AN13047

K32W041AM RF Report for Bluetooth LE and IEEE 802.15.4 Applications

Rev. 0 — 16 November 2022 Application note

Document information

Information	Content
Keywords	K32W041AM RF, Bluetooth LE, IEEE 802.15.4 applications, TX, RX
Abstract	This document provides the K32W041AM RF evaluation test results

1 Introduction

This document provides the RF evaluation test results of the K32W041AM for:

- Bluetooth Low Energy applications on Two Frequency Shift Keying (2FSK) modulation
- IEEE 802.15.4 applications (OQPSK modulation)

It includes the test setup description and the tools used to perform the tests. To get the K32W041AM radio parameters, see the *K32W041AM Data Sheet* (document K32W041AM).

2 Bluetooth LE applications

2.1 Test presentation

2.1.1 List of tests

Conducted tests on K32W041AM:

- TX tests:
  - Bench setup
  - Frequency accuracy
  - Phase noise
  - TX power
  - TX power in band
  - TX spurious (H2 to H5, ETSI, and FCC)
  - Upper band edge
  - Modulation characteristics
  - Carrier frequency offset and drift
- RX tests:
  - Bench setup
  - Sensitivity
  - Receiver maximum input level
  - RX spurious (from 30 MHz to 12.5 GHz)
  - Receiver interference rejection performances
    - C/I and receiver selectivity performances
    - Receiver blocking
    - Blocking interferers
  - Intermodulation
- Return loss (S11):
  - RX
  - TX

2.1.2 Software

Before the measurements, load a binary code (connectivity software) in the flash memory of the board. The connectivity tool supports receiver and transmitter functions of the device.

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The version of the software is 1.0.6. The radio driver version is 2093.

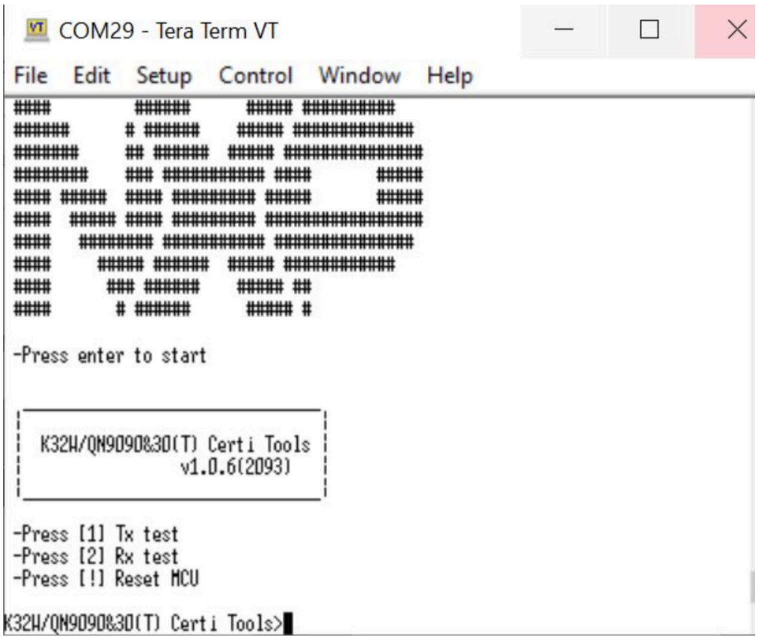

Figure 1. Certi_tool evaluation software

2.1.3 List of equipment

The list of equipment used for the RX and TX measurements are as follows:

- DK6 board and a K32W module with SMA connector (same design as modules with an M10 printed antenna)
- R&S SMBV100A signal generator
- R&S FSV spectrum analyzer – 13 GHz for harmonic measurements up to H5
- R&S ZND vector network analyzer – for S11 measurements
- R&S RF shielded box (to avoid interferences)
- PC equipped with a GPIB card

2.2 Test summary

RF PHY Bluetooth test specification: RF-PHY.TS.4.2.0 (2014-12-09)

The list of measurements is given in Table 1 for Europe and Table 2 for the US:

Table 1. List of tests for Europe

Name	Measurements	Reference	Limit	Status
Transmission	TX maximum power	Bluetooth LE 4.2, BV-01-C	-20 dBm ≤ PAVG ≤ +10 dBm EIRP	PASS
		Bluetooth LE 5.0	20 dBm ≤ PAVG ≤ +20 dBm EIRP	

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Table 1. List of tests for Europe*...continued*

Name	Measurements	Reference	Limit	Status
	TX power in band	Bluetooth LE 4.2, BV-03-C	PTX <= -20 dBm for (fTX +/- 2 MHz) PTX <= -20 dBm for (fTX +/-4 MHz and +/-5 MHz)	PASS
		Bluetooth LE 5.0	PTX <= -30 dBm for (fTX +/- [3 + n] MHz]); PTX <= -30 dBm for (fTX +/- [6+n] MHz)	
	Modulation characteristics	Bluetooth LE 4.2, BV-05-C	225 kHz <= delta f1avg <= 275 kHz	PASS
		Bluetooth LE 5.0	450 kHz <= delta f1avg <= 550 kHz	
	Carrier frequency offset and drift	Bluetooth LE 4.2, BV-06-C Bluetooth LE 5.0	fTX – 150 kHz <= fn <= fTX + 150 kHz where fTX is the nominal transmit frequency and n=0,1,2,3…k |f0 – fn| <= 50 kHz where n=2,3,4…k	PASS
	Spurious 30 MHz – 1 GHz	ETSI EN 300 328	-36 dBm or -54 dBm (depends on frequency) (100 kHz BW)	PASS
	Spurious 1 GHz - 12.5 GHz	ETSI EN 300 328	-30 dBm (1 MHz BW)	PASS
	Eirp TX spectral density	ETSI EN 300 328	10 dBm/MHz	FAIL
		FCC part 15.247	8 dBm/3 kHz	PASS
	Phase noise (unspread)	NA	NA	For information
Reception	RX sensitivity	Bluetooth LE 4.2, BV-01-C Bluetooth LE 5.0	Packet Error Rate (PER) 30.8 % with a minimum of 1500 packets	PASS
	Co-channel	Bluetooth LE 4.2, BV-03-C Bluetooth LE 5.0	> 21 dB	PASS
	Adjacent channel interference rejection (N +/-1,2,3+MHz)	Bluetooth LE 4.2, BV-03-C Bluetooth LE 5.0	> 15 dB, -17 dB, -27 dB	PASS

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Table 1. List of tests for Europe*...continued*

Name	Measurements	Reference	Limit	Status
	Blocking interferers	Bluetooth LE 4.2, BV-04-C Bluetooth LE 5.0	-30 dBm / -35 dBm	PASS[1]
	Intermodulation performance	Bluetooth LE 4.2, BV-05-C Bluetooth LE 5.0	PER 30.8 % with a minimum of 1500 packets	PASS
	RX maximum input level	Bluetooth LE 4.2, BV-06-C Bluetooth LE 5.0	PER 30.8 % with a minimum of 1500 packets	PASS
	RX emissions 30 MHz – 1 GHz	ETSI EN 300 328	-57 dBm (100 kHz)	PASS
	RX emissions 1 GHz - 12.5 GHz	ETSI EN 300 328	-47 dBm (1 MHz)	PASS
Miscellaneous	Return loss (S11)	Return loss in TX mode	For information	
		Return loss in RX mode		

[1] Blockers below 2399 GHz and above 2484 GHz are not measured in this report.

Table 2. List of tests for the US

Name	Measurements	Reference	Limit	Status
Transmission	TX maximum power	FCC part 15.247	PAVG ≤ 100 mW +20 dBm EIRP	PASS
	Spurious 1 GHz - 12.5 GHz	FCC part 15.249	Field strength < 50 mV/m at 3 m	PASS
			-41.12 dBm (1 MHz BW)	

2.3 TX conducted tests

This section lists the details about TX tests.

2.3.1 TX test setup

Figure 2 and Figure 3 show the TX test setups.

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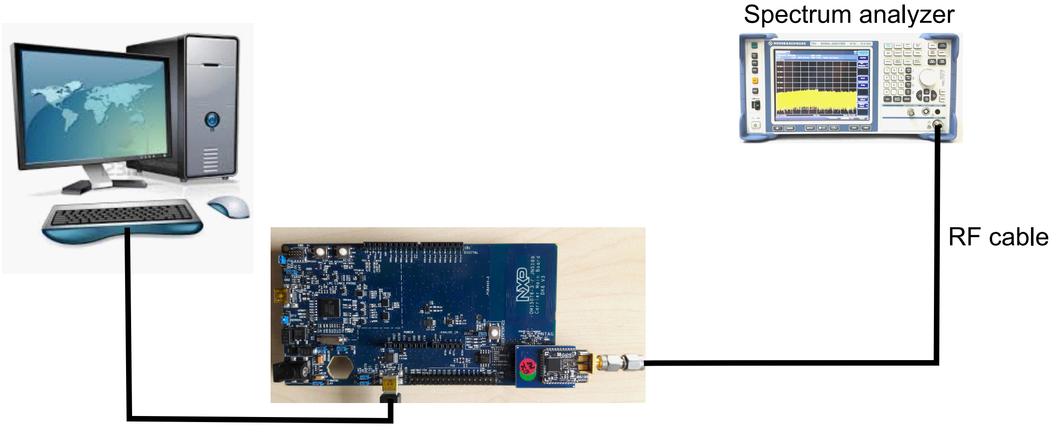

Figure 2. Conducted TX test setup

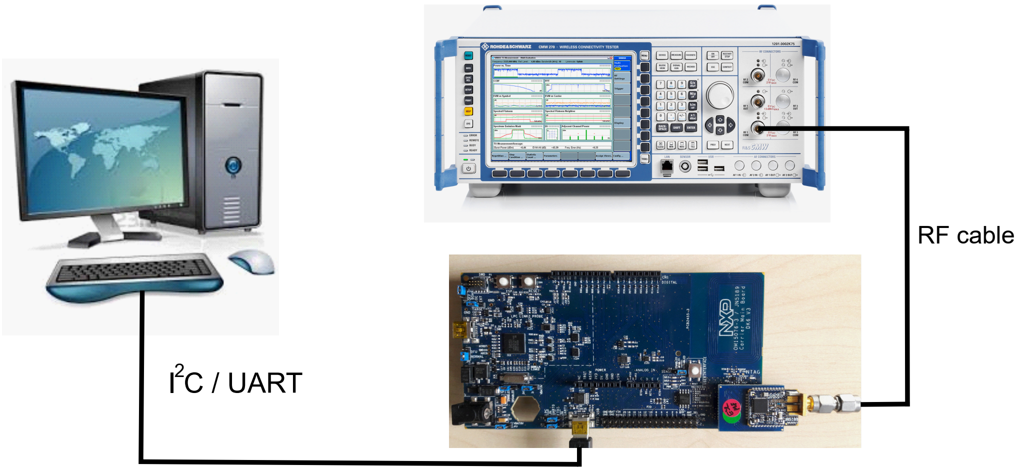

Figure 3. Specific conducted TX test setup

2.3.2 Test results

The test results for the TX conducted tests are as follows:

2.3.2.1 Frequency accuracy

Test method:

1. Set the radio to:
   - TX mode
   - CW
   - Continuous mode
   - Frequency: Channel 19
2. Set the analyzer to:
   - Center frequency = 2.44 GHz
   - Span = 1 MHz
   - Ref amp = 20 dBm
   - RBW = 10 kHz
   - VBW = 100 kHz
3. Measure the CW frequency with the marker of the spectrum analyzer.

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Result for 1 MB/s is shown in Figure 4:

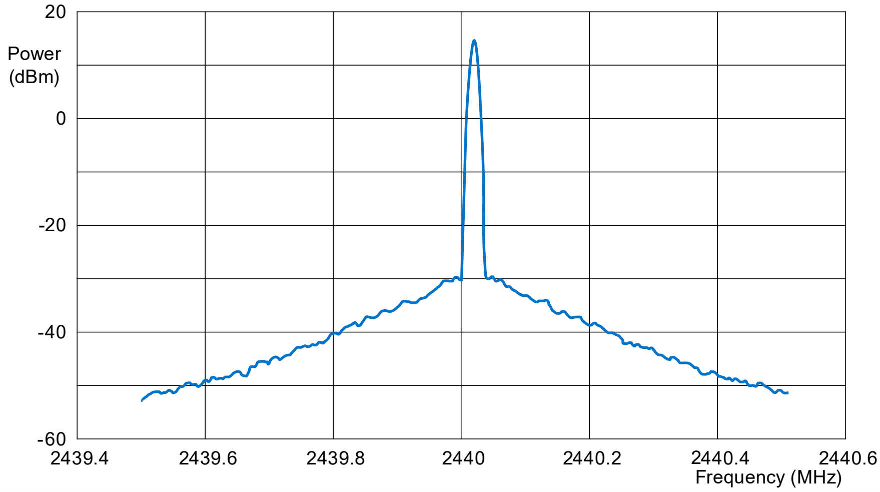

Figure 4. Frequency accuracy of TX for 1 MB/s

- Measured frequency = 2.440014 GHz
- ppm value = +5.8 ppm

Table 3. Frequency accuracy

Result	Target
+5.8 ppm	+/-25 ppm

Result for 2 MB/s is shown in Figure 5:

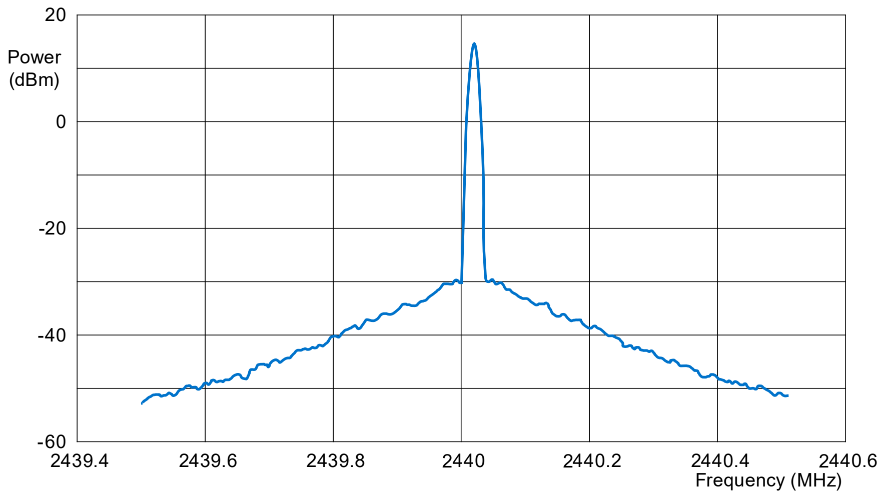

Figure 5. Frequency accuracy of TX for 2 MB/s

- Measured frequency = 2.4440018 GHz
- ppm value = +7.4 ppm

Table 4. Frequency accuracy

Result	Target
+7.4 ppm	+/-25 ppm

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Note: *The frequency accuracy depends on the XTAL model.*

Conclusion:

- The frequency accuracy complies with the data sheet.

2.3.2.2 Phase noise

Test method:

1. Set the radio to:
   - TX mode
   - CW
   - Continuous mode
   - Frequency: Channel 19
2. Set the analyzer to:
   - Center frequency = 2.44 GHz
   - Span = 1 MHz
   - Ref amp = 20 dBm
   - RBW = 10 kHz
   - VBW = 100 kHz
3. Measure the phase noise at the 100 kHz offset frequency:
   - RBW (spectrum analyzer) = 10 kHz (20 log (10 kHz) = 40 dBc)

Result:

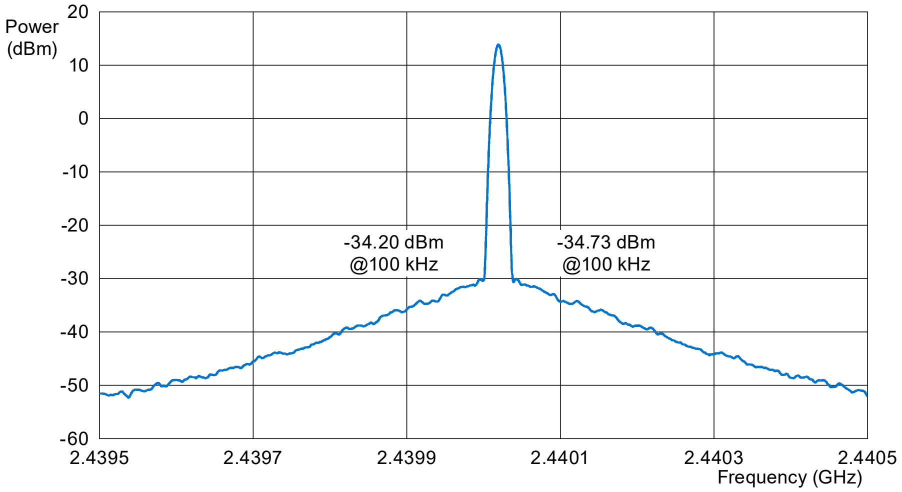

Figure 6. Conducted phase noise (1 MB/s)

- Marker value (delta) = -34.20 dBm / RBW 10 kHz = -74.20 dBc/Hz

Note: *The phase noise is just for informational purposes. No specific issue on this parameter.*

Conclusion:

- The result is the same for 2 MB/s data rate.

2.3.2.3 TX power (fundamental)

Test method:

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1. Set the radio to:
   - TX mode 1 M
   - Unmodulated
   - Continuous mode (00)
2. Set the analyzer to:
   - Start frequency = 2.4 GHz
   - Stop frequency = 2.5 GHz
   - Ref amp = 20 dBm
   - Sweep time = 11.3 µs
   - RBW = 3 MHz
   - VBW = 3 MHz
   - Maximum Hold mode
   - Detector = RMS
3. Sweep all the channels from channel 0 to channel 39.

Result:

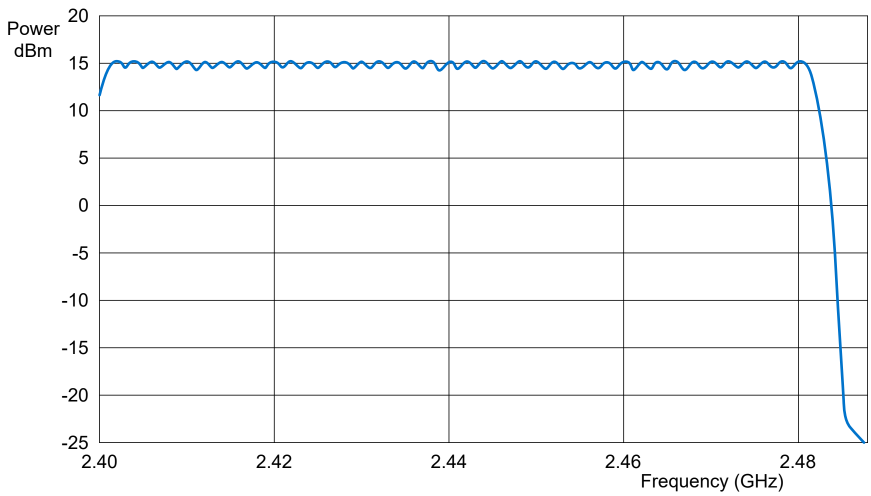

Figure 7. TX power for 1 MB/s

- Maximum power is on channel 36: 15.25 dBm
- Minimum power is on channel 26: 15.08 dBm
- Tilt over frequencies is 0.17 dB

The same test is performed when setting 2 MB/s. Figure 8 shows the result:

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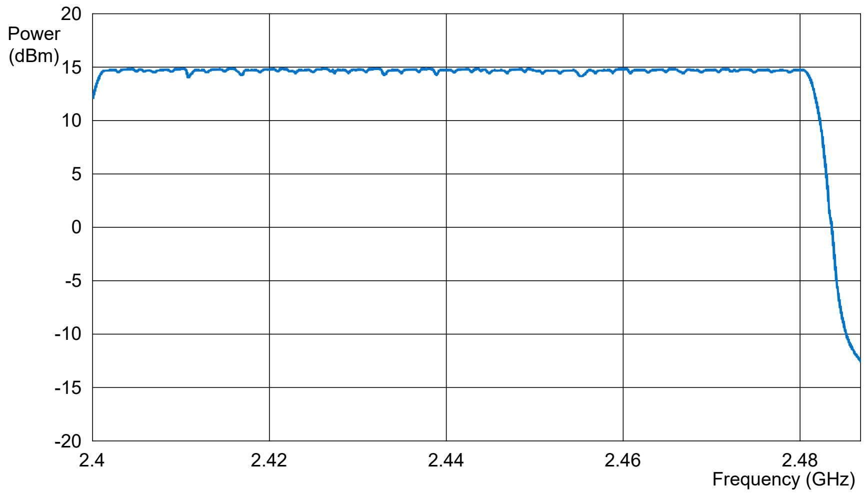

Figure 8. TX power for 2 MB/s

- Maximum power is on channel 8: 14.92 dBm
- Minimum power is on channel 36: 14.80 dBm
- Tilt over frequencies is 0.12 dB

Conclusion:

- The default transmit output power is in line with the expected results.
- The power is flat over frequencies.

