Choose Scandinavian trust

RADIO TEST REPORT – REP044593

Type of assessment:

Final product testing

Applicant:

EchoStar Mobile Limited (EML)
3 Dublin Landings, North Wall Quay,
Dublin 1, D01 C4E0 - Ireland

Product:

OEM module sensor

Model:

EM2050

FCC ID:

2A8O9-EM2050

IC Registration number:

29249-EM2050

Specifications:

- FCC 47 CFR Part 15 Subpart C, §15.247
- RSS-247, Issue 3, August 2023, Section 5
- RSS-Gen, Issue 5, April 2018, Amd 1 (March 2019), Amd 2 (Feb 2021)

Date of issue: June 17, 2024

P. Barbieri	
Tested by	Signature
D. Guarnone	
Reviewed by	Signature

Lab locations

Company name	Nemko Spa
Address	Via del Carroccio, 4
City	Biassono
Province	MB
Postal code	20853
Country	Italy
Telephone	+39 039 220 12 01
Facsimile	+39 039 220 12 21
Website	www.nemko.com
ISED number	9109A
FCC registration number	682159

Limits of responsibility

Note that the results contained in this report relate only to the items tested and were obtained in the period between the date of initial receipt of samples and the date of issue of the report. This test report has been completed in accordance with the requirements of ISO/IEC 17025. All results contain in this report are within Nemko Spa ISO/IEC 17025 accreditation.

Copyright notification

Table of Contents

Section 1 Report summary

1.1 Test specifications

FCC 47 CFR Part 15, Subpart C, Clause 15.247	Operation in the 902–928 MHz, 2400–2483.5 MHz, and 5725–585 MHz
RSS-247, Issue 3, August 2023, Section 5	Digital Transmission Systems (DTSs), Frequency Hopping Systems (FHSs) and Licence-Exempt Local Area Network (LE-LAN) Devices
RSS-Gen, Issue 5, April 2018, Amd 1 (March 2019), Amd 2 (Feb 2021), §6.9	General Requirements for Compliance of Radio Apparatus, Operating bands and selection of test frequencies
RSS-Gen, Issue 5, April 2018, Amd 1 (March 2019), Amd 2 (Feb 2021), §8.8	General Requirements for Compliance of Radio Apparatus, AC power line conducted emissions limits

1.2 Test methods

558074 D01 15.247 Meas Guidance v05r02 (April 2, 2019)	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.
662911 D01 Multiple Transmitter Output v02r01 (October 31, 2013)	Emissions Testing of Transmitters with Multiple Outputs in the Same Band
DA 00-705, Released March 30, 2000	Filing and Measurement Guidelines for Frequency Hopping Spread Spectrum Systems
ANSI C63.10 v2013	American National Standard of Procedures for Compliance Testing of Unlicensed Wireless Devices
RSS-102, Issue 5 (March 19, 2015), Amd 1 (February 2, 2021)	Radio Frequency (RF) Exposure Compliance of Radiocommunication Apparatus (All Frequency Bands)

1.3 Exclusions

None

1.4 Statement of compliance

In the configuration tested, the EUT was found compliant.

Testing was performed against all relevant requirements of the test standard except as noted in section 1.3 above. Results obtained indicate that the product under test complies In full with the requirements tested. The test results relate only to the items tested.

See "Summary of test results" for full details.

1.5 Test report revision history

Table 1.5-1: *Test report revision history*

Revision #	Date of issue	Details of changes made to test report
REP044593	June 17, 2024	Original report issued

Section 2 Engineering considerations

2.1 Modifications incorporated in the EUT for compliance

There were no modifications performed to the EUT during this assessment.

2.2 Technical judgment

None

2.3 Deviations from laboratory tests procedures

No deviations were made from laboratory procedures.

Section 3 Test conditions

3.1 Atmospheric conditions

Temperature	15 °C – 35 °C
Relative humidity	20 % – 75 %
Air pressure	86 kPa (860 mbar) – 106 kPa (1060 mbar)

When it is impracticable to carry out tests under these conditions, a note to this effect stating the ambient temperature and relative humidity during the tests shall be recorded and stated.

The following instruments are used to monitor the environmental conditions:

Equipment	Manufacturer	Model no.	Asset no.	Cal date	Next cal.
Thermo-hygrometer data loggers	Testo	175-H2	20012380/305	2022-12	2024-12
Thermo-hygrometer data loggers	Testo	175-H2	38203337/703	2022-12	2024-12
Barometer	Castle	GPB 3300	072015	2024-04	2025-04

3.2 Power supply range

The normal test voltage for equipment to be connected to the mains shall be the nominal mains voltage. For the purpose of the present document, the nominal voltage shall be the declared voltage, or any of the declared voltages ±5 %, for which the equipment was designed.

Section 4 Measurement uncertainty

4.1 Uncertainty of measurement

The measurement uncertainty was calculated for each test and quantity listed in this test report, according to CISPR 16-4-2, ETSI TR 100 028-1, ETSI TR 100 028-2 and other specific test standards and is documented in Nemko Spa working manuals WML1002 and WML0078.
The assessment of conformity for each test performed on the equipment is performed not taking into account the measurement uncertainty. The two following possible verdicts are stated in the report:
P (Pass) - The measured values of the equipment respect the specification limit at the points tested. The specific risk of false accept is up to 50% when the measured result is close to the limit.
F (Fail) - One or more measured values of the equipment do not respect the specification limit at the points tested. The specific risk of false reject is up to 50% when the measured result is close to the limit.
Hereafter Nemko's measurement uncertainties are reported:

EUT	Type	Test	Range	Measurement Uncertainty	Notes
Transmitter	Conducted	Frequency error	0.001 MHz ÷ 40 GHz	0.08 ppm	(1)
		Carrier power RF Output Power	0.009 MHz ÷ 30 MHz	1.1 dB	(1)
			30 MHz ÷ 18 GHz	1.5 dB	(1)
			18 MHz ÷ 40 GHz	3.0 dB	(1)
			40 MHz ÷ 140 GHz	5.0 dB	(1)
		Adjacent channel power	1 MHz ÷ 18 GHz	1.4 dB	(1)
		Conducted spurious emissions	0.009 MHz ÷ 18 GHz	3.0 dB	(1)
			18 GHz ÷ 40 GHz	4.2 dB	(1)
			40 GHz ÷ 220 GHz	6.0 dB	(1)
		Intermodulation attenuation	1 MHz ÷ 18 GHz	2.2 dB	(1)
		Attack time – frequency behaviour	1 MHz ÷ 18 GHz	2.0 ms	(1)
		Attack time – power behaviour	1 MHz ÷ 18 GHz	2.5 ms	(1)
		Release time – frequency behaviour	1 MHz ÷ 18 GHz	2.0 ms	(1)
		Release time – power behaviour	1 MHz ÷ 18 GHz	2.5 ms	(1)
		Transient behaviour of the transmitter– Transient frequency behaviour	1 MHz ÷ 18 GHz	0.2 kHz	(1)
		Transient behaviour of the transmitter – Power level slope	1 MHz ÷ 18 GHz	9%	(1)
		Frequency deviation - Maximum permissible frequency deviation	0.001 MHz ÷ 18 GHz	1.3%	(1)
		Frequency deviation - Response of the transmitter to modulation frequencies above 3 kHz	0.001 MHz ÷ 18 GHz	0.5 dB	(1)
		Dwell time	-	3%	(1)
		Hopping Frequency Separation	0.01 MHz ÷ 18 GHz	1%	(1)
		Occupied Channel Bandwidth	0.01 MHz ÷ 18 GHz	2%	(1)
		Modulation Bandwidth	0.01 MHz ÷ 18 GHz	2%	(1)
	Radiated	Radiated spurious emissions	0.009 MHz ÷ 26.5 GHz	6.0 dB	(1)
			26.5 GHz ÷ 66 GHz	8.0 dB	(1)
			66 GHz ÷ 220 GHz	10 dB	(1)
		Effective radiated power transmitter	10 kHz ÷ 26.5 GHz	6.0 dB	(1)
			26.5 GHz ÷ 66 GHz	8.0 dB	(1)
			66 GHz ÷ 220 GHz	10 dB	(1)

NOTES:
(1) The reported expanded uncertainty of measurement is stated as the standard uncertainty of measurement multiplied by the coverage factor k = 2, which for a normal distribution corresponds to a coverage probability of approximately 95 %

Section 5 Information provided by the applicant

5.1 Disclaimer

This section contains information provided by the applicant and has been utilized to support the test plan. Inaccurate information provided by the applicant can affect the validity of the results contained within this test report. Nemko accepts no responsibility for the information contained within this section and the impact it may have on the test plan and resulting measurements.

5.2 Applicant/Manufacture

Applicant name	EchoStar Mobile Limited (EML)
Applicant address	3 Dublin Landings, North Wall Quay, Dublin 1, D01 C4E0 - Ireland
Manufacture name	Same as applicant
Manufacture address	Same as applicant

5.3 EUT information

Product	OEM module sensor
Model	EM2050
Serial number	4659020001 (Number assigned by Nemko Spa)
Power supply requirements	DC: 3.3 V
Product description and theory of operation	The EUT is an OEM module sensor capable of transmitting and receiving both multiband LoRa® and LR-FHSS signals in licensed S band and ISM band, for the intended scope of satellite communication.

5.4 Radio technical information

Category of Wideband Data Transmission equipment	☒ Frequency Hopping Spread Spectrum (FHSS) equipment ☒ Other types of Wideband Data Transmission equipment (e.g. DSSS, OFDM, etc.).
Frequency band	902–928 MHz
Frequency Min (MHz)	902.3 MHz for 125 kHz BW and 903.0 MHz for 500 kHz BW and LR-FHSS
Frequency Max (MHz)	914.9 MHz for 125 kHz BW and 914.2 MHz for 500 kHz BW and LR-FHSS
Channel numbers	64 channels numbered 0 to 63 utilizing LoRa 125 kHz BW 8 channels numbered 64 to 71 utilizing LoRa 500 kHz BW and LR-FHSS
RF power Max (W), Conducted	0.123 W and (20.9 dBm)
Field strength, dBµV/m @ 3 m	N/A
Measured BW (kHz), 99% OBW	126.9 kHz for LoRa 125 kHz BW 504.5 kHz for LoRa 500 kHz BW 1567.7 kHz for LR-FHSS
Type of modulation	LoRa standard
Emission classification	W7D
Transmitter spurious, dBµV/m @ 3 m	53.8 dBµV/m Peak @ 5489.5 MHz
Antenna information	Antenna not provided (U.FL connector)

5.5 EUT setup details

5.5.1 Radio exercise details

Operating conditions	The EUT has been forced in TX mode with the following AT commands send by Tera Term application: LoRa 125 kHz BW AT+TCW=10,902300000,22,1 AT+TCW=10,908500000,22,1 AT+TCW=10,914900000,22,1 LoRa 500 kHz BW AT+TXRAW=10,0,903000000,22,0,2,12,1,100 AT+TXRAW=10,0,907800000,22,0,2,12,1,100 AT+TXRAW=10,0,914200000,22,0,2,12,1,100 LR-FHSS AT+TXRAW=10,0,903000000,22,2,8,0,1,20 AT+TXRAW=10,0,907800000,22,2,8,0,1,20 AT+TXRAW=10,0,914200000,22,2,8,0,1,20
Transmitter state	Transmitter set in to continuous mode with AT commands

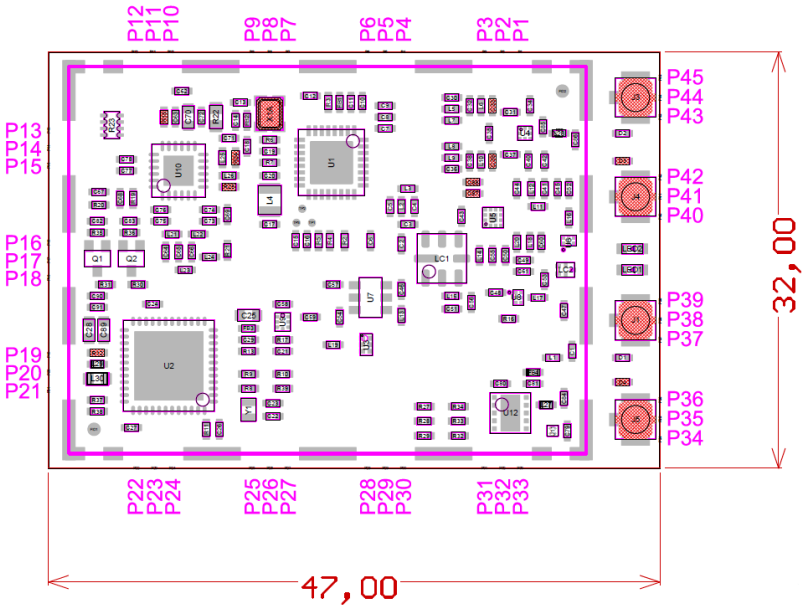
5.5.2 EUT setup configuration

Table 5.5-1: *EUT sub assemblies*

Description	Brand name	Model, Part number, Serial number, Revision level
--	--	--

Table 5.5-2: *EUT interface ports*

Description	Qty.
Pin 1 to 45	1



EUT setup configuration, continued

Pin number	Pin Name	Pin Type / Direction	Description
P1	UART_RX	DIG. INPUT	UART RXD input from external application MCU
P2	GND	PWR	
P3	UART_TX	DIG. OUTPUT	UART TXD output to external application MCU
P4	TX_2G_CE	DIG. OUTPUT	H=TX S-BAND active L=TX S-BAND inactive
P5	GND	PWR	
P6	LNA_GPS_ON	DIG. OUTPUT	H=Enable External GPS LNA L=Disable External GPS LNA
P7	SW_ON	DIG. OUTPUT	H=Enable External S-BAND Switch L=Disable External S-BAND Switch
P8	GND	PWR	
P9	VCC	PWR	3.3VDC supply
P10	MCU_RSTn	DIG. INPUT	Apply an external GND level to reset the radio MCU. Internal 10Kohm pullup.
P11	MCU_PH3	DIG. I/O	Reserved, internal 10K pulldown
P12	DNC		
P13	DNC		
P14	DNC		
P15	GND	PWR	
P16	VCC	PWR	3.3VDC supply
P17	GND	PWR	
P18	DNC		
P19	MCU_BUSY / CTSn / EN_BOOTLOADER	DIG. I/O	H=Radio MCU in sleep mode L=Radio MCU in active mode Internal 100Kohm pullup Sampled after reset for bootloader activation
P20	RTSn	DIG. I/O	H=Application MCU in sleep mode L=Application MCU in active mode Requires external 100kohm pullup for low-power operation. If low-power operation is not required, connect to GND through a 10kohm pulldown.
P21	GND	PWR	
P22	GND	PWR	
P23	I2C_SDA	DIG. I/O	I2C bus, SDA line. Internal 1K8 pullup
P24	I2C_SCL	DIG. i/o	I2C bus, SCL line. Internal 1K8 pullup
P25	GND	PWR	
P26	GND	PWR	
P27	GND	PWR	
P28	VCC	PWR	3.3VDC supply
P29	GND	PWR	
P30	GND	PWR	
P31	GND	PWR	

EUT setup configuration, continued

P32	GND	PWR	
P33	VCC_PA	PWR	3.3VDC supply to the Power Amplifier, max. current 500mA. Tracks must be kept as short as possible to minimize voltage drops.
P34	GND	PWR	
P35	TX_S-BAND_ANT	RF OUT	S-Band TX output port
P36	GND	PWR	
P37	GND	PWR	
P38	RX_GPS_ANT	RF INPUT	RF input for GNSS signal
P39	GND	PWR	
P40	GND	PWR	
P41	RX_S-BAND_ANT	RF INPUT	S-Band RX input port
P42	GND	PWR	
P43	GND	PWR	
P44	868_915_RF	RF I/O	TX/RX port for sub-GHz ISM bands (868 / 915MHz)
P45	GND	PWR	

Table 5.5-3: *Support equipment*

Description	Brand name	Model, Part number, Serial number, Revision level
PC	Dell	Latitude 7480

