AN12902

QN9090/QN9030 Power Consumption Analysis

Rev. 3 — 24 June 2022

Application Note

Contents

1 Introduction

This document provides information about the power consumption of QN9090 wireless MCU, how the hardware is designed and optimized for low-power operation, and how the software is configured to achieve the best low-power profile. In this document, only QN9090 is mentioned but the measurements apply to the complete family of products including QN9030, QN9090(T), and QN9030(T). This document provides an overview and guidance on how to achieve the best low-power profile while still keeping the high performance of the system. The setup and the procedures to measure the current consumption of the QN9090 chip are also described in this document.

The power consumption of wireless devices is a critical requirement for the fast-coming Internet of Things (IoT) world. As a result, the hardware has been gradually improved and optimized from the power consumption perspective and new communication standards have been developed. Bluetooth Smart also known as Bluetooth® Low Energy (Bluetooth LE) is part of these new standards that have been developed for long-term battery operation, typically years.

QN9090 is a radio wireless MCU that supports Bluetooth LE v5.0 protocol.

The prerequisites for understanding this document are that the reader has good knowledge about Bluetooth Smart protocol, as well as basic knowledge about ARM MCU architecture, and radio communication basics.

2 Bluetooth Smart Power metrics

2.1 Communication steps

During Bluetooth Low Energy communication steps, both MCU and radio are in a different state at a different moment. They are either in active, sleep, or deep sleep mode. The time spent in sleep/deep sleep is the longest compared to all other operation modes as explained in the below figure.

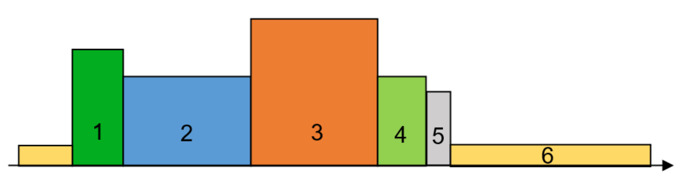

Figure 1. Bluetooth Low Energy communication steps

1. The MCU is woken up and performs system initialization and pre-processing
2. The radio transceiver is woken up and ready to operate. The MCU may enter the STOP mode of the MCU if the software allows it.
3. The radio transceiver is performing one or more RX/TX sequences

4. The MCU is processing the received or transmitted packets
5. The radio transceiver is put back in sleep mode
6. The MCU enters low-power (sleep/deep sleep mode)

2.2 Bluetooth Low Energy events

Two events are considered during Bluetooth Low Energy (Bluetooth LE) communication. They are described in the following sections and their power consumption is described in Advertising mode and Connect mode.

2.2.1 Advertising mode

All communications between two devices start from advertising events.

Devices can advertise for various reasons:

–To broadcast promiscuously

–To transmit signed data to a previously bonded device.

–To advertise their presence to a device wanting to connect.

–To reconnect asynchronously due to a local event.

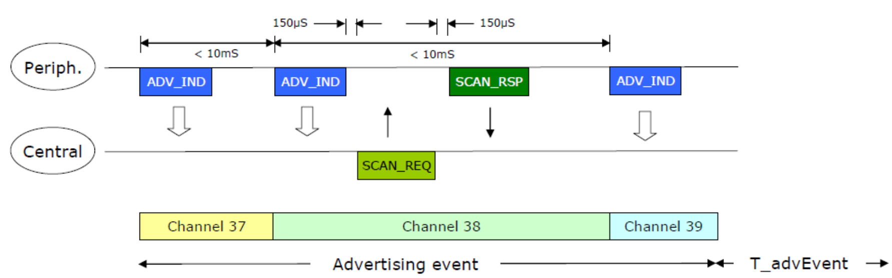

Figure 2. Communication start process between two devices

2.2.2 Connect mode

Once a connection is established:

- Master informs slave of hopping sequence and when to wake
- All subsequent transactions are performed in the 37 data channels (from channel 0 to channel 36)
- Transactions can be encrypted
- Both devices can go into deep sleep between transactions

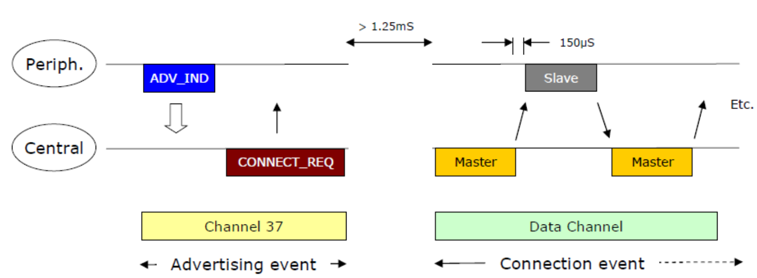

Figure 3. Connection mode process between two devices

- It occurs even when one (or both) sides have no data to send:

— Occurs periodically

— Slave devices can use slave latency, that is number of times it can ignore connection events from the master when there is no data to transmit

3 Getting ready for low-power measurement

Specific applications software and hardware are used for the current measurements. The below sections describe how to set the hardware and the software to set the device in different modes to perform the low-power measurement. All the low-power measurements are done on the slave device. However, a master device will also be needed to perform measurements in connected mode.

3.1 Hardware configuration

The power consumption is measured on an optimized DK6 board for low-power tests with the QN9090 module fitted as slave. The master device is a DK6 board with a QN9090 module fitted. This board is available in the QN9090DK Development Kit. The QN9090 module is plugged into the DK6 board (JM1/JM2) because of the mezzanine interface.

The slave device is a DK6 board that has been modified for low-power measurement as presented in the IoT-ZTB-DK006 Development Kit user guide UM11393. More details on the connection are described in the next chapter.

The test set-up block diagram is shown in the following figure.