2.3.2.4 TX power in band

Test method:

1. Set the radio to:
   - TX mode
   - Modulated
   - Continuous mode
2. Set the analyzer to:
   - Start frequency = 2.35 GHz
   - Stop frequency = 2.5 GHz
   - Ref amp = 20 dBm
   - Sweep time = 100 ms
   - RBW = 100 kHz
   - VBW = 300 kHz
   - Maximum Hold mode
   - Detector = RMS
   - Number of sweeps = 10
3. Sweep on channel 2, channel 19, and channel 37

Result:

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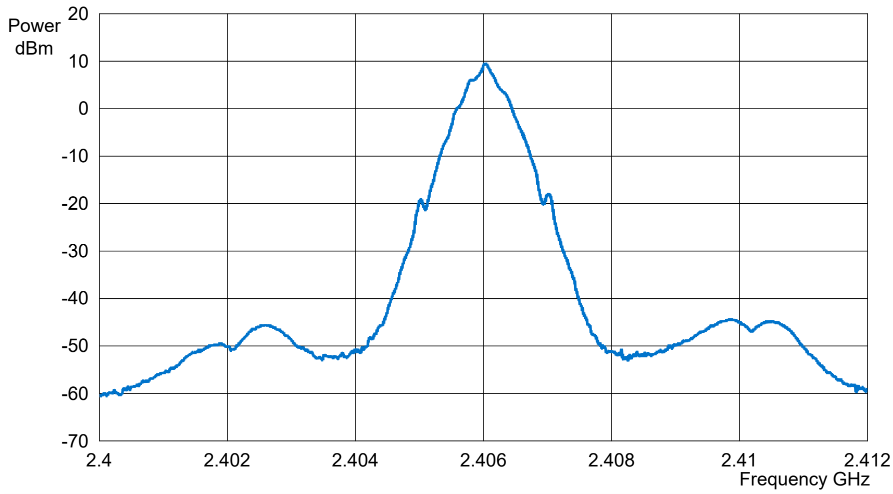

Figure 9. TX power in band, channel 2 for 1 MB/s

Table 5 shows the statistics on 1 MHz bandwidth using CMW270 equipment measurement:

Table 5. For 1 MB/s

Bandwidth	Specification	Measurement (dBm)
Max peak level <= -2 MHz	-20	-47.2
Max peak level >= +2 MHz	-20	-43.8
Max peak level <= -3 MHz	-30	-43.5
Max peak level >= +3 MHz	-30	-44.5

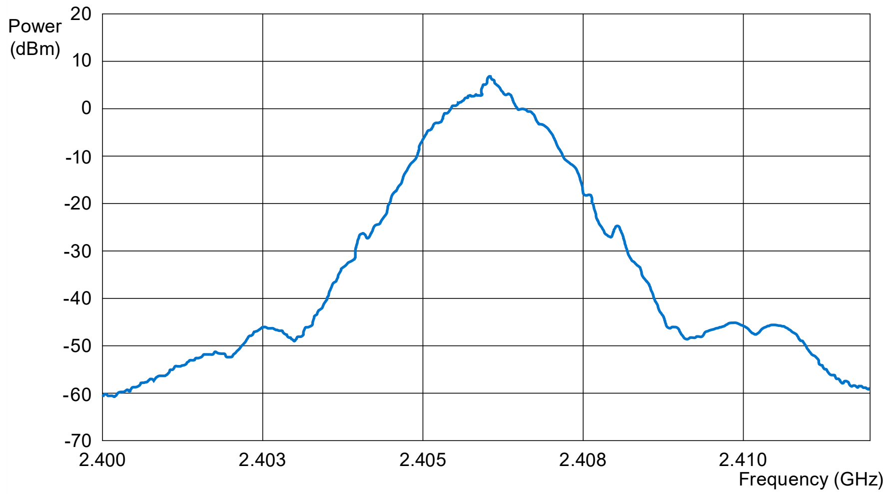

Figure 10. TX power in band, channel 2 for 2 MB/s

Table 6 shows the statistics on 1 MHz bandwidth using CMW270 equipment measurement:

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Table 6. For 2 MB/s

Bandwidth	Specification	Measurement (dBm)
Max peak level <= -4 MHz	-20	-44.0
Max peak level >= +4 MHz	-20	-42.4
Max peak level <= -6 MHz	-	-
Max peak level >= +6 MHz	-30	-49.0

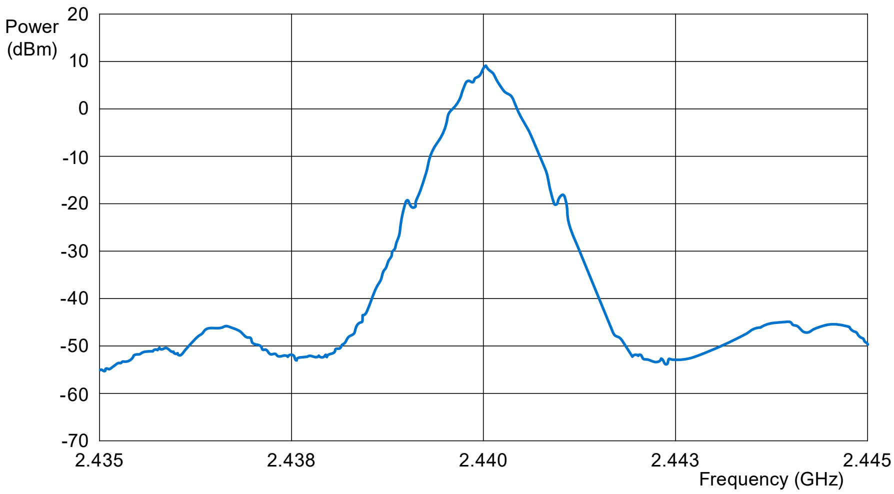

Figure 11. TX power in band, channel 19 for 1 MB/s

Table 7 shows the statistics on 1 MHz bandwidth using CMW270 equipment measurement:

Table 7. For 1 MB/s

Bandwidth	Specification	Measurement (dBm)
Max peak level <= -2 MHz	-20	-43.5
Max peak level >= +2 MHz	-20	-43.6
Max peak level <= -3 MHz	-30	-48.4
Max peak level >= +3 MHz	-30	-45.1

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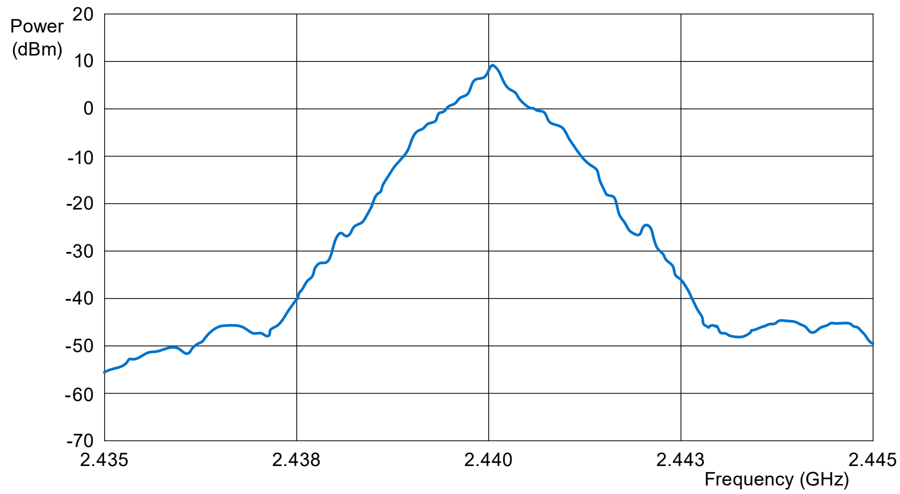

Figure 12. TX power in band, channel 19 for 2 MB/s

Table 8 shows the statistics on 1 MHz bandwidth using CMW270 equipment measurement:

Table 8. For 2 MB/s

Bandwidth	Specification	Measurement (dBm)
Max peak level <= -4 MHz	-20	-44.3
Max peak level >= +4 MHz	-20	-42.7
Max peak level <= -6 MHz	-30	-48.5
Max peak level >= +6 MHz	-30	-49.3

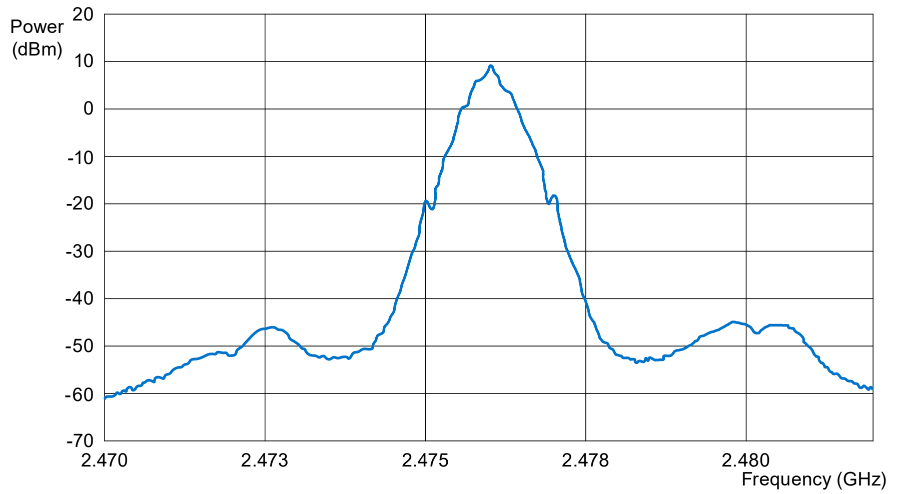

Figure 13. TX power in band, channel 37 for 1 MB/s

Table 9 shows the statistics on 1 MHz bandwidth using CMW270 equipment measurement:

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Table 9. For 1 MB/s

Bandwidth	Specification	Measurement (dBm)
Max peak level <= -2 MHz	-20	-43.1
Max peak level >= +2 MHz	-20	-43.6
Max peak level <= -3 MHz	-30	-48.1
Max peak level >= +3 MHz	-30	-44.9

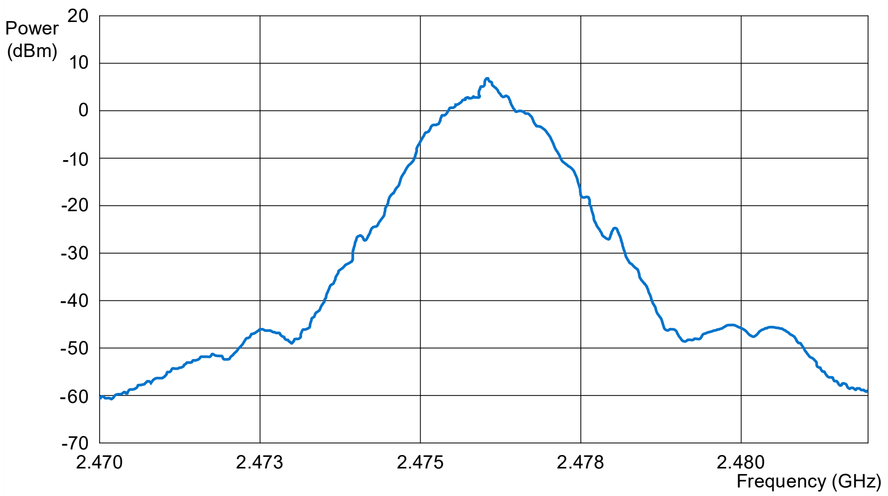

Figure 14. TX power in band, channel 37 for 2 MB/s

Table 10 shows the statistics on 1 MHz bandwidth using CMW270 equipment measurement:

Table 10. For 2 MB/s

Bandwidth	Specification	Measurement (dBm)
Max peak level <= -4 MHz	-20	-45.5
Max peak level >= +4 MHz	-20	-43.3
Max peak level <= -6 MHz	-30	-49.8
Max peak level >= +6 MHz	-	-

Conclusion:

- These results are compliant to Bluetooth LE 4.2 and Bluetooth LE 5.0.

2.3.2.5 TX spurious

2.3.2.5.1 30 MHz to 12.5 GHz

Spurious overview of the full band from 30 MHz to 12.5 GHz when the device is in the transmission mode is as follows:

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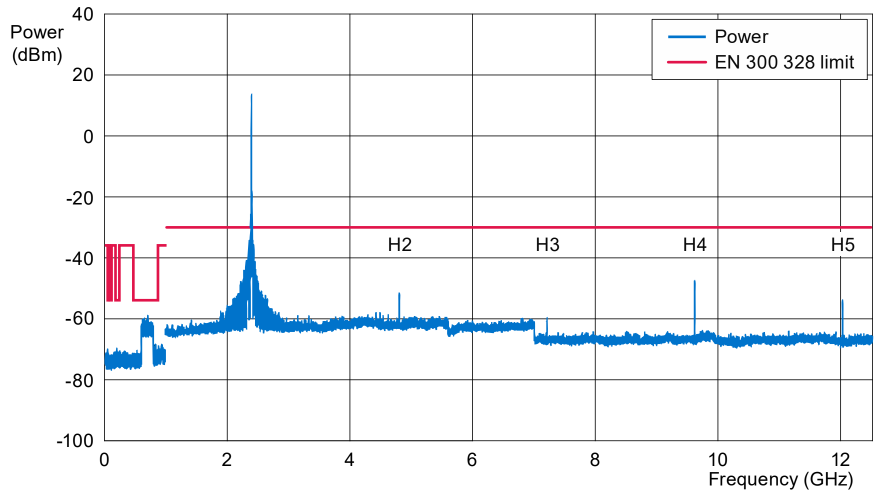

Figure 15. Conducted TX spurious for 1 MB/s (30 MHz to 12.5 GHz)

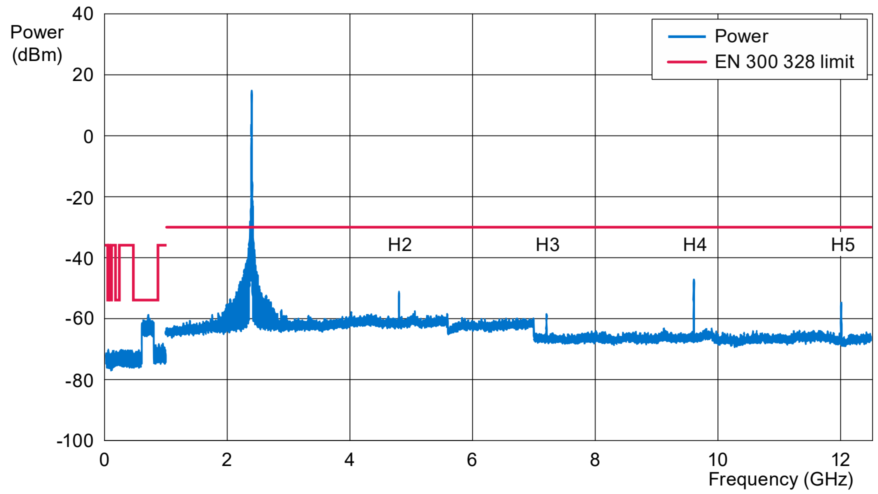

Figure 16. Conducted TX spurious for 2 MB/s (30 MHz to 12.5 GHz)

Conclusion:

- There are no TX spurs above the EN 300 328 limit (more than 10 dB margin).
- Harmonics are measured in the following sections. Since there is no major change between 1 MB/s and 2 MB/s spurious, they are measured at 1 MB/s.

2.3.2.5.2 H2 (ETSI test conditions, peak measurement)

Test method:

1. Set the radio to:
   - TX mode
   - Modulated
   - Continuous mode
2. Set the analyzer to:
   - Start frequency = 4.7 GHz
   - Stop frequency = 5 GHz
   - Ref amp = -20 dBm

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- Sweep time = 100 ms
- RBW = 1 MHz
- VBW = 3 MHz
- Maximum Hold mode
- Detector: Peak

3. Sweep all the channels from channel 0 to channel 39.

Result:

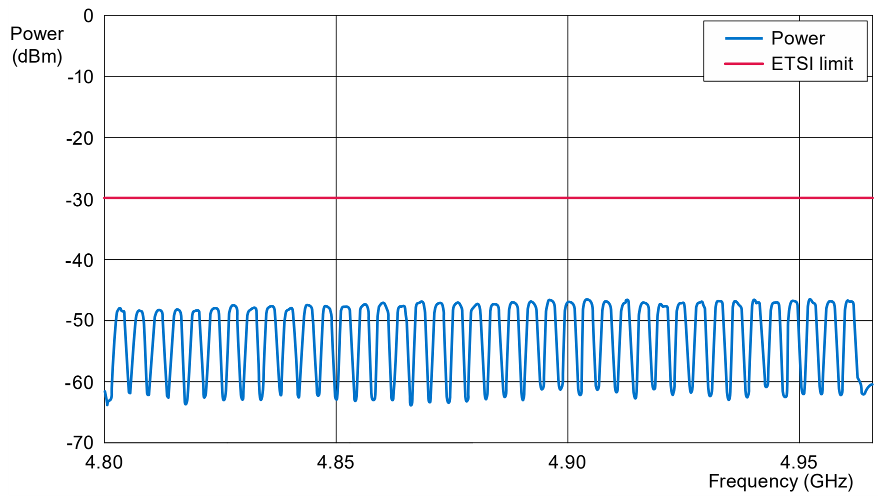

Figure 17. Conducted H2 spurious

- Maximum power at channel 38 is -46.3 dBm

Conclusion:

- There is 16.3 dB margin to the ETSI limit.

2.3.2.5.3 H3 (ETSI test conditions, peak measurement)

The test method is the same as for the H2, except the spectrum analyzer frequency start/ stop is set to 7.0 GHz and 7.5 GHz.

Result:

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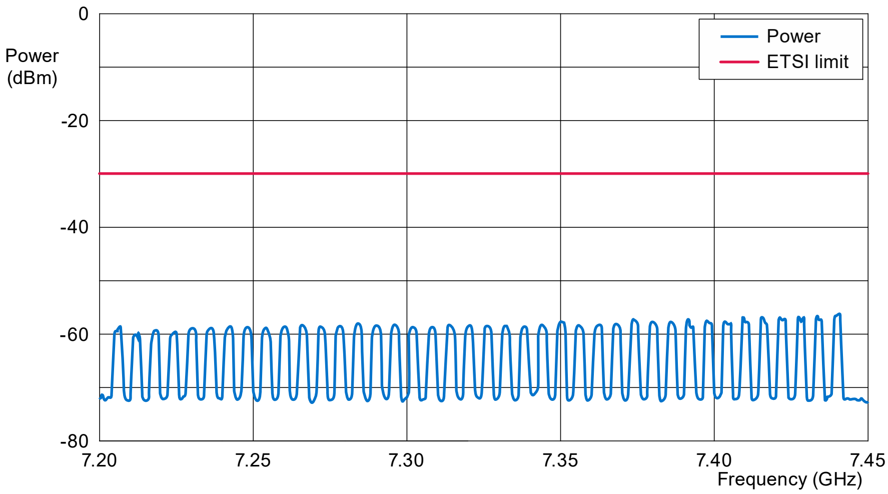

Figure 18. Conducted H3 spurious

- H3 maximum power is at channel 40: -55.8 dBm

Conclusion:

- There is 25.8 dB margin to the ETSI limit.