Table 5.5-4: *Inter-connection cables*

Cable description	From	To	Length (m)
USB (USB/UART TTL converter)	EUT	PC	1.5

EUT setup configuration, continued

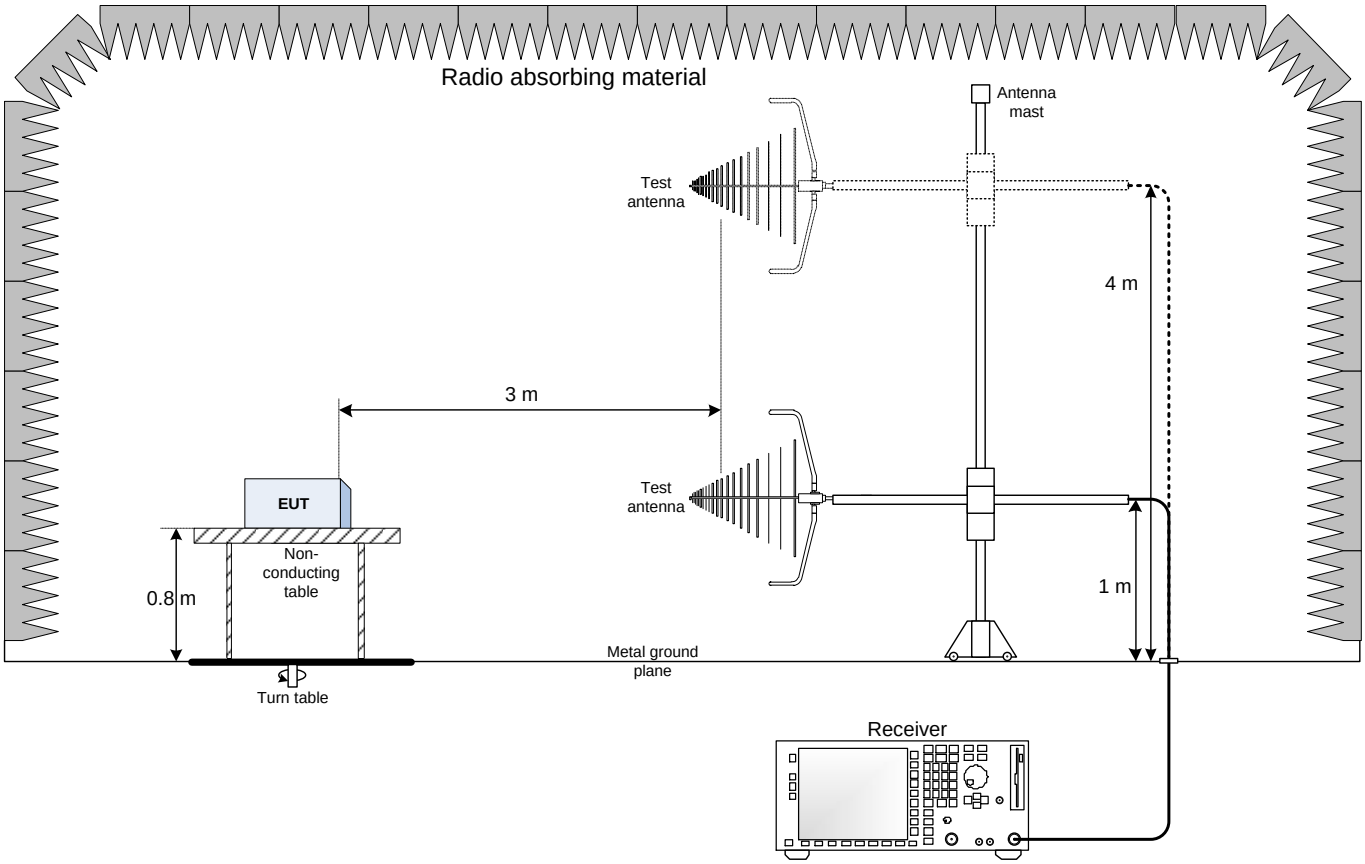


Figure 5.5-1: *Radiated testing block diagram (below 1 GHz)*

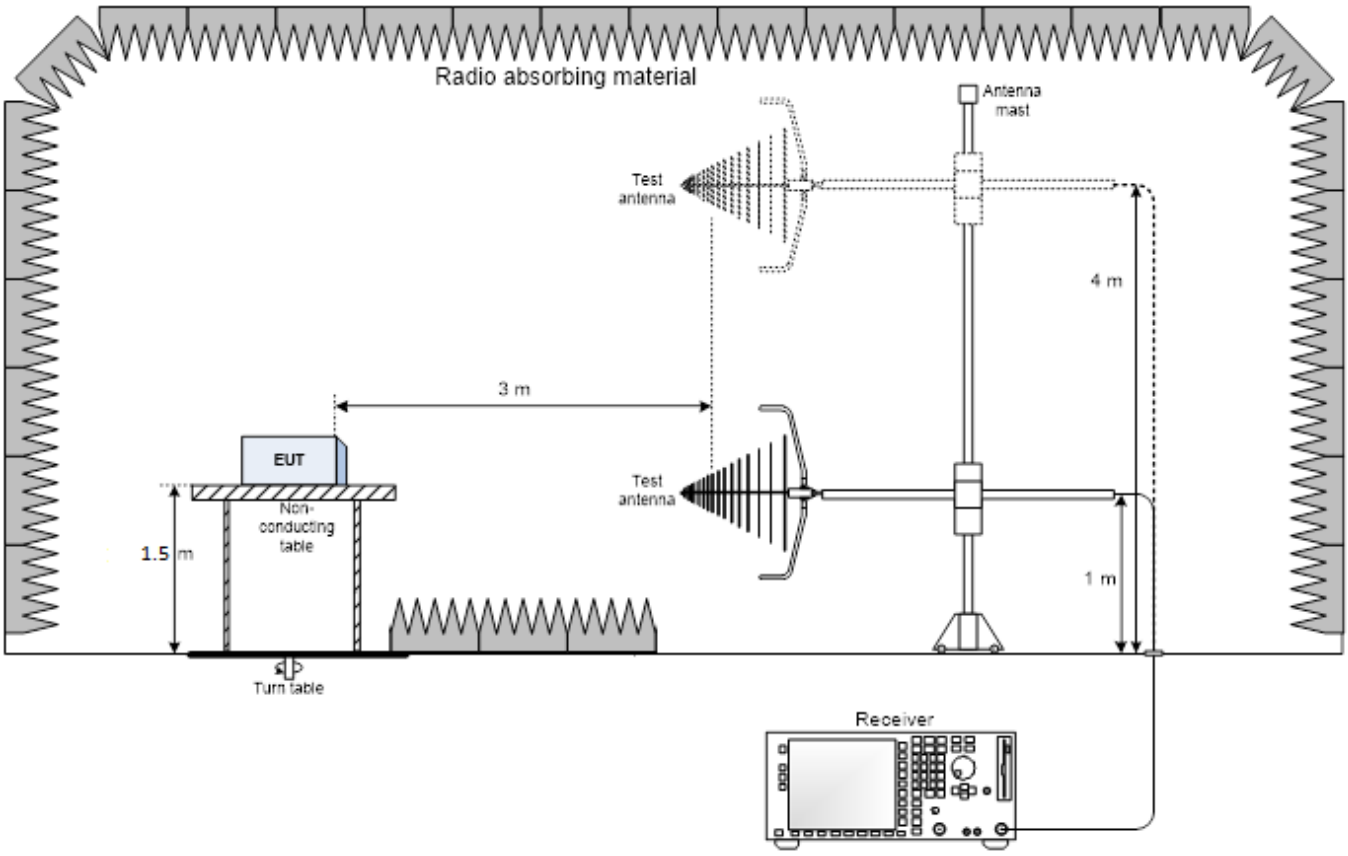


Figure 5.5-2: *Radiated testing block diagram (above 1 GHz)*

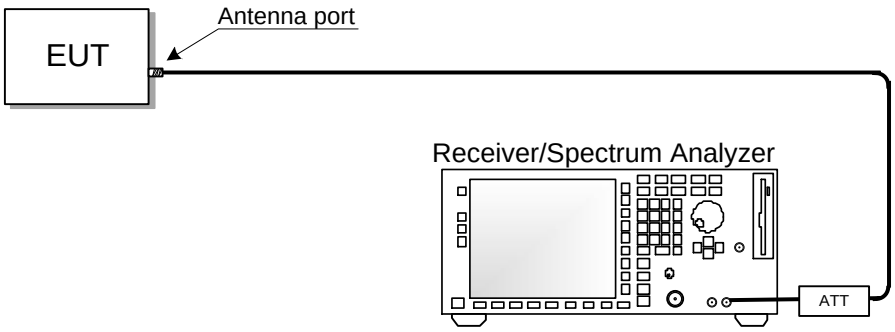


Figure 5.5-3: *Antenna port testing block diagram*

Section 6 Summary of test results

6.1 Testing location

Test location (s)	Nemko S.p.A. Via Del Carroccio, 4 20853 Biassono (MB) Italy

6.2 Testing period

Test start date	May 27, 2024	Test end date	June 14, 2024

6.3 Sample information

Receipt date	June 7, 2022	Nemko sample ID number(s)	4659020001

6.4 FCC Part 15 Subpart A and C, general requirements test results

Table 6.4-1: *FCC general requirements results*

Part	Test description	Verdict
§15.207(a)	Conducted limits	Pass
§15.31(i)	Variation of power source	Pass
§15.31(m)	Number of tested frequencies	Pass
§15.203	Antenna requirement	Pass

Notes: --

6.5 FCC Part §15.247 test results for frequency hopping spread spectrum systems (FHSS)

Table 6.5-1: *FCC FHSS requirements results*

Part	Test description	Verdict
§15.247(a)(1)(i)	Requirements for operation in the 902–928 MHz band	Pass
§15.247(a)(1)(ii)	Requirements for operation in the 5725–5850 MHz band	Not applicable
§15.247(a)(1)(iii)	Requirements for operation in the 2400–2483.5 MHz band	Not applicable
§15.247(b)(1)	Maximum peak output power in the 2400–2483.5 MHz band and 5725–5850 MHz band	Not applicable
§15.247(b)(2)	Maximum peak output power in the 902–928 MHz band	Pass
§15.247(c)(1)	Fixed point-to-point operation with directional antenna gains greater than 6 dBi	Not applicable
§15.247(c)(2)	Transmitters operating in the 2400–2483.5 MHz band that emit multiple directional beams	Not applicable
§15.247(d)	Spurious emissions	Pass
§15.247(f)	Time of occupancy for hybrid systems	Pass
§15.247(i)	Radiofrequency radiation exposure evaluation	Pass

Notes: --

6.6 FCC Part §15.247 test results for digital transmission systems (DTS)

Table 6.6-1: *FCC DTS requirements results*

Part	Test description	Verdict
§15.247(a)(2)	Minimum 6 dB bandwidth	Pass
§15.247(b)(3)	Maximum peak output power in the 902–928 MHz, 2400–2483.5 MHz, and 5725–5850 MHz bands	Pass
§15.247(c)(1)	Fixed point-to-point operation with directional antenna gains greater than 6 dBi	Not applicable
§15.247(c)(2)	Transmitters operating in the 2400–2483.5 MHz band that emit multiple directional beams	Not applicable
§15.247(d)	Spurious emissions	Pass
§15.247(e)	Power spectral density	Pass
§15.247(f)	Time of occupancy for hybrid systems	Pass

Notes: --

6.7 ISED RSS-Gen, Issue 5, April 2018, Amd 1 (March 2019), Amd 2 (Feb 2021) test results

Table 6.7-1: *RSS-Gen requirements results*

Part	Test description	Verdict
7.3	Receiver radiated emission limits	Not applicable
7.4	Receiver conducted emission limits	Not applicable
6.9	Operating bands and selection of test frequencies	Pass
8.8	AC power-line conducted emissions limits	Pass

Notes: [1]According to sections 5.2 and 5.3 of RSS-Gen, Issue 5 the EUT does not have a stand-alone receiver neither scanner receiver, therefore exempt from receiver requirements.

6.8 ISED RSS-247, Issue 3, test results for frequency hopping spread spectrum systems (FHSS)

Table 6.8-1: *ISED FHSS requirements results*

Part	Test description	Verdict
5.1 (a)	Bandwidth of a frequency hopping channel	Pass
5.1 (b)	Minimum channel spacing	Pass
5.1 (c)	Systems operating in the 902–928 MHz band	Pass
5.1 (d)	Systems operating in the 2400–2483.5 MHz band	Not applicable
5.1 (e)	Systems operating in the 5725–5850 MHz band	Not applicable
5.3	Hybrid Systems	
5.3 (a)	Digital modulation turned off	Pass
5.3 (b)	Frequency hopping turned off	Pass
5.4	Transmitter output power and e.i.r.p. requirements	
5.4 (a)	Systems operating in the 902–928 MHz band	Pass
5.4 (b)	Systems operating in the 2400–2483.5 MHz band	Not applicable
5.4 (c)	Systems operating in the 5725–5850 MHz	Not applicable
5.4 (e)	Point-to-point systems in 2400–2483.5 MHz and 5725–5850 MHz band	Not applicable
5.4 (f)	Transmitters which operate in the 2400–2483.5 MHz band with multiple directional beams	Not applicable
5.5	Unwanted emissions	Pass

Notes: --

6.9 ISED RSS-247, Issue 3, test results for digital transmission systems (DTS)

Table 6.9-1: *ISED DTS requirements results*

Part	Test description	Verdict
5.2 (a)	Minimum 6 dB bandwidth	Pass
5.2 (b)	Maximum power spectral density	Pass
5.3	Hybrid Systems	
5.3 (a)	Digital modulation turned off	Pass
5.3 (b)	Frequency hopping turned off	Pass
5.4	Transmitter output power and e.i.r.p. requirements	
5.4 (d)	Systems employing digital modulation techniques	Pass
5.4 (e)	Point-to-point systems in 2400–2483.5 MHz and 5725–5850 MHz band	Not applicable
5.4 (f)	Transmitters which operate in the 2400–2483.5 MHz band with multiple directional beams	Not applicable
5.5	Unwanted emissions	Pass

Notes: --

Section 7 Test equipment

7.1 Test equipment list

Table 7.1-1: *Equipment list*

Equipment	Manufacturer	Model no.	Asset no.	Cal cycle	Next cal.
Spectrum Analyzer	Rohde & Schwarz	FSW43	101767	2023-12	2024-12
EMI Receiver	Rohde & Schwarz	ESW44	101620	2023-08	2024-08
Antenna Trilog 25MHz - 8GHz	Schwarzbeck Mess-Elektronik	VULB9162	9162-025	2021-07	2024-07
Antenna 1 - 18 GHz	Schwarzbeck Mess-Elektronik	STLP9148	STLP 9148-152	2021-09	2024-09
Double Ridge Horn Antenna	RFSpin	DRH40	061106A40	2023-04	2026-04
Broadband Amplifier	Schwarzbeck Mess-Elektronik	BBV9718C	00121	2024-03	2025-03
Broadband Bench Top Amplifier	Sage	STB-1834034030-KFKF-L1	18490-01	2024-05	2025-05
Controller	Maturo	FCU3.0	10041	NCR	NCR
Tilt antenna mast	Maturo	TAM4.0-E	10042	NCR	NCR
Turntable	Maturo	TT4.0-5T	2.527	NCR	NCR
Semi-anechoic chamber	Nemko S.p.a.	10m semi-anechoic chamber	530	2023-09	2025-09
EMI receiver	R&S	ESU8	100202	2023-09	2024-09
Attenuator	Aeroflex / Weinschel	2	CC8577	2023-07	2024-07
LISN 9 kHz ÷ 30 MHz	R&S	ESH2-Z5	881 362/006	2024-03	2025-03
Shielded room	Siemens	Conducted emission test room	1862	NCR	NCR
Cable set	Rosenberger	ST.ALO-02	1.650	2023-10	2024-10
Software turntable and mast	Maturo	mcApp	8.1.0.5410	NCR	NCR

Notes: NCR - no calibration required, VOU - verify on use

Section 8 Testing data

8.1 Variation of power source

8.1.1 References, definitions and limits

FCC §15.31 (e):

For intentional radiators, measurements of the variation of the input power or the radiated signal level of the fundamental frequency component of the emission, as appropriate, shall be performed with the supply voltage varied between 85% and 115% of the nominal rated supply voltage. For battery operated equipment, the equipment tests shall be performed using a new battery.

8.1.2 Test summary

Verdict	Pass		
Tested by	P. Barbieri	Test date	May 28, 2024

8.1.3 Observations, settings and special notes

The testing was performed as per ANSI C63.10 Section 5.13.

a) Where the device is intended to be powered from an external power adapter, the voltage variations shall be applied to the input of the adapter provided with the device at the time of sale. If the device is not marketed or sold with a specific adapter, then a typical power adapter shall be used.
b) For devices, where operating at a supply voltage deviating ±15% from the nominal rated value may cause damages or loss of intended function, test to minimum and maximum allowable voltage per manufacturer's specification and document in the report.
c) For devices with wide range of rated supply voltage, test at 15% below the lowest and 15% above the highest declared nominal rated supply voltage.
d) For devices obtaining power from an input/output (I/O) port (USB, firewire, etc.), a test jig is necessary to apply voltage variation to the device from a support power supply, while maintaining the functionalities of the device.

