FCC Measurement/Technical Report on

BoB Assistant V2 US915
50-80-003

FCC ID: 2AGTV-50-80-003
IC: 32028 - 5080003

Test Report Reference: MDE_NKE_2101_FCC_02

Test Laboratory:
7layers GmbH
Borsigstrasse 11
40880 Ratingen
Germany

Deutsche Akkreditierungsstelle
D-PL-12140-01-01
D-PL-12140-01-02
D-PL-12140-01-03

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1 APPLIED STANDARDS AND TEST SUMMARY

1.1 APPLIED STANDARDS

Type of Authorization
Certification for an Intentional Radiator.

Applicable FCC Rules

Prepared in accordance with the requirements of FCC Rules and Regulations as listed in 47 CFR Ch.1 Parts 2 and 15 (10-1-22 Edition). The following subparts are applicable to the results in this test report.

Part 2, Subpart J - Equipment Authorization Procedures, Certification

Part 15, Subpart C – Intentional Radiators

§ 15.201 Equipment authorization requirement

§ 15.207 Conducted limits

§ 15.209 Radiated emission limits; general requirements

§ 15.247 Operation within the bands 902-928 MHz, 2400-2483.5 MHz

Note:
The tests were selected and performed with reference to the FCC Public Notice "Guidance for Compliance Measurements on Digital Transmission System, Frequency Hopping Spread Spectrum System, and Hybrid System Devices Operating under Section 15.247 of the FCC Rules, 558074 D01 15.247 Meas Guidance v05r02, 2019-04-02". ANSI C63.10–2013 is applied.

1.2 FCC-IC CORRELATION TABLE

Correlation of measurement requirements for FHSS (e.g. Bluetooth®) equipment from FCC and IC

FHSS equipment

Measurement	FCC reference	IC reference
Conducted emissions on AC Mains	§ 15.207	RSS-Gen Issue 5: 8.8
Occupied bandwidth	§ 15.247 (a) (1)	RSS-247 Issue 2: 5.1 (b)
Peak conducted output power	§ 15.247 (b) (1), (4)	RSS-247 Issue 2: 5.4 (b)
Transmitter spurious RF conducted emissions	§ 15.247 (d)	RSS-Gen Issue 5: 6.13/8.9/8.10; RSS-247 Issue 2: 5.5
Transmitter spurious radiated emissions	§ 15.247 (d); § 15.209 (a)	RSS-Gen Issue 5: 6.13 / 8.9/8.10; RSS-247 Issue 2: 5.5
Band edge compliance	§ 15.247 (d)	RSS-247 Issue 2: 5.5
Dwell time	§ 15.247 (a) (1) (iii)	RSS-247 Issue 2: 5.1 (d)
Channel separation	§ 15.247 (a) (1)	RSS-247 Issue 2: 5.1 (b)
No. of hopping frequencies	§ 15.247 (a) (1) (iii)	RSS-247 Issue 2: 5.1 (d)
Hybrid systems (only)	§ 15.247 (f); § 15.247 (e)	RSS-247 Issue 2: 5.3
Antenna requirement	§ 15.203 / 15.204	RSS-Gen Issue 5: 8.3
Receiver spurious emissions	–	-

1.3 MEASUREMENT SUMMARY

47 CFR CHAPTER I FCC PART 15 Subpart C §15.247 — **§ 15.247 (a) (1)**

Occupied Bandwidth (20 dB)

The measurement was performed according to ANSI C63.10, chapter 6.9.2 — **Final Result**

OP-Mode Radio Technology, Operating Frequency	Setup	Date	FCC	IC
LoRa (FHSS), high	S01_AO01	2023-07-27	Passed	Passed
LoRa (FHSS), low	S01_AO01	2023-07-27	Passed	Passed
LoRa (FHSS), mid	S01_AO01	2023-07-27	Passed	Passed

47 CFR CHAPTER I FCC PART 15 Subpart C §15.247 — **IC RSS-Gen; Ch. 6.7 & Ch. 8**

Occupied Bandwidth (99%)

The measurement was performed according to ANSI C63.10, chapter 6.9.3 — **Final Result**

OP-Mode Radio Technology, Operating Frequency	Setup	Date	FCC	IC
LoRa (FHSS), high	S01_AO01	2023-07-27	N/A	Performed
LoRa (FHSS), low	S01_AO01	2023-07-27	N/A	Performed
LoRa (FHSS), mid	S01_AO01	2023-07-27	N/A	Performed

47 CFR CHAPTER I FCC PART 15 Subpart C §15.247 — **§ 15.247 (b) (1) (2)**

Peak Power Output

The measurement was performed according to ANSI C63.10, chapter 11.9.1.3 — **Final Result**

OP-Mode Radio Technology, Operating Frequency, Measurement method	Setup	Date	FCC	IC
LoRa (FHSS), high, conducted	S01_AO01	2023-07-27	Passed	Passed
LoRa (FHSS), low, conducted	S01_AO01	2023-07-27	Passed	Passed
LoRa (FHSS), mid, conducted	S01_AO01	2023-07-27	Passed	Passed

47 CFR CHAPTER I FCC PART 15 Subpart C §15.247 — **§ 15.247 (d)**

Spurious RF Conducted Emissions

The measurement was performed according to ANSI C63.10, chapter 11.11 — **Final Result**

OP-Mode Radio Technology, Operating Frequency	Setup	Date	FCC	IC
LoRa (FHSS), high	S01_AO01	2023-08-01	Passed	Passed
LoRa (FHSS), low	S01_AO01	2023-08-01	Passed	Passed
LoRa (FHSS), mid	S01_AO01	2023-08-01	Passed	Passed

47 CFR CHAPTER I FCC PART 15 Subpart C §15.247 **§ 15.247 (d)**

Transmitter Spurious Radiated Emissions

The measurement was performed according to ANSI C63.10, chapter 6.4, 6.5, 6.6.5 **Final Result**

OP-Mode Radio Technology, Operating Frequency, Measurement range	Setup	Date	FCC	IC
LoRa (FHSS), high, 1 GHz - 10 GHz	S01_AQ02	2023-10-19	Passed	Passed
LoRa (FHSS), high, 30 MHz - 1 GHz	S01_AQ02	2023-10-19	Passed	Passed
LoRa (FHSS), high, 9 kHz - 30 MHz	S01_AQ02	2023-10-19	Passed	Passed
LoRa (FHSS), low, 1 GHz - 10 GHz	S01_AQ02	2023-10-19	Passed	Passed
LoRa (FHSS), low, 30 MHz - 1 GHz	S01_AQ02	2023-10-19	Passed	Passed
LoRa (FHSS), low, 9 kHz - 30 MHz	S01_AQ02	2023-10-19	Passed	Passed
LoRa (FHSS), mid, 1 GHz - 10 GHz	S01_AQ02	2023-10-19	Passed	Passed
LoRa (FHSS), mid, 30 MHz - 1 GHz	S01_AQ02	2023-10-19	Passed	Passed
LoRa (FHSS), mid, 9 kHz - 30 MHz	S01_AQ02	2023-10-19	Passed	Passed

47 CFR CHAPTER I FCC PART 15 Subpart C §15.247 **§ 15.247 (d)**

Band Edge Compliance Conducted

The measurement was performed according to ANSI C63.10, chapter 11.11 **Final Result**

OP-Mode Radio Technology, Operating Frequency, Band Edge	Setup	Date	FCC	IC
LoRa (FHSS), high, high	S01_AO01	2023-08-01	Passed	Passed
LoRa (FHSS), low, low	S01_AO01	2023-08-01	Passed	Passed

47 CFR CHAPTER I FCC PART 15 Subpart C §15.247 **§ 15.247 (a) (1)**

Channel Separation

The measurement was performed according to ANSI C63.10, chapter 7.8.2 **Final Result**

OP-Mode Radio Technology	Setup	Date	FCC	IC
LoRa (FHSS)	S01_AO01	2023-07-27	Passed	Passed

47 CFR CHAPTER I FCC PART 15 Subpart C §15.247 **§ 15.247 (a) (1) (i) (ii) (iii)**

Dwell Time

The measurement was performed according to ANSI C63.10, chapter 7.8.4 **Final Result**

OP-Mode Radio Technology	Setup	Date	FCC	IC
LoRa (FHSS)	S01_AO01	2023-07-27	Passed	Passed

47 CFR CHAPTER I FCC PART 15 Subpart C §15.247	§ 15.247 (a) (1) (i) (ii) (iii)			
Number of Hopping Frequencies The measurement was performed according to ANSI C63.10, chapter 7.8.3			**Final Result**	
OP-Mode Radio Technology	**Setup**	**Date**	**FCC**	**IC**
LoRa (FHSS)	S01_AO01	2023-07-27	Passed	Passed

N/A: Not applicable
N/P: Not performed

2 REVISION HISTORY / SIGNATURES

Report version control			
Version	**Release date**	**Change Description**	**Version validity**
initial	2024-04-11	--	valid
--	--	--	--

COMMENT: -

(responsible for accreditation scope)
Dipl.-Ing. Marco Kullik

(responsible for testing and report)
BSc. Mhd Mouaz Saad

7 layers GmbH, Borsigstr. 11
40880 Ratingen, Germany
Phone +49 (0)2102 749 0

3 ADMINISTRATIVE DATA

3.1 TESTING LABORATORY

Company Name:	7layers GmbH
Address:	Borsigstr. 11 40880 Ratingen Germany

The test facility is accredited by the following accreditation organisation:

Laboratory accreditation no:	DAkkS D-PL-12140-01-01| -02 | -03
FCC Designation Number:	DE0015
FCC Test Firm Registration:	929146
ISED CAB Identifier	DE0007; ISED#: 3699A
Responsible for accreditation scope:	Dipl.-Ing. Marco Kullik
Report Template Version:	2023-09-29

3.2 PROJECT DATA

Responsible for testing and report:	BSc. Mhd Mouaz Saad
Employees who performed the tests:	documented internally at 7Layers
Date of Report:	2024-04-11
Testing Period:	2023-07-27 to 2023-10-19

3.3 APPLICANT DATA

Company Name:	Watteco
Address:	165 rue de la Montagne du Salut Pôle Technellys – Bâtiment H - Boite aux lettres N°60 56600 LANESTER France
Contact Person:	Julien Lefort

3.4 MANUFACTURER DATA

Company Name:	please see Applicant Data
Address:	
Contact Person:	

4 TEST OBJECT DATA

4.1 GENERAL EUT DESCRIPTION

Kind of Device product description	Vibration sensor
Product name	BoB Assistant V2 US915
Type	50-80-003
Declared EUT data by the supplier	
Voltage Type	Lithium battery (not rechargeable)
Voltage Level	3.6 V
Antenna / Gain	internal (PCB antenna) / -2.6dBi
Tested Modulation Type	LoRa (FHSS)
General product description	The EUT is a Vibration sensor that analyses the vibration signature of an industrial equipment, ensuring its remote monitoring. The data is transmitted via a public or private LoRaWANTM radio frequency network.
Max Output Power	20 dBm
Operating Channel Width(s) (OCW)	125 kHz
Channel Spacing	200 kHz
No of Hopping channels	64
Special software used for testing	The EUTs have special Test software, that enable continuously modulated signals (non-hopping mode tests) and hopping signals too.

4.2 EUT MAIN COMPONENTS

Sample Name	**Sample Code**	**Description**
EUT O	DE1497001ao01	Conducted Sample (US)
Sample Parameter	**Value**	
Serial No.	0801720003	
HW Version	H	
SW Version	1.0	
Comment		

Sample Name	**Sample Code**	**Description**
EUT Q	DE1497001aq02	Radiated Sample (US)
Sample Parameter	**Value**	
Serial No.	0801720013	
HW Version	H	
SW Version	1.0	
Comment		

NOTE:The short description is used to simplify the identification of the EUT in this test report.

4.3 ANCILLARY EQUIPMENT

For the purposes of this test report, ancillary equipment is defined as equipment which is used in conjunction with the EUT to provide operational and control features to the EUT. It is necessary to configure the system in a typical fashion, as a customer would normally use it. But nevertheless Ancillary Equipment can influence the test results.

Device	**Details (Manufacturer, Type Model, OUT Code)**	**Description**
-	-	-

4.4 AUXILIARY EQUIPMENT

For the purposes of this test report, auxiliary equipment is defined as equipment which is used temporarily to enable operational and control features especially used for the tests of the EUT which is not used during normal operation or equipment that is used during the tests in combination with the EUT but is not subject of this test report. It is necessary to configure the system in a typical fashion, as a customer would normally use it.
But nevertheless Auxiliary Equipment can influence the test results.

Device	**Details (Manufacturer, Type Model, HW, SW, S/N)**	**Description**
-	-	-

4.5 EUT SETUPS

This chapter describes the combination of EUTs and equipment used for testing. The rationale for selecting the EUTs, ancillary and auxiliary equipment and interconnecting cables, is to test a representative configuration meeting the requirements of the referenced standards.

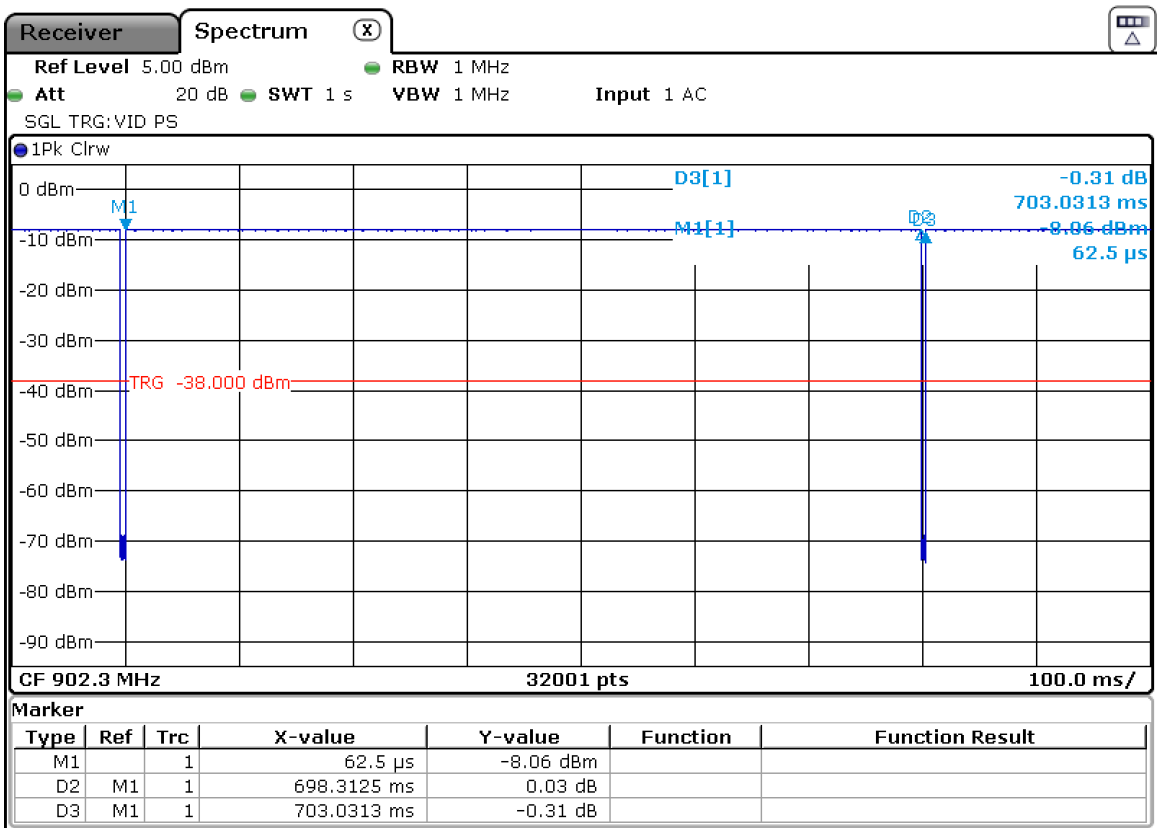
Setup	**Combination of EUTs**	**Description and Rationale**
S01_AQ02	EUT Q	Radiated Setup
S01_AO01	EUT O	Conducted Setup

4.6 OPERATING MODES / TEST CHANNELS

This chapter describes the operating modes of the EUTs used for testing.

	900 MHz ISM 902 - 926 MHz		
LoRa(FHSS) Test Channels:	**low**	**mid**	**High**
Channel:	0	31	63
Frequency [MHz]	902.3	908.5	914.9

Duty Cycle:



Duty Cycle = 99.3 %

4.7 PRODUCT LABELLING

4.7.1 FCC ID LABEL

Please refer to the documentation of the applicant.

4.7.2 LOCATION OF THE LABEL ON THE EUT

Please refer to the documentation of the applicant.

5 TEST RESULTS

5.1 OCCUPIED BANDWIDTH (20 DB)

Standard **FCC Part 15 Subpart C**

The test was performed according to:
ANSI C63.10, chapter 6.9.2

5.1.1 TEST DESCRIPTION

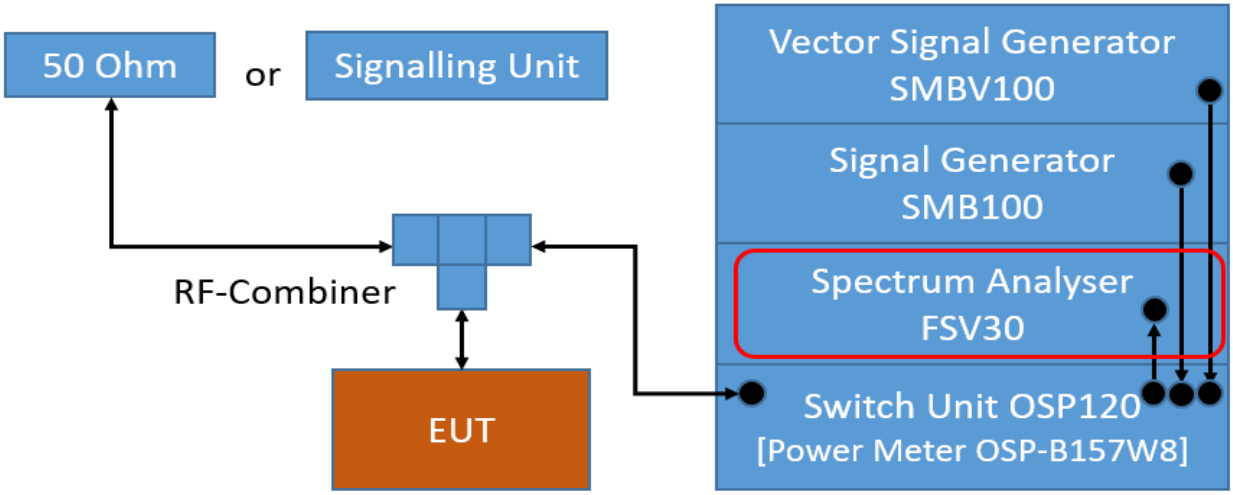
The Equipment Under Test (EUT) was set up to perform the occupied bandwidth measurements.
The reference level is the level of the highest amplitude signal observed from the transmitter at either the fundamental frequency or first-order modulation products in all typical modes of operation, including the unmodulated carrier, even if atypical.
The results recorded were measured with the modulation which produce the worst-case (widest) emission bandwidth.

