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QN908x RF Evaluation Test Guide

Rev. 1 — May 2018   **Application note**

Revision history

Rev	Date	Description
0	04/2018	Initial release.
1	05/2018	Modified the firmware project name for BLE RF test.

1. Introduction

This document provides the RF evaluation and certification test of the QN908x MCU for the BLE and GFSK applications. It includes the test setup, test procedure, equipment, and software tools which help to build the performance test. The RF evaluation test is used to estimate the QN908x RF performance.

The whole test case is done using the QN908x DK board. For more information about the QN9080x DK board, see the *QN908x DK User's Guide* (document QN908x-DK).

Because the QN908x provides the BLE and generic GFSK for different applications, there are different methods using for the RF test. The s-parameters test includes the return loss and impedance shown in a smith chart.

2. Test summary

2.1 RF test cases

The RF test includes the BLE DTM test, GFSK RF test, and normal RF test.

The BLE DTM test includes the Tx transmitting test and Rx receiving test.

Tx transmitting test:

- Tx output power (maximum and average power).
- Carrier frequency offset and drift.
- Modulation characteristics (frequency deviation).
- Tx in-band emissions.

Rx receiving test:

- Rx sensitivity.

The GFSK RF test includes the Tx transmitting test and Rx receiving test.

Tx transmitting test:

- Tx power (maximum and average power).
- Carrier frequency offset.
- Modulation characteristics (frequency deviation).
- FSK error.
- Tx in-band emissions.
- Tx out-of-band spurious.
- Phase noise.

Rx receiving test:

- Rx sensitivity.
- Rx carrier/interferer rejection.

2.2 Test setup

2.2.1 Test condition

- Chip power supply Vcc=3.0 V.
- Crystal frequency: 16 MHz or 32 MHz.
- The test is done under room temperature.

2.2.2 List of equipment

This is the equipment used in the BLE and GFSK RF test procedures:

- Spectrum analyzer.
- MXA signal analyzer (Keysight N9020B).
- RF signal generator (Keysight N5182B).
- Network analyzer (Keysight E5080A).
- CWM270 (R&S)

2.2.3 Test RF cable

The QN908x RF signal is tested by the on-trace RF connector on the DK board. This RF connector is built by Murata and has an RF switch. There is a coaxial connector test probe (part number MXHQ87WJ3000). The insertion loss of the MXHQ87WJ3000 is about 1.5 dB, which must be taken into consideration during the sensitivity and output power tests.

2.2.4 RS232 interface with expansion board

When performing the RF connectivity DTM test using the CMW270 instruments system, there must be an expansion board to match the signal voltage level from the UART to the RS232 interface. The RS232 expansion board is supplied from the QN908x DK board through the connectors. The connection of the two boards is shown in Fig 1.
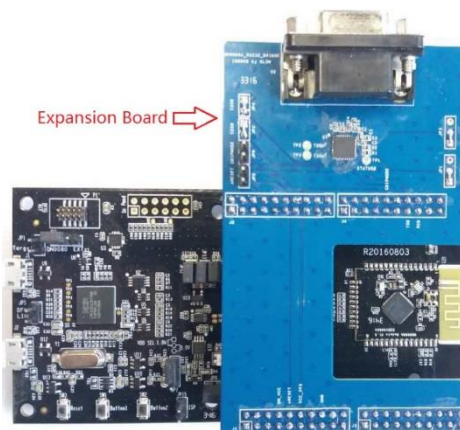

Fig 1.   RF DTM test with expansion board

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3. RF test for BLE

3.1 Tx test

3.1.1 Tx output power

The Tx output power is measured by the CMW270 equipment in the DTM mode.

Test method:

- Use the "*hci-black-box*" project in the SDK and download it to the EUT.
- Connect the EUT to the CMW270 equipment and set the CWM270 into the loopback mode.
- Select the "TX Measurement Power vs. Time" option.

Test results:

- The Tx output power test results contain the average power, peak power, delta value between the peak power and the average power, and the leakage power. The test results are shown in Fig 2.

TX Measurement Power vs. Time				
Statistics	Current	Average	Max	Min
Average Power [dBm]	−0.94	−0.94	−0.94	−0.96
Peak Power [dBm]	−0.65	−0.65	−0.61	−0.69
Peak Power - Average Power [dB]	0.29	0.29	0.33	0.26
Leakage Power [dBm]	−68.83	−70.13	−68.31	−72.26

Statistic Count	Out of Tolerance
100 / 100	0.00 %

Fig 2.   Tx output power

3.1.2 Tx modulation measurement

The Tx modulation is measured by the CMW270 equipment in the DTM mode.

Test method:

- Use the "*hci-black-box*" project in the SDK and download it to the EUT.
- Connect the EUT to the CMW270 equipment and set the CWM270 into the loopback mode.
- Select the "TX Measurement Modulation" option.

Test results:

- The Tx modulation measurement test contains the frequency accuracy, frequency offset, and frequency drift frequency deviation (Δf1 and Δf2), where Freq. Dev. Δf1 is tested with a payload of "00001111" 8-bit subsequence, and Freq. Dev. Δf2 is tested with a payload of "10101010" 8-bit subsequence. The test result is shown in Fig 3.

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TX Measurement Modulation				
Δf 2 99.9% [kHz]	225.6			
Statistics	**Current**	**Average**	**Max**	**StdDev**
Freq Accuracy [kHz]	−0.1	−0.2	−0.9	0.2
Freq Offset [kHz]	0.4	0.0	0.7	0.4
Freq Drift [kHz]	0.5	0.2	1.2	0.5
Initial Freq Drift [kHz]	0.1	0.2	0.9	0.2
Max Drift Rate [kHz/50µs]	0.4	0.0	−0.9	0.5
Statistics	**Current**	**Average**	**Max**	**Min**
Freq Dev Δf 1avg [kHz]	NCAP	NCAP	NCAP	NCAP
Freq Dev Δf 1min [kHz]	NCAP	NCAP	NCAP	NCAP
Freq Dev Δf 1max [kHz]	NCAP	NCAP	NCAP	NCAP
Freq Dev Δf 2avg [kHz]	227.9	227.8	228.3	227.2
Freq Dev Δf 2min [kHz]	225.8	226.0	226.8	225.1
Freq Dev Δf 2max [kHz]	229.4	229.5	230.4	228.8

Statistic Count	Out of Tolerance	Nominal Power
100 / 100	0.00 %	−0.94 dBm

Fig 3. Tx modulation measurement

The modulation ratio Δf2 avg/Δf1 avg is the ratio of the smallest measured frequency deviation min(Δf2 avg) to the largest one max(Δf1 avg). This result is not provided for the LE-coded PHY.

3.1.3 Tx in-band emission

The Tx in-band emission is measured by the CMW270 equipment in the DTM mode.

Test method:

- Use the "*hci-black-box*" project in the SDK and download it to the EUT.
- Connect the EUT to the CMW270 equipment and set the CWM270 into the loopback mode.
- Select the "Spectrum ACP" option, and select the "All channel" or "ACP +/-5 channel" measurement mode.

