Reference Design: RM00226

QN9090/JN5189 Coin-cell Switch

This reference design shows how use a QN9090 or JN5189 device in a cost effective 2-layer PCB running from a coin cell.

1 Reference Design

1.1 Features

The board has the following features

- 2-layer QN9090/JN5189 reference design with printed antenna
- NFC antenna for direct connection to the device
- Optional external NFC device connected on the I^{2}C interface with Field Detect (FD pin) connected to PIO1
- Programming header compatible with USB programming dongle
- Reset button
- 4 push buttons connected to PIO2, PIO7, PIO15 and PIO19
- Expansion Port compatible with the DK006 Evaluation Kit
- Can be powered from
  - CR2032 coin cell
  - External NFC device
  - Expansion Port
  - Programming interface

1.2 Package Overview

The zip contains the following folders:

- BOM Bill of materials
- DOC Documentation
- Gerbers Gerber Files
- Pads Mentor PADS Source Files
- Schematic Schematic in PDF format

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1.3 Board Overview

Below shows an overview of the board

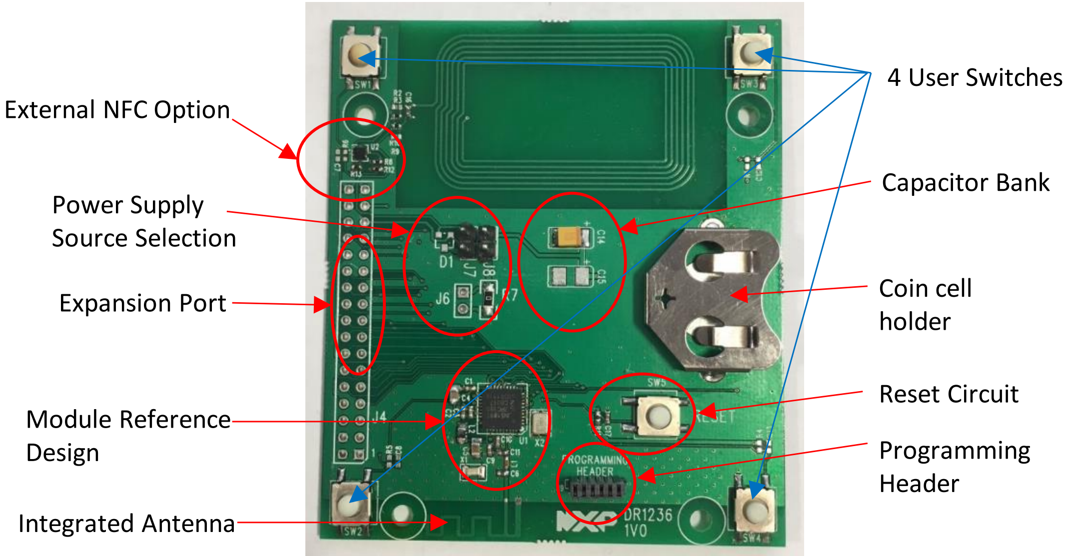

Figure 1 - Overview of the PCB

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2 Programming Interface Connector

Connector J9 on the board is wired to UART0 of the device. This header is compatible with the DR1128 USB Programming dongle pictured below.

Figure 2 - USB Programming Dongle

The pinout for this connector is given below in Table 1. The J9 connector is used during application development to:

- Program the Flash memory
- Allow UART communication during application development, such as to provide debug messages
- Supply 3.3V power through pin 4 during software development and programming

Pin	Name	Use
1	PIO8	Transmit UART data – connects UART0 PIO8 of the QN9090/JN5189.
2	PIO9	Receive UART data – connects to UART0 PIO9 of the QN9090/JN5189.
3	PIO5	Control line to connect to ISP_ENTRY of the QN9090/JN5189 – used in conjunction with RESETN to put the device into programming mode.
4	VCC	3V supply input from programming interface.
5	RESETN	RESETN of the QN9090/JN5189 - used in conjunction with ISP_ENTRY to put the device into programming mode. Also used to reset the device after a programming cycle.
6	GND	Ground

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The image below shows the USB programming dongle orientation on the PCB

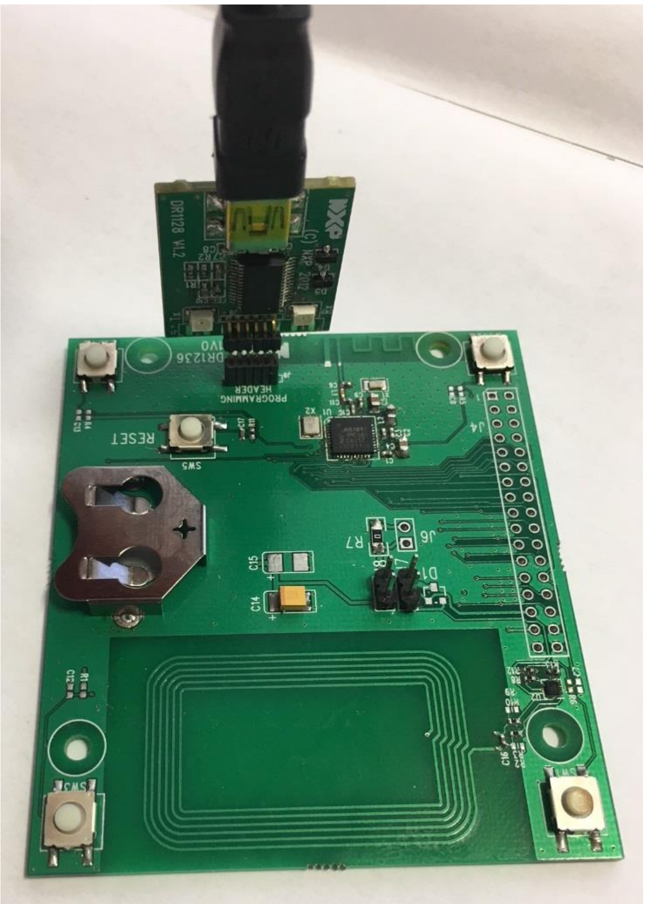

Figure 3 - Programming the Device

2.1 Board Assembly Options

2.1.1 External NTAG

By default, the BOM connects the NTAG antenna to the internal NTAG in the QN9090T/JN5189T. If the external NTAG option is required, then the following changes are required

- Fit U2. This is an NT3H1201 NTAG device.
- Fit R3 and R10 instead of R2 and R9 if using external NTAG and fit R10. This redirects the antenna to the external NTAG device
- Fit R8 and R12. These are the I^2C pullups for the external NTAG device
- Fit R12 with 0R resistor. This connects the external NTAG devices FD (Field Detect) pin to GPIO1

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2.1.2 Power Supply Source Selection

The board is powered by the CR2032 coin cell via jumper J8. If the external NFC device is fitted, then the VOUT signal can be used to power the board via jumper J7. There is an option to remove both jumpers and fitted D1 (BAT754C) so that both supplies can be used simultaneously. We aware that there will be a voltage drop (typically 0.3V) on this option which will have the effect of shortening the battery life and a stronger field will be required when powering from the NFC field.

For debug and programming, the PCB can be powered by the programming connector (J9) using the USB programming dongle. External 3V can be applied using the expansion port connector (J4) pin 31.

2.1.3 Measuring the Current Consumption

By default, R7 (0 ohm) is fitted remove this resistor and the current consumption can be measured across J6.

2.1.4 Improve the RF Rejection

Some of the harmonics are close to the limit as the PCB is a 2-layer design. There is an optional resistor (R14) in the RF Path. It is recommended that customers include this resistor in their own 2-layer designs, in case another lumped element is required to improve the rejection.

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3 Radio Testing

This was performed using a JN5189T device so IEEE802.15.4 testing is performed.

3.1 List of Tests

The following list of tests have been performed

A- Conducted tests
  a. Tx tests
    i. Frequency accuracy
    ii. Phase noise
    iii. Tx power
    iv. TX spurious
    v. Harmonics
    vi. EVM & Offset EVM
    vii. Upper band edge

  b. Rx tests
    i. Sensitivity
    ii. Max Input Level
    iii. Rx spurious
    iv. LO leakage
    v. Interferers (as per 802.15.4 requirements)
    vi. Co-channel
    vii. Receiver Blocking (as per ETSI 300 328 requirements)

B- Return loss

  a. Rx

3.2 Software Used for Testing

Prior to the measurement a binary code must be loaded into the Flash memory of the board by using the DK6 Flash Programmer application JN-SW-4407.

The binary code that has been used for the following tests is the CMET (Customer Module Evaluation Tool) version 3001.

```
***********************************************
*    Customer Module Evaluation Tool          *
*    Version 3001                             *
*    Compiled Sep 10 2018 17:02:22            *
*    Radio Test version 2030                  *
*    Radio Driver version 2038                *
*    Chip ID 000e2111                         *
***********************************************
```

The TERATERM terminal emulator is used to communicate with the chip.

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3.3 Test equipment

Spectrum analyser	Generators
R&S FSP	R&S SFU
R&S FSU	R&S SMBV100A

4 Conducted Tests

4.1 TX modes

Three different modulation modes exist in transmission:

- Regular
- Proprietary 1
- Proprietary 2

In regular mode the whole OQPSK spectrum is transmitted without any filtering. In proprietary mode 1 the spectrum is slightly digitally filtered and in proprietary mode 2 the spectrum is more heavily filtered.

