

# **Application Note**

### **RTC Calibration application notes**

### Introduction

The Nsing Technology 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.



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### 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).



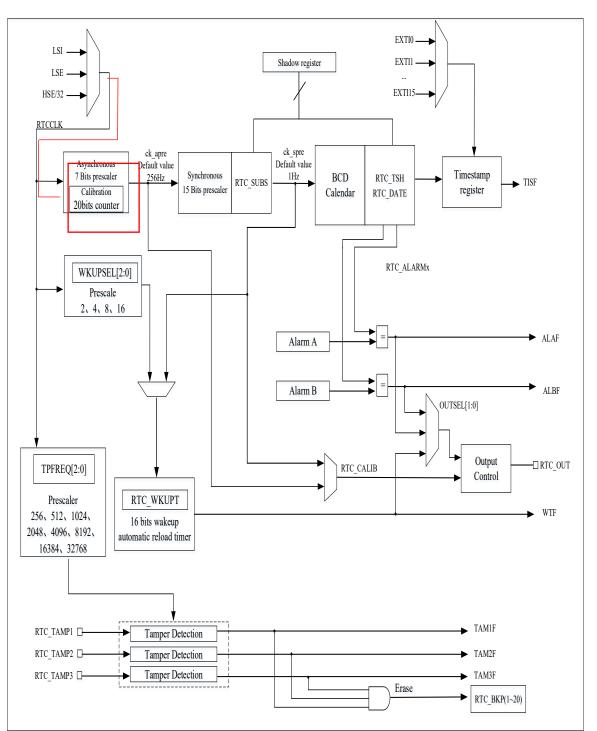


Figure 1-1 Block Diagram of N32 RTC

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.

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### **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<sup>11</sup> 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.



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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:







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\_SmouthCalibMinusPulsesValue 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\_SmouthCalibMinusPulsesValue)

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 SmouthCalibMinusPulsesValue));
 /* Disable the write protection for RTC registers */
  RTC->WRP = 0xCA;
 RTC \rightarrow 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_SmouthCalibMinusPulsesValue);
   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:

Ç			•	
	RTC Asynchrono	us 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 Asynchronou	us Prescaler (DIVA) $\leq 3$		
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 32768.031Hz= 32768Hz \*  $(1 + \frac{1*512-511}{2^{20}+511-1*512})$ , 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.