Test results:

- The Tx in-band emission scans all the LE channels (they are analyzed in 1-MHz half-channels and centered at 2401 MHz, 2402 MHz, …, 2480 MHz. The test result is shown in Fig 4.
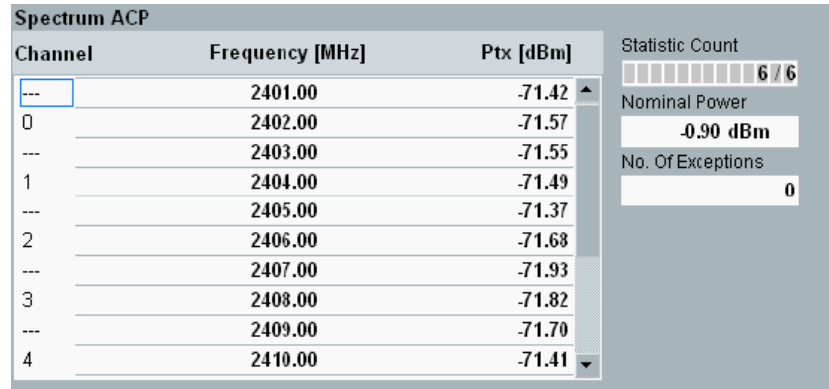
Fig 4.   In-band emission all channels

The Tx in-band emission scans the ACP +/-5 channels. The test result is shown in Fig 5.
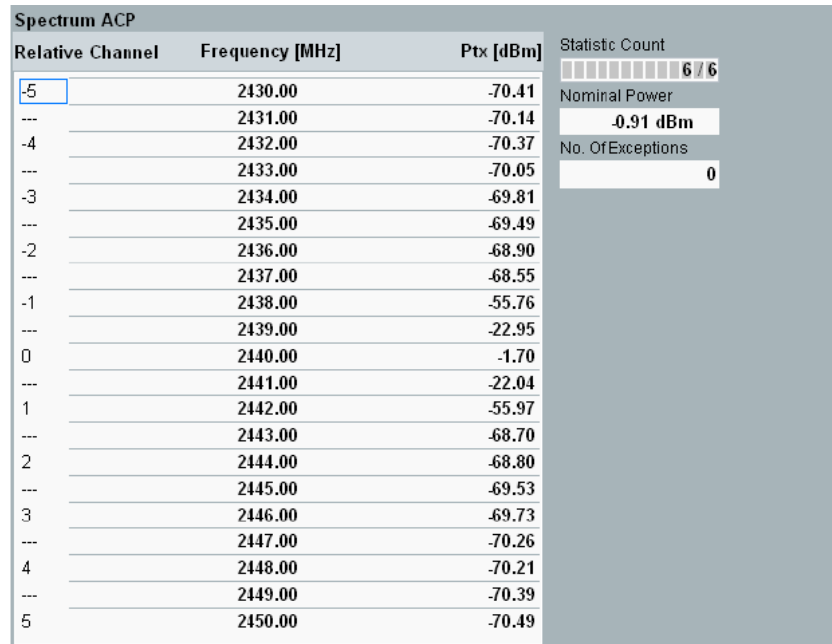

Fig 5.   In-band emission ACP +/-5 channels

In the test result, the relative channel number indicates the center frequency offset in relation to the current RF frequency in blocks of 2 MHz. The value of 2 MHz corresponds to the LE channel band width.

3.2 Rx test

3.2.1 Rx sensitivity

The Rx sensitivity is measured by the CMW270 equipment in the DTM mode.

Test method:

- Use "*hci-black-box*" project in SDK and download it to EUT.
- Connect the EUT to the CMW270 equipment and set the CWM270 into the loopback mode.

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- Select the "LE RX Measurement" option.

Test results:

- The Rx sensitivity test is the PER measurement for the LE. There are 1500 packages sent from the CWM and received by the EUT. The test result is shown in Fig 6.
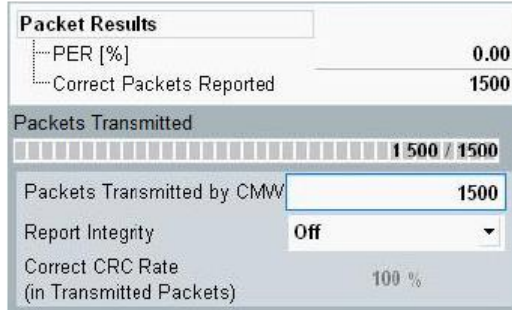

Fig 6.   Rx PER test result

4. RF test for GFSK
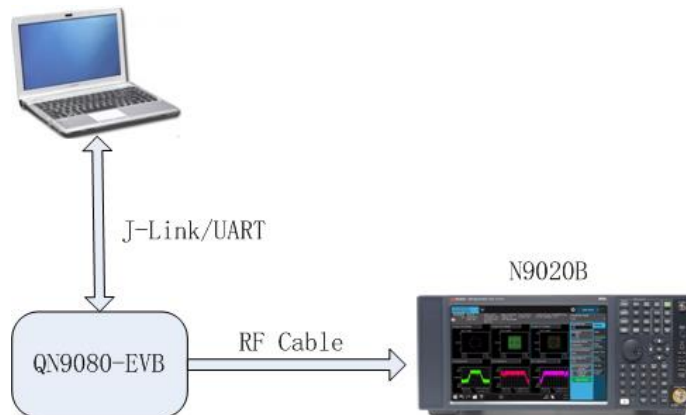
4.1 Tx test

4.1.1 Test setup

Fig 7.   RF GFSK Tx test with N9020B

4.1.2 Tx output power

The Tx output power is measured by the MXA signal analyzer. The insertion loss of the RF cable is 0.24 dB and it is compensated in the test result.

Test method:

- Use the *"QN908x GFSK test"* project and download it to the EUT.
- Set the EUT into the Tx continuous mode with modulation signals.
- Set the N9020B into the vector signal analysis mode.

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– Trig: free run.

– Digital demodulation:

– Modulation format: 2-FSK.

– Sample rate: 1 MHz.

– Measure filter: none

– Ref filter: gaussian.

– BT: 0.5.

- Select and open the "FSK Measure Time(IQ)", "Demodulation bits", "Spectrum", and "Demodulation Results" measurement windows.

