AN01786

QN908x Power Consumption Analysis

Rev. 2 — 29 January 2018 **Application Note**

Document information

Info	Content
Keywords	QN908x, BLE, BTLE, Average Power, Current, Power consumption, Bluetooth Smart
Abstract	This Application Note describes in brief power consumption testing using the QN908x Evaluation boards. The terms BLE, BTLE and Bluetooth Smart will be used interchangeably.

Revision history

Rev	Date	Description
2	20180129	Parameters and data updating based on current QN908x SDK.
1	20170612	Additional test information, BLE average power test procedure.
0	20150513	QN908x Power consumption test.

Contact information

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1. Introduction

When designing a system, power consumption is one of the most important indicators to verify the optimization of the design. The Bluetooth Low Energy (BLE) or Bluetooth Smart standard from inception was drafted to be a low-power protocol. Initially the target industry was wearable and fitness. With new innovations on the horizon, BTLE is also being used for medical devices, robotics, direction finding beacons, etc. The varying portfolio has prompted designers to verify, test and optimize power consumption to build systems that can have a longer field life, without the need of changing batteries or being recharged.

This application note shows how to measure power consumption for NXP's QN908x series of BLE products. Of the QN9080 sample being showcased in this application note, the same setup arrangement and measurement matrix can be used for all the QN908x BTLE products. QN908x is a SOC which comprises of MCU and RF circuitry. The total power consumption of the QN908x is a combination of the power consumed by each of the system blocks. Therefore, power optimization requires tweaking these sections individually to obtain an efficient low power system. In this application note, we consider the power consumption test setup with a specific profile loaded on the QN9080. The results will vary on the profile selected by the user.

The reader of this application note is assumed to understand the BTLE standard and has gone through the QN908x product datasheet. Tests mentioned in this document have been performed in a lab, and is for customer reference only. The test results may be different from those shown in this application note because they are dominated by the test equipment at the customer site and other system details.

2. QN908x power consumption testing

This section describes what a power consumption test setup could look like. An example power measurement of the QN908x will be shown using the DK for QN9080. This development kit can be ordered through NXP website.

2.1 Test preparation

2.1.1 Test setup

1. Hardware
   - NXP's QN9080 DK
   - NXP's QN9080 USB dongle
   - Test equipment: Power analyzer or Oscilloscope&Ammeter
2. Software
   - Keil, IAR or MCUXpresso IDE environments
   - Application: Power evaluation project power_profiling under QN908x SDK directory
   - QTool: It behaves as a master together with USB dongle and can be found in Startup menu by directory NXP/QN908X/Tools/Connectivity QTool.

2.1.2 Power consumption test connector

Fig 1. Power consumption test connector

JP14 is the power consumption test connector, supplying the power to QN9080(U1). It's shorted normally by a jumper. When testing power consumption, it connects a test equipment, which may be an Ammeter, Oscilloscope or a Power Analyzer.

When project power_profiling is used to test power consumption, JP8 is disconnected to prevent leakage from UART. JP15 is open to prevent leakage from the GPIO pin.

2.1.3 Interval change

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

1. Advertisement interval change

   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 as shown in Fig 2.

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

Fig 2. Default advertising interval

Generally, two macros don't share the same values, so the BLE controller can choose 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.

2. Connection interval change

   Connection interval modification can only be set after setup connection by the connection parameters change commands. PC based tool, QTool and USB dongle, is used to set up the connection and issue parameter update commands, so that a connection interval can be set as expected. Fig 3 shows the screenshot of QTool window.

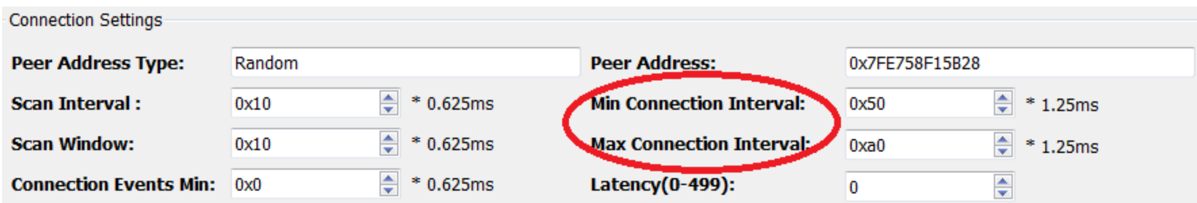

Fig 3. Connection interval change

To have a known and fixed interval, set both the minimum and maximum interval in the unit of 1.25ms. For a 1 s interval, we can set the parameters as below:

```
Min Connection Interval: 800
Max Connection Interval: 800
Slave Latency: 0
Supervision Timeout: 4000
```

2.1.4 Test firmware updating

You can update the power consumption firmware by:

- Updating the bin file via UART interface by ISP Download option in QN908x Programming Tool;
- Downloading the firmware directly by SWD interface after compiling by Keil, IAR or MCUXpresso IDE environments.