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CALM[8:0]	置位后减 少计数的	减少计数 RTC <sub>CLK</sub>	减少计数 的RTC <sub>CLK</sub>	减少计数 的	RTCOUT 1HZ	秒间隔															
	RTCCLK	起始点	步进值	RTC <sub>CLK</sub> 位	1	2	3	4	5	6	7	8	9	10	11	12	13		14	15	16
CALM[0]	1	2 <sup>19</sup>		2 <sup>18</sup> +2 <sup>19</sup> •N	15	15	15	15	15	15	15	15	15	15	15	15	11		15		1s+30.5us
CALM[1]	2	218	219	(N ∈ [0,1]) 2 <sup>17</sup> +2 <sup>18</sup> *N	15	15	15	15	15	15	15	1s+30.5us	15	15	15	15	11		15	15	15
CALM[2]	4	217	2 <sup>18</sup>	(N € [0,3])	15	15	15	1s+30.5us	15	15	15	15	15	15	15	15+30.50	us ls		15	15	15
CALM[3]	8	216	2 <sup>17</sup>	$2^{16} + 2^{17} + N$ (N $\in [0,7]$ )	15	1s+30.5us	15	15	15	1s+30.5us	15	15	15	1s+30.5us	15	15	15	15+3	80.5us	15	15
CALM[4]	16	218	2 <sup>14</sup>	2 <sup>15</sup> +2 <sup>16</sup> *N (N E [0.15])	1s+30.5us	15	1s+30.5us	15	1s+30.5us	15	1s+30.5us	15	1s+30.5us	15	1s+30.5us	15	1s+30	15us 1	15 15	+30.5us	15
CALM[5]	32	214	218	2 <sup>14</sup> +2 <sup>15</sup> *N (N E [0.31])	1s+30.5us	1s+30.5us	1s+30.5us	1s+30.5us	1s+30.5us	1s+30.5us	1s+30.5us	1s+30.5us	1s+30.5us	1s+30.5us	1s+30.5us	15+30.50	us 1s+30	15us 1s+3	80.5us 1s	+30.5us	1s+30.5us
CALM[6]	64	213	214	2 <sup>13</sup> +2 <sup>14</sup> •N (N E [0.63])	1s+30.5+2us	1s+30.5+2us	1s+30.5*2us	1s+30.5+2us	1s+30.5+2us	1s+30.5*2us	1s+30.5*2us	1s+30.5+2us	1s+30.5+2us	1s+30.5+2us	1s+30.5+2us	15+30.5+2	tus 1s+30:	5+2us 1s+30	0.5+2us 1s+	30.5+2us	1s+30.5*2us
CALM[7]	129	212	2 <sup>13</sup>	2 <sup>12</sup> +2 <sup>13</sup> +N (N E [0.127])	1s+30.5+4us	1s+30.5+4us	ls+30.5+4us	1s+30.5+4us	1s+30.5+4us	1s+30.5+4us	1s+30.5+4us	1s+30.5+4us	1s+30.5+4us	1s+30.5+4us	1s+30.5+4us	1s+30.5+4	ius 1s+30.	5+4us 1s+30	0.5+4us 1s+	30.5+4us	1s+30.5+4us
CALM[8]	256	211	212	2 <sup>11</sup> +2 <sup>12</sup> •N (N ∈ [0.255])	1s+30.5+8us	1s+30.5+8us	1s+30.5*8us	1s+30.5+8us	1s+30.5+8us	1s+30.5+8us	1s+30.5+8us	1s+30.5+8us	1s+30.5+8us	1s+30.5+8us	1s+30.5+8us	1s+30.5+8	Bus 15+30.	5+8us 1s+30	0.5+8us 1s-	30.5+8us	1s+30.5*8us
0x1FF	511				1s+30.5+16us	1s+30.5+16us	1s+30.5+16us	1s+30.5+16us	1s+30.5+16us	1s+30.5+16us 1	ls+30.5+16us	1s+30.5+16us	1s+30.5+16us	1s+30.5+16us	1s+30.5+16us	15+30.5+1	6us 1s+30.5	+16us 1s+30	5+16us 15+	30.5+16us 1	s+30.5+16us
CALP	置位后增 加计数的 RTC <sub>CLK</sub>	増加计数 RTC <sub>CLK</sub> 起始点	增加计数 的RTC <sub>CLK</sub> 步进值	増加计数 的 RTC <sub>CLK</sub> 位 置	RTCOUT 1HZ	2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	3	4	5	6	7	8	9	10	11	12	1:	3 1	14	15	16
CALP[0]=1	512	211	211	2 <sup>11</sup> +2 <sup>11</sup> +N (N ∈ [0,511])	1s-30.5us-16	15-30.5us+16	15-30.5u5+16	1s-30.5us-16	15-20.5us-16	1s-30.5us-16	1s-30.5us+16	1s-30.5us+16	1s-30.5us+16	1s-20.5us+16	1s-30.5us+16	1s-20.5us	-16 15-20.5	us-16 1s-30.	5us-16 1s-	30.5us+16	1s-30.5us+16
CALM[8:0]= 0x1FF CALP[0]=1					1s +30.5+16us -30.5us+16	1s +30.5+16us -30.5us+16	1s +30.5+16us -30.5us+16	ls +30.5+16us -30.5us+16	ls 1 +20.5+16us - -20.5us+16 -	ls 1 + 30.5+16us 4 - 30.5us+16 -	s : - 30.5+16us - - 30.5us+16 -	ls + 30.5+16us - 30.5us+16	ls +30.5+16us -30.5us+16	ls +30.5+16us -30.5us+16	ls +30.5+16us -30.5us+16	ls + 30.5+16us - 30.5us+16	1s + 30.5+1 - 30.5us	ls 6us +30.5+1 +16 -30.5us	1s 16us +30 1+16 -30:	1: 5*16us + 5us*16 -	; 20.5+16us 20.5us+16
	重位后减	减少计数	减少计数	减少计数的	RTCOUT 1H	z秒间隔															