Test results:

- The Tx output power measurement result is in the "Demodulation Results" field. The Tx output power measurement with the GFSK data rate of 250 kbit/s is shown in Fig 8.
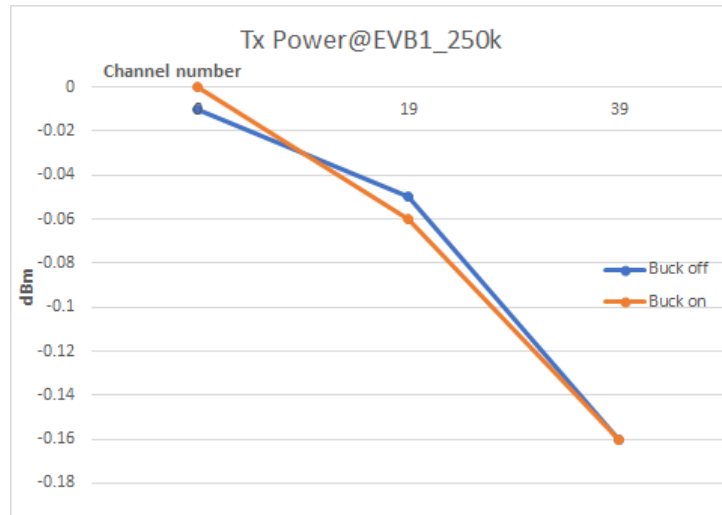

Fig 8.   Tx output power @ 250 kbit/s

4.1.3 Carrier frequency offset

The carrier frequency offset is measured by the MXA signal analyzer.

Test method:

- Use the *"QN908x GFSK test"* project and download it to the EUT.
- Set the EUT into the Tx continuous mode with modulation signals.
- Set the N9020B into the vector signal analysis mode.

– Trig: free run.

– Digital demodulation:

– Modulation format: 2-FSK.

– Sample rate: 1 MHz.

– Measure filter: none.

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– Ref filter: gaussian.

– BT: 0.5.

- Select and open the "FSK Measure Time(IQ)", "Demodulation bits", "Spectrum", and "Demodulation Results" measurement windows.

Test results:

- The carrier frequency offset measurement result is in the "Demodulation Results" field. The carrier frequency offset measurement with the GFSK data rate of 250 kbit/s is shown in Fig 9.

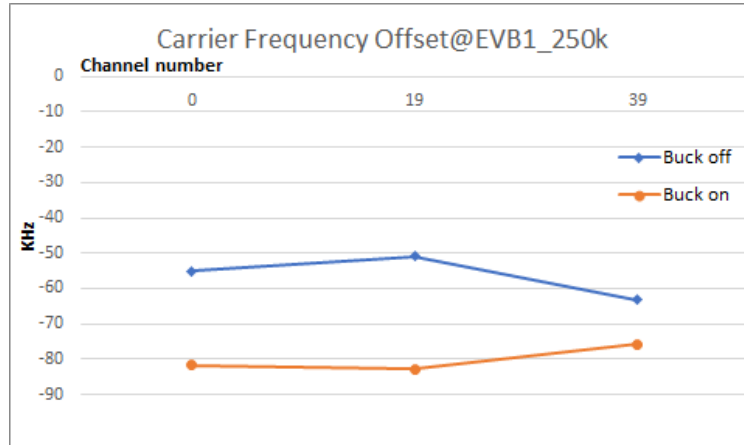**Fig 9.   Carrier frequency offset @ 250 kbit/s**

The carrier frequency offset measurement with the GFSK data rate of 500 kbit/s is shown in Fig 10.
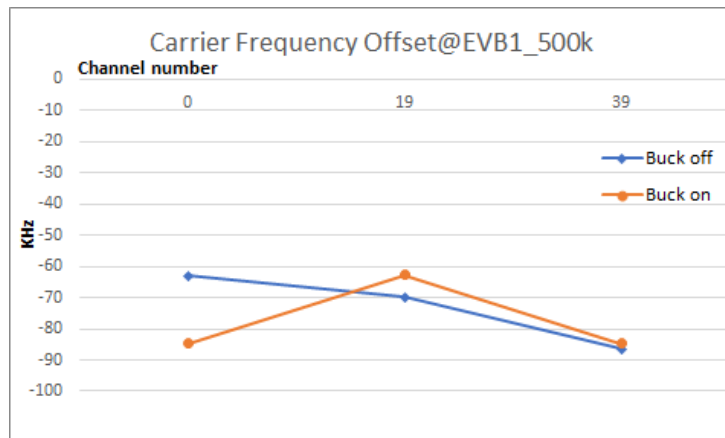
Fig 10.   Carrier frequency offset @ 500 kbit/s

4.1.4 Modulation characteristics

The frequency deviation is measured by the MXA signal analyzer with a payload of 0x0F and 0xAA.

Test method:

- Use the *"QN908x GFSK test"* project and download it to the EUT.
- Set the EUT into the Tx continuous mode with modulation signals.

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- Set the N9020B into the vector signal analysis mode.
  - Trig: free run.
  - Digital demodulation:
    - Modulation format: 2-FSK.
    - Sample rate: 1 MHz.
    - Measure filter: none.
    - Ref filter: gaussian.
    - BT: 0.5.
- Select and open the "FSK Measure Time(IQ)", "Demodulation bits", "Spectrum", and "Demodulation Results" measurement windows.

Test results:

- The frequency deviation measurement result is in the "Demodulation Results" field.
- The frequency deviation measurement at the GFSK data rate of 250 kbit/s with the buck on is shown in Fig 11.
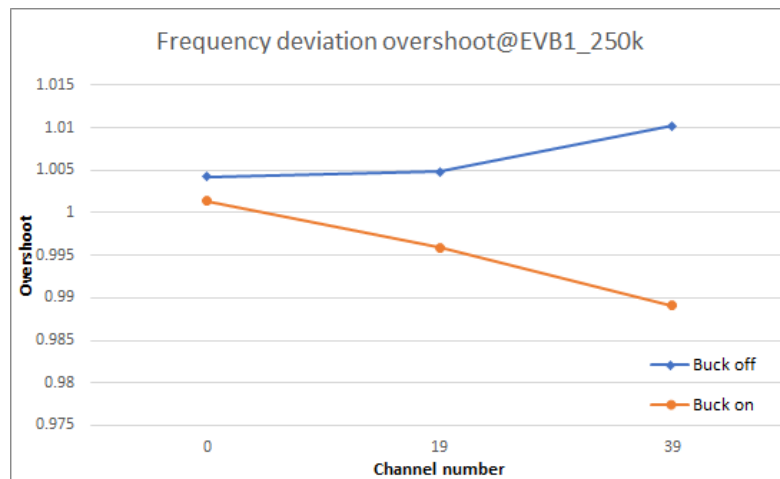
Fig 11.   Frequency deviation @ 250 kbit/s with buck on

- There is a definition for the frequency deviation test that the payload of Δf1 is 0x0F and Δf2 is 0xAA.
- The modulation ratio should be $\frac{\Delta f2\ avg}{\Delta f1\ avg} \geq 0.8$.

