 4mA, which cannot meets the requirements of the battery-powered work for 24 hours, it is necessary to take measures to reduce the average operating current of the temperature measurement unit.
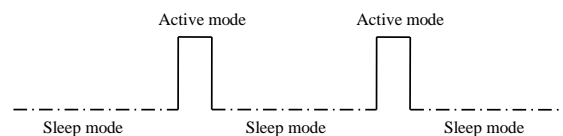


**Figure 7:** The diagram microcontroller running status

In practice, the temperature is sampled every 10 minutes, so there is no need to keep the measuring unit working all the time. Microcontroller usually enter sleep mode, and waked up every 10 minutes for temperature sampling or other tasks, after processing and then go to sleep, the operating status of the microcontroller is shown in Figure7. Temperature sensor does not work when microcontroller is in sleep mode, REG710-5 voltage output can be closed by microcontroller. The current consuming is about 200uA in sleep mode, take into account the power conversion efficiency, it consumes 400uA. These measures can meet the requirements of temperature measurement unit battery-powered work for 24 hours.

## 5. Experimental Results

*5.1 Static test*

The three temperature measurement unit samples sent to Guangdong Institute of Metrology (South China National Center Of Metrology) for testing, test equipment for the standard platinum resistance thermometer (second-class standard), at 15 ~ 35℃ to take 10 data points detection. The maximum error of Sample 1 is 0.04℃, the maximum error of Sample 2 is 0.05℃, and the maximum error of Sample 3 is 0.05℃. Measurement result satisfies the precision request of 0.1℃.

*5.2 Dynamic test*

There are two temperature field environment, one is the temperature field of 25℃, the other is the temperature field of 54℃, the temperature difference between the two temperature is 29℃, the temperature dynamic response curve of measurement unit is shown in Figure8. The temperature sensor was transferred from the temperature field of 25℃ to 54℃, and the reading of the measuring unit gradually increased. At 45 seconds, the reading was 52.55℃, at which 95% of the temperature difference was reached, the rise time $t_r$ was 45 seconds, 105 seconds later reading up to 54℃; While the temperature sensor was transferred from a temperature field of 54℃ to 25℃, the readings of the measuring unit gradually decreased. At 25 seconds the reading was 26.45℃, at which 95% of the temperature difference was reached, the fall time $t_f$ was 25 seconds, and after 30 seconds the reading reached 25℃.

The temperature measurement unit has a sampling period of 10 minutes and the system dynamic characteristics meets the requirements of temperature measurement.
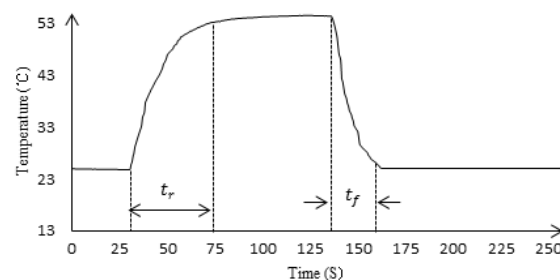


**Figure 8:** The temperature dynamic response curve

## 6. Conclusion

Based on TSic506, this paper presents and realizes the high precision temperature measurement unit in the calibration system. The measurement accuracy of this temperature measurement unit is 0.1℃, which can work over 24 hours with battery power supply. The experimental results from the metrology institute show that the temperature measurement unit meets the accuracy requirements.

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