CALM[8:0]	少计数的 RTC <sub>CLK</sub>	RTC <sub>CLK</sub> 起始点	的RTC <sub>CLK</sub> 步进值	RTC <sub>CLK</sub>	17	18	19	20	21	22	23	24	2	5 2	26			29	30	31	32
CALM[0]	1	219		-		15	15									27	28				
CALM[1]			-		15		12	15	15	15	15	15	1:	s :		27 15	28 15	15	15	15	15
	2	218	210	$2^{18} + 2^{19} + N$ (N $\in [0, 1]$ )	15	15	15	15	15	15 15	15 15				ls					15	15
CALM[2]	2	2 <sup>18</sup> 2 <sup>17</sup>	2 <sup>19</sup> 2 <sup>18</sup>									15		s :	ls	15	15	15	15		
CALM[2]				$(N \in [0,1])$ $2^{17} + 2^{18} + N$ $(N \in [0,3])$ $2^{16} + 2^{17} + N$	15	15	15	15	15	15	15	15 15+30.5	us 1:	5	15	15	15 15	15 15	15	15	15
	4	2 <sup>17</sup>	2 <sup>18</sup>	$(N \in [0,1])$ $2^{17} + 2^{18} + N$ $(N \in [0,3])$	15 15	15	15 15	1s 1s+30.5us	15 15	15	15	1s 1s+20.5 1s 1s	us li	s :: s :: s ::15+3	15 15 15 10.5us	15 15 15	1s 1s 1s+30.5us	15 15 15	15 15 15	15	15 15 15
CALM[3]	4	2 <sup>17</sup> 2 <sup>14</sup>	2 <sup>18</sup> 2 <sup>17</sup>	$\begin{array}{c} (\mathbb{N} \in [0,1]) \\ 2^{57} + 2^{58} + \mathbb{N} \\ (\mathbb{N} \in [0,3]) \\ 2^{58} + 2^{57} + \mathbb{N} \\ (\mathbb{N} \in [0,7]) \\ 2^{58} + 2^{58} + \mathbb{N} \\ (\mathbb{N} \in [0,15]) \\ 2^{54} + 2^{55} + \mathbb{N} \\ (\mathbb{N} \in [0,31]) \end{array}$	15 15 15	1s 1s 1s+30.5us	13 15 15	15 15+30.5us 15	15 15 15	15 15 15+30.5us	15 15 15+20.503	15 15+20.5 15 15 5 15	us 11 11 12 15+30	s : s : s 1s+3	15 15 15 15 15 15 15 15 15 15 15 15 15 1	1s 1 1s 1 1s 1 1s 2 -30.5us	15 15 15+30.5us 15	15 15 15	1s 1s 1s 1s+30.5us	15 15 15 15+30.5	ls ls ius ls
CALM[3] CALM[4]	4 8 16	2 <sup>17</sup> 2 <sup>16</sup> 2 <sup>18</sup>	2 <sup>18</sup> 2 <sup>17</sup> 2 <sup>14</sup>	$\begin{array}{l} (N \in [0,1]) \\ 2^{17} + 2^{18} \times N \\ (N \in [0,3]) \\ 2^{16} + 2^{17} \times N \\ (N \in [0,7]) \\ 2^{16} + 2^{14} \times N \\ (N \in [0,7]) \\ 2^{16} + 2^{16} \times N \\ (N \in [0,7]) \\ 2^{14} + 2^{16} \times N \\ (N \in [0,3]) \\ 2^{15} + 2^{14} \times N \\ (N \in [0,63]) \end{array}$	1s 1s 1s 1s+30.5us	1s 1s 1s+30.5us 1s	15 15 15+30.5us	15 15+20.5us 15 15	15 15 15 15+30.5us	1s 1s 1s+30.5us 1s	1s           1s           1s           1s           1s+30.503	1s           1s+305           1s	us 11 11 11 15+30 us 15+30	s :: s :: 0.5us :: 0.5us ::	15 15 15 15 15 15 15 15 15 15 15 15 15 1	1s 1s 1s 1s 1s -30.5us -30.5us	15 15 15+30.5us 15 15	1s 1s 1s 1s 1s+30.5us	15 15 15+30.505 15	1s 1s 1s+30.9 1s+30.9	1s           1s           1s           ius           ius           1s+30.
CALM[3] CALM[4] CALM[5]	4 8 16 32	2 <sup>17</sup> 2 <sup>16</sup> 2 <sup>18</sup> 2 <sup>14</sup>	2 <sup>18</sup> 2 <sup>17</sup> 2 <sup>18</sup> 2 <sup>18</sup>	$\begin{array}{l} (N \in [0,1]) \\ 2^{17} + 2^{18} + N \\ (N \in [0,3]) \\ 2^{16} + 2^{17} + N \\ (N \in [0,7]) \\ 2^{16} + 2^{16} + N \\ (N \in [0,15]) \\ 2^{14} + 2^{16} + N \\ (N \in [0,15]) \\ 2^{13} + 2^{14} + N \\ (N \in [0,63]) \\ 2^{12} + 2^{14} + N \\ (N \in [0,63]) \\ 2^{12} + 2^{14} + N \\ (N \in [0,127]) \end{array}$	1s 1s 1s 1s+30.5us 1s+30.5us	15 15 15+30.5us 15 15+30.5us	15 15 15 1s+30.5us 1s+30.5us	15 15+20.5us 15 15 15+20.5us	15 15 15 15+30.5us 15+30.5us	15 15 15+30.5US 15 15+30.5US	1s           1s           1s           1s+30.500           1s+30.500           1s+30.500	13 14+305 15 15 15 15 15 15 15 15 15 1	us 11 11 12 15+30 205 15+30	s 15+3 s 15+3 0.5us 15+3 0.5us 15+3 5+2us 15+30	15 1 15 1 15 1 10.5us 1 15 15 1 10.5us 15 1 15 15 1 15 15 1 15 15 15 15 15 15 15 15 15 15 15 15 15 1	15 1 15 1 15 1 -30.5us 1 -30.5us 1 20.5+2us 1	1s 1s 1s+30.5us 1s 1s 1s+30.5us	15 15 15 15+30.5us 15+30.5us	15 15 15 15+30.505 15 15+30.505	1s           1s           1s           1s           1s           1s+30!           1s+30!           1s+30!	1s           1s           1s           sus           sus           1s+30.5