The EUT was connected to the test system as described in the block diagram below. The complete attenuation of the measurement path is known and considered.

Analyser settings:

- Resolution Bandwidth (RBW): 1% to 5 % of the OBW
- Video Bandwidth (VBW): ≥ 3 x RBW
- Span: 2 to 5 times the OBW
- Trace: Maxhold
- Sweeps: Till stable (min. 1000, max. 30000)
- Sweeptime: Auto
- Detector: Peak

The technology depending measurement parameters can be found in the measurement plot.



5.1.2 TEST REQUIREMENTS / LIMITS

FCC Part 15, Subpart C, §15.247 (a) (2)

For the band: 902 – 928 MHz
FCC Part 15, Subpart C, §15.247 (a) (1) (i)

The maximum allowed 20 dB bandwidth of the hopping channel is 500 kHz

Frequency hopping systems shall have hopping channel carrier frequencies separated by a minimum of 25 kHz or the 20 dB bandwidth of the hopping channel, whichever is greater. Alternatively, frequency hopping systems operating in the 2400–2483.5 MHz band may have hopping channel carrier frequencies that are separated by 25 kHz or two-thirds of the 20 dB bandwidth of the hopping channel, whichever is greater, provided the systems operate with an output power no greater than 125 mW. The system shall hop to channel frequencies that are selected at the system hopping rate from a pseudo randomly ordered list of hopping frequencies. Each frequency must be used equally on the average by each transmitter. The system receivers shall have input bandwidths that match the hopping channel bandwidths of their corresponding transmitters and shall shift frequencies in synchronization with the transmitted signals.

Implication by the test laboratory:
Since the Bluetooth technology defines a fixed channel separation of 1 MHz this design parameter defines the maximum allowed occupied bandwidth depending on the EUT's output power:
1. Under the provision that the system operates with an output power not greater than 125 mW (21.0 dBm):
Implicit Limit: Max. 20 dB BW = 1.0 MHz / 2/3 = 1.5 MHz

2. If the system output power exceeds 125 mW (21.0 dBm):
Implicit Limit: Max. 20 dB BW = 1.0 MHz

Used conversion factor: Output power (dBm) = 10 log (Output power (W) / 1mW)

The measured output power of the system is below 125 mW (21.0 dBm). For the results, please refer to the related chapter of this report.
Therefore the limit is determined as 1.5 MHz.

5.1.3 TEST PROTOCOL

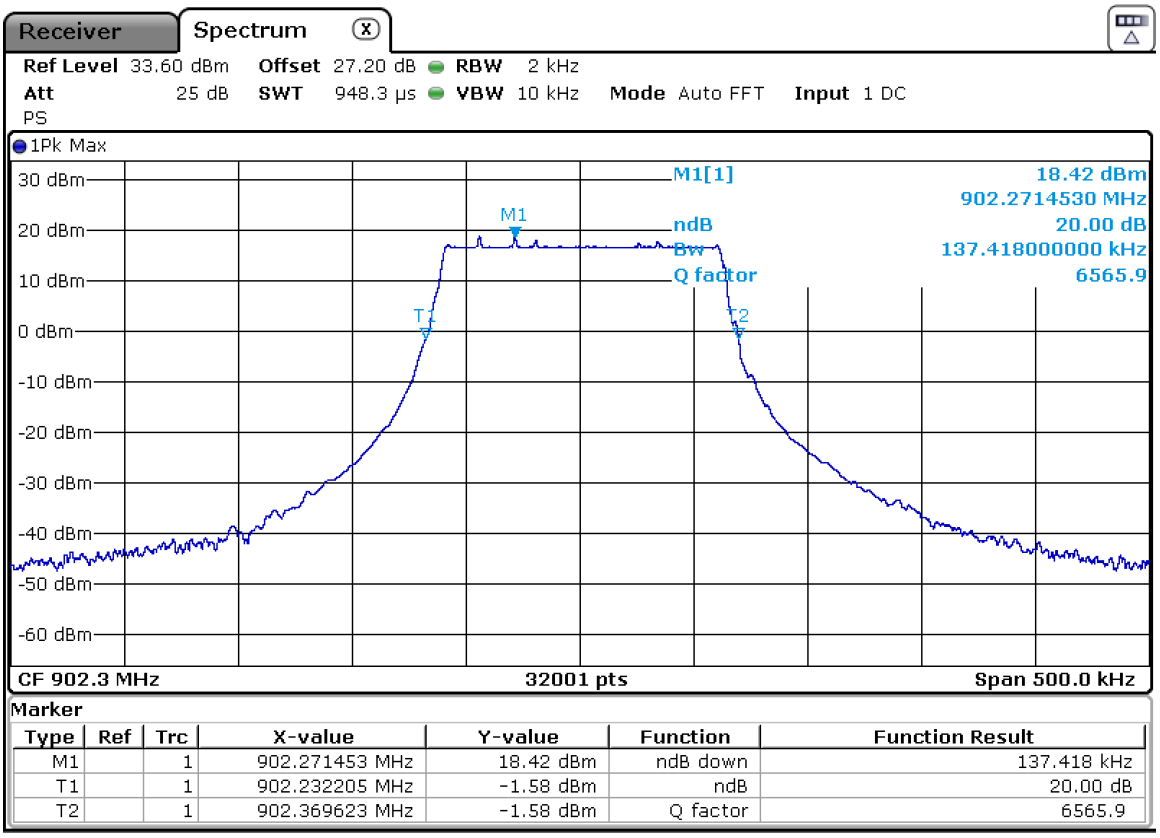
Ambient temperature:	22 °C
Air Pressure:	998 hPa
Humidity:	41 %
LoRaWAN; FHSS 125 kHz; 5470 bps	

Band	Channel No.	Frequency [MHz]	20 dB Bandwidth [MHz]	Limit [MHz]	Margin to Limit [MHz]
900 MHz Band	0	902.3	0.137	0.5	0.363
	31	908.5	0.137	0.5	0.363
	63	914.9	0.137	0.5	0.363

Remark: Please see next sub-clause for the measurement plot.

5.1.4 MEASUREMENT PLOT (EXAMPLE PLOT, SHOWING WORST CASE, IF APPLICABLE)

Radio Technology = LoRa (FHSS), Operating Frequency = low (S01_AO01)



Type	Ref	Trc	X-value	Y-value	Function	Function Result
M1		1	902.271453 MHz	18.42 dBm	ndB down	137.418 kHz
T1		1	902.232205 MHz	-1.58 dBm	ndB	20.00 dB
T2		1	902.369623 MHz	-1.58 dBm	Q factor	6565.9

5.1.5 TEST EQUIPMENT USED

- Radio Lab

5.2 OCCUPIED BANDWIDTH (99%)

Standard **FCC Part 15 Subpart C**

The test was performed according to:
ANSI C63.10, chapter 6.9.3

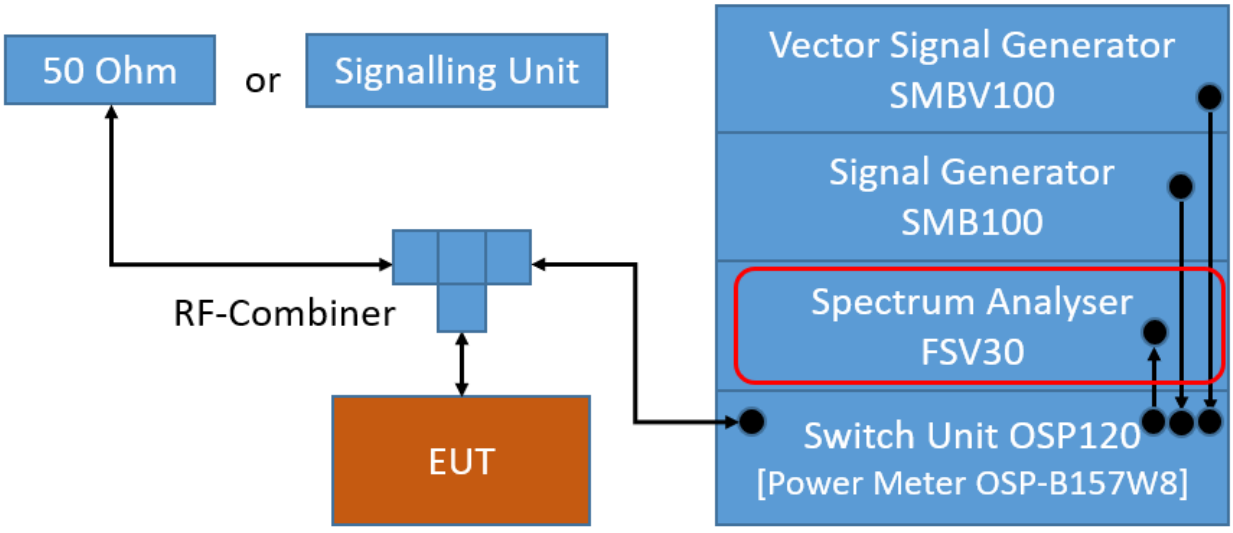
5.2.1 TEST DESCRIPTION

The Equipment Under Test (EUT) was set up to perform the occupied bandwidth measurements.
The reference level is the level of the highest amplitude signal observed from the transmitter at either the fundamental frequency or first-order modulation products in all typical modes of operation, including the unmodulated carrier, even if atypical.

The EUT was connected to the test system as described in the block diagram below. The complete attenuation of the measurement path is known and considered.

Analyser settings:

- Resolution Bandwidth (RBW): 1 to 5 % of the OBW
- Video Bandwidth (VBW): ≥ 3 times the RBW
- Span: 1.5 to 5 times the OBW
- Trace: Maxhold
- Sweeps: Till stable (min. 500, max. 75000)
- Sweeptime: Auto
- Detector: Peak



5.2.2 TEST REQUIREMENTS / LIMITS

No applicable limit:

5.2.3 TEST PROTOCOL

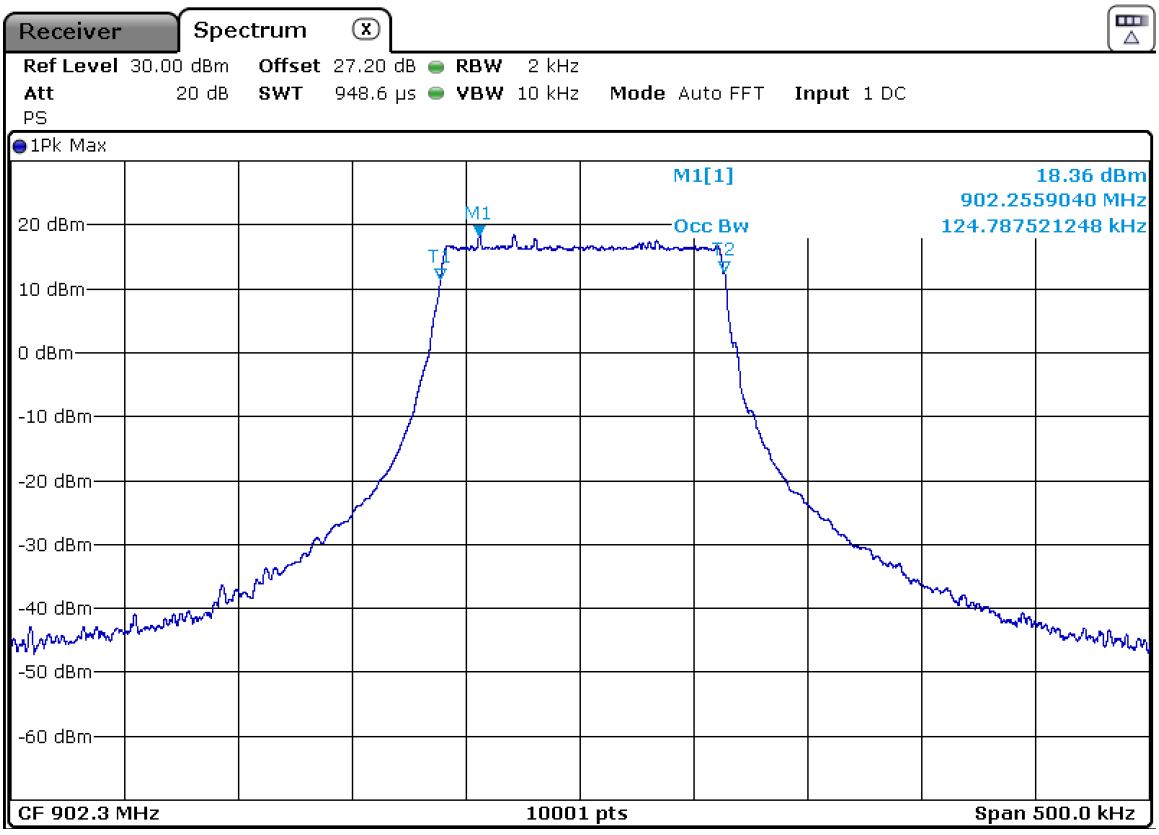
Ambient temperature: 22 °C
Air Pressure: 998 hPa
Humidity: 41 %
LoRaWAN; FHSS 125 kHz; 5470 bps

Band	Channel No.	Frequency [MHz]	99 % Bandwidth [MHz]
900 MHz Band	0	902.3	0.12
	31	908.5	0.12
	63	914.9	0.12

Remark: Please see next sub-clause for the measurement plot.

5.2.4 MEASUREMENT PLOT (EXAMPLE PLOT, SHOWING WORST CASE, IF APPLICABLE)

Radio Technology = LoRa (FHSS), Operating Frequency = low (S01_AO01)



5.2.5 TEST EQUIPMENT USED

- Radio Lab

5.3 PEAK POWER OUTPUT

Standard **FCC Part 15 Subpart C**

The test was performed according to:
ANSI C63.10, chapter 11.9.1.3

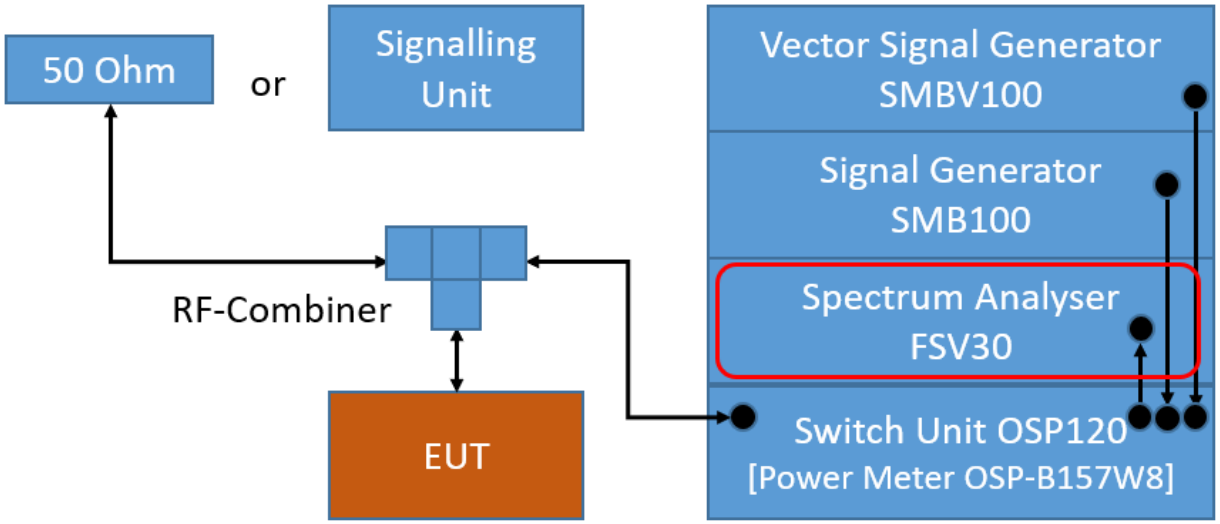
5.3.1 TEST DESCRIPTION

FHSS EQUIPMENT:
The Equipment Under Test (EUT) was set up to perform the output power measurements. The results recorded were measured with the modulation which produces the worst-case (highest) output power. The reference level of the spectrum analyser was set higher than the output power of the EUT.

The EUT was connected to the test system as described in the block diagram below. The complete attenuation of the measurement path is known and considered.

Analyser settings:

- Resolution Bandwidth (RBW): ≥ 20 dB BW
- Video Bandwidth (VBW): ≥ 3 times RBW
- Trace: Maxhold
- Sweeps: Till stable (min. 300, max. 15000)
- Sweeptime: Auto
- Detector: Peak



5.3.2 TEST REQUIREMENTS / LIMITS

Frequency Hopping Systems:

FCC Part 15, Subpart C, §15.247 (b) (2)
For frequency hopping systems operating in the 902-928 MHz band: 1 watt for systems employing at least 50 hopping channels; and, 0.25 watts for systems employing less than 50 hopping channels, but at least 25 hopping channels, as permitted under paragraph (a)(1)(i) of this section.