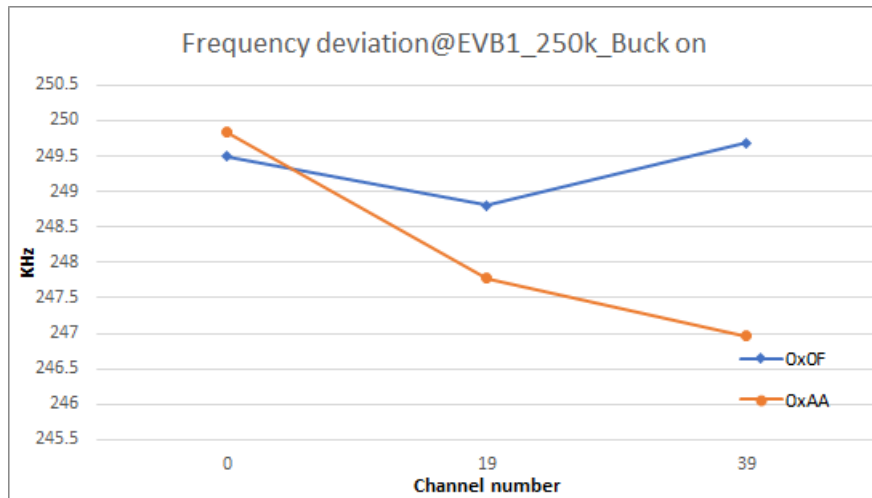The modulation ratio with the GFSK data rate of 250 kbit/s is shown in Fig 12.

Fig 12. Frequency deviation overshoot @ 250 kbit/s

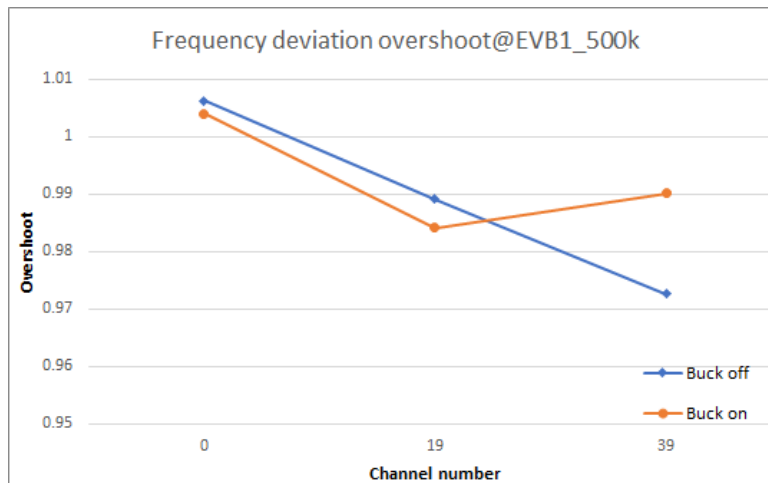The frequency deviation overshoot with the GFSK data rate of 500 kbit/s is shown in Fig 13.

Fig 13. Frequency deviation overshoot @ 500 kbit/s

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4.1.5 FSK error

The FSK error is measured by the MXA signal analyzer.

Test method:

- Use the *"QN908x GFSK test"* project and download it to the EUT.
- Set the EUT into the Tx continuous mode with modulation signals.
- Set the N9020B into the vector signal analysis mode.
  - Trig: free run.
  - Digital demodulation:
    - Modulation format: 2-FSK.
    - Sample rate: 1 MHz.
    - Measure filter: none.
    - Ref filter: gaussian.
    - BT: 0.5.
- Select and open the "FSK Measure Time(IQ)", "Demodulation bits", "Spectrum", and "Demodulation Results" measurement windows.

Test results:

- The FSK error measurement result is in the "Demodulation Results" field.
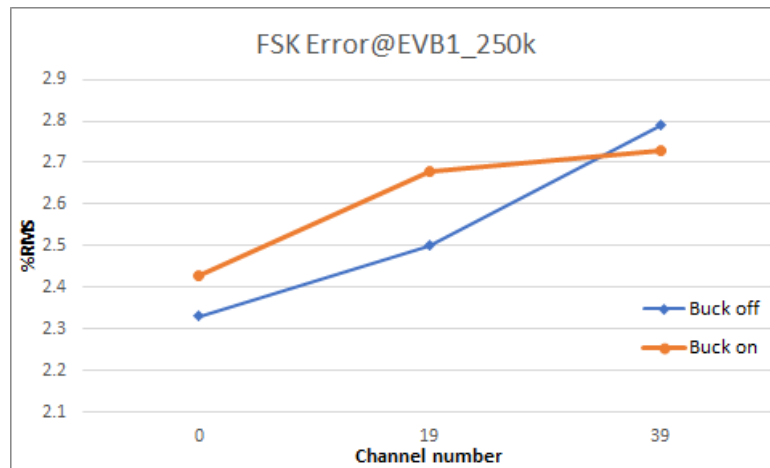- The FSK error with the GFSK data rate of 250 kbit/s is shown in Fig 14.

Fig 14. FSK error @ 250 kbit/s

- The FSK error with the GFSK data rate of 500 kbit/s is shown in Fig 15.
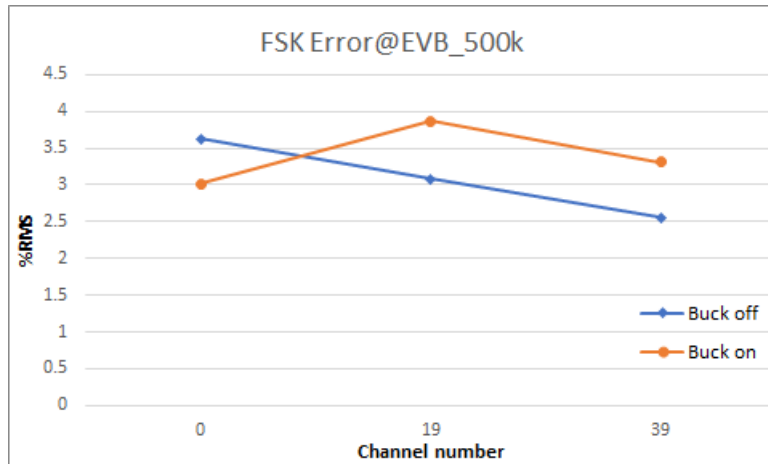

Fig 15. FSK error @ 500 kbit/s

4.1.6 Tx in-band emissions

The Tx in-band emissions are measured by the MXA signal analyzer. The EUT is in the burst transmitting mode at 2440 MHz.

Test method:

- Use the *"QN908x GFSK test"* project and download it to the EUT.
- Set the EUT into the Tx continuous mode with modulation signals.
- Set the N9020B into the BLE in-band emissions mode.
    - Trig: free run.
    - Center frequency: 2440 MHz.
    - Span: 81 MHz.
    - RBW: 100 kHz.

Test results:

- The Tx in-band emissions with the GFSK data rate of 250 kbit/s are shown in Fig 16.