CALM[3] CALM[4] CALM[5] CALM[6] CALM[7] CALM[7]	4 8 16 32 64	2 <sup>17</sup> 2 <sup>16</sup> 2 <sup>16</sup> 2 <sup>14</sup>	2 <sup>18</sup> 2 <sup>17</sup> 2 <sup>18</sup> 2 <sup>16</sup> 2 <sup>14</sup>	$\begin{array}{c} (N \in [0,1]) \\ 2^{17} + 2^{18} + N \\ (N \in [0,3]) \\ 2^{16} + 2^{17} + N \\ (N \in [0,7]) \\ 2^{16} + 2^{16} + N \\ (N \in [0,15]) \\ 2^{14} + 2^{16} + N \\ (N \in [0,15]) \\ 2^{13} + 2^{14} + N \\ (N \in [0,63]) \\ 2^{13} + 2^{14} + N \\ (N \in [0,63]) \\ 2^{12} + 2^{14} + N \\ (N \in [0,63]) \\ 2^{12} + 2^{14} + N \\ (N \in [0,63]) \\ 2^{12} + 2^{14} + N \\ (N \in [0,63]) \\ 2^{12} + 2^{14} + N \\ (N \in [0,63]) \\ 2^{12} + 2^{14} + N \\ (N \in [0,63]) \\ 2^{14} + 2^{14} + N \\ (N \in [0$	15 15 15-20.5us 15+20.5us 15+20.5us	15 15+30.5us 15 15+20.5us 15+20.5us	15 15 15+20.5us 15+20.5us 15+20.5+2us	15 15+30.5us 15 15 15+30.5us 15+30.5+2us	1s 1s 1s 1s+20.5us 1s+20.5us 1s+20.5+2us	15 15 15+30.505 15 15+30.505 15+30.5+20	1s           1s           1s           1s+30.5us           1s+30.5us           1s+30.5us           1s+30.5us           1s+30.5us           1s+30.5us	1s         1s+20.5           1s         1s           1s         1s+20.5*           1s+20.5*         1s+20.5*	11           12	s :: s :: s :: 15+3 0.5us	15   15   15   10.505   15-205   15+205	13 13 13 13 13 13 13 13 13 13 13 13 13 1	15 15 15+30.5us 15 15 15 15+30.5us 5+30.5v2us	15 15 15 15 15+20.5us 15+20.5us 15+20.5us	15 15 15+30.5us 15 15+30.5us 15+30.5us	1s           1s           1s           1s+30:           1s+20:           1s+20:5           1s+20:5	1s           1s+20.5
CALM[2] CALM[4] CALM[5] CALM[6] CALM[7]	4 8 16 32 64 129	2 <sup>17</sup> 2 <sup>14</sup> 2 <sup>14</sup> 2 <sup>14</sup> 2 <sup>13</sup> 2 <sup>12</sup>	2 <sup>18</sup> 2 <sup>17</sup> 2 <sup>14</sup> 2 <sup>15</sup> 2 <sup>14</sup> 2 <sup>13</sup>	$\begin{array}{c} (N \in [0,1]) \\ 2^{17} + 2^{18} + N \\ (N \in [0,3]) \\ 2^{16} + 2^{17} + N \\ (N \in [0,7]) \\ 2^{16} + 2^{16} + N \\ (N \in [0,7]) \\ 2^{16} + 2^{16} + N \\ (N \in [0,13]) \\ 2^{13} + 2^{14} + N \\ (N \in [0,33]) \\ 2^{13} + 2^{14} + N \\ (N \in [0,33]) \\ 2^{12} + 2^{13} + N \\ (N \in [0,127]) \\ 2^{12} + 2^{13} + N \\ (N \in [0,127]) \\ 2^{12} + 2^{13} + N \\ (N \in [0,127]) \\ 2^{11} + 2^{12} + N \\ (N \in [0,127]) \\ (N \in [$	15 15 15 15+20505 15+20505 15+20505 15+205-205 15+205-205	1s 1s=20.3us 1s=20.5us 1s=20.5us 1s=20.5=2us 1s=20.5=4us	1s 1s 1s 1s+30.5us 1s+30.5us 1s+30.5-2us 1s+30.5-4us	15 15+205us 15 15 15+205us 15+205us 15+205-2us 15+205-2us	15 15 15 15+20.5us 15+20.5us 15+20.5us 15+20.5+2us 15+20.5+4us	13 15 15+20.5us 15 15+20.5us 15+20.5us 2s+20.5us 2s+20.5us	1s           1s           1s           1s           1s           1s+30.5ux	1s           1s+20.5           1s           1s+20.5*           1s+20.5*	UUS         11           11	s : : : : : : : : : : : : : : : : : : :	15 15 15	1s         1           1s         1           