AN12104

QN908x Crystals Load Capacitance Calibration

Rev. 2.1 — 04 June 2018

Application note

Revision history

Rev	Date	Description
1.0	2017/12/22	QN908x Crystals Load Capacitance Calibration initial version.
2.0	2018/02/21	Added description to get the binary file hci_black_box.bin, added indicator on where to setup the connection with QN9080 DK.
2.1	2018/06/04	Minor edits.

Contact information

For more information, please visit: http://www.nxp.com

1. Introduction

QN908x is designed with no load capacitors needed for both 16 MHz/32 MHz and 32.768 kHz crystal oscillators, the load capacitor is integrated inside chips to reduce the BOM cost without affecting the crystal accuracy. An accurate crystal oscillator results in better RF performance.

The 16 MHz/32 MHz crystal circuitry decides the performance of the RF peripheral, while the 32.768 kHz crystal circuitry decides the accuracy of RTC and the power consumption of BLE connection.

As part of the crystal circuitry, the load capacitance is crucial to the accuracy of clock from the crystal oscillator.

2. Load Capacitance Parameters

QN908x is integrated with load capacitance for both high and low frequency crystals.

2.1 Registers for Load Capacitance Configuration

The value of load capacitance is configured by registers.

For high frequency crystal, the bits 22 to 28 of register ANA_CTRL0 is used for setting load capacitance. Refer to table 1 below for details.

Table 1. ANA_CTRL0

Bit	Symbol	Access	Reset value	Description
27:22	XTAL_LOAD_CAP	RW	0x20	register-controlled load cap of the XTAL in normal mode. XTAL load cap =5 pF + 0.35 pF $\times$ XTAL_LOAD_CAP + 5 pF $\times$ XTAL_EXTRA_CAP
28	XTAL_EXTRA_CAP	RW	0x0	add extra 16/32 MHz XTAL load cap

For low frequency crystal, the bits 8 to 14 of register XTAL32K_CTRL is used for setting load capacitance. Refer to table 2 below for details.

Table 2. XTAL32K_CTRL

Bit	Symbol	Access	Reset value	Description
13:8	XTAL32K_LOAD_CAP	RW	0x30	load cap selection of XTAL32K; XTAL32K load cap = 3.6 pF + 0.4 pF $\times$ XTAL32K_LOAD_CAP + 6.4 pF $\times$ XTAL32K_EXTRA_CAP
14	XTAL32K_EXTRA_CAP	RW	0x0	add extra XTAL32K load cap or not

2.2 Configuration Step for Load Capacitance

Based on the table 1 and table 2 above, the step configurable of load capacitances is 0.35 pF and 0.4 pF respectively for high and low frequency crystals.

2.3 Extra Value for Load Capacitance

To add an extra load capacitance, set the corresponding register. The extra values are 5 pF and 6.4 pF respectively for the high and low frequency crystals.

2.4 Adjustable range of Load Capacitance

With the predefined step and extra value, we can get the adjusting range of load capacitance. Refer to table 3 and table 4 below for details.

Table 3. High Frequency Crystal Adjustable Range of Load Capacitance

Extra addition capacitor option	Capacitor for the crystal	Capacitor pre-step for each
NO	5 pF ~ 27.05 pF	0.35 pF
YES	10 pF ~ 32.05 pF	0.35 pF

Table 4. Low Frequency Crystal Adjustable Range of Load Capacitance

Extra addition capacitor option	Capacitor range for the crystal	Capacitor pre-step for each
NO	5 pF ~ 27.05 pF	0.4 pF
YES	10 pF ~ 32.05 pF	0.4 pF