For battery-operated equipment, the equipment tests shall be performed using a variable power supply.

8.1.4 Test data

EUT Power requirements:	☐ AC	☒ DC	☐ Battery
If EUT is an AC or a DC powered, was the noticeable output power variation observed?	☐ YES	☒ NO	☐ N/A
If EUT is battery operated, was the testing performed using fresh batteries?	☐ YES	☐ NO	☒ N/A
If EUT is rechargeable battery operated, was the testing performed using fully charged batteries?	☐ YES	☐ NO	☒ N/A

8.2 Number of frequencies

8.2.1 References, definitions and limits

FCC §15.31:

(m) Measurements on intentional radiators or receivers shall be performed and, if required, reported for each band in which the device can be operated with the device operating at the number of frequencies in each band specified in the following table.

RSS-Gen, Clause 6.9:

Except where otherwise specified, measurements shall be performed for each frequency band of operation for which the radio apparatus is to be certified, with the device operating at the frequencies in each band of operation shown in table below. The frequencies selected for measurements shall be reported in the test report.

Table 8.2-1: *Frequency Range of Operation*

Frequency range over which the device operates (in each band)	Number of test frequencies required	Location of measurement frequency inside the operating frequency range
1 MHz or less	1	Center (middle of the band)
1–10 MHz	2	1 near high end, 1 near low end
Greater than 10 MHz	3	1 near high end, 1 near center and 1 near low end

Notes: "near" means as close as possible to or at the centre / low end / high end of the frequency range over which the device operates.

8.2.2 Test summary

Verdict	Pass		
Tested by	P. Barbieri	Test date	May 28, 2024

8.2.3 Observations, settings and special notes

ANSI C63.10, Clause 5.6.2.1:

The number of channels tested can be reduced by measuring the center channel bandwidth first and then applying the following relaxations as appropriate:

a) For each operating mode, if the measured channel bandwidth on the middle channel is at least 150% of the minimum permitted bandwidth, then it is not necessary to measure the bandwidth on the high and low channels.

b) For multiple-input multiple-output (MIMO) systems, if the measured channel bandwidth on testing the middle channel exceeds the minimum permitted bandwidth by more than 50% on one transmit chain, then it is not necessary to repeat testing on the other chains.

c) If the measured channel bandwidth on the middle channel is less than 50% of the maximum permitted bandwidth, then it is not necessary to measure the bandwidth on the high and low channels.

ANSI C63.10, Clause 5.6.2.2:

For devices with multiple operating modes, measurements on the middle channel can be used to determine the worst-case mode(s). The worst-case modes are as follows:

a) Band edge requirements—Measurements on the mode with the widest bandwidth can be used to cover the same channel (center frequency) on modes with narrower bandwidth that have the same or lower output power for each modulation family (e.g., OFDM and direct sequence spread spectrum).

b) Spurious emissions—Measure the mode with the highest output power and the mode with the highest output power spectral density for each modulation family (e.g., OFDM and direct sequence spread spectrum).

c) In-band PSD—Measurements on the mode with the narrowest bandwidth can be used to cover all modes within the same modulation family of an equal or lower output power provided the result is less than 50% of the limit.

8.2.4 Test data

Table 8.2-2: *Test channels selection for LoRa 125 kHz BW*

Start of Frequency range, MHz	End of Frequency range, MHz	Frequency range bandwidth, MHz	Low channel, MHz	Mid channel, MHz	High channel, MHz
902	928	26	902.3	908.5	914.9

Table 8.2-3: *Test channels selection for LoRa 500 kHz BW and LR-FHSS*

Start of Frequency range, MHz	End of Frequency range, MHz	Frequency range bandwidth, MHz	Low channel, MHz	Mid channel, MHz	High channel, MHz
902	928	26	903.0	907.8	914.2

8.3 Antenna requirement

8.3.1 References, definitions and limits

FCC §15.203:

An intentional radiator shall be designed to ensure that no antenna other than that furnished by the responsible party shall be used with the device. The use of a permanently attached antenna or of an antenna that uses a unique coupling to the intentional radiator shall be considered sufficient to comply with the provisions of this section. The manufacturer may design the unit so that a broken antenna can be replaced by the user, but the use of a standard antenna jack or electrical connector is prohibited. This requirement does not apply to intentional radiators that must be professionally installed, such as perimeter protection systems and some field disturbance sensors, or to other intentional radiators which, in accordance with §15.31(d), must be measured at the installation site. However, the installer shall be responsible for ensuring that the proper antenna is employed so that the limits in this part are not exceeded.

FCC §15.247:

(b) The maximum peak conducted output power of the intentional radiator shall not exceed the following:

(4) The conducted output power limit specified in paragraph (b) of this section is based on the use of antennas with directional gains that do not exceed 6 dBi. Except as shown in paragraph (c) of this section, if transmitting antennas of directional gain greater than 6 dBi are used, the conducted output power from the intentional radiator shall be reduced below the stated values in paragraphs (b)(1), (b)(2), and (b)(3) of this section, as appropriate, by the amount in dB that the directional gain of the antenna exceeds 6 dBi.

RSS-Gen, Clause 6.8:

The applicant for equipment certification shall provide a list of all antenna types that may be used with the transmitter, where applicable (i.e. for transmitters with detachable antenna), indicating the maximum permissible antenna gain (in dBi) and the required impedance for each antenna. The test report shall demonstrate the compliance of the transmitter with the limit for maximum equivalent isotropically radiated power (e.i.r.p.) specified in the applicable RSS, when the transmitter is equipped with any antenna type, selected from this list.

For expediting the testing, measurements may be performed using only the antenna with highest gain of each combination of transmitter and antenna type, with the transmitter output power set at the maximum level. However, the transmitter shall comply with the applicable requirements under all operational conditions and when in combination with any type of antenna from the list provided in the test report.

8.3.2 Test summary

Verdict	Pass		
Tested by	P. Barbieri	Test date	May 28, 2024

8.3.3 Observations, settings and special notes

None

8.3.4 Test data

Must the EUT be professionally installed?	☒ YES	☐ NO	
Does the EUT have detachable antenna(s)?	☐ YES	☒ NO	
If detachable, is the antenna connector(s) non-standard?	☐ YES	☐ NO	☒ N/A

Table 8.3-1: *Antenna information*

Antenna type	Manufacturer	Model number	Maximum gain	Connector type
--	--	--	--	--

Note: Antenna not provided. The EUT is a chip to be use in a hosting device.

8.4 AC power line conducted emissions limits

8.4.1 References, definitions and limits

FCC §15.207:

(a) Except as shown in paragraphs (b) and (c) of this section, for an intentional radiator that is designed to be connected to the public utility (AC) power line, the radio frequency voltage that is conducted back onto the AC power line on any frequency or frequencies, within the band 150 kHz to 30 MHz, shall not exceed the limits in the following table, as measured using a 50 µH/50 Ω line impedance stabilization network (LISN). Compliance with the provisions of this paragraph shall be based on the measurement of the radio frequency voltage between each power line and ground at the power terminal. The lower limit applies at the boundary between the frequency ranges.

ANSI C63.10, Clause 6.2:

If the EUT normally receives power from another device that in turn connects to the public utility ac power lines, measurements shall be made on that device with the EUT in operation to demonstrate that the device continues to comply with the appropriate limits while providing the EUT with power. If the EUT is operated only from internal or dedicated batteries, with no provisions for connection to the public utility ac power lines (600 VAC or less) to operate the EUT (such as an adapter), then ac power-line conducted measurements are not required.

For direct current (dc) powered devices where the ac power adapter is not supplied with the device, an "off-the-shelf" unmodified ac power adapter shall be used. If the device is supposed to be installed in a host (e.g., the device is a module or PC card), then it is tested in a typical compliant host.

RSS-Gen, Clause 8.8:

A radio apparatus that is designed to be connected to the public utility (AC) power line shall ensure that the radio frequency voltage, which is conducted back onto the AC power line on any frequency or frequencies within the band 150 kHz to 30 MHz, shall not exceed the limits in table below.

Unless the requirements applicable to a given device state otherwise, for any radio apparatus equipped to operate from the public utility AC power supply either directly or indirectly (such as with a battery charger), the radio frequency voltage of emissions conducted back onto the AC power lines in the frequency range of 0.15 MHz to 30 MHz shall not exceed the limits shown in table below. The more stringent limit applies at the frequency range boundaries.

Table 8.4-1: *Conducted emissions limit*

	Conducted emissions limit, dBµV	
Frequency of emission, MHz	**Quasi-peak**	**Average****
0.15–0.5	66 to 56*	56 to 46*
0.5–5	56	46
5–30	60	50

Notes: * - The level decreases linearly with the logarithm of the frequency.
** - A linear average detector is required.

8.4.2 Test summary

Verdict	Pass		
Tested by	P. Barbieri	Test date	May 28, 2024

8.4.3 Observations, settings and special notes

Port under test – Coupling device	DC power port – Artificial Mains Network (AMN)
EUT power input during test	3.3 V_{DC} (via external laboratory power supply)
EUT setup configuration	Table top
Measurement details	A preview measurement was generated with the receiver in continuous scan mode. Emissions detected within 10 dB or above the limit were re-measured with the appropriate detector against the correlating limit and recorded as the final measurement.
Additional notes:	– The EUT was set up as tabletop configuration per ANSI C63.10-2013 measurement procedure. – The spectral scan has been corrected with transducer factors (i.e. cable loss, LISN factors, and attenuators) for determination of compliance. Correction factor (dB) = LISN factor IL (dB) + cable loss (dB) + attenuator (dB) – Emissions that were continuously present for a minimum of 1 second and occurred more than once for every 15 seconds observation period were considered valid emissions. The maximum value of valid emissions has been recorded.

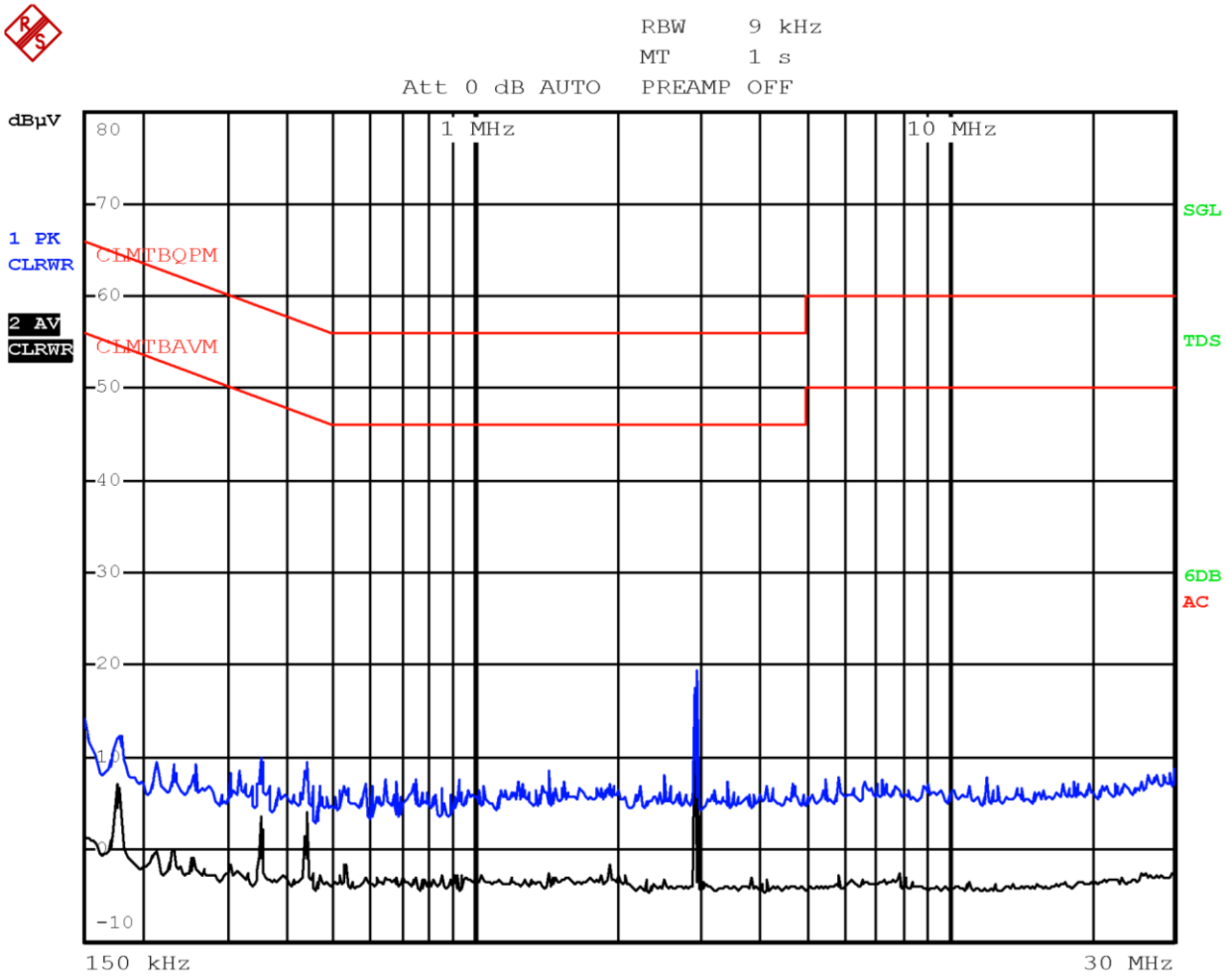
Receiver settings:

Resolution bandwidth	9 kHz
Video bandwidth	30 kHz
Detector mode	Peak and Average (Preview), Quasi-peak and CAverage (Final)
Trace mode	Max Hold
Measurement time	100 ms (Preview), 1 sec (Final)

8.4.4 Test equipment used

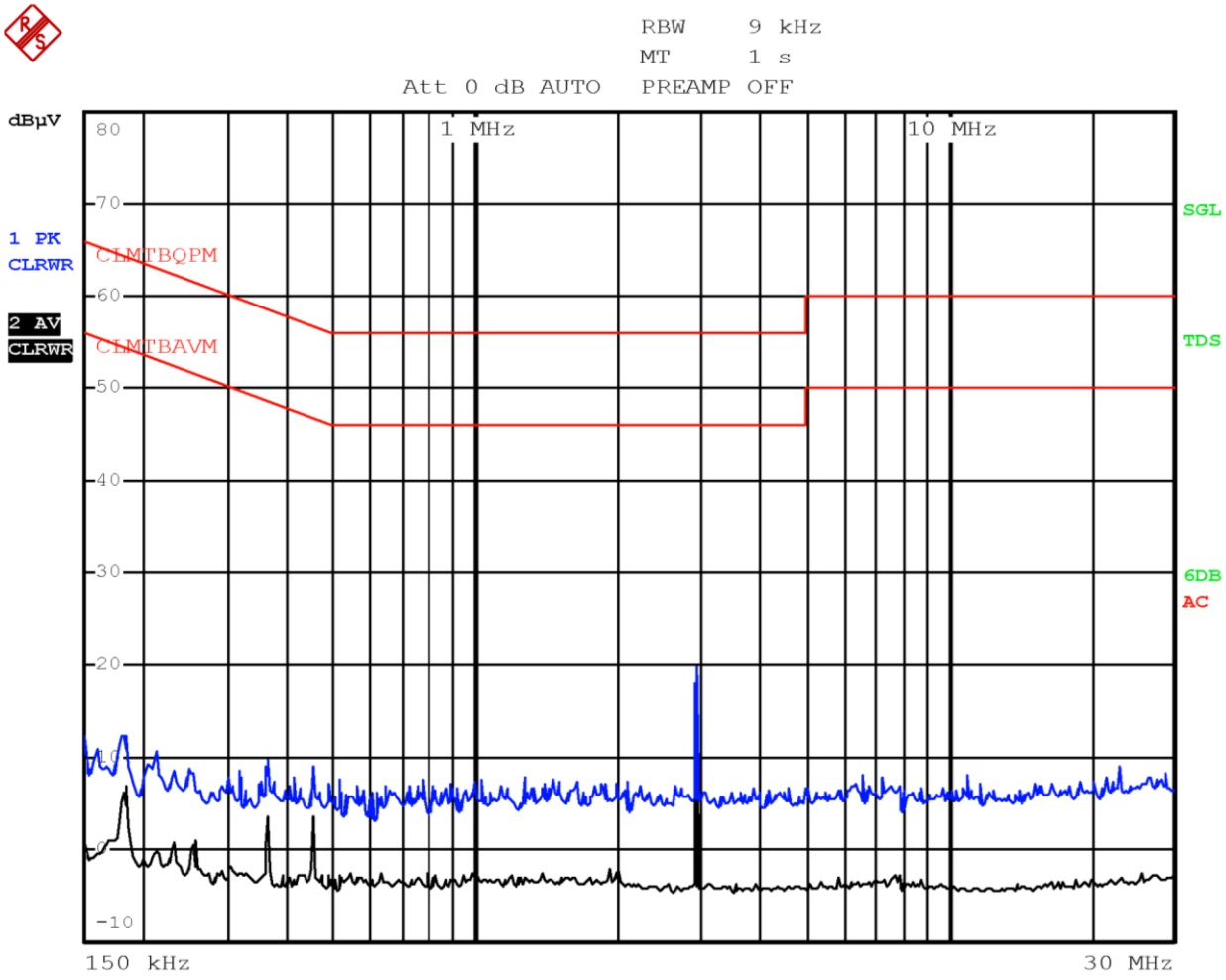
Equipment	Manufacturer	Model no.	Asset no.
EMI receiver	R&S	ESU8	100202
Attenuator	Aeroflex / Weinschel	2	CC8577
LISN 9 kHz ÷ 30 MHz	R&S	ESH2-Z5	881 362/006
Shielded room	Siemens	Conducted emission test room	1862

8.4.5 Test data



Plot 8.4-1: *Conducted emissions on phase line*

Test data, continued



Plot 8.4-2: *Conducted emissions on neutral line*

8.5 Frequency Hopping Systems requirements, 900 MHz operation

8.5.1 References, definitions and limits

FCC §15.247:

(a) Operation under the provisions of this Section is limited to frequency hopping and digitally modulated intentional radiators that comply with the following provisions:

(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.