Filtering the spectrum can be useful to pass the FCC upper band-edge test without reducing the TX power on channel 26.

Filtering the TX spectrum also allows the receiver to benefit from its full selectivity performances (see annex A for details)

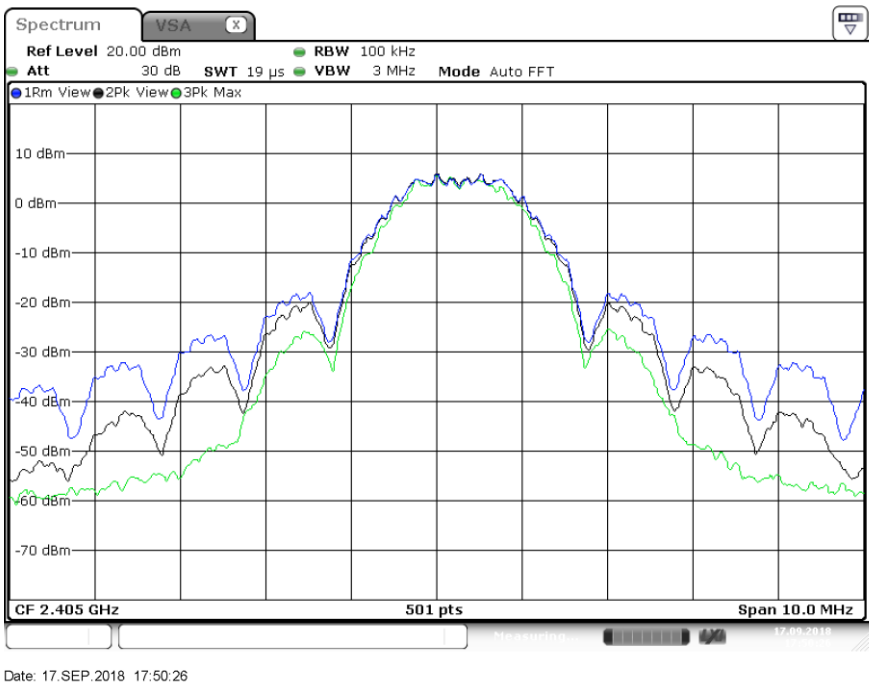

Figure 4 – JN5189T TX spectrum

- Blue graph: regular mode
- Black graph: proprietary mode 1
- Green graph: proprietary mode 2

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The measurements included in this document have been done in regular mode otherwise specified.

4.2 TX tests

The TX power of the JN5189T is set to +**10 dBm**

4.2.1 Test Set-Up

Connect the RF port of the module to the spectrum analyzer

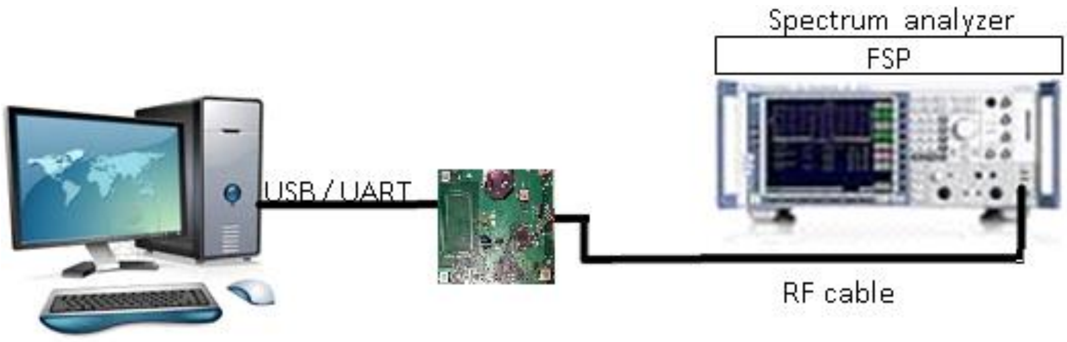

Figure 5 – Conducted TX test set up

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4.2.2 Frequency Accuracy

Test method:

- Set the radio in:
    - TX mode, CW, continuous mode, frequency : channel 18
- Set analyzer to:
    - Center frequency = 2.44 GHz, span = 1 MHz, Ref amp = 20 dBm, RBW = 10 kHz
- Measure the CW frequency with the marker of the spectrum analyzer

Result:

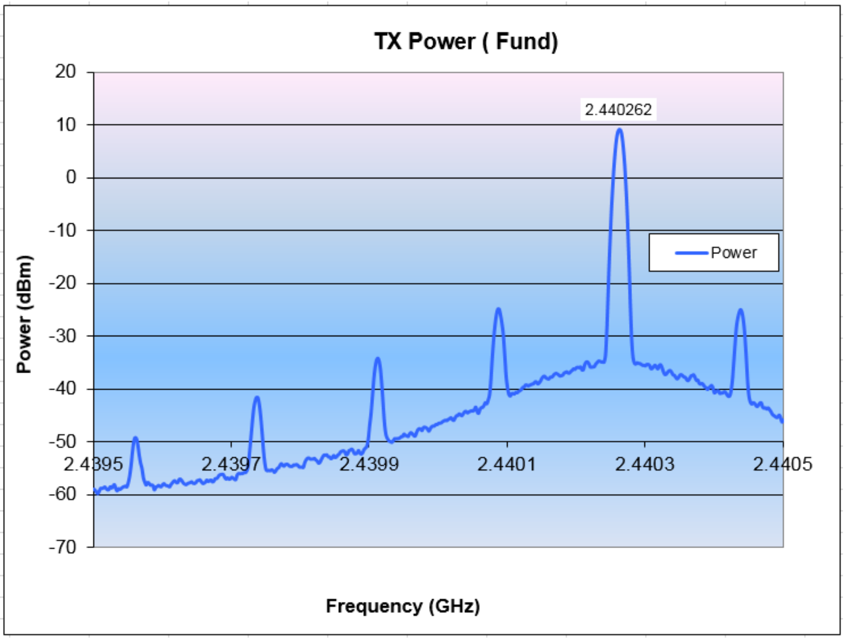

Figure 6 : Frequency accuracy

- Measured frequency: 2.440262 GHz
- ppm value = +3 ppm

Result	Target	802.15.4 limit
+3 ppm	+/- 25 ppm	+/- 40 ppm

Conclusion: The channel frequency can be centered by SW tool to be fully compliant with the IEEE802.15.4 specifications.

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4.2.3 Phase Noise @ 100 kHz offset

Test method:

- Set the radio in:
    - TX mode, CW continuous mode, frequency: channel 18
- Set analyzer to:
    - Center frequency = 2.44 GHz, span = 1 MHz, Ref amp = 20 dBm
- Measure the phase noise at 100 kHz offset frequency
    - RBW = 10KHz (40dBc)

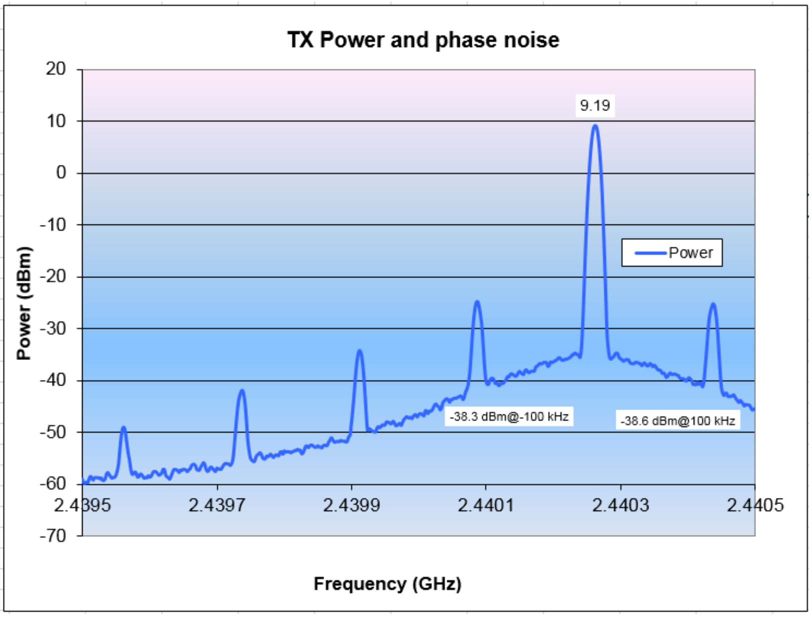

Figure 7: Phase noise

Results:

- Marker value = - 38.3 dBm within 10kHz RBW ➔
    - Marker delta = 9.2 - (-38.3) = 47.5 dB
    - Phase noise at 100 kHz offset = - 47.5-10 Log (10kHz) = **- 87.5 dBc/Hz**

Note:

- Phase noise is for information only.