Used conversion factor: Limit (dBm) = 10 log (Limit (W)/1mW)

5.3.3 TEST PROTOCOL

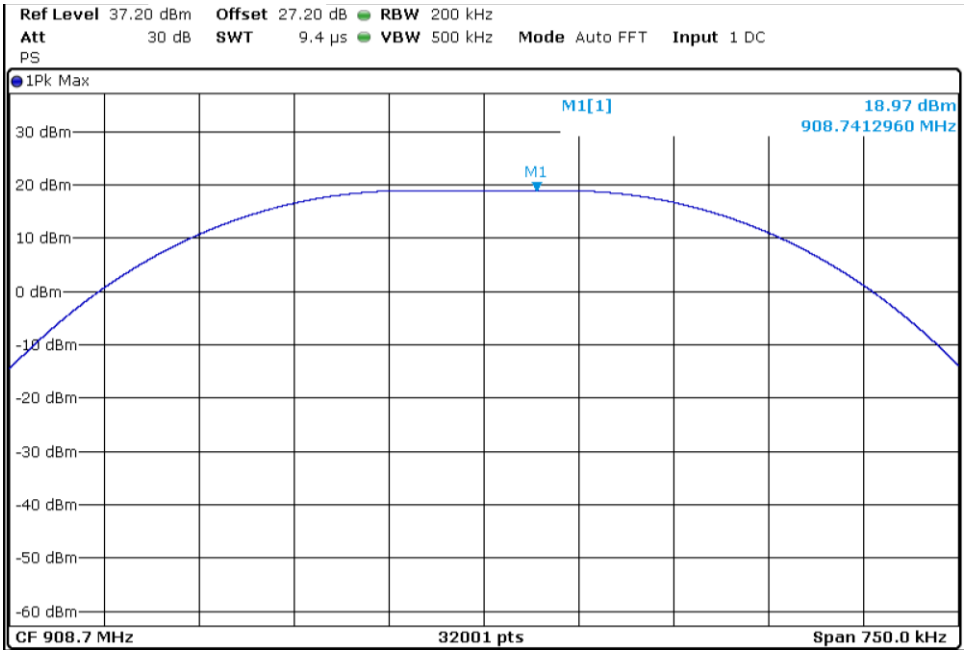
Ambient temperature: 22 °C
Air Pressure: 998 hPa
Humidity: 41 %
LoRaWAN; FHSS 125 kHz; 5470 bps

Band	Channel No.	Frequency [MHz]	Peak Power [dBm]	Limit [dBm]	Margin to Limit [dB]	E.I.R.P [dBm]
900 MHz Band	0	902.3	19.0	30.0	11.0	16.4
	31	908.5	19.0	30.0	11.0	16.4
	63	914.9	18.9	30.0	11.1	16.3

Remark: Please see next sub-clause for the measurement plot.

5.3.4 MEASUREMENT PLOT (EXAMPLE PLOT, SHOWING WORST CASE, IF APPLICABLE)

Radio Technology = LoRa (FHSS), Operating Frequency = mid (S01_AO01)



5.3.5 TEST EQUIPMENT USED

- Radio Lab

5.4 SPURIOUS RF CONDUCTED EMISSIONS

Standard **FCC Part 15 Subpart C**

The test was performed according to:
ANSI C63.10, chapter 11.11

5.4.1 TEST DESCRIPTION

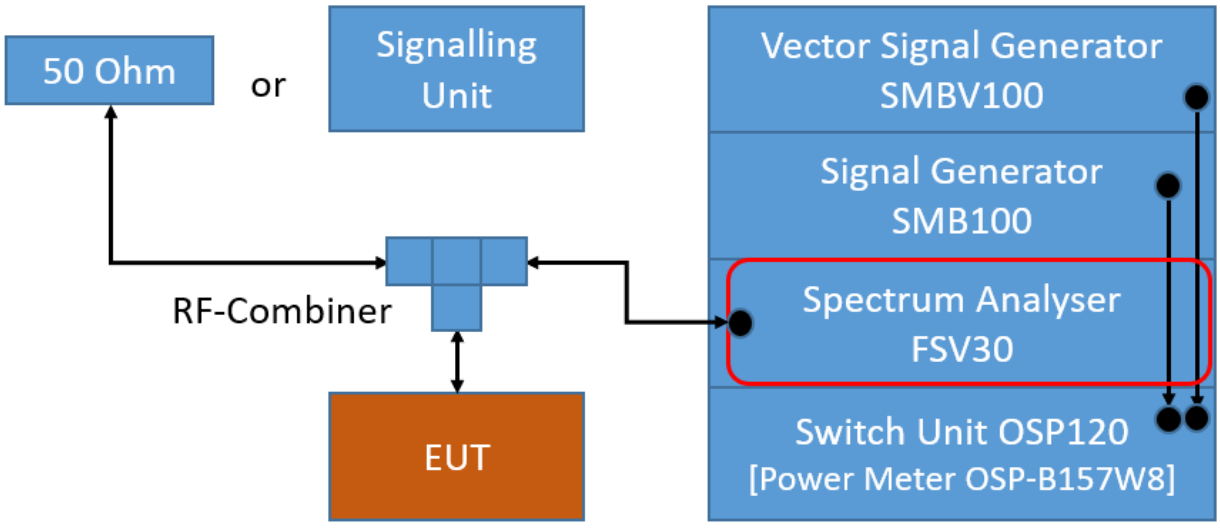
The Equipment Under Test (EUT) was set up to perform the spurious emissions measurements.

The EUT was connected to the test system as described in the block diagram below. The complete attenuation of the measurement path is known and considered.

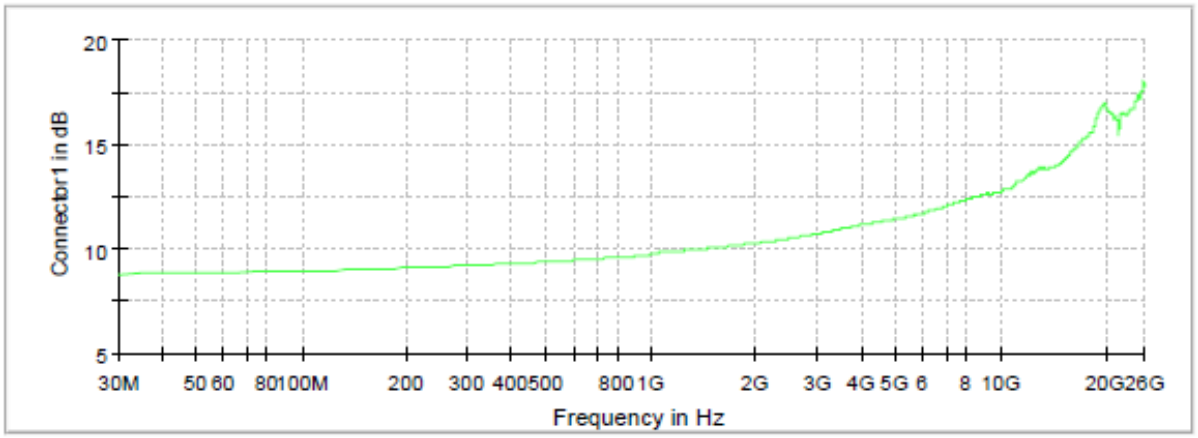
Analyser settings:

- Frequency range: 30 – 26000 MHz
- Resolution Bandwidth (RBW): 100 kHz
- Video Bandwidth (VBW): 300 kHz
- Trace: Maxhold
- Sweeps: Till Stable (max. 120)
- Sweep Time: Auto
- Detector: Peak

The reference value for the measurement of the spurious RF conducted emissions is determined during the test "band edge compliance conducted". This value is used to calculate the 20 dBc or 30 dBc limit.



TS8997; Spurious RF Conducted Emissions



Attenuation of the measurement part

5.4.2 TEST REQUIREMENTS / LIMITS

FCC Part 15, Subpart C, §15.247 (c)
In any 100 kHz bandwidth outside the frequency band in which the spread spectrum intentional radiator is operating, the radio frequency power that is produced by the intentional radiator shall be at least 20 dB below that in the 100 kHz bandwidth within the band that contains the highest level of the desired power, based on either an RF conducted or a radiated measurement, provided the transmitter demonstrates compliance with the peak conducted power limits. If the transmitter complies with the conducted power limits based on the use of RMS averaging over a time interval, as permitted under paragraph (b)(3) of this section, the attenuation required under this paragraph shall be 30 dB instead of 20 dB.

5.4.3 TEST PROTOCOL

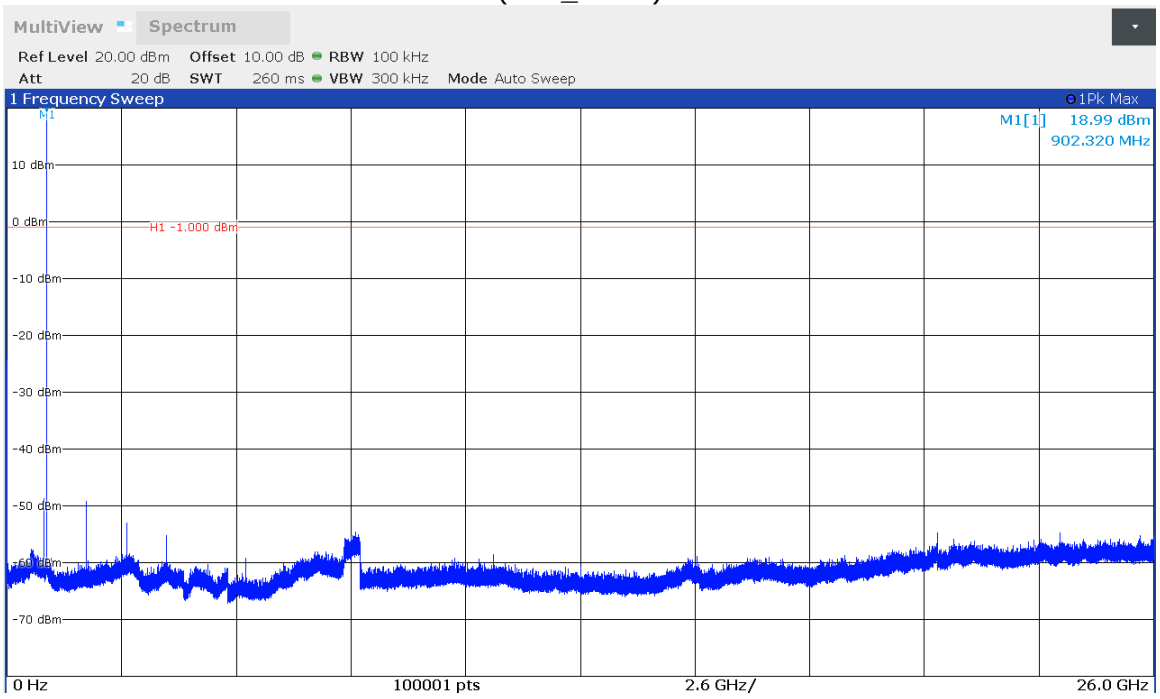
Ambient temperature: 23 °C
Air Pressure: 1001 hPa
Humidity: 38 %
LoRaWAN; FHSS 125 kHz; 5470 bps

Channel No	Channel Center Freq. [MHz]	Spurious Freq. [MHz]	Spurious Level [dBm]	Detector	RBW [kHz]	Ref. Level [dBm]	Limit [dBm]	Margin to Limit [dB]
0	902.3	-	-	PEAK	100	18.99	-1.01	>20 dB
31	908.5	-	-	PEAK	100	18.77	-1.23	>20 dB
63	914.9	-	-	PEAK	100	18.60	-1.40	>20 dB

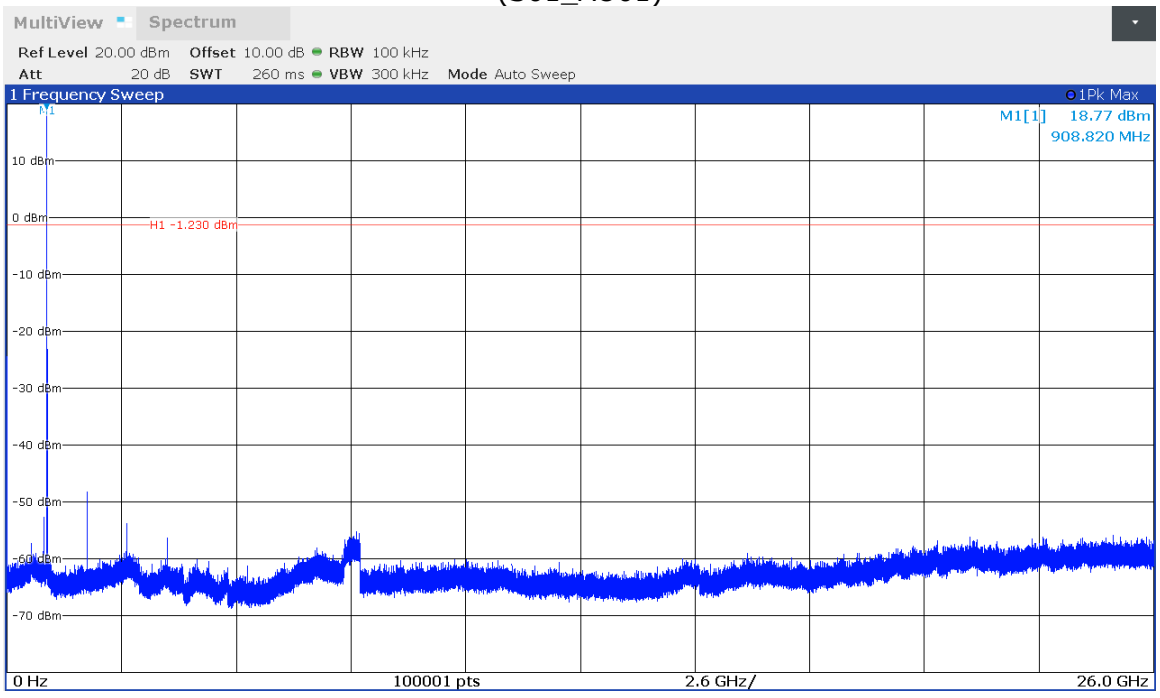
Remark: Please see next sub-clause for the measurement plot.

5.4.4 MEASUREMENT PLOT (EXAMPLE PLOT, SHOWING WORST CASE, IF APPLICABLE)

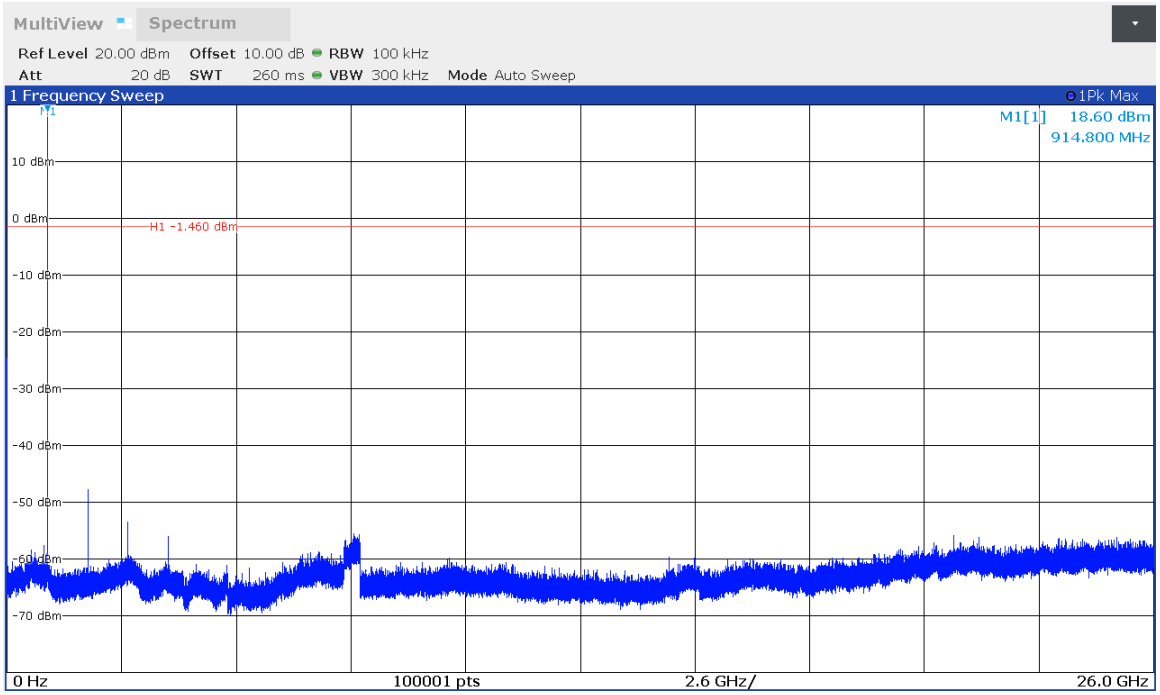
Radio Technology = LoRa (FHSS), Operating Frequency = low (S01_AO01)



Radio Technology = LoRa (FHSS), Operating Frequency = mid (S01_AO01)



Radio Technology = LoRa (FHSS), Operating Frequency = high (S01_AO01)



5.4.5 TEST EQUIPMENT USED

- R&S TS8997

5.5 TRANSMITTER SPURIOUS RADIATED EMISSIONS

Standard **FCC Part 15 Subpart C**

The test was performed according to:
ANSI C63.10, chapter 6.4, 6.5, 6.6.5

5.5.1 TEST DESCRIPTION

The test set-up was made in accordance to the general provisions of ANSI C63.10 in a typical installation configuration. The measurements were performed according the following sub-chapters of ANSI C63.10:

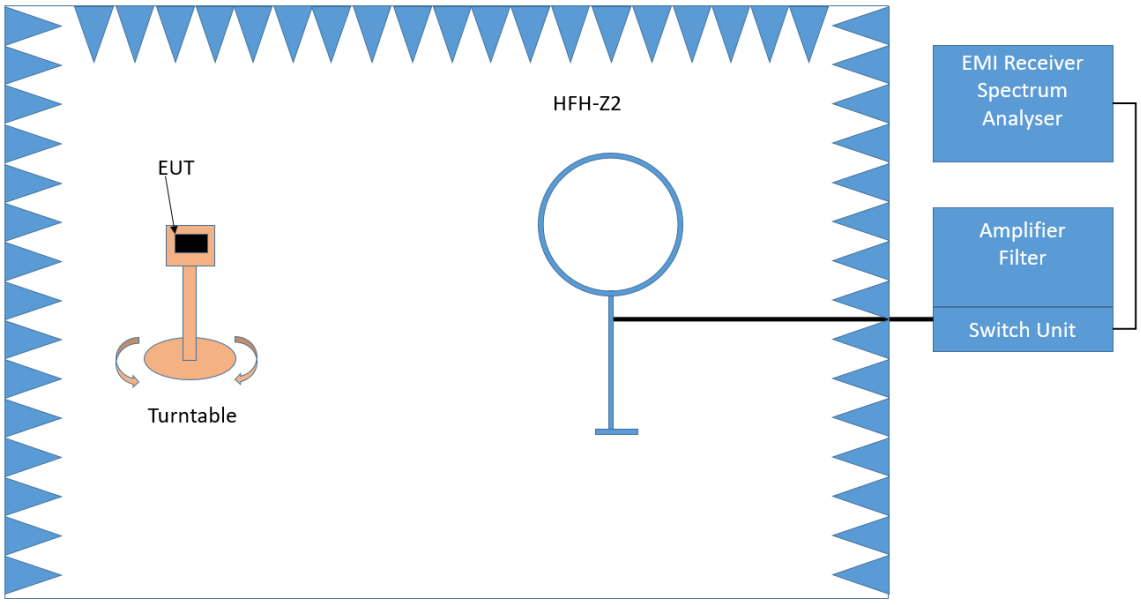
- < 30 MHz: Chapter 6.4
- 30 MHz – 1 GHz: Chapter 6.5
- > 1 GHZ: Chapter 6.6 (procedure according 6.6.5 used)

The measurement procedure is implemented into the EMI test software EMC32 from R&S. Exploratory tests are performed at 3 orthogonal axes to determine the worst-case orientation of a body-worn or handheld EUT. The final test on all kind of EUTs is also performed at 3 axes. A pre-check is performed while the EUT is powered.

