

# Application Note

---

## RTC Calibration

---

### Introduction

The NSING Technologies microcontroller has a built-in RTC module that provides functions such as calendar and alarm, while also offering digital calibration function to enhance the working accuracy of the RTC module in response to environmental temperature changes.

This document aims to assist users in correctly utilizing the digital calibration function of the RTC module, reducing the impact on the RTC working accuracy caused by external crystal frequency deviation due to environmental temperature changes.

## Contents

<b>1. OVERVIEW</b> .....	<b>1</b>
1.1 RTC BRIEF INTRODUCTION .....	1
1.2 PRINCIPLE OF RTC DIGITAL CLOCK PRECISION CALIBRATION .....	3
<b>2. OPERATION METHOD</b> .....	<b>4</b>
2.1 RTC DIGITAL CLOCK OUTPUT I/O PIN CONFIGURATION .....	4
2.2 RTC DIGITAL CLOCK PRECISION CALIBRATION CONFIGURATION API .....	6
2.3 RTC CALIBRATION FORMULA CALCULATION .....	8
<b>3. RTC 32-SECOND DIGITAL CLOCK CALIBRATION APPLICATION EXAMPLE</b> .....	<b>8</b>
3.1 RTC DIGITAL CLOCK PRECISION CALIBRATION CONFIGURATION API .....	8
3.2 DETAILED EXPLANATION OF RTC DIGITAL CLOCK PRECISE CALIBRATION ALGORITHM.....	8
3.3 MEASUREMENT OF RTC DIGITAL CLOCK PRECISION CALIBRATION ALGORITHM.....	9
<b>4. TEMPERATURE COMPENSATION OF LSE USING PRECISE CALIBRATION APPLICATION EXAMPLE</b> .....	<b>10</b>
4.1 LSE TEMPERATURE CURVE .....	10
4.2 THEORETICAL CALIBRATION VALUE OF RTC PRECISION CALIBRATION MODULE .....	11
4.3 RTC PRECISION CALIBRATION CONFIGURATION CODE .....	11
4.4 RTC PRECISION CALIBRATION AND ACTUAL MEASUREMENT .....	12
<b>5. VERSION HISTORY</b> .....	<b>13</b>
<b>6. DISCLAIMER</b> .....	<b>14</b>

## 1. Overview

### 1.1 RTC Brief Introduction

RTC provides the ability to automatically wake up in low power mode.

The Real Time Clock (RTC) is an independent BCD timer/counter. RTC provides a clock/calendar with programmable alarm interrupts. The RTC also includes a periodically programmable wake-up flag with an interrupt function.

Two 32-bit registers contain decimal format (BCD) for sub second, second, minute, hour (12 or 24 hour format), day (day of the week), month, and year. The system can automatically perform monthly compensation for 28, 29 (leap years), 30, and 31 days. Daylight saving time compensation is also available.

The sub second value is provided in binary format as a separate 32-bit register. Other 32-bit registers contain programmable alarm clock sub seconds, seconds, minutes, hours, days, and days.

The digital calibration function can compensate for deviations in the accuracy of the crystal oscillator.

After the Backup domain is reset, all RTC registers are protected against possible accidental write access.

When enabling events on GPIO and saving the current calendar in a register, the timestamp function can be enabled.

As long as RTC is enabled and the voltage remains within the operating range, RTC will not stop regardless of the device status (RUN, SLEEP, STOP, or STANDBY Mode).