(i) For frequency hopping systems operating in the 902–928 MHz band: if the 20 dB bandwidth of the hopping channel is less than 250 kHz, the system shall use at least 50 hopping frequencies and 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 system shall use at least 25 hopping frequencies and the average time of occupancy on any frequency shall not be greater than 0.4 seconds within a 10 second period. The maximum allowed 20 dB bandwidth of the hopping channel is 500 kHz.

(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. The power spectral density conducted from the intentional radiator to the antenna due to the digital modulation operation of the hybrid system, with the frequency hopping operation turned off, shall not be greater than 8 dBm in any 3 kHz band during any time interval of continuous transmission.

Table 8.5-1: *Summary of the basic requirements*

$P_{max\text{-}pk} \leq 1$ W	$P_{max\text{-}pk} \leq 0.125$ W
$N_{ch} \geq 75$	$N_{ch} \geq 15$
$\Delta f \geq$ MAX { 25 kHz, $BW_{20\ dB}$ }	$\Delta f \geq$ MAX [MAX { 25 kHz, 0.67×$BW_{20\ dB}$ } OR MAX{25 kHz, $BW_{20\ dB}$}]
max. $BW_{20\ dB}$ not specified	max. $BW_{20\ dB}$ not specified
$t_{ch} \leq 0.4$ s for T = 0.4×Nch	$t_{ch} \leq 0.4$ s for T = 0.4×Nch

Note: t_{ch} = average time of occupancy; T = period; N_{ch} = # hopping frequencies; BW = bandwidth; Δf = hopping channel carrier frequency separation

RSS-247, Clause 5.1:

a. The bandwidth of a frequency hopping channel is the 20 dB emission bandwidth, measured with the hopping stopped. The system's radio frequency (RF) bandwidth is equal to the channel bandwidth multiplied by the number of channels in the hopset. The system shall hop to channel frequencies that are selected at the system hopping rate from a pseudo randomly ordered list of hopping frequencies. 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.

c. For FHSs in the band 902–928 MHz: if the 20 dB bandwidth of the hopping channel is less than 250 kHz, the system shall use at least 50 hopping channels and the average time of occupancy on any channel 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 system shall use at least 25 hopping channels and the average time of occupancy on any channel shall not be greater than 0.4 seconds within a 10‑second period. The maximum 20 dB bandwidth of the hopping channel shall be 500 kHz.

RSS-247, Clause 5.3:

Hybrid systems employ a combination of both frequency hopping and digital transmission techniques and shall comply with the following:

a. With the digital transmission operation of the hybrid system turned off, the frequency hopping operation shall have an average time of occupancy on any frequency not exceeding 0.4 seconds within a duration in seconds equal to the number of hopping frequencies multiplied by 0.4.

8.5.2 Test summary

Verdict	Pass		
Tested by	P. Barbieri	Test date	May 29, 2024

8.5.3 Observations, settings and special notes

Carrier frequency separation was tested per ANSI C63.10 subclause 7.8.2. Spectrum analyser settings:

Resolution bandwidth	Start with the RBW set to approximately 30% of the channel spacing; adjust as necessary to best identify the center of each individual channel.
Video bandwidth	≥ RBW
Frequency span	Wide enough to capture the peaks of two adjacent channels
Detector mode	Peak
Trace mode	Max Hold

Number of hopping frequencies was tested per ANSI C63.10 subclause 7.8.3. Spectrum analyser settings:

Resolution bandwidth	To identify clearly the individual channels, set the RBW to less than 30% of the channel spacing or the 20 dB bandwidth, whichever is smaller.
Video bandwidth	≥ RBW
Frequency span	The frequency band of operation. Depending on the number of channels the device supports, it may be necessary to divide the frequency range of operation across multiple spans, to allow the individual channels to be clearly seen.
Detector mode	Peak
Trace mode	Max Hold

Time of occupancy (dwell time) was tested per ANSI C63.10 subclause 7.8.4. Spectrum analyser settings:

Resolution bandwidth	shall be ≤ channel spacing and where possible RBW should be set >> 1 / T, where T is the expected dwell time per channel.
Video bandwidth	≥ RBW
Frequency span	Zero span, centered on a hopping channel.
Detector mode	Peak
Trace mode	Max Hold

20 dB bandwidth was tested per ANSI C63.10 subclause 6.9.2. Spectrum analyser settings:

Resolution bandwidth	≥ 1–5% of the 20 dB bandwidth
Video bandwidth	≥ RBW
Frequency span	approximately 2 to 5 times the 20 dB bandwidth, centered on a hopping channel
Detector mode	Peak
Trace mode	Max Hold

8.5.4 Test equipment used

Equipment	Manufacturer	Model no.	Asset no.
Spectrum Analyzer	Rohde & Schwarz	FSW43	101767

8.5.5 Test data

Table 8.5-2: *20 dB bandwidth results for LoRa 125 kHz BW*

Frequency, MHz	20 dB bandwidth, kHz
902.3	138.4
908.5	137.9
914.9	138.4

Table 8.5-3: *99% occupied bandwidth results for LoRa 125 kHz BW*

Frequency, MHz	99% occupied bandwidth, kHz
902.3	126.9
908.5	126.8
914.9	126.8

Notes: There is no 99% occupied bandwidth limit in the standard's requirements the measurement results provided for information purposes only.

Table 8.5-4: *Carrier frequency separation results for LoRa 125 kHz BW*

Carrier frequency separation, kHz	Minimum limit, kHz	Margin, kHz
200	25 or 20 dB BW whichever is greater	61.6

Table 8.5-5: *Number of hopping frequencies results for LoRa 125 kHz BW*

Number of hopping frequencies	Minimum limit	Margin
8	No requirement	--

Notes: The EUT use a hybrid mode

Table 8.5-6: *Average time of occupancy results for LoRa 125 kHz BW*

Dwell time of each pulse, ms	Number of pulses within period	Total dwell time within period, ms	Limit, ms	Margin, ms
--	--	390	400	10

Notes: Test performed with a LoRa tester model RWC5020M provided by the manufacturer. It was not possible to force the EUT in hopping mode without it.

