AN12106

QN908x 32k RCO Calibration

Rev. <1.0> — 22 December 2017 Application note

Document information

Info	Content
Keywords	RCO, 32 kHz, Calibration, ppm, RTC Calibration, SCA
Abstract	The AN describes the details of 32 kHz RCO calibration of QN908x.

Revision history

Rev	Date	Description
0.1	2016-11-16	Draft
1.0	2017-12-22	Initial release

1. Introduction

QN908x is a power effective BLE SoC. Four clock sources are available on QN908x, two high frequency clocks and two low frequency clocks. The low frequency clock can be the external 32.768k crystal or the internal 32k RC oscillator.

For the cost sensitive applications, the low frequency clock can choose 32k RC oscillator. But as the 32k RCO can't get same accuracy as with the external 32k crystal and Bluetooth specification requires the sleep clock accuracy (SCA) should meet ±500 ppm, the RTC and BLE Sleep Timer of QN908x support calibration feature, with which these peripherals can get the same accuracy as with an input clock of ±500 ppm accuracy.

2. Key Features of QN908x for Supporting Calibration

1) One of capture input signals (CAP[2]) of 32-bit timer(CTimer) of QN908x connects with 32k RCO clock, which makes it easier to measure the clock from 32k RCO with another accurate clock.
2) QN908x contains digital calibration circuit, which can calibrate and make sure 32k RCO get accuracy of ±35000ppm.
3) The RTC and BLE sleep timer of QN908x supports calibration feature, by which the compensation can be made to improve the accuracy.

3. QN908x 32k RCO Calibration Related Peripherals

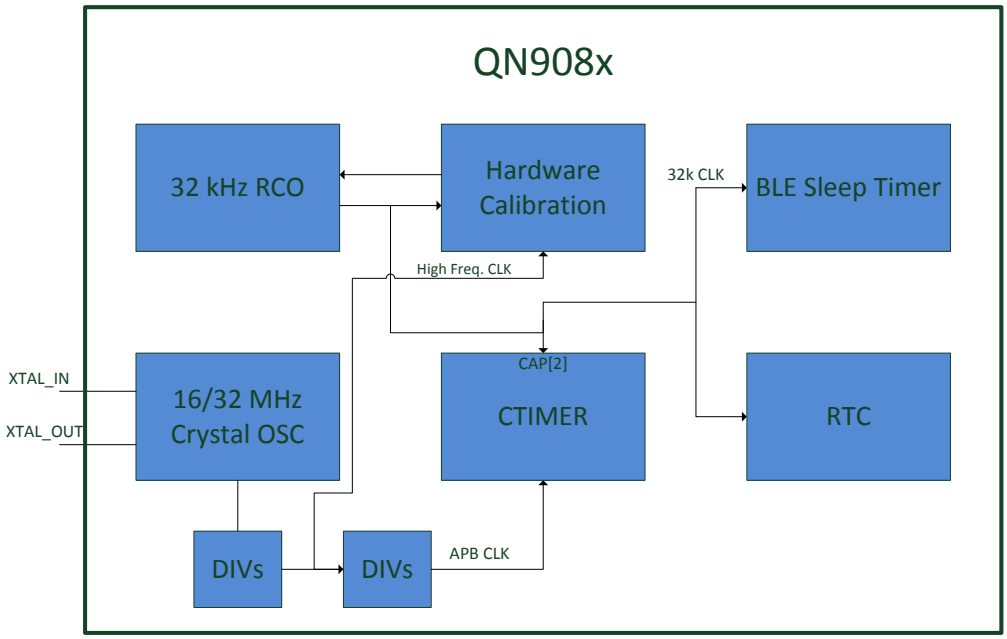


Figure 1: QN908x 32k RCO calibration related peripherals

As illustrated in figure 1, the high accuracy clock from 16/32 MHz crystal and standard 32-bit timer is used for measuring the period of 32k RCO clock. According the AN of QN908x Hardware Design Consideration, the 16/32 MHz crystal should be at least with the accuracy of ±20 ppm, with which the 32k RCO clock measurement is more accurate.

The Hardware Calibration block is designed to calibrate the clock from 32k RCO firstly. The accuracy of the clock after hardware calibration can get about ±35000ppm.