Follow the steps below for firmware updating in Keil environments.

1. Power up DK with USB cable via connector J2.
2. Press the Build button or F7 to build the project.
3. Press the Download button or F8 to load the output bin file to DK.
4. Press the Reset button.

2.1.5 Mode change in project power_profiling

QN908x supports four power modes. After power-up, QN908x would be in power down 1 mode. Button 1 is used to switch mode from one mode to the other, until advertisement.

Table 1. QN908x power modes

Button 1 Pressing (times)	Mode	Comments
0	Power down 1	Default state after boot up
1	Power down 0	32K clock running
2	sleep	MCU sleep, BLE sleep
3	Active	MCU active, BLE idle
4	Advertising	Dynamic states

2.2 Measuring current with a DC power analyzer

Test setup

- Power supply: USB cable & Power Analyzer
- TX power: 0 dBm
- Application project: power_profiling
- Equipment: Keysight N6705B Power Analyzer
- Voltage from N6705B: 3 V
- Current: Auto
- Sample Points: 256 K
- SDK project: power_profiling (Bare Metal)

Fig 4. Measuring current with a DC power analyzer

2.2.1 Power down 0/Power down 1

Test procedure

1. Follow steps in 2.1.5 to download application firmware by SWD interface.
2. DK would be in Power Down 1 state after starting up.
3. Push Button1 to make DK in Power Down 0 state if Power Down 0 state to be tested.
4. Setup the power analyzer and capture data.

Table 2. Power consumption in static state

	DC-DC	Power supply (V)	Power down 1 (uA)	Power down 0 (uA)	Sleep (uA)	Active (uA)
Bare metal	ON	1.8	0.99	2.38	556.50	1180.32
		3.0	0.98	2.35	387.47	798.99
	OFF	1.8	0.99	2.37	652.12	1421.08
		3.0	0.98	2.30	681.45	1473.21
FreeRTOS	ON	1.8	1.40	2.78	566.11	1202.32
		3.0	1.39	2.71	390.64	806.59
	OFF	1.8	1.41	2.78	658.48	1443.36
		3.0	1.39	2.71	687.55	1482.42

2.2.2 Advertisement

1. Test procedures
   a. Follow the steps in 2.1.4 to change the advertisement interval.
   b. Follow steps in 2.1.5 to download application firmware by SWD interface.
   c. Push Button1 four times to make DK advertising.
   d. Set up the power analyzer and capture the data.
2. Test result
   a. DC-DC 3.0 V 100 ms interval payload 31 bytes.