Test data, continued

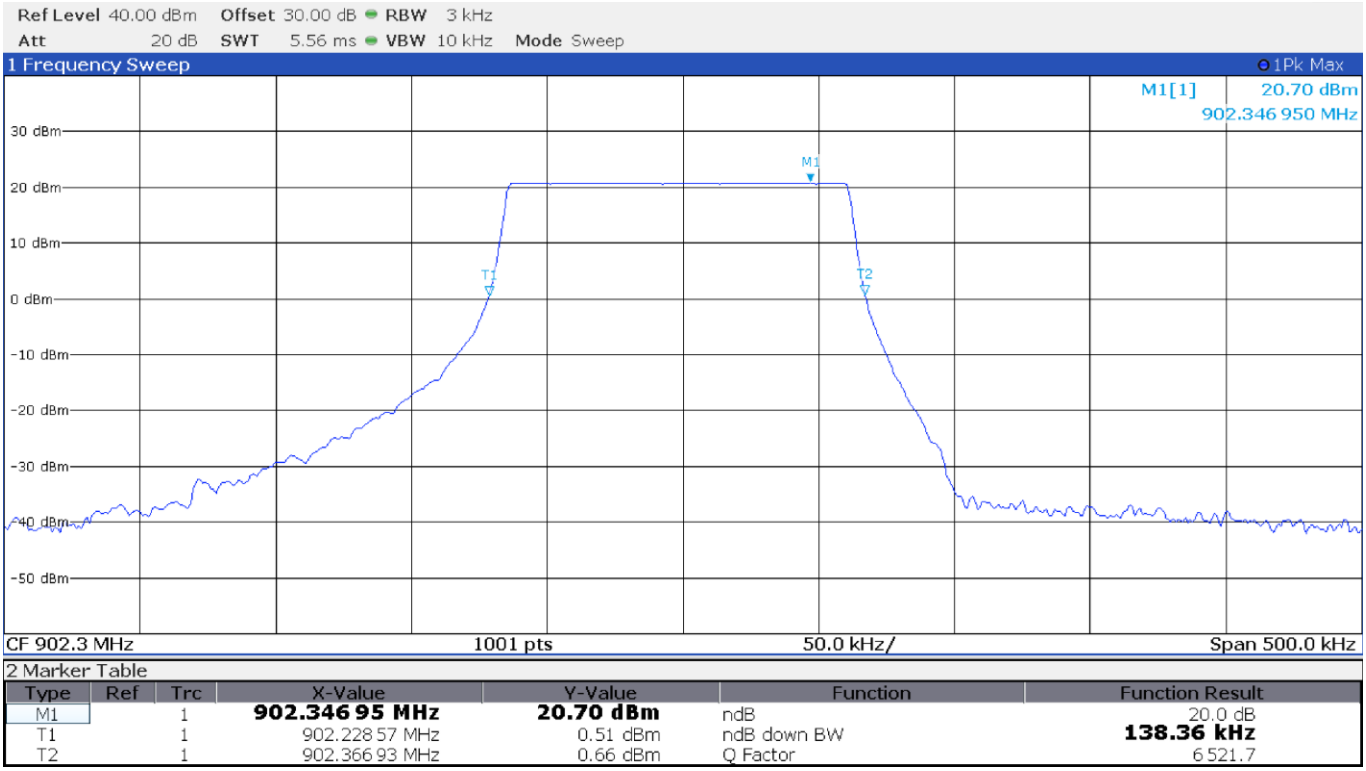


Figure 8.5-1: *20 dB bandwidth on low channel for LoRa 125 kHz BW*

Test data, continued

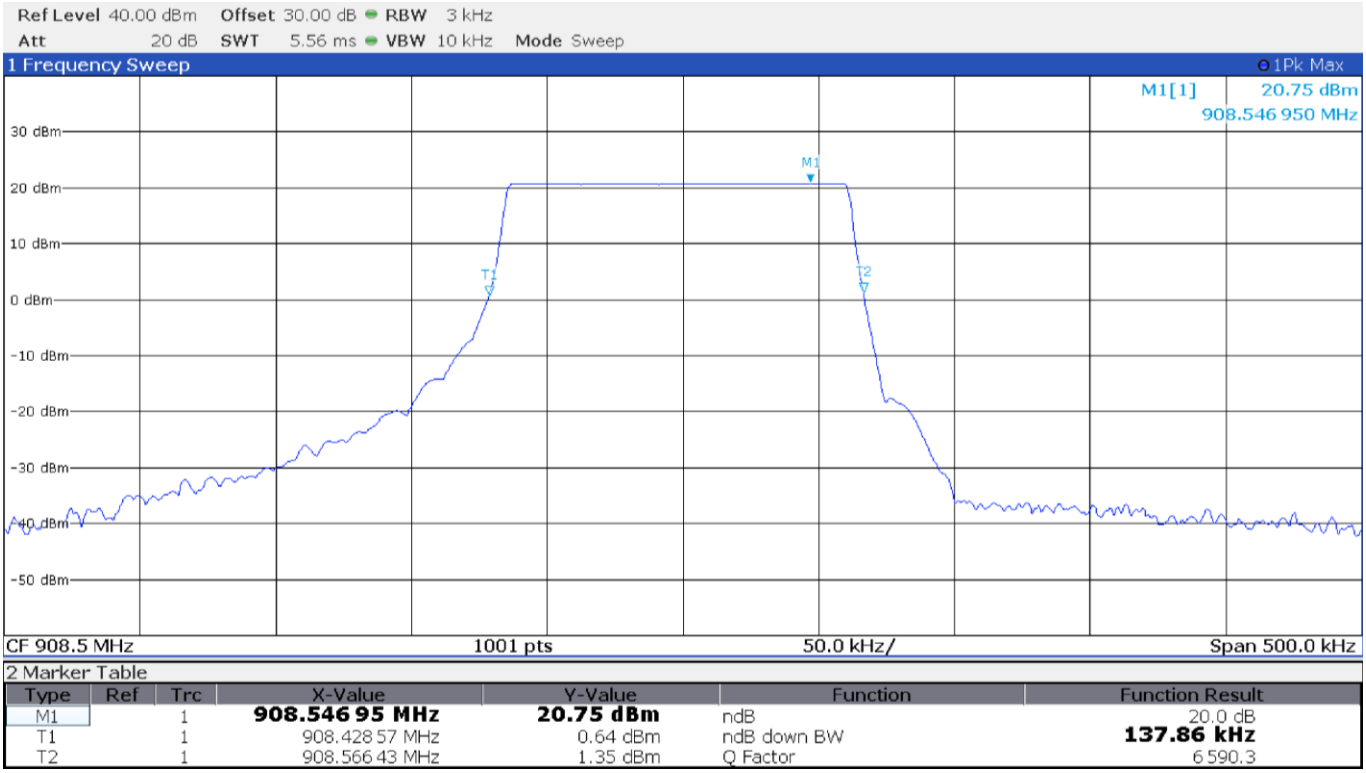


Figure 8.5-2: *20 dB bandwidth on mid channel for LoRa 125 kHz BW*

Test data, continued

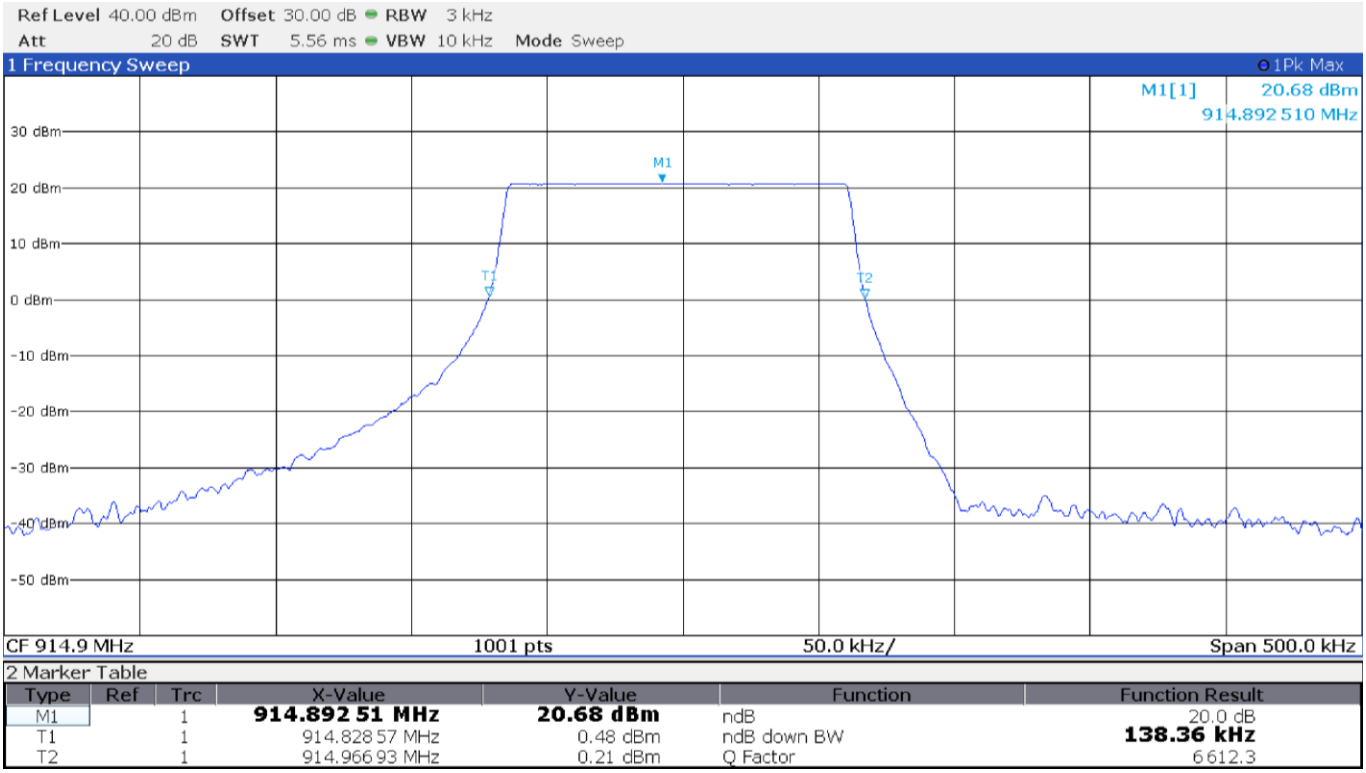


Figure 8.5-3: *20 dB bandwidth on high channel for LoRa 125 kHz BW*

Test data, continued

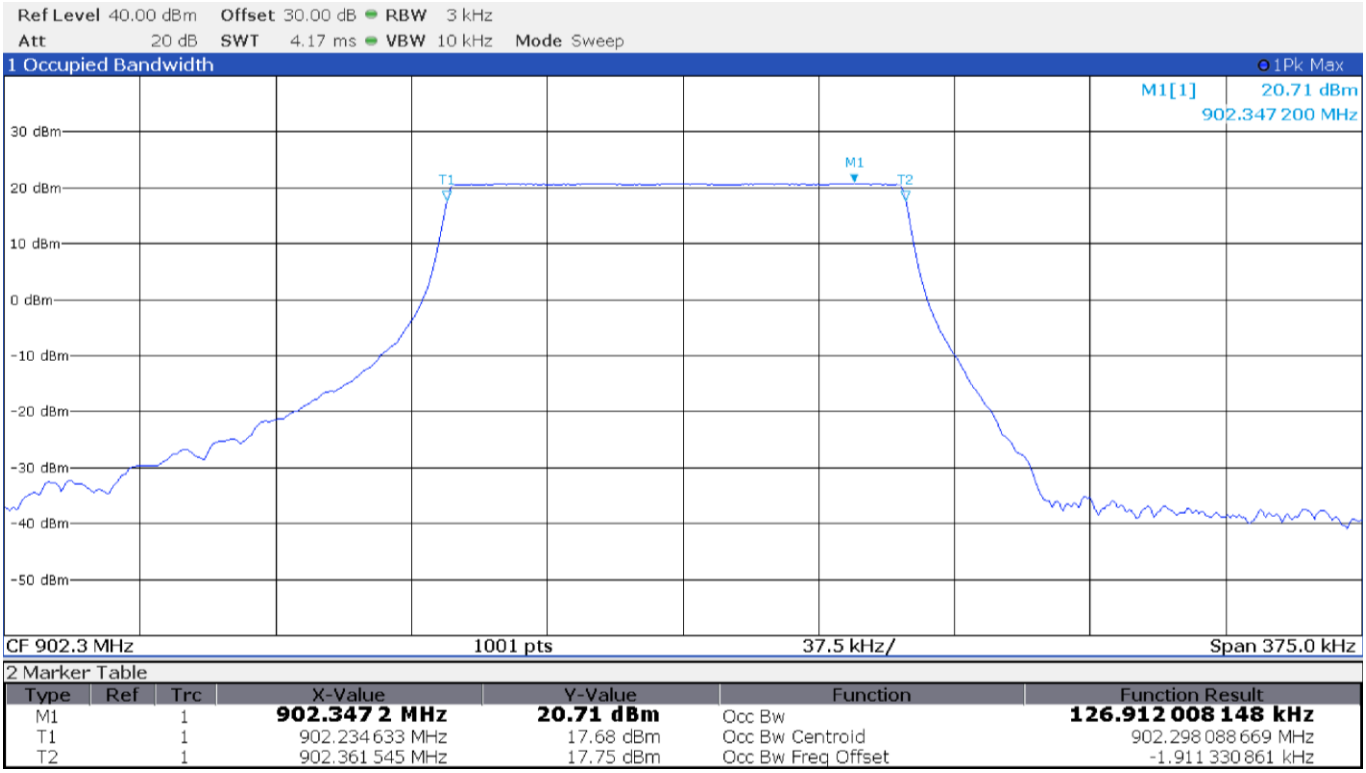


Figure 8.5-4: *99% bandwidth on low channel for LoRa 125 kHz BW*

Test data, continued

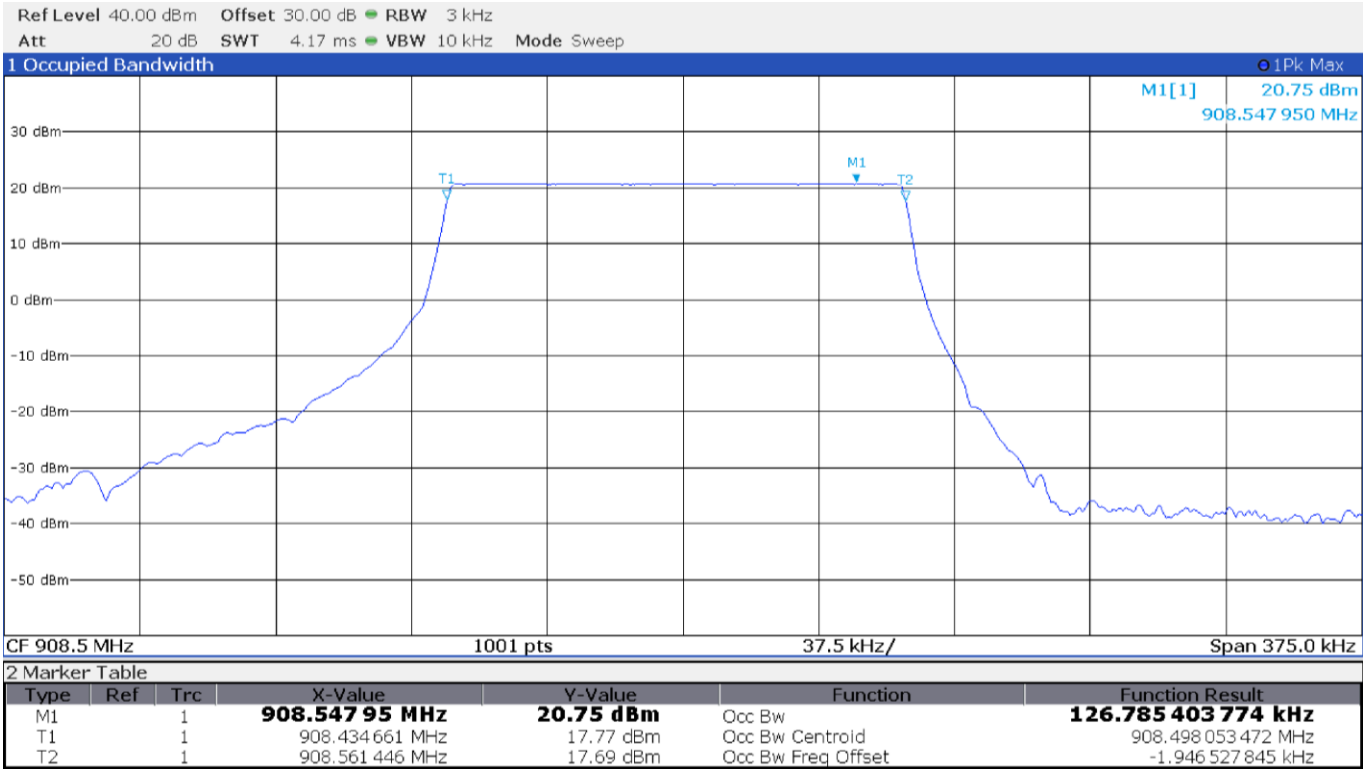


Figure 8.5-5: *99% bandwidth on mid channel for LoRa 125 kHz BW*

Test data, continued

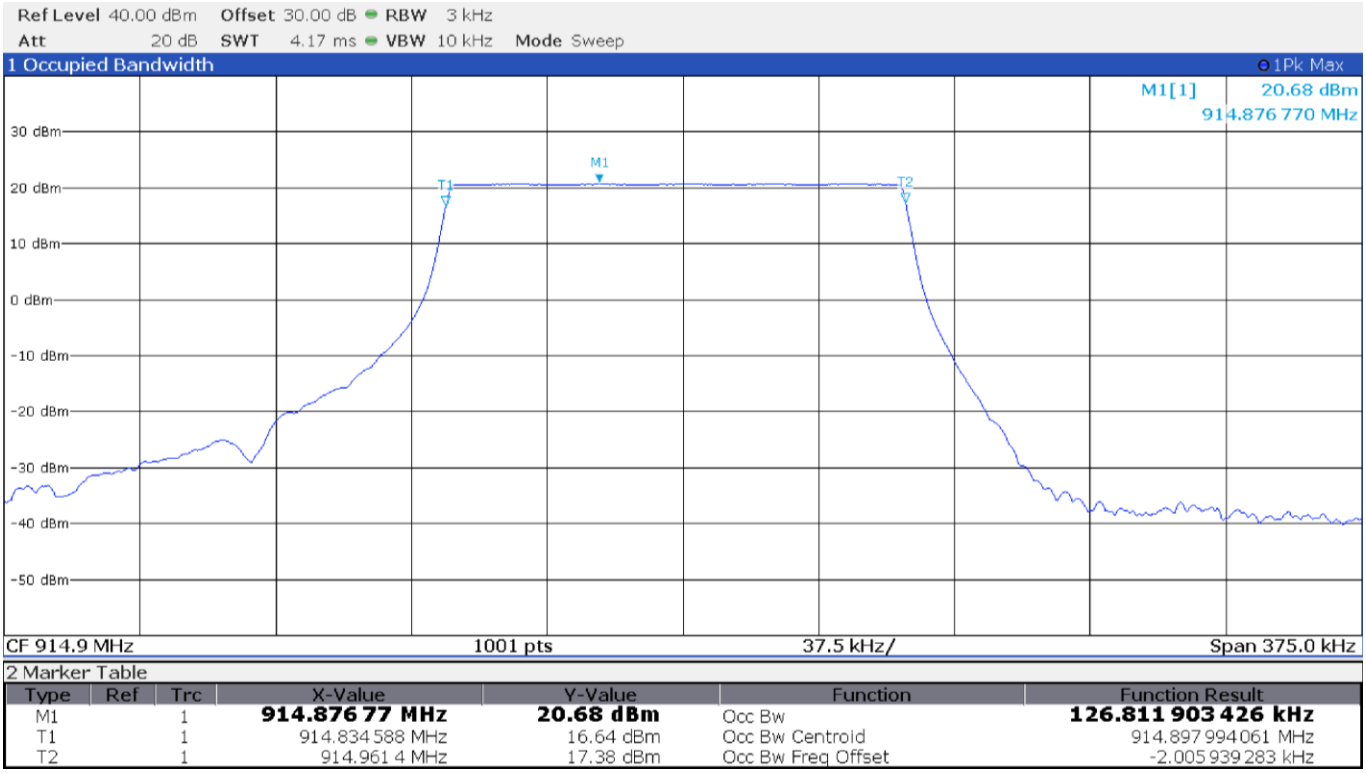


Figure 8.5-6: *99% bandwidth on high channel for LoRa 125 kHz BW*

Test data, continued

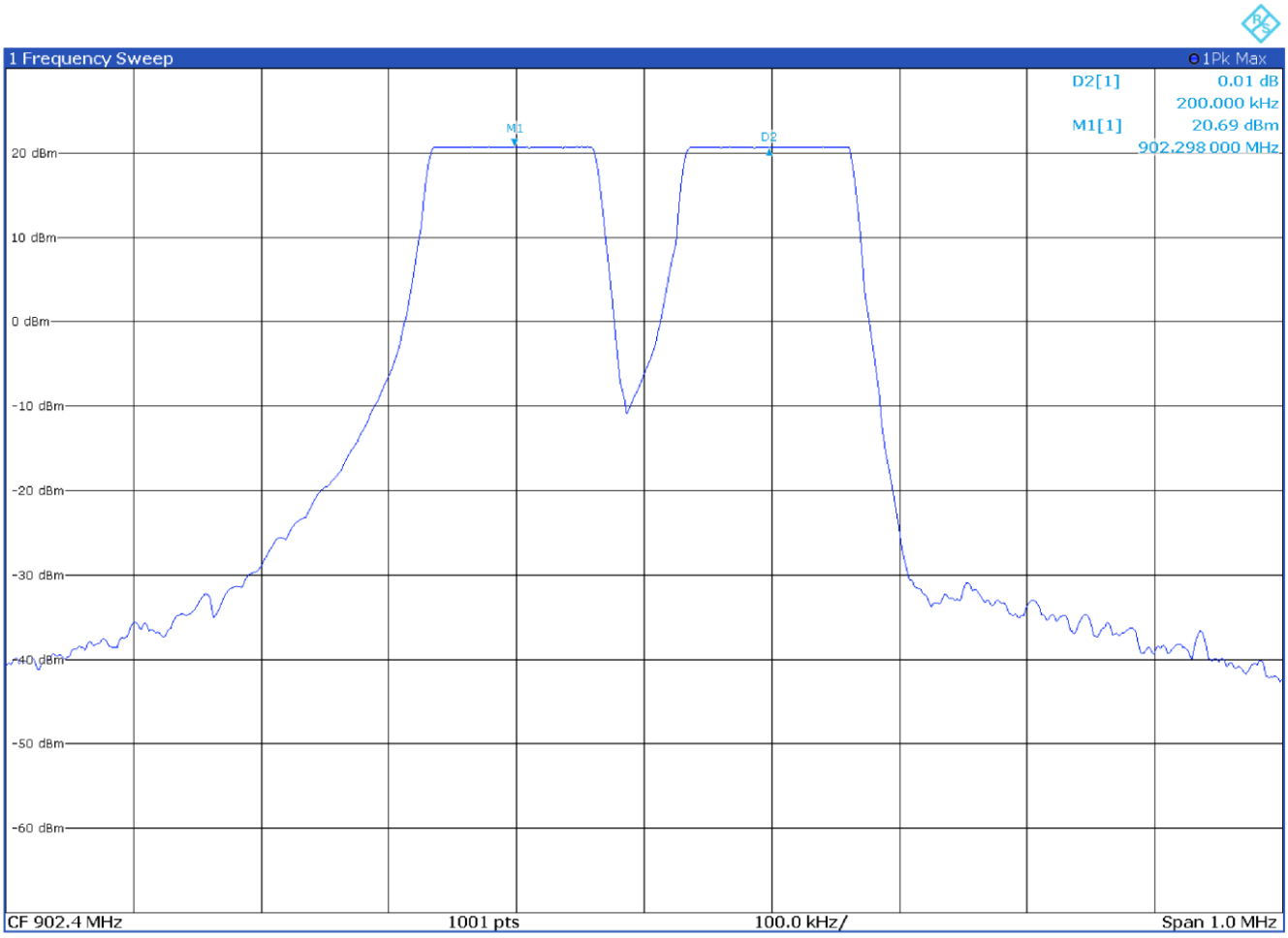


Figure 8.5-7: *Carrier frequency separation for LoRa 125 kHz BW*

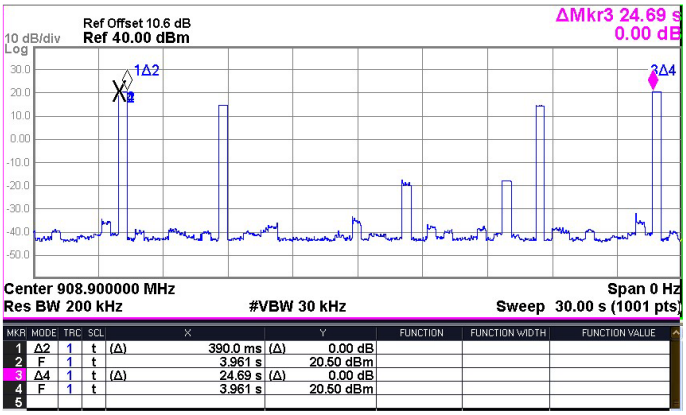


Figure 8.5-8: *Dwell time for LoRa 125 kHz BW*

[TEST DATE & TIME]
16/06/2022 17:51:26 (UTC2H)