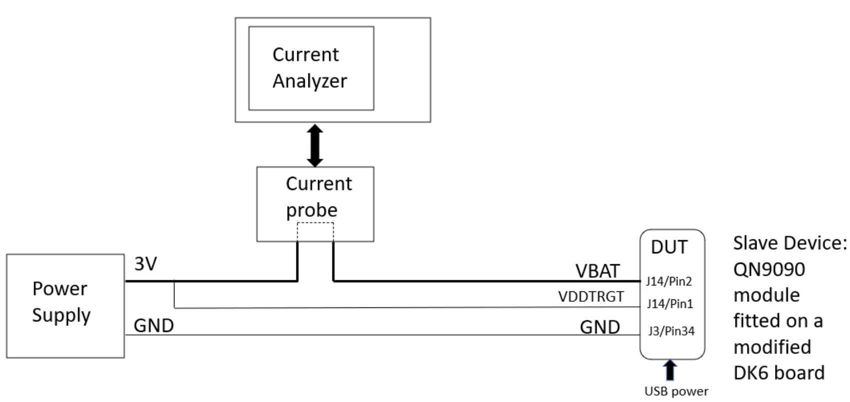

Figure 4. Test setup block diagram for power profile measurement

The board configuration is as follows:

The current probe of the current analyzer (Keysight CX3322A for instance), in series with an external power supply, is connected to J14 on pin 2.

From a supply standpoint VBAT = VDDTRGT.

A picture of the test connections is shown here:

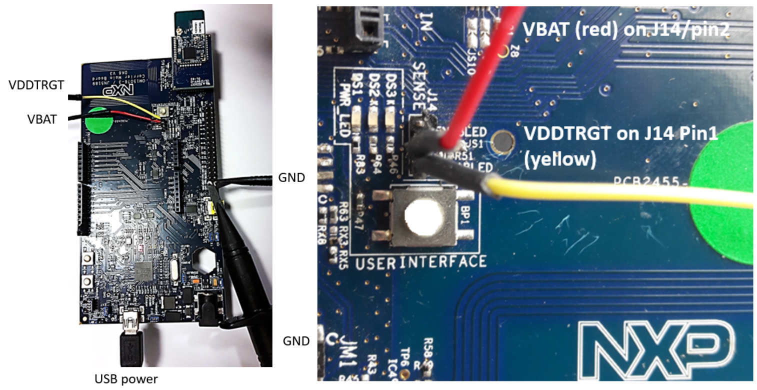

Figure 5. Hardware connection for Low-power measurement (external power supply)

NOTE

Especially for the deep power-down currents, a power supply capable of measuring low currents such as Keysight B2902A Source/Measure Unit is preferred to the current waveform analyzer. The test set-up block diagram is shown in the following figure.

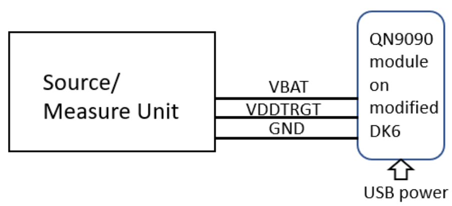

Figure 6. Test setup block diagram for deep power-down currents with a Source/Measure Unit

3.1.1 QN9090 DC-DC converter modes

On both the devices, only the Buck mode is enabled.

More details can be found in the DC-DC guidelines application note AN12893.

3.1.2 QN9090 Low-Power modes

Power-Down currents from the data sheet are described below:

Table 1. Deep Power-Down and Power-Down modes

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
I_{DD}	Supply current	Deep Power-Down (everything is powered off, wake-up on HW reset only)	-	250	-	nA
		Deep Power-Down-IO (everything is powered off, wake-up on HW reset only or an event on any of the 22 GPIOs and NTAG interrupt)	-	350	-	nA
		Power-Down (wake-up on HW reset or an IO	-	800	-	nA

Table continues on the next page...

Table 1. Deep Power-Down and Power-Down modes (continued)

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
		event, wake-up timer ON, 32 kHz FRO on, no SRAM retention)				
		Power-Down-4K (wake-up on HW reset or an IO event, wake-up timer on, 32 kHz FRO on, with 4 KB SRAM retention)	-	1025	-	nA
		Power-Down-8K (wake-up on HW reset or an IO event, wake-up timer on, 32 kHz FRO on, with 8 KB SRAM retention)	-	1120	-	nA

NOTE

Each additional 4 KB consumes around 105 nA.

On the slave device, the modes are selected when the **User interface** button (BP1) is pushed.

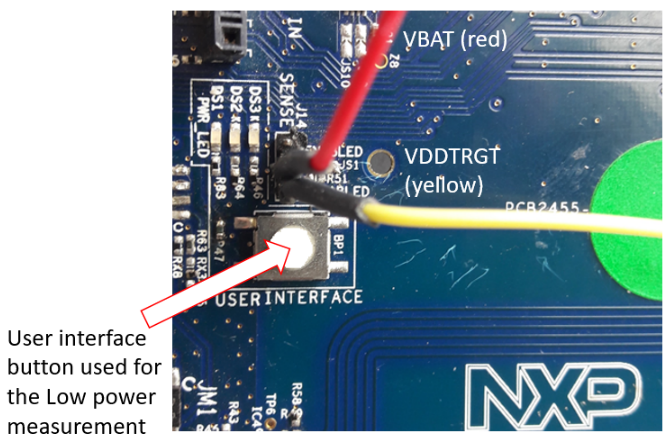

Figure 7. User interface button location

The user can evaluate low-power currents in the configurations described below by pressing the user interface button to navigate from one state to the next.

Table 2. Low-power application modes

Button press	Mode	Corresponding data sheet mode	Comments	Reference value @ 3 V
0 / power ON	Power-Down mode	Power-Down (wake-up on HW reset or an IO event, wake-up timer ON, 32 kHz FRO on, no SRAM retention).	Bluetooth LE device is in Power-Down mode where all blocks are de-activated except the low-power timer and QN9090 is waiting for an internal wake-up event from its low-power timer or IO event (no memory retention).	800 nA

Table continues on the next page...