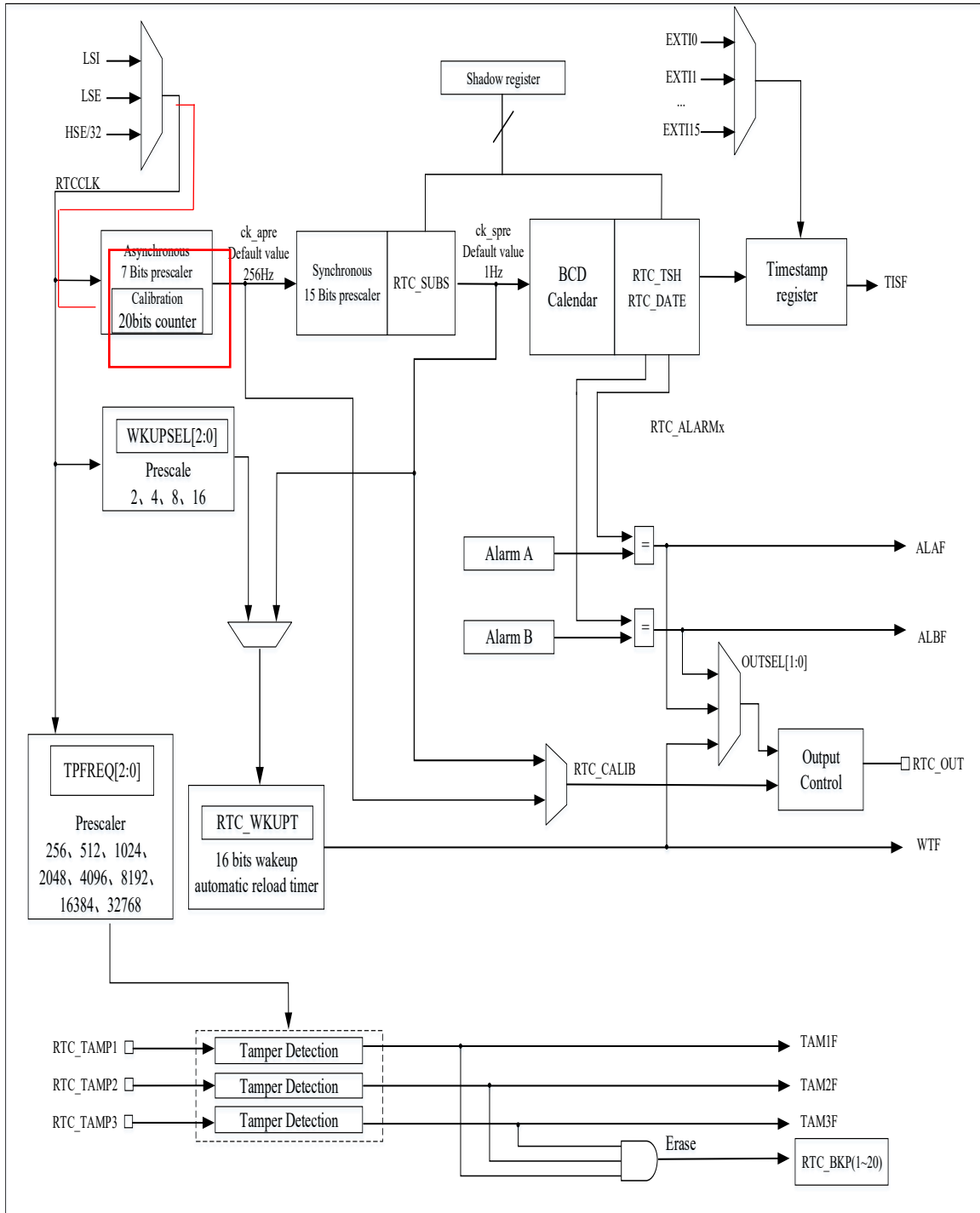


Figure 1-1 Block Diagram of N32 RTC

The red wireframe in the figure is the digital calibration module, which can adjust the clock input to the calendar module, thereby adjusting the timing accuracy of the RTC calendar.

## 1.2 Principle Of RTC Digital Clock Precision Calibration

Digital precision calibration is achieved by adjusting the number of RTC clock pulses in the calibration period. Digital precision calibration resolution is 0.954 PPM with the range from -487.1 PPM to +488.5 PPM.