[LINK MESSAGE]

```
 L CH DR SF  BW    Pow  Time  DEL FCNT Adr Ack FP AAR B Port M   Dwell   CMD                    CNTS
 [AES Encryption]
 U  5  3  7  125   18.7  30.3s -  0077  1  0    -   0 0  100 U     66  DataUp             ByteLen=14
[17:51:30.609] 40 01 00 00 00 80 77 00 64 80 0C C6 00 00 14 00 0A BE FE E0 3E 06 14 45 9F DA 6C

 D  5 13  7  500  -30.0 ------ 1  0046  1  0    0   - -  224 U     14  EchoPayloadReq     EchoLen=10
[17:51:31.675] 60 01 00 00 00 80 46 00 E0 08 01 02 03 04 05 06 07 08 09 0A 98 55 0E 05

 U  6  3  7  125   23.2  1.09s -  0078  1  0    -   0 0  224 U     61  EchoPayloadAns     Echo PASS
[17:51:31.703] 40 01 00 00 00 80 78 00 E0 08 02 03 04 05 06 07 08 09 0A 0B 47 28 50 56

 D  6 13  7  500  -30.0 ------ 1  0047  1  0    0   - -  224 U     16  EchoPayloadReq     EchoLen=16
[17:51:32.764] 60 01 00 00 00 80 47 00 E0 08 01 02 03 04 05 06 07 08 09 0A 0B 0C 0D 0E 0F 10 F2 C8 32 11

 U  0  3  7  125   30.7  1.11s -  0079  1  0    -   0 0  224 U     71  EchoPayloadAns     Echo PASS
[17:51:32.795] 40 01 00 00 00 80 79 00 E0 08 02 03 04 05 06 07 08 09 0A 0B 0C 0D 0E 0F 10 11 9E 1D 5D E7

 D  0 13  7  500  -30.0 ------ 1  0048  1  0    0   - -  224 U     17  EchoPayloadReq     EchoLen=20
[17:51:33.866] 60 01 00 00 00 80 48 00 E0 08 01 02 03 04 05 06 07 08 09 0A 0B 0C 0D 0E 0F 10 11 12 13 14 05 F1 E3 84

 U  4  3  7  125   30.7  1.11s -  007A  1  0    -   0 0  224 U     77  EchoPayloadAns     Echo PASS
[17:51:33.897] 40 01 00 00 00 80 7A 00 E0 08 02 03 04 05 06 07 08 09 0A 0B 0C 0D 0E 0F 10 11 12 13 14 15 14 62 1F 4D

 D  4 13  7  500  -30.0 ------ 1  0049  1  0    0   - -  224 U     98  EchoPayloadReq     EchoLen=241
[17:51:34.974] 60 01 00 00 00 80 49 00 E0 08 01 02 03 04 05 06 07 08 09 0A 0B 0C 0D 0E 0F 10 11 12 13 14 15 16 17 18 19 1A
1B 1C 1D 1E 1F 20 21 22 23 24 25 26 27 28 29 2A 2B 2C 2D 2E 2F 30 31 32 33 34 35 36 37 38 39 3A 3B 3C 3D 3E 3F 40 41 42 43 44 45 46
47 48 49 4A 4B 4C 4D 4E 4F 50 51 52 53 54 55 56 57 58 59 5A 5B 5C 5D 5E 5F 60 61 62 63 64 65 66 67 68 69 6A 6B 6C 6D 6E 6F 70 71 72
73 74 75 76 77 78 79 7A 7B 7C 7D 7E 7F 80 81 82 83 84 85 86 87 88 89 8A 8B 8C 8D 8E 8F 90 91 92 93 94 95 96 97 98 99 9A 9B 9C 9D 9E
9F A0 A1 A2 A3 A4 A5 A6 A7 A8 A9 AA AB AC AD AE AF B0 B1 B2 B3 B4 B5 B6 B7 B8 B9 BA BB BC BD BE BF C0 C1 C2 C3 C4 C5 C6 C7 C8 C9 CA
CB CC CD CE CF D0 D1 D2 D3 D4 D5 D6 D7 D8 D9 DA DB DC DD DE DF E0 E1 E2 E3 E4 E5 E6 E7 E8 E9 EA EB EC ED EE EF F0 F1 51 39 FE BB

 U  1  3  7  125   18.8  1.53s -  007B  1  0    -   0 0  224 U    390  EchoPayloadAns     Echo PASS
[17:51:35.098] 40 01 00 00 00 80 7B 00 E0 08 02 03 04 05 06 07 08 09 0A 0B 0C 0D 0E 0F 10 11 12 13 14 15 16 17 18 19 1A 1B
1C 1D 1E 1F 20 21 22 23 24 25 26 27 28 29 2A 2B 2C 2D 2E 2F 30 31 32 33 34 35 36 37 38 39 3A 3B 3C 3D 3E 3F 40 41 42 43 44 45 46 47
48 49 4A 4B 4C 4D 4E 4F 50 51 52 53 54 55 56 57 58 59 5A 5B 5C 5D 5E 5F 60 61 62 63 64 65 66 67 68 69 6A 6B 6C 6D 6E 6F 70 71 72 73
74 75 76 77 78 79 7A 7B 7C 7D 7E 7F 80 81 82 83 84 85 86 87 88 89 8A 8B 8C 8D 8E 8F 90 91 92 93 94 95 96 97 98 99 9A 9B 9C 9D 9E 9F
A0 A1 A2 A3 A4 A5 A6 A7 A8 A9 AA AB AC AD AE AF B0 B1 B2 B3 B4 B5 B6 B7 B8 B9 BA BB BC BD BE BF C0 C1 C2 C3 C4 C5 C6 C7 C8 C9 CA CB
CC CD CE CF D0 D1 D2 D3 D4 D5 D6 D7 D8 D9 DA DB DC DD DE DF E0 E1 E2 E3 E4 E5 E6 E7 E8 E9 EA EB EC ED EE EF F0 F1 F2 4D 31 A7 D8
```

8.6 Transmitter output power and e.i.r.p. requirements for FHSS 900 MHz

8.6.1 References, definitions and limits

FCC §15.247:

(b) The maximum peak conducted output power of the intentional radiator shall not exceed the following:

(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.

(4) The conducted output power limit specified in paragraph (b) of this section is based on the use of antennas with directional gains that do not exceed 6 dBi. Except as shown in paragraph (c) of this section, if transmitting antennas of directional gain greater than 6 dBi are used, the conducted output power from the intentional radiator shall be reduced below the stated values in paragraphs (b)(1), (b)(2), and (b)(3) of this section, as appropriate, by the amount in dB that the directional gain of the antenna exceeds 6 dBi.

RSS-247, Clause 5.4:

Devices shall comply with the following requirements, where applicable:

a. For FHSs operating in the band 902–928 MHz, the maximum peak conducted output power shall not exceed 1.0 W, and the e.i.r.p. shall not exceed 4 W if the hopset uses 50 or more hopping channels; the maximum peak conducted output power shall not exceed 0.25 W and the e.i.r.p. shall not exceed 1 W if the hopset uses less than 50 hopping channels.

8.6.2 Test summary

Verdict	Pass		
Tested by	P. Barbieri	Test date	May 31, 2024

8.6.3 Observations, settings and special notes

Conducted output power was tested per ANSI C63.10 subclause 7.8.5. The hopping shall be disabled for this test. Spectrum analyser settings:

Resolution bandwidth	> 20 dB bandwidth of the emission being measured
Video bandwidth	≥ RBW
Frequency span	approximately 5 times the 20 dB bandwidth, centered on a hopping channel
Detector mode	Peak
Trace mode	Max Hold

8.6.4 Test equipment used

Equipment	Manufacturer	Model no.	Asset no.
Spectrum Analyzer	Rohde & Schwarz	FSW43	101767

8.6.5 Test data

Table 8.6-1: *Output power and EIRP results for LoRa 125 kHz BW*

Frequency, MHz	Output power, dBm	Output power limit, dBm	Margin, dB	Antenna gain, dBi	EIRP, dBm	EIRP limit, dBm	EIRP margin, dB
902.3	20.9	30.00	-9.1	0	20.9	36.00	-15.1
908.5	20.9	30.00	-9.1	0	20.9	36.00	-15.1
914.9	20.9	30.00	-9.1	0	20.9	36.00	-15.1

Notes: EIRP = Output power + Antenna gain (assuming a maximum antenna gain of 0 dBi)

Test data, continued

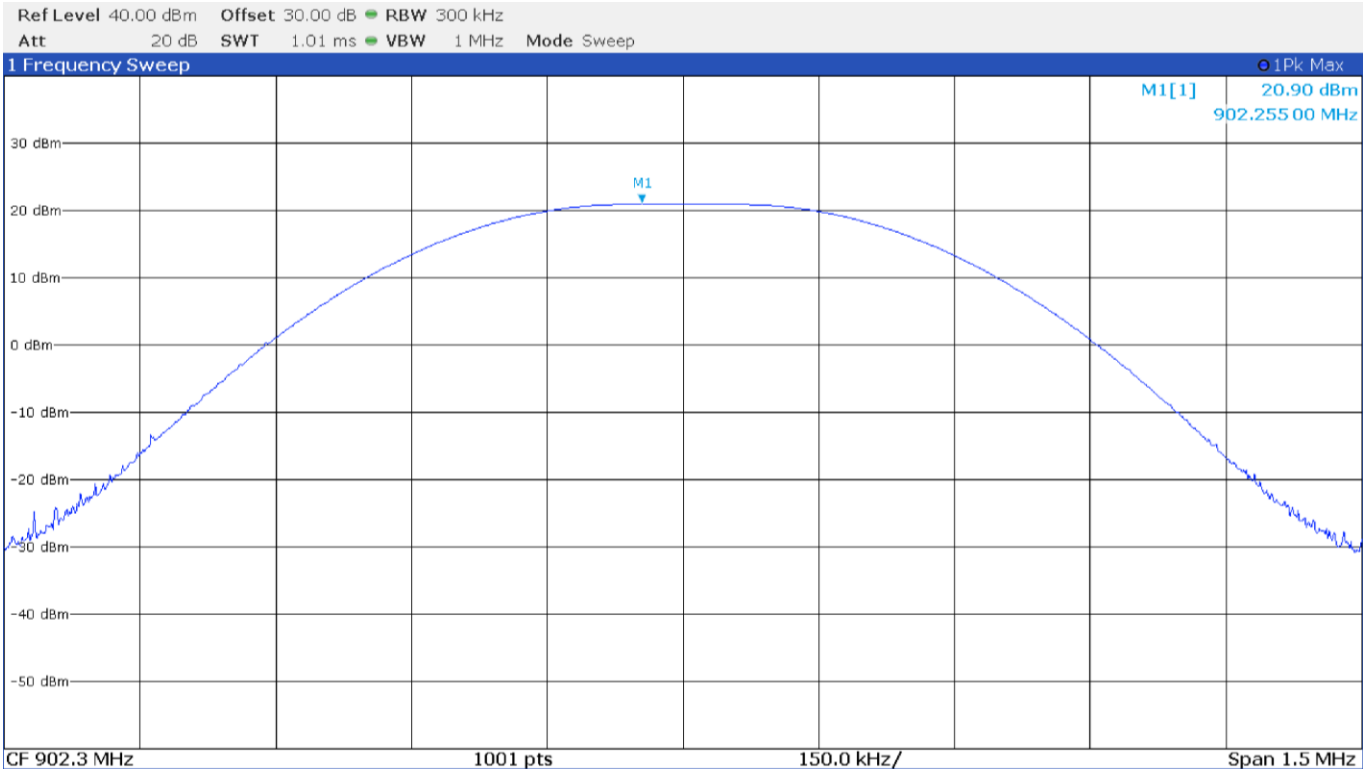


Figure 8.6-1: *Output power on low channel for LoRa 125 kHz BW*

Test data, continued

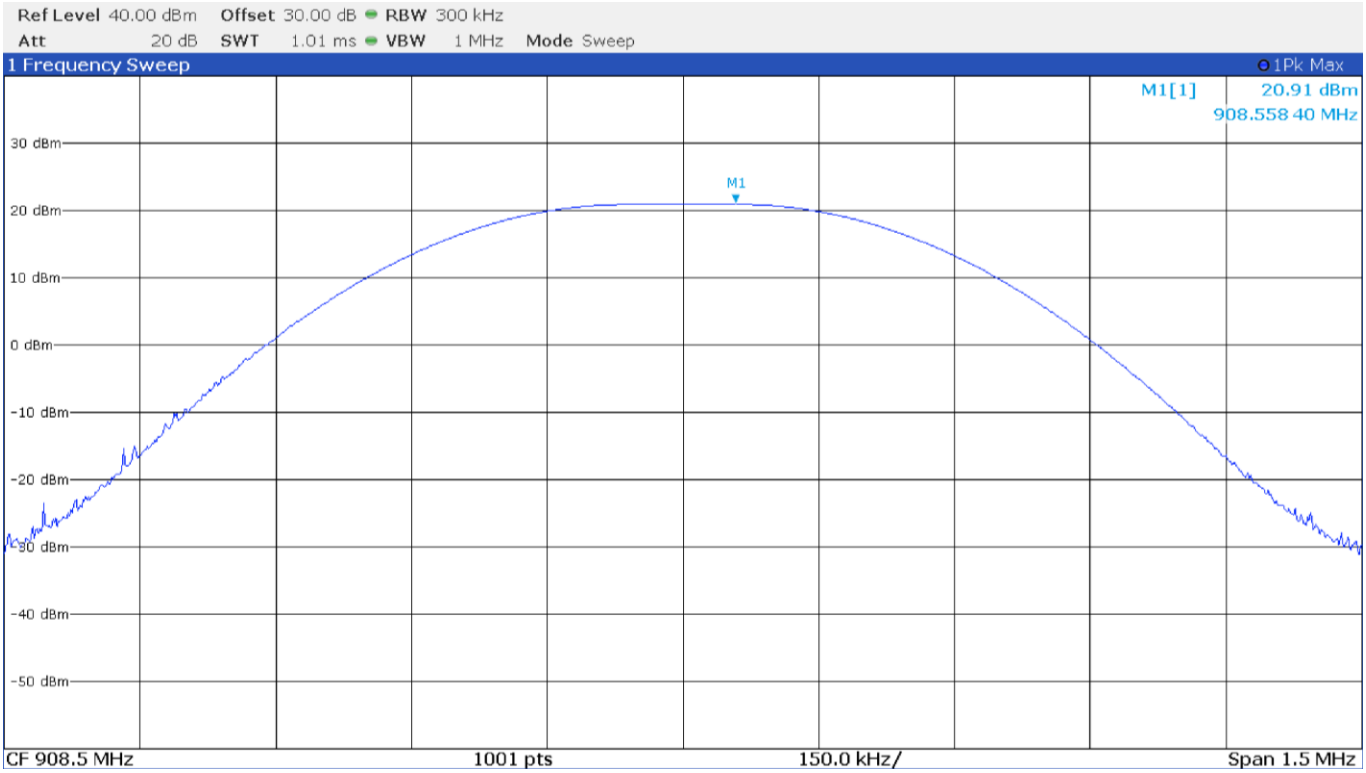


Figure 8.6-2: *Output power on mid channel for LoRa 125 kHz BW*

Test data, continued

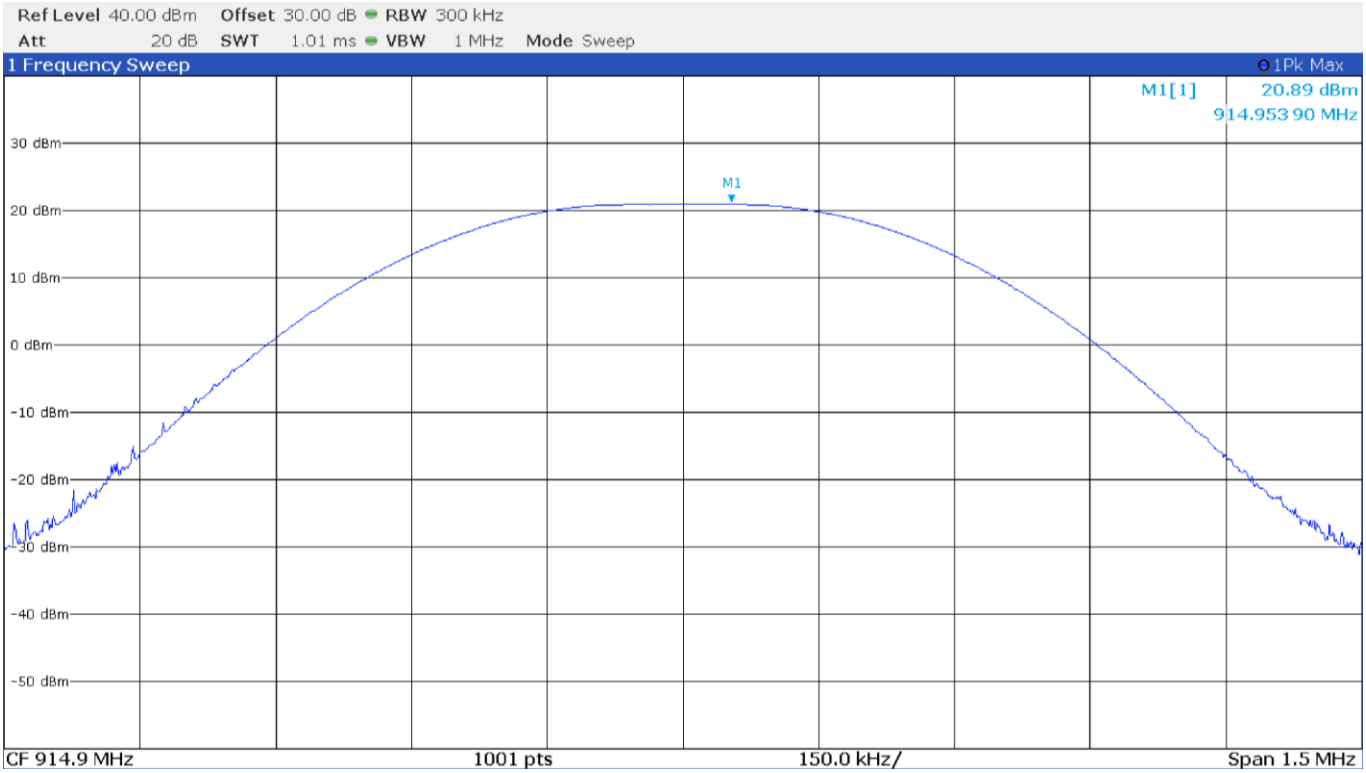


Figure 8.6-3: *Output power on high channel for LoRa 125 kHz BW*

8.7 Minimum 6 dB bandwidth for DTS systems

8.7.1 References, definitions and limits

FCC §15.247:

(a) Operation under the provisions of this Section is limited to frequency hopping and digitally modulated intentional radiators that comply with the following provisions:

(2) Systems using digital modulation techniques may operate in the 902–928 MHz, 2400–2483.5 MHz, and 5725–5850 MHz bands. The minimum 6 dB bandwidth shall be at least 500 kHz.

RSS-247, Clause 5.2:

DTSs include systems that employ digital modulation techniques resulting in spectral characteristics similar to direct sequence systems. The following applies to the bands 902-928 MHz and 2400-2483.5 MHz:

a. The minimum 6 dB bandwidth shall be 500 kHz.

RSS-Gen, Clause 6.7:

6 dB bandwidth is defined as the frequency range between two points, one at the lowest frequency below and one at the highest frequency above the carrier frequency, at which the maximum power level of the transmitted emission is attenuated 6 dB below the maximum in-band power level of the modulated signal, where the two points are on the outskirts of the in-band emission.

For the 99% emission bandwidth, the trace data points are recovered and directly summed in linear power level terms. The recovered amplitude data points, beginning at the lowest frequency, are placed in a running sum until 0.5% of the total is reached, and that frequency recorded. The process is repeated for the highest frequency data points (starting at the highest frequency, at the right side of the span, and going down in frequency). This frequency is then recorded. The difference between the two recorded frequencies is the occupied bandwidth (or the 99% emission bandwidth).

8.7.2 Test summary

Verdict	Pass		
Tested by	P. Barbieri	Test date	May 31, 2024

8.7.3 Observations, settings and special notes

The test was performed as per KDB 558074, section 8.2 with reference to ANSI C63.10 subclause 11.8.
Spectrum analyser settings:

Resolution bandwidth	6 dB BW: 100 kHz; 99% OBW: 1–5% of OBW
Video bandwidth	≥3 × RBW
Frequency span	≥3 × OBW
Detector mode	Peak
Trace mode	Max Hold

8.7.4 Test equipment used

Equipment	Manufacturer	Model no.	Asset no.
Spectrum Analyzer	Rohde & Schwarz	FSW43	101767

8.7.5 Test data

Table 8.7-1: *99% occupied bandwidth results*

Modulation	Frequency, MHz	99% occupied bandwidth, kHz
LoRa 500 kHz BW	903.0	504.2
LoRa 500 kHz BW	907.8	504.5
LoRa 500 kHz BW	914.2	504.2
LR-FHSS	903.0	1567.7
LR-FHSS	907.8	1552.3
LR-FHSS	914.2	1566.2

Notes: There is no 99% occupied bandwidth limit in the standard's requirements, the measurement results provided for information purposes only.

Table 8.7-2: *6 dB bandwidth results*

Modulation	Frequency, MHz	6 dB bandwidth, MHz	Minimum limit, MHz	Margin, MHz
LoRa 500 kHz BW	903.0	0.65	0.500	-0.15
	907.8	0.65	0.500	-0.15
	914.2	0.64	0.500	-0.14
LR-FHSS	903.0	1.65	0.500	-1.15
	907.8	1.65	0.500	-1.15
	914.2	1.64	0.500	-1.14