Below 1 GHz:

The Equipment Under Test (EUT) was set up on a non-conductive table in the semi-anechoic chamber. The influence of the EUT support table that is used between 30–1000 MHz was evaluated.

1. Measurement up to 30 MHz



Test Setup; Spurious Emission Radiated (SAC), 9 kHz – 30 MHz

The Loop antenna HFH2-Z2 is used.

Step 1: pre measurement

- Anechoic chamber
- Antenna distance: 3 m
- Antenna height: 1 m
- Detector: Peak-Maxhold
- Frequency range: 0.009 - 0.15 MHz and 0.15 – 30 MHz
- Frequency steps: 0.05 kHz and 2.25 kHz
- IF–Bandwidth: 0.2 kHz and 9 kHz
- Measuring time / Frequency step: 100 ms (FFT-based)

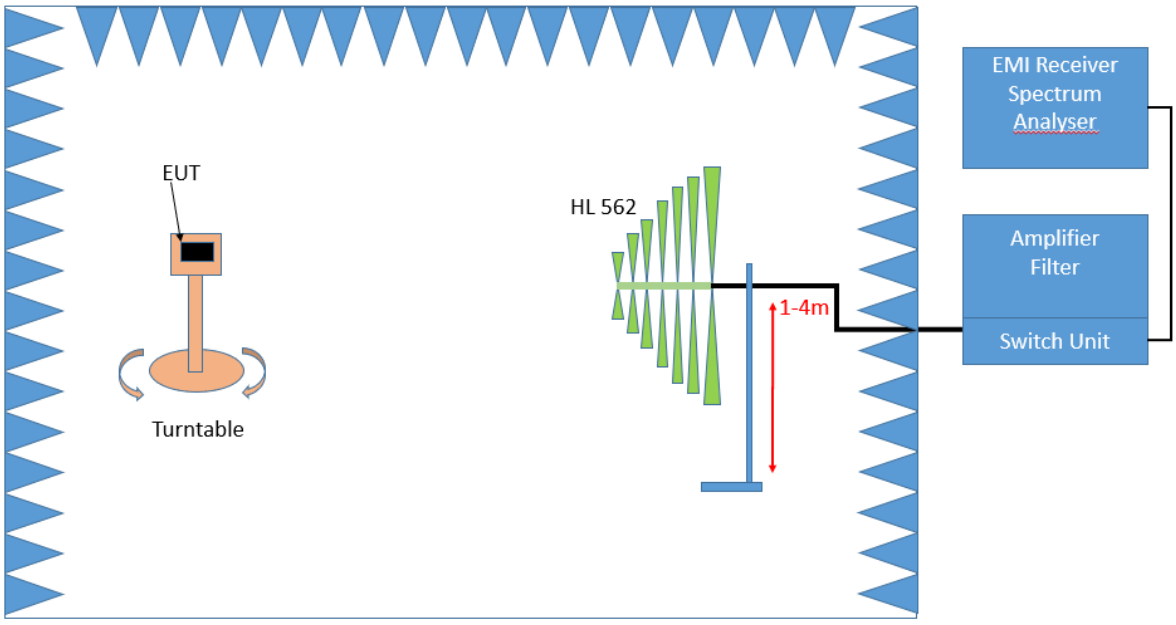
Intention of this step is, to determine the radiated EMI-profile of the EUT. Afterwards the relevant emissions for the final measurement are identified.

Step 2: final measurement

For the relevant emissions determined in step 1, an additional measurement with the following settings will be performed. Intention of this step is to find the maximum emission level.

- Detector: Quasi-Peak (9 kHz – 150 kHz, Peak / Average 150 kHz- 30 MHz)
- Frequency range: 0.009 – 30 MHz
- Frequency steps: measurement at frequencies detected in step 1
- IF–Bandwidth: 0.2 - 10 kHz
- Measuring time / Frequency step: 1 s

2. Measurement above 30 MHz and up to 1 GHz



Test Setup; Spurious Emission Radiated (SAC), 30 MHz- 1GHz

Step 1: Preliminary scan

This is a preliminary test to identify the highest amplitudes relative to the limit.

Settings for step 1:

- Antenna distance: 3 m
- Detector: Peak-Maxhold / Quasipeak (FFT-based)
- Frequency range: 30 – 1000 MHz
- Frequency steps: 30 kHz
- IF–Bandwidth: 120 kHz
- Measuring time / Frequency step: 100 ms
- Turntable angle range: –180° to 90°

- Turntable step size: 90°
- Height variation range: 1 – 4 m
- Height variation step size: 1.5 m
- Polarisation: Horizontal + Vertical

Intention of this step is, to determine the radiated EMI-profile of the EUT. Afterwards the relevant emissions for the final measurement are identified.

Step 2: Adjustment measurement

In this step the accuracy of the turntable azimuth and antenna height will be improved. This is necessary to find out the maximum value of every frequency.

For each frequency, which was determined the turntable azimuth and antenna height will be adjusted. The turntable azimuth will slowly vary by 360°. During this action, the value of emission is continuously measured. The turntable azimuth at the highest emission will be recorded and adjusted. In this position, the antenna height will also slowly vary between 1 – 4 meter. During this action, the value of emission is also continuously measured. The antenna height of the highest emission will also be recorded and adjusted.

- Detector: Peak – Maxhold
- Measured frequencies: in step 1 determined frequencies
- IF – Bandwidth: 120 kHz
- Measuring time: 100 ms
- Turntable angle range: 360 °
- Height variation range:1 – 4 m
- Antenna Polarisation: max. value determined in step 1

Step 3: Final measurement with QP detector

With the settings determined in step 2, the final measurement will be performed:

EMI receiver settings for step 3:

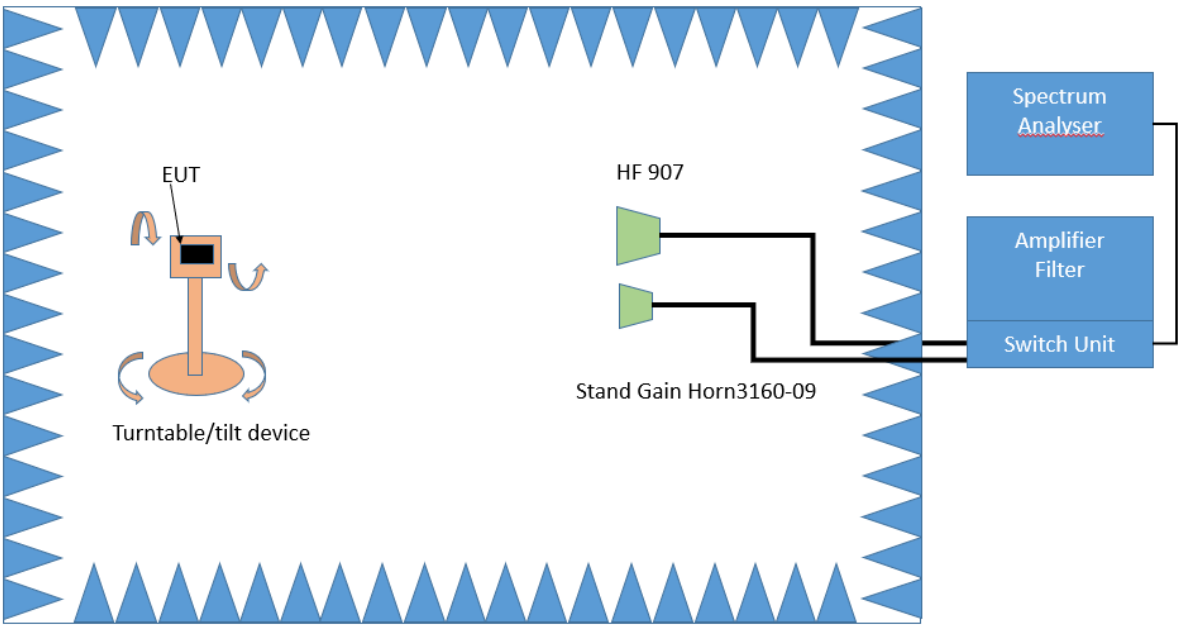
- Detector: Quasi-Peak (< 1 GHz)
- Measured frequencies: in step 1 determined frequencies
- IF – Bandwidth: 120 kHz
- Measuring time: 1 s

After the measurement a plot will be generated which contains a diagram with the results of the preliminary scan and a chart with the frequencies and values of the results of the final measurement.

Above 1 GHz:

The Equipment Under Test (EUT) was set up on a non-conductive support (tilt device) at 1.5 m height in the fully-anechoic chamber.
All steps were performed with one height (1.5 m) of the receiving antenna only.

3. Measurement above 1 GHz



Test Setup; Spurious Emission Radiated (FAC), 1 GHz-26.5 GHz

Step 1:
The EUT is turned during the preliminary measurement across the elevation axis, with a step size of 90 °.
The turn table step size (azimuth angle) for the preliminary measurement is 45 °.
Spectrum analyser settings:
- Detector: Peak, Average
- RBW = 1 MHz
- VBW = 3 MHz

Step 2:
The turn table azimuth will slowly vary by ± 22.5°.
The elevation angle will slowly vary by ± 45°
Spectrum analyser settings:
- Detector: Peak

Step 3:
Spectrum analyser settings for step 3:
- Detector: Peak / CISPR Average
- Measured frequencies: in step 1 determined frequencies
- RBW = 1 MHz
- VBW = 3 MHz
- Measuring time: 1 s

5.5.2 TEST REQUIREMENTS / LIMITS

FCC Part 15, Subpart C, §15.247 (d)
... In addition, radiated emissions which fall in the restricted bands, as defined in Section 15.205(a), must also comply with the radiated emission limits specified in Section 15.209(a) (see Section 15.205(c)).

FCC Part 15, Subpart C, §15.209, Radiated Emission Limits

Frequency in MHz	Limit (µV/m)	Measurement distance (m)	Limits (dBµV/m)
0.009 – 0.49	2400/F(kHz)@300m	3	(48.5 – 13.8)@300m
0.49 – 1.705	24000/F(kHz)@30m	3	(33.8 – 23.0)@30m
1.705 – 30	30@30m	3	29.5@30m

The measured values are corrected with an inverse linear distance extrapolation factor (40 dB/decade) according FCC 15.31 (2).

Frequency in MHz	Limit (µV/m)	Measurement distance (m)	Limits (dBµV/m)
30 – 88	100@3m	3	40.0@3m
88 – 216	150@3m	3	43.5@3m
216 – 960	200@3m	3	46.0@3m
960 - 26000	500@3m	3	54.0@3m
26000 - 40000	500@3m	1	54.0@3m

The measured values above 26 GHz are corrected with an inverse linear distance extrapolation factor (20 dB/decade).

§15.35(b) ..., there is also a limit on the radio frequency emissions, as measured using instrumentation with a peak detector function, corresponding to 20 dB above the maximum permitted average limit....

Used conversion factor: Limit (dBµV/m) = 20 log (Limit (µV/m)/1µV/m)

5.5.3 TEST PROTOCOL

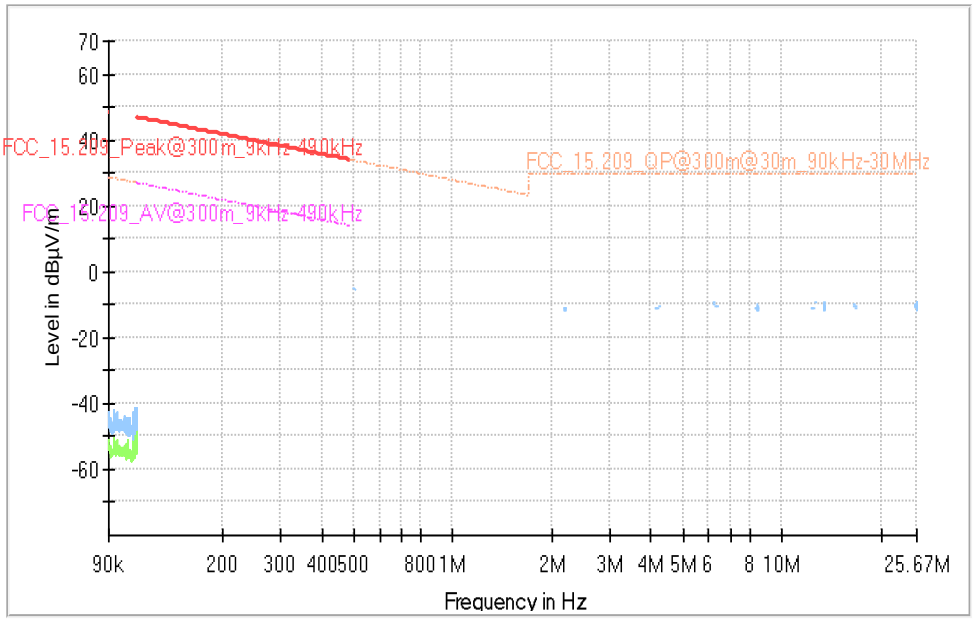
Ambient temperature: 25 °C
Air Pressure: 985 hPa
Humidity: 43 %
LoRaWAN; FHSS 125 kHz; 5470 bps
Applied duty cycle correction (AV): 0.1 dB

Ch. No	Ch. Center Freq. [MHz]	Spurious Freq. [MHz]	Spurious Level [dBµV/m]	Detec-tor	RBW [kHz]	Limit [dBµV/m]	Margin to Limit [dB]	Limit Type
0	902.3	5413.7	51.5	AV	1000	54.0	2.5	RB
0	902.3	5413.7	56.3	PEAK	1000	74.0	17.7	RB
0	902.3	8120.0	47.1	AV	1000	54.0	6.9	RB
0	902.3	8120.0	57.7	PEAK	1000	74.0	16.3	RB
0	902.3	9022.7	48.8	AV	1000	54.0	5.2	RB
0	902.3	9022.7	55.7	PEAK	1000	74.0	18.3	RB
31	908.5	5452.5	49.0	AV	1000	54.0	5.0	RB
31	908.5	5452.5	56.4	PEAK	1000	74.0	17.6	RB
31	908.5	7269.9	53.4	AV	1000	54.0	0.6	RB
31	908.5	7269.9	58.9	PEAK	1000	74.0	15.1	RB
31	908.5	8178.1	52.5	AV	1000	54.0	1.5	RB
31	908.5	8178.1	57.7	PEAK	1000	74.0	16.3	RB
31	908.5	9087.2	49.1	AV	1000	54.0	4.9	RB
31	908.5	9087.2	55.7	PEAK	1000	74.0	18.3	RB
63	914.9	2744.8	50.2	AV	1000	54.0	3.8	RB
63	914.9	2744.8	53.0	PEAK	1000	74.0	21.0	RB
63	914.9	3659.2	53.6	PEAK	1000	74.0	20.4	RB
63	914.9	3659.2	47.2	AV	1000	54.0	6.8	RB
63	914.9	7318.8	55.9	PEAK	1000	74.0	18.1	RB
63	914.9	7318.8	48.9	AV	1000	54.0	5.1	RB
63	914.9	8234.4	48.2	AV	1000	54.0	5.8	RB
63	914.9	8234.4	54.9	PEAK	1000	74.0	19.1	RB
63	914.9	9148.8	47.8	AV	1000	54.0	6.2	RB
63	914.9	9148.8	54.7	PEAK	1000	74.0	19.3	RB

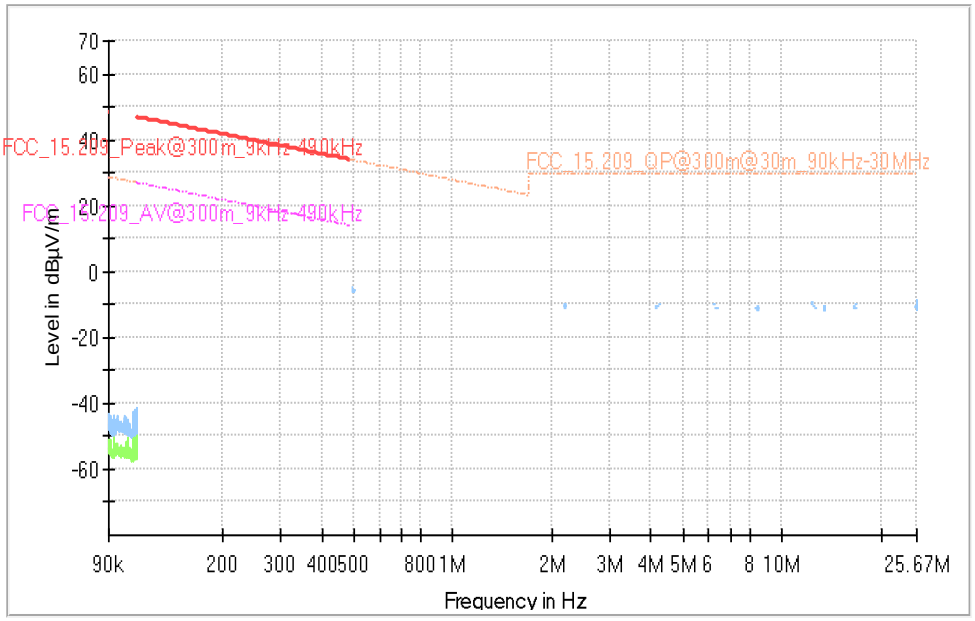
Remark: Please see next sub-clause for the measurement plot.