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4.2.4 TX Power (fundamental)

Test method:

- Set the radio in:
  - TX mode, modulated, continuous mode
- Set analyzer to:
  - Start frequency = 2.4 GHz, Stop frequency = 2.5 GHz,

    Ref amp = 20 dBm, sweep time = 100 ms, RBW = 3 MHz
  - Max Hold mode
  - Detector: Peak
- Sweep all the channels from ch11 to ch26

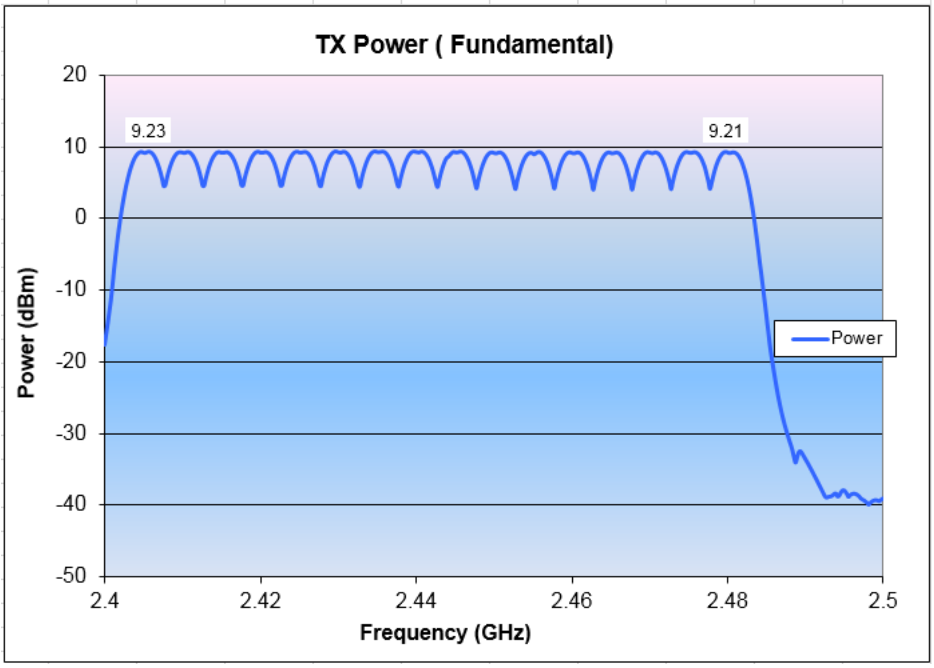

Figure 8: TX max power

Result:

Maximum power is on channel 17: +9.2 **dBm**

Minimum power is on channel 20: **+** 9.1 **dBm**

Tilt over frequencies is **0.**1 **dB**

Conclusion:

- the default TX power is in line with the expected results
- the power is flat over frequency

4.2.5 TX spurious

4.2.5.1.1 Global view from 0.3 GHz to 30.0 GHz (wanted = channel 18)

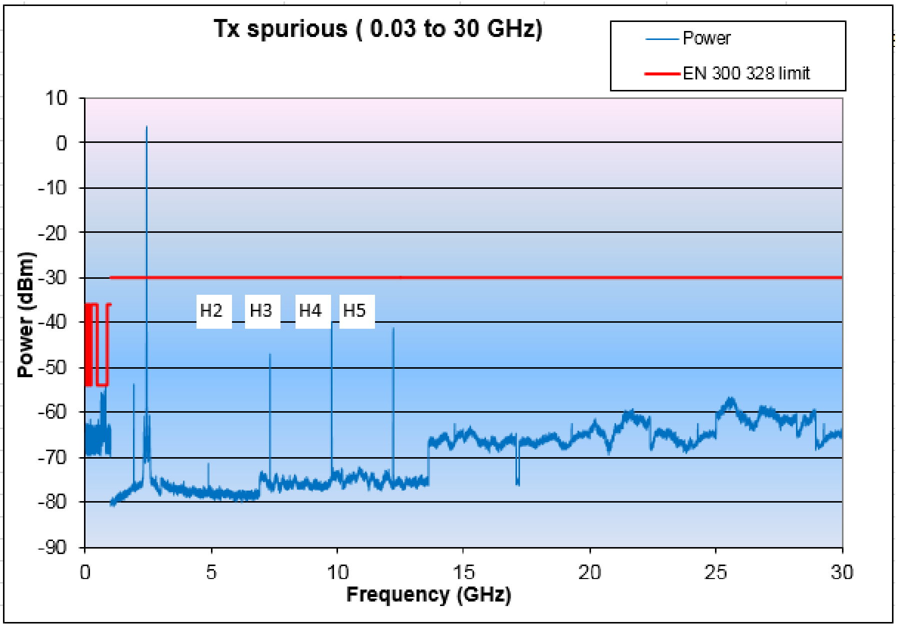

Figure 9: Conducted TX spurious

<u>Conclusion:</u>

- There are no TX spurs above the EN 300 328 limit
- Harmonics are specifically measured in the following paragraphs.

4.2.5.2 H2 (ETSI test conditions)

<u>Test method:</u>

- Set the radio in:
  - TX mode, modulated, continuous mode
- Set analyzer to:
  - Start frequency = 4.8 GHz, Stop frequency = 5 GHz ,

    Ref amp = -20 dBm, sweep time = 100 ms, RBW = 1 MHz
  - Max Hold mode
  - Detector Peak
- Sweep all the channels from ch11 to ch26

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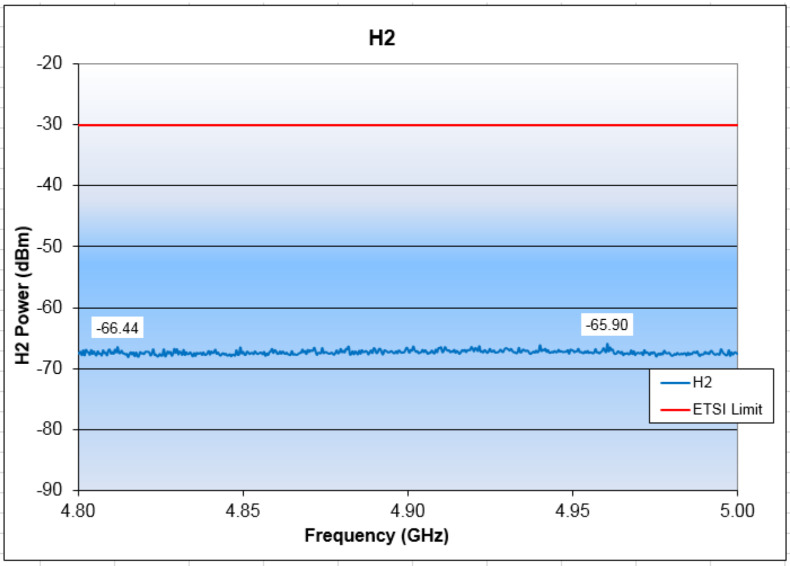

Figure 10: Conducted H2 spurious

Results:

Maximum power is on channel 26: **- 65.9 dBm**

Conclusion:

- There is **35.9** dB margin to the ETSI limit.

4.2.5.3 H3 (ETSI test conditions)

Same method as H2 except the spectrum analyzer frequency start/stop are set to 7.2 GHz and 7.5 GHz.

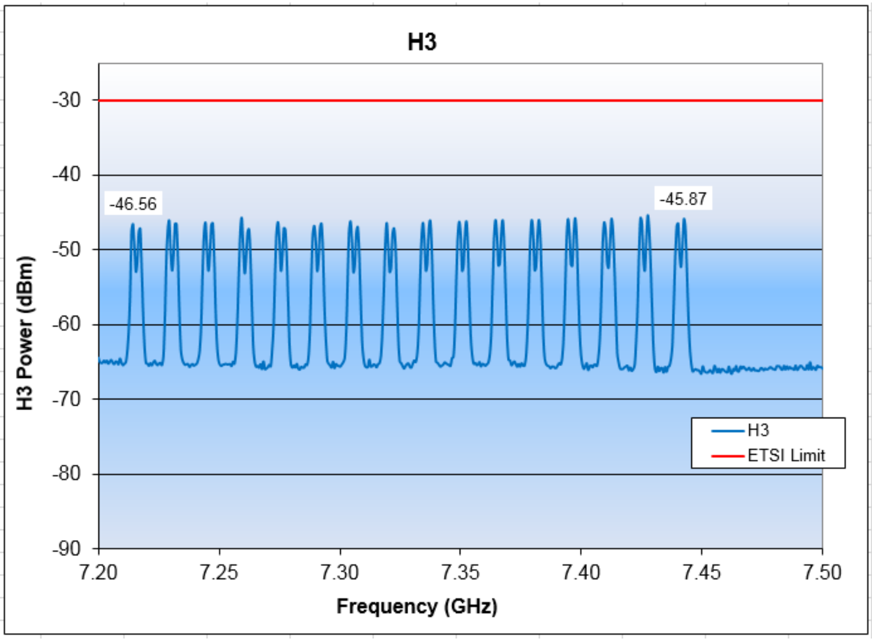

Figure 11: Conducted H3 spurious

Results:

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Maximum power is on channel 25: **- 45.4 dBm**

Conclusion:

- There is 15.4 dB margin to the ETSI limit.

4.2.5.4 H4 (ETSI test conditions)

Same method as H2 except the spectrum analyzer frequency span is set from 9.6 to 10.0 GHz.