When the input frequency is 32768 Hz, calibration period can be configured as  $2^{20}/2^{19}/2^{18}$  RTCCLK cycles or 32/16/8 seconds. The precision calibration register (RTC\_CALIB) indicates that RTC\_CALIB.CM[8:0] RTCCLK clock cycles will be reduced within the specified cycle.

The value of RTC\_CALIB.CM[8:0] represents the number of RTCCLK pulses to be reduced during specified period. While RTC\_CALIB.CP can be used to increase 488.5 PPM, every  $2^{11}$  RTCCLK cycles will inserts a RTCCLK pulse.

When using RTC\_CALIB.CM[8:0] and RTC\_CALIB.CP in combination, it can increase cycles range from -511 to +512 RTCCLK cycles. The calibration range from -487.1 ppm to +488.5 ppm, and the resolution is about 0.954 ppm.

The effective calibrated frequency ( $f_{CAL}$ ) can be calculated by the following formula:

$$f_{CAL} = f_{RTCCLK} * \left( 1 + \frac{RTC\_CALIB.CP*512 - RTC\_CALIB.CM[8:0]}{2^n + RTC\_CALIB.CM[8:0] - RTC\_CALIB.CP * 512} \right)$$

Note:  $n=20/19/18$

### Calibrated when RTC\_PRE .DIVA[6:0]<3

When the asynchronous prescaler value (RTC\_PRE.DIVA[6:0]) is less than 3, the RTC\_CALIB.CP cannot be programmed to 1, and RTC\_CALIB.CP value will be ignored if the it has been set to 1.

When RTC\_PRE .DIVA[6:0]<3, the value of RTC\_PRE.DIVS[14:0] should be decrease. Assume RTCCLK frequency is 32768Hz:

- When RTC\_PRE .DIVA[6:0] =2, RTC\_PRE.DIVS[14:0]=8189.
- When RTC\_PRE .DIVA[6:0] =1, RTC\_PRE.DIVS[14:0]=16379.
- When RTC\_PRE .DIVA[6:0] =0, RTC\_PRE.DIVS[14:0]=32759.

The effective calibrated frequency ( $f_{CAL}$ ) can be calculated by the following formula:

$$f_{CAL} = f_{RTCCLK} * \left( 1 + \frac{256 - RTC\_CALIB.CM[8:0]}{2^n + RTC\_CALIB.CM[8:0] - 265} \right)$$

Note:  $n=20/19/18$

### Verify RTC calibration

RTC output 1Hz waveform for measuring and verifying RTC precision.

Up to 2 RTCCLK cycles measurement error may occur when measure the RTC frequency in a limit measurement period. If the measurement period is the same as calibration period, the error can be eliminated.

- The calibration period is 32 seconds (default).
  - Using an accurate 32-second period to measure the 1Hz calibration output can ensure that the measurement error is within 0.447ppm (0.5 RTCCLK cycles within 32 seconds).
- The calibration period is 16 seconds.

Using an accurate 16-second period to measure the 1Hz calibration output can ensure that the measurement error is within 0.954ppm (0.5 RTCCLK cycles within 16 seconds).

- The calibration period is 8 seconds.

Using an accurate 8-second period to measure the 1Hz calibration output can ensure that the measurement error is within 1.907ppm (0.5 RTCCLK cycles within 8 seconds).

### Dynamic recalibration

When RTC\_INITSTS.INITF=0, RTC\_CALIB register can update by using following steps:

- Wait RTC\_INITSTS.RECPF=0.
- A new value is written to the RTC\_CALIB, then RTC\_INITSTS.RECPF is automatically set to 1.
- The new calibration settings will take effect within 3 ck\_apre cycles after a data write to the RTC\_CALIB.

## 2. Operation Method

### 2.1 RTC Digital Clock Output I/O Pin Configuration

This function configures PC13 as the RTC\_OUT function pin, outputting a 1Hz digital clock waveform without calibration.