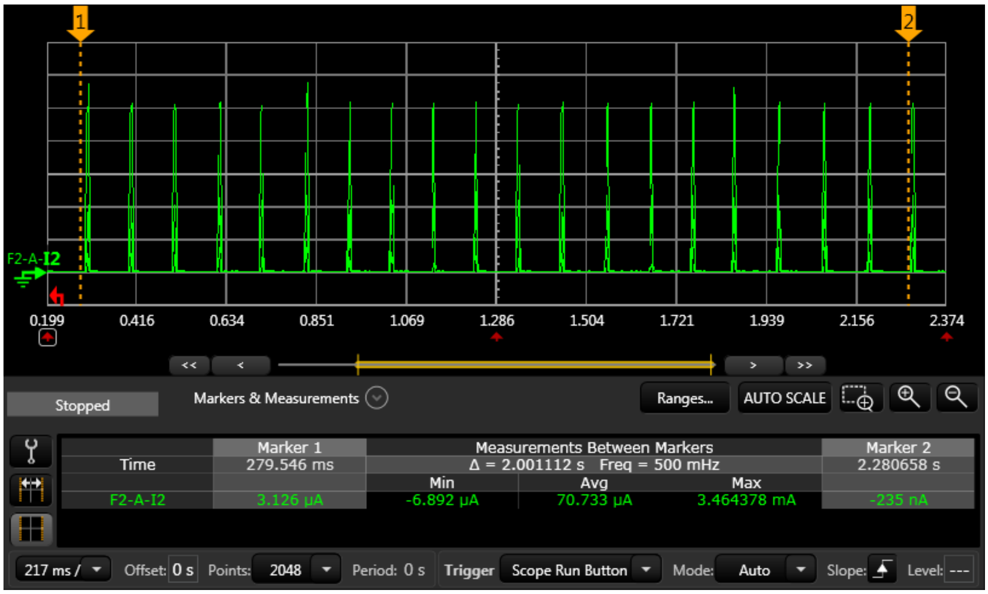

Fig 5. DC-DC 3.0V 100 ms interval - Advertisement

b. DC-DC 3.0 V 1 s interval payload 31 bytes.

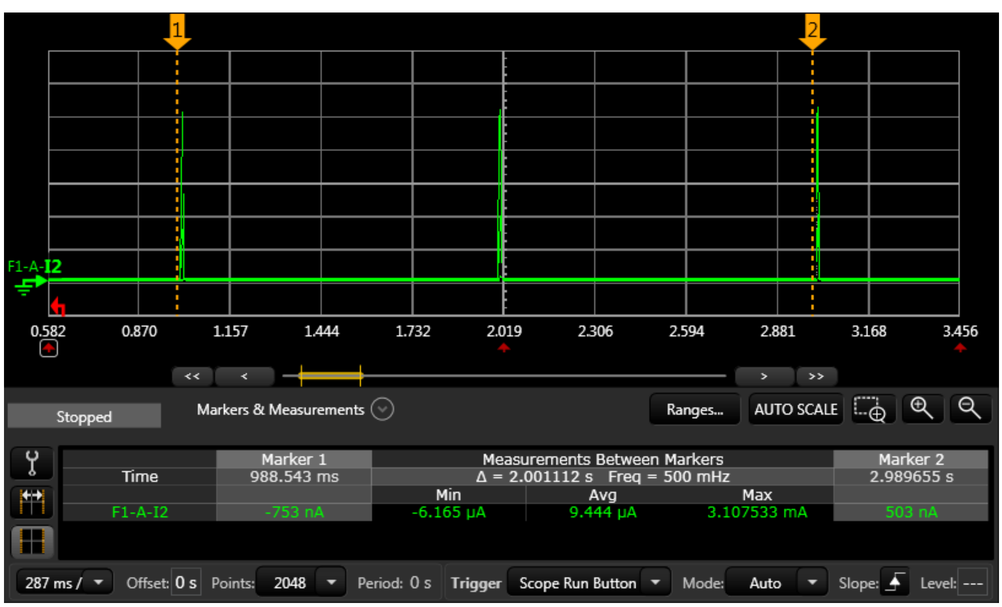

Fig 6. DC-DC 3.0 V 1 s interval - Advertisement

Table 3 is a summary of power consumption in various advertisement cases.

Table 3. Power consumption in various advertisement cases

		Advertisement, payload 31 bytes			
		100 ms interval		1000 ms interval	
	Power supply (V)	Avg. current (uA)	Max. current (mA)	Avg. current (uA)	Max. current (mA)
DC-DC ON	1.8	105.40	5.44	12.94	5.02
	3.0	70.73	3.46	9.44	3.10
DC-DC OFF	1.8	132.31	6.78	16.64	6.84
	3.0	135.95	6.85	17.18	7.07

Remark: How to switch DC-DC on/off? In the main function of the power_profiling project, there is a public API: void POWER_EnableDCDC(bool flag) can help. The flag **True** means DC-DC ON and **False** means DC-DC OFF.

The Jumper 7 on the QN9080 DK can help to switch between VDD 1.8 V and 3.0 V.

2.2.3 Connection

1. Test procedures
   a. Follow steps in 2.1.5 to load application firmware by SWD interface.
   b. Plug in the USB dongle to test PC and run QTool.
   c. Push Button1 four times on DK to start advertising
   d. Click “Connect” on QTool to set up the connection.
   e. Follow steps in 2.1.4 to set the required connection parameters.
   f. Click **Update** to set the connection interval.
   g. Set up the power analyzer and capture the data.
2. Test result
   a. DC-DC 3.0V 100 ms interval empty packet.