5.5.4 MEASUREMENT PLOT (EXAMPLE PLOT, SHOWING WORST CASE, IF APPLICABLE)

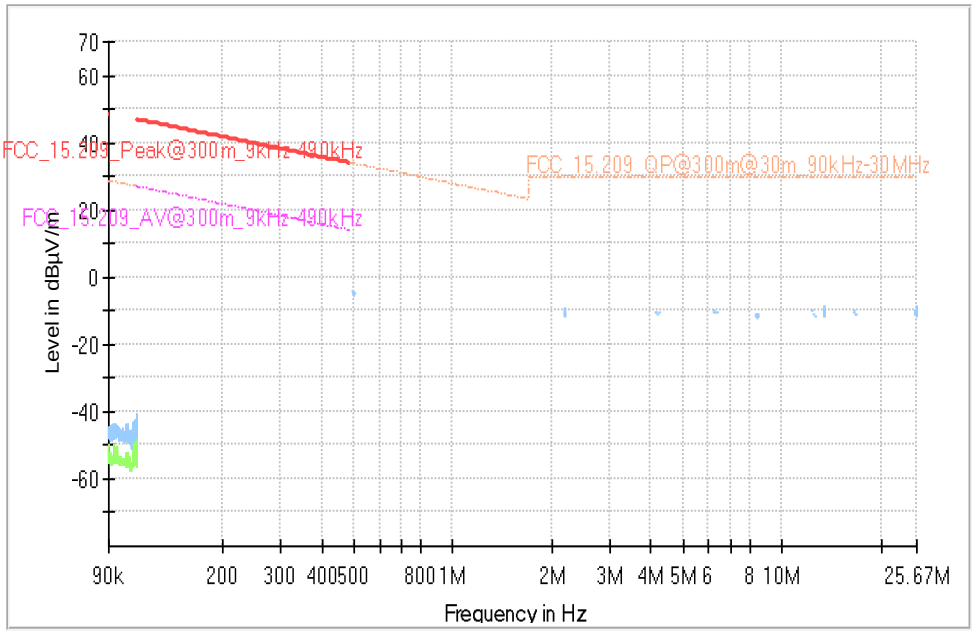
Radio Technology = LoRa (FHSS), Operating Frequency = low,
Measurements Rang = 9k – 30 MHz
(S01_AQ02)



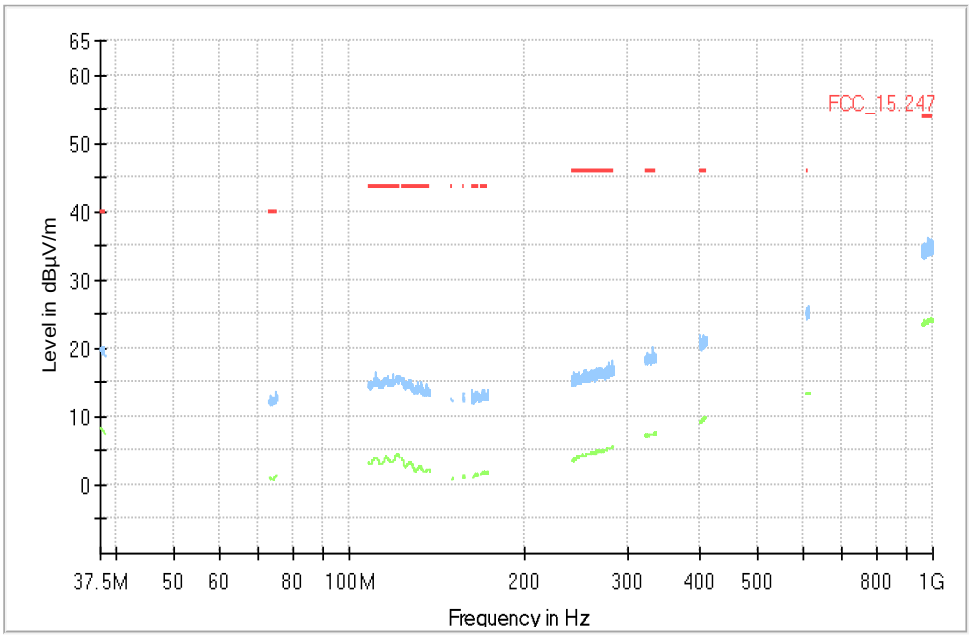
Radio Technology = LoRa (FHSS), Operating Frequency = mid,
Measurements Rang = 9k – 30 MHz
(S01_AQ02)



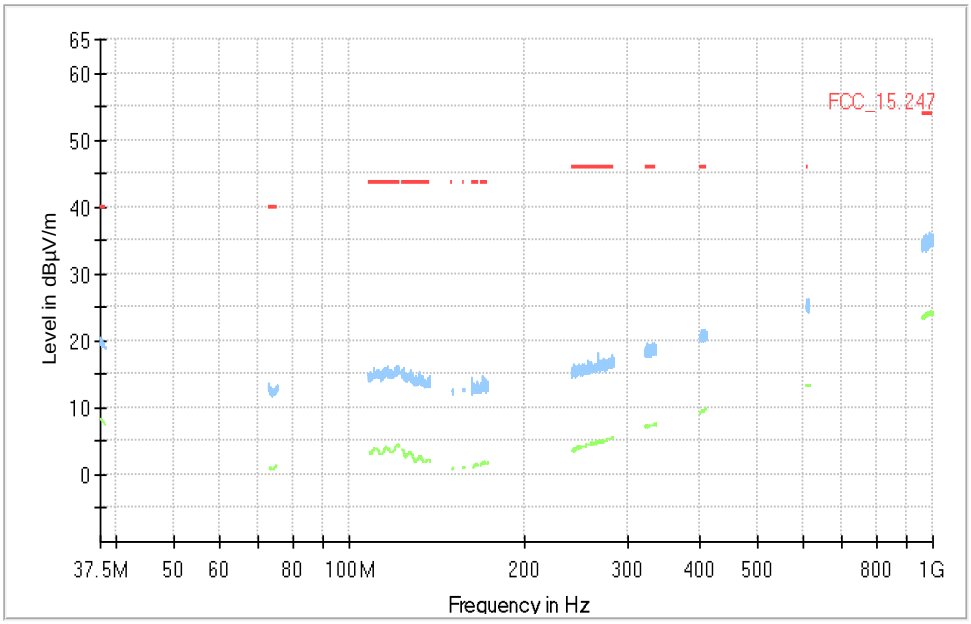
Radio Technology = LoRa (FHSS), Operating Frequency = high,
Measurements Rang = 9k – 30 MHz
(S01_AQ02)



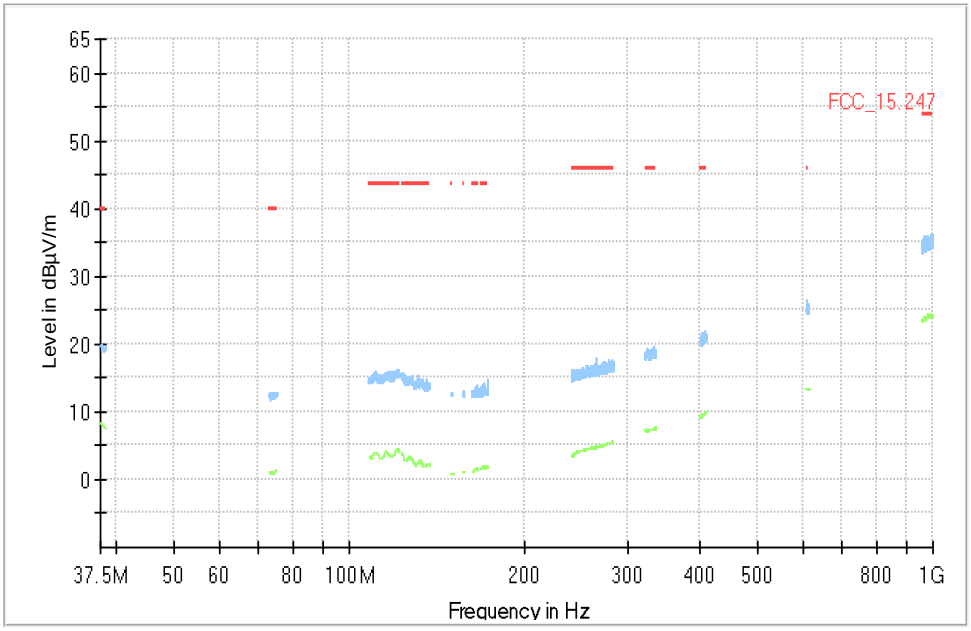
Radio Technology = LoRa (FHSS), Operating Frequency = low,
Measurements Rang = 30 MHz - 1 GHz
(S01_AQ02)



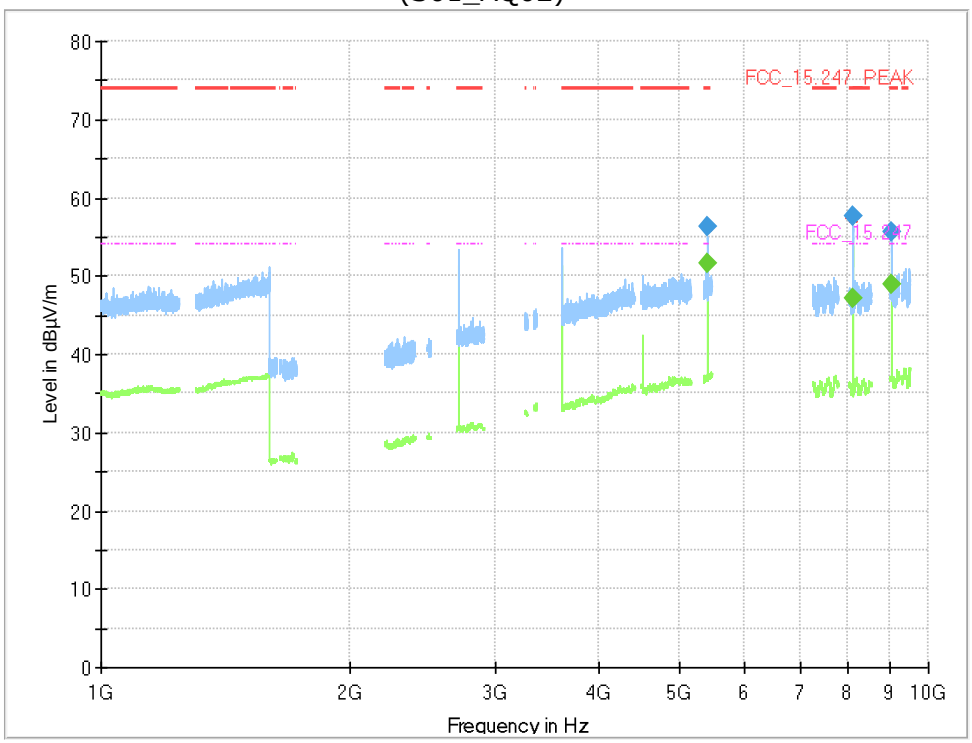
Radio Technology = LoRa (FHSS), Operating Frequency = mid,
Measurements Rang = 30 MHz - 1 GHz
(S01_AQ02)



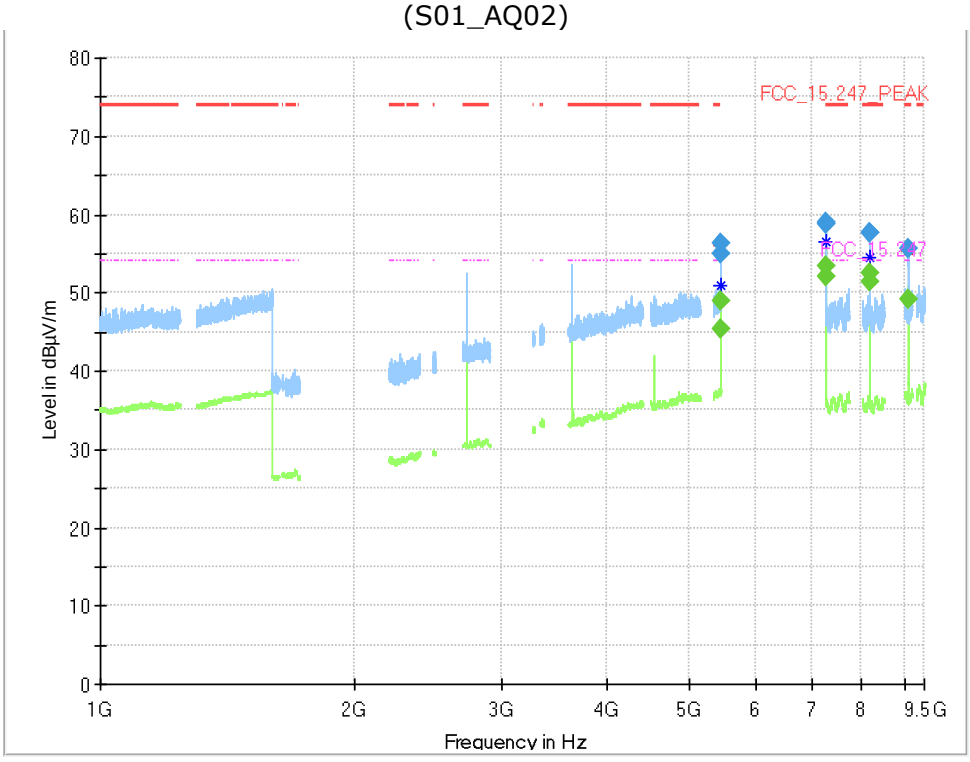
Radio Technology = LoRa (FHSS), Operating Frequency =high,
Measurements Rang = 30 MHz - 1 GHz
(S01_AQ02)



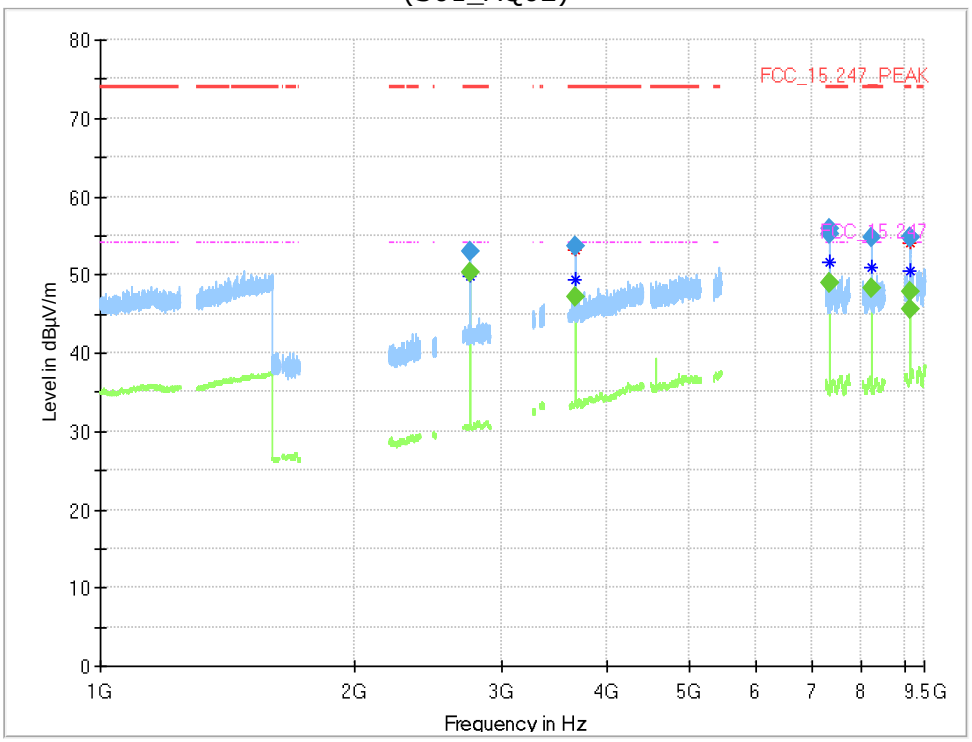
Radio Technology = LoRa (FHSS), Operating Frequency = low,
Measurements Rang = 1 - 10 GHz
(S01_AQ02)



Radio Technology = LoRa (FHSS), Operating Frequency = mid,
Measurements Rang = 1 - 10 GHz
(S01_AQ02)



Radio Technology = LoRa (FHSS), Operating Frequency = high,
Measurements Rang = 1 - 10 GHz
(S01_AQ02)



5.5.5 TEST EQUIPMENT USED

- Radiated Emissions SAC H-Field
- Radiated Emissions SAC up to 1 GHz
- Radiated Emissions FAR 2.4 GHz FCC

5.6 BAND EDGE COMPLIANCE CONDUCTED

Standard **FCC Part 15 Subpart C**

The test was performed according to:
ANSI C63.10, chapter 11.11

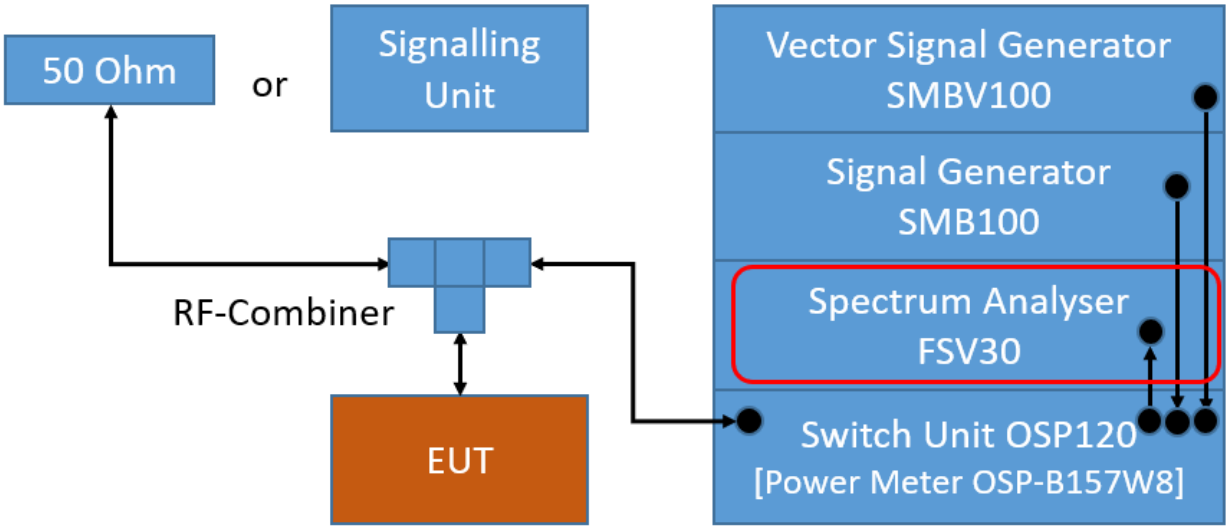
5.6.1 TEST DESCRIPTION

For the conducted measurement, the Equipment Under Test (EUT) is placed in a shielded room. The reference power was measured in the test case "Spurious RF Conducted Emissions".

The EUT was connected to the test system as described in the block diagram below. The complete attenuation of the measurement path is known and considered.

Analyser settings:

- Lower Band Edge:
  Measured range: 2310.0 MHz to 2483.5 MHz
  Upper Band Edge
  Measured range: 2400.0 MHz to 2500 MHz
- Detector: Peak
- Resolution Bandwidth (RBW): 100 kHz
- Video Bandwidth (VBW): 300 kHz
- Sweeptime: Auto
- Sweeps: Till stable (min. 300, max. 15000)
- Trace: Maxhold



5.6.2 TEST REQUIREMENTS / LIMITS

FCC Part 15.247 (d)
"In any 100 kHz bandwidth outside the frequency band in which the spread spectrum or digitally modulated intentional radiator is operating, the radio frequency power that is produced by the intentional radiator shall be at least 20 dB below that in the 100 kHz bandwidth within the band that contains the highest level of the desired power, based on either an RF conducted or a radiated measurement, provided the transmitter demonstrates compliance with the peak conducted power limits. ...
If the transmitter complies with the conducted power limits based on the use of RMS averaging over a time interval, as permitted under paragraph (b)(3) of this section, the attenuation required under this paragraph shall be 30 dB instead of 20 dB. Attenuation below the general limits specified in Section 15.209(a) is not required. In addition, radiated emissions which fall in the restricted bands, as defined in Section 15.205(a), must also comply with the radiated emission limits specified in Section 15.209(a) (see Section 15.205(c))."

