AN12769

RTC deviation

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Document information

Information	Content
Keywords	NHS31xx, TFRO, RTC, Calibration
Abstract	How to recalibrate the RTC HW block? How to improve timestamps?

Revision history

Rev	Date	Description
v1.1	20210430	Update for SDK 12.4.1
v1.0	20200309	Update for SDK 12.4
Modifications:	• Major format update and refresh of contents	
v0.5	20180615	Update for SDK 11.2
v0.4	20170323	Update for SDK 10
v0.3	20170113	Update for SDK 9
v0.2	20161215	Adding how to improve timestamps
v0.1	20160625	Initial version

1 Introduction

All ICs of the NHS31xx family are ideally suited for cold-chain logging and monitoring use cases. The HW provides the building blocks for complex and standalone operations. These building blocks are an internal RTC driven by a free-running oscillator, an accurate temperature sensor, and plenty of volatile and non-volatile memory. The NHS31xx ICs also include an open Arm Cortex M0+ processor where the firmware can be fully tailored for each customer and use case.

The RTC is based on a trimmed 32 kHz free running oscillator. The calibration is performed during a manufacturing step done by NXP Semiconductors. This document describes how the RTC HW block can be recalibrated. It also provides a software technique to achieve a much better time accuracy for the timestamps stored by the firmware.

1.1 RTC

Several sources cause variations of the clock tick accuracy:

- The manufacturing silicon process
- The ICs operating temperature (ambient temperature)
- The supplied battery voltage

It leads to a different inaccuracy profile for each IC. A full description of the RTC HW block can be found:

- In the section Real-time clock (RTC) timer of the NHS3100 data sheet (Ref. 1).
- In the section Real-time clock (RTC) of the NHS31xx user manual (Ref. 2).

1.2 Calibration

The TFRO is a free running oscillator which is factory-calibrated to 32 kHz ± 3 % at 30 °C. The frequency measured during the calibration step is stored in EEPROM and loaded during boot time in the RTC calibration register `CAL`. This value is IC-specific and an error in this value results in a deviation of the RTC clock.

The RTC calibration register sets the overflow value of the counter running on the TFRO clock. The result is a "time tick" of 1 second each time the register value matches the frequency value of the TFRO.

2 Recalibration

By recalibrating, the customer can determine a new value for the RTC calibration register. The main application can then set the value immediately at boot time. The set value is only accurate for the temperature and the IC voltage during the recalibration.

2.1 Test program

First flash the following program in the IC to output the TFRO frequency on pin PIO0_1:

```
Board_Init();
Chip_IOCON_SetPinConfig(NSS_IOCON, IOCON_PIO0_1, IOCON_FUNC_1);
Chip_Clock_Clkout_SetClockSource(CLOCK_CLKOUTSOURCE_TFRO);
for(;;);
return 0;
```

2.2 Measurement equipment

Measure the frequency on pin PIO0_1 with a high-quality frequency counter. Using an oscilloscope only provides a limited accuracy. When using a gate time of 1 second, the integer part of the frequency measured in Hz is the value to be used for RTC calibration register.

Ensure that the temperature environment is stable and uniform and the power supply supplies a stable voltage level.

2.3 Firmware update

When an updated value has been determined, add this code to your Arm firmware application:

```
void ResetISR(void)
{
    /* Replace the number with the value determined above. */
    #define CUSTOMER_DEFINED_CAL 32768
    Chip_RTC_SetCalibration(NSS_RTC, CUSTOMER_DEFINED_CAL);
    Startup_VarInit();
    main();
}
```

3 Improving timing accuracy

For temperature logging applications, the RTC is used to time the sampling of new temperature values. The IC typically measures the temperature at fixed intervals with each time point expressed in full seconds. When the IC is started, it runs unattended using the RTC for its own notion of time. We call it the "island time" of the IC.

Even after careful calibration, the deviation of the RTC block can be significant. It fluctuates with changing temperatures and voltage levels. The fluctuation can be several percentages under extreme conditions. The RTC deviation does not get worse over time. When looking at excursion lengths, the past lifetime of the RTC deviation or past excursions does not affect the RTC deviation.

To determine the deviation and calculate the actual interval with which was measured, additional SW can be added, either in the tag firmware or the tag reader APP. The interval after correction then becomes a fixed floating point number, close to the interval that the RTC dictates.

When the data is read out, time according to the IC (the so-called "island time") can be compared with the time according to the tag reader. The tag reader has the correct time. With a constant RTC deviation, all that must be calculated is the absolute time deviation of the RTC HW block per interval and then added cumulatively to the timestamp of each measurement point.