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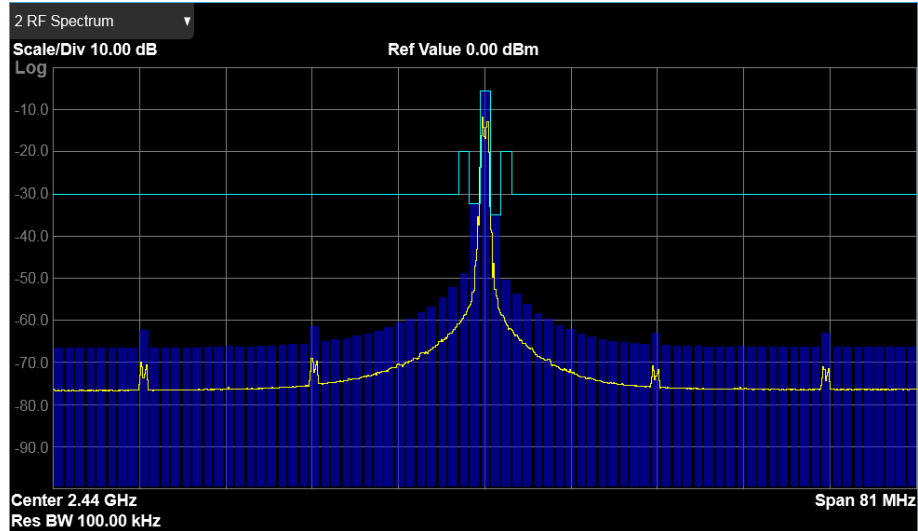
Fig 16.   Tx in-band emissions @ 250 kbit/s with buck on

4.1.7 Tx out-of-band spurious

The Tx out-of-band spurious is measured by the MXA signal analyzer with the spectrum analyzing function. The EUT is tested at 2426 MHz.

Test method:

- Use the *"QN908x GFSK test"* project and download it to the EUT.
- Set the EUT into the Tx continuous mode with modulation signals.
- Set the N9020B into the spectrum analyzer mode.
    - Trig: free run.
    - Span: 30 MHz to 12.75 GHz.
    - RBW: 100 kHz (30 MHz – 1 GHz), 1 MHz (1 GHz – 12.75 GHz).

Test results:

- The Tx out-of-band spurious with the GFSK data rate of 250 kbit/s and frequency band from 30 MHz to 1 GHz is shown in .

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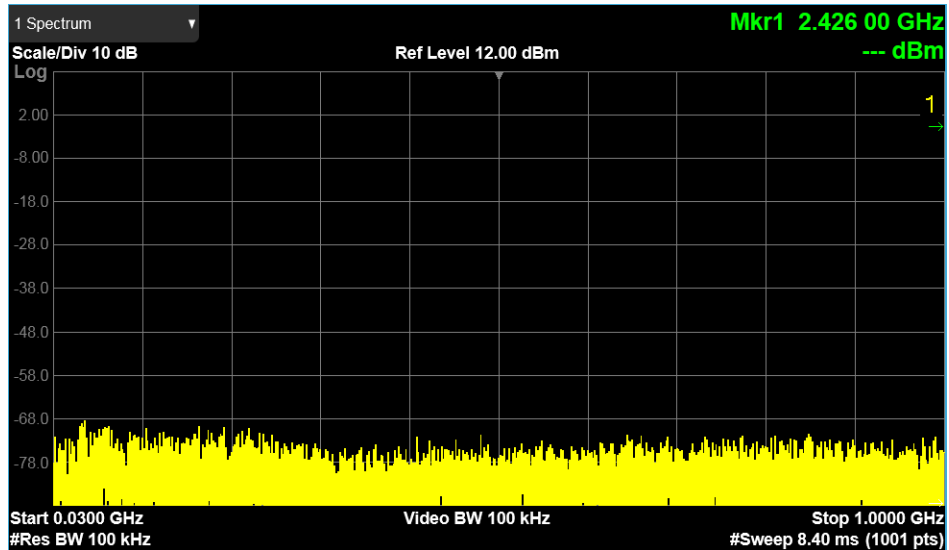**Application note** **Rev. 1 — May 2018** **15 of 27**

Fig 17. Tx out-of-band spurious @ 250 kbit/s

- The Tx out-of-band spurious with the GFSK data rate of 250 kbit/s and frequency band from 1 GHz to 12.75 GHz is shown in Fig 18.
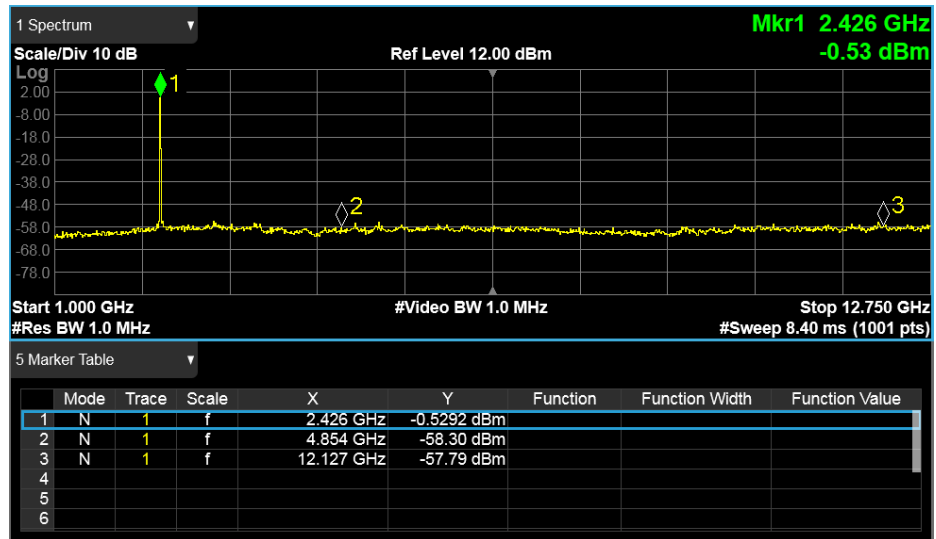

Fig 18. Tx out-of-band spurious @ 250 kbit/s

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4.1.8 Tx phase noise

The Tx phase noise is measured by the MXA signal analyzer. The EUT is tested at 2426 MHz.

Test method:

- Use the *"QN908x GFSK test"* project and download it to the EUT.
- Set the EUT into the Tx continuous mode with unmodulated signals.
- Set the N9020B into the phase noise mode.
    - Trig: free run.
    - Start offset: 1 kHz.
    - Stop offset: 10 MHz.