For the conducted measurement the RF power at the band edge shall be "at least 20 dB below that in the 100 kHz bandwidth within the band that contains the highest level of the desired power..."

5.6.3 TEST PROTOCOL

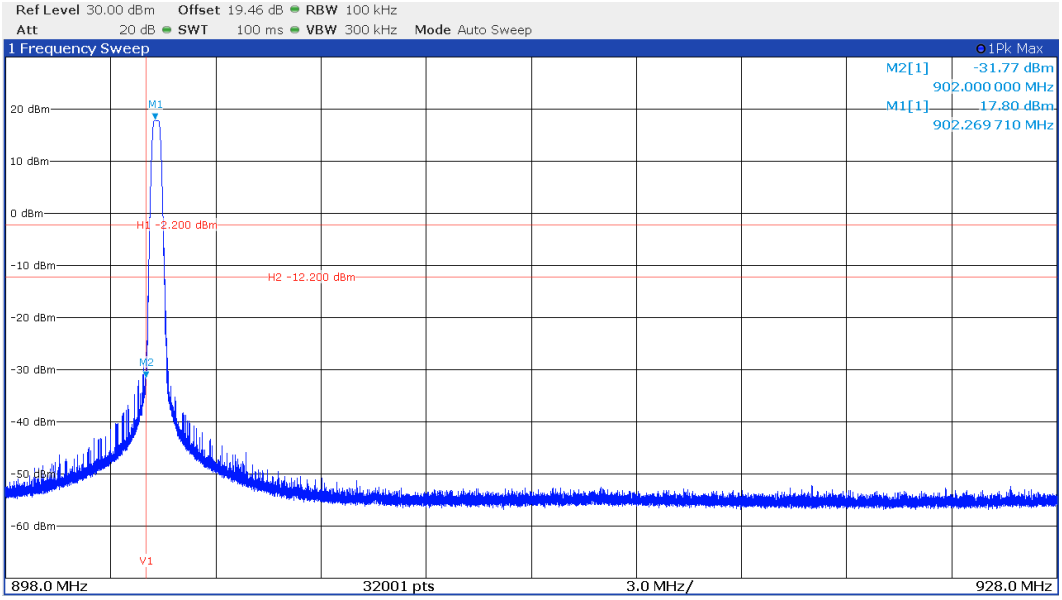
Ambient temperature: 23 °C
Air Pressure: 1001 hPa
Humidity: 38 %
LoRaWAN; FHSS 125 kHz; 5470 bps

Channel No.	Channel Center Frequency [MHz]	Band Edge Freq. [MHz]	Spurious Level [dBm]	Detector	RBW [kHz]	Ref. Level [dBm]	Limit [dBm]	Margin to Limit [dB]
0	902.3	902.0	-	PEAK	100	17.80	-2.20	>20 dB
63	914.9	928.0	-	PEAK	100	17.67	-2.33	>20 dB
Hopping	Hopping	902.0	-	PEAK	100	17.79	-2.21	>20 dB
Hopping	Hopping	928.0	-	PEAK	100	17.79	-2.21	>20 dB

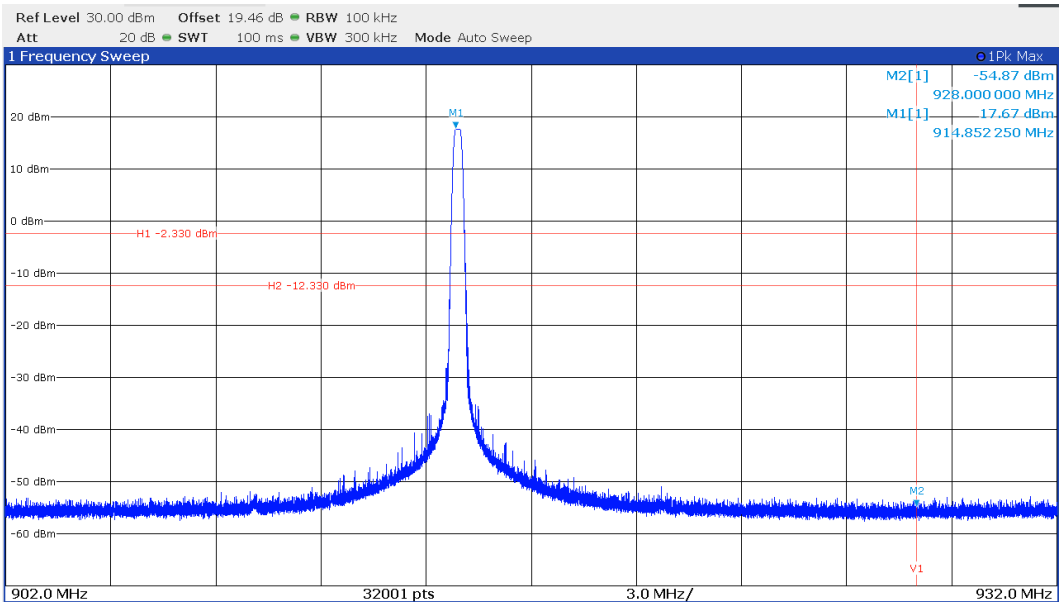
Remark: Please see next sub-clause for the measurement plot.

5.6.4 MEASUREMENT PLOT (EXAMPLE PLOT, SHOWING WORST CASE, IF APPLICABLE)

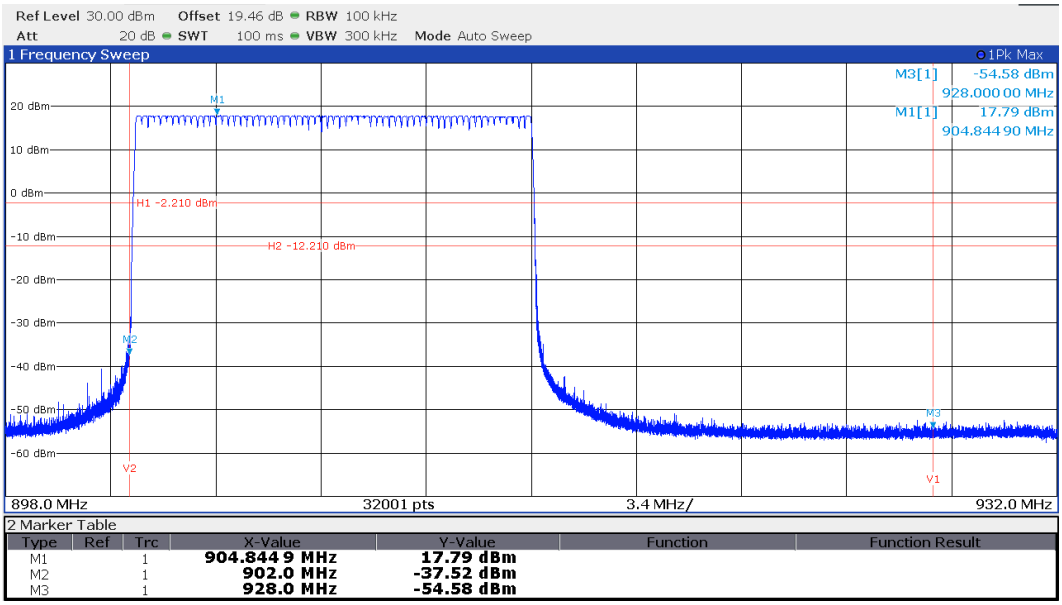
Radio Technology = LoRa (FHSS), Operating Frequency = low (S01_AO01)



Radio Technology = LoRa (FHSS), Operating Frequency = high (S01_AO01)



Radio Technology = LoRa (FHSS), Operating Frequency = hopping (S01_AO01)



5.6.5 TEST EQUIPMENT USED

- Radio Lab

5.7 CHANNEL SEPARATION

Standard **FCC Part 15 Subpart C**

The test was performed according to:
ANSI C63.10, chapter 7.8.2

5.7.1 TEST DESCRIPTION

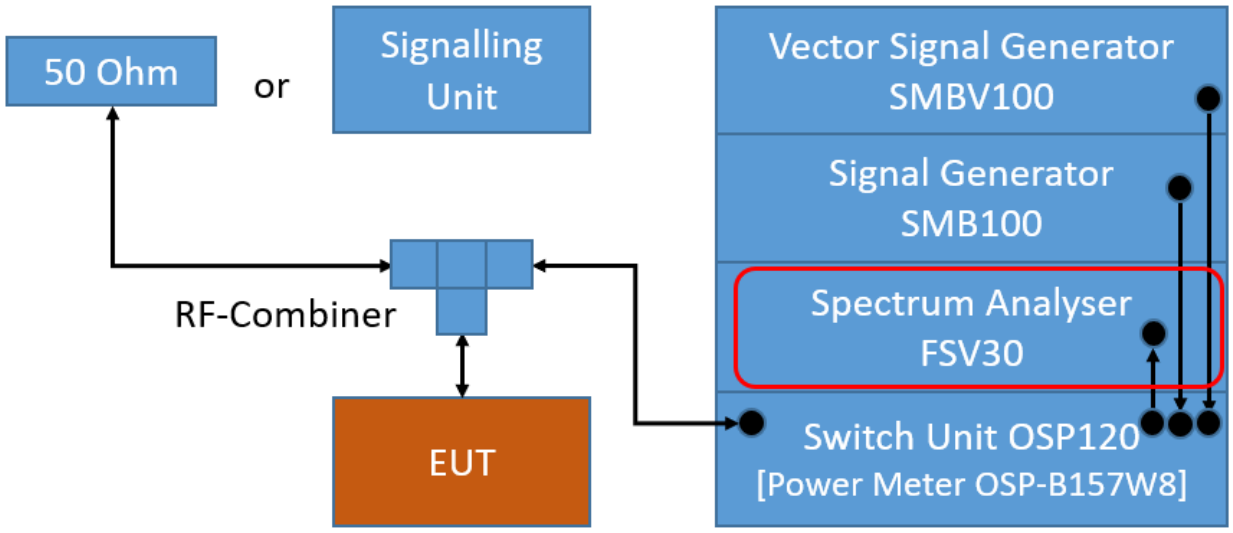
The Equipment Under Test (EUT) was set up to perform the channel separation measurement. The channel separation is independent of the modulation pattern.

The EUT was connected to the test system as described in the block diagram below. The complete attenuation of the measurement path is known and considered.

Analyser settings:

- Detector: Peak
- Trace: Maxhold
- Span: appr. 3 x OBW
- Centre Frequency: approximate mid of two channels
- Resolution Bandwidth (RBW): appr. 30 % of channel spacing
- Video Bandwidth (VBW): ≥ RBW
- Sweep Time: Auto
- Sweeps: Till stable (min. 2000, max. 30000)

The technology depending measurement parameters can be found in the measurement plot.



5.7.2 TEST REQUIREMENTS / LIMITS

FCC Part 15, Subpart C, §15.247 (a) (1)

Frequency hopping systems shall have hopping channel carrier frequencies separated by a minimum of 25 kHz or the 20 dB bandwidth of the hopping channel, whichever is greater. Alternatively, frequency hopping systems operating in the 2400–2483.5 MHz band may have hopping channel carrier frequencies that are separated by 25 kHz or two-thirds of the 20 dB bandwidth of the hopping channel, whichever is greater, provided the systems operate with an output power no greater than 125 mW. The system shall hop to channel frequencies that are selected at the system hopping rate from a pseudo randomly ordered list of hopping frequencies. Each frequency must be used equally on the average by each transmitter. The system receivers shall have input bandwidths that match the hopping channel bandwidths of their corresponding transmitters and shall shift frequencies in synchronization with the transmitted signals.

5.7.3 TEST PROTOCOL

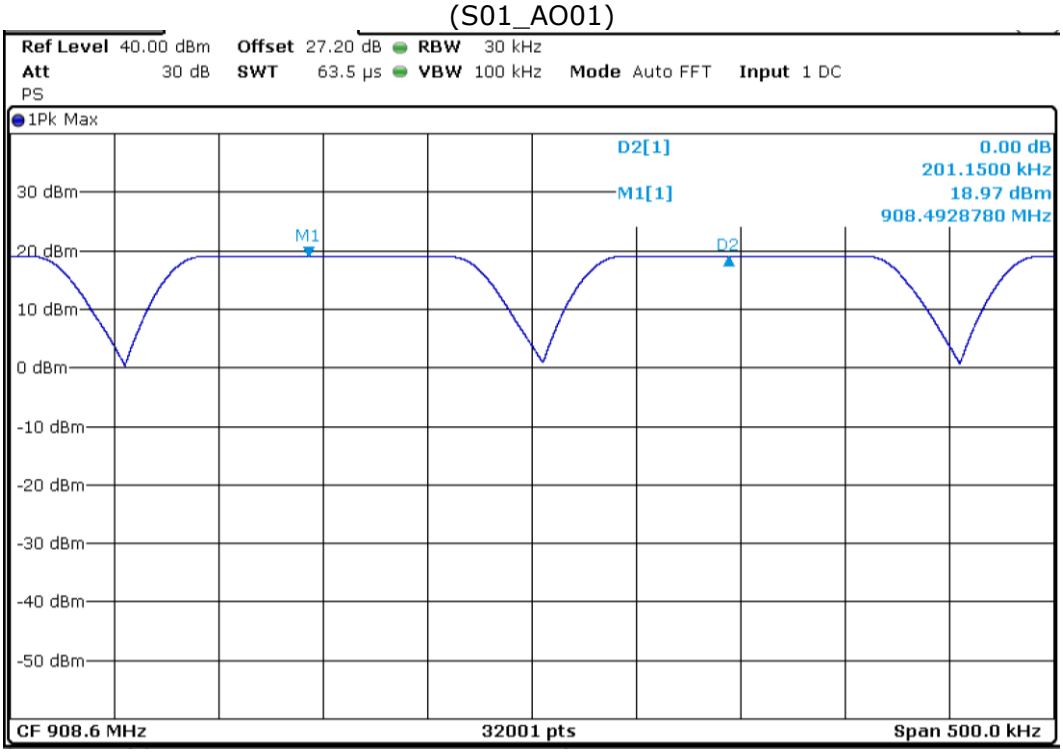
Ambient temperature:	22 °C
Air Pressure:	998 hPa
Humidity:	41 %

Radio Technology	Channel Separation [MHz]	Limit [MHz]	Margin to Limit [MHz]
LoRaWAN; FHSS 125 kHz; 5470 bps	0.201	0.137	0.064

Remark: Please see next sub-clause for the measurement plot.

5.7.4 MEASUREMENT PLOT (EXAMPLE PLOT, SHOWING WORST CASE, IF APPLICABLE)

Radio Technology = LoRa (FHSS), Operating Frequency = hopping (S01_AO01)



5.7.5 TEST EQUIPMENT USED

- Radio Lab

5.8 DWELL TIME

Standard **FCC Part 15 Subpart C**

The test was performed according to:
ANSI C63.10, chapter 7.8.4

5.8.1 TEST DESCRIPTION

The Equipment Under Test (EUT) was set up to perform the dwell time measurement.
The dwell time is independent of the modulation pattern.
The EUT is set to its maximum dwell time.

The dwell time is measured by spectrum analyser and power meter in parallel. The spectrum analyser video output is connected to the power meter allowing the power meter to measure transmission time only when the EUT is actively transmitting on the measured channel. The power meter is using a time resolution of 1 µs resulting in a more accurate measurement then possible using the spectrum analyser. In addition, measurement of burst length on more than one transmission is performed this way.
In addition to the calculated dwell time from single burst length, measured dwell time summing up all measured bursts lengths as measured by the power meter is given in the result table.

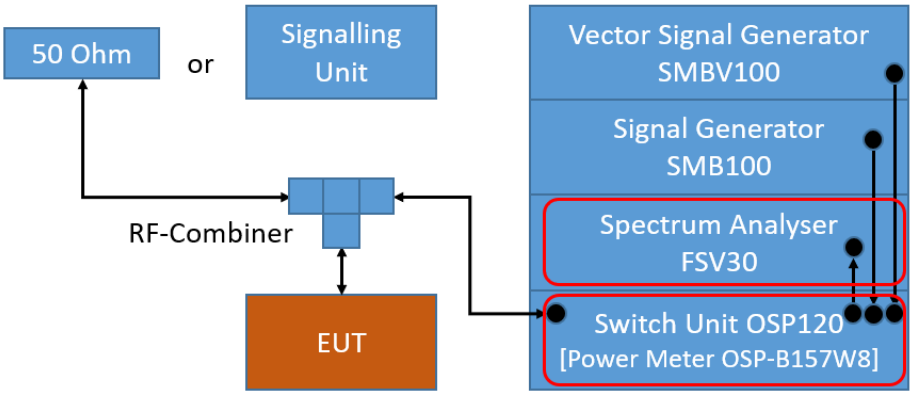
Calculation for Bluetooth Classic:
Maximum Duty Cycle is given for DH5 packets, resulting in 5 time slots transmission, 1 time slots reception. Each time slot lasts 625 µs.

Dwell time is calculated as: measured length of a single 5 time slot transmission multiplied by the number of bursts measured by the power meter.

Analyser Settings single 5 slot burst:
- Centre Frequency: mid channel frequency
- Span: Zero span
- Detector: Peak
- Resolution Bandwidth (RBW): ≤ Channel separation
- Trigger: Video
- Sweep Time: 3 ms
- Sweep Points: 30001
- Single Sweep

Analyser setting full sweep:
- Centre Frequency: mid channel frequency
- Span: Zero span
- Detector: Peak
- Resolution Bandwidth (RBW): ≤ Channel separation
- Trigger: External
- Sweep Time: 31.6 s
- Sweep Points: 30001
- Single Sweep

Time resolution of power meter: 1 µs



5.8.2 TEST REQUIREMENTS / LIMITS

For the band: 902 – 928 MHz
FCC Part 15, Subpart C, §15.247 (a) (1) (i)

If the 20 dB bandwidth of the hopping channel is less than 250 kHz the average time of occupancy on any frequency shall not be greater than 0.4 seconds within a 20 second period. If the 20 dB bandwidth of the hopping channel is 250 kHz or greater, the average time of occupancy on any frequency shall not be greater than 0.4 seconds within a 10 second period.