The configuration program is as follows:

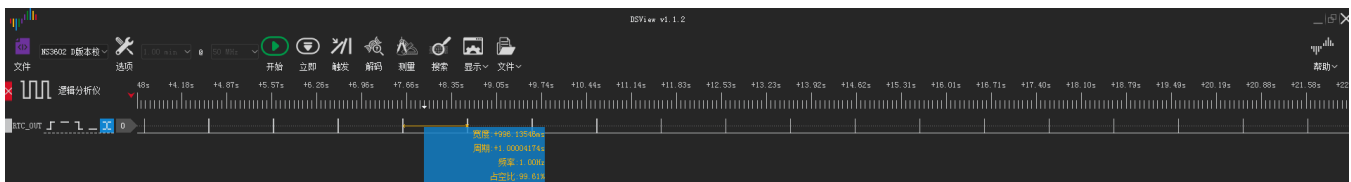
```

/* Calibrate output 1Hz signal */
RTC_ConfigCalibOutput(RTC_CALIB_OUTPUT_1HZ);

/* Calibrate output config,push pull */
RTC_ConfigOutputType(RTC_OUTPUT_PUSHPULL);

/* Calibrate output enable*/
RTC_EnableCalibOutput(ENABLE);
    
```

RTC\_OUT output is shown in the figure below:



**Figure 2-1 Precise calibration output waveform of RTC digital clock**

When configuring RTC\_OUT as a digital clock that has been precisely calibrated to output, measure the time interval of the RTC\_OUT pin output after RTC calendar calibration to understand whether the digital clock precision calibration module is inserted and reduces RTC\_CLK

## 2.2 RTC Digital Clock Precision Calibration Configuration API

The API for precise calibration configuration of RTC digital clocks is provided in the SDK RTC driver file. The code is as follows:

```

/**
 * @brief Configures the Smooth Calibration Settings.
 * @param RTC_SmoothCalibPeriod Select the Smooth Calibration Period.
 * This parameter can be can be one of the following values:
 * @arg SMOOTH_CALIB_32SEC The smooth calibration periode is 32s.
 * @arg SMOOTH_CALIB_16SEC The smooth calibration periode is 16s.
 * @arg SMOOTH_CALIB_8SEC The smooth calibartion periode is 8s.
 * @param RTC_SmoothCalibPlusPulses Select to Set or reset the CALP bit.
 * This parameter can be one of the following values:
 * @arg RTC_SMOOTH_CALIB_PLUS_PULSES_SET Add one RTCCLK puls every 2**11 pulses.
 * @arg RTC_SMOOTH_CALIB_PLUS_PULSES__RESET No RTCCLK pulses are added.
 * @param RTC_SmouhCalibMinusPulsesValue Select the value of CALM[8:0] bits.
 * This parameter can be one any value from 0 to 0x000001FF.
 * @return An ErrorStatus enumeration value:
 * - SUCCESS: RTC Calib registers are configured
 * - ERROR: RTC Calib registers are not configured
 */
ErrorStatus RTC_ConfigSmoothCalib(uint32_t RTC_SmoothCalibPeriod,
                                  uint32_t RTC_SmoothCalibPlusPulses,
                                  uint32_t RTC_SmouhCalibMinusPulsesValue)
{
    ErrorStatus status = ERROR;
    uint32_t recalpfcount = 0;
    /* Check the parameters */
    assert_param(IS_RTC_SMOOTH_CALIB_PERIOD_SEL(RTC_SmoothCalibPeriod));
    assert_param(IS_RTC_SMOOTH_CALIB_PLUS(RTC_SmoothCalibPlusPulses));
    assert_param(IS_RTC_SMOOTH_CALIB_MINUS(RTC_SmouhCalibMinusPulsesValue));
}