Test results:

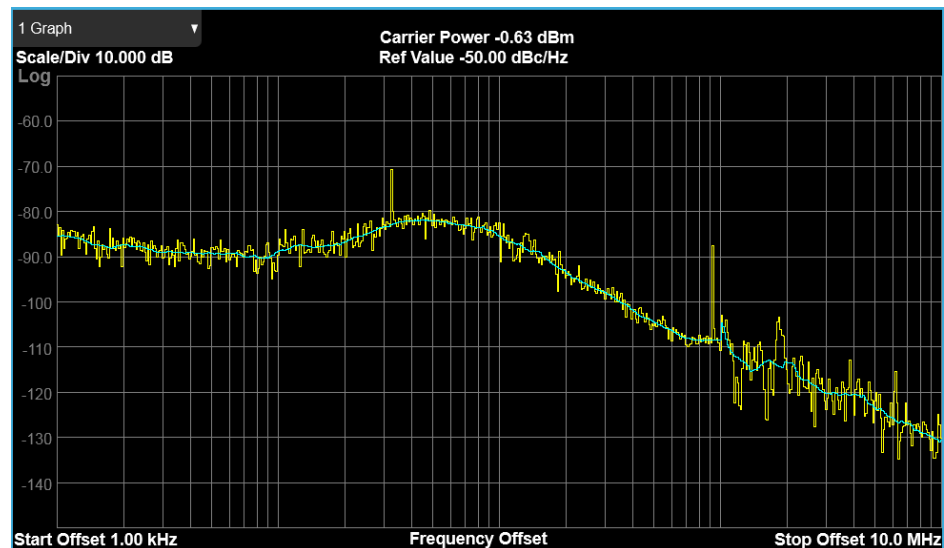- The Tx phase noise with the GFSK data rate of 250 kbit/s is shown in Fig 19.
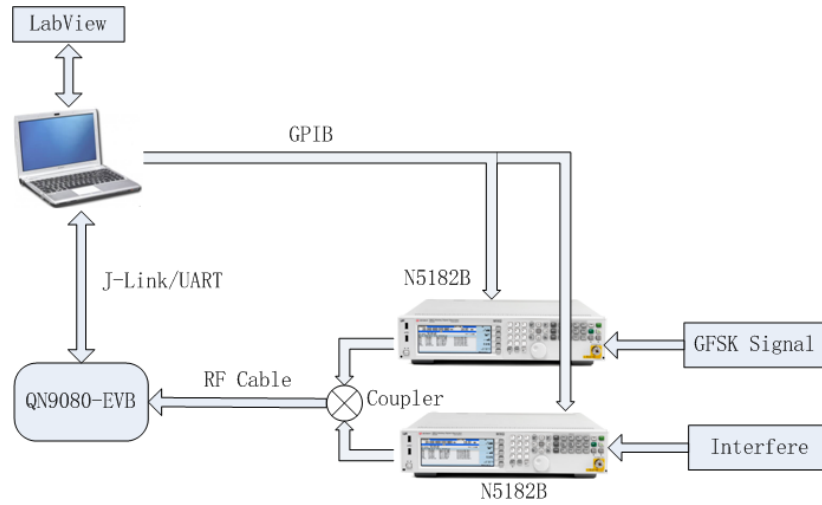

Fig 19. Phase noise @ 250 kbit/s

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4.2 Rx test

4.2.1 Test setup

Fig 20.   GFSK Rx sensitivity test with N5182B
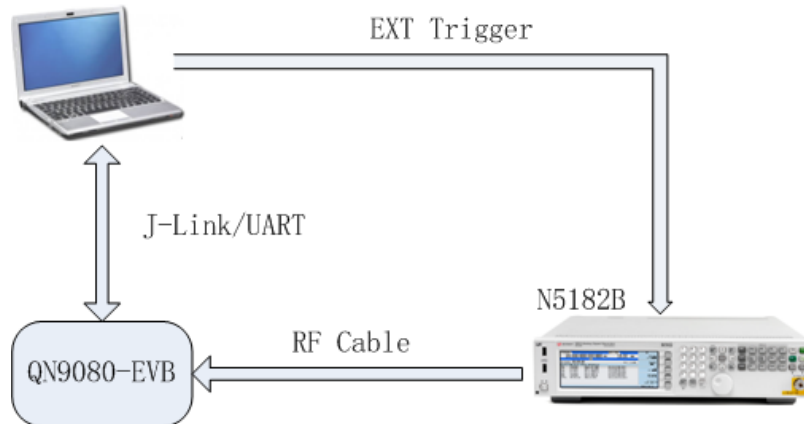
Fig 21.   GFSK Rx interfere test with N5182B

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4.2.2 Rx sensitivity

The Rx sensitivity is measured by reading the internal register value of "VALID_PCK_NUM" which is a counter for receiving the vailed package. The GFSK signal is generated and modulated by the RF generator before it is output to the EUT. For both the 250 kbit/s and 500 kbit/s data rates, one of the source GFSK data files contains 50 packages of the GFSK data. Trigger the generator for 30 times to send 1500 packages and calculate the PER rate for the EUT. The criteria is 30.8 % for 1500 packages.

Test method:

- Use the *"QN908x GFSK test"* project and download it to the EUT.
- Set the EUT into the Rx mode with different data rates (250 kbit/s or 500 kbit/s).
- Set the N5182B into the ARB mode.

  – Frequency: 2401 MHz (channel frequency: 1 MHz).

  – Amplitude: -95 dBm (Decrease the receiving power level until you reach the PER threshold of 30.8 % with 1500 packages).

  – ARB settings:

  – Waveform: the GFSK REP2 file for the 500 kbit/s data rate and the GFSK REP4 file for the 250 kbit/s data rate.

  – Sample rate: 8 MHz.

  – Trig: single trig.

  – Trig source: EXT.

Test results:

- The Rx sensitivity test result contains channel 0, channel 19, and channel 39 (three-channel testing data). The PER rate is shown in the RFCOMM software and the Rx sensitivity power level is taken from the N5189B. The PER rate is shown in Fig 22.
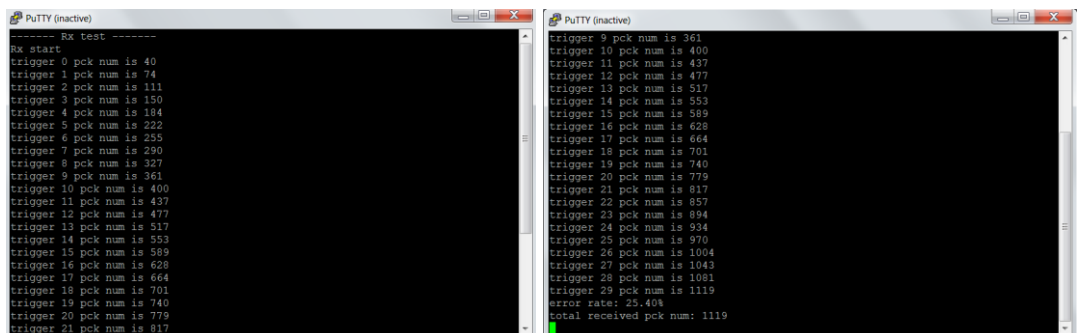

Fig 22. Rx sensitivity PER rate

The Rx sensitivity with the GFSK data rate of 250 kbit/s is shown in Fig 23.