2.3.2.5.4 H4 (ETSI test conditions, peak measurement)

The test method is the same as for the H2, except that the spectrum analyzer frequency span is set from 9.4 GHz to 10.0 GHz.

Result:

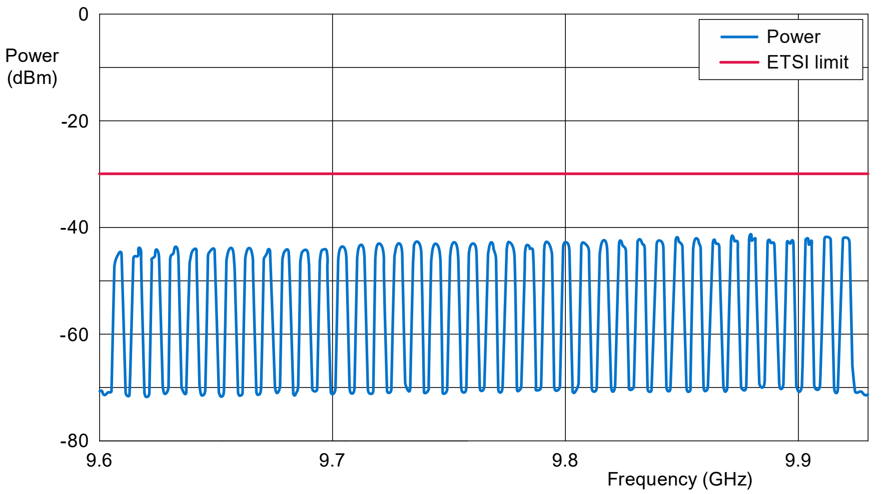

Figure 19. Conducted H4 spurious

- Maximum power is at channel 35: -41.7 dBm

Conclusion:

- There is 11.7 dB margin to the ETSI limit.

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2.3.2.5.5 H5 (ETSI test conditions, peak measurement)

The test method is the same as for the H2, except that the spectrum analyzer frequency span is set from 11.7 GHz to 12.5 GHz.

Result:

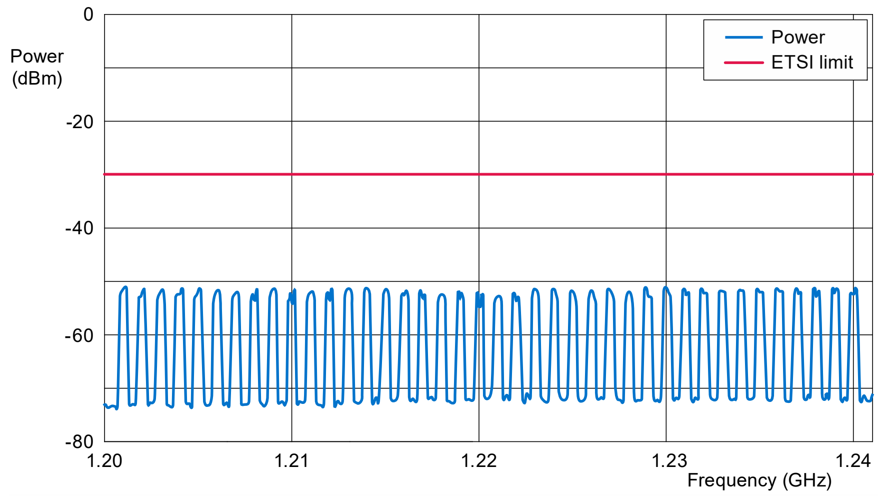

Figure 20. Conducted H5 spurious

- Maximum power is at channel 30: -51.0 dBm

Conclusion:

- There is 21.0 dB margin to the ETSI limit.

2.3.2.5.6 H2 (FCC test conditions, average measurements)

Test method:

1. Set the radio to:
   - TX mode
   - Modulated
   - Continuous mode
2. Set the analyzer to:
   - Start frequency = 4.7 GHz
   - Stop frequency = 5 GHz
   - Sweep time = 100 ms
   - RBW = 1 MHz
   - VBW = 3 MHz
   - Trace: Maximum Hold mode
   - Detector: RMS
3. Sweep all the channels from channel 0 to channel 39. For this case and in the next sections, only 4 is represented.

Result:

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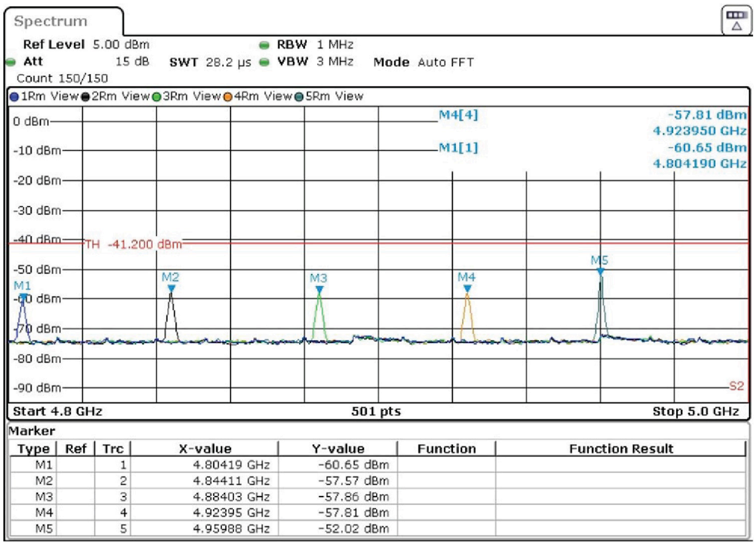

Figure 21. Conducted H2 FCC spurious

Conclusion:

- There is around 11.2 dB margin to the FCC limit.

2.3.2.5.7 H3 (FCC test conditions, average measurements)

The test method is the same as for the H2, except that the spectrum analyzer frequency span is set from 7.0 GHz to 7.5 GHz.

Result:

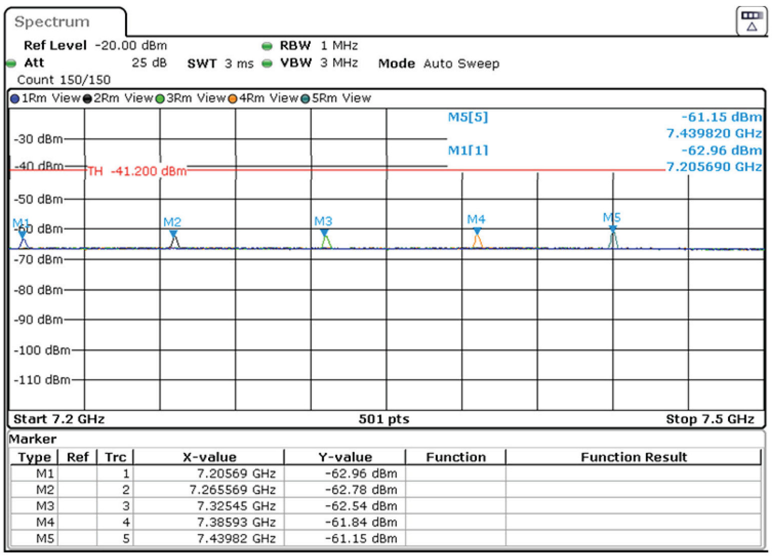

Figure 22. Conducted H3 FCC spurious

- Power is -66 dBm below noise floor of this measurement.

Conclusion:

- There is 20 dB margin to the FCC limit.

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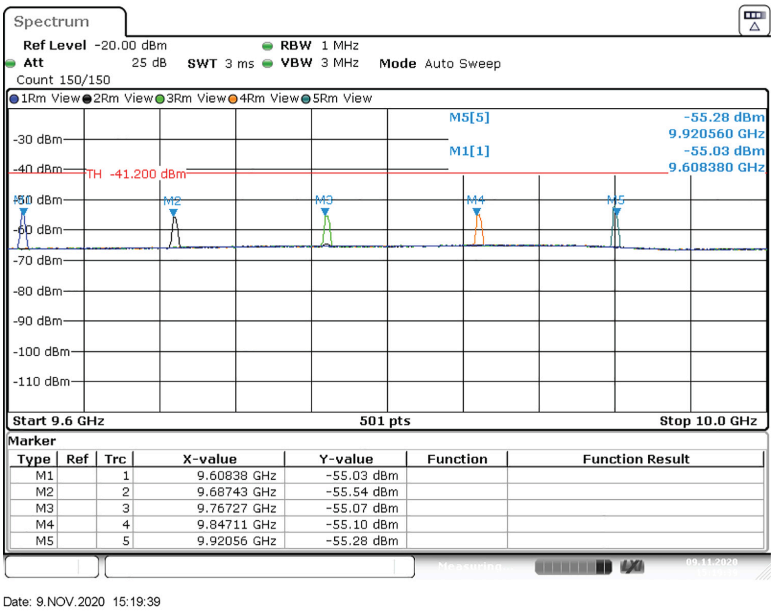
2.3.2.5.8 H4 (FCC test conditions, average measurements)

The test method is same as for the H2, except that the spectrum analyzer frequency span is set from 9.4 GHz to 10 GHz.

Result:



Type	Ref	Trc	X-value	Y-value	Function	Function Result
M1		1	9.60838 GHz	-55.03 dBm		
M2		2	9.68743 GHz	-55.54 dBm		
M3		3	9.76727 GHz	-55.07 dBm		
M4		4	9.84711 GHz	-55.10 dBm		
M5		5	9.92056 GHz	-55.28 dBm		

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Figure 23. Conducted H4 FCC spurious

Conclusion:

- There is around 14 dB margin to the FCC limit.

2.3.2.5.9 H5 (FCC test conditions, average measurements)

The test method is same as for the H2, except that the spectrum analyzer frequency span is set from 11.7 GHz to 12.5 GHz.

Result:

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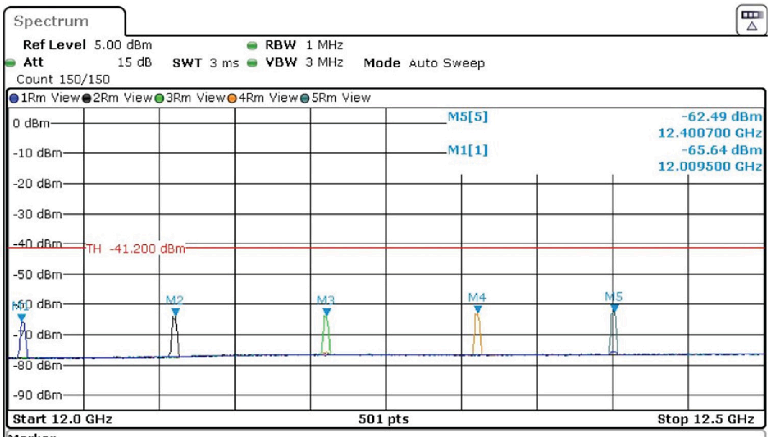

Type	Ref	Trc	X-value	Y-value	Function	Function Result
M1		1	12.0095 GHz	-65.64 dBm		
M2		2	12.1113 GHz	-63.82 dBm		
M3		3	12.2111 GHz	-63.70 dBm		
M4		4	12.3109 GHz	-62.62 dBm		
M5		5	12.4007 GHz	-62.49 dBm		

Figure 24. Conducted H5 FCC spurious

Conclusion:

- There is around 21 dB margin to the FCC limit.

2.3.2.6 Upper band edge

Test method:

1. Set the radio to:
   - TX mode
   - Modulated
   - Continuous mode
2. Set the analyzer to:
   - Start frequency = 2.475 GHz
   - Stop frequency = 2.485 GHz
   - Ref amp = 20 dBm
   - Sweep time = 100 ms
   - RBW = 1 MHz
   - VBW = 3 MHz
   - Detector = Average
   - Average mode = Power
   - Number of sweeps = 100
   - Set the channel 39 (2.48 GHz)

Results:

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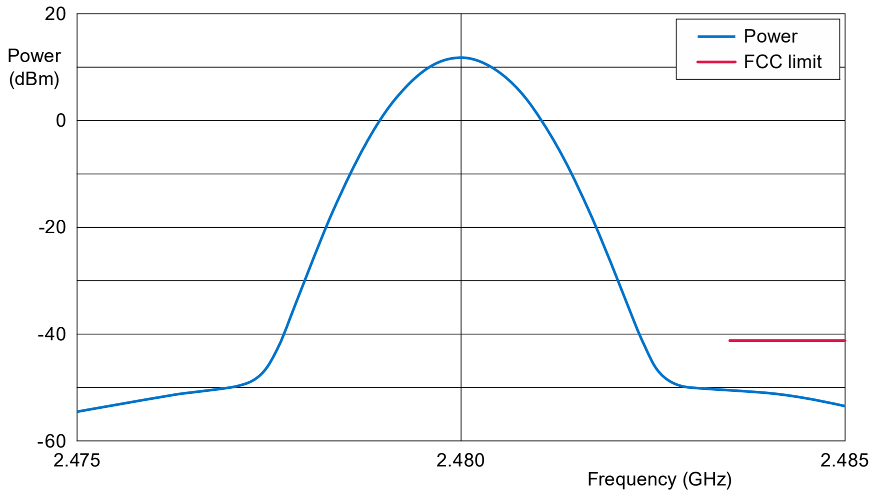

Figure 25. Upper band edge for 1 MB/s - channel 39

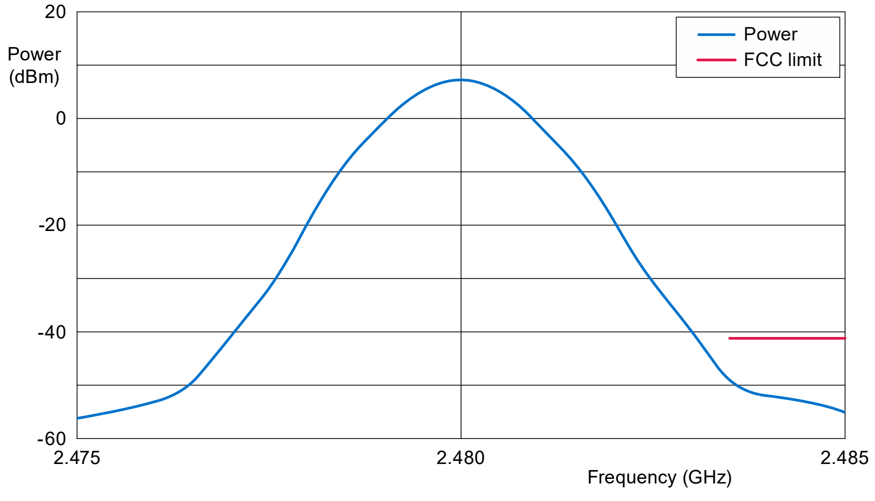

Figure 26. Upper band edge for 2 MB/s - channel 39

Conclusion:

- The upper band edge test passes the FCC certification.
- There is 9.0 dB margin for 1 MB/s and 8.5 dB margin for 2 MB/s to the FCC limit.

2.3.2.7 Modulation characteristics

A CMW equipment is used to measure the frequency deviation df1 and df2.

A specific binary is flashed: `hci_blackbox_bm.bin` (version V1) from the SDK.

Test method:

- Generator for the desired signal: CMW R&S
- Criterion: PER < 30.8 % with 1500 packets
- Channels under test: 0, 19, and 39

Result:

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Table 11. Modulation characteristics at 1 MB/s

Frequency deviation	Channel number			Specification	
	0	19	39	min	max
Frequency deviation df1 Average (kHz)	251.67	251.27	251.36	225	275
Frequency deviation df2 99.9 % (kHz)	212.64	213.04	212.04	185	-
Frequency deviation df2 Average / df1 Average	0.9	0.91	0.9	0.8	-

Table 12. Modulation characteristics at 2 MB/s

Frequency deviation	Channel number			Specification	
	0	19	39	min	max
Frequency deviation df1 Average (kHz)	501.09	502.32	503.97	450	550
Frequency deviation df2 99.9 % (kHz)	425.07	431.27	422.87	370	-
Frequency deviation df2 Average / df1 Average	0.88	0.89	0.88	0.8	-

Conclusion: The margins are good and in line with the expected results.

2.3.2.8 Carrier frequency offset and drift

A CMW equipment is used to measure the frequency deviation df1 and df2. A specific binary is flashed: `hci_blackbox_bm.bin` (version V1) from the SDK.

Test method:

- Generator for the desired signal: CMW270 R&S
- Criterion: PER < 30.8 % with 1500 packets
- Channels under test: 0, 19, and 39

Result:

Table 13. Carrier frequency offset and drift at 1 MB/s

Frequency offset and drift	Channel number			Specification	
	0	19	39	min	max
Frequency drift (kHz)	-10.06	-10.24	-11.16	-50	50

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Table 13. Carrier frequency offset and drift at 1 MB/s...*continued*

Frequency offset and drift	Channel number			Specification	
	0	19	39	min	max
Max drift rate (kHz/50 µs)	-3.37	-3.47	-3.34	-20	20
Frequency offset (kHz)	22.18	22.84	23.67	-150	150
Initial frequency drift (kHz)	-8.19	-8.29	-9.45	-23	23

Table 14. Carrier frequency offset and drift at 2 MB/s

Frequency offset and drift	Channel number			Specification	
	0	19	39	min	max
Frequency drift (kHz)	-8.06	-8.89	-10.41	-50	50
Max drift rate (kHz/50 µs)	-4.72	-2.86	-2.71	-20	20
Frequency offset (kHz)	21.12	22.13	24.02	-150	150
Initial frequency drift (kHz)	-4.55	-6.37	-7.62	-23	23

Conclusion:

- Margins are good and in line with the expected results.

For next receiver measurements below, the software used is the connectivity tool 1.0.6.

2.4 RX tests

This section lists the details about RX tests.

2.4.1 Test setup

The Module and DK6 board must be placed into an RF shielded box. Figure 27 to Figure 30, shows the conducted RX test setups.