```



```

/* Disable the write protection for RTC registers */
RTC->WRP = 0xCA;
RTC->WRP = 0x53;
/* check if a calibration is pending*/
if ((RTC->INITSTS & RTC_INITSTS_RECPF) != RESET)
{
    /* wait until the Calibration is completed*/
    while (((RTC->INITSTS & RTC_INITSTS_RECPF) != RESET) && (recalpfcount != RECALPF_TIMEOUT))
    {
        recalpfcount++;
    }
}
/* check if the calibration pending is completed or if there is no calibration operation at all*/
if ((RTC->INITSTS & RTC_INITSTS_RECPF) == RESET)
{
    /* Configure the Smooth calibration settings */
    RTC->CALIB          =          (uint32_t)((uint32_t)RTC_SmoothCalibPeriod          |
(uint32_t)RTC_SmoothCalibPlusPulses
    | (uint32_t)RTC_SmoothCalibMinusPulsesValue);
    status = SUCCESS;
}
else
{
    status = ERROR;
}
/* Enable the write protection for RTC registers */
RTC->WRP = 0xFF;
return (ErrorStatus)(status);
}

```

The users can use this function to control the RTC digital clock precise calibration module to increase or decrease RTC\_CLK within a specified clock period, thereby controlling the increase or decrease of

calendar time

### 2.3 RTC Calibration Formula Calculation

The users can confirm the error value after calibration by setting the period and the number of added or subtracted RTCCLKs in the "RTC calibration formula calculation excel sheet.xlsx", calculate the offset value (PPM) after calibration settings.

As shown in the following figure:

RTC Asynchronous Prescaler (DIVA) ≥ 3				
Error After Calibration (PPM)	Frequency After Calibration (f <sub>CAL</sub> )	Calibration Cycle (S)	Reduce The Number Of RTCCLKs (CM)	Increase The Number Of RTCCLKs (CP)
-487.0902032	32752.03903	32	511	0
RTC Asynchronous Prescaler (DIVA) ≤ 3				
Error After Calibration (PPM)	Frequency After Calibration (f <sub>CAL</sub> )	Calibration Cycle (S)	Reduce The Number Of RTCCLKs (CM)	Increase The Number Of RTCCLKs (CP)
973.6949624	32799.90604	8	1	512

Figure 2-2 RTC Digital Clock Precise Calibration Error Calculation Excel Spreadsheet Chart

## 3. RTC 32-Second Digital Clock Calibration Application Example

### 3.1 RTC Digital Clock Precision Calibration Configuration API

The RTC digital clock precise calibration algorithm is described in Section 1.2.

The following example illustrates the calibration algorithm of the RTC digital clock precise calibration module, with RTC\_CLK=32.768KHz, calibration period of 32 seconds, CP=1, CM=511 used as an example to explain the process of RTC precise calibration.