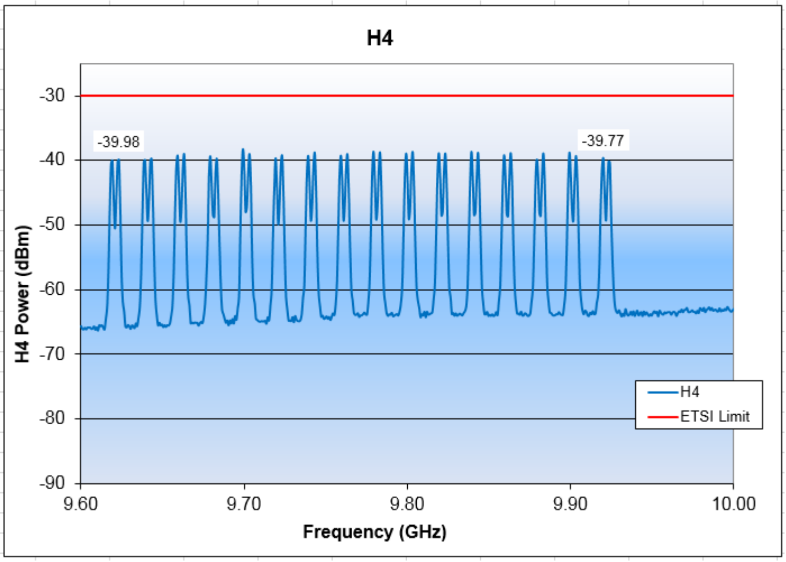

Figure 12: Conducted H4 spurious

Results:

Maximum power is on channel 15: **- 38.3 dBm**

Conclusion:

- There is **8.3** dB margin to the ETSI limit.

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4.2.5.5 H5 (ETSI test conditions)

Same method as H2 except the spectrum analyzer frequency span is set from 12.0GHz to 12.5 GHz

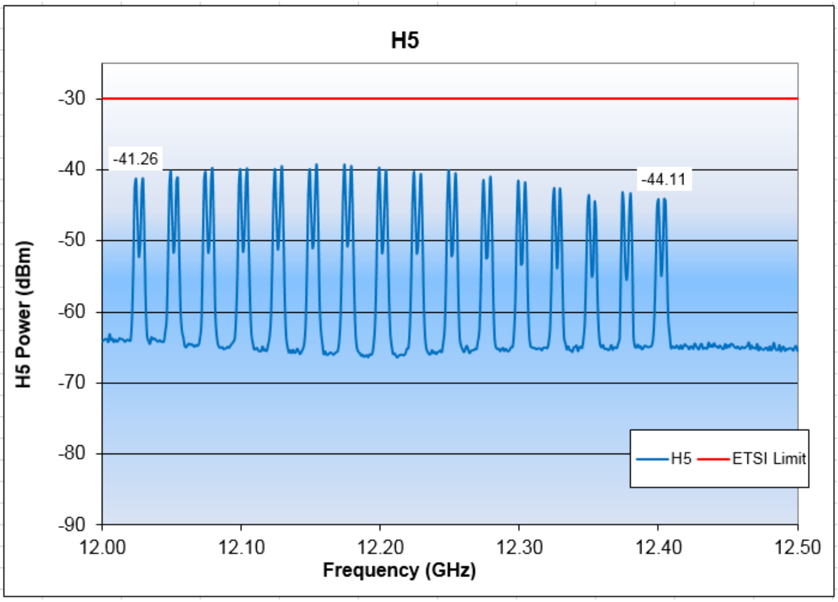

Figure 13: Conducted H5 spurious

Results:

Maximum power is on channel 17: **-39.2 dBm**

Conclusion:

- There is **9.2** dB margin to the ETSI limit.

4.2.5.6 H2 (FCC test conditions, average measurement)

Test method:

- Set the radio in:
  - TX mode, modulated, continuous mode
- Set analyzer to:
  - Start frequency= 4.8 GHz, Stop frequency = 5 GHz,
    Ref amp = -20 dBm, RF attenuation = sweep time = 100 ms, RBW = 1 MHz
  - Trace mode : Average
  - Detector RMS
- Sweep all the channels from ch11 to ch26

Results:

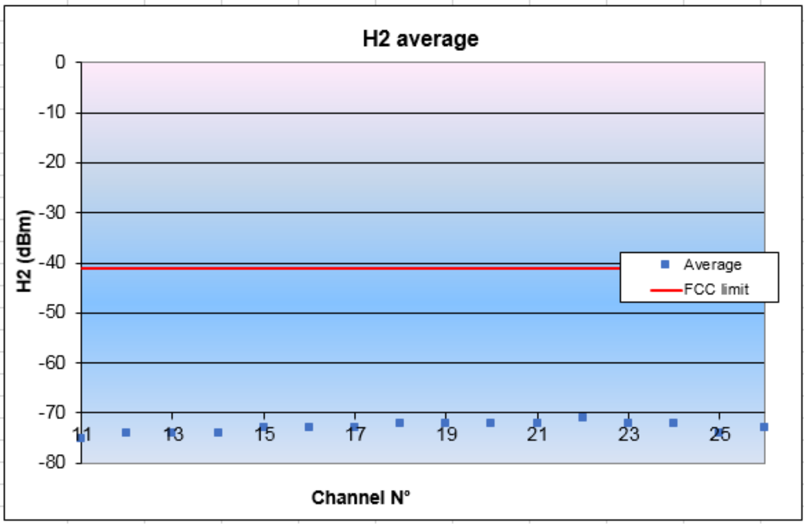

Figure 14: Conducted H2 spurious

Maximum power is on channel 22: **-71.0dBm**

Conclusion:

- There is **30** dB margin to the FCC limit.

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1.1.1.1 H3 (FCC test conditions, average measurement)

Same method as H2 except the spectrum analyzer frequency start/stop are set to 7.2 and 7.5 GHz.

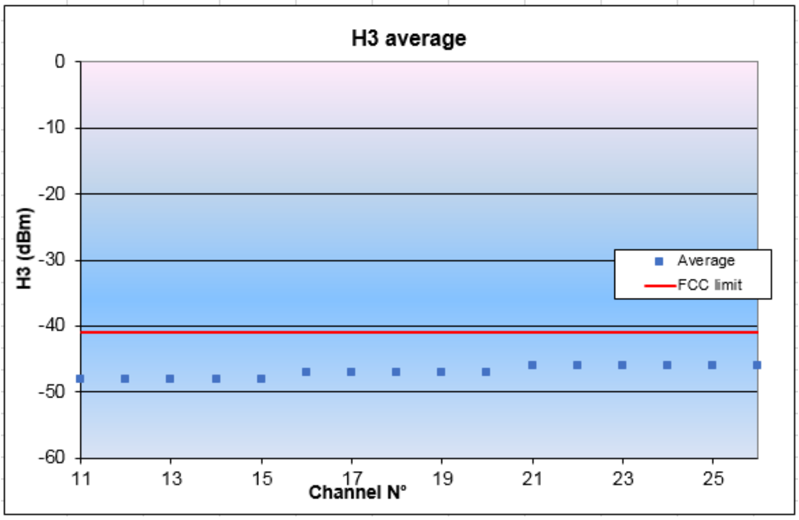

Figure 15: Conducted H3 spurious

Results:

Maximum power is on channels 21 to 26: **-46 dBm**

Conclusion:

- There is only **5** dB margin to the ETSI limit.

4.2.5.7 H4 (FCC test conditions, average measurement)

Same method as H2 except the spectrum analyzer frequency span is set from 9.6 to 10.0 GHz.

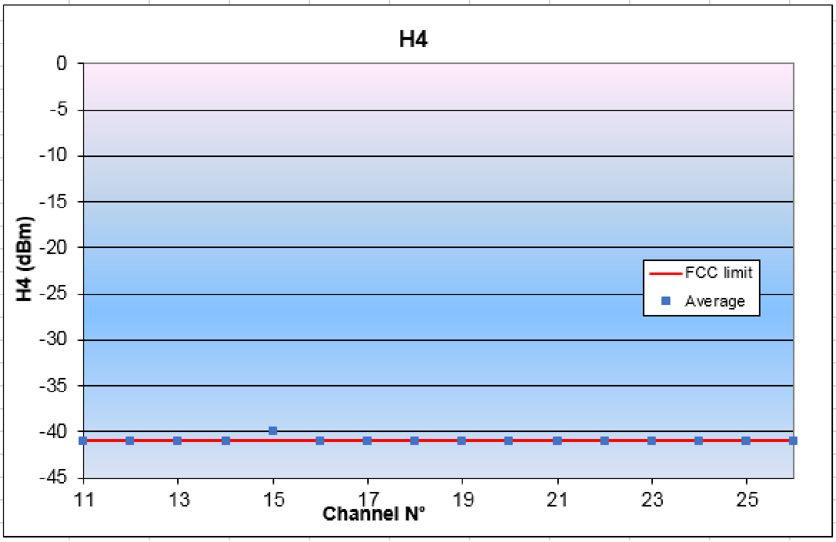

Figure 16: Conducted H4 spurious

Results: Maximum power is on channel 15: **-40 dBm**

Conclusion:

- There is **no** margin to the FCC limit.

4.2.5.8 H5 (FCC test conditions, average measurement)

Same method as H2 except the spectrum analyzer frequency span is set from 12 GHz to 12.5 GHz

Result:

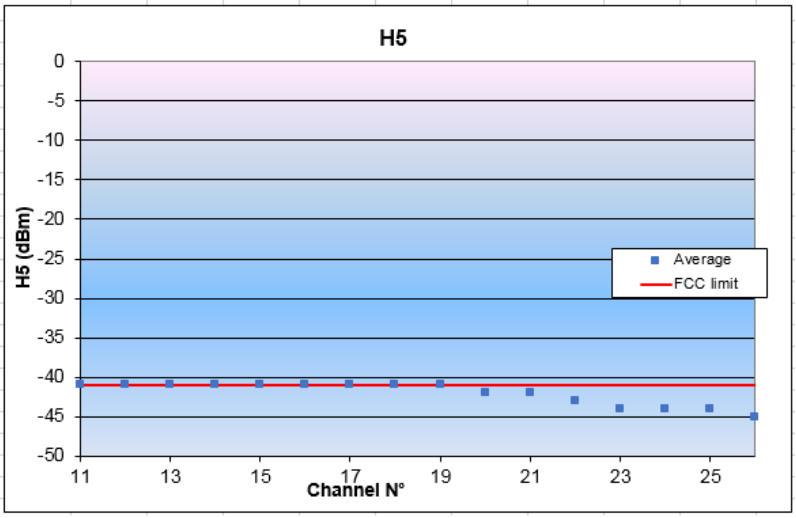

Figure 17: Conducted H5 spurious

Maximum power is on channels 11 to 19: **-41 dBm**

Conclusion:

- There is **no** margin to the FCC limit.