1s         1           1s         1           -20.5us         1           -20.5us         1           20.5-2us         1           20.5-2us         1           20.5-4us         1           20.5-8us         1	15 15+30.5us 15 15 15 15+30.5us 5+30.5us 5+30.5+2us 5+30.5+4us	15 15 15 15-20.5us 15+20.5us 15+20.5us 15+20.5-2us	13 13 15 15-30.505 15 15-30.505 15+30.540 15+30.540 15+30.540	1s           1s           1s           1s           1s           1s+303           1s+303           1s+305           1s+305           1s+305           1s+305	15           15
CALM[3] CALM[4] CALM[5] CALM[5] CALM[6] CALM[7] CALM[8]	4 8 16 32 64 129 256 511 量位层增加计数的	2 <sup>17</sup> 2 <sup>14</sup> 2 <sup>15</sup> 2 <sup>14</sup> 2 <sup>12</sup> 2 <sup>12</sup> 2 <sup>11</sup> <sup>11</sup>	2 <sup>18</sup> 2 <sup>17</sup> 2 <sup>14</sup> 2 <sup>14</sup> 2 <sup>13</sup> 2 <sup>13</sup> 2 <sup>12</sup>	(N ∈ [0.1])           2 <sup>17</sup> +2 <sup>18</sup> +N           (N ∈ [0.3])           2 <sup>16</sup> +2 <sup>17</sup> +N           (N ∈ [0.4])           2 <sup>16</sup> +2 <sup>18</sup> +N           (N ∈ [0.4])           [0.5]           [0.4]           [0.4]           [0.3]           2 <sup>16</sup> +2 <sup>14</sup> +N           (N ∈ [0.3])           [0.127])           2 <sup>15</sup> +2 <sup>14</sup> +N           (N ∈ [0.255])           2 <sup>15</sup> +2 <sup>13</sup> +N           (N ∈ [0.255])           3 <sup>1</sup> µµi†数	13 15 15 15+20 5us 15+20 5us 15+20 5-2us 15+20 5-2us 15+20 5-2us 15+20 5-2us 15+20 5-2us	13 15+20 505 15+20 505 15+20 505 15+20 5-205 25+20 5-405 15+20 5-405 15+20 5-405	13 15 15 15+20545 15+205445 15+205445 15+205445 15+205445	13 15+20 Sus 15 15 15+20 Sus 15+20 S-205 15+20 S-205 15+20 S-405 15+20 S-405	15 25 15 15+20545 15+20545 15+205+245 15+205+245 15+205+245 15+205+245	1s           1s=20.5us           1s=30.5us           1s           1s=30.5us           1s=20.5us           1s=30.5us           1s=20.5us           1s=20.5us           1s=20.5us           1s=20.5us	1s           1s           1s           1s           1s+20.5ux           1s+20.5ux           1s+20.5ux           1s+20.5ux           1s+20.5ux           1s+20.5ux           1s+20.5ux           1s+20.5ux           1s+20.5ux	15           1s+30.5           1s           1s+30.5*           1s+30.5*           1s+30.5*	11           12           13           14           15           15           15           15           15           15           15           15           15	s 2 s 3 2 5 2 5 2 5 5 5 5 5 5 5 4 15 5 5 5 5 5 5 5 5 5 5 5 5 5 5	15         1           15         1           10         1	15         1           15         2           15         2           -20.505         2           20.5-205         2           20.5-205         2           20.5-205         2           20.5-205         2           20.5-205         2           20.5-205         2           20.5-205         2           20.5-205         2           20.5-205         2	1s           1s           1s+20.5us           1s           st-20.5us           s+20.5us           s+20.5us           s+20.5us	15 15 15 15 15+20.5us 15+20.5us 15+20.5-2us 15+20.5-4us 15+20.5-4us	15 15 15 15+20.5us 15+20.5us 15+20.5us 15+20.5us 15+20.5us 15+20.5us 15+20.5us 15+20.5us	1s           1s           1s           1s+201           1s+201           1s+205           1s+205           1s+205           1s+205           1s+205	15           15