The program configuration is as follows

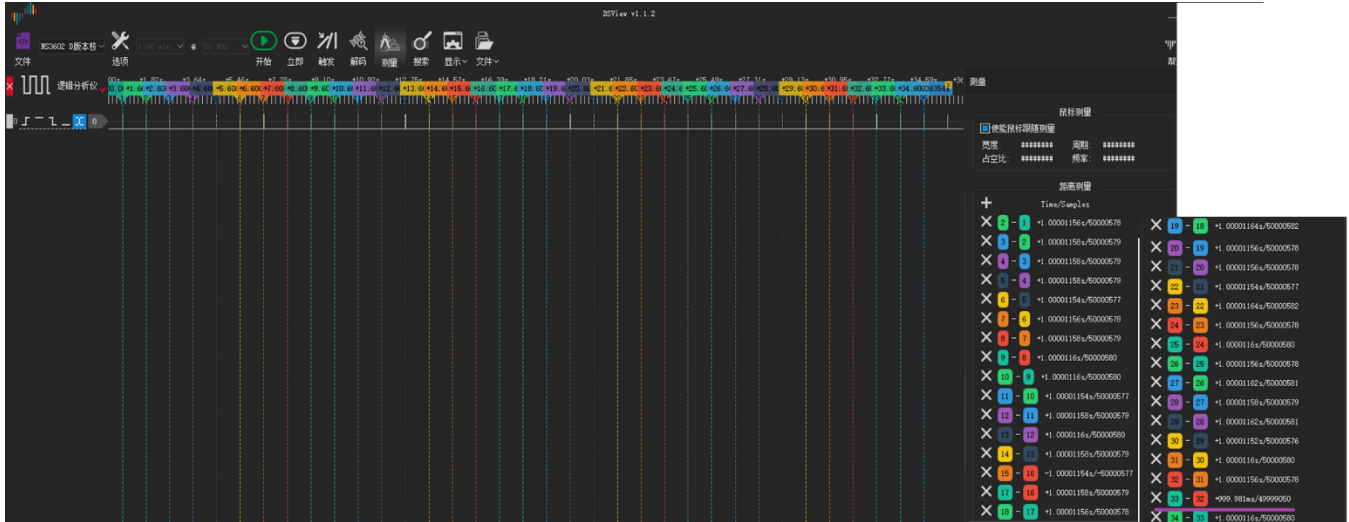
```
RTC_ConfigSmoothCalib(SMOOTH_CALIB_32SEC,RTC_SMOOTH_CALIB_PLUS_PULSES_SET,511);
```

### 3.2 Detailed Explanation Of RTC Digital Clock Precise Calibration Algorithm

The calibration cycle for the above API configuration is 32S. When CP=1, 512 RTC\_CLK clocks will be added within 32S. When CM=511, 511 RTC\_CLK clocks will be reduced within 32S. According to the calibration formula  $32768.031\text{Hz} = 32768\text{Hz} * (1 + \frac{1*512-511}{2^{20} + 511 - 1 * 512})$ , it is known that the f<sub>CAL</sub> after calibration is 32768.031Hz, According to the calibration algorithm, we can obtain the insertion or reduction of RTC\_CLK in the digital clock precision calibration module every second.

The following table details the number of RTC\_CLK clocks per second for the digital clock tight calibration module.





## 4. Temperature Compensation of LSE Using Precise Calibration Application Example

### 4.1 LSE Temperature Curve

If high-precision RTC calendar timing is required in practical applications, external quartz crystals are often used to provide clocks for RTC modules. However, the external quartz crystal is affected by the environment, The actual frequency also fluctuates. At this time, it is necessary to use the digital clock precision calibration module to calibrate the external quartz crystal. The following figure shows the temperature curve corresponding to the frequency deviation of a certain crystal model.