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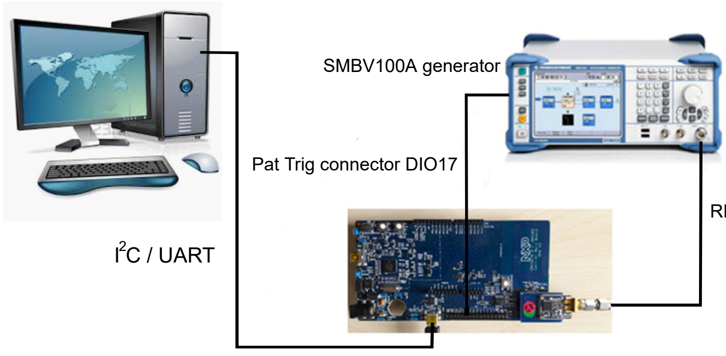

Figure 27. Conducted RX test setup for sensitivity with RF generator and faraday box

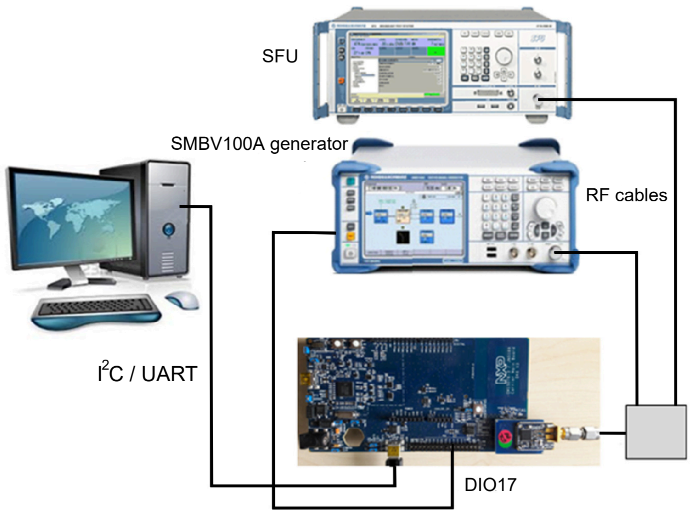

Figure 28. Conducted RX test setup for interference rejection

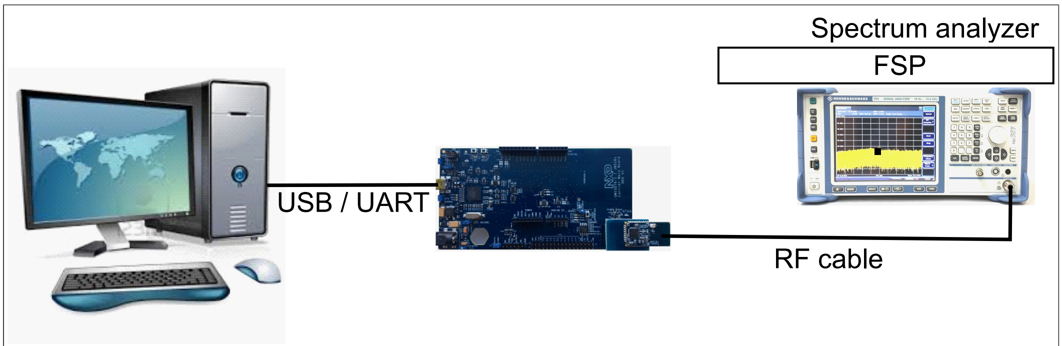

Figure 29. Conducted RX test setup for spurious

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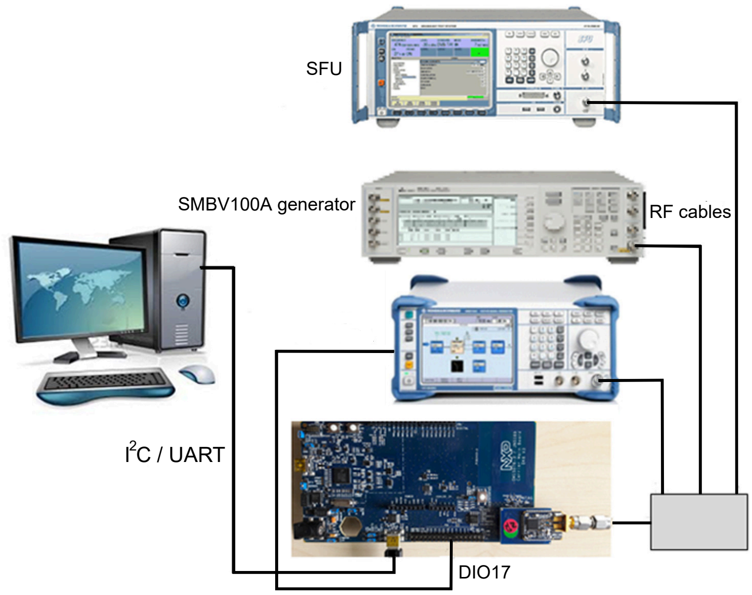

Figure 30. Conducted RX test setup for intermodulation performances

2.4.2 RX sensitivity

Test method:

To remain immune to the external parasitic signals, DK6 board is kept in an RF shielded box.

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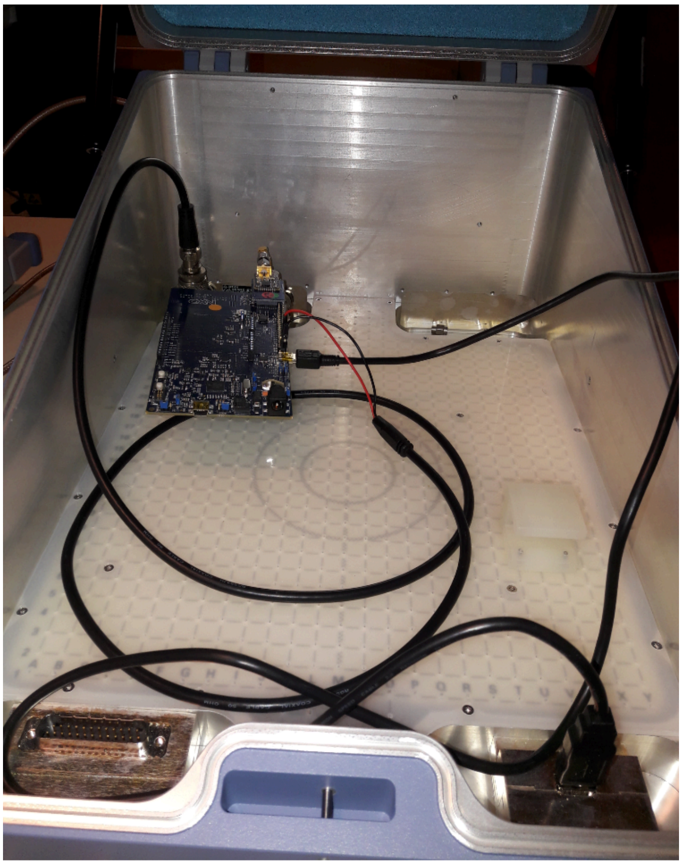

Figure 31. Sensitivity test

The generator (SMBV100A) is used in the ARB mode to generate a pattern of 1500 packets (DIO17 of DK6 connected to signal generator Trig in). The TERATERM window is used to control the module.

1. Set it to channel 0
2. The connection is automatically established and the Packet Error Rate (PER) is measured
3. Decrease the level of the SMBV at the RF input of the module until PER = 30.8 %
4. Repeat it up to channel 39

The results of the few manually measured channels are as follows:

Results for 1 MB/s data rate:

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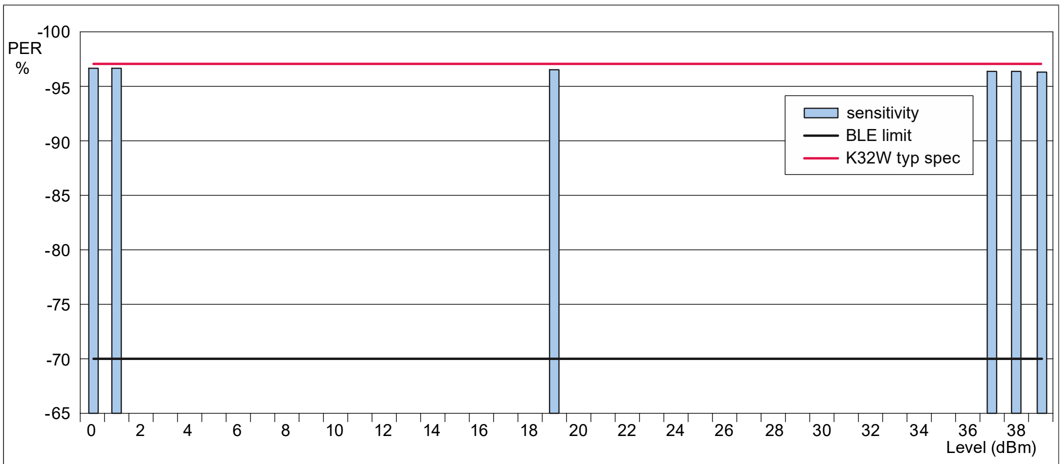

Figure 32. 1 MB/s sensitivity result

- The best sensitivity is on channel 1: -96.7 dBm
- The lowest sensitivity is: -96.3 dB
- Delta over channels: 0.4 dB

Results for 2 MB/s data rate:

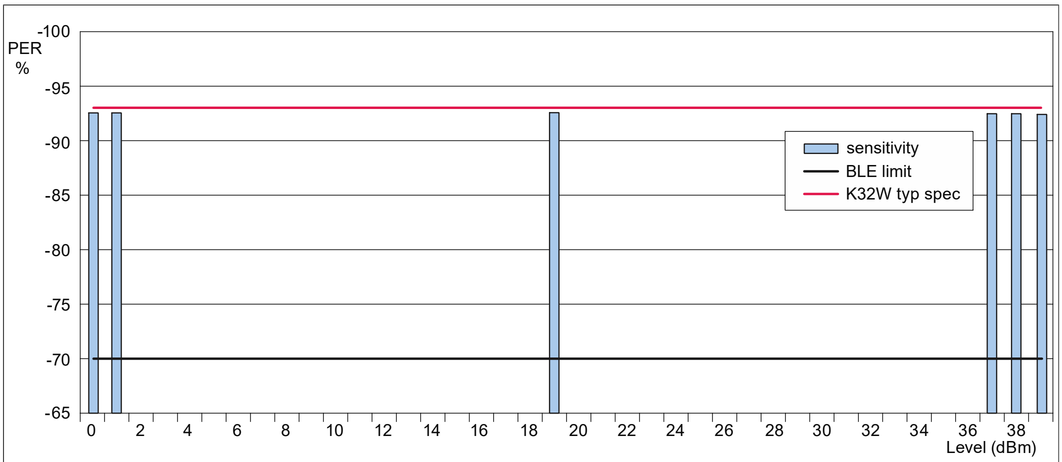

Figure 33. 2 MB/s sensitivity result

- The best sensitivity is on channel 0, 1, 19: -92.7 dBm
- The lowest sensitivity is: -92.6 dB
- Delta over channels: 0.1 dB

Conclusion:

- Sensitivity average value is -96.5 dBm for 1 MB/s and -92.7 dBm for 2 MB/s. These results are in line with characterization results.

2.4.3 Receiver maximum input level

Test method:

- The test setup is the same as for the sensitivity test.
- The signal level is increased up to the PER = 30.8 % with 1500 packets.

Results at 1 MB/s:

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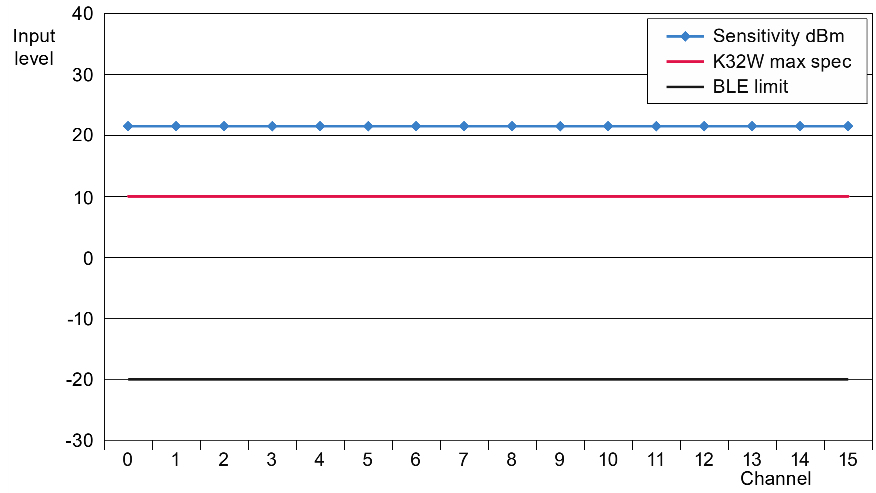

Figure 34. Maximum input power (1 MB/s)

Results at 2 MB/s:

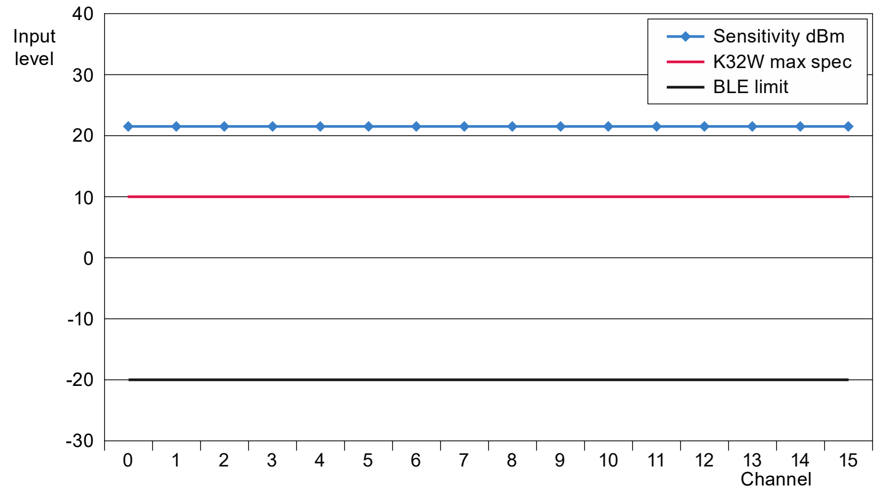

Figure 35. Maximum input power (2 MB/s)

Conclusion:

- The data sheet specified value is only for the information purpose.
- According to the test results from above, there is a margin to increase the input power level up to 20 dBm.
- Therefore, from a system perspective, these results are consistent with the expected values.

2.4.4 RX spurious

Test method:

1. Set the radio to:
   - Receiver mode

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- Frequency: Channel 18

2. Set the analyzer to:
   - Ref amp = -20 dBm
   - Trace = Max Hold
   - Detector = Max Peak
   - Start/stop frequency = 30 MHz/1 GHz
   - RBW = 100 kHz, VBW = 300 kHz
   - Set the start/stop frequency = 1 GHz/12.5 GHz
   - RBW = 1 MHz, VBW = 3 MHz

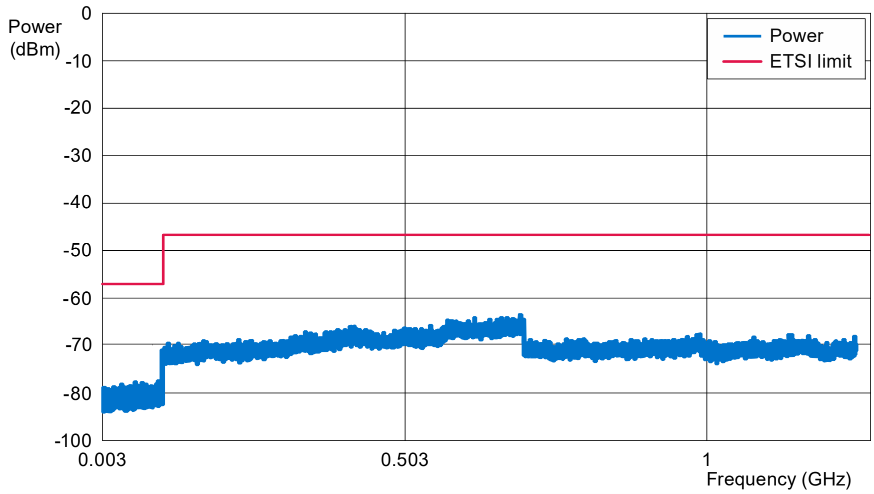

Figure 36. Conducted RX spurious 30 MHz – 12.5 GHz

Conclusion:

- There are no spurs above the spectrum analyzer noise floor.
- More than 13 dB margin.

2.4.5 Receiver interference rejection performances

2.4.5.1 Adjacent, alternate, and co-channel rejection

The interferers are at the adjacent channel (+/-1 MHz, +/-2 MHz, +/-3 MHz) or co-channel. The test is performed with only one interfering unmodulated signal at a time.

Test method:

- Generator for the desired signal: SMBV100A
- Generator for interferers: R&S SFU
- Criterion: PER < 30.8 % with 1500 packets
- The wanted signal is set to -67 dBm; the interferer is increased until the PER threshold is reached
- Channel under test = 2

Results for 1 MB/s:

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	ch2			
	2406			
	n-2 MHz	n-1 MHz	n+1 MHz	n+2 MHz
	2404	2405	2407	2408
Interferer Read value	-27.4	-26.9	-27.7	-13.9
Interferer level (dBm)	-32.4	-31.9	-32.7	-18.9
Interferer level (C/I dB)	-34.6	-35.1	-34.3	-48.1
BLE 4.2 limit (C/I dB)	-17	15	15	-17
Margin (dB)	17.6	50.1	49.3	31.1

	ch2		Co-channel ch2
	2406		2406
	n-3 MHz	n+3 MHz	n
	2403	2409	2406
Interferer Read value	-13.7	-7.5	-63
Interferer level (dBm)	-18.7	-12.5	-68.0
Interferer level (C/I dB)	**-48.3**	**-54.5**	**1.0**
BLE 4.2 limit (C/I dB)	-27	-27	21
Margin (dB)	21.3	27.5	20.0

Figure 37. Adjacent, alternate, and co-channel rejection

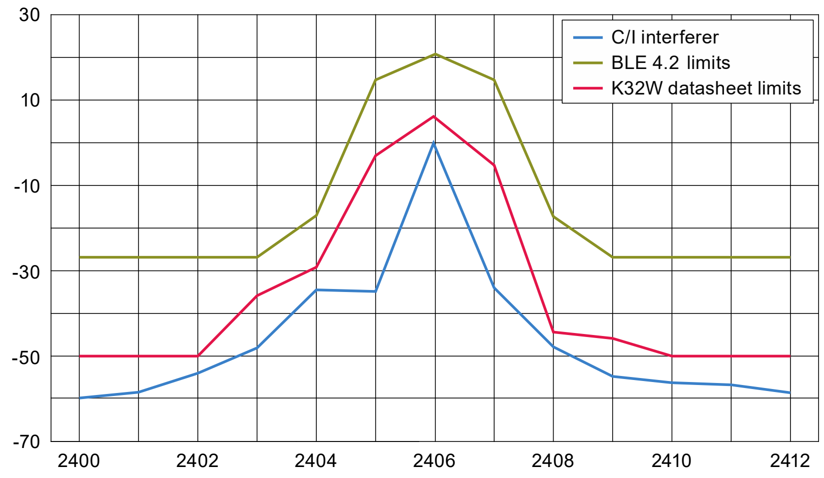

Figure 38. Adjacent, alternate, and co-channel rejection at channel 2

Results for 2 MB/s:

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	ch2			
	2406			
	n-4 MHz	n-2 MHz	n+2 MHz	n+4 MHz
	2402	2404	2408	2410
Interferer Read value	-32.0	-26.9	-22	-13.4
Interferer level (dBm)	-37.0	-31.9	-27.0	-18.4
Interferer level (C/I dB)	-30.0	-35.1	-40.0	-48.6
BLE 5.0 limit (C/I dB)	-17	15	15	-17
Margin (dB)	13.0	50.1	55.0	31.6

	ch2		Co-channel ch2
	2406		2406
	n-6 MHz	n+6 MHz	n
	2400	2412	2406
Interferer Read value	-13.7	-11.5	-65.1
Interferer level (dBm)	-18.7	-16.5	-70.1
Interferer level (C/I dB)	**-48.3**	**-50.5**	**3.1**
BLE 5.0 limit (C/I dB)	-27	-27	21
Margin (dB)	21.3	23.5	17.9

Figure 39. Adjacent, alternate, and co-channel rejection

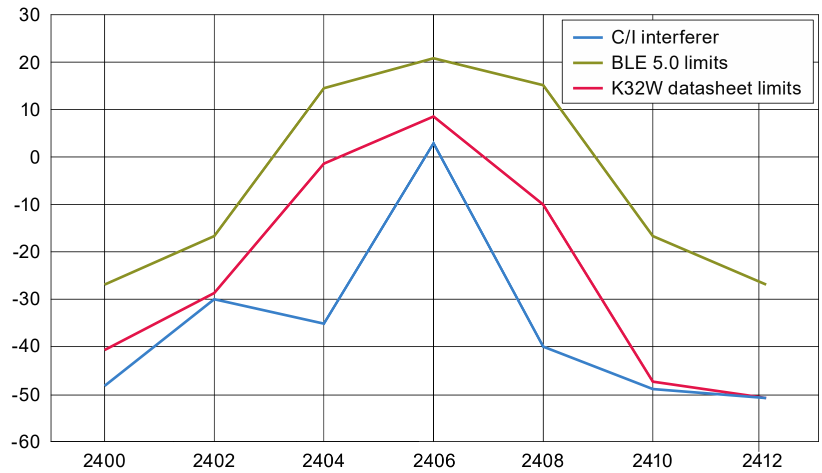

Figure 40. Adjacent, alternate, and co-channel rejection at channel 2

Conclusion:

- The shape of the curve is due to CW interferer.
- The results are compliant with the K32W specification and Bluetooth LE limits.