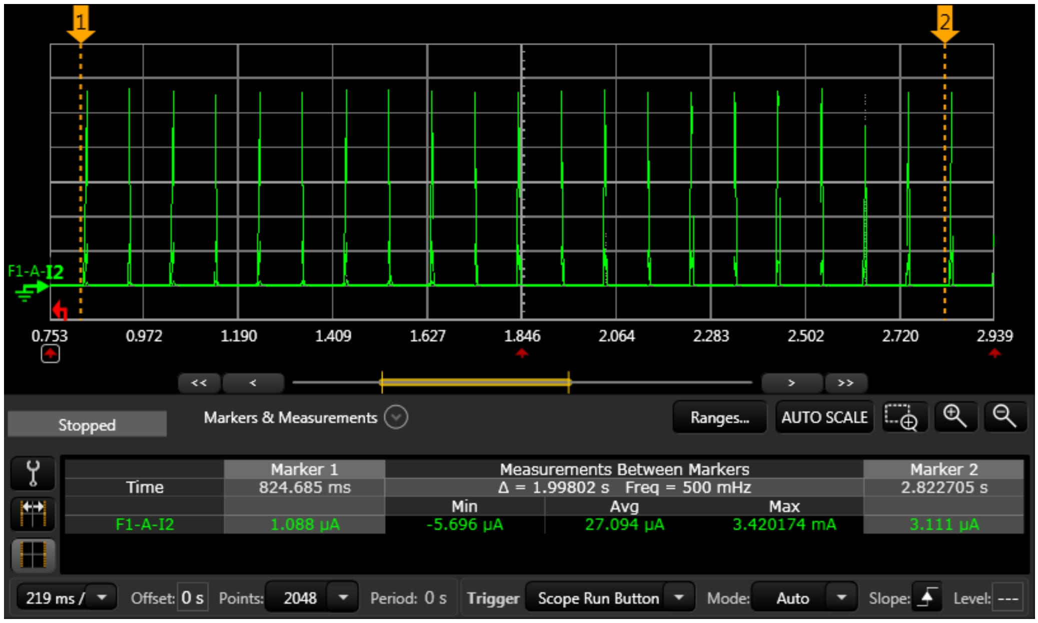

Fig 7. DC-DC 3.0 V 100 ms interval - Connection

b. DC-DC 3.0 V 1 s interval payload 31 bytes

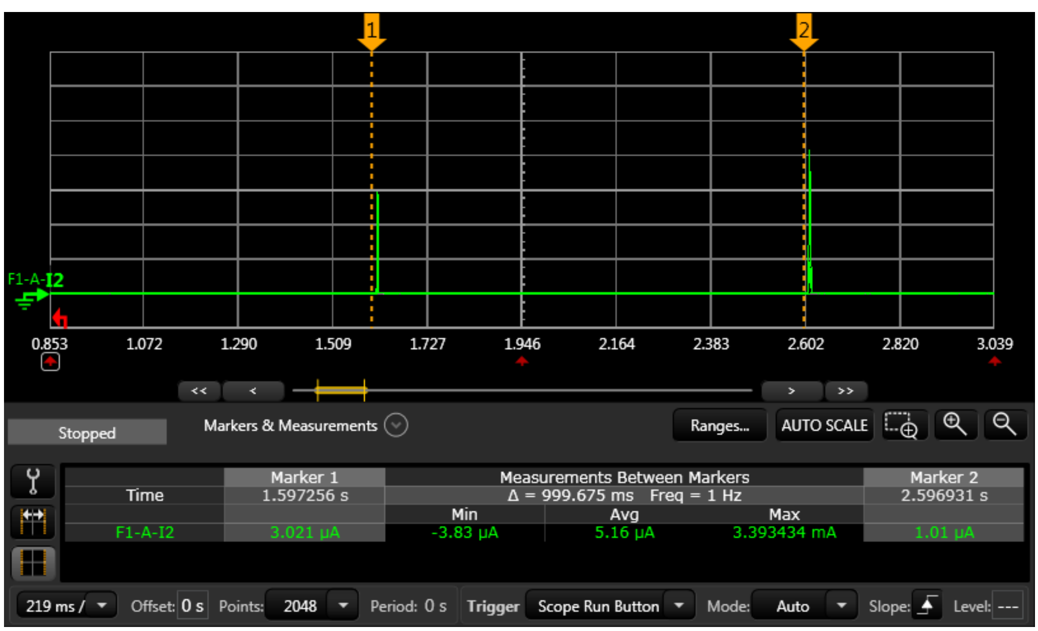

Fig 8. DC-DC 3.0 V 1 s interval - Connection

Table 4 is a summary of power consumption in various connection cases.