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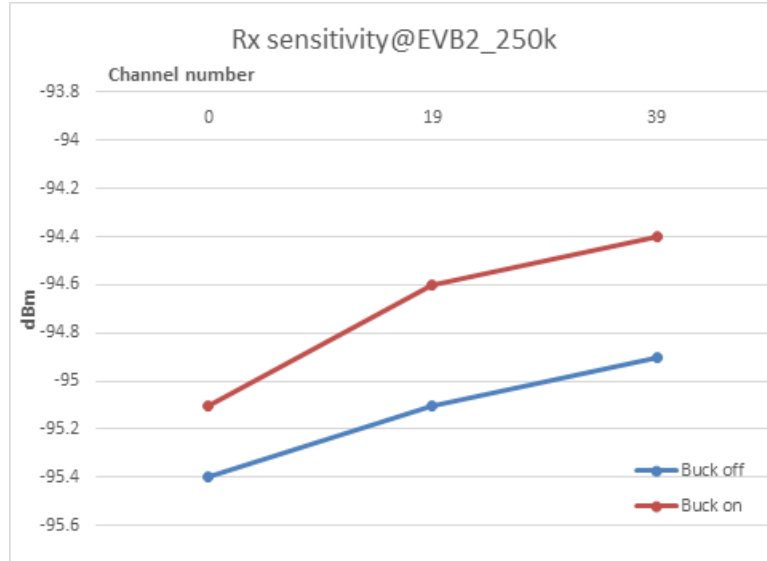**Application note** **Rev. 1 — May 2018** **19 of 27**

Fig 23. Rx sensitivity test @ 250 kbit/s

The Rx sensitivity with the GFSK data rate of 500 kbit/s is shown in Fig 24.

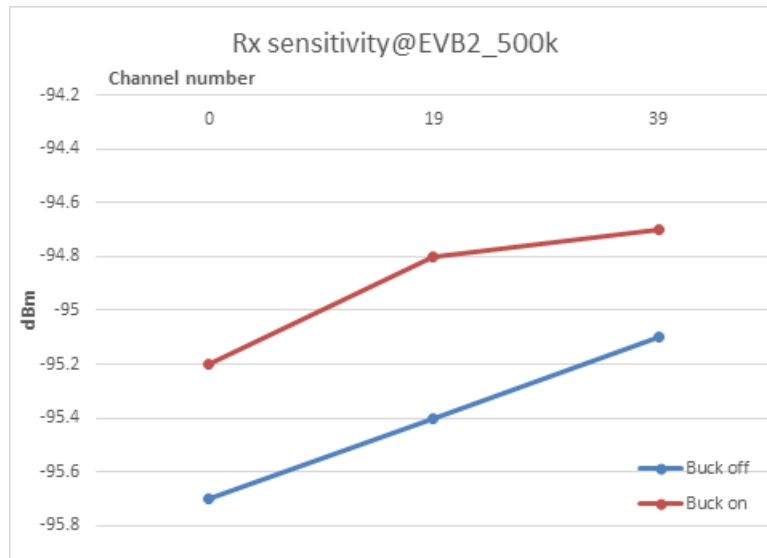**Fig 24. Rx sensitivity test @ 500 kbit/s**

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4.2.3 Rx carrier/interfere rejection

The Rx carrier/interfere rejection is measured by two N5182B RF generators. One generator is used to send the wanted GFSK signal and the second one is used to send the interfering signal. The tested channel is 2426 MHz.

Test method:

- Use the *"QN908x GFSK test"* project and download it to the EUT.
- Set the EUT into the Rx mode with different data rates (250 kbit/s or 500 kbit/s).
- Set the wanted N5182B signal generator into the ARB mode.
    - Frequency: 2425 MHz (channel frequency: 1 MHz).
    - Amplitude: -67 dBm (the wanted signal power is set to -67 dBm).
    - ARB settings:
        - Waveform: GFSK REP2 file for the 500 kbit/s data rate and GFSK REP4 file for the 250 kbit/s data rate.
        - Sample rate: 8 MHz.
        - Trig: single trig.
        - Trig source: EXT.
- Set the interfering signal generator N5182B into the ARB mode.
    - Frequency: 2424 MHz (channel frequency offset=[fTx +/- n MHz], n=1,2,3,4,5).
    - Amplitude: increase the interfering signal power level until you reach the PER threshold of 30.8 % for 1500 packages.
    - ARB settings:
        - Waveform: GFSK REP2 file for the 500 kbit/s data rate and GFSK REP4 file for the 250 kbit/s data rate.
        - Sample rate: 8 MHz.
        - Trig: single trig.
        - Trig source: EXT, controlled by LabView or manual operation.

Test results:

- The Rx carrier/interfere rejection with the GFSK data rate of 250 kbit/s is shown in <u>Fig 25</u>.
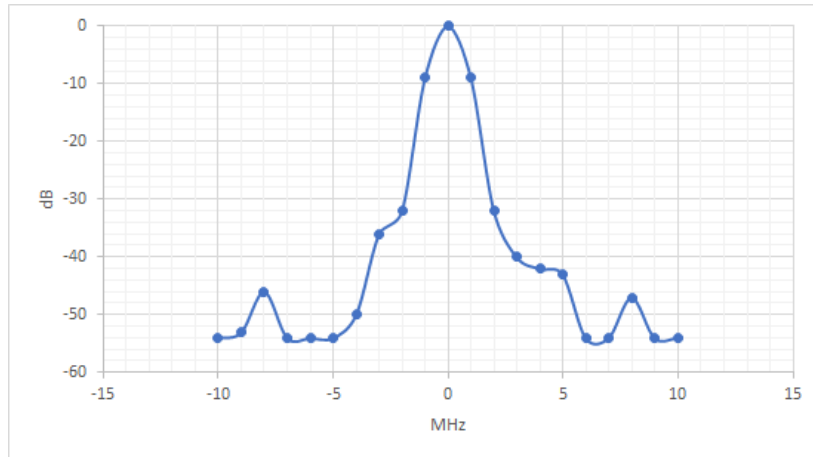
Fig 25.   Rx carrier/interfere rejection test @ 250 kbit/s

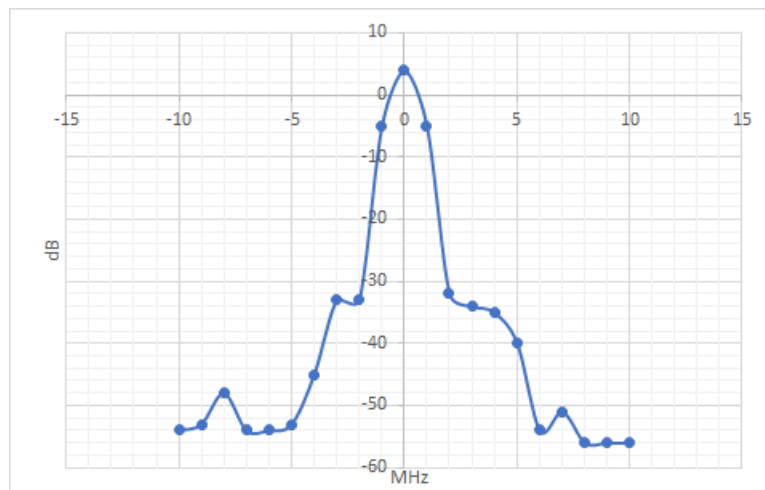The Rx carrier/interfere rejection with the GFSK data rate of 250 kbit/s is shown in Fig 26.