2.4.5.2 Receiver Blocking

The blocking interferers are positioned at the out of band channels depending on the receiver category.

2.4.5.2.1 Receiver category 2

The test is performed with only one interfering signal at a time, for more details see the ETSI 300.328 2.1.1 chapter 4.3.1.12.4.3)

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Test method:

- Generator for the desired signal: R&S SMBV100
- Generator for interferers: R&S SFU
- Criterion: PER < 10 % (sensitivity at 10 % PER must be measured before)
- The wanted signal is set to Pmin at 10 % PER + 6 dB; the interferer is increased until the PER threshold is reached
- Channels under test: 0 and 39
- Test is performed for 1 MB/s then for 2 MB/s

Result for 1 MB/s:

	1 MBps			
	ch0	**ch0**	**ch39**	**ch39**
	2402	2402	2480	2480
	Low	**Low**	**High**	**High**
	2380	2503.5	2380	2503.5
Interferer level (dBm)	**-22.6**	**-16.7**	**-18.4**	**-19.7**
Interferer level (dBc)	67.4	73.3	71.6	70.3
EN 300 328 V2.1.1 limit (dBm)	-57	-57	-57	-57
Margin (dB)	34.4	40.3	38.6	37.3

	1 MBps			
	ch0	**ch0**	**ch39**	**ch39**
	2402	2402	2480	2480
	Low	**Low**	**High**	**High**
	2300	2583.5	2300	2583.5
Interferer level (dBm)	**-18.4**	**-15.7**	**-18.1**	**-15.9**
Interferer level (dBc)	71.6	74.3	71.9	74.1
EN 300 328 V2.1.1 limit (dBm)	-47	-47	-47	-47
Margin (dB)	28.6	31.3	28.9	31.1

Figure 41. Receiver blocking (out of band) rejection for 1 MB/s (Pmin at 10 % PER + 6 dB = -90.0 dBm)

Result for 2 MB/s:

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	2 MBps			
	ch0	ch0	ch39	ch39
	2402	2402	2480	2480
	Low	Low	High	High
	2380	2503.5	2380	2503.5
Interferer level (dBm)	-23.0	-16.7	-18.3	-20.4
Interferer level (dBc)	67.0	73.3	71.7	69.6
EN 300 328 V2.1.1 limit (dBm)	-57	-57	-57	-57
Margin (dB)	34.0	40.3	38.7	36.6

	2 MBps			
	ch0	ch0	ch39	ch39
	2402	2402	2480	2480
	Low	Low	High	High
	2300	2583.5	2300	2583.5
Interferer level (dBm)	-18.4	-15.8	-18.4	-15.9
Interferer level (dBc)	71.6	74.2	71.6	74.1
EN 300 328 V2.1.1 limit (dBm)	-47	-47	-47	-47
Margin (dB)	28.6	31.2	28.6	31.1

Figure 42. Receiver blocking (out of band) rejection for 2 MB/s (Pmin at 10 % PER + 6 dB = -86.3 dBm)

Conclusion:

- There is a good margin to ETSI specification for blockers category 2.

2.4.5.3 Intermodulation

This test verifies that the receiver intermodulation performance is adequate. Two interferers are used in combination with the desired signal. The first interferer is a sinusoid non-modulated signal and the second interferer is a modulated signal with PRSB15 data.

Test method:

- Generator for the desired signal: R&S SMBV100A
- Generator for the first interferer (CW): Agilent E4438
- Generator for the second interferer (PRBS15): R&S SFU
- Criterion: PER < 30.8 % with 1500 packets
- The wanted signal is set to -64 dBm
- Channels under test: 0, 19 and 39

Results for 1 MB/s:

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	ch0	ch0	ch0	ch0	ch0	ch0
	2402	2402	2402	2402	2402	2402
	Low	Low	Low	Low	Low	Low
Interferer1 (CW) (MHz)	-5	-4	-3	3	4	5
Interferer2 (Mod) (MHz)	-10	-8	-6	6	8	10
Interferer level (dBm)	**-29.7**	**-28.7**	**-29.0**	**-22.3**	**-26.9**	**-28.9**
Interferer level (dBc)	34.3	35.3	35.0	41.7	37.1	35.1
Datasheet limit (dBm)	-30	-29	-27	-27	-29	-30
Margin (dB)	9.5	9.5	7.2	13.9	11.3	10.3

	ch19	ch19	ch19	ch19	ch19	ch19
	2440	2440	2440	2440	2440	2440
	Mid	Mid	Mid	Mid	Mid	Mid
Interferer1 (CW) (MHz)	-5	-4	-3	3	4	5
Interferer2 (Mod) (MHz)	-10	-8	-6	6	8	10
Interferer level (dBm)	**-30.0**	**-29.0**	**-29.3**	**-22.4**	**-27.2**	**-29.0**
Interferer level (dBc)	34.0	35.0	34.7	41.6	36.8	35.0
Datasheet limit (dBm)	-30	-29	-27	-27	-29	-30
Margin (dB)	9.2	9.2	6.9	13.8	11.0	10.2

	ch39	ch39	ch39	ch39	ch39	ch39
	2480	2480	2480	2480	2480	2480
	High	High	High	High	High	High
Interferer1 (CW) (MHz)	-5	-4	-3	3	4	5
Interferer2 (Mod) (MHz)	-10	-8	-6	6	8	10
Interferer level (dBm)	**-29.7**	**-28.7**	**-29.0**	**-22.2**	**-27.8**	**-28.8**
Interferer level (dBc)	34.3	35.3	35.0	41.8	36.2	35.2
Datasheet limit (dBm)	-30	-29	-27	-27	-29	-30
Margin (dB)	9.5	9.5	7.2	14.0	10.4	10.4

Figure 43. Intermodulation results for 1 MB/s

Results for 2 MB/s:

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	ch0	ch0	ch0	ch0	ch0	ch0
	2402	2402	2402	2402	2402	2402
	Low	Low	Low	Low	Low	Low
Interferer1 (CW) (MHz)	-10	-8	-6	6	8	10
Interferer2 (Mod) (MHz)	-20	-16	-12	12	16	20
Interferer level (dBm)	**-29.2**	**-31.3**	**-31.2**	**-30.7**	**-30.7**	**-30.2**
Interferer level (dBc)	34.8	32.7	32.8	33.3	33.3	33.8
Datasheet limit (dBm)	-30.5	-32.5	-32	-32	-32.5	-30.5
Margin (dB)	10.5	10.4	10.0	10.5	11.0	9.5

	ch19	ch19	ch19	ch19	ch19	ch19
	2440	2440	2440	2440	2440	2440
	Mid	Mid	Mid	Mid	Mid	Mid
Interferer1 (CW) (MHz)	-10	-8	-6	6	8	10
Interferer2 (Mod) (MHz)	-20	-16	-12	12	16	20
Interferer level (dBm)	**-29.2**	**-31.3**	**-31.4**	**-30.9**	**-30.5**	**-30.3**
Interferer level (dBc)	34.8	32.7	32.6	33.1	33.5	33.7
Datasheet limit (dBm)	-30.5	-32.5	-32	-32	-32.5	-30.5
Margin (dB)	10.5	10.4	9.8	10.3	11.2	9.4

	ch39	ch39	ch39	ch39	ch39	ch39
	2480	2480	2480	2480	2480	2480
	High	High	High	High	High	High
Interferer1 (CW) (MHz)	-10	-8	-6	6	8	10
Interferer2 (Mod) (MHz)	-20	-16	-12	12	16	20
Interferer level (dBm)	**-29.0**	**-31.0**	**-31.0**	**-30.6**	**-30.5**	**-29.9**
Interferer level (dBc)	35.0	33.0	33.0	33.4	33.5	34.1
Datasheet limit (dBm)	-30.5	-32.5	-32	-32	-32.5	-30.5
Margin (dB)	10.7	10.7	10.2	10.6	11.2	9.8

Figure 44. Intermodulation results for 2 MB/s

Conclusion:

- The results are compliant with the specified values from data sheet.

2.5 Return loss

The SMA connector is used for the measurements.

2.5.1 RX

In the RX mode, the return loss measurement is performed by setting the LNA gain of K32W to the maximum.

Hardware: DK6 board

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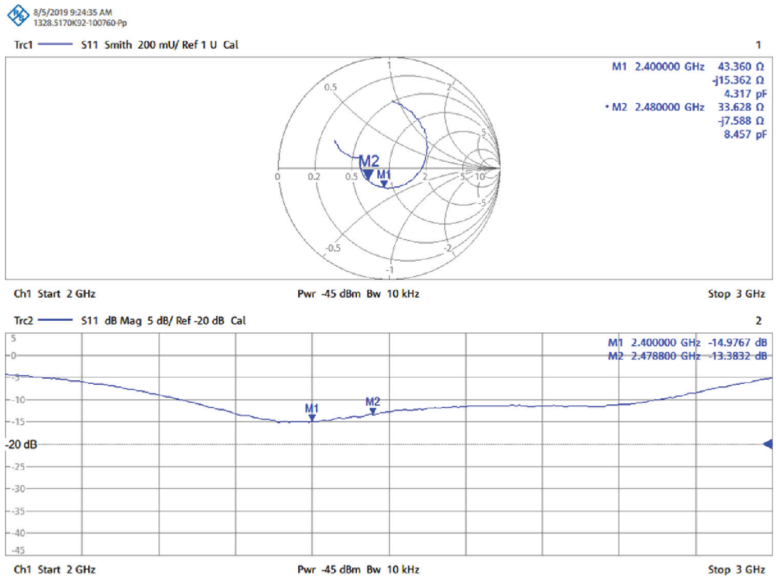

Figure 45. S11 diagram (RX mode)

Results:

- Return loss: -15.0 dB (2.4 GHz) < S11 < -13.3 dB (2.48 GHz)

Note: *There is no specification for the return loss.*

Conclusion:

- The return loss (S11) is lower than -10 dB.

2.5.2 TX

In the TX mode, the return loss measurement is performed by setting the K32W RF output power to the minimum.

Hardware: DK6 board

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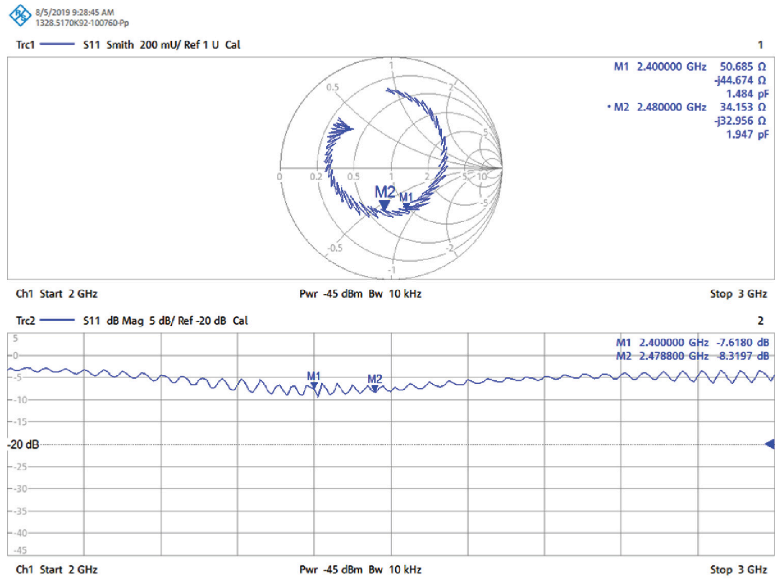

Figure 46. S11 diagram (TX mode)

Results:

- Return loss: -8.3 dBm (2.48 GHz) < S11 < -7.6 dB (2.4 GHz)

Note: *There is no specification for the return loss.*

Conclusion:

- The return loss (S11) is lower than -7 dB.

2.6 Conclusion

The results are compliant with the specification and Bluetooth Low Energy standard.

3 Applications

3.1 Test presentation

Conducted tests:

3.1.1 List of tests

1. TX tests:
    - Frequency accuracy
    - Phase noise
    - TX power
    - TX spurious
    - Harmonics
    - EVM and offset EVM

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  - Upper band edge
2. RX tests:
  - Sensitivity
  - Maximum input level
  - RX spurious
  - LO leakage
  - Interferers (as per IEEE 802.15.4 requirements)
  - Co-channel
  - Receiver blocking (as per ETSI 300 328 requirements)
3. Return loss
  - RX

3.1.2 Software

Before the measurement, load a binary code in the flash memory of the board by using the flash programmer application JN-SW-4407. The binary code used for the following tests is the Customer Module Evaluation Tool (CMET) version 2042 compiled on September 21, 2020.

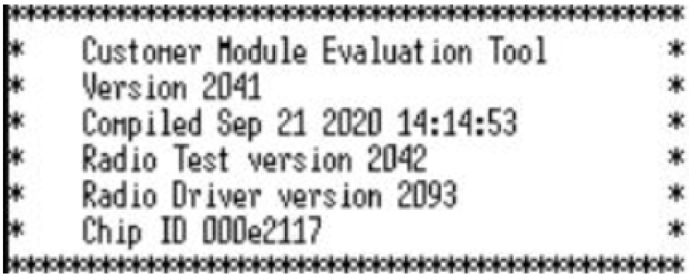

Figure 47. CMET evaluation software version

The TERATERM terminal emulator is used to communicate with the K32W UART0. Two USB ports are available on the DK6 board to control the K32W with CMET: LPC Link2 and FTDI.

Section 5 provides the selected options to perform the following tests.

3.1.3 Test equipment

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

3.2 Test summary

This section synthetizes in Table 15 and Table 16 the main tests performed on the K32W modules. Most of the test results and setup details are described in this document. For further information, contact your NXP local contact.

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Table 15. List of tests for Europe

Name	Measurements	Reference	Limit	Status
Transmission	TX maximum power	ETSI EN 300 328	20 dBm, 100 mW (radiated)	PASS
	Eirp TX spectral density	ETSI EN 300 328 FCC part 15.247	10 dBm/MHz 8 dBm/3 kHz	FAIL PASS
	TX spectral density	IEEE 802.15.4_ 2011	-20 dBc or -30 dBm (100 kHZ, f-fc > 3.5 MHz)	PASS
	Spurious 30 MHz – 1 GHz	ETSI EN 300 328	-36 dBm or -54 dBm (depends on frequency) (100 kHz BW)	PASS
	Spurious 1 GHz - 12.5 GHz	ETSI EN 300 328	-30 dBm (1 MHz BW)	PASS
	EVM	IEEE 802.15.4_ 2011	35 %	PASS
	TX frequency tolerance	IEEE 802.15.4_ 2011	+/- 40 ppm	PASS
Reception	Reachable low limit of maximum power	IEEE 802.15.4_ 2011	-3 dBm	PASS
	Phase noise (unspread)	IEEE 802.15.4_ 2003	NA	For information
	RX emissions 30 MHz - 1 GHz	ETSI EN 300 328	-57 dBm (100 kHz)	PASS
	RX emissions 1 GHz - 12.5 GHz	ETSI EN 300 328	-47 dBm (1 MHz)	PASS
	RX sensitivity	IEEE 802.15.4	-85 dBm	PASS
	Adjacent channel interference rejection N+/-1	IEEE 802.15.4_ 2011	0 dB	PASS
	Adjacent channel interference rejection N+/-2	IEEE 802.15.4_ 2011	30 dB	PASS
	Receiver blocking	ETSI EN 300 328	-57 dBm/-47 dBm	PASS
	RX maximum input level	IEEE 802.15.4_ 2011	-20 dBm	PASS
Miscellaneous	Return loss (S11)	Return loss in TX mode Return loss in RX mode	For information	

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Table 16. List of tests for US

Name	Measurements	Reference	Limit	Status
Transmission	Spurious 1 GHz - 12.5 GHz	FCC part 15	-41.12 dBm	PASS
			(1 MHz BW)	

3.3 TX conducted tests

3.3.1 TX modes

Three different modulation modes exist in K32W transmission as follows:

- 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 Section 4 for details.

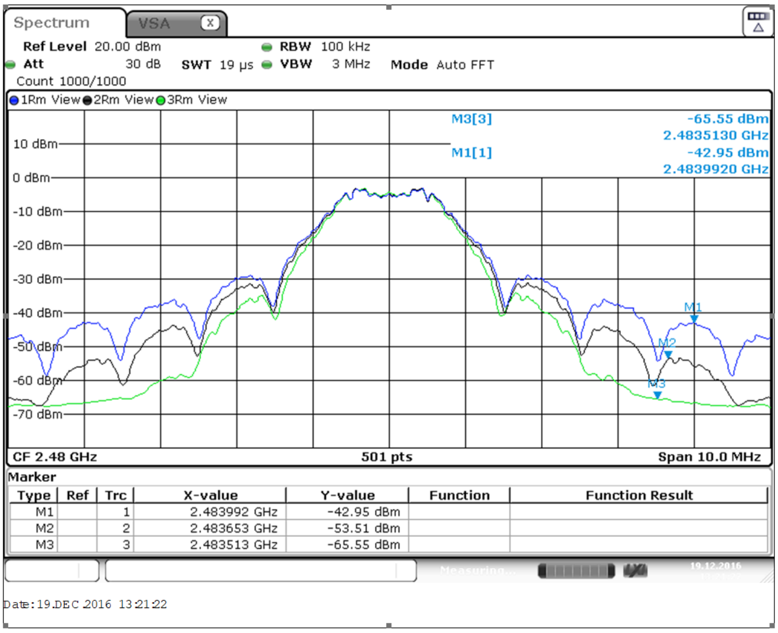

Figure 48. K32W TX spectrum

- Blue graph: Regular mode
- Black graph: Proprietary mode 1
- Green graph: Proprietary mode 2

Note: *The measurements included in this document have been done in Regular mode otherwise specified.*

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3.3.2 Test setup

The TX power of the K32W is set to +15 dBm. Connect the RF port of the module to the spectrum analyzer.

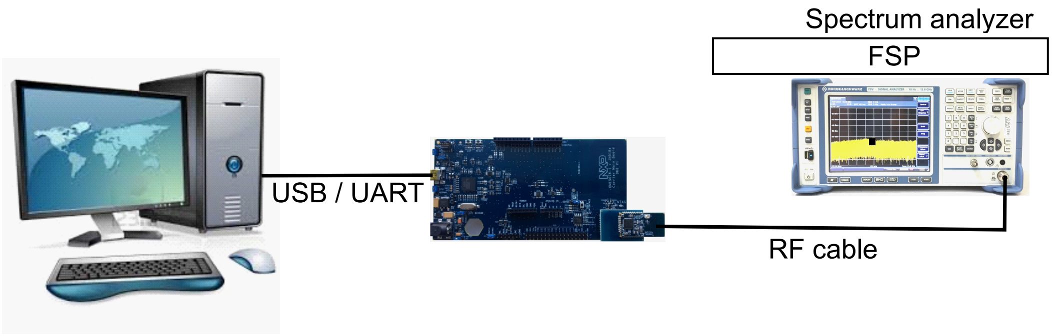

Figure 49. Conducted TX test setup

3.3.3 Test results

The test results are as follows:

3.3.3.1 Frequency accuracy

Test method:

1. Set the radio in:
   - TX mode
   - CW
   - Continuous mode
   - Frequency: Channel 18
2. Set analyzer to:
   - Center frequency = 2.44 GHz
   - Span = 1 MHz
   - Ref amp = 20 dBm
   - RBW = 10 kHz
3. Measure the CW frequency with the marker of the spectrum analyzer.