Table 2. Low-power application modes (continued)

Button press	Mode	Corresponding data sheet mode	Comments	Reference value @ 3 V
1	DPD-IO	Deep Power-Down-IO. Everything is powered off, wake-up on HW reset only or an event on any of the 22 GPIOs and NTAG interrupt) (for QN9090(T) or QN9030(T))	Bluetooth LE device is in Deep Power-Down mode where all blocks are de-activated and QN9090 is waiting for an IO event (no memory retention).	350 nA
2	Sleep	N/A	Sleep mode Bluetooth LE Device is in sleep mode where most of the blocks are activated and SRAM content is maintained.	1 .9 mA
3	Rx Idle	-	Bluetooth LE device is fully operational and able to receive and transmit at any time.	2.4 mA (receiving or ready to receive, No TX)
4	Advertising mode WARNING The current measure is between two advertising events	Power-Down 36 KB (between Advertising events)	Between two advertising events, the Bluetooth LE device is in Power-Down mode where several blocks are off except the low-power timer, and the SRAM retention is at 36 KB to ensure a fast wake-up. This mode can also be used between connection events. NOTE If time accuracy is required for connection event wake up, XTAL 32 kHz shall be used instead of FRO 32 kHz.	1.9 µA

3.2 Software configuration

3.2.1 Bluetooth Smart application configuration

The software is configured for two devices namely: Master and Slave. The slave is configured to advertise and then connect to the master. The master is configured to scan and connect to the slave device. As mentioned before, all the low-power measurements are done on the slave device. However, a master device will also be needed to achieve the measurements in connected mode. This can be achieved in two ways:

- By using a second DK6 board mounted with its corresponding QN9090 modules (available in QN9090DK) connected to a computer.
- Or by using NXP IoT Toolbox mobile phone application.

Different configurations for the Master side will be detailed in chapter 3.2.2.2

3.2.2 Preparing the Slave software

The software can be uploaded from the SDK. The slave application is named `QN9090dk6_power_profiling_bm`. To upload the bin files to the master and slave devices, use a flash programmer. For the detailed instructions, see application note JN-SW-4407 in the Tools folder of the SDK. To perform the power measurements, flash `QN9090dk6_power_profiling_bm.bin` must be on the slave device.

3.2.2.1 Software modification required to the power profiling project

To achieve the power setting, the following changes are required to the power profiling project within the SDK. An explanation of how to import the application is detailed in “Getting Started with MCUXpresso SDK for QN9090.pdf” delivered with the QN9090 SDK. Once the application is imported, the following files and changes are required prior to compiling and testing.

3.2.2.2 App_preinclude.h

Because the app only requires one button to switch from one power state to another, the following lines inside app_preinclude.h of the power profile project must be changed as follows:

```
/* Defines the number of available keys for the keyboard module: counting buttons and TSI keys  */
#define gKBD_KeysCount_c                1
```

The LEDs that are detailed in this document show the mode that the device is in. The LEDs must be disabled to achieve the low-power values detailed in this document. Therefore, the following line of code must be changed as below:

```
/* Specifies the number of physical LEDs on the target board */
#define gLEDsOnTargetBoardCnt_c         0
```

The UART debug must be disabled and it is done by adding the following line of code:

```
/* disable debug */
#define SDK_DEBUGCONSOLE DEBUGCONSOLE_DISABLE
```

To prevent any compilation issue, you must remove the definition of SDK_DEBUGCONSOLE in the project settings by removing the below preprocessor symbol:

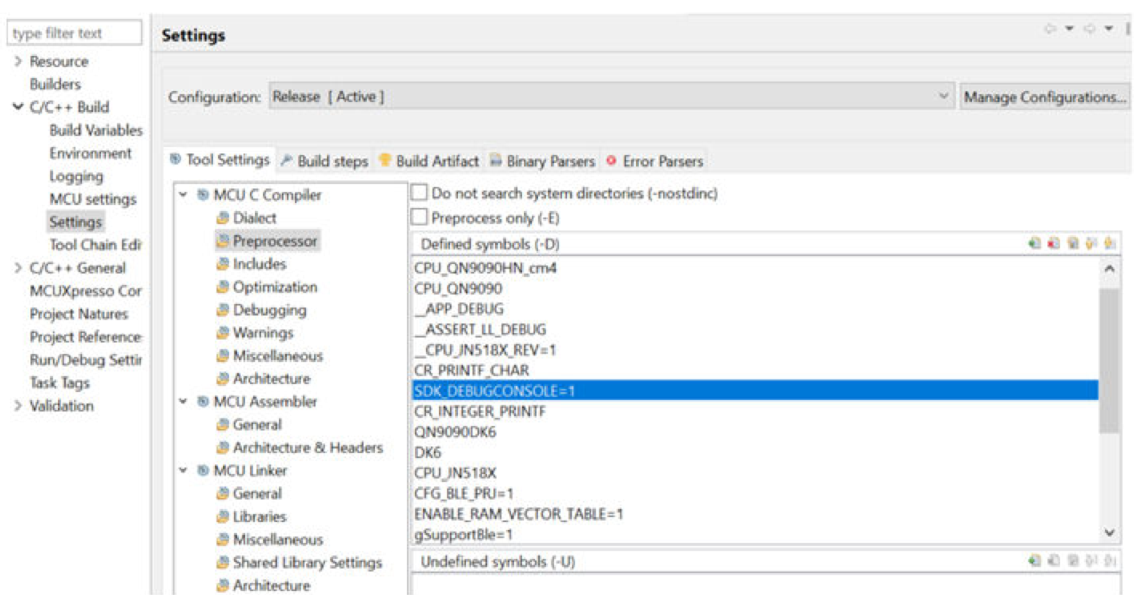

Figure 8. Power profiling preprocessor settings

3.2.2.3 powerprofile.h

Average power consumption varies with the value of interval in both advertising and connection events. The less the interval is, the higher the power consumption is. Interval tuning for a specific application is crucial to leverage between power consumption and transaction time. Advertising interval can be adjusted by modifying the macro definition in the project file.