Fig 26.   Rx carrier/interfere rejection test @ 500 kbit/s

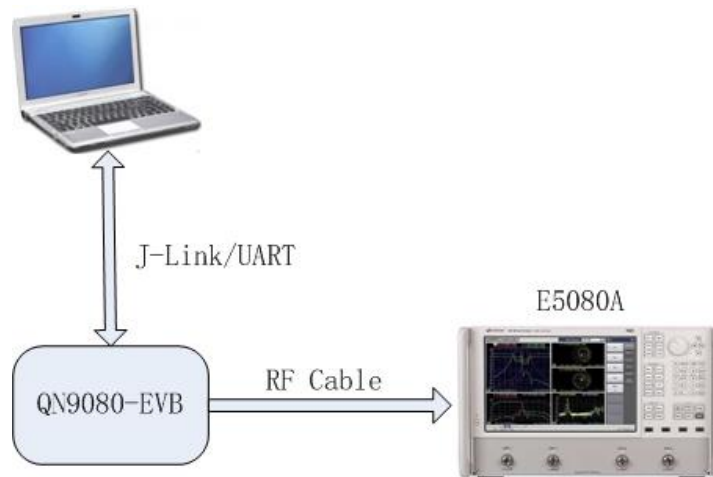# 5. S-parameters

5.1 Test setup

Fig 27. Rx S-parameters with smith chart

5.2 S-parameters for RX

The Rx S-parameters are measured by network analyzer E5080A.

Test method:

- Use the *"QN908x GFSK test"* project and download it to the EUT.
- Set the EUT into the Rx mode.
- Set the E5080A into the S11 measurement mode.
    - Frequency: 2 GHz to 3 GHz.
    - Measurement: S11.
    - Format: smith chart.

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Test results:

- The Rx S-parameters test result is shown in Fig 28.
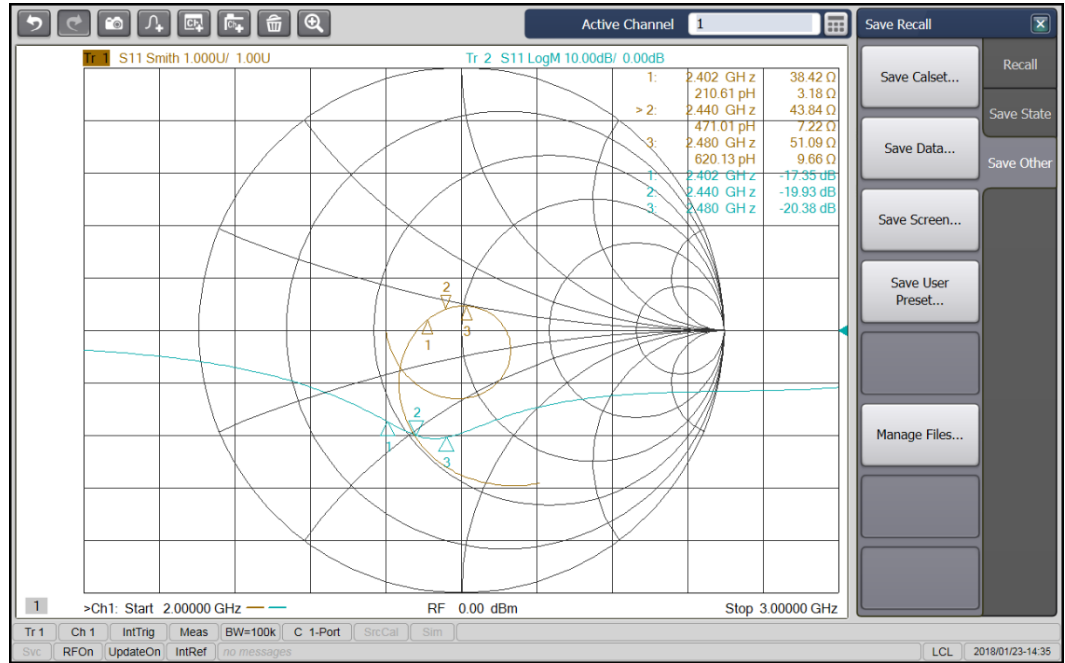

Fig 28.   Rx return loss with smith chart

5.3 S-parameters for TX

The Tx S-parameters are measured by network analyzer E5080A.

Test method:

- Use the *"QN908x GFSK test"* project and download it to the EUT.
- Set the EUT into the Tx mode.
- Set the E5080A into the S11 measurement mode.
  - Frequency: 2 GHz to 3 GHz.
  - Measurement: S11.
  - Format: smith chart.

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Test results:

- The Tx S-parameters test result is shown in Fig 29.
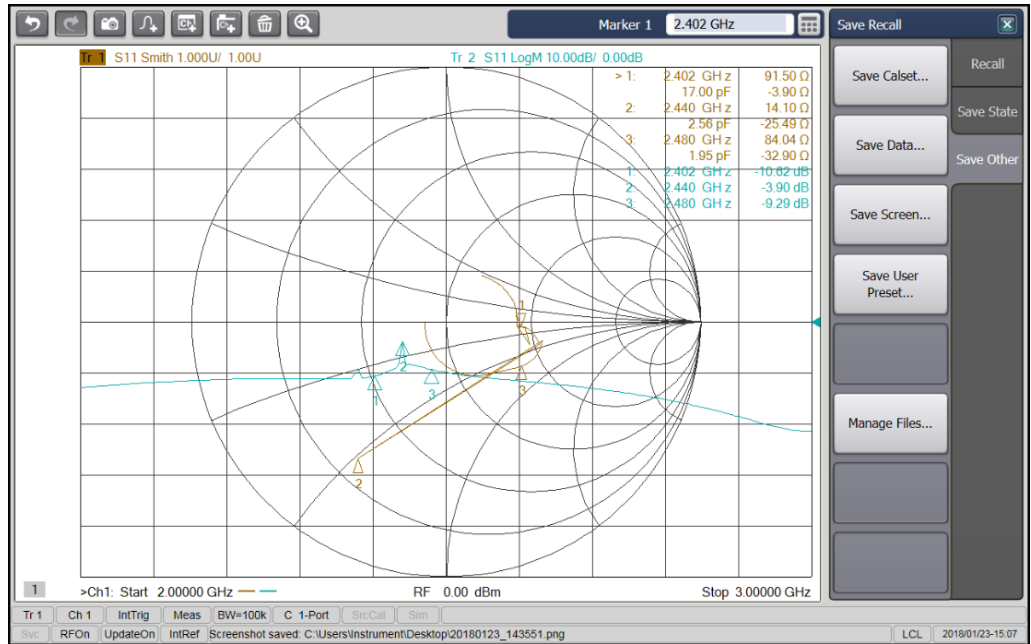
Fig 29.   Tx return loss with smith chart

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