Result:

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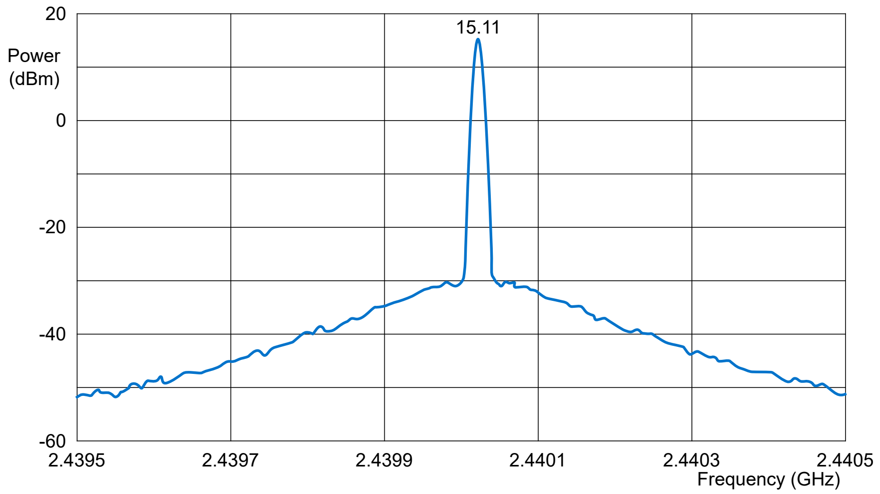

Figure 50. Frequency accuracy

- Measured frequency = 2.440022 GHz
- ppm value = 9.0 ppm

Result	Target	IEEE 802.15.4 limit
9.0 ppm	+/- 25 ppm	+/- 40 ppm

Note: *The frequency accuracy depends on the XTAL model. The model used on the RF module is NX2016SA EXS00A-CS11213-6pF from NDK.*

Conclusion:

- The channel frequency is correctly centered therefore fully compliant with the IEEE 802.15.4 specifications.

3.3.3.2 Phase noise at 100 kHz offset

Test method:

1. Set the radio in:
   - TX mode
   - CW
   - Continuous mode
   - Frequency: Channel 18
2. Set analyzer to:
   - Center frequency = 2.44 GHz
   - Span = 1 MHz
   - Ref amp = 20 dBm
3. Measure the phase noise at 100 kHz offset frequency:
   - RBW = 10 kHz (40 dBc)

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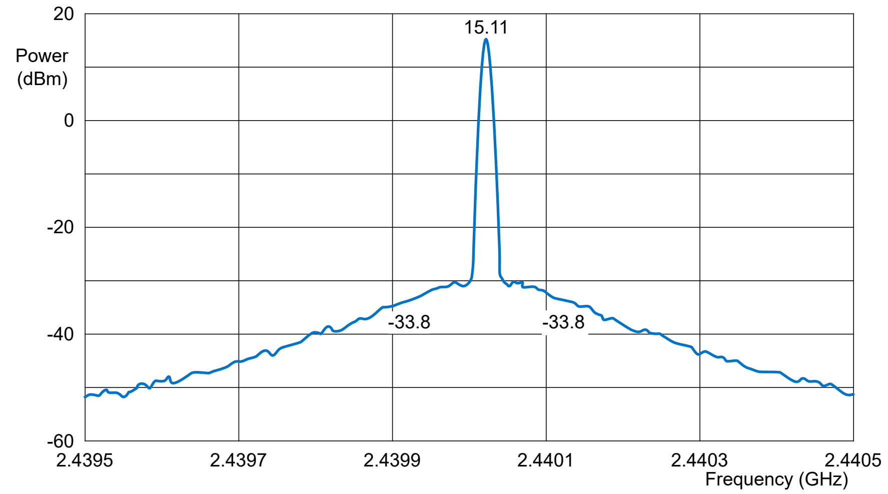

Figure 51. Phase noise

Results:

- Marker value = -36.4 dBm within 10 kHz RBW
  - Marker delta = 10.0 - (-33.8) = 43.8 dB
  - Phase noise at 100 kHz offset = -43.8-10 log (10 kHz) = -83.8 dBc/Hz

Note: *Phase noise is for information only.*

3.3.3.3 TX power (fundamental)

Test method:

1. Set the radio in:
   - TX mode
   - Modulated
   - Continuous mode
2. Set analyzer to:
   - Start frequency = 2.4 GHz
   - Stop frequency = 2.5 GHz
   - Ref amp = 20 dBm
   - Sweep time = 100 ms
   - RBW = 3 MHz
3. Max Hold mode
4. Detector: Peak
5. Sweep all the channels from ch11 to ch26

Result:

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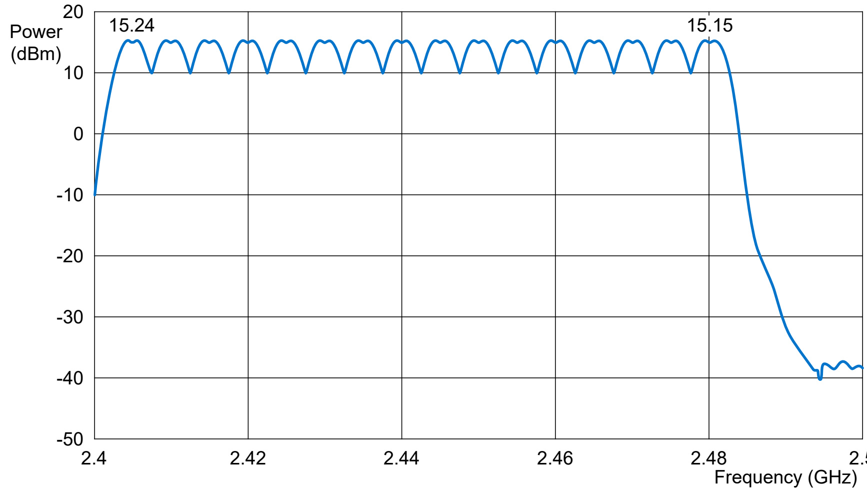

Figure 52. TX maximum power

- Maximum power is on channel 12: +15.26 dBm
- Minimum power is on channel 17: +15.14 dBm
- Tilt over frequencies is 0.09 dB

Conclusion:

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

3.3.3.4 TX spurious

3.3.3.4.1 Global view from 0.3 GHz to 12.5 GHz (desired = channel 18)

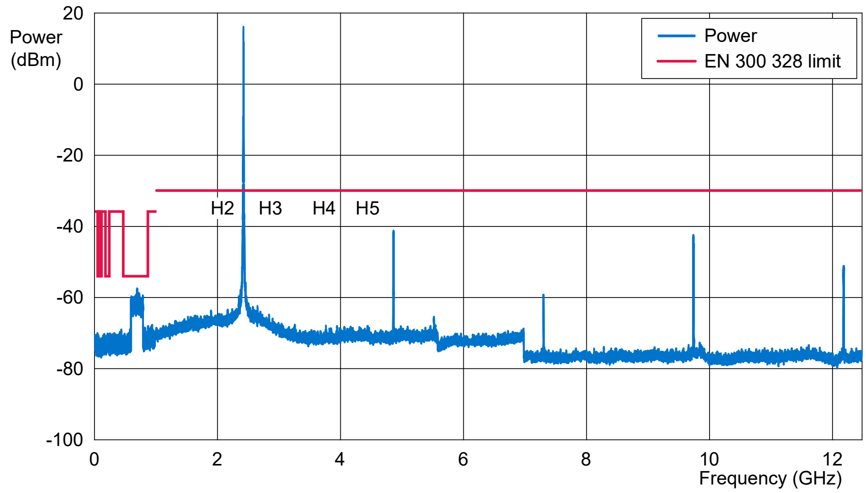

Figure 53. Conducted TX spurious (0.03 GHz to 30 GHz)

Conclusion:

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

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3.3.3.4.2 H2 (ETSI test conditions)

Test method:

1. Set the radio in:
   - TX mode
   - Modulated
   - Continuous mode
2. Set analyzer to:
   - Start frequency = 4.8 GHz
   - Stop frequency = 5 GHz
   - Ref amp = -20 dBm
   - Sweep time = 100 ms
   - RBW = 1 MHz
3. Max Hold mode
4. Detector: Peak
5. Sweep all the channels from ch11 to ch26

Results:

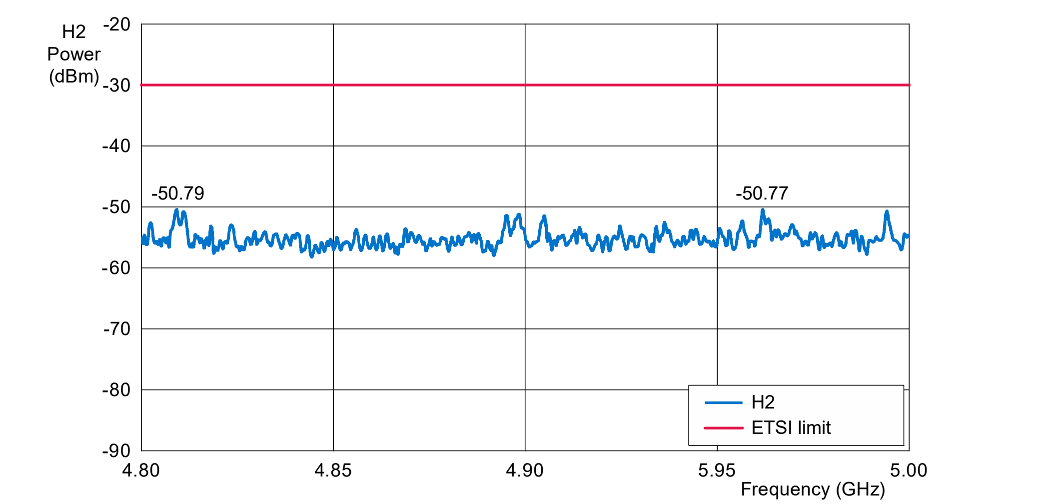

Figure 54. Conducted H2 spurious

- Maximum power is on channel 26: -50.8 dBm

Conclusion:

- There is 20.8 dB margin to the ETSI limit.

3.3.3.4.3 H3 (ETSI test conditions)

The test method is the same as for the H2, except the spectrum analyzer frequency start/stop is set to 7.2 GHz and 7.5 GHz.

Results:

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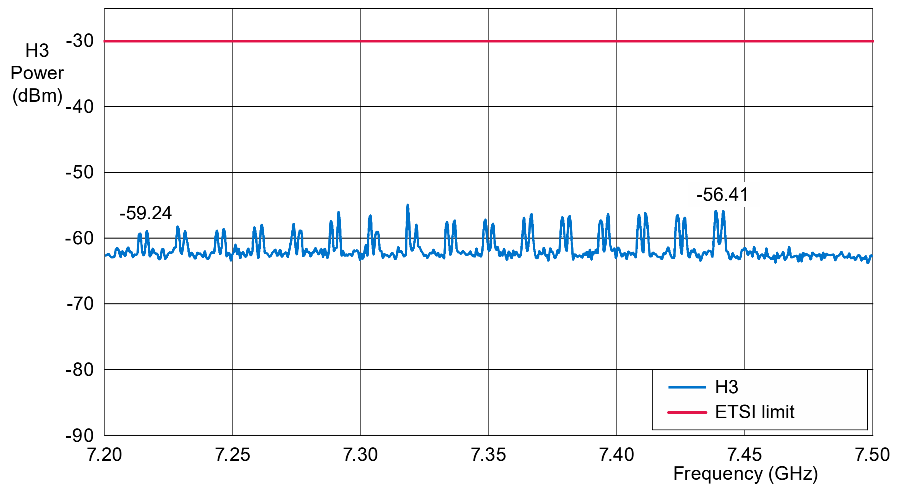

Figure 55. Conducted H3 spurious

- Maximum power is on channel 18: -55.7 dBm

Conclusion:

- There is 25.7 dB margin to the ETSI limit.

3.3.3.4.4 H4 (ETSI test conditions)

The test method is the same as for the H2, except the spectrum analyzer frequency span is set from 9.6 GHz to 10.0 GHz.

Result:

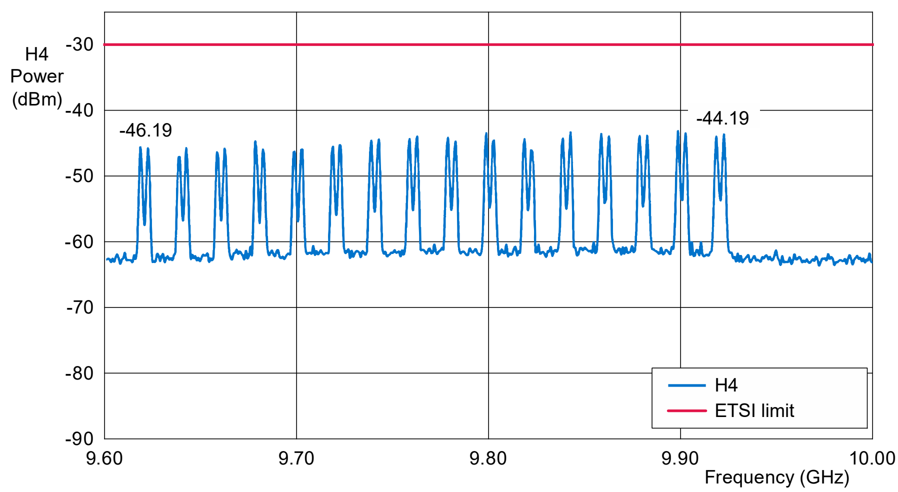

Figure 56. Conducted H4 spurious

- Maximum power is on channel 25: -43.7 dBm

Conclusion:

- There is 17.7 dB margin to the ETSI limit.

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3.3.3.4.5 H5 (ETSI test conditions)

The test method is the same as for the H2, except the spectrum analyzer frequency span is set from 12.0 GHz to 12.5 GHz.

Result:

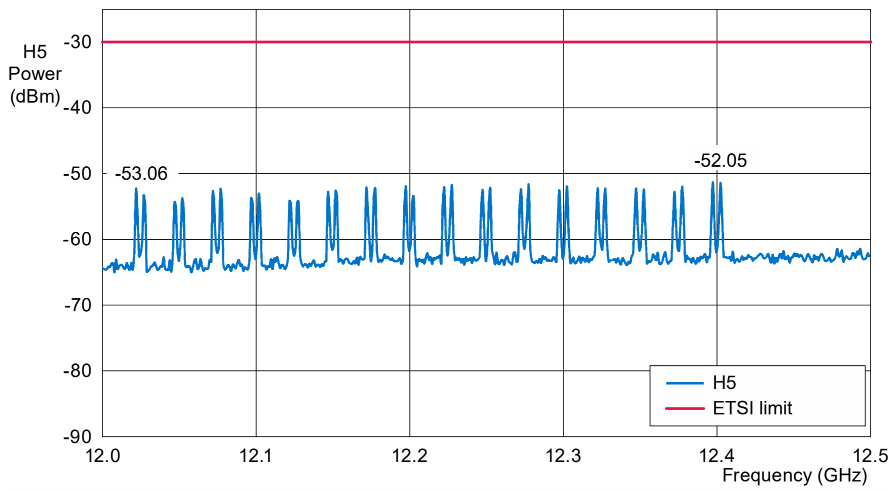

Figure 57. Conducted H5 spurious

- Maximum power is on channel 26: -52.05 dBm

Conclusion:

- There is 22 dB margin to the ETSI limit.

3.3.3.4.6 H2 (FCC test conditions)

Test method:

1. Set the radio in:
   - TX mode
   - Modulated
   - Continuous mode
2. 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
3. Trace mode: Average
4. Detector: RMS
5. Sweep all the channels from ch11 to ch26

Result:

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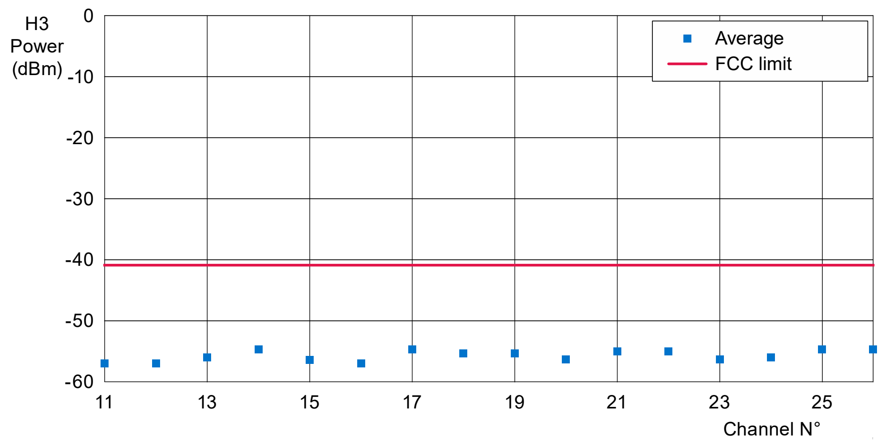

Figure 58. Conducted H2 spurious

- Maximum power on channels 14, 17 to 19, 21, 22, 25, 26 is: -55.0 dBm

Conclusion:

- There is 14 dB margin to the FCC limit.

3.3.3.4.7 H3 (FCC test conditions)

The test method is similar as for the H2, except the spectrum analyzer frequency start/stop are set to 7.2 GHz and 7.5 GHz.

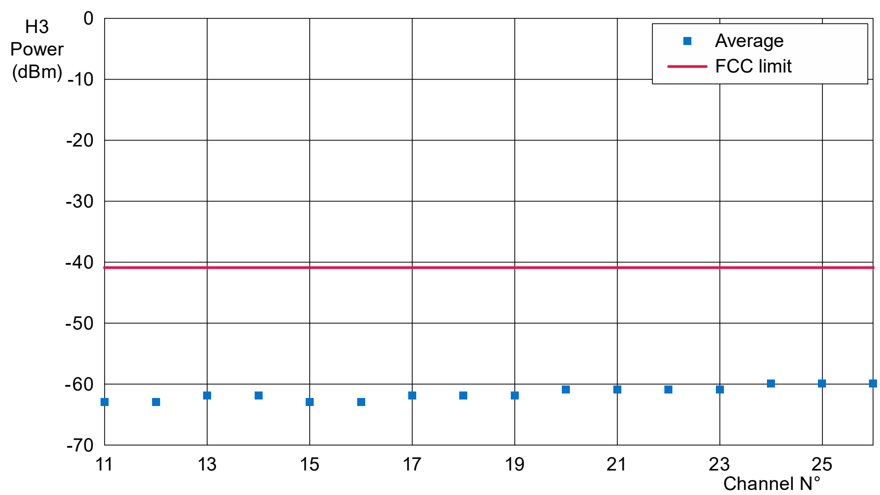

Figure 59. Conducted H3 spurious

Results:

- Maximum power is on channels 24 to 26: -60 dBm

Conclusion:

- There is 19 dB margin to the ETSI limit.

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3.3.3.4.8 H4 (FCC test conditions)

The test method is the same as for the H2, except the spectrum analyzer frequency span is set from 9.6 GHz to 10.0 GHz.

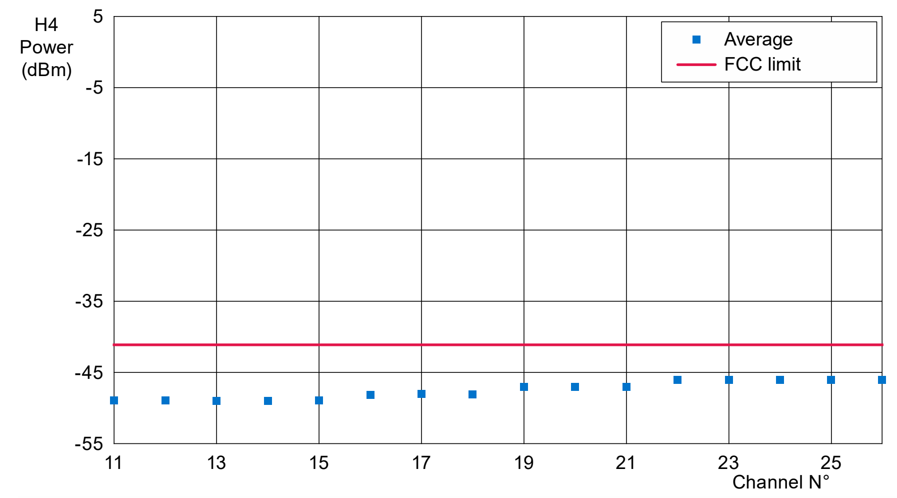

Figure 60. Conducted H4 spurious

Results:

- Maximum power is on channels 22 to 26: -46 dBm

Conclusion:

- There is 5 dB margin to the FCC limit.