Table 4. Power consumption in various connection cases

		Connection, empty packet			
		100 ms interval		1000 ms interval	
	Power supply	Avg. current (uA)	Max. current (mA)	Avg. current (uA)	Max. current (mA)
DC-DC ON	1.8	36.99	5.39	6.45	4.88
	3.0	27.09	3.42	5.16	3.39
DC-DC OFF	1.8	40.75	6.86	7.21	5.92
	3.0	45.51	7.06	7.83	6.27

Remark: How to switch DC-DC on/off? In the main function of the power_profiling project, there is a public API: void POWER_EnableDCDC(bool flag) can help. The flag **True** means DC-DC ON and **False** means DC-DC OFF.

The Jumper 7 on the QN9080 DK can help to switch between VDD 1.8 V and 3.0 V.

2.3 Measuring current with an ammeter and an oscilloscope

QN908x power consumption under Power down 0/Power down 1 mode is only about 1 uA to 2 uA typically. An oscilloscope can't measure such current accurately due to limited sensitivity. The feasible combination is Ammeter and Oscilloscope. An Ammeter can be used for static current, while an oscilloscope for dynamic current from advertisement/connection.

2.3.1 Power consumption calculation

Power consumption is made up of static and dynamic power consumption. When testing with an Ammeter and an Oscilloscope, the test result from the ammeter is static current, while from the oscilloscope is the dynamic current.

With the combination of Ammeter and Oscilloscope, the formula of average power consumption is as below:

$$I = I_{static} + I_{dynamic}$$

$$I_{dynamic} = V_{avg}/R * T_{sampling} / T_{interval}$$

- I_{static} is the current in Sleep mode, which can be read by Ammeter as described above.
- V_{avg} is the average current during advertising/connecting event.
- R is the resistor between the power consumption test connector. The value is less, and the result is more accurate.
- $T_{interval}$ is the time duration between two events.
- $T_{sampling}$ is the time duration of a complete event.

2.3.2 Statistic current test

1. Test setup
   - Power supply: USB cable
   - TX power: 0 dBm
   - Application project: power_profiling
   - Equipment: Agilent 34410A
   - NPLC: 0.006
   - Manual range: 10 mA

Fig 9. Statistic current test - setup

2. Test procedures
   a. Follow steps in 2.1.5 to load application firmware by SWD interface.
   b. DK would be in Power down 1 state after booting up.
   c. Set up the ammeter and read the current value of Deep Sleep on the ammeter.
   d. Push button 1 once, and the DK would be in Power down 0.
   e. Read the current value on the ammeter.
3. Test result

   Table 5 lists the test results for QN908x.

Table 5. Power consumption in power-down mode

	Current	Test result
Power down 1	1.0 uA	0.98 uA
Power down 0	2.3 uA	2.35 uA

2.3.3 Dynamic current test

Test setup

A resistor connects to the power test connector. Oscilloscope is used to monitor the voltage change between the two sides of the resistor. The impedance should be tens of ohm to lower the voltage drop.

- Power supply: USB cable
- TX power: 0 dBm
- Application project: power_profiling
- Equipment: Agilent DSO80204A
- Sample rate: 50 MSa/s
- Probes: 1X attenuation