The advertising interval modification can be accomplished by changing values of macro definitions in file `power_profiling.h` of the `power_profiling` project. The default values are:

```
#define gReducedPowerMinAdvInterval_c   1600 /* 1 s */
#define gReducedPowerMaxAdvInterval_c   4000 /* 2.5 s */
```

By default, during the advertising interval, two macros do not share values, so that the Bluetooth LE controller can select a proper one. To have a known and fixed interval, these two macros take the same value in the unit of 0.625 ms. In the case of a specified 500 ms interval, a value 800 = (500 ms / 0.625 ms) is set for the two macros. Therefore, the values must be changed to:

```
#define gReducedPowerMinAdvInterval_c   1600 /* 1 s */
#define gReducedPowerMaxAdvInterval_c   1600 /* 1 s */
```

3.2.2.4 powerprofile.c

In the file `powerprofile.c` of the power profile project, the following 2 lines of code must be added to confirm that the radio setting is set to 0 dBm, as defined in `board.h`. The lines of code must be added after the function call to Bas_Start (&basServiceConfig).

```
/* Set power level - default in board.h but can be overwritten in app_preinclude.h */
Gap_SetTxPowerLevel(gAdvertisingPowerLeveldBm_c, gTxPowerAdvChannel_c);
Gap_SetTxPowerLevel(gConnectPowerLeveldBm_c, gTxPowerConnChannel_c);
```

3.2.2.5 Gpio_pins.h

Changes are only required within this file if the user is not using a DK6 board as the slave. In this example, the slave device is a modified DK6 with a QN9090 module fitted which uses a user interface (GPIO 1) to change functionality. Therefore the following must be changed, to represent a GPIO that is an input/button/switch on their designed board:

```
#define BOARD_USER_BUTTON1_GPIO_PIN          1U
```

After all these needed modifications are done, the slave application is ready to be compiled and flash into the QN9090 module. The next needed part is to configure the master device.

3.2.3 Preparing the Master software

As mentioned before, the master can be either a QN9090 module plugged into the DK6 board (JM1/JM2), properly configured, and connected to a laptop or a smartphone with the NXP IoT Toolbox application installed. In this chapter, we explain how to set up and use both configurations.

3.2.3.1 QN9090 module acting as Master

To use as QN9090 module as a master, the easiest solution is to use the QN9090dk6_ble_fsci_black_box_bm application. This application can be found in the SDK and must be flashed on the master device. It must be used with the Connectivity Qtool application running on a laptop to control the master device. Connectivity Qtool can be downloaded from here.

1. Run Connectivity Qtool on the PC. The following screen should be displayed:

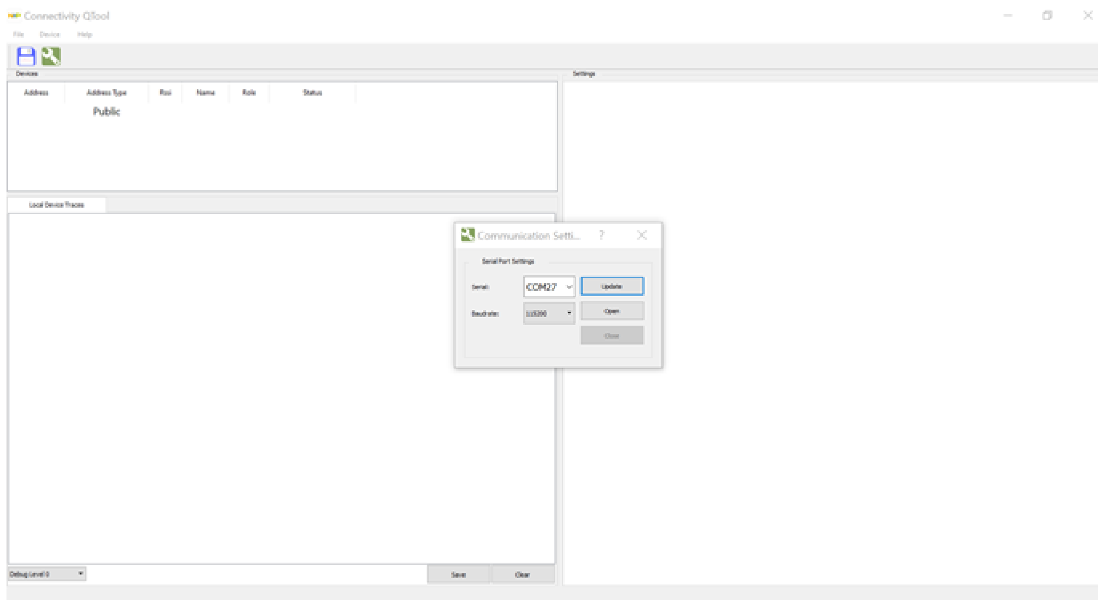

Figure 9. Master device communication port opening

2. Select the serial port of the master device and click Open.
3. A device address appears in the Devices window.

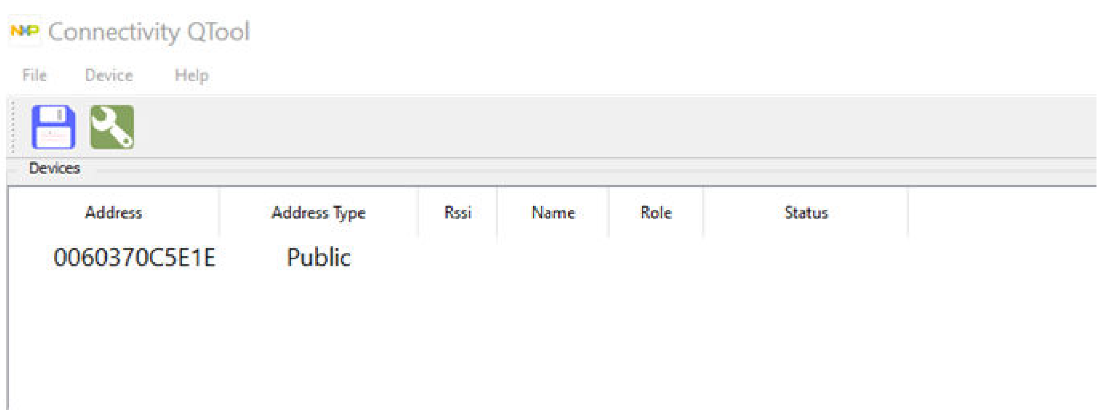

Figure 10. Master device address (example)