3. Typical Crystal Circuitry

The typical crystal circuitry is illustrated in figure 1, which you can find in other QN908x documents. The load capacitance is inside QN908x, the crystal circuitry would have crystal connected outside only. Cp1 and Cp2 are the parasitic capacitance between crystal pads, tracks and ground.
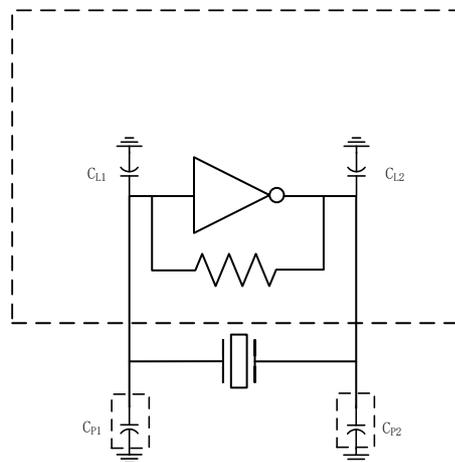
Figure 1 QN908x Crystal Circuitry

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3.1 Advantages of Inside Integrated Load Capacitance

QN908x is a BLE SoC targeting wearable and fitness product, which are always cost and size sensitive. With the on-chip capacitor feature, the design based on QN908x can save cost and valuable PCB space.

The carrier of QN908x RF is based on the high frequency clock, the accurate load capacitance of the high-frequency crystal can get an accurate RF signal. With the on-chip capacitor, we can adjust the load capacitance by small step (0.35 pf) to get more accurate RF frequency.

The RTC accuracy depends on the accuracy of the low-frequency crystal circuit. With the on-chip adjustable load capacitance, it can get a good accuracy.

4. Fine Tuning the Load Capacitance

As described in section 3.1, the accuracy of crystal circuit has impact on the performance of peripherals. It is necessary to fine tune it during the product design phase.

4.1 High Frequency Crystal Tuning

1) Hardware
   - Spectrum Analyzer
   - QN908x based DUT
   - A test PC
   - USB to UART cable
   - Coaxial cable
2) Software tool & firmware
   - Firmware: hci_black_box.bin (the project file is located in the SDK folder ...`\boards\qn908xcdk\wireless_examples\bluetooth\hci_bla ck_box`, compile the project to generate the binary)
   - Software tool: QN908x_CrystalCal.exe, a PC based tool.

4.1.1 Hardware Setup

The 2.4 GHz TX carrier is derived from the high frequency crystal oscillator, the load capacitance is better matched if the carrier frequency is closer to the frequency the DUT intends to transmit. For measuring the frequency accuracy, the TX carrier frequency is easily measured with spectrum analyzer. The DUT can be controlled to transmit signals only after burning the binary file hci_black_box.bin. The software tool QN908x_CrystalCal.exe is running on a test PC and send commands to DUT by UART interface.

The hardware setup is illustrated in figure 2 below.
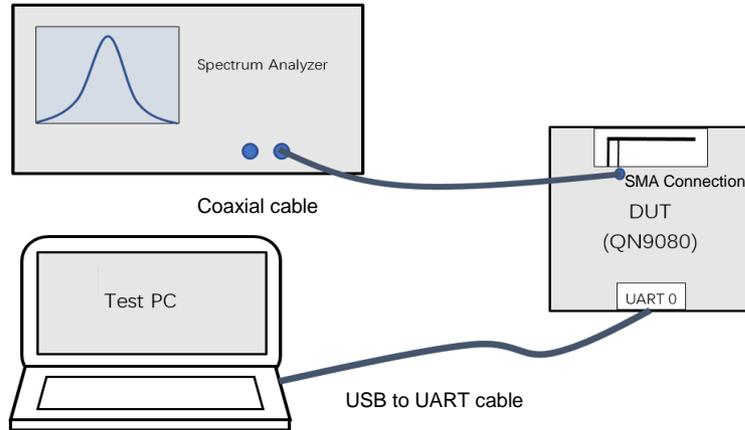
Figure 2 Hardware Setup for High Frequency Crystal Calibration