The RTC and BLE Sleep Timer are the peripherals to be compensated to improve accuracy. The compensation is conducted in the value of ppm. The minimum compensation unit is 1 ppm. The formula to calculate ppm is shown below:

ppm = $(f_0/f_1 - 1) \times 1000000$, where $f_0 = 32000$

The two peripherals can get about ±500ppm accuracy after calibration. Test result can be found at section 4.6.

As only 32k clock available at power down 0 state, RTC is also used as timer to trigger calibration periodically.

4. Procedures of Calibrating and Compensation

The procedures for calibration 32k RCO and compensation to RTC & BLE Sleep Timer are illustrated in figure 2 below. Three steps mainly needed to complete the calibration and compensation operations. Hardware calibration is firstly completed during system initialization. With the calibrated 32k RCO clock as capture input and the APB clock as input, Software Calibration is completed at second step. The 3rd step is compensating the RTC and BLE Sleep Timer by the ppm value got from the 2nd step.

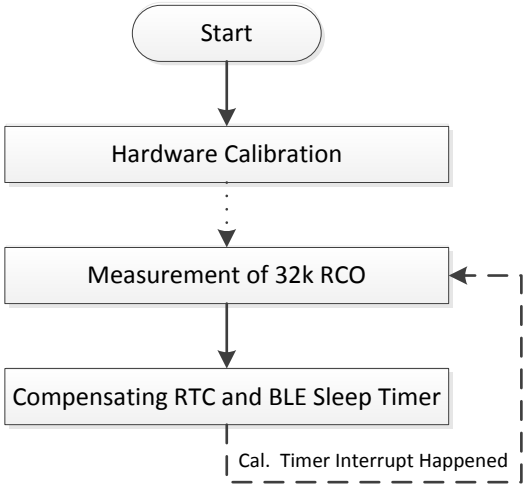


Figure 2: QN908x 32k RCO Calibration and Compensation Flow

4.1 Hardware Calibration

As illustrated in figure 1, 32 kHz RCO is calibrated firstly with hardware calibration block. Hardware calibration aims to improve accuracy of 32k RCO clock There is dedicated digital register RCO_RC_REF_OSC_CODE in QN908x for the purposes. Four bits in the registers is used to tune the RCO capacitor to get the least deviation of 32k clock. The clock accuracy after calibration can be within the range of ±35000 ppm.

During initialization, firmware would do calibration to get proper code and set it to the register RCO_RC_REF_OSC_CODE. The code is around 0x05 typically under room temperature, and decreases to 0x0 when temperature is around 100 Celsius degrees.

With temperature changing, software calibration would adjust the code got during initialization to make the accuracy of RCO clock within the range of ±35000 ppm.

4.2 Implementation of Hardware Calibration

The hardware calibration is implemented in function CALIB_CalibRCO32K() in file fsl_calibration.c in QN908x SDK. It's fine-tuned by NXP, not intended for customer revising.

4.3 Software Calibration

Software calibration of 32k RCO is comprised of two operations:

1. Read the capture value from CTimer to calculate ppm value and set the result to RTC and BLE sleep timer
2. Monitor if ppm value is bigger than a preset threshold. If so, firmware would adjust the code and set it to the register RCO_RC_REF_OSC_CODE.

4.4 Implementation of Software Calibration

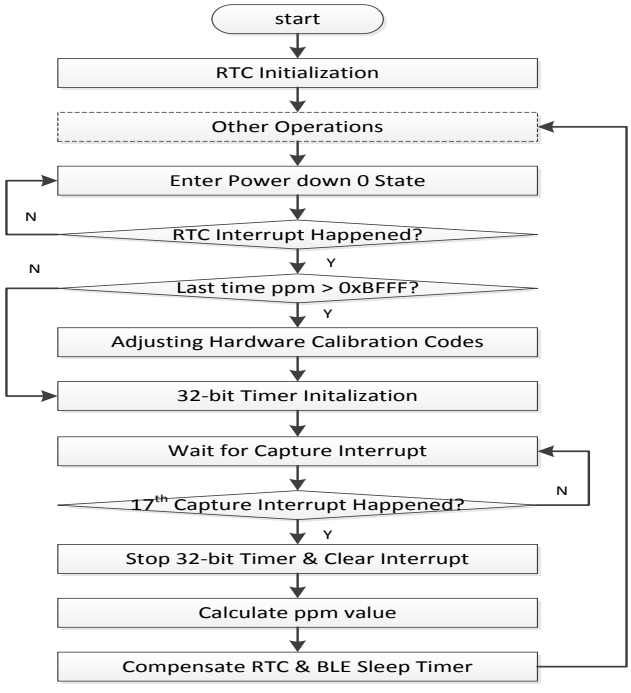


Figure 3: Software calibration work flow

The flow chart of software calibration is shown in Figure 3. The key parameters and key operations are described in the following:

1. The Timer for calibration: As calibration needs to be performed periodically even system entering Power Down 0 mode, and only 32 kHz clock is available in this mode, RTC is the only choice as the calibration timer.
2. 32-bit Timer for calibration: Four 32-bit timers are available in QN908x, and all with the capture input CAP[2], any of the four timers is ok to measure the period of 32k RCO. The CTimer 3 is chosen in SDK projects.
3. Calibration interval: As MCU would be waken up from Power Down 0 state to calculate ppm and set the ppm value to RTC and BLE Sleep Timer, the smaller the interval is, the higher the power consumption would be and the better accuracy of RTC and BLE Sleep timer can get. To balance between the accuracy and power consumption, according to the testing of NXP on typical scenario, chose 1 second as the interval for calibration.
4. ppm counting length: The 32k RCO clock is connected to the third capture input (CAP[2]) of CTimer, a capture interrupt would be generated on the rising edge of the 32k RCO clock. There is always jitter in the capture value when the counting length is small. The cycle of the clock is 32.5us, according to the testing of NXP, 16 cycles are a reasonable interval to get the capture result and calculate ppm. Figure 3 illustrates the power profiling with 32k RCO calibration enabled.

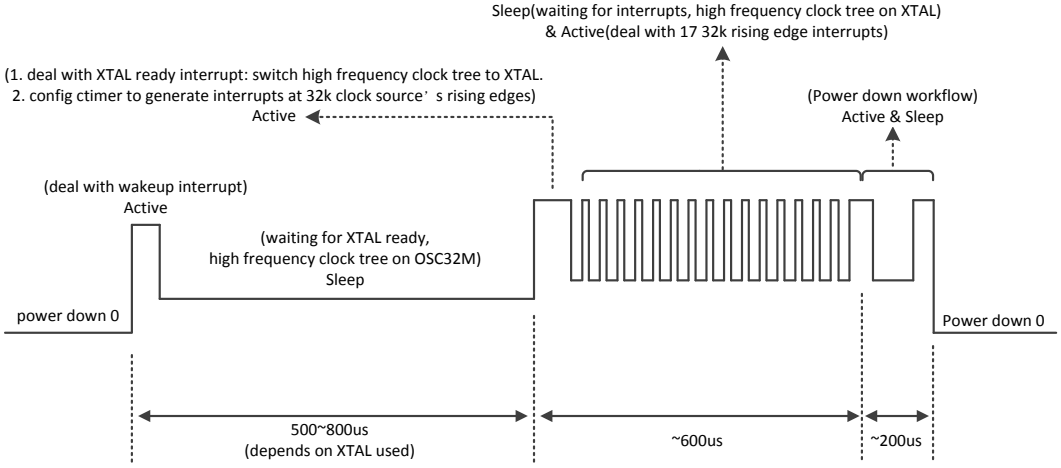


Figure 4 Power Profile of RCO32K's measurement

5. ppm value triggering the code change for hardware calibration

   The accuracy of 32k RCO clock is within ±35000ppm. The code should be changed if a ppm value calculated is out of the range. The threshold is set to 0xBFFF in current SDK projects, which is a value verified by NXP.

6. Compensation to RTC and BLE Sleep Timer

   1) RTC of QN908x contains two counter CNT0 and CNT1, and supports two modes RTC mode and free-running mode. CNT0 and CNT1 work together to generate second interrupt under RTC mode. CNT1 can work solely and generates free-

running interrupt under free-running mode. Only CNT0 is designed with calibration feature, RTC can be compensated under RTC mode only.

The Calibration register (offset = 0x10) in QN908x RTC is used for RTC compensation, two directions supported and the precision is 1ppm. The register is illustrated in figure below.