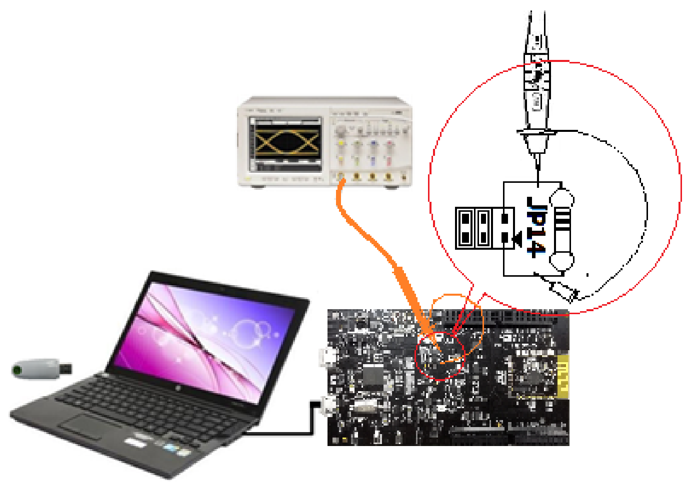

Fig 10. Dynamic current test - setup

2.3.3.1 Advertising

1. Test procedures
   a. Change the advertisement interval
   b. Follow steps in 2.1.5 to download application firmware by SWD interface.
   c. Push Button1 to make the DK advertising.
   d. Set up the power analyzer and capture the data.
2. Test result (try to capture screenshot of whole event, so we can have an accurate average number).

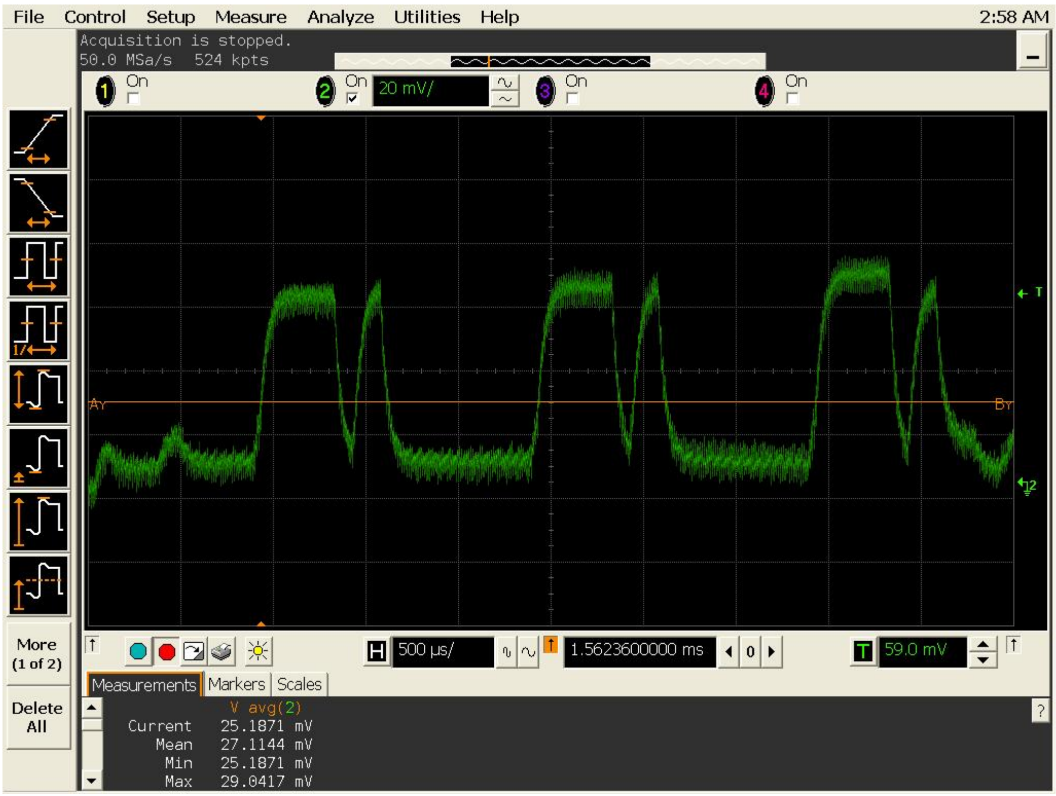

Fig 11. Dynamic current test – test result - advertising

3. Calculation
   - Static current: Per the test result in 2.3.2, Istatic = 2.5uA
   - Dynamic current: Idynamic = 27.11/22*5ms /1000ms = 6.16 uA
   - Per the formula above, Iavg = Istatic+Idynamic = 6.16 + 2.35 = 8.51 uA

2.3.3.2 Connection

1. Test procedures
   a. Follow steps in 2.1.5 to download application firmware by SWD interface.
   b. Plug in the USB dongle to test PC and run the QTool.
   c. Push button 1 on DK to toggle advertising.
   d. Click **Connect** on the QTool to set up connection.
   e. Set the required connection parameters.
   f. Click **Update** to set the connection interval.
   g. Set up the power analyzer and capture the data.
2. Test result