The average time of occupancy on any channel shall not be greater than 0.4 seconds within a period of 0.4 seconds multiplied by the number of hopping channels employed. Since the Bluetooth technology uses 79 channels this period is calculated to be 31.6 seconds.

FCC Part 15, Subpart C, §15.247 (f)

(f) For the purposes of this section, hybrid systems are those that employ a combination of both frequency hopping and digital modulation techniques. The frequency hopping operation of the hybrid system, with the direct sequence or digital modulation operation turned-off, shall have an average time of occupancy on any frequency not to exceed 0.4 seconds within a time period in seconds equal to the number of hopping frequencies employed multiplied by 0.4.

5.8.3 TEST PROTOCOL

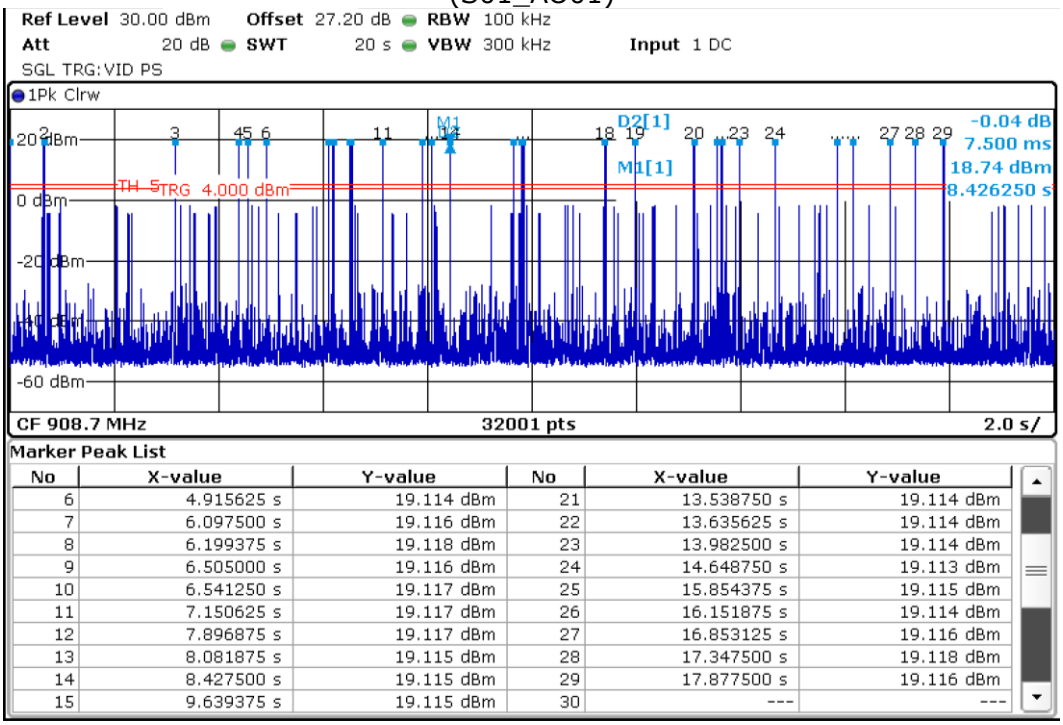
Ambient temperature: 22 °C
Air Pressure: 998 hPa
Humidity: 41 %

Radio Technology	Time Slot Length [ms]	Number of Bursts [Burst]	Dwell Time [ms]	Limit [s]	Margin to Limit [ms]
LoRaWAN; FHSS 125 kHz; 5470 bps	7.500	29	217.500	0.4	182.500

Remark: Please see next sub-clause for the measurement plot.

5.8.4 MEASUREMENT PLOT (EXAMPLE PLOT, SHOWING WORST CASE, IF APPLICABLE)

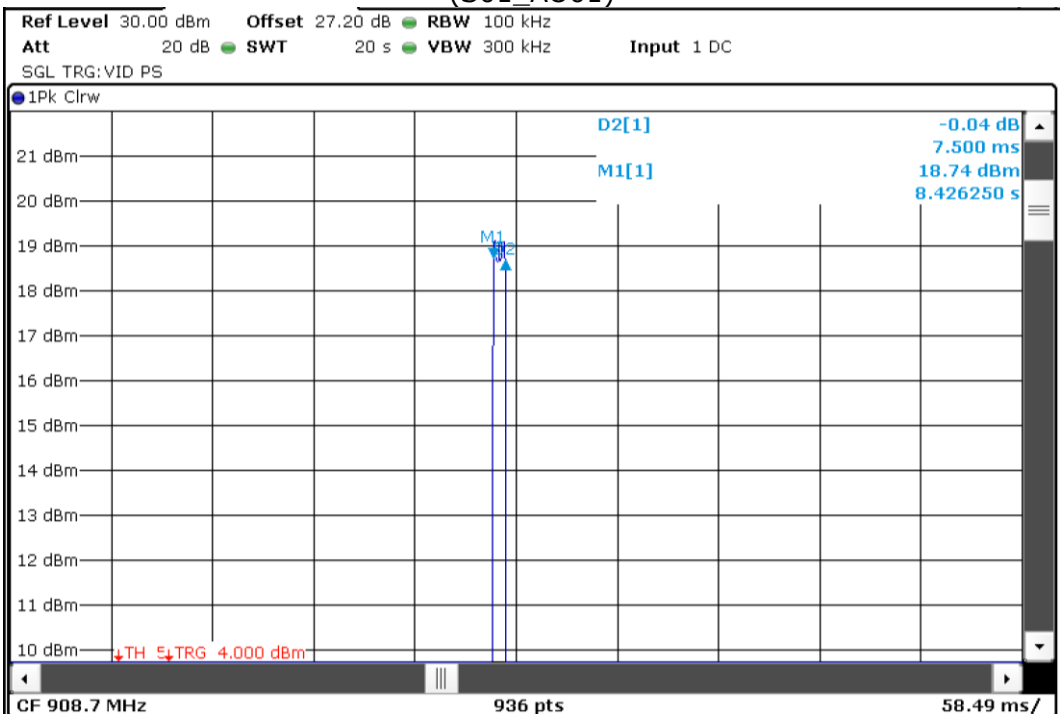
Radio Technology = LoRa (FHSS), Operating Frequency = hopping, Full spectrum (S01_AO01)



Marker Peak List

No	X-value	Y-value	No	X-value	Y-value
6	4.915625 s	19.114 dBm	21	13.538750 s	19.114 dBm
7	6.097500 s	19.116 dBm	22	13.635625 s	19.114 dBm
8	6.199375 s	19.118 dBm	23	13.982500 s	19.114 dBm
9	6.505000 s	19.116 dBm	24	14.648750 s	19.113 dBm
10	6.541250 s	19.117 dBm	25	15.854375 s	19.115 dBm
11	7.150625 s	19.117 dBm	26	16.151875 s	19.114 dBm
12	7.896875 s	19.117 dBm	27	16.853125 s	19.116 dBm
13	8.081875 s	19.115 dBm	28	17.347500 s	19.118 dBm
14	8.427500 s	19.115 dBm	29	17.877500 s	19.116 dBm
15	9.639375 s	19.115 dBm	30	---	---

Radio Technology = LoRa (FHSS), Operating Frequency = hopping, zoomed spectrum (S01_AO01)



5.8.5 TEST EQUIPMENT USED

- Radio Lab

5.9 NUMBER OF HOPPING FREQUENCIES

Standard **FCC Part 15 Subpart C**

The test was performed according to:
ANSI C63.10, chapter 7.8.3

5.9.1 TEST DESCRIPTION

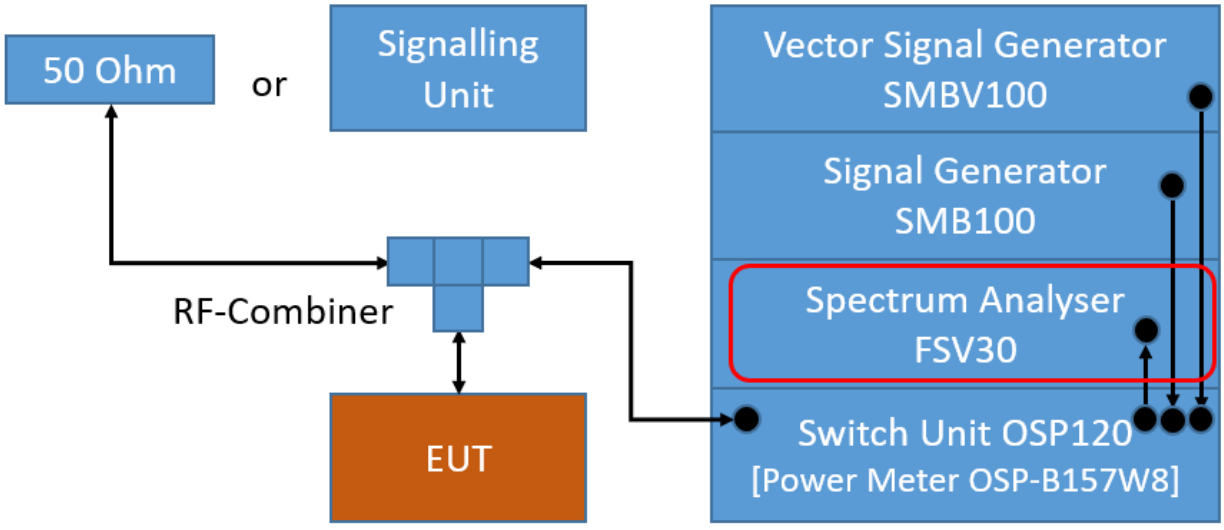
The Equipment Under Test (EUT) was set up to perform the number of hopping frequencies measurement. The number of hopping frequencies is independent of the modulation pattern.

The EUT was connected to the test system as described in the block diagram below. The complete attenuation of the measurement path is known and considered.

Analyser settings:

- Detector: Peak
- Trace: Maxhold
- Frequency span: Frequency band of operation
- Resolution Bandwidth (RBW): < 30 % of channel spacing or 20 dB bandwidth (whichever is smaller)
- Video Bandwidth (VBW): 3 x RBW
- Sweep Time: Auto
- Sweeps: Till stable (min. 300, max. 15000)

The technology depending measurement parameters can be found in the measurement plot.



5.9.2 TEST REQUIREMENTS / LIMITS

For the band: 902 – 928 MHz
FCC Part 15, Subpart C, §15.247 (a) (1) (i)

If the 20 dB bandwidth of the hopping channel is less than 250 kHz, the system shall use at least 50 hopping frequencies.
If the 20 dB bandwidth of the hopping channel is 250 kHz or greater, the system shall use at least 25 hopping frequencies

5.9.3 TEST PROTOCOL

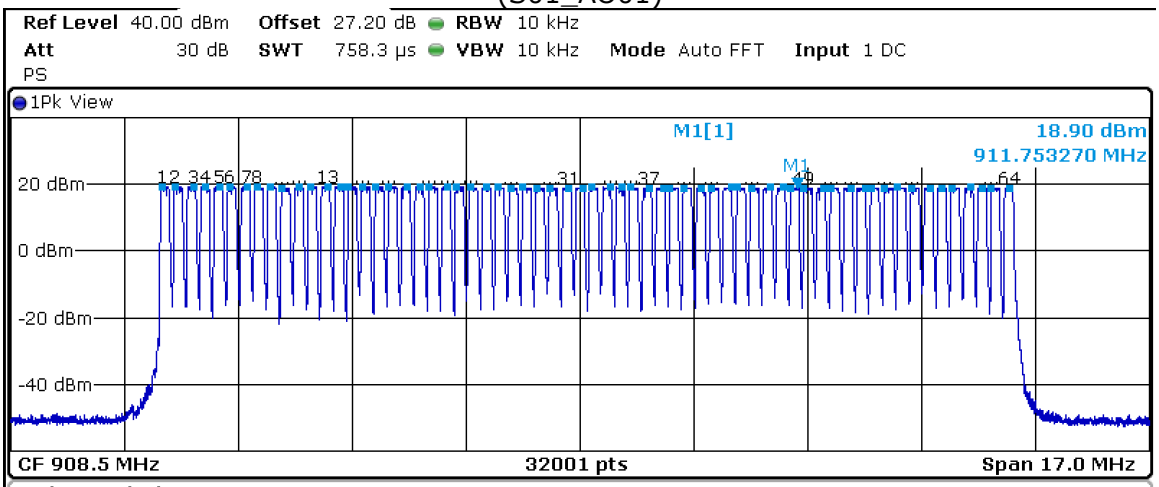
Ambient temperature:	22 °C
Air Pressure:	998 hPa
Humidity:	41 %

Radio Technology	Number of Hopping Frequencies	Limit	Margin to Limit
LoRaWAN; FHSS 125 kHz; 5470 bps	64	50	14

Remark: Please see next sub-clause for the measurement plot.

5.9.4 MEASUREMENT PLOT (EXAMPLE PLOT, SHOWING WORST CASE, IF APPLICABLE)

Radio Technology = LoRa (FHSS), Operating Frequency = hopping, (S01_AO01)



Marker Peak List

No	X-value	Y-value	No	X-value	Y-value
1	902.254820 MHz	19.023 dBm	33	908.674240 MHz	19.021 dBm
2	902.443410 MHz	19.024 dBm	34	908.951020 MHz	19.031 dBm
3	902.733460 MHz	19.094 dBm	35	909.119950 MHz	19.053 dBm
4	902.907170 MHz	19.035 dBm	36	909.243200 MHz	19.006 dBm
5	903.121260 MHz	19.060 dBm	37	909.540690 MHz	18.994 dBm
6	903.273730 MHz	19.031 dBm	38	909.752650 MHz	19.001 dBm
7	903.532970 MHz	19.023 dBm	39	909.844550 MHz	18.999 dBm
8	903.686490 MHz	19.006 dBm	40	910.042700 MHz	18.997 dBm
9	903.868180 MHz	19.049 dBm	41	910.297690 MHz	19.000 dBm
10	904.053050 MHz	19.003 dBm	42	910.452810 MHz	18.997 dBm

5.9.5 TEST EQUIPMENT USED

- Radio Lab

6 TEST EQUIPMENT

6.1 TEST EQUIPMENT HARDWARE

1 R&S TS8997
2.4 and 5 GHz Bands Conducted Test Lab

Ref.No.	Device Name	Description	Manufacturer	Serial Number	Last Calibration	Calibration Due
1.1	Opus10 TPR (8253.00)	T/P Logger 13	Lufft Mess- und Regeltechnik GmbH	13936	2021-10	2023-10
1.2	SMB100A	Signal Generator 9 kHz - 6 GHz	Rohde & Schwarz	107695	2021-06	2024-06
1.3	EX520	Digital Multimeter 12	Extech Instruments Corp	05157876	2022-06	2024-06
1.4	FSV30	Signal Analyzer 10 Hz - 30 GHz	Rohde & Schwarz	103005	2022-06	2024-06
1.5	NGSM 32/10	Power Supply	Rohde & Schwarz GmbH & Co. KG	3456	2022-01	2024-01
1.6	FSW43	Signal Analyser	Rohde & Schwarz GmbH & Co. KG	102013	2023-07	2025-07
1.7	SMBV100A	Vector Signal Generator 9 kHz - 6 GHz	Rohde & Schwarz	259291	2023-01	2026-01
1.8	OSP120	Contains Power Meter and Switching Unit OSP-B157W8 PLUS	Rohde & Schwarz	101158	2021-08	2024-08
1.9	CS-RUB6	Rubidium Frequency Standard	Rohde & Schwarz GmbH & Co. KG	100321	2022-10	2023-10

2 Radiated Emissions FAR 2.4 GHz FCC

Radiated emission tests for 2.4 GHz ISM devices in a fully anechoic room

Ref.No.	Device Name	Description	Manufacturer	Serial Number	Last Calibration	Calibration Due
2.1	Opus10 TPR (8253.00)	T/P Logger 13	Lufft Mess- und Regeltechnik GmbH	13936	2021-10	2023-10
2.2	Innco Systems CO3000	Controller for bore sight mast FAC		CO3000/1460/54740522/P		
2.3	AMF-7D00101800-30-10P-R	Broadband Amplifier 100 MHz - 18 GHz	Miteq		N/A	N/A
2.4	Anechoic Chamber 03	FAR, 8.80m x 4.60m x 4.05m (l x w x h)	Albatross Projects	P26971-647-001-PRB	N/A	N/A
2.5	Fluke 177	Digital Multimeter 03 (Multimeter)	Fluke Europe B.V.	86670383	2023-08	2025-08
2.6	FSW43	Spectrum Analyzer	Rohde & Schwarz GmbH & Co. KG	103779	2023-04	2025-04
2.7	WHKX 7.0/18G-8SS	High Pass Filter	Wainwright Instruments GmbH	09	N/A	N/A
2.8	MA3000/0800-XP-ET-compact	Bore Sight Antenna Mast			N/A	N/A
2.9	TT 1.5 WI	Turn Table	Maturo GmbH	-	N/A	N/A
2.10	5HC3500/18000-1.2-KK	High Pass Filter	Trilithic	200035008	N/A	N/A
2.11	Opus 20 THI (8120.00)	ThermoHygro Datalogger	Lufft Mess- und Regeltechnik GmbH	115.0318.0802.033	2023-08	2025-08
2.12	TD1.5-10kg	EUT Tilt Device (Rohacell)	Maturo GmbH	TD1.5-10kg/024/3790709	N/A	N/A
2.13	AFS42-00101800-25-S-42	Broadband Amplifier 25 MHz - 18 GHz	Miteq	2035324	N/A	N/A
2.14	HF 907	Double-ridged horn	Rohde & Schwarz	102444	2021-09	2024-09

3 Radiated Emissions SAC H-Field

Radiated emission tests in the H-Field in a semi anechoic room

Ref.No.	Device Name	Description	Manufacturer	Serial Number	Last Calibration	Calibration Due
3.1	N5000/NP	Filter for EUT, 2 Lines, 250 V, 16 A	ETS-LINDGREN	241515	N/A	N/A
3.2	ESW44	EMI Receiver / Spectrum Analyzer	Rohde & Schwarz GmbH & Co. KG	101603	2022-01	2024-01
3.3	Anechoic Chamber 01	SAC/FAR, 10.58 m x 6.38 m x 6.00 m	Frankonia	none	N/A	N/A
3.4	Fluke 177	Digital Multimeter 03 (Multimeter)	Fluke Europe B.V.	86670383	2023-08	2025-08
3.5	DS 420S	Turn Table 2 m diameter	HD GmbH	420/573/99	N/A	N/A
3.6	HFH2-Z2	Loop Antenna + 3 Axis Tripod	Rohde & Schwarz GmbH & Co. KG	829324/006	2021-01	2024-01
3.7	CS-RUB6	Rubidium Frequency Standard	Rohde & Schwarz GmbH & Co. KG	100321	2022-10	2023-10