Test data, continued

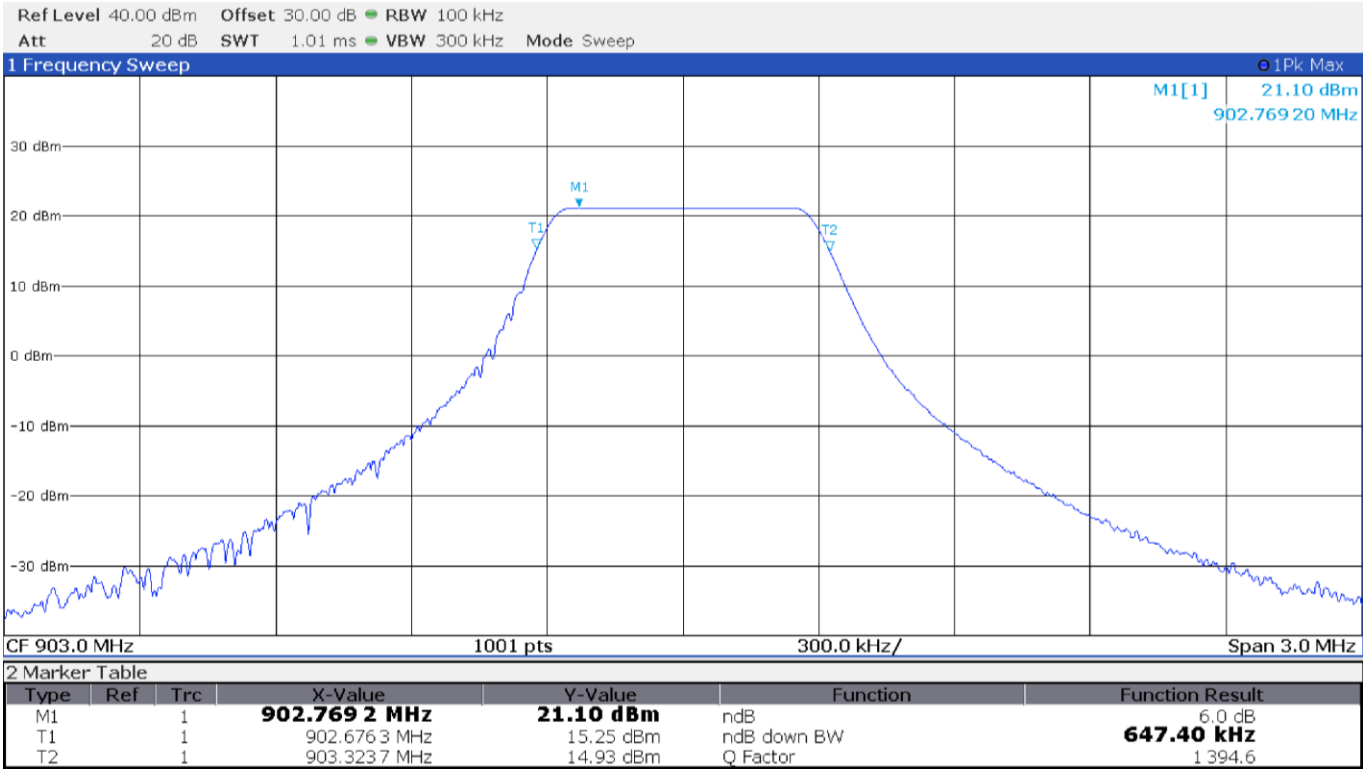


Figure 8.7-1: *6 dB bandwidth on low channel for LoRa 500 kHz BW*

Test data, continued

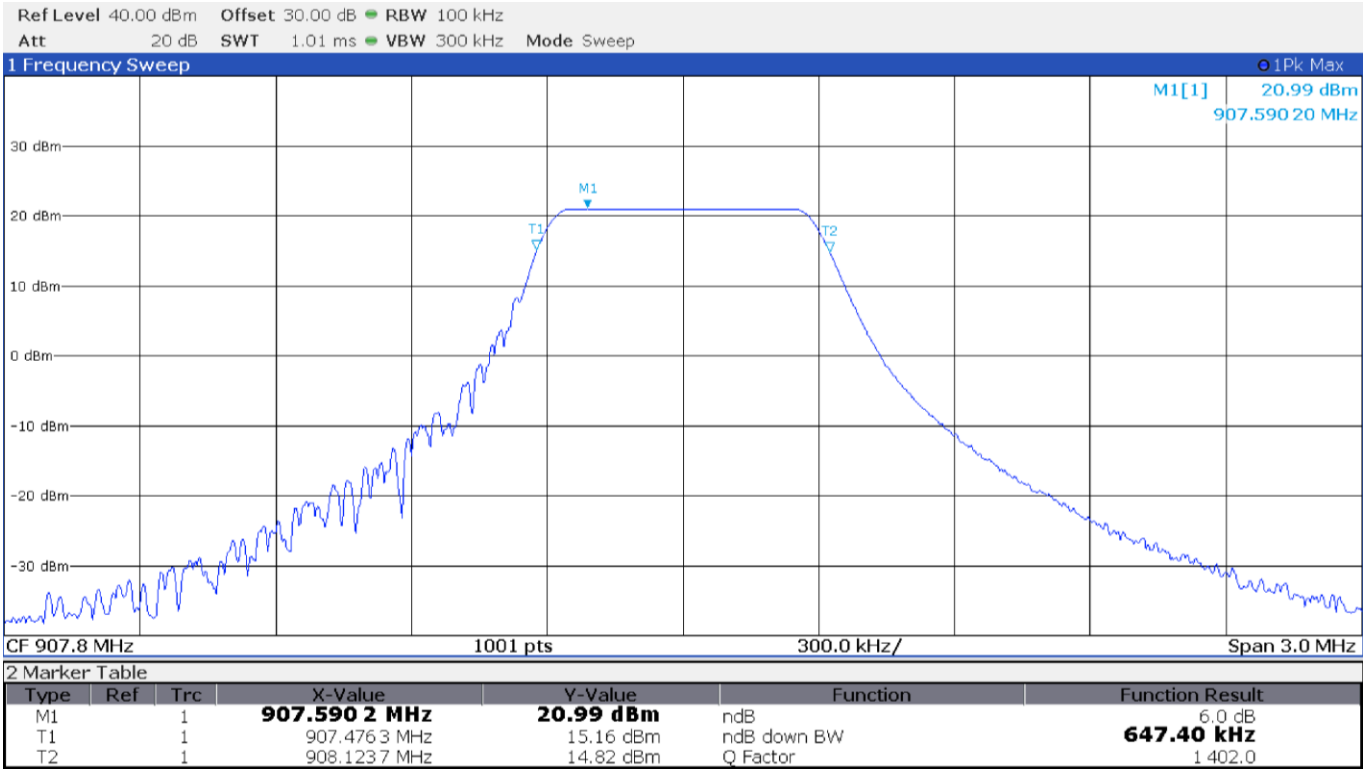


Figure 8.7-2: *6 dB bandwidth on mid for channel LoRa 500 kHz BW*

Test data, continued

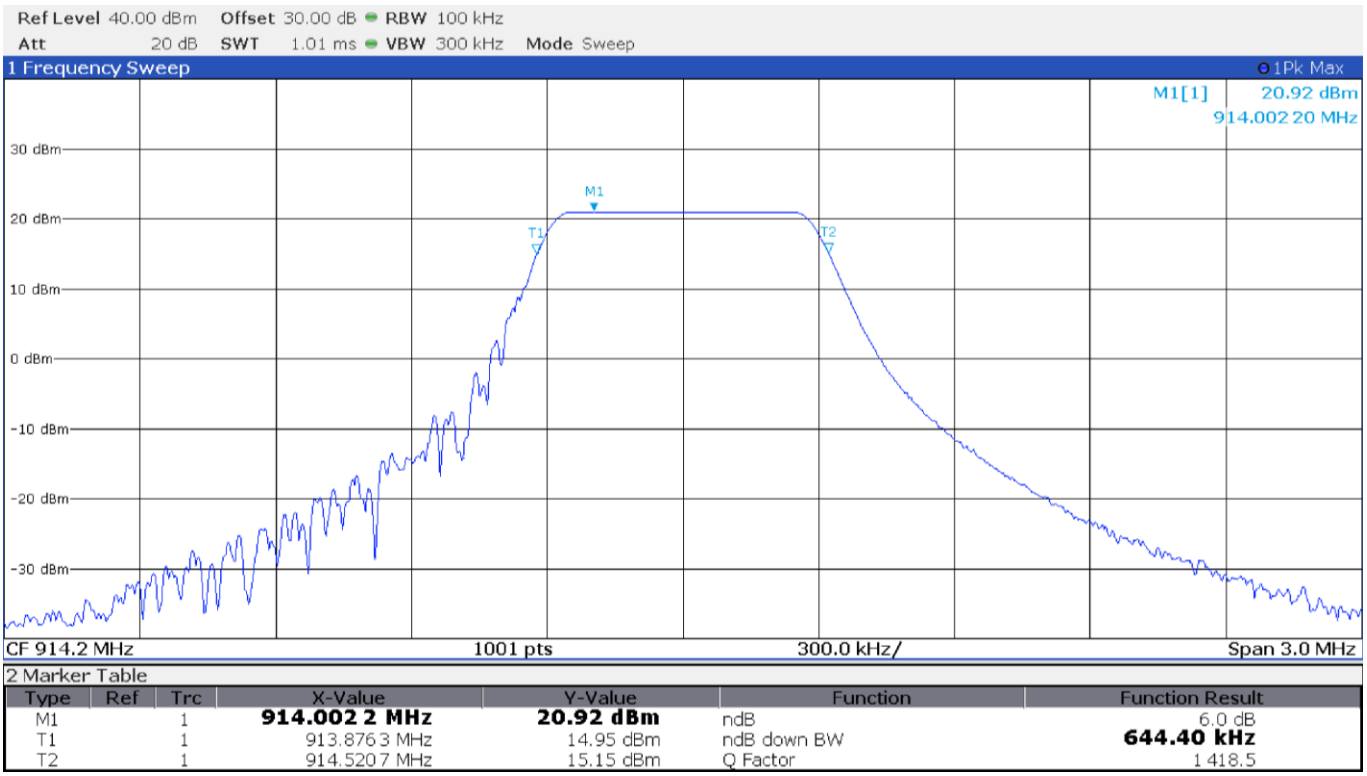


Figure 8.7-3: *6 dB bandwidth on high channel for LoRa 500 kHz BW*

Test data, continued

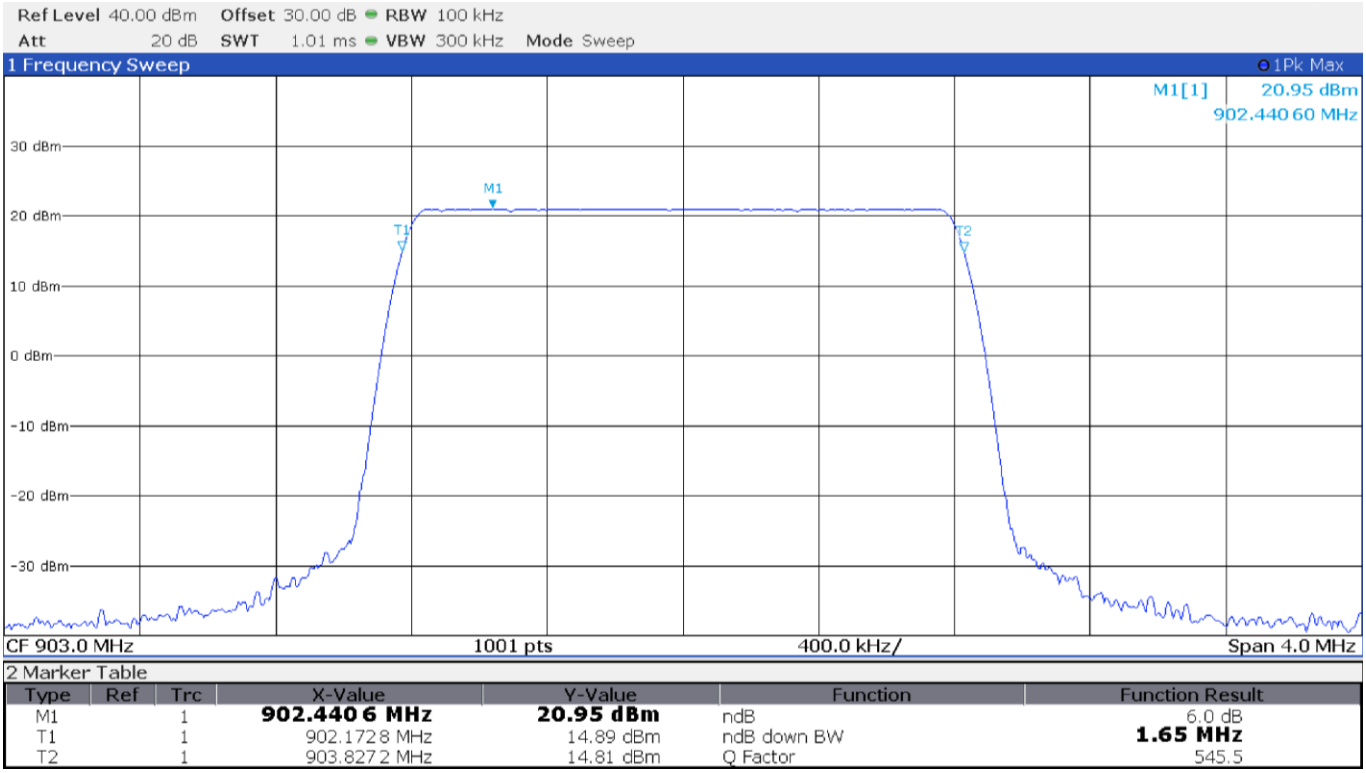


Figure 8.7-4: *6 dB bandwidth on low channel for LR-FHSS*

Test data, continued

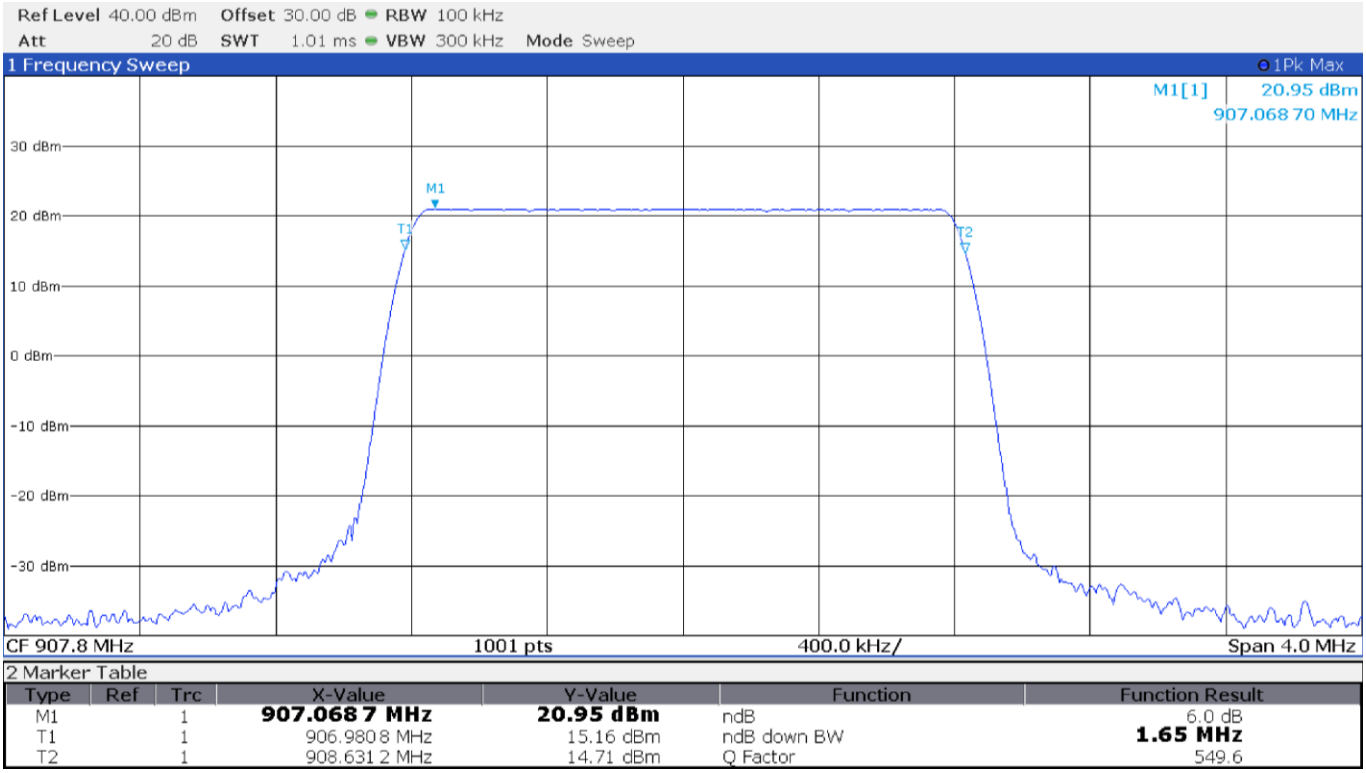


Figure 8.7-5: *6 dB bandwidth on mid channel for LR-FHSS*

Test data, continued

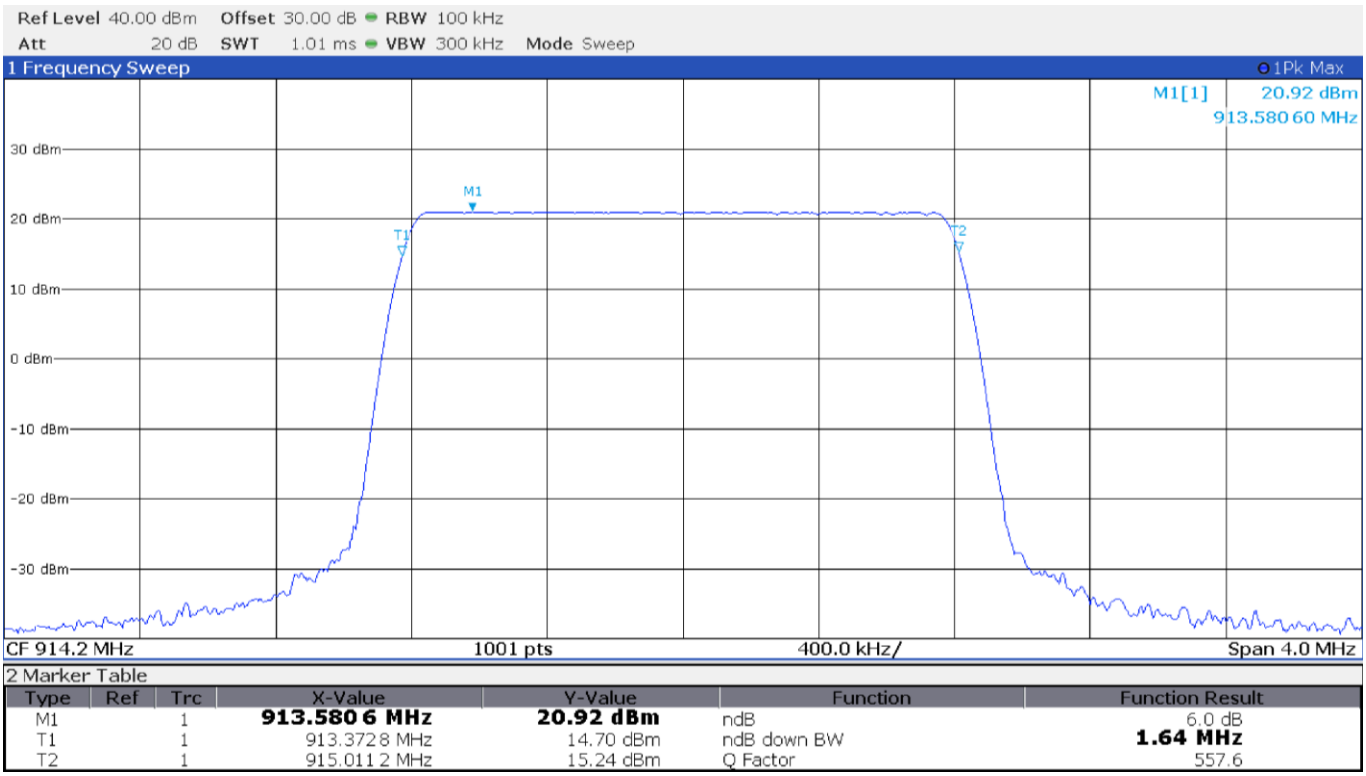


Figure 8.7-6: *6 dB bandwidth on high channel for LR-FHSS*

Test data, continued

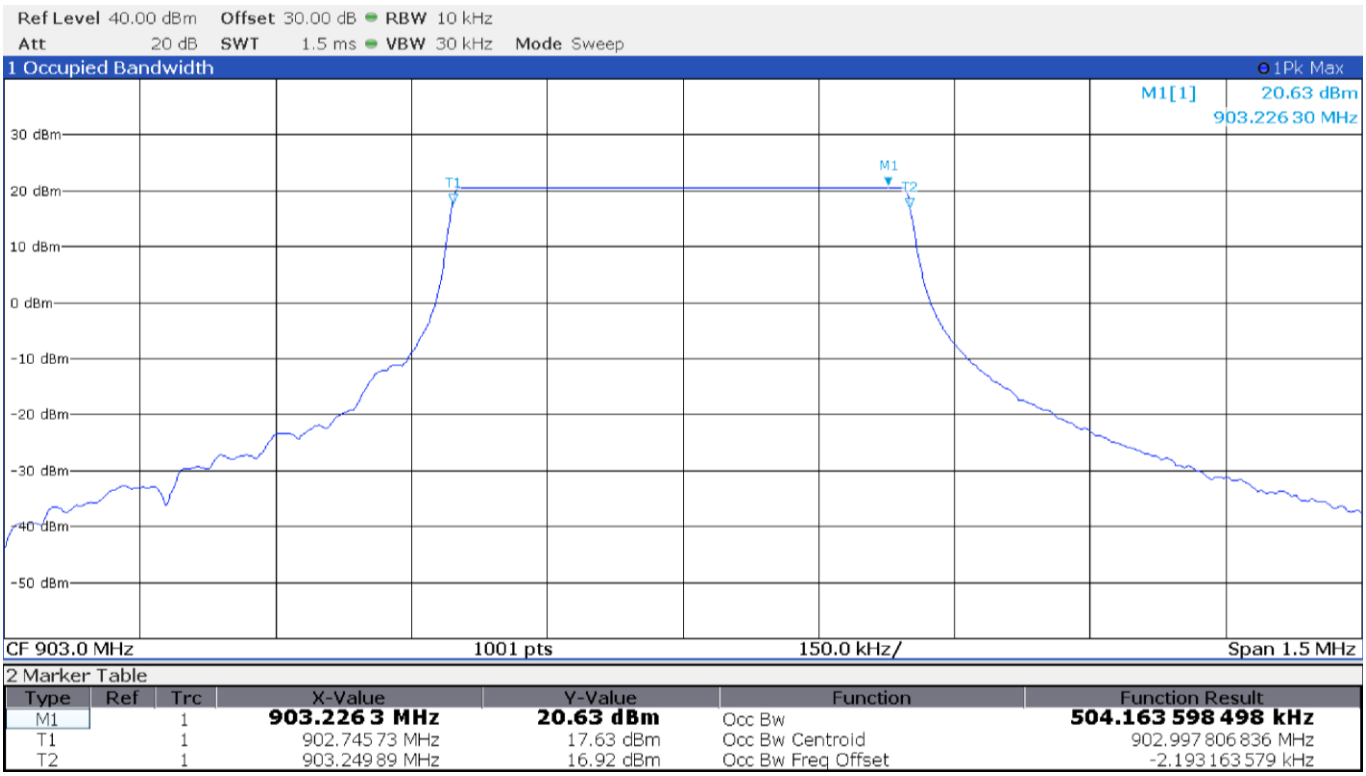


Figure 8.7-7: *99% bandwidth on low channel for LoRa 500 kHz BW*

Test data, continued

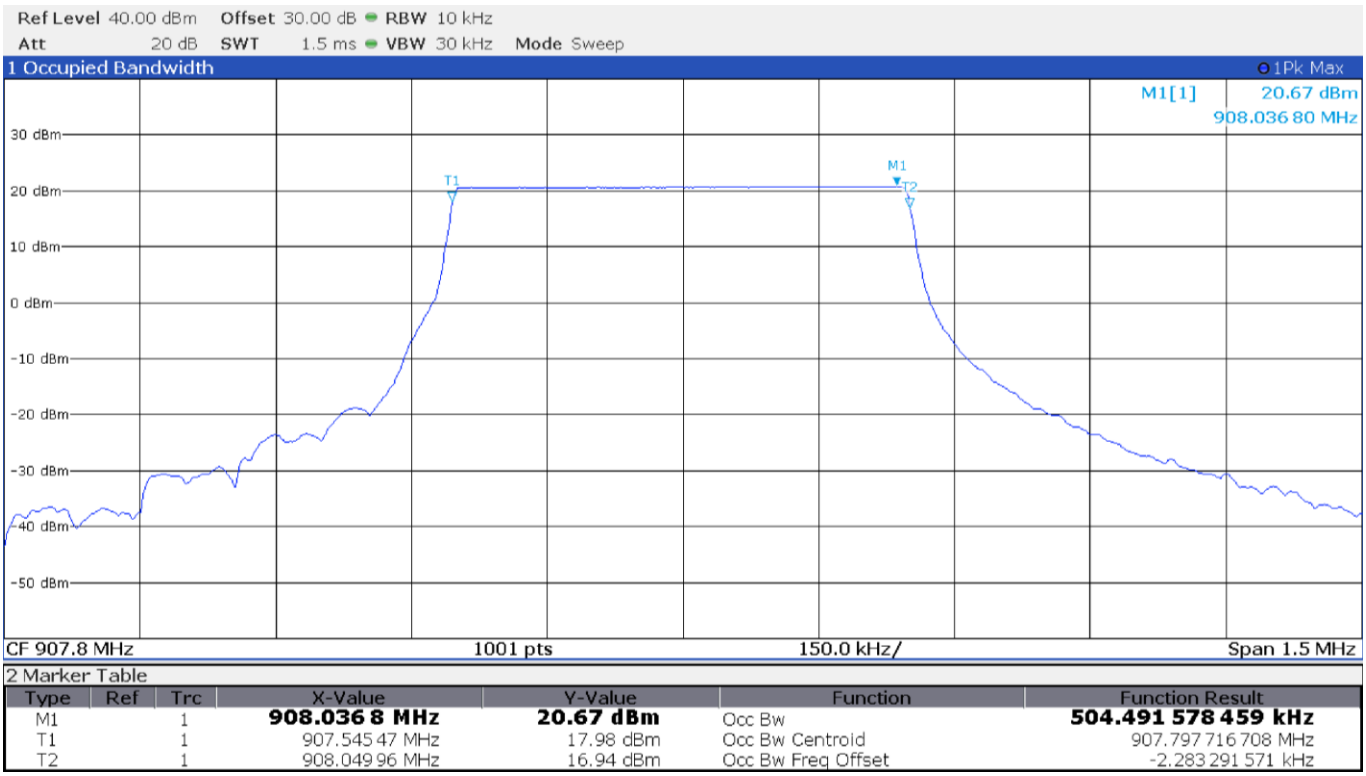


Figure 8.7-8: *99% bandwidth on mid channel for LoRa 500 kHz BW*

Test data, continued