CALM[2] CALM[4] CALM[4] CALM[5] CALM[5] CALM[7] CALM[2] CALM[20]= CALM[20]= CALM[20]=	4 8 15 32 64 129 256 511 室位后增 第TC <sub>CK</sub>	2 <sup>17</sup> 2 <sup>16</sup> 2 <sup>14</sup> 2 <sup>13</sup> 2 <sup>12</sup> 2 <sup>11</sup> <u>#mit &amp; Buha</u>	2 <sup>18</sup> 2 <sup>17</sup> 2 <sup>14</sup> 2 <sup>14</sup> 2 <sup>13</sup> 2 <sup>12</sup> 2 <sup>12</sup>	$\begin{array}{c} (N \in [0,1])\\ (2^{17} + 2^{18} + N)\\ (2^{17} + 2^{18} + N)\\ (N \in [0,1])\\ 2^{18} + 2^{17} + N \\ (N \in [0,1])\\ 2^{18} + 2^{18} + N \\ (N \in [0,1])\\ 2^{18} + 2^{18} + N \\ (0,21])\\ 2^{19} + 2^{18} + N \\ (0,21])\\ 2^{19} + 2^{18} + N \\ (N \in [0,23])\\ 2^{19} + 2^{18} + N \\ (N \in [0,23])\\ 2^{19} + 2^{18} + N \\ (N \in [0,23])\\ 2^{19} + 2^{18} + N \\ (N \in [0,23])\\ 2^{19} + 2^{18} + N \\ (N \in [0,23])\\ N \in [0,23])\\ RT C_{out}(\Omega + N \\ RT C_{ou$	13 15 15 15+205u5 15+205u5 15+205-2u5 15+205-2u5 15+205-2u5 15+205-2u5 15+205-2u5	13 15 15+20.545 15 15+20.5445 15+20.5445 15+20.5445 15+20.5445 15+20.5445 15+20.5445	13 15 15 15+205u5 15+205u5 15+205+403 15+205+403 15+205+604 15+205+604	13 15-205us 13 13 15+205us 15+205-2us 15+205-2us 15+205-2us 15+205-2us	13 15 15 15+20545 15+20545 15+205+245 15+205+245 15+205+245 15+205+245 15+205+245	11           15           15-80.5us           15           15           15-80.5us           15           15-80.5us           22	13           15           15           15           15           15-30502           15+30502	11           11-205           11-205           11           15           15           15           15           15           15           15           15           15           15-205           15+205+           15+205+           15+205+           15+205+           15+205+           15+205+           24	11           12	s 2 s 3 s 4 s 5 s 5 s 5 s 5 s 5 s 4 s 5 s 4 s 5 s 4 s 5 s 4 s 5 s 4 s 5 s 4 s 5 s 5 s 5 s 5 s 5 s 5 s 5 s 5	13         1           13         1           15         1           10.5         1           15         1	15         1           15         2           15         2           -30.505         2           -30.512         2           -30.5245         2           20.5-945         2           20.5-945         2           20.5-945         2           20.5-945         2           20.5-945         2           20.5-945         2	15           16           17           18           19           10           10           10           10           10           10           10	13 13 13 15 15-20505 15+20505 15+205-205 15+205-405 15+205-405 15+205-405	15 15 15 15+20545 15+20545 15+20545 15+20546 15+20546 15+20546 15+20546	1s           1s           1s           1s           1s+201           1s+203           1s+203           1s+205           31	115           16           15           16           15           16           15           16           17           18           18           18           18           18           18           18           18           18           18           18           18           18           18           18           18           18           18