4 Radiated Emissions SAC up to 1 GHz
Radiated emission tests up to 1 GHz in a semi anechoic room

Ref.No.	Device Name	Description	Manufacturer	Serial Number	Last Calibration	Calibration Due
4.1	N5000/NP	Filter for EUT, 2 Lines, 250 V, 16 A	ETS-LINDGREN	241515	N/A	N/A
4.2	Opus10 TPR (8253.00)	T/P Logger 13	Lufft Mess- und Regeltechnik GmbH	13936	2021-10	2023-10
4.3	ESW44	EMI Receiver / Spectrum Analyzer	Rohde & Schwarz GmbH & Co. KG	101603	2022-01	2024-01
4.4	Anechoic Chamber 01	SAC/FAR, 10.58 m x 6.38 m x 6.00 m	Frankonia	none	N/A	N/A
4.5	HL 562 ULTRALOG	Biconical-log-per antenna (30 MHz - 3 GHz) with HL 562E biconicals	Rohde & Schwarz GmbH & Co. KG	830547/003	2021-09	2024-09
4.6	DS 420S	Turn Table 2 m diameter	HD GmbH	420/573/99	N/A	N/A
4.7	CS-RUB6	Rubidium Frequency Standard	Rohde & Schwarz GmbH & Co. KG	100321	2022-10	2023-10
4.8	AM 4.0	Antenna Mast 4 m	Maturo GmbH	AM4.0/180/1192 0513	N/A	N/A

5 Radio Lab
Conducted Radio Test Lab

Ref.No.	Device Name	Description	Manufacturer	Serial Number	Last Calibration	Calibration Due
5.1	1575	Broadband Resistive Power Divider DC to 40 GHz	API Weinschel, Inc.	4070	N/A	N/A
5.2	FSV30	Signal Analyzer 10 Hz - 30 GHz	Rohde & Schwarz	103005	2022-06	2024-06
5.3	SMP03	Signal Generator 2 GHz - 27 GHz	Rohde & Schwarz	833680/003	N/A	N/A
5.4	SMB100A	Signal Generator 100 kHz - 40 GHz	Rohde & Schwarz Vertriebs-GmbH	181486	2023-01	2026-01
5.5	A8455-4	4 Way Power Divider (SMA)		-	N/A	N/A

The calibration interval is the time interval between “Last Calibration” and “Calibration Due”

6.2 TEST EQUIPMENT SOFTWARE

Semi-Anechoic Chamber:	
Software	Version
EMC32 Measurement Software	10.60.10
INNCO Mast Controller	1.02.62
MATURO Mast Controller	12.19
MATURO Turn-Table Controller	30.10
Fully-Anechoic Chamber:	
Software	Version
EMC32 Measurement Software	10.60.10
MATURO Turn-Unit Controller	11.10
MATURO Mast Controller	12.10
MATURO Turntable Controller	12.11
INNCO Mast Controller	1.02.62
TS 8997	
WMC32 Measurement Software	11.40.00

7 ANTENNA FACTORS, CABLE LOSS AND SAMPLE CALCULATIONS

This chapter contains the antenna factors with their corresponding path loss of the used measurement path for all antennas as well as the insertion loss of the LISN.

7.1 ANTENNA R&S HFH2-Z2 (9 KHZ – 30 MHZ)

Frequency	AF HFH-Z2)	Corr.	cable loss 1 (inside chamber)	cable loss 2 (outside chamber)	cable loss 3 (switch unit)	cable loss 4 (to receiver)	distance corr. (-40 dB/ decade)	d_{Limit} (meas. distance (limit)	d_{used} (meas. distance (used)
MHz	dB (1/m)	dB	dB	dB	dB	dB	dB	m	m
0.009	20.50	-79.6	0.1	0.1	0.1	0.1	-80	300	3
0.01	20.45	-79.6	0.1	0.1	0.1	0.1	-80	300	3
0.015	20.37	-79.6	0.1	0.1	0.1	0.1	-80	300	3
0.02	20.36	-79.6	0.1	0.1	0.1	0.1	-80	300	3
0.025	20.38	-79.6	0.1	0.1	0.1	0.1	-80	300	3
0.03	20.32	-79.6	0.1	0.1	0.1	0.1	-80	300	3
0.05	20.35	-79.6	0.1	0.1	0.1	0.1	-80	300	3
0.08	20.30	-79.6	0.1	0.1	0.1	0.1	-80	300	3
0.1	20.20	-79.6	0.1	0.1	0.1	0.1	-80	300	3
0.2	20.17	-79.6	0.1	0.1	0.1	0.1	-80	300	3
0.3	20.14	-79.6	0.1	0.1	0.1	0.1	-80	300	3
0.49	20.12	-79.6	0.1	0.1	0.1	0.1	-80	300	3
0.490001	20.12	-39.6	0.1	0.1	0.1	0.1	-40	30	3
0.5	20.11	-39.6	0.1	0.1	0.1	0.1	-40	30	3
0.8	20.10	-39.6	0.1	0.1	0.1	0.1	-40	30	3
1	20.09	-39.6	0.1	0.1	0.1	0.1	-40	30	3
2	20.08	-39.6	0.1	0.1	0.1	0.1	-40	30	3
3	20.06	-39.6	0.1	0.1	0.1	0.1	-40	30	3
4	20.05	-39.5	0.2	0.1	0.1	0.1	-40	30	3
5	20.05	-39.5	0.2	0.1	0.1	0.1	-40	30	3
6	20.02	-39.5	0.2	0.1	0.1	0.1	-40	30	3
8	19.95	-39.5	0.2	0.1	0.1	0.1	-40	30	3
10	19.83	-39.4	0.2	0.1	0.2	0.1	-40	30	3
12	19.71	-39.4	0.2	0.1	0.2	0.1	-40	30	3
14	19.54	-39.4	0.2	0.1	0.2	0.1	-40	30	3
16	19.53	-39.3	0.3	0.1	0.2	0.1	-40	30	3
18	19.50	-39.3	0.3	0.1	0.2	0.1	-40	30	3
20	19.57	-39.3	0.3	0.1	0.2	0.1	-40	30	3
22	19.61	-39.3	0.3	0.1	0.2	0.1	-40	30	3
24	19.61	-39.3	0.3	0.1	0.2	0.1	-40	30	3
26	19.54	-39.3	0.3	0.1	0.2	0.1	-40	30	3
28	19.46	-39.2	0.3	0.1	0.3	0.1	-40	30	3
30	19.73	-39.1	0.4	0.1	0.3	0.1	-40	30	3

Sample calculation

E (dB µV/m) = U (dB µV) + AF (dB 1/m) + Corr. (dB)
U = Receiver reading
AF = Antenna factor
Corr. = sum of single correction factors of used cables, switch unit, distance correction, amplifier (if applicable)
distance correction = -40 * LOG (d_{Limit}/ d_{used})
Linear interpolation will be used for frequencies in between the values in the table.
Table shows an extract of values

7.2 ANTENNA R&S HL562 (30 MHZ – 1 GHZ)

(d_{Limit} = 3 m)

Frequency	AF R&S HL562	Corr.	cable loss 1 (inside chamber)	cable loss 2 (outside chamber)	cable loss 3 (switch unit)	cable loss 4 (to receiver)	distance corr. (-20 dB/ decade)	d_{Limit} (meas. distance (limit)	d_{used} (meas. distance (used)
MHz	dB (1/m)	dB	dB	dB	dB	dB	dB	m	m
30	18.6	0.6	0.29	0.04	0.23	0.02	0.0	3	3
50	6.0	0.9	0.39	0.09	0.32	0.08	0.0	3	3
100	9.7	1.2	0.56	0.14	0.47	0.08	0.0	3	3
150	7.9	1.6	0.73	0.20	0.59	0.12	0.0	3	3
200	7.6	1.9	0.84	0.21	0.70	0.11	0.0	3	3
250	9.5	2.1	0.98	0.24	0.80	0.13	0.0	3	3
300	11.0	2.3	1.04	0.26	0.89	0.15	0.0	3	3
350	12.4	2.6	1.18	0.31	0.96	0.13	0.0	3	3
400	13.6	2.9	1.28	0.35	1.03	0.19	0.0	3	3
450	14.7	3.1	1.39	0.38	1.11	0.22	0.0	3	3
500	15.6	3.2	1.44	0.39	1.20	0.19	0.0	3	3
550	16.3	3.5	1.55	0.46	1.24	0.23	0.0	3	3
600	17.2	3.5	1.59	0.43	1.29	0.23	0.0	3	3
650	18.1	3.6	1.67	0.34	1.35	0.22	0.0	3	3
700	18.5	3.6	1.67	0.42	1.41	0.15	0.0	3	3
750	19.1	4.1	1.87	0.54	1.46	0.25	0.0	3	3
800	19.6	4.1	1.90	0.46	1.51	0.25	0.0	3	3
850	20.1	4.4	1.99	0.60	1.56	0.27	0.0	3	3
900	20.8	4.7	2.14	0.60	1.63	0.29	0.0	3	3
950	21.1	4.8	2.22	0.60	1.66	0.33	0.0	3	3
1000	21.6	4.9	2.23	0.61	1.71	0.30	0.0	3	3

(d_{Limit} = 10 m)

30	18.6	-9.9	0.29	0.04	0.23	0.02	-10.5	10	3
50	6.0	-9.6	0.39	0.09	0.32	0.08	-10.5	10	3
100	9.7	-9.2	0.56	0.14	0.47	0.08	-10.5	10	3
150	7.9	-8.8	0.73	0.20	0.59	0.12	-10.5	10	3
200	7.6	-8.6	0.84	0.21	0.70	0.11	-10.5	10	3
250	9.5	-8.3	0.98	0.24	0.80	0.13	-10.5	10	3
300	11.0	-8.1	1.04	0.26	0.89	0.15	-10.5	10	3
350	12.4	-7.9	1.18	0.31	0.96	0.13	-10.5	10	3
400	13.6	-7.6	1.28	0.35	1.03	0.19	-10.5	10	3
450	14.7	-7.4	1.39	0.38	1.11	0.22	-10.5	10	3
500	15.6	-7.2	1.44	0.39	1.20	0.19	-10.5	10	3
550	16.3	-7.0	1.55	0.46	1.24	0.23	-10.5	10	3
600	17.2	-6.9	1.59	0.43	1.29	0.23	-10.5	10	3
650	18.1	-6.9	1.67	0.34	1.35	0.22	-10.5	10	3
700	18.5	-6.8	1.67	0.42	1.41	0.15	-10.5	10	3
750	19.1	-6.3	1.87	0.54	1.46	0.25	-10.5	10	3
800	19.6	-6.3	1.90	0.46	1.51	0.25	-10.5	10	3
850	20.1	-6.0	1.99	0.60	1.56	0.27	-10.5	10	3
900	20.8	-5.8	2.14	0.60	1.63	0.29	-10.5	10	3
950	21.1	-5.6	2.22	0.60	1.66	0.33	-10.5	10	3
1000	21.6	-5.6	2.23	0.61	1.71	0.30	-10.5	10	3

Sample calculation

E (dB µV/m) = U (dB µV) + AF (dB 1/m) + Corr. (dB)
U = Receiver reading
AF = Antenna factor
Corr. = sum of single correction factors of used cables, switch unit, distance correction, amplifier (if applicable)
distance correction = -20 * LOG (d_{Limit}/ d_{used})
Linear interpolation will be used for frequencies in between the values in the table.
Tables show an extract of values.

7.3 ANTENNA R&S HF907 (1 GHZ – 18 GHZ)

Frequency	AF R&S HF907	Corr.	cable loss 1 (relay + cable inside chamber)	cable loss 2 (outside chamber)	cable loss 3 (switch unit, atten-uator & pre-amp)	cable loss 4 (to receiver)		
MHz	dB (1/m)	dB	dB	dB	dB	dB		
1000	24.4	-19.4	0.99	0.31	-21.51	0.79		
2000	28.5	-17.4	1.44	0.44	-20.63	1.38		
3000	31.0	-16.1	1.87	0.53	-19.85	1.33		
4000	33.1	-14.7	2.41	0.67	-19.13	1.31		
5000	34.4	-13.7	2.78	0.86	-18.71	1.40		
6000	34.7	-12.7	2.74	0.90	-17.83	1.47		
7000	35.6	-11.0	2.82	0.86	-16.19	1.46		

Frequency	AF R&S HF907	Corr.	cable loss 1 (relay inside chamber)	cable loss 2 (inside chamber)	cable loss 3 (outside chamber)	cable loss 4 (switch unit, atten-uator & pre-amp)	cable loss 5 (to receiver)	used for FCC 15.247
MHz	dB (1/m)	dB	dB	dB	dB	dB	dB	
3000	31.0	-23.4	0.47	1.87	0.53	-27.58	1.33	
4000	33.1	-23.3	0.56	2.41	0.67	-28.23	1.31	
5000	34.4	-21.7	0.61	2.78	0.86	-27.35	1.40	
6000	34.7	-21.2	0.58	2.74	0.90	-26.89	1.47	
7000	35.6	-19.8	0.66	2.82	0.86	-25.58	1.46	

Frequency	AF R&S HF907	Corr.	cable loss 1 (relay inside chamber)	cable loss 2 (High Pass)	cable loss 3 (pre-amp)	cable loss 4 (inside chamber)	cable loss 5 (outside chamber)	cable loss 6 (to receiver)
MHz	dB (1/m)	dB	dB	dB	dB	dB	dB	dB
7000	35.6	-57.3	0.56	1.28	-62.72	2.66	0.94	1.46
8000	36.3	-56.3	0.69	0.71	-61.49	2.84	1.00	1.53
9000	37.1	-55.3	0.68	0.65	-60.80	3.06	1.09	1.60
10000	37.5	-56.2	0.70	0.54	-61.91	3.28	1.20	1.67
11000	37.5	-55.3	0.80	0.61	-61.40	3.43	1.27	1.70
12000	37.6	-53.7	0.84	0.42	-59.70	3.53	1.26	1.73
13000	38.2	-53.5	0.83	0.44	-59.81	3.75	1.32	1.83
14000	39.9	-56.3	0.91	0.53	-63.03	3.91	1.40	1.77
15000	40.9	-54.1	0.98	0.54	-61.05	4.02	1.44	1.83
16000	41.3	-54.1	1.23	0.49	-61.51	4.17	1.51	1.85
17000	42.8	-54.4	1.36	0.76	-62.36	4.34	1.53	2.00
18000	44.2	-54.7	1.70	0.53	-62.88	4.41	1.55	1.91

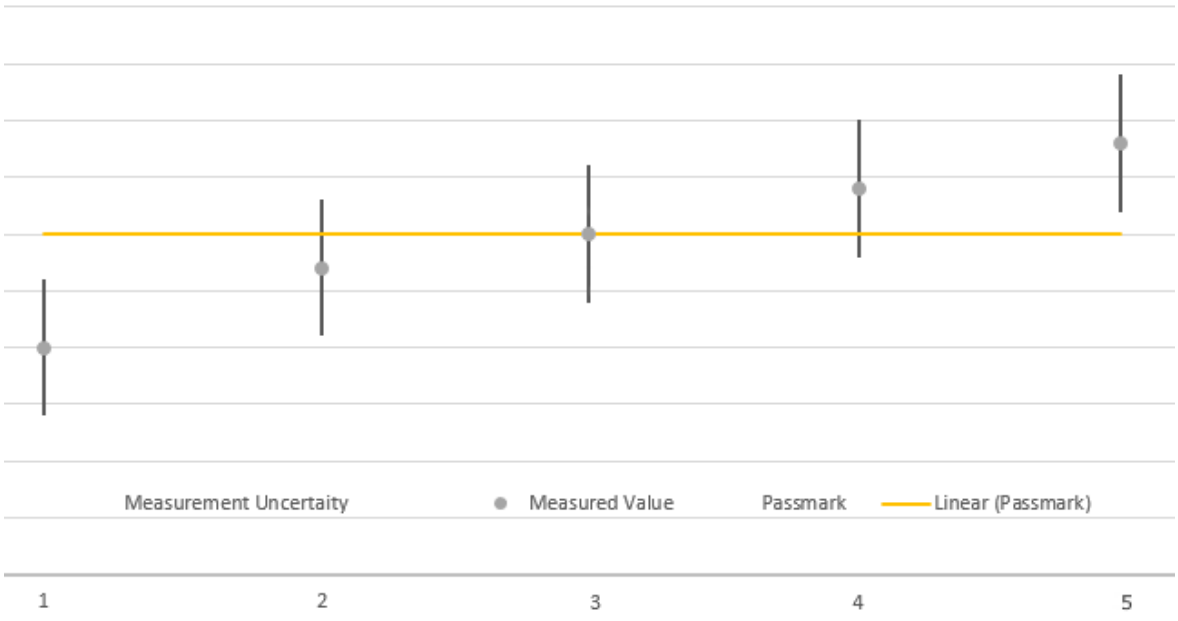
Sample calculation

E (dB µV/m) = U (dB µV) + AF (dB 1/m) + Corr. (dB)
U = Receiver reading
AF = Antenna factor
Corr. = sum of single correction factors of used cables, switch unit, distance correction, amplifier (if applicable)
Linear interpolation will be used for frequencies in between the values in the table.
Tables show an extract of values.

8 MEASUREMENT UNCERTAINTIES

Test Case	Parameter	Uncertainty
AC Power Line	Power	± 3.4 dB
Field Strength of spurious radiation	Power	± 5.5 dB
6 dB / 26 dB / 99% Bandwidth	Power Frequency	± 2.9 dB ± 11.2 kHz
Conducted Output Power	Power	± 2.2 dB
Band Edge Compliance	Power Frequency	± 2.2 dB ± 11.2 kHz
Frequency Stability	Frequency	± 25 Hz
Power Spectral Density	Power	± 2.2 dB

The measurement uncertainties for all parameters are calculated with an expansion factor (coverage factor) k = 1.96. This means, that the true value is in the corresponding interval with a probability of 95 %.



The verdicts in this test report are given according the above diagram:

Case	Measured Value	Uncertainty Range	Verdict
1	below pass mark	below pass mark	Passed
2	below pass mark	within pass mark	Passed
3	on pass mark	within pass mark	Passed
4	above pass mark	within pass mark	Failed
5	above pass mark	above pass mark	Failed

That means, the laboratory applies, as decision rule (see ISO/IEC 17025:2017), the so-called shared risk principle.

9 PHOTO REPORT

Please see separate photo report.

**********END OF TEST REPORT**********