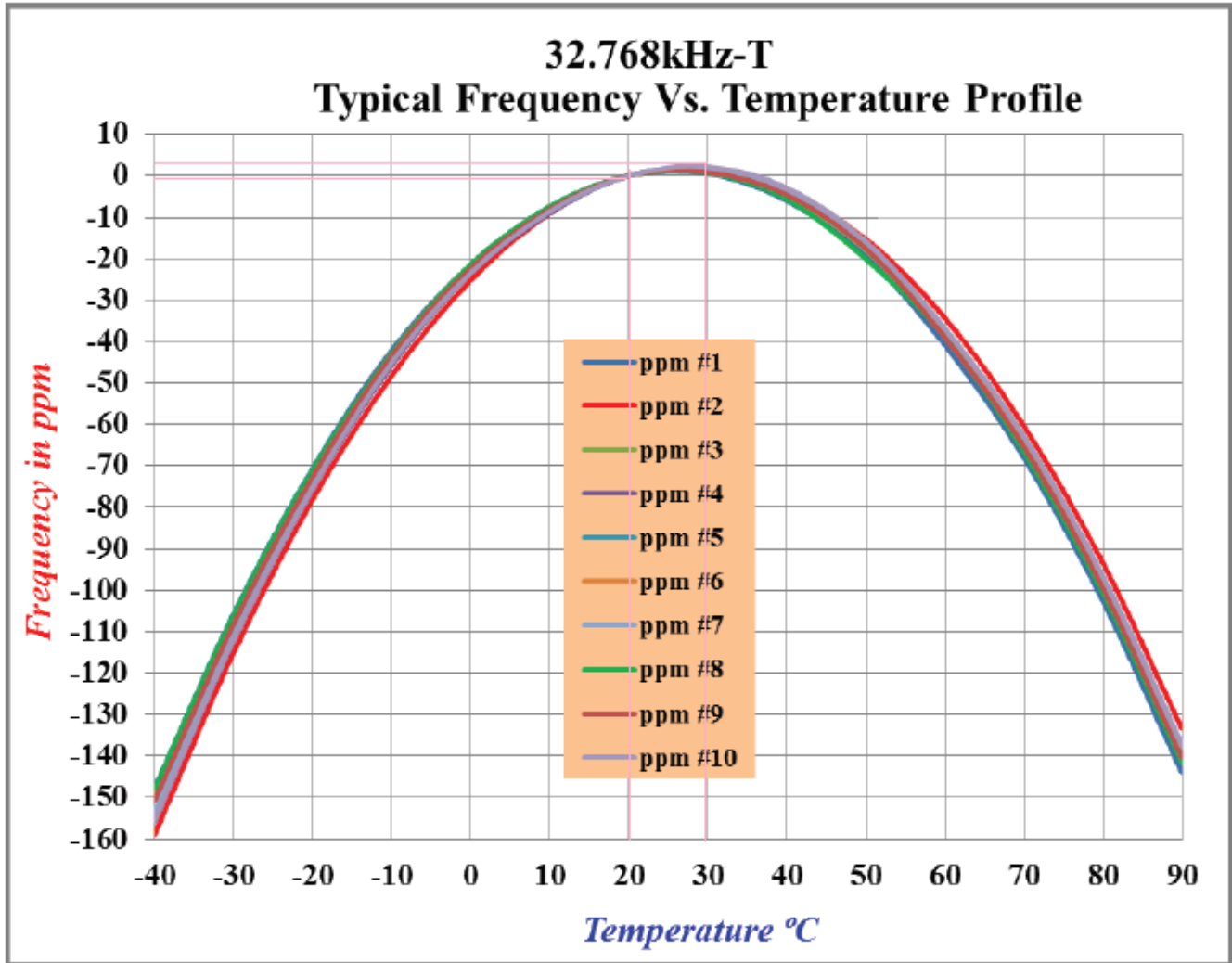


Figure 4-1 Temperature Curve of Quartz Crystal Frequency Deviation

### 4.2 Theoretical Calibration Value of RTC Precision Calibration Module

The resolution of the RTC precision calibration module is approximately 0.954 ppm (32S calibration cycle). According to the frequency deviation temperature curve of quartz crystal in Figure 4-1, the theoretical error of this crystal at room temperature (20 to 30°C) is about - 2 to 4 ppm. It can be concluded that in theory, the RTC precision calibration module 32S requires a reduction of 2 ~ -4.19 RTC\_CLKs. To compensate for the temperature deviation caused by temperature changes when using this crystal frequency.

### 4.3 RTC Precision Calibration Configuration Code

Based on the above theoretical calculation, select to insert 2 RTC\_CLKs to compensate for external crystal 2ppm. The calibration configuration code is as follows:

RTC\_ConfigSmoothCalib(SMOOTH\_CALIB\_32SEC,RTC\_SMOOTH\_CALIB\_PLUS\_PULSES\_SET,510);