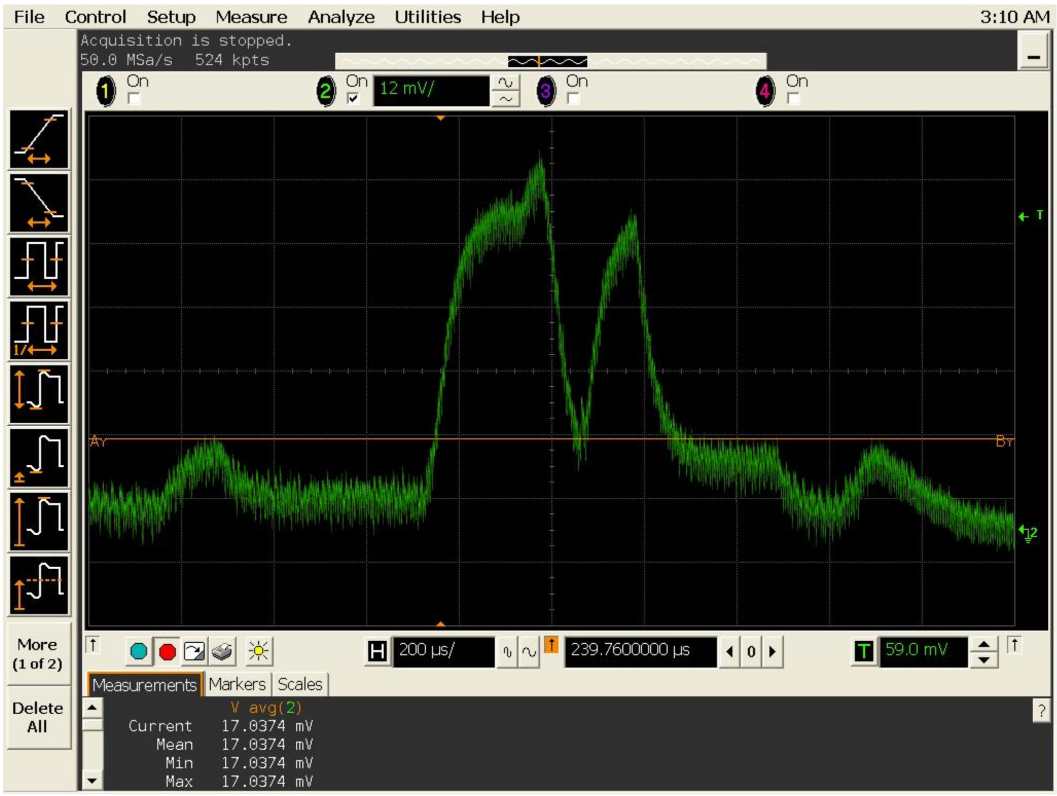

Fig 12. Dynamic current test – test result - connection

3. Calculation
   - Static current: Per the test result in 2.3.2, Istatic = 2.35 uA
   - Dynamic current: Idynamic = 17.04/22*200us *10/1000ms = 1.55 uA
   - Per the formula above, Iavg = Istatic+Idynamic = 1.55 + 2.35 = 3.90 uA

2.4 Power Profile of BLE events

A single BLE event has various power states, such as, Sleep, Active, Tx, Rx, etc. To get a correct assessment of power consumption, obtain an average power consumption from the start of one BLE event to another. Between BLE events, the system, if there is no processing information, is in Sleep mode.

Fig 13 shows a single BLE event when captured on a DC power analyzer. The zoomed in waveform shows the various states in which the BLE SOC QN9080 goes through during a single BLE event.

0 - Power down

1 - DC-DC

2 - Start-up

3 - Pre-processing

4 - BLE RX

5 - RX/TX transition

6 – BLE TX

7 – Post processing

Fig 13. BLE connection event

You can perform the similar analysis when the BLE device under test is in Advertising state.

The tests help to identify individual power consumption of each state and help designers to understand the design constraints optimizing their BLE system.

2.5 Example average power consumption spreadsheet

Power consumption in a single BLE event can be calculated, based on which average power consumption can be evaluated. It’s feasible to get battery life based on the average power consumption for a typical application. A spreadsheet is provided for such purpose.

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4. Contents

Date of release: 29 January 2018
Document identifier: AN01786