4.1.2 Firmware and Software Tool Introduction

The hci_black_box.bin is the firmware used for QN908x DTM test, as well as handling vendor specific commands, such as Read/Write QN908x registers.
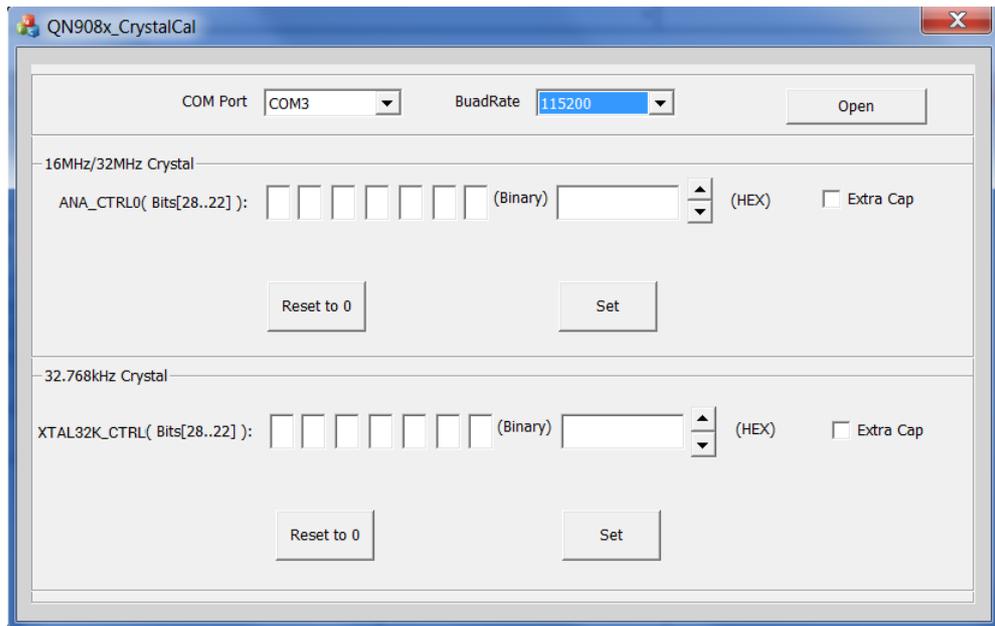
Figure 3 Crystal Calibration Tool

As illustrated in figure 2, QN908x_CrystalsCal.exe is the Windows based PC tool used for QN908x load capacitance calibration test, which consists of controlling QN908x for TX carrier transmission and calibration related register accessing.

4.1.3 Test Procedure

During the hardware design phase, the hardware engineer should choose the crystal following the rules addressed in the QN908x Hardware Design Consideration Application Note.

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QN908x is shipping with default value used for setting the load capacitance value by register ANA_CTRL0. The value is 0x08, which is a verified value for QN9080 DK. But even the crystal is from the same vendor and with the same parameters, the load capacitance shall be re-calibrated if PCB design/manufacturer is changed.

The test procedure for the hih-crystal load capacitance calibration test is as the following:

1. Setup the hardware connection as illustrated in figure 2.

2. Download the firmware hci_black_box.bin into QN908x.

3. Start the calibration tool QN908x_CrystalsCalc.exe.

4. Input an initial Hex value in Hex input box.

5. Click Set button in 16 MHz/32 MHz group to trigger TX carrier transmission.

6. Observe the frequency value in spectrum analyzer.

7. Adjust the value upwards if minus frequency offset found by up/down button.

8. Repeat from step 5 until the smallest offset is found.

4.2 Low Frequency Crystal Tuning

1) Hardware
   - Oscilloscope
   - QN908x based DUT
   - A test PC
   - USB to UART cable
2) Software tool & firmware
   - Firmware: hci_black_box.bin (the project file located in the SDK folder ...`\boards\qn908xcdk\wireless_examples\bluetooth\hci_bla ck_box`, compile the project to generate the binary)
   - Software tool: QN908x_CrystalCal.exe, a PC based tool.

4.2.1 Hardware Setup

The low frequency clock in QN908x is used by RTC and Sleep Timer. Aa accurate timing is needed for two BLE device to sync in between the connection events. And the RTC accuracy for timing function also depends on the accuracy of the clock.