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4.2.5.9 H6 (FCC test conditions, average measurement)

Same method as H2 except the spectrum analyzer frequency span is set from 14.4GHz to 15.0GHz

Result:

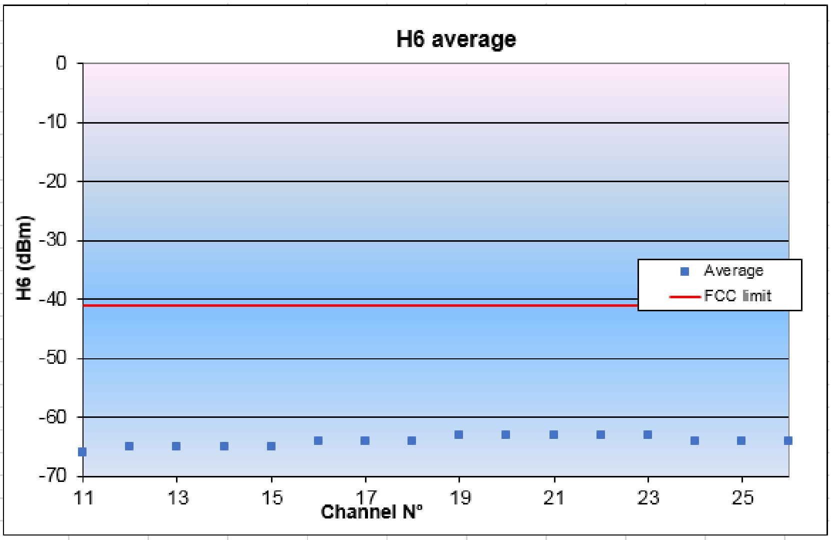

Figure 18: Conducted H6 spurious

Maximum power is: -63 **dBm**

Conclusion:

- There is **22** dB margin to the FCC limit.

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4.2.5.10 H7 (FCC test conditions, average measurement)

Same method as H2 except the spectrum analyzer frequency span is set from 16.8GHz to 17.5GHz

Result:

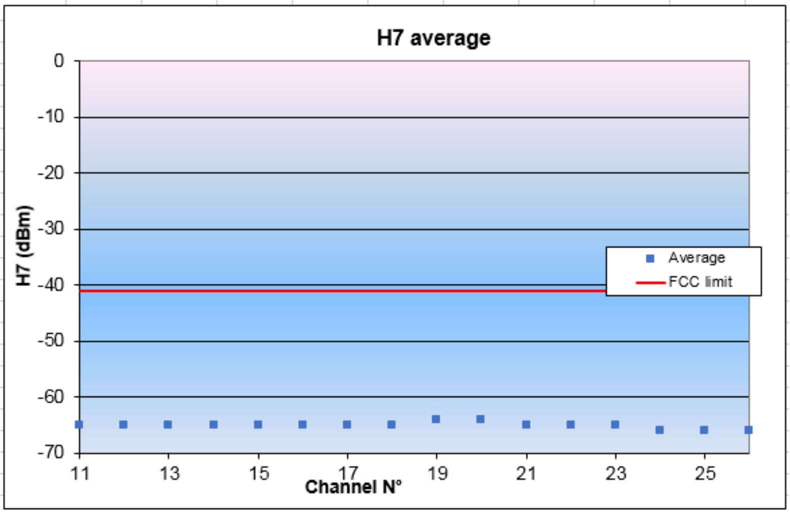

Figure 19: Conducted H7 spurious

Maximum power is: -64 **dBm**

Conclusion:

- There is **23** dB margin to the FCC limit.

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4.2.5.11 H8 (FCC test conditions, average measurement)

Same method as H2 except the spectrum analyzer frequency span is set from 19.2GHz to 20.0GHz

Result:

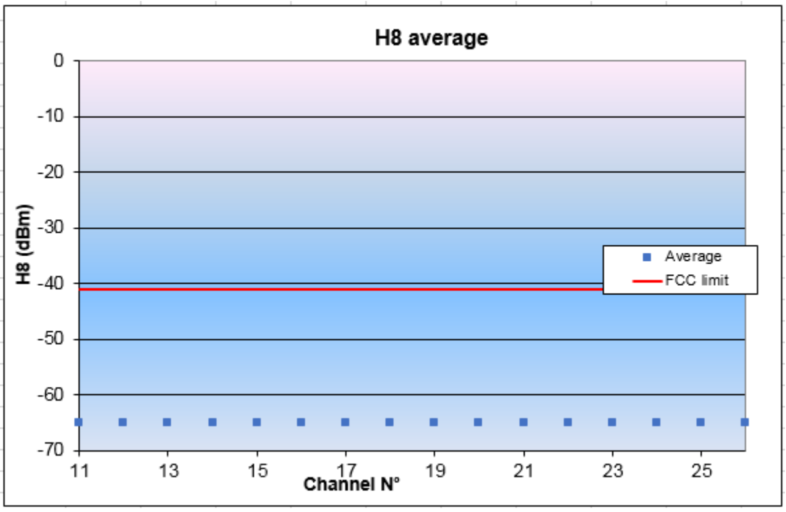

Figure 20: Conducted H8 spurious

Maximum power is: -65 **dBm**

Conclusion:

- There is 24 dB margin to the FCC limit.

4.2.5.12 H9 (FCC test conditions, average measurement)

Same method as H2 except the spectrum analyzer frequency span is set from 21.6GHz to 22.5GHz

Result:

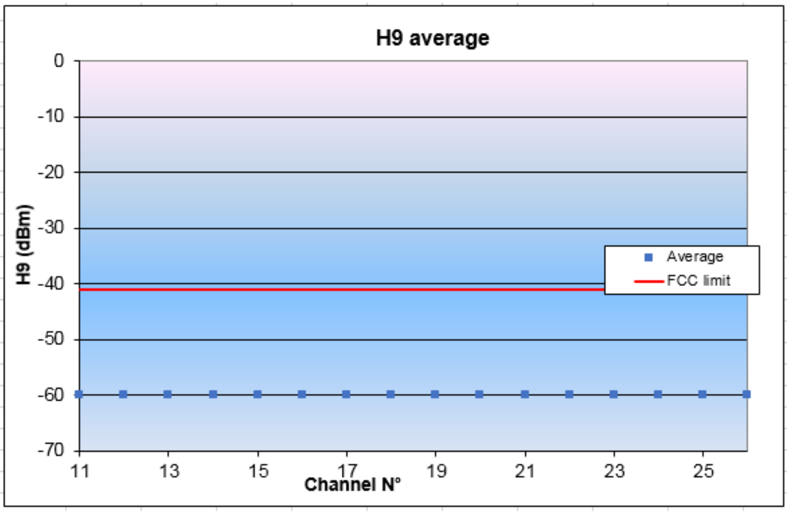

Figure 21: Conducted H9 spurious

Maximum power is on channel: -60 **dBm**

Conclusion:

- There is **19** dB margin to the FCC limit.

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4.2.5.13 H10 (FCC test conditions, average measurement)

Same method as H2 except the spectrum analyzer frequency span is set from 24GHz to 25GHz

Result:

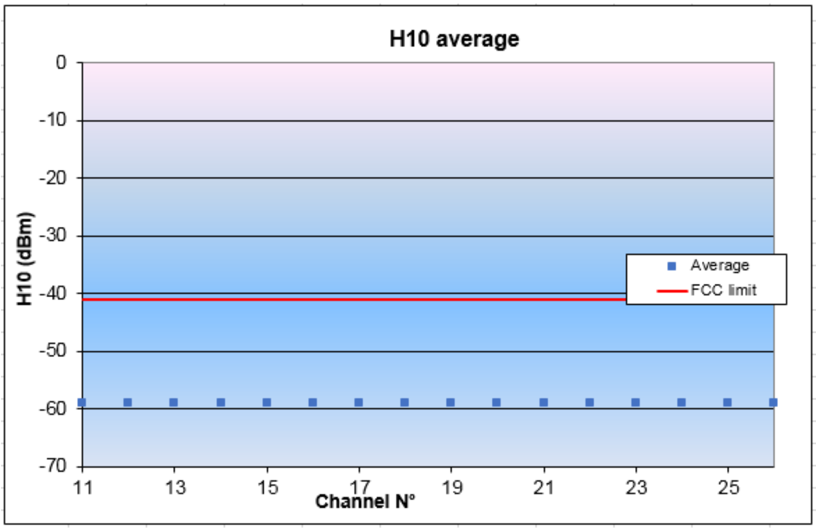

Figure 22: Conducted H10 spurious

Maximum power is: -59 **dBm**

Conclusion:

- There is **18** dB margin to the FCC limit.