3.3.3.4.9 H5 (FCC test conditions)

The test method is the same as for the H2, except the spectrum analyzer frequency span is set from 12 GHz to 12.5 GHz.

Result:

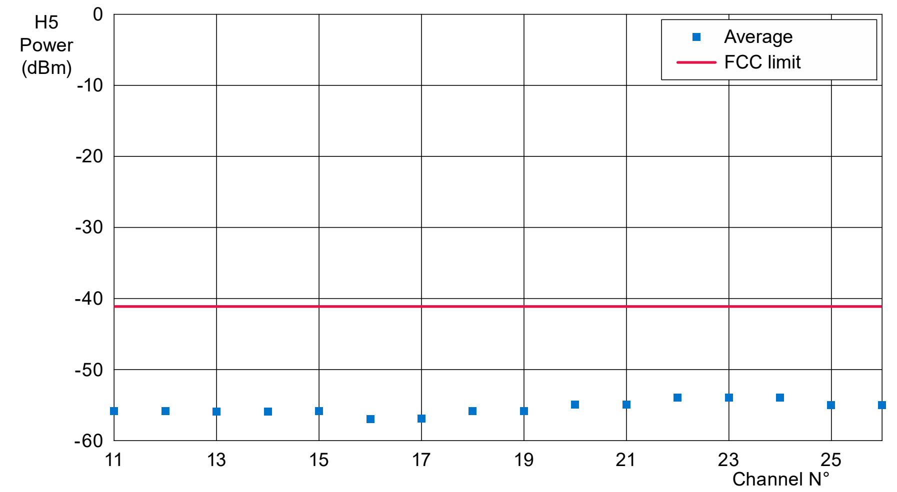

Figure 61. Conducted H5 spurious

Maximum power is on channel 13: -54 dBm

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Conclusion:

- There is 13 dB margin to the FCC limit.

3.3.3.4.10 Other harmonics (FCC test conditions)

The test method is similar as for the H5. H6, H7, H8, H9, H10 are measured on another spectrum analyzer (capable to measure up to 30 GHz) frequency span that is set accordingly.

Result:

- -67 dBm < H6 < -63 dBm
- -75 dBm < H7 < -70 dBm
- H8 is at -75 dBm
- -71 dBm < H9 < -69 dBm
- -70 dBm < H10 < -68 dBm

Conclusion:

- For H6, there is 22 dB margin to the FCC limit.
- For H7, there is 29 dB margin to the FCC limit.
- For H8, there is 34 dB margin to the FCC limit.
- For H9, there is 28 dB margin to the FCC limit.
- For H10, there is 27 dB margin to the FCC limit.

3.3.3.5 TX modulation

3.3.3.5.1 EVM

Test method:

- Connect the RF port of the module to the R&S FSV30 spectrum analyzer. To do the EVM measurement, use the specific menu of the SA.
- Set the K32W in continuous Modulated mode
- Set the TX frequency to channel 11
- Measure the offset EVM value
- Repeat the test for each channel

Filtering the spectrum with Proprietary mode 1 or Proprietary mode 2 affects the EVM and offset EVM.

The following graphs show the EVM value for both the Proprietary mode 2 and the Regular mode.

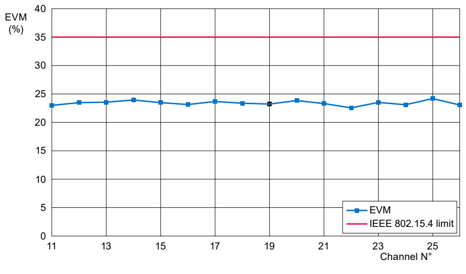

Figure 62. EVM in Proprietary mode 2

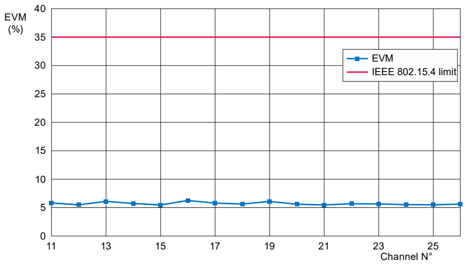

Figure 63. EVM in Regular mode

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Result:

- Proprietary mode 2 maximum value on channel 25 = 24.2 %
- Regular mode maximum value on channel 26 = 6.3 %

Conclusion:

- Very good margin vs IEEE 802.15.4 limit in Regular mode.
  Note: *Although the EVM is degraded in Proprietary mode 2, there is still good margin to IEEE 802.15.4 limit.*

3.3.3.5.2 Offset EVM

Test method:

- The test method is same as for the EVM measurement

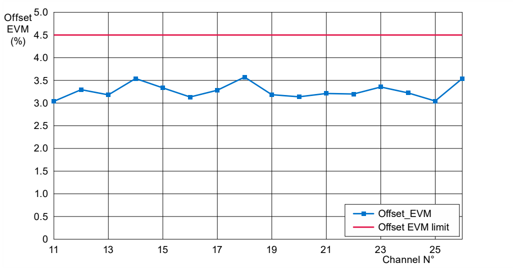

Figure 64. Offset EVM in Proprietary mode 2

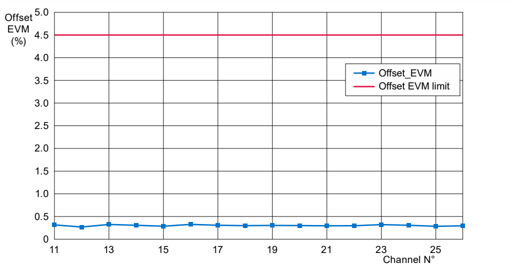

Figure 65. Offset EVM in Regular mode

Result:

- Proprietary mode 2 maximum value on channel 18 = 3.57 %
- Regular mode maximum value on channel 23 = 0.34 %

Conclusion:

- Very good margin vs K32W specification in Regular mode.

Note: *Although the offset EVM is degraded in Proprietary mode 2, there is still a good margin to K32W specification.*

3.3.3.6 Upper band edge

Test method:

1. Set the radio to:
   - TX mode
   - Modulated
   - Continuous mode
2. Set the analyzer to:
   - Start frequency = 2.475 GHz
   - Stop frequency = 2.485 GHz
   - Ref amp=-20 dBm
   - Sweep time=100 ms
   - RBW = 1 MHz
   - VBW = 3 MHz
   - Detector = Average
   - Average mode: Power

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- Number of sweeps = 100
- Set the channel 26 (2.48 GHz)

Result:

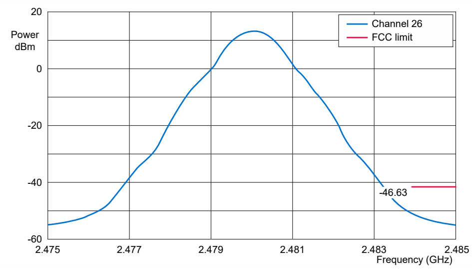

Figure 66. Upper band edge in Proprietary mode 2

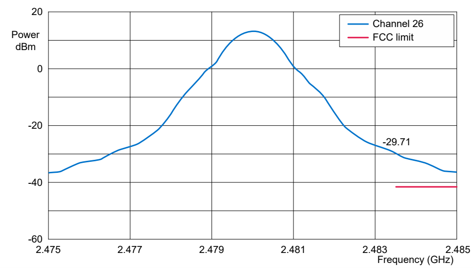

Figure 67. Upper band edge in Regular mode

Conclusion:

- The upper band edge test passes the ETSI certification in the Proprietary mode 2.

3.4 RX tests

3.4.1 Test setup

Figure 68 to Figure 70 shows the test setups conducted for RX.

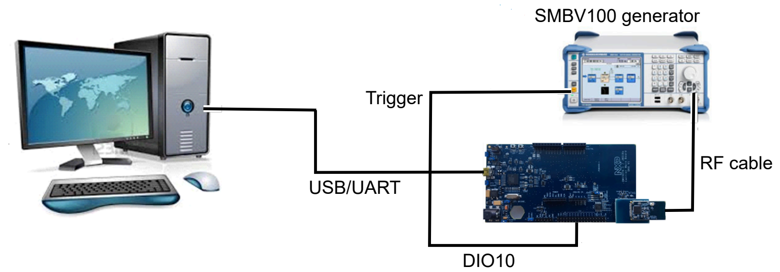

Figure 68. Conducted RX test setup for sensitivity and receiver maximum input level

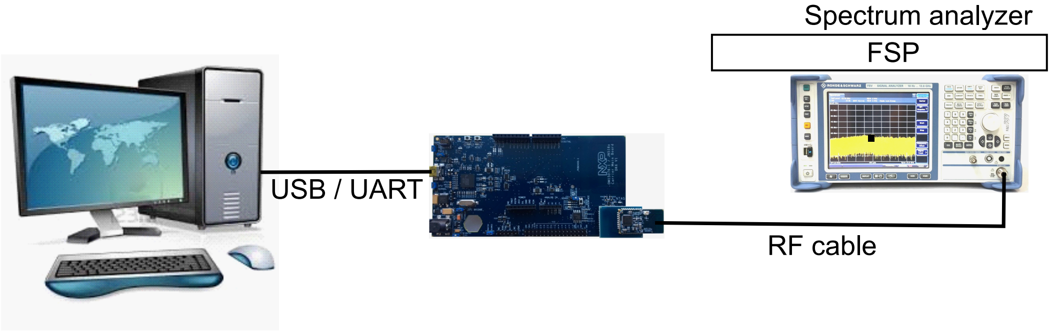

Figure 69. Conducted RX test setup for spurious

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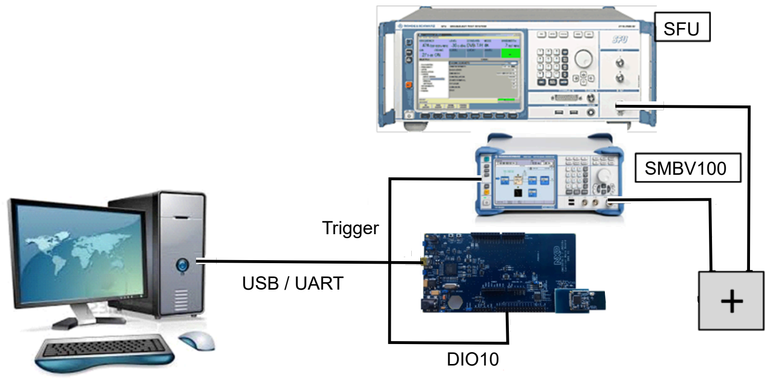

Figure 70. Conducted RX test setup for interference rejection

3.4.2 RX sensitivity

Test method:

The carrier board and K32W module are placed in an RF shield box 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 DIO10 of the K32W 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 Packet Error Rate (PER) is measured
- Decrease the level of the generator at the RF input of the module until PER = 1 %

Result:

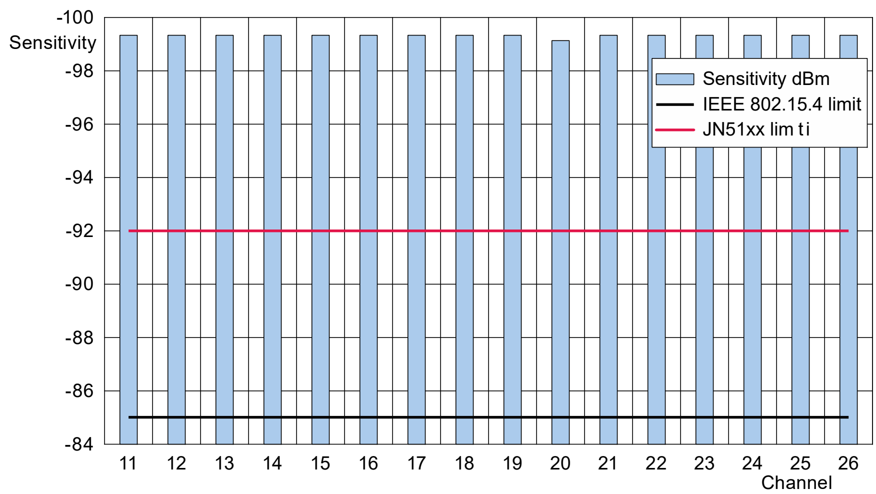

Figure 71. Receiver sensitivity

Conclusion:

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- Minimum value: - 99.5 dBm on channels 11 to 16, 19, 25
- Maximum value: -99.2 dBm on channel 20

3.4.3 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 DIO10 of the K32W 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 is measured
- Increase the level of the generator at the RF input of the module until PER = 1 %
- Do the same for other channels

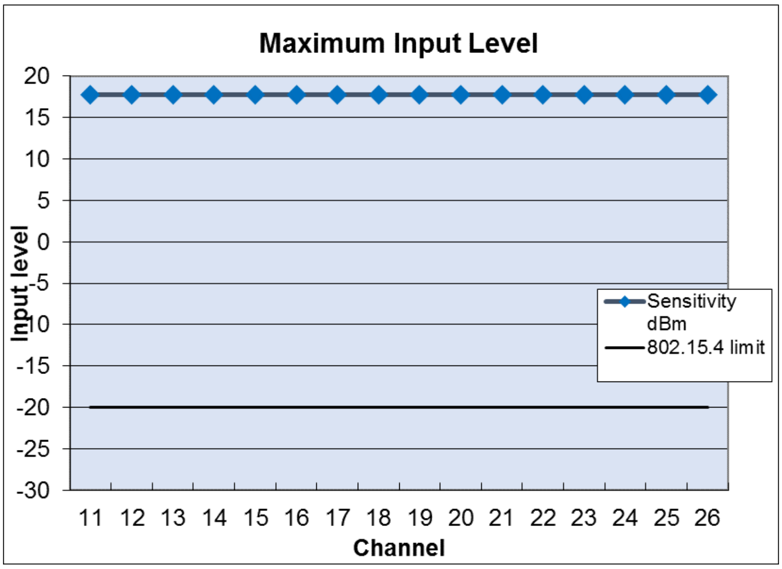

Figure 72. Maximum input power

Conclusion:

- The actual maximum input level cannot be measured with the test environment. The maximum level that can be delivered to the K32W is limited by the maximum output power of the generator and the cable losses.
- The maximum input level of K32W is higher than 17.8 dBm on all channels.

3.4.4 RX spurious

3.4.4.1 Wide band

Test method:

1. Set the radio in:
   - Receiver mode

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- Frequency: Channel 18

2. Set the analyzer to:
   - Ref amp = -20 dBm
   - Trace = Max Hold
   - Detector = Max Peak
   - Start/stop frequency: 30 MHz/1 GHz, RBW = 100 kHz
   - Start/stop frequency: 1 GHz/12.75 GHz, RBW = 1 MHz

Result:

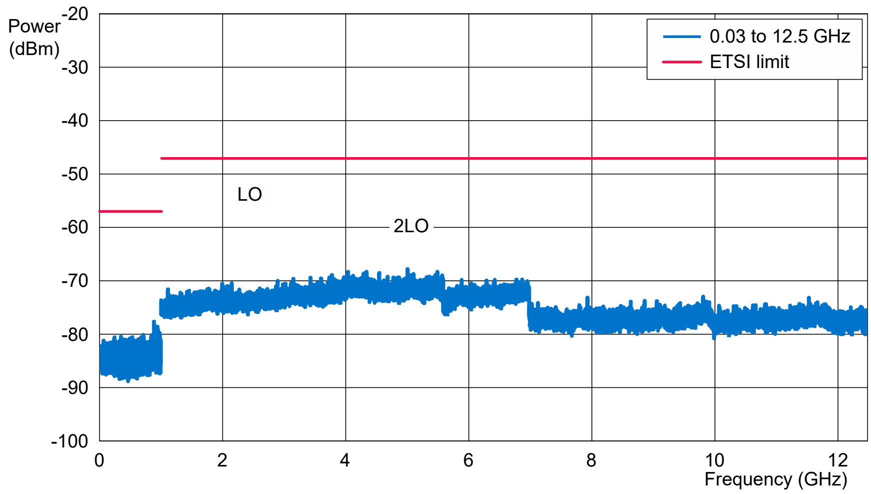

Figure 73. Conducted RX spurious (0.03 GHz to 12.5 GHz)

Note: *No spur has been detected.*

3.4.4.2 LO leakage

Test frequency: 2440 MHz (channel 18)

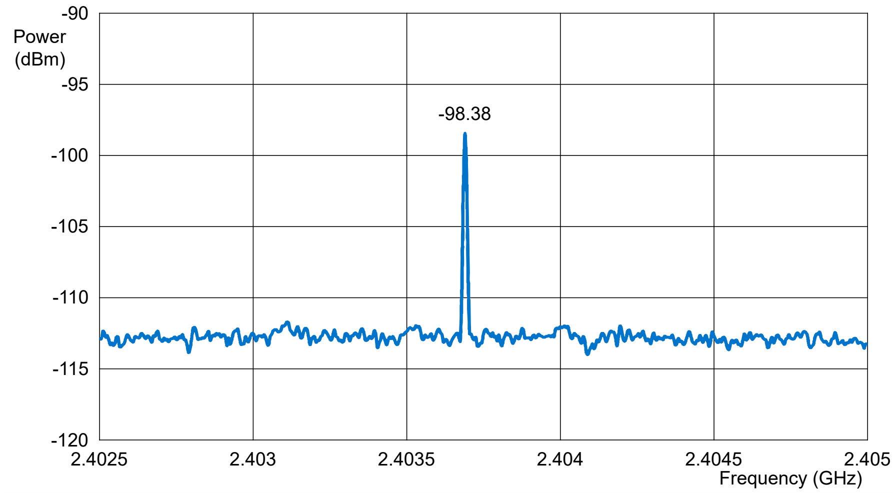

Figure 74. LO leakage

Result:

- -98.4 dBm

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Conclusion:

- 51.4 dB margin to ETSI limit.

3.4.5 Receiver interference rejection

3.4.5.1 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: Rohde&Schwarz SMBV100A generator (modulated)

Generator for interferers: R&S SFU (modulated)

Criterion: PER < 1 %

The desired 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 (dBm)	-35.6	-46.5	-45.7	-35.4	-35.6	-46.5	-45.7	-35.2	-35.6	-46.5	-45.5	-35.2
Interferer level (dBc)	46.4	35.5	36.3	46.6	46.4	35.5	36.3	46.8	46.4	35.5	36.5	46.8
IEEE 802.15.4 limit (dB)	30	0	0	30	30	0	0	30	30	0	0	30
Margin (dB)	16.4	35.5	36.3	16.6	16.4	35.5	36.3	16.8	16.4	35.5	36.5	16.8

Figure 75. Adjacent and alternate rejection

Conclusion:

- Good margin, in line with the expected results.