To get the accuracy clock, the capacitance matching with the external 32k crystal can also be tuned. The tool QN908x_CrystalCal.exe is also used to help on low frequency clock calibration.

The hardware setup is illustrated in figure 4 below.

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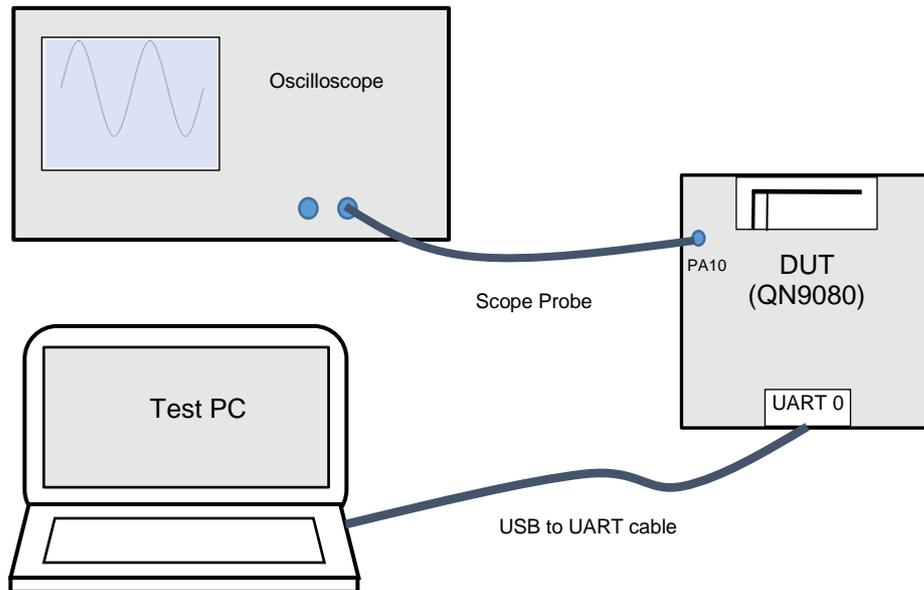
Figure 4 Hardware Setup for Low Frequency Crystal Calibration

4.2.2 Firmware and Software Tool Introduction

The low-frequency crystal calibration uses the same firmware and software tool as the High Frequency Crystal Calibration. Please refer to the section 4.1.2 for details.

The only difference is that the firmware hci_black_box.bin needs one GPIO pin configured as 32 k clock output function. Open the project file hci_black_box located in the SDK folder `..\boards\qn908xcdk\wireless_examples\bluetooth\hci_black_box`, and add sentence as below in the main function:

IOCON->CLK_CTRL |= SYSCON_CLK_CTRL_CLK_32K_OE_MASK;

IOCON->PIO_WAKEUP_EN1 |= kCLOCK_Clkout_PA10_32K;

Compile the project and generate binary file hci_black_box.bin, which is used for the low-frequency crystal calibration test.

4.2.3 Test Procedure

During the hardware design phase, the hardware engineer should choose the crystal following the rules addressed in the QN908x Hardware Design Consideration Application Note.

QN908x is shipping with default value used for setting the load capacitance value by register XTAL32K_CTRL. The value is 0x30, which is a verified value for QN9080 DK. But even the crystal is from the same vendor with the same parameters, the load capacitance shall be re-calibrated if PCB design/manufacturer is changed.

The test procedure for the low-crystal load capacitance calibration test is as the following:

1. Setup the hardware connection as illustrated in figure 4.

2. Download the firmware hci_black_box.bin into QN908x.

3. Start the calibration tool QN908x_CrystalsCalc.exe.

4. Input an initial Hex value in Hex input box.

5. Click Set button to set the value in the corresponding register of QN908x.

6. Observe the clock accuracy in oscilloscope.

7. Repeat from step 5 until the smallest offset is found.

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