4.2.6 TX Modulation

4.2.7 EVM

Test method:

- Connect the RF port of the module to the R&S FSV30 spectrum analyzer. Use the specific menu of the SA to do the EVM measurement
- Set the JN5189T in continuous modulated mode
- Set the TX frequency to channel 11
- Measure the offset EVM value.
- Repeat the test for each channel

The graphs below show the EVM value for the regular mode.

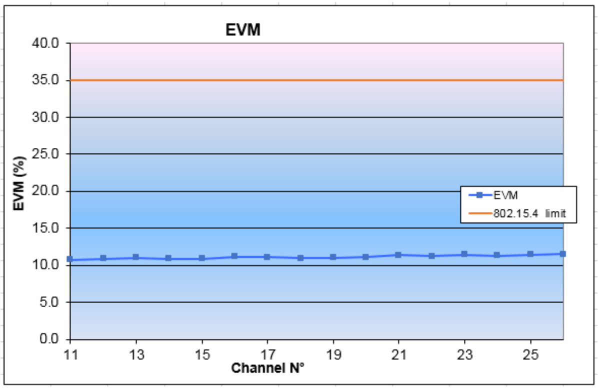

Figure 23: EVM in regular mode

Result:

Regular mode max value on ch 26 = **11.5 %**

Conclusion:

- Very good margin vs 802.15.4 limit in regular mode
- there is still good margin to 802.15.4 limit

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4.2.8 Offset EVM

Test method:

- Same method as EVM measurement

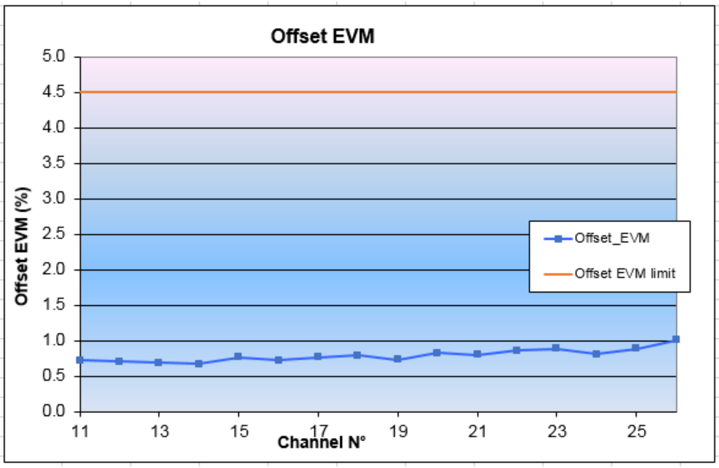

Figure 24: Offset EVM in regular mode

Result:

Regular mode max value on ch 26 = **1.01 %**

Conclusion:

- Very good margin vs JN5189T specification in regular mode
- There is still a good margin to JN5189T specification

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4.2.9 Upper band edge

Test method:

- Set the radio to:
  - TX mode, modulated, continuous mode
- Set the analyzer to:
  - Start freq = 2.475 GHz, Stop freq=2.485 GHz, Ref amp=-20 dBm, sweep time=100 ms,
  - RBW = 1MHz, Video BW = 3MHz
  - Detector = Average
  - Average mode: power
  - Number of Sweeps = 100
  - Set the channel 26 (2.48GHz)

Result:

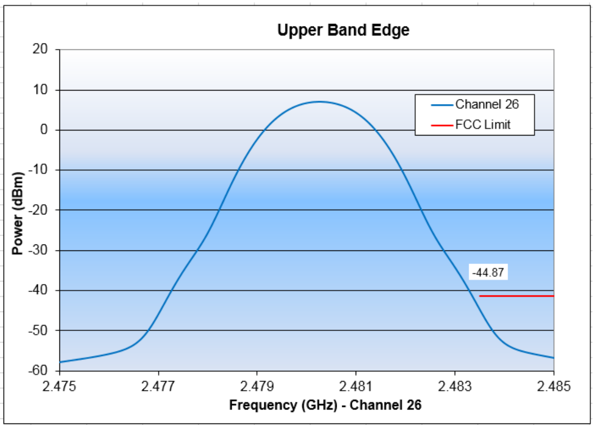

Figure 25: Upper band edge, proprietary mode 2

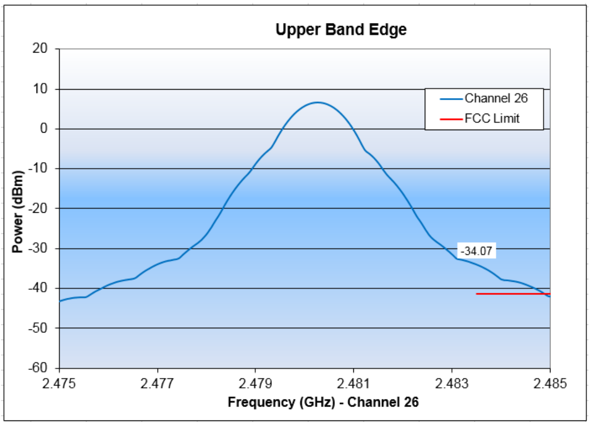

Figure 26: Upper band edge in regular mode

Conclusion:

The Upper Band Edge test pass the ETSI certification in the proprietary mode 2.

4.3 RX tests

4.3.1 Test Set-Up

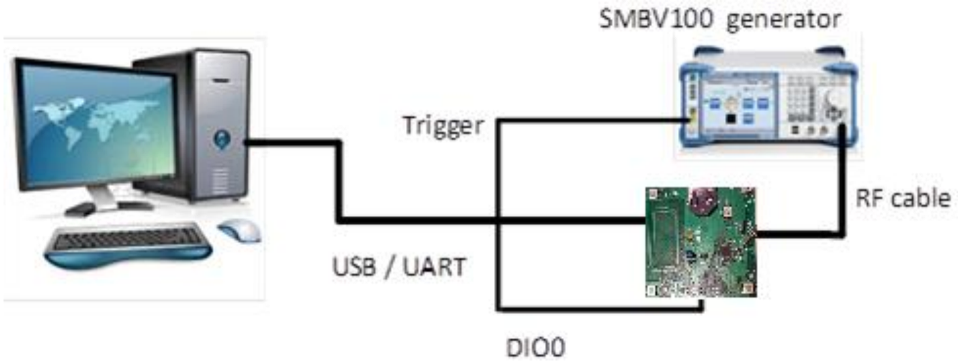

Figure 27: Conducted Rx test set up for sensitivity and receiver maximum input level

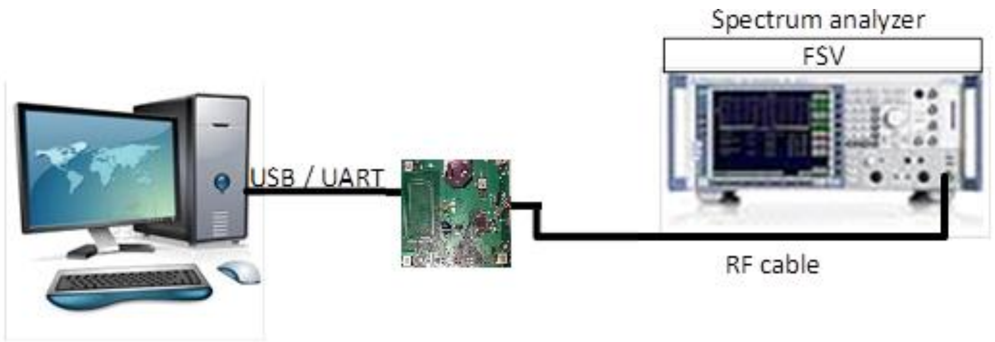

Figure 28: Conducted Rx test set up for spurious

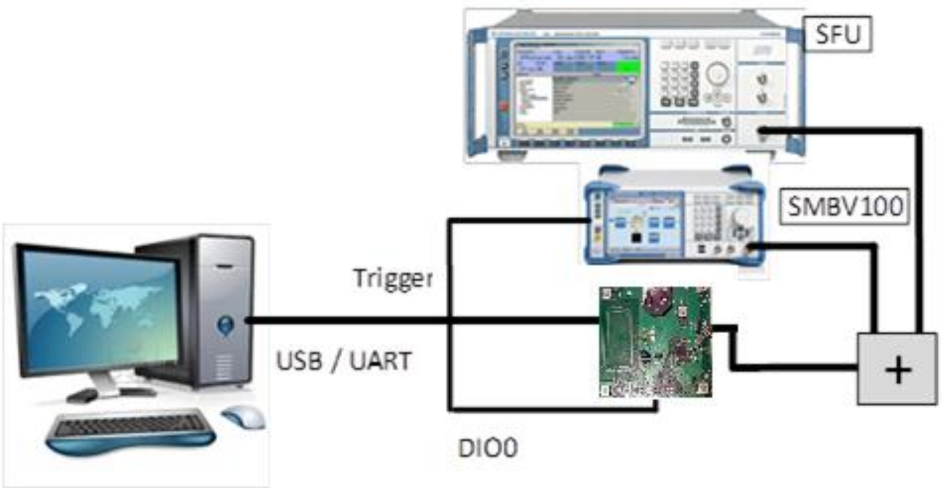

Figure 29: Conducted Rx test set up for interference rejection

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4.3.2 Sensitivity

Test method:

The board is placed in a RF shield box in order to avoid any interference.