3.4.5.2 N-3 and N+3 channels with standard interferers

Test method:

The test method is same as for the 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 (dBm)	-30.3	-30.3	-30.3	-30.3	-30.3	-30.3
Interferer level (dBc)	**51.7**	**51.7**	**51.7**	**51.7**	**51.7**	**51.7**
Datasheet typical value (dB)	48	48	48	48	48	48
Margin (dB)	3.7	3.7	3.7	3.7	3.7	3.7

Figure 76. N-/+3 band rejection

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Conclusion:

- In line with the expected values

3.4.5.3 Co-channel

	ch11	ch18	ch26
	2405	2440	2480
	co-ch	co-ch	co-ch
	2405	2440	2480
Interferer level (dBm)	-84.5	-84.5	-84.2
Interferer level (dBc)	**-2.5**	**-2.5**	**-2.2**
Datasheet typical value (dB)	48	48	48
Margin (dB)	-50.5	-50.5	-50.2

Figure 77. Co-channel

Conclusion:

- In line with expected values

3.4.5.4 Adjacent and alternate channels with filtered interferers (as generated by a K32W in Proprietary mode 2)

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: Rohde&Schwarz SMBV100A generator (modulated)

Generator for interferers: R&S SFU (modulated and filtered frame)

Criterion: PER < 1 %

The desired 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)	62.2	58.2	59.7	62.2	62.2	58.2	59.2	62.2	62.7	58.2	59.7	63.2
IEEE 802.15.4 limit (dBm)	30	0	0	30	30	0	0	30	30	0	0	30
Margin (dB)	32.2	58.2	59.7	32.2	32.2	58.2	59.2	32.2	32.7	58.2	59.7	33.2

Figure 78. Adjacent and alternate rejection

Conclusion:

- By using K32W to build a network that transmits in Proprietary mode 2, we can improve the immunity to alternate interferers by 23 dB and the immunity to alternate interferers by more than 15 dB.

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3.4.5.5 N-3 and N+3 channels with filtered interferers (as generated by a K32W in Proprietary mode 2)

Test method:

The test method is same as for the 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)	**56.7**	**58.2**	**56.7**	**59.2**	**57.2**	**59.2**

Figure 79. N-/+3 band rejection

Conclusion:

- By using K32W to build a network that transmits in proprietary mode 2, we can improve immunity to n-3 or n+3 interferers by more than 16 dB.

3.4.5.6 Co-channel with a filtered interferer

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

Figure 80. Co-Channel

Conclusion:

- There is no significant difference in co-channel when using a standard interferer or a filtered interferer. The results are compliant with the specifications.

3.4.6 Receiver blocking

The K32W is equipment of category 1 as defined by the ETSI 300 328 (TX signal is higher than 10 dBm). Tests and limits are used according to category 1. Interferer is a CW signal.

3.4.6.1 Test 1

	ch11	ch11	ch26	ch26
	2405	2405	2480	2480
	Low	High	Low	High
	2380	2503.5	2380	2503.5
Interferer level (dBm)	**-22.7**	**-20.6**	**-20.6**	**-23.1**
Interferer level (dBc)	71.3	73.4	73.4	70.9
IEEE 802.15.4 limit (dBm)	-53	-53	-53	-53
Margin (dB)	30.3	32.4	32.4	29.9

Figure 81. Receiver blocking test 1

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Conclusion:

- Very good margin

3.4.6.2 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)	**-19.3**	**-20.1**	**-21.6**	**-19.6**	**-19.9**	**-20.5**
Interferer level (dBc)	74.7	73.9	72.4	74.4	74.1	73.5
IEEE 802.15.4 limit (dBm)	-53	-53	-53	-53	-53	-53
Margin (dB)	33.7	32.9	31.4	33.4	33.1	32.5

Figure 82. Receiver blocking test 2

Conclusion:

- Very good margin

3.4.6.3 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)	**-20.1**	**-20.4**	**-20.1**	**-20.1**	**-19.8**	**-19.9**
Interferer level (dBc)	73.9	73.6	73.9	73.9	74.2	74.1
IEEE 802.15.4 limit (dBm)	-53	-53	-53	-53	-53	-53
Margin (dB)	32.9	32.6	32.9	32.9	33.2	33.1

	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)	**-21.5**	**-21.0**	**-20.6**	**-20.2**	**-19.8**	**-19.9**
Interferer level (dBc)	72.5	73.0	73.4	73.8	74.2	74.1
IEEE 802.15.4 limit (dBm)	-53	-53	-53	-53	-53	-53
Margin (dB)	31.5	32.0	32.4	32.8	33.2	33.1

Figure 83. Receiver blocking test 3

Conclusion:

- Very good margin

3.4.7 Packet Error Rate (PER) versus RX input power

PER value is picked up when input power is decreased.

Test method:

Generator for desired signal: Rohde&Schwarz SMBV100A generator

Results:

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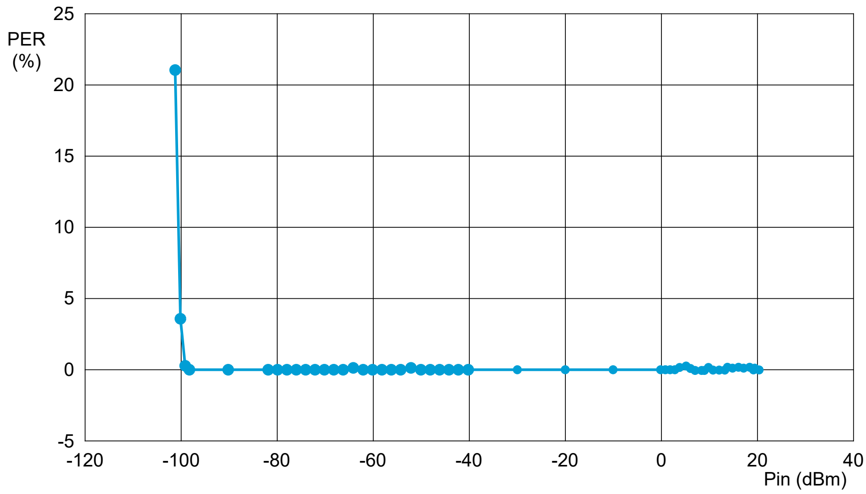

Figure 84. PER versus RX input power

3.5 Return loss

3.5.1 RX return loss

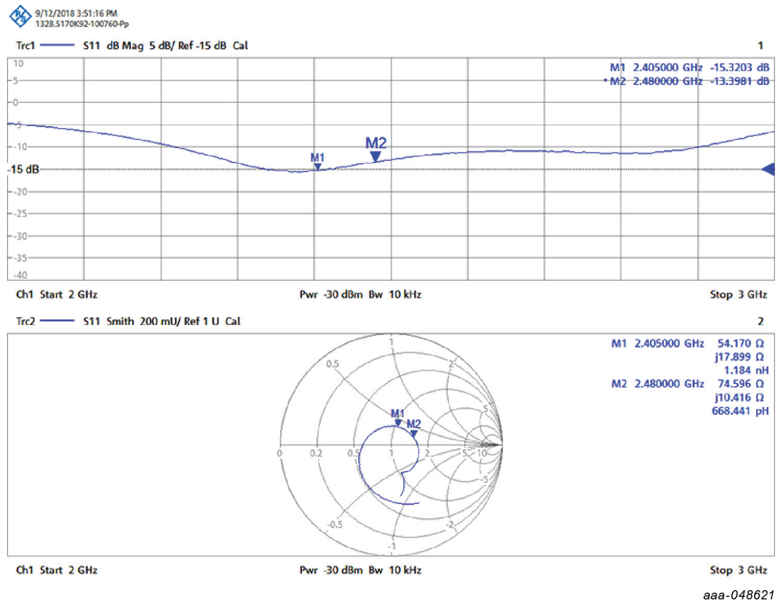

Figure 85. S11 RX

S11 < -12 dB at 2.405 – 2.480 GHz

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3.5.2 TX return loss

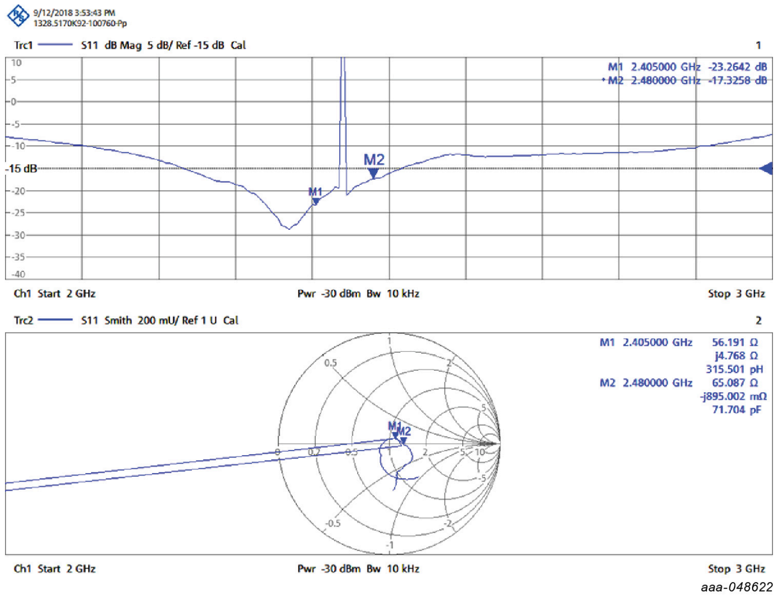

Figure 86. S11 TX

S11 < -17 dB at 2.405 – 2.480 GHz

Conclusion:

The S11 TX and RX are better than the NXP -10 dB target.

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 in the same network.

3.6 Conclusion

Beyond RED, 802.15.4, and FCC compliance, these radio tests prove the good RF performances of the K32W041AM.

Due to high spectral density, it is recommended to target FCC certification only.

4 Benefits of Proprietary mode

The benefit of using a Proprietary mode in a Zigbee network:

- Consider a K32W configured in ZigBee RX mode, while a second K32W generates the desired channel when configured in ZigBee TX mode.
- Consider that a third K32W is configured in Transmit mode and generates an interferer ZigBee in a near-by channel.
- The side lobes of the ZigBee modulation in this case limit the interferer immunity of the K32W receiver if the interferer signal is generated without any filtering.
- The K32W radio has better performances in terms of interferers immunity compared to the side lobes limitation of the ZigBee modulation. Therefore, using the Proprietary mode for the transmitter that generates the interferer improves the interferer immunity of the K32W which is configured in RX mode.

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- Alternatively, when the K32W interferer uses the Proprietary mode as opposed to the Regular mode, the level of the interferer can be higher relative to the desired channel.

5 CMET settings

This section includes CMET settings for the tests presented in this application note.

1. For tests in Transmit mode:

Section	CMET selection	CMET evaluation software
Section 3.3.3.1 Frequency accuracy	b) a) a)	
Section 3.3.3.2 Phase noise at 100 kHz offset	b) a) a)	
Section 3.3.3.3 TX power fundamental	b) a) a) +/-	
Section 3.3.3.4 TX spurious	b) a) b) a)	
Section 3.3.3.5 TX modulation	b) a) b) a)	
Section 3.3.3.5.1 EVM	b) a) b) a) +/-	
Section 3.3.3.5.2 Offset EVM	b) a) b) a) +/-	
Section 3.3.3.6 Upper band edge	b) a) b) a) Ch26	
Section 3.5.2 TX return loss	b) a) b) a)	

2. For tests in Receive mode:

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Section	CMET selection	CMET evaluation software
Section 3.5.1 RX return loss	b) a) h)	 *** * Customer Module Evaluation Tool * * Version 2041 * * Compiled Sep 21 2020 14:14:53 * * Radio Test version 2042 * * Radio Driver version 2093 * * Chip ID 000e2117 * *** a) Standard Module b) Standard HI TX power Module /) Reset CMET Please choose an option >b Standard HI TX power Module in High TX mode Selected *** * ZigBee Mode * *** a) Regular b) Proprietary 1 c) Proprietary 2 d) Regular with flash write/read in test Please choose an option >a ZigBee Regular Mode Selected *** * Customer Module Evaluation Tool * *** * Radio Tests * a) TX Power Test (CW) b) TX Power Test (Modulated) c) Receive Test d) Oscillator Frequency Test e) Current Measurement Test f) RF Power Measurement g) Trigger Packet Test h) Receive Packets Test i) Transmit Packets Test j) Connectionless Packet Error Rate Test k) CCA Test l) LQI Test m) Turnaround Tests

3. For PER test:

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<table>
<tr><th>Section</th><th>CMET selection</th><th>CMET evaluation software</th></tr>
<tr><td>Section 3.4.2 RX sensitivity</td><td>b) a) g) 'A' 'g' +/-</td><td rowspan="3">***
* Customer Module Evaluation Tool *
* Version 2041 *
* Compiled Sep 21 2020 14:14:53 *
* Radio Test version 2042 *
* Radio Driver version 2093 *
* Chip ID 000e2117 *
****

a) Standard Module
b) Standard HI TX power Module
/) Reset CMET

Please choose an option >b
Standard HI TX power Module in High TX mode Selected

****
* ZigBee Mode *
****

a) Regular
b) Proprietary 1
c) Proprietary 2
d) Regular with flash write/read in test

Please choose an option >a
ZigBee Regular Mode Selected

****
* Customer Module Evaluation Tool *
****

* Radio Tests *

a) TX Power Test (CW)
b) TX Power Test (Modulated)
c) Receive Test
d) Oscillator Frequency Test
e) Current Measurement Test
f) RF Power Measurement
g) Trigger Packet Test
h) Receive Packets Test
i) Transmit Packets Test
j) Connectionless Packet Error Rate Test
k) CCA Test
l) LQI Test
m) Turnaround Tests

* NFC Tests *

n) NTAG Tests

* XTAL temperature compensation *

o) Change XTAL32M IECLoad and parasitic caps values
p) XTAL32M CapLoad temperature trimming
q) Change XTAL32k IECLoad and parasitic caps values
r) XTAL32k CapLoad temperature trimming
s) SPI FLASH Tests

/) Return to root menu

Please choose an option g

New radio calibration not needed

Enter Trigger DIO in Hexadecimal [0, 1, 2, 3, A, B, E, F]
or G for DIO16, J for DIO19 and K for DIO20
(default = A)</td></tr>
<tr><td>Section 3.4.3 Receiver maximum input level</td><td>b) a) c)</td></tr>
<tr><td>Section 3.4.4 RX spurious
• Section 3.4.4.1 Wide band
• Section 3.4.5.1 Adjacent and alternate channels with standard interferers
• Section 3.4.5.2 N-3 and N+3 channels with standard interferers
• Section 3.4.5.3 Co-channel
• Section 3.4.5.4 Adjacent and alternate channels with filtered interferers (as generated by a K32W in Proprietary mode 2)
• Section 3.4.5.5 N-3 and N+3 channels with filtered interferers (as generated by a K32W in Proprietary mode 2)
• Section 3.4.5.6 Co-channel with a filtered interferer
Section 3.4.6 Receiver blocking</td><td>b) a) c)</td></tr>
</table>

6 K32W_certi_tool settings

This section includes K32W_certi_tool settings for the tests presented in this application note.

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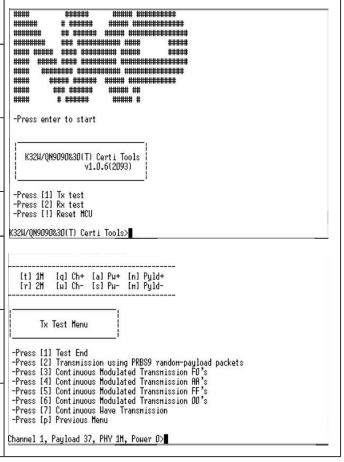
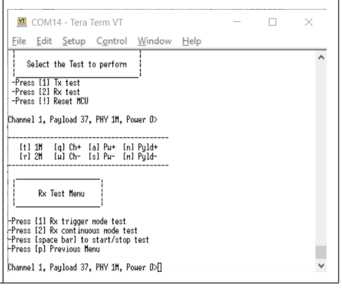
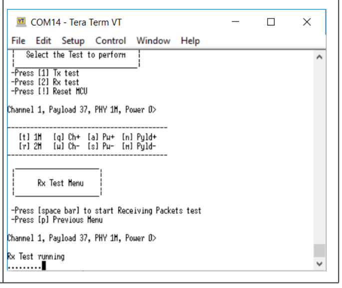
1. For tests in Transmit mode:

Section	K32W_certi_tool selection	Certi_tool evaluation software
Section 2.3.2.1 Frequency accuracy	[1], [7]	
Section 2.3.2.2 Phase noise	[1], [7]	
Section 2.3.2.3 TX power (fundamental)	[1], [7], [q] or [w]	
Section 2.3.2.4 TX power in band	[1], [2], [t] or [r]	
Section 2.3.2.5 TX spurious	[1], [2], [t] or [r]	
Section 2.3.2.6 Upper band edge	[1], [2], [t] or [r], [q] up to channel 39	
Section 2.3.2.7 Modulation characteristics	[1], [2], [t] or [r], [q] or [w] on CMW equipment	
Section 2.3.2.8 Carrier frequency offset and drift	On CMW equipment (CMWrun)	

2. For tests in Receive mode:

Section	K32W_certi_tool selection	Certi_tool evaluation software
Section 3.5.1 RX return loss	[2], [2]	

3. For PER test:

Section	K32W_certi_tool selection	Certi_tool evaluation software
Section 2.4.2 RX sensitivity Section 2.4.3 Receiver maximum input level Section 2.4.4 RX spurious • Section 2.4.5.1 Adjacent, alternate, and co-channel rejection • Section 2.4.5.2 Receiver blocking • Section 2.4.5.3 Intermodulation	[2], [q] or [w], [t] or [r], space bar	

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Signal generator sends the packets to the K32W device. Then, the packets received by the K32W device are counted during 15 seconds and ratio of **packets received** to **sent packets** is calculated and displayed.
If no packets are received, PER is 100 % as follows:

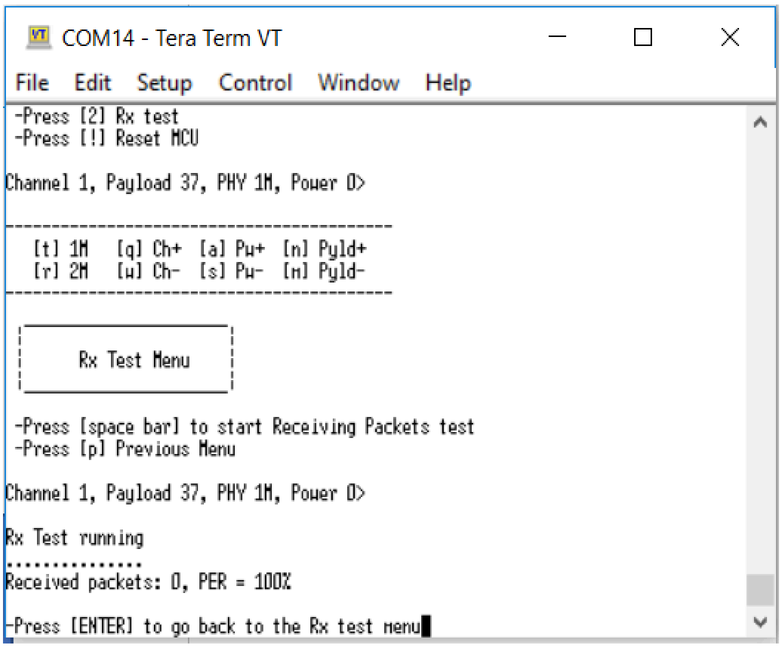

Figure 87. Certi_tool evaluation software

7 References

- **FCC**: 47 CFR Part 15C
- **RED**: European Radio Equipment Directive applied from June 2016
- **R&TTE**: Radio and Telecommunications Terminal Equipment Directive (R&TTED) (1999/5/EC) has been stopped on June 2016.
- **ETSI 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 2.4 GHz ISM band, 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)
- **RF-PHY TS 4.2.0/5.0**: Bluetooth Test Specification. This document defines test structures and procedures for qualification testing of Bluetooth implementations of the Bluetooth Low Energy RF PHY.
- **FCC Part 15**: Operation to FCC Part 15 is subject to two conditions. First, the device may not cause harmful interference and, second, the device must accept any interference received, including interference that may cause undesired operation. Hence, there is no guaranteed quality of service when operating a Part 15 device.

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8 Revision history

The Table 17 lists the substantive changes done to this document since the initial release.

Table 17. Revision history

Revision number	Date	Substantive changes
0	16 November 2022	Initial release

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