### 4.4 RTC Precision Calibration And Actual Measurement

After actual measurement at normal temperature (20~30 °C)) without using the RTC precision calibration module, the error is 18.4PPM. Considering that the actual situation is more complicated than the ideal temperature curve of LSE, the actual situation deviates from the theoretical value by more than ten PPM. Normal, the actual value needs to be measured to get it.

```
(221015_16:54:49.071) The current date (WeekDay-Date-Month-Year) is : 3-20-11-19 RTC
(221015_16:54:49.071) //===== Current Time Display =====// Calendar
(221015_16:54:49.071) The current time (Hour-Minute-Second) is : 4:41:43 RTC
Log timestamp RTC error is 1591ms in 24h, which is about 18.4PPM Time
```

```
(221016_16:54:50.662) The current date (WeekDay-Date-Month-Year) is : 4-21-11-19 RTC
(221016_16:54:50.662) //===== Current Time Display =====// Calendar
(221016_16:54:50.662) The current time (Hour-Minute-Second) is : 4:41:43 RTC
Log timestamp RTC Time
```

Through continuous calibration attempts at room temperature (20 to 30 °C) and insert 5 LSEs in a 32S cycle, RTC 24-hour error 171ms (1.97ppm) , which can significantly improve the RTC time accuracy.

RTC\_ConfigSmoothCalib(SMOOTH\_CALIB\_32SEC,RTC\_SMOOTH\_CALIB\_PLUS\_PULSES\_SET,506);

```
(221125_09:21:21.113) The current date (WeekDay-Date-Month-Year) is : 3-20-11-19 RTC
(221125_09:21:21.113) //===== Current Time Display =====// Calendar
(221125_09:21:21.113) The current time (Hour-Minute-Second) is : 4:22:32 RTC
Log timestamp RTC error 171ms in 24h, i.e. 1.979PPM Time
```

```
(221126_09:21:21.284) The current date (WeekDay-Date-Month-Year) is : 4-21-11-19 RTC
(221126_09:21:21.284) //===== Current Time Display =====// Calendar
(221126_09:21:21.284) The current time (Hour-Minute-Second) is : 4:22:32 RTC
Log timestamp RTC Time
```

## 5. Version History

Version	Date	Changes
V1.0	2022.11.16	Create a document

## 6. Disclaimer

This document is the exclusive property of NSING TECHNOLOGIES PTE. LTD.(Hereinafter referred to as NSING). This document, and the product of NSING described herein (Hereinafter referred to as the Product) are owned by NSING under the laws and treaties of Republic of Singapore and other applicable jurisdictions worldwide. The intellectual properties of the product belong to Nations Technologies Inc. and Nations Technologies Inc. does not grant any third party any license under its patents, copyrights, trademarks, or other intellectual property rights. Names and brands of third party may be mentioned or referred thereto (if any) for identification purposes only. NSING reserves the right to make changes, corrections, enhancements, modifications, and improvements to this document at any time without notice. Please contact NSING and obtain the latest version of this document before placing orders.

Although NATIONS has attempted to provide accurate and reliable information, NATIONS assumes no responsibility for the accuracy and reliability of this document. It is the responsibility of the user of this document to properly design, program, and test the functionality and safety of any application made of this information and any resulting product. In no event shall NATIONS be liable for any direct, indirect, incidental, special, exemplary, or consequential damages arising in any way out of the use of this document or the Product. NATIONS Products are neither intended nor warranted for usage in systems or equipment, any malfunction or failure of which may cause loss of human life, bodily injury or severe property damage. Such applications are deemed, 'Insecure Usage'. Insecure usage includes, but is not limited to: equipment for surgical implementation, atomic energy control instruments, airplane or spaceship instruments, all types of safety devices, and other applications intended to supporter sustain life. All Insecure Usage shall be made at user's risk. User shall indemnify NATIONS and hold NATIONS harmless from and against all claims, costs, damages, and other liabilities, arising from or related to any customer's Insecure Usage Any express or implied warranty with regard to this document or the Product, including, but not limited to. The warranties of merchantability, fitness for a particular purpose and non-infringement are disclaimed to the fullest extent permitted by law. Unless otherwise explicitly permitted by NATIONS, anyone may not use, duplicate, modify, transcribe or otherwise distribute this document for any purposes, in whole or in part.