4. To start the scanning of the master device, select the device and click Start Scanning button.

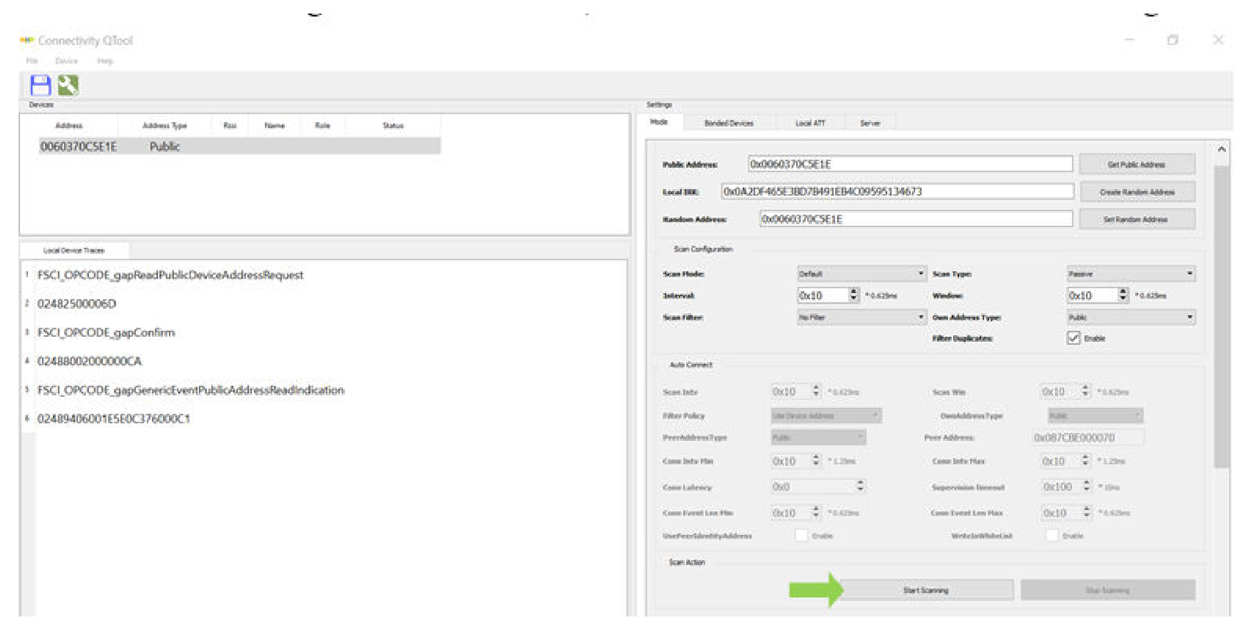

Figure 11. Master device scanning start

5. If the slave is advertising (if not, press the user interface button on the slave device to start it), it should appear in the Devices menu.

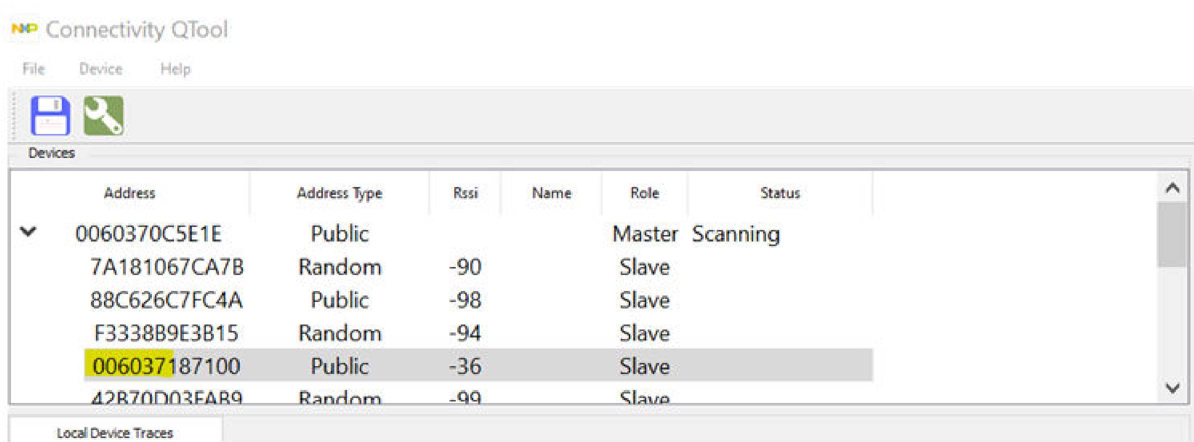

Figure 12. Slave device address (example)

Once the slave is scanned, scanning can be stopped with the Stop Scanning button in Qtool.

6. Select the slave device (left-click it) and set the connection parameter in the right panel. In our test, the connection interval is set to 100 ms (80*1.25 ms)