Generator: R&S SMBV100

The generator is used in ARB mode. It generates a pattern of 1000 packets of 20 octets. The DIO0 of the JN5189T is connected to the trigger input of the generator.

A TERATERM window is used to control the module.

- Set the receive frequency to channel 11
- Set the module in “Trigger packet test”.
- The connection is automatically established and the PER (Packet Error Rate) is measured.
- Decrease the level of the generator at the RF input of the module until PER = 1%.

Result:

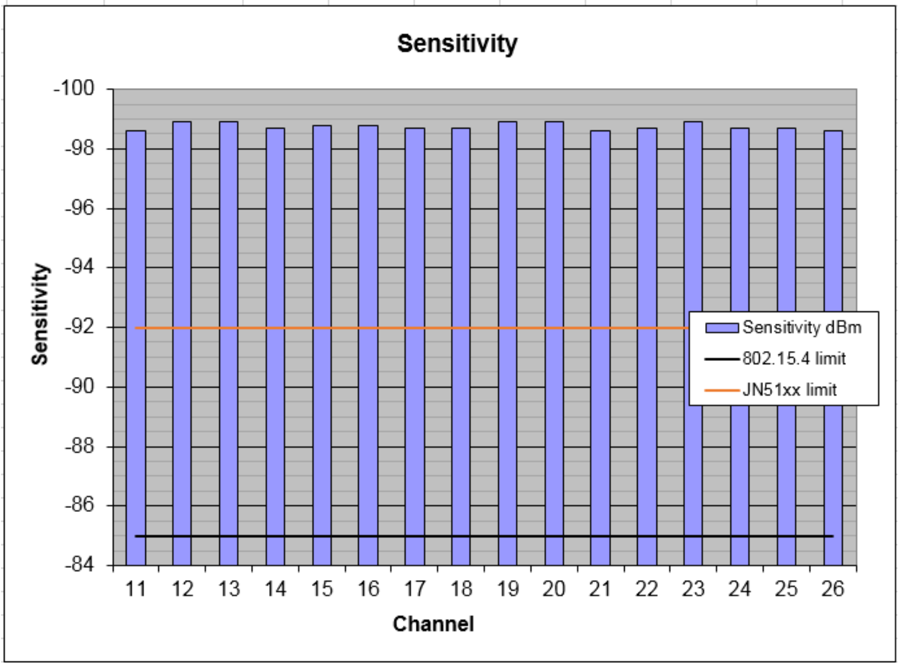

Figure 30: Sensitivity

Conclusion:

Min value: **- 98.6 dBm on channel 11,21,26**

Max value: **-98.9 dBm on channels 12,13,19,20**

Sensitivity is a less than 0.5dB below of the reference design one, so very close.

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4.3.3 Receiver Maximum Input Level

Test method:

Generator: R&S SMBV100

The generator is used in ARB mode. It generates a pattern of 1000 packets of 20 octets. The DIO0 of the JN5189T is connected to the trigger input of the generator.

A TERATERM window is used to control the module.

- Set the receive frequency to channel 11
- Set the module in “Trigger packet test”.
- The connection is automatically established and the PER (Packet Error Rate) is measured.
- Increase the level of the generator at the RF input of the module until PER = 1%.
- Do the same for other channels.

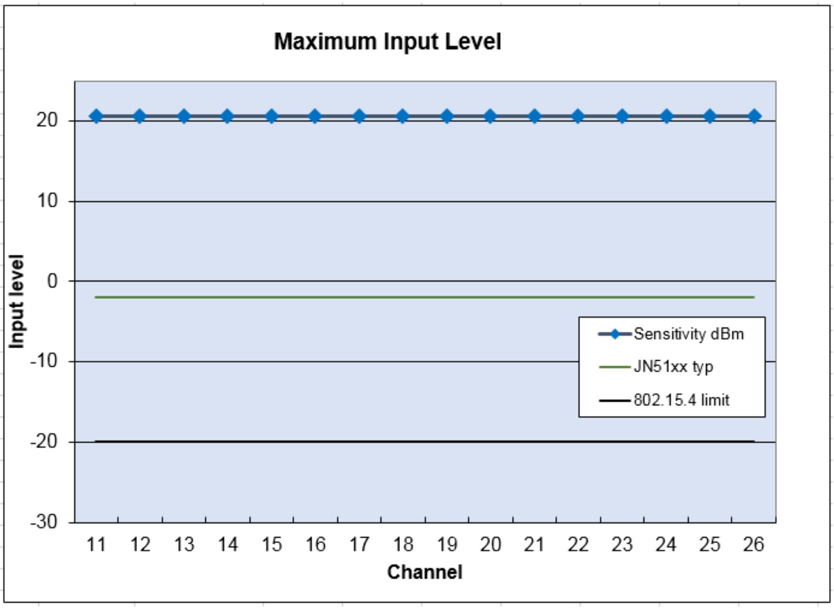

Figure 31: Maximum input power

Conclusion:

The actual maximum input level could not be measured with the test environment. The maximum level that can be delivered to the JN5189T is limited by the maximum output power of the generator and the cable losses.

The maximum input level of JN5189 is higher than **19.5 dBm** on all channels.

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4.3.4 RX spurious

4.3.4.1 Wide Band

Test method:

- Set the radio in:
  - Receiver mode, frequency: channel 18
- Set the analyzer to:
  - Ref amp = - 20 dBm, Trace = max hold, detector = max peak
    - Start/Stop frequency: 30 MHz / 1GHz
      - ✓ RBW = 100 kHz,
    - Then Start/Stop frequency: 1 GHz/12.75 GHz
      - ✓ RBW = 1 MHz

Results:

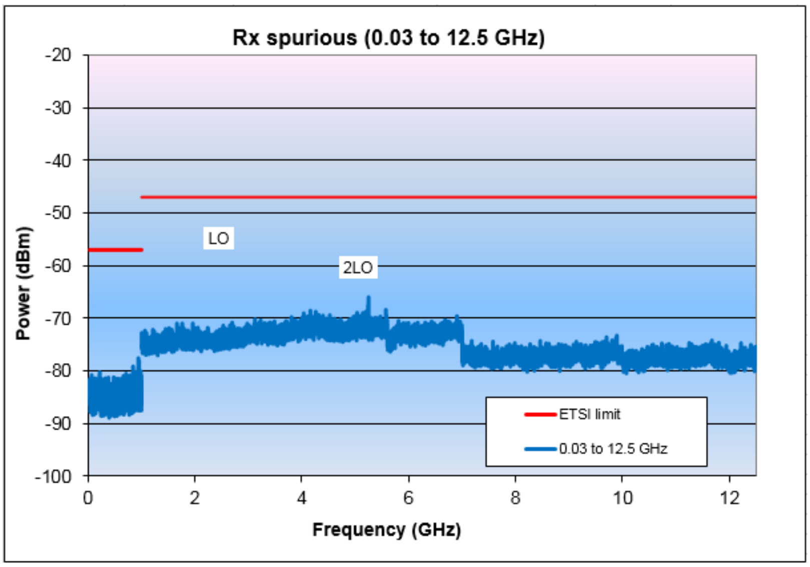

Figure 32: Conducted Rx spurious

Note: no spur has been detected.

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4.3.4.2 LO leakage

Test Frequency: 2440 MHz (channel 18)

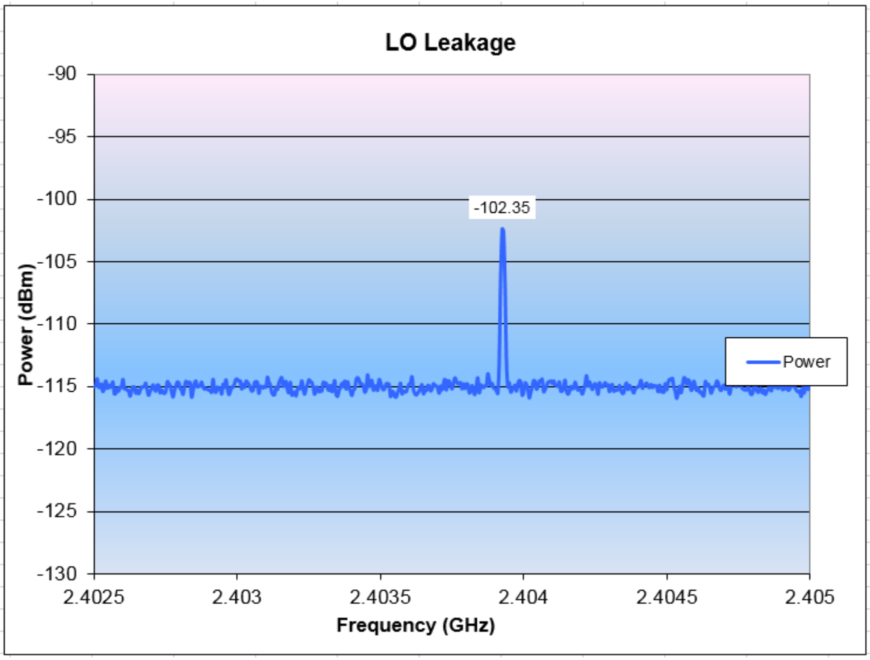

Figure 33: LO leakage

<u>Results:</u>

- **- 102.3** dBm

<u>Conclusion</u>:

- **More than 50 dB** margin to ETSI limit

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4.3.5 Receiver Interference Rejection

4.3.5.1 Adjacent and alternate channels with standard interferers

Interferers are located in the adjacent channel (n-1 and n+1) or alternate channels (n-2 and n+2).The test is performed with only one interfering signal at a time.