Using this simple technique, SW can be used to reduce the clock drift significantly by determining an updated interval, which differs slightly from the configured interval and allows the reconstruction of the actual timestamps with a very high accuracy.

In most use cases, where the expected temperature range is much less than the full range the IC is validated in (−40 °C to +85 °C), the maximum deviation is significantly less. After making an SW correction for the timestamps, cold-chain applications can typically achieve a timing accuracy of 0.2 % and better.

3.1 Calculations

When two synchronization points are present, calculations can be carried out.

- The first synchronization point is at the time the tag reader (typically an NFC-enabled cell phone) taps the NFC antenna of the NHS31xx IC. Configuration details are sent to the IC (among which the required interval δ between two measurements), after which the firmware starts monitoring and logging. The exact time can be sent to the IC as well, providing a correct start time s.
- The second synchronization point is when the tag reader taps again, at some later point, reading out all samples. The IC reports the island time T' and the tag reader knows the correct time T. During the time between the two taps, several measurements, n, are done. Using the island time, each measurement has a corresponding timestamp t'_n. The time between two successive measurements is variable and has an average δ' which is close to but not equal to δ.

Let t_n be the recalculated timestamps. These give a better indication of the time of sampling.

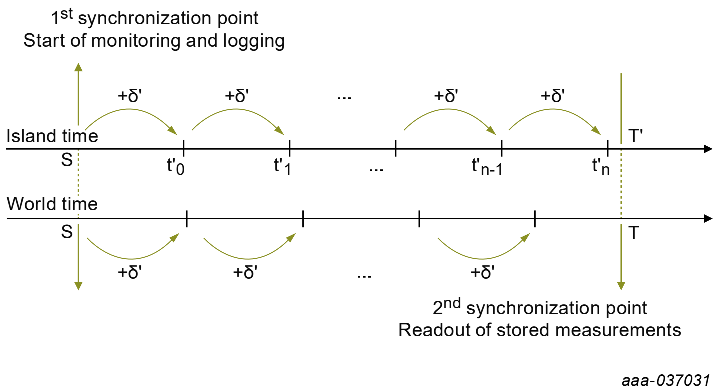

Figure 1. Two synchronization points

The correction factor is the division between the two different timespans:

$$p = \frac{T - S}{T^{island} - S} \quad (1)$$

`p` is a strict positive number:

- A value of `1` indicates that, on average, both clocks ran with the exact same speed
- A value of `1.01` indicates that, on average, the IC clock ran 1 % too slow

The timestamps can then be recalculated as:

$$t_n = s + (t_n^{island} - s) \cdot p \quad (2)$$

This timestamp stretches or condenses the measurement times in a uniform way.

The deviation can be calculated as a percentage using:

$$pct = | 1 - p | \cdot 100 \quad (3)$$

Note: *These calculations can be carried out on either the tag reader or on the Arm inside the NHS31xx. An example implementation has been added in the mobile demo applications `tlogger` and `monitor`. It can be found in the SDK under `sw/XF`.*

3.2 Example figures

3.2.1 Uncorrected

Assuming an average RTC deviation of 2.5 %, Table 1 provides the possible minimum and maximum intervals. These numbers are before correction using the correct time at a second synchronization point.

Table 1. Minimum and maximum intervals

Elapsed time	2.50 %	
	Minimum	Maximum
15 minutes	14 m 37 s	15 m 23 s
1 hour	58 m 30 s	1 h 1 m 30 s
8 hours	7 h 48 m 0 s	8 h 12 m 0 s
1 day	23 h 24 m	1 d 0 h 36 m
30 days	29 d 6 h	30 d 18 h
90 days	87 d 18 h	92 d 6 h
180 days	175 d 12 h	184 d 12 h
270 days	263 d 6 h	276 d 18 h

3.2.2 Corrected

When the recalculation of the timestamps using the deviation between the island time and the correct time yields an accuracy of 0.2 % or better:

Table 2. Minimum and maximum intervals

Elapsed time	0.20 %	
	Minimum	Maximum
15 minutes	14 m 58 s	15 m 2 s
1 hour	59 m 53 s	1 h 0 m 7 s
8 hours	7 h 59 m 2 s	8 h 0 m 58 s
1 day	23 h 57 m	1 d 0 h 2 m
30 days	29 d 22 h	30 d 1 h
90 days	89 d 19 h	90 d 4 h
180 days	179 d 15 h	180 d 8 h
270 days	269 d 11 h	270 d 12 h

4 References

[1] **NHS3100 data sheet** — Temperature logger; 2020, NXP Semiconductors

[2] **UM10876 user manual** — NHS31xx user manual; 2020, NXP Semiconductors

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