Bit	Symbol	Access	Reset value	Description
15:0	PPM	RW	0x0	RTC calibration ppm value; the precision is 1 ppm
16	DIR	RW	0x0	RTC calibration direction indicator 0: forward calibrate 1: backward calibrate
31:17	RESERVED	-	-	-

2) The BLE Stack of QN908x provides API function set_32k_ppm() to do the compensation to BLE Sleep Timer. When the BLE stack configures the 32k Hz sourced sleep timer by the API, it will take the ppm information into consideration. For example, if the RCO32K is 2500ppm faster, and the BLE stack needs to wakeup 1 second (32000 ticks of 32.000kHz) later, BLE stack will configure a value of 32000 * (1 – 2500 / 1000000) = 31920 into BLE sleep timer, but not 32000.

4.5 Customization of the Software Calibration

1. Enabling the 32k RCO function

   The macro BOARD_XTAL1_CLK_HZ in clock_config.h is used to enable internal 32k RCO clock. The changes to the macro is shown in the sentences below.

~~*#define BOARD_XTAL1_CLK_HZ 32768U*~~

=>

#define BOARD_XTAL1_CLK_HZ 0U

The hardware and software calibrations are enabled when the internal 32k RCO clock is enabled.

2. Adjusting the calibration interval.

   The input parameter of the function RCO32K_InitSwCalib() in file app_ble.c is the value of the interval to do the software calibration in the unit of millisecond.

3. Adjusting the counting length.

   The macro RCO32K_17TH_EDGE in rco32k_calibration.h is used to configure the interval of ppm calibration in the unit of 32k RCO clock cycle.

4.6 Verification of the 32k RCO Calibration

As only the RTC mode of QN908x RTC supports the calibration feature, the second interrupt must be enabled. The accuracy of 32k RCO clock would reflect to the accuracy of the RTC with calibration enabled.

Under the RTC mode, the second interrupt would be generated when RTC counter reaches 32k if the interrupt is enabled. Toggling a GPIO of QN908x in second interrupt handler and monitoring it with oscilloscope, we can get the accuracy of the RTC.

The codes changes for verifying 32K RCO accuracy are as the below:

1. In Function TA_Init(), enable second interrupt by the sentence: RTC_EnableInterrupts(RTC, kRTC_SecondInterruptEnable);
2. Toggle GPIO04 in function RTC_SEC_IRQHandler() by the sentence: GPIO_TogglePinsOutput(GPIOA, 1U <<4U);

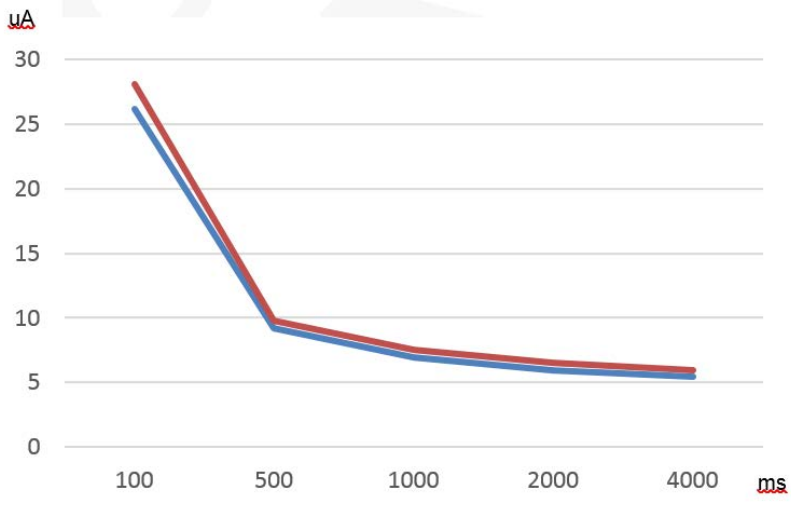
The test result of RTC accuracy after compensation is shown in table 1:

Table 1: RTC accuracy after compensation

Sample No.	Avg. Accuracy(ppm)	Peak Accuracy(ppm)	Test conditions
1	40	180	QN908x DK, 3V power supply, DC-DC enabled, Room Temperature
2	20	-100	
3	40	140	
4	40	100	
5	20	-180	

4.7 Power Consumption with 32k RCO Enabled

The power consumption with 32k RCO enabled will be a little high than that of using 32k crystal. The figure below illustrates the power consumption comparison.



Test conditions:

Hardware: QN908x DK (3V power supply)

SDK project: ble_power_profiling, DC-DC on

Calibration interval: 1 second

Connection: 100ms to 4000ms interval, empty packet

Temperature: room temperature

Please be noted that test result is hardware and sdk project revision dependent.

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