CALM[2] CALM[4] CALM[5] CALM[5] CALM[6] CALM[7] CALM[7] CALM[8] CALM[8] CALM[8]	4 8 16 32 64 129 256 511 量位层增加计数的	2 <sup>17</sup> 2 <sup>14</sup> 2 <sup>15</sup> 2 <sup>14</sup> 2 <sup>12</sup> 2 <sup>12</sup> 2 <sup>11</sup> <sup>11</sup>	2 <sup>18</sup> 2 <sup>17</sup> 2 <sup>14</sup> 2 <sup>14</sup> 2 <sup>13</sup> 2 <sup>13</sup> 2 <sup>12</sup>	(N ∈ [0,1])           2 <sup>17</sup> +2 <sup>18</sup> +N           (N ∈ [0,3])           2 <sup>16</sup> +2 <sup>17</sup> +N <sup>1</sup> (N ∈ [0,7])           2 <sup>16</sup> +2 <sup>17</sup> +N <sup>1</sup> (N ∈ [0,7])           (N ∈ [0,7])           2 <sup>16</sup> +2 <sup>16</sup> +N <sup>1</sup> (N ∈ [0,13])           2 <sup>16</sup> +2 <sup>16</sup> +N <sup>1</sup> (N ∈ [0,03])           (0,127])           2 <sup>12</sup> +2 <sup>12</sup> +N <sup>1</sup> (N ∈ [0,127])           2 <sup>12</sup> +2 <sup>12</sup> +N <sup>1</sup> (N ∈ [0,255])	13 15 15 15+20 5us 15+20 5us 15+20 5-2us 15+20 5-2us 15+20 5-2us 15+20 5-2us 15+20 5-2us	13 15+20 505 15+20 505 15+20 505 15+20 5-205 25+20 5-405 15+20 5-405 15+20 5-405	13 15 15 15+20545 15+205445 15+205445 15+205445 15+205445	13 15+20 Sus 15 15 15+20 Sus 15+20 S-205 15+20 S-205 15+20 S-405 15+20 S-405	15 25 15 15+20545 15+20545 15+205+245 15+205+245 15+205+245 15+205+245	1s           1s=20.5us           1s=30.5us           1s           1s=30.5us           1s=20.5us           1s=30.5us           1s=20.5us           1s=20.5us           1s=20.5us           1s=20.5us	13           15           15           15           15           15-30502           15+30502           15+30502           15+30502           15+30502           15+30502           15+30502           15+30502           15+30502           15+30502           15+30502           15+30502           15+30502           23	11           11-205           11-205           11           15           15           15           15           15           15           15           15           15           15-205           15+205+           15+205+           15+205+           15+205+           15+205+           15+205+           24	11           12	s 2 s 3 s 4 s 5 s 5 s 5 s 5 s 5 s 4 s 5 s 4 s 5 s 4 s 5 s 4 s 5 s 4 s 5 s 4 s 5 s 5 s 5 s 5 s 5 s 5 s 5 s 5	13         1           13         1           15         1           10.5         1           15         1	15         1           15         2           15         2           -30.505         2           -30.512         2           -30.5245         2           20.5-945         2           20.5-945         2           20.5-945         2           20.5-945         2           20.5-945         2           20.5-945         2	1s           1s           1s+20.5us           1s           st-20.5us           s+20.5us           s+20.5us           s+20.5us	15 15 15 15 15+20.5us 15+20.5us 15+20.5-2us 15+20.5-4us 15+20.5-4us	15 15 15 15+20.5us 15+20.5us 15+20.5us 15+20.5us 15+20.5us 15+20.5us 15+20.5us 15+20.5us	1s           1s           1s           1s           1s+201           1s+203           1s+203           1s+205           31	115           16           15           16           15           16           15           16           17           18           18           18           18           18           18           18           18           18           18           18           18           18           18           18           18           18           18