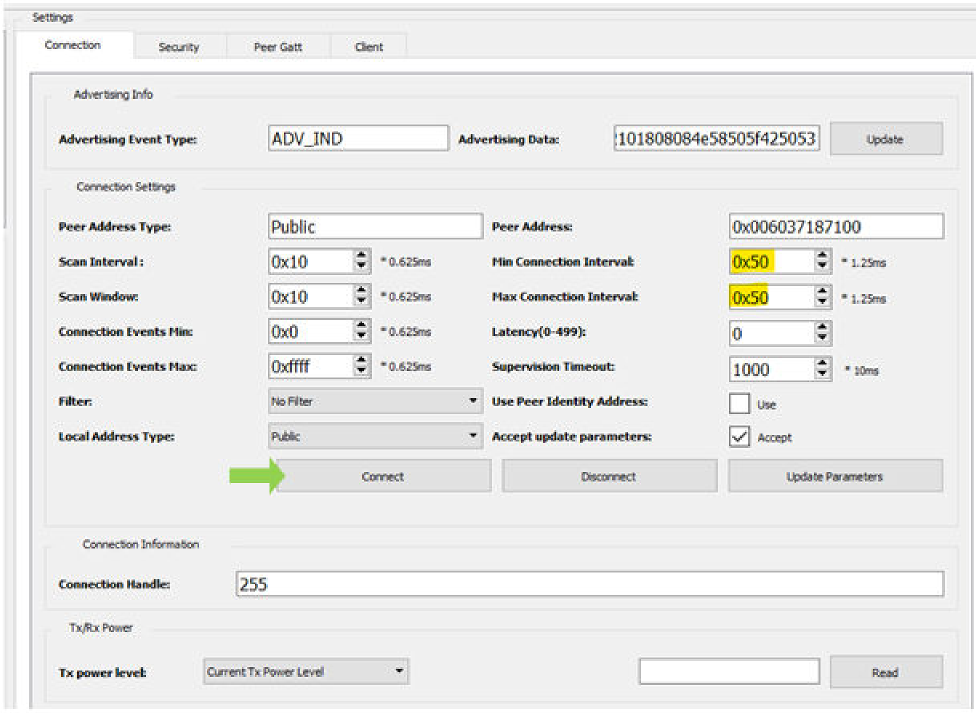

Figure 13. Connection to the slave device

3.2.3.2 Smartphone acting as Master

Test set-up: A smartphone with IoT Toolbox application (available on Google® Play as well as on Apple® App Store) and the QN9090 fitted on modified DK6 with the slave binary on the modified DK6 board as in chapters above.

The procedure is as follows:

1. Open the IoT toolbox application on your cell phone.
2. Select the Blood Pressure icon.
3. The cell phone automatically starts scanning for available slave devices.
4. On the slave device, press sequentially 4 times on the user interface button to go into advertising mode.
5. The cell phone detects the slave device. The following figure shows the cell phone app prior to connecting to the slave.

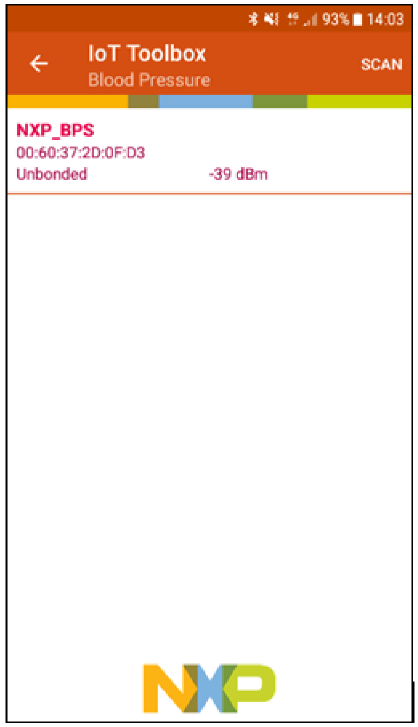

Figure 14. Screen capture of scanning step

The slave device is detected as 'NXP_BPS' in this example.

6. Click the NXP BPS device on your mobile application to connect to it.

   When connected, the data is received and can be displayed as:

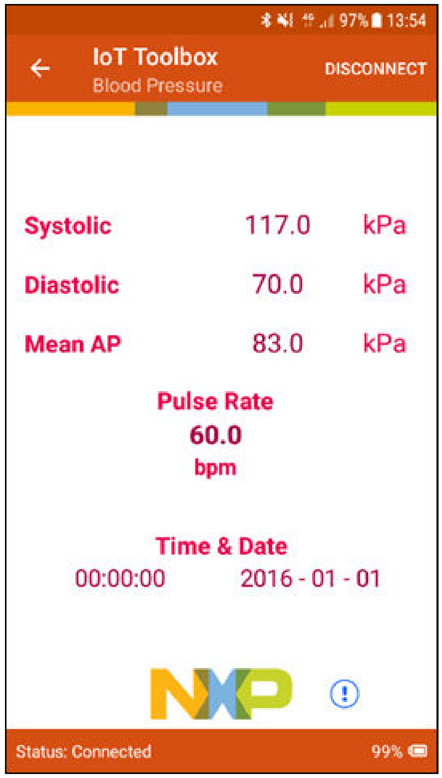

Figure 15. Screen capture of connecting step

The measurements can be run on the slave device in the same way as with the QN9090 FSCI Black Box application as master.

4 Low-power results

4.1 Low-Power modes

Table 3. Low-Power modes

Button pressure #	Reference values	Measurement @ 3 V	Unit
0 / power ON	800	890	nA
1	350	330	nA
2	1.90	2.20[1]	mA
3	2.40	2.31	mA
4	1.90	1.80	µA

1. The current can be lowered a little without the Pull Up resistance (R47) and be closer to 1.90 mA

4.2 Advertising mode

Device configuration:

- TX output power: 0 dBm
- RAM retention: 36 kB
- Payload: 31 B
- Clock: 32 MHz

After pressing 4 times the user interface switch on the slave device, the advertising mode is launched as described in Table 2.

A sniffer is used to capture over-the-air communication. The following is an example:

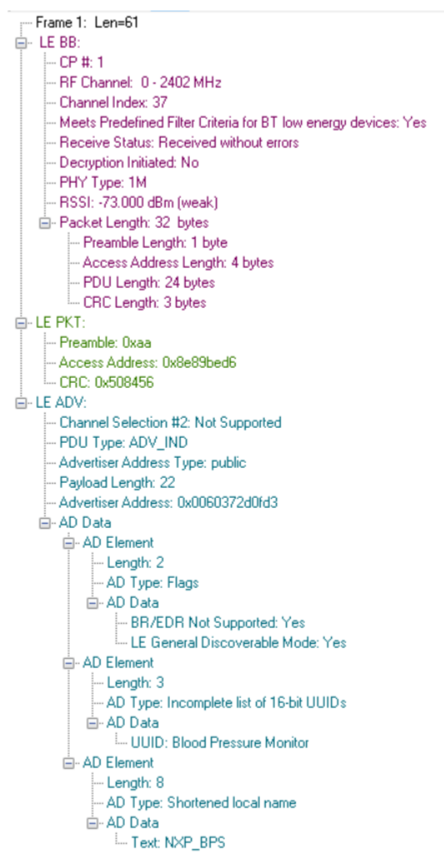

Figure 16. Advertising sniffer log

At this point, the current can be measured. The waveform of the advertising event is as follows:

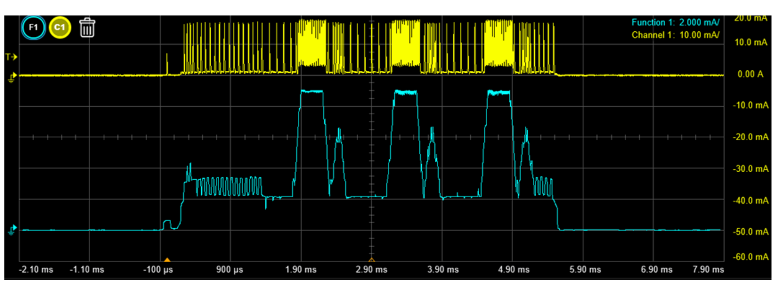

Figure 17. Advertising event

The power profile is analyzed and the energy consumption can be measured at 6.288nAh under 3.0 V. The total event duration is 5.64 ms.

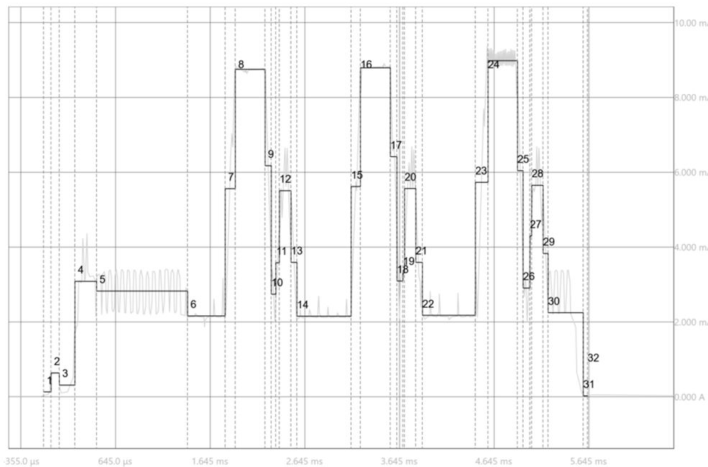

Figure 18. Advertising power profile

Table 4. Advertising break down table

Event	Duration	Current at 3 V
1Power-Down mode	-	1.80 µA
2. awakes from Power-Down mode	86.7 µs	638.7 µA
3 to 6. Pre-processing [including stack and Radio initialization]	1.752 ms	311.2 µA to 3.085 mA
7. TX warm up	106.8 µs	5.561 mA
8. Active TX	314.9 µs	8.750 mA
9 to 11. TX to RX	150.1 µs	4.439 mA
12. Active RX	123.0 µs	5.507 mA
13. Rx warm down	62.75 µs	3.592 mA
14. MCU STOP	572.3 µs	2.153 mA
15. TX Warm up	97.89 µs	5.620 mA
16. Active TX	316.3 µs	8.793 mA
17 to 19. TX to RX	150.6 µs	4.273 mA
20. Active RX	118.0 µs	5.565 mA
21. Rx warm down	70.28 µs	3.592 mA

Table continues on the next page...

Table 4. Advertising break down table (continued)

Event	Duration	Current at 3 V
22. MCU STOP	559.7 µs	2.176 mA
23. TX Warm up	133.0 µs	5.732 mA
24. Active TX	311.2 µs	8.982 mA
25 to 27. TX to RX	150.6 µs	4.415 mA
28. Active RX	120.5 µs	5.652 mA
29. Rx warm down	52.71 µs	3.830 mA
30. Post processing	416.68 µs	2.271 mA
31. Power Down mode	-	1.80 µA

NOTE

With a 48 MHz clock, the total energy is 5.603 nAh under 3.0 V.

4.3 Connect mode

Device configuration:

- TX output power: 0 dBm
- RAM retention: 36 kB
- Payload: 0 B
- Clock: 32 MHz

When the advertising is launched on the slave device, the scanning and connection on the master can be started as described in QN9090 Low-Power modes.

The connect waveform is as follows:

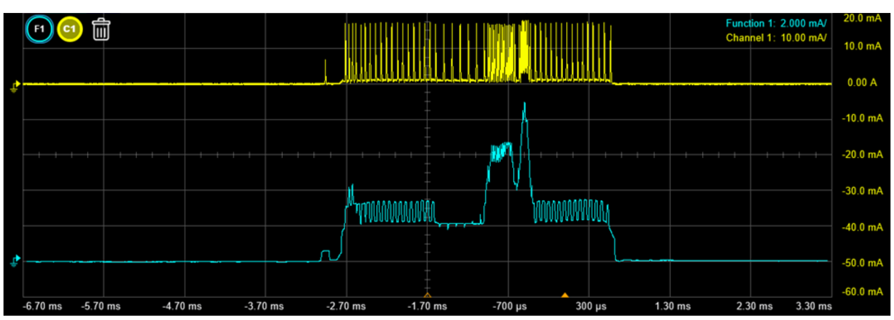

Figure 19. Connect event

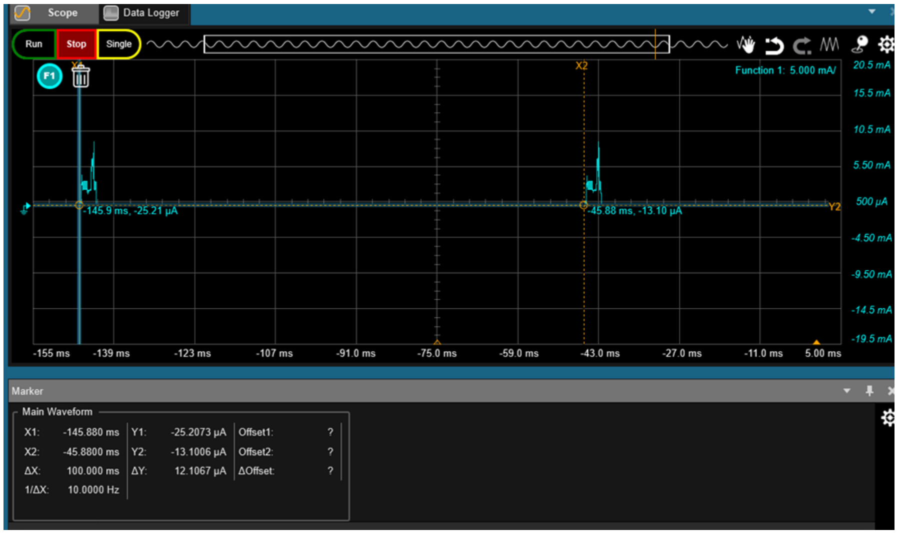

Figure 20. Connect period 100 ms

Following is an example of a sniffer capture of a Connect event.