Test method:
Generator for desired signal: Rhode&Schwarz SMBV100A generator (modulated)
Generator for interferers: R&S SFU (modulated)
Criterion: PER < 1 %
The wanted signal is set to - 82 dBm. The interferer is increased until the PER threshold has been reached.
Channels under test: 11, 18 and 26 (although n-1, n-2 are not system relevant for channel 11 and n+, n+2 are not system relevant for channel 26).

Results:

	ch11				ch18				ch26			
	2405				2440				2480			
	n-2	**n-1**	**n+1**	**n+2**	**n-2**	**n-1**	**n+1**	**n+2**	**n-2**	**n-1**	**n+1**	**n+2**
	2395	2400	2410	2415	2430	2435	2445	2450	2470	2475	2485	2490
Interferer level (dBc)	46.2	35.2	36.3	46.3	45.8	35.0	36.0	46.1	46.1	35.4	36.2	46.3
802.15.4 limit (dB)	30	0	0	30	30	0	0	30	30	0	0	30
Margin (dB)	16.2	35.2	36.3	16.3	15.8	35.0	36.0	16.1	16.1	35.4	36.2	16.3

Figure 34: Adjacent and alternate rejection

Conclusion: Good margin, in line with the expected results

4.3.5.2 N-3 & n+3 channels with standard interferers

Test method:
Same as adjacent and alternate channels but the interferer is set at +/- 15 MHz offset from the desired channel.

Results:

	ch11		ch18		ch26	
	2405		2440		2480	
	n-3	**n+3**	**n-3**	**n+3**	**n-3**	**n+3**
	2390	2420	2425	2455	2465	2495
Interferer level (dBc)	**51.8**	**52.4**	**51.6**	**52.4**	**51.5**	**52.4**

Figure 35: N-/+3 band rejection

Conclusion:
In line with expected values

4.3.5.3 Co-channel

	ch11	ch18	ch26
	2405	2440	2480
	co-ch	**co-ch**	**co-ch**
	2405	2440	2480
Interferer level (dBc)	**-2.8**	**-3.0**	**-2.6**

Figure 36: co-channel

Conclusion: In line with expected values

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4.3.6 Receiver Blocking

The JN5189T is an equipment of Category 1 as defined by the ETSI 300 328 (TX signal higher than 10 dBm)

Tests and limits are used according to category 1

Interferer is a CW signal.

4.3.6.1 Test 1

	ch11	ch11	ch26	ch26
	2405	2405	2480	2480
	Low	**High**	**Low**	**High**
	2380	2503.5	2380	2503.5
Interferer level (dBm)	**-22.6**	**-20.5**	**-25.2**	**-25.2**
Interfere level (dBc)	71.4	73.5	68.8	68.8
802.15.4 limit (dBm)	-53	-53	-53	-53
Margin (dB)	30.4	32.5	27.8	27.8

Figure 37: Receiver blocking test1

<u>Conclusion:</u> very good margin

4.3.6.2 Test 2

	ch11	ch11	ch11	ch26	ch26	ch26
	2405	2405	2405	2480	2480	2480
	Low	**Low**	**Low**	**Low**	**Low**	**Low**
	2300	2330	2360	2300	2330	2360
Interferer level (dBm)	**-19.8**	**-20.0**	**-21.2**	**-24.6**	**-24.9**	**-25.2**
Interfere level (dBc)	74.2	74.0	72.8	69.4	69.1	68.8
802.15.4 limit (dBm)	-53	-53	-53	-53	-53	-53
Margin (dB)	33.2	33.0	31.8	28.4	28.1	27.8

Figure 38: Receiver blocking test2

<u>Conclusion:</u> very good margin

4.3.6.3 Test 3

	ch11	ch11	ch11	ch11	ch11	ch11
	2405	2405	2405	2405	2405	2405
	High	**High**	**High**	**High**	**High**	**High**
	2523.5	2553.5	2583.5	2613.5	2643.5	2673.5
Interferer level (dBm)	**-20.5**	**-20.4**	**-20.3**	**-20.1**	**-20.3**	**-20.1**
Interfere level (dBc)	73.5	73.6	73.7	73.9	73.7	73.9
802.15.4 limit (dBm)	-53	-53	-53	-53	-53	-53
Margin (dB)	32.5	32.6	32.7	32.9	32.7	32.9

	ch26	ch26	ch26	ch26	ch26	ch26
	2480	2480	2480	2480	2480	2480
	High	**High**	**High**	**High**	**High**	**High**
	2523.5	2553.5	2583.5	2613.5	2643.5	2673.5
Interferer level (dBm)	**-25.2**	**-25.2**	**-25.2**	**-24.8**	**-25.0**	**-25.0**
Interfere level (dBc)	68.8	68.8	68.8	69.2	69.0	69.0
802.15.4 limit (dBm)	-53	-53	-53	-53	-53	-53
Margin (dB)	27.8	27.8	27.8	28.2	28.0	28.0

Figure 39: Receiver blocking test3

<u>Conclusion:</u> very good margin

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Return loss

4.3.7 RX

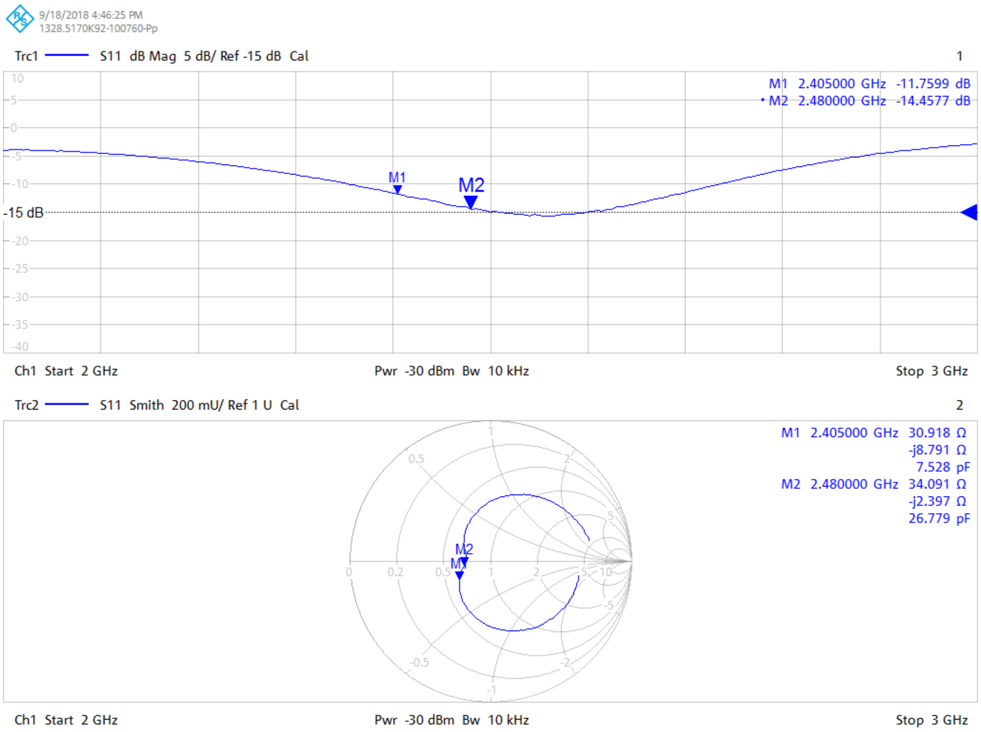

Figure 40: S11 Rx

S11 < -11.7 dB @ 2.405 – 2.480 GHz

Note:

- There is no specification for the return loss.
- On a module with a SMA connector instead of a µFl connector, the return loss is improved by 1 dB with the same matching network.

Conclusion:

- The S11 is better than the NXP -10 dB target.

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4.4 Conclusion

Harmonics 4 and 5 are close to the limit,1dB missing in TX power and 0.5 dB missing in sensitivity, these radio tests prove the good RF performances of the JN5189T on a coin cell board.

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4.5 References

FCC: 47 CFR Part 15C

ETS EN 300 328: European Telecommunication Standard - Radio Equipment and Systems (RES) Wideband data transmission systems, Technical characteristics and test conditions for data transmission equipment operating in the 2.4GHz ISM band and using spread spectrum modulation techniques

IEEE 802.15.4: IEEE standard for Information technology – Telecommunications and information exchange between systems – Local and metropolitan area networks – Specific requirements – Part 15.4: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low Rate Wireless Personnel Area Networks (LR-WPANs)

4.6 ANNEXE A

4.6.1 Benefit of using a proprietary mode in a Zigbee network

Consider a JN5189T configured in Rx mode ZigBee while another JN5189T is configured in Tx mode ZigBee and generates the wanted channel.

Consider that a 3rd JN5189T is configured in Transmit mode and generates an interferer ZigBee in a near-by channel.

In this case if the interferer signal is generated without any filtering then the interferer immunity of the JN5189T receiver will be severely limited by the side lobes of the ZigBee modulation.

As the JN5189T radio has much better performances in terms of interferers immunity compared to the side lobes limitation of the ZigBee modulation, then using the proprietary mode for the Transmitter that generates the interferer will improve the interferer immunity of the JN5189T which is configured in Rx mode.

In other words, the level of the interferer can be higher relatively to the wanted channel when the JN5189T interferer uses the proprietary mode compared to the regular mode.

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