Figure 2-2 RTC	<b>CLK</b> distribution	diagram for	calibration cvd	cle 325/CP=1/	CM=511 per second
	_CERCUISCINSULION	anabrannion	cumbration cyc	cic 323/ ci -1/	CIVI-SII PCI SCCOIIG

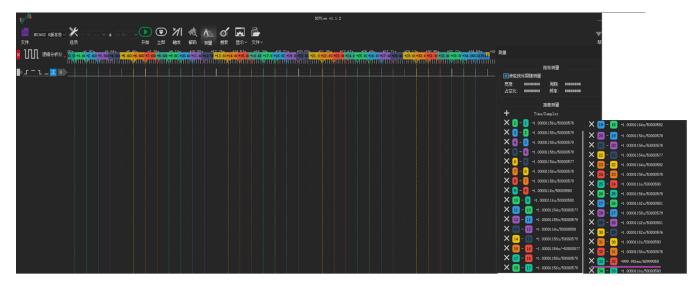
From the figure above, it can be seen that the 32nd S actually decreases by 30.5us (adding an RTC\_CLK), which is 999.965ms.

### **3.3 Measurement of RTC Digital Clock Precision Calibration Algorithm**

By measuring the RTC calibration signal output from the RTC\_OUT pin, it was found that the actual time for 1-31 seconds was 1 second, and for the 32nd second, the RTC calendar actually measured 999.981ms. This aligns with the theoretical calibration algorithm calculation values in Section 3.2



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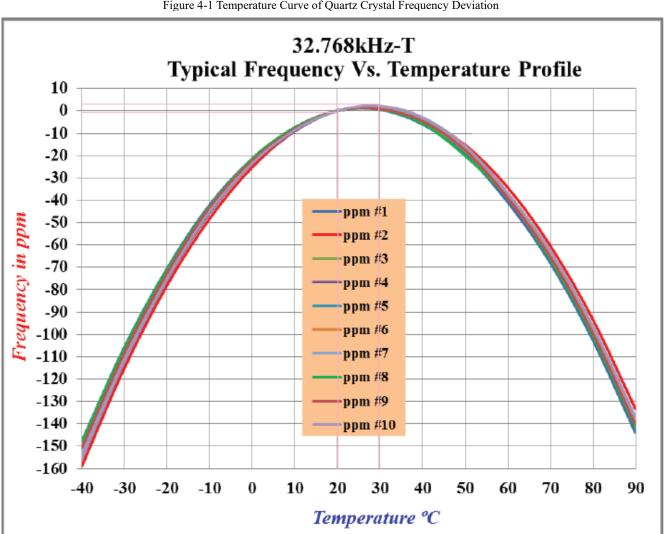


### 4. Temperature Compensation of LSE Using Precise Calibration Application Example

### 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  $2 \sim -4.19$  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:

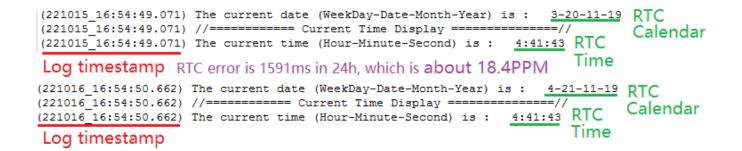
11/14



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

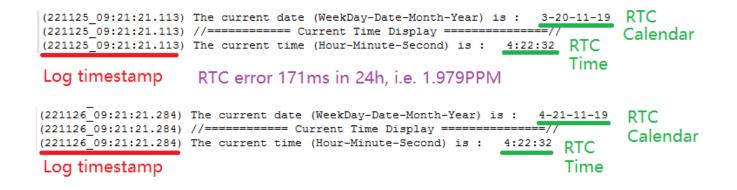
### 4.4 RTC Precision Calibration And Actual Measurement

After actual measurement at normal temperature ( $20 \sim 30 \ ^{\circ}C$ )) 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.



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);



**12 /** 14



## 5. Version History

Version	Date	Changes
V1.0	2022.11.16	Initial version



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