The first frame is a Link Layer Feature Request from the master device.

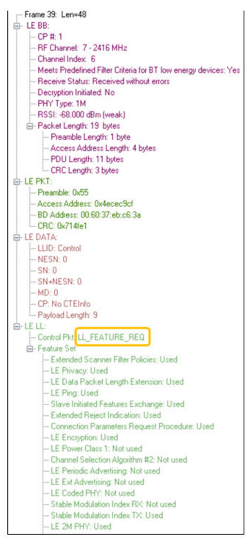

Figure 21. 1st Connect frame sniffer log

The slave corresponding packet response is as follows:

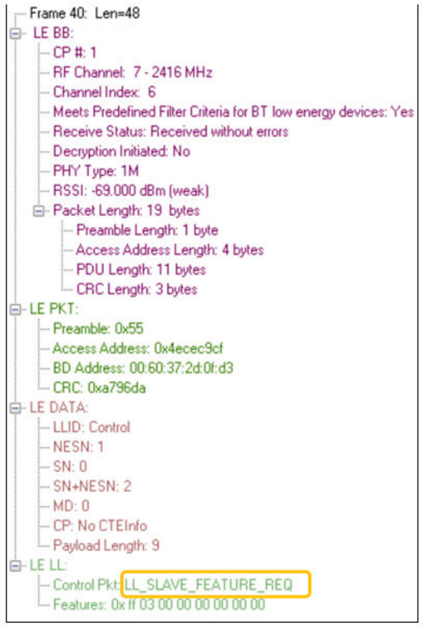

Figure 22. 2nd Connect frame sniffer log

The master then responds to the slave feature request.

Figure 23. 3rd Connect frame sniffer log

And the slave responds to the master feature request.

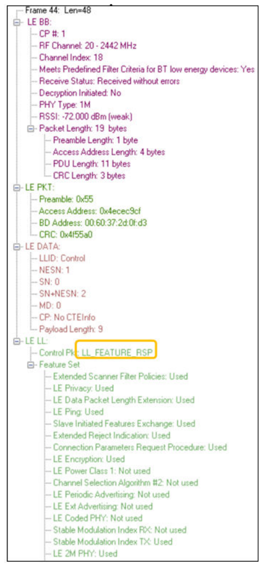

Figure 24. 4th Connect frame sniffer log

At this point, the devices are connected.

The power profile of the connect event is shown in the following figure, the total energy is 3.044 nAh under 3.0 V. The total event duration is 3.299 ms.

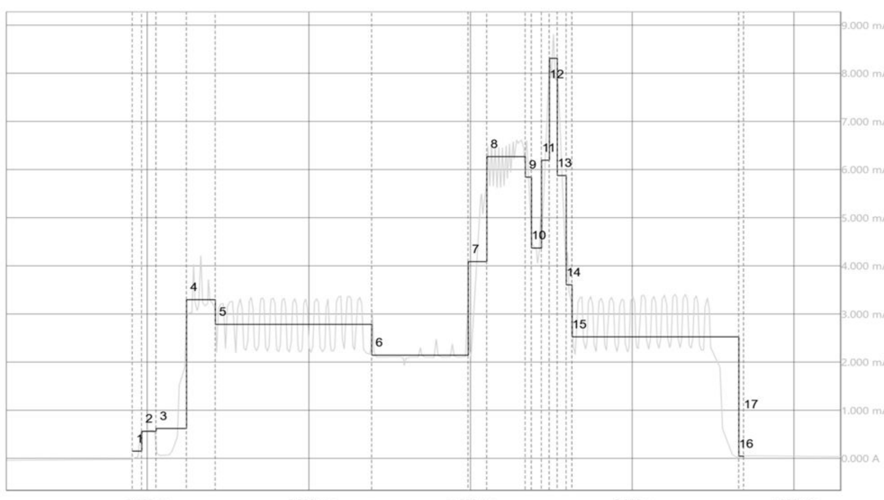

Figure 25. Connect event power profile

Table 5. Connect event breakdown table

Event	Duration	Current at 3 V
1. Device in Power-Down mode	-	1.80 µA
2 to 6. Pre-processing [including stack and Radio initialization]	2.019 ms	561 µA to 3.298 mA

Table continues on the next page...

Table 5. Connect event breakdown table (continued)

Event	Duration	Current at 3 V
7. RX Warm up	115.1 µs	4.087 mA
8. Active RX	238.1 µs	6.269 mA
9 to 11. RX to TX transition	148.9 µs	5.468 mA
12. Active TX	48.81 µs	8.310 mA
13 to 14.TX warm down	88.97 µs	4.989 mA
15 to 16. MCU Post-processing	1.061 ms	2.455 mA
17. SoC back to Power-Down mode	-	1.80 µA

5 Conclusion

This application note provides an overview of how to evaluate the low-power current consumption on a QN9090 during Bluetooth LE communication events. The measurements are done on an NXP QN9090DK development kit and can be replicated on the customer side. All the measurements are in line with the specification.

6 Revision History

Table 6. Revision history

Revision number	Date	Substantive changes
0	06/2020	Initial release
1	07/2020	Latest NXP template
2	31 May 2022	Sections 2.1, 3, 4 are updated, section 5 is removed.
3	24 June 2022	Figure 4 is updated, minor corrections

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Definitions

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Date of release: 24 June 2022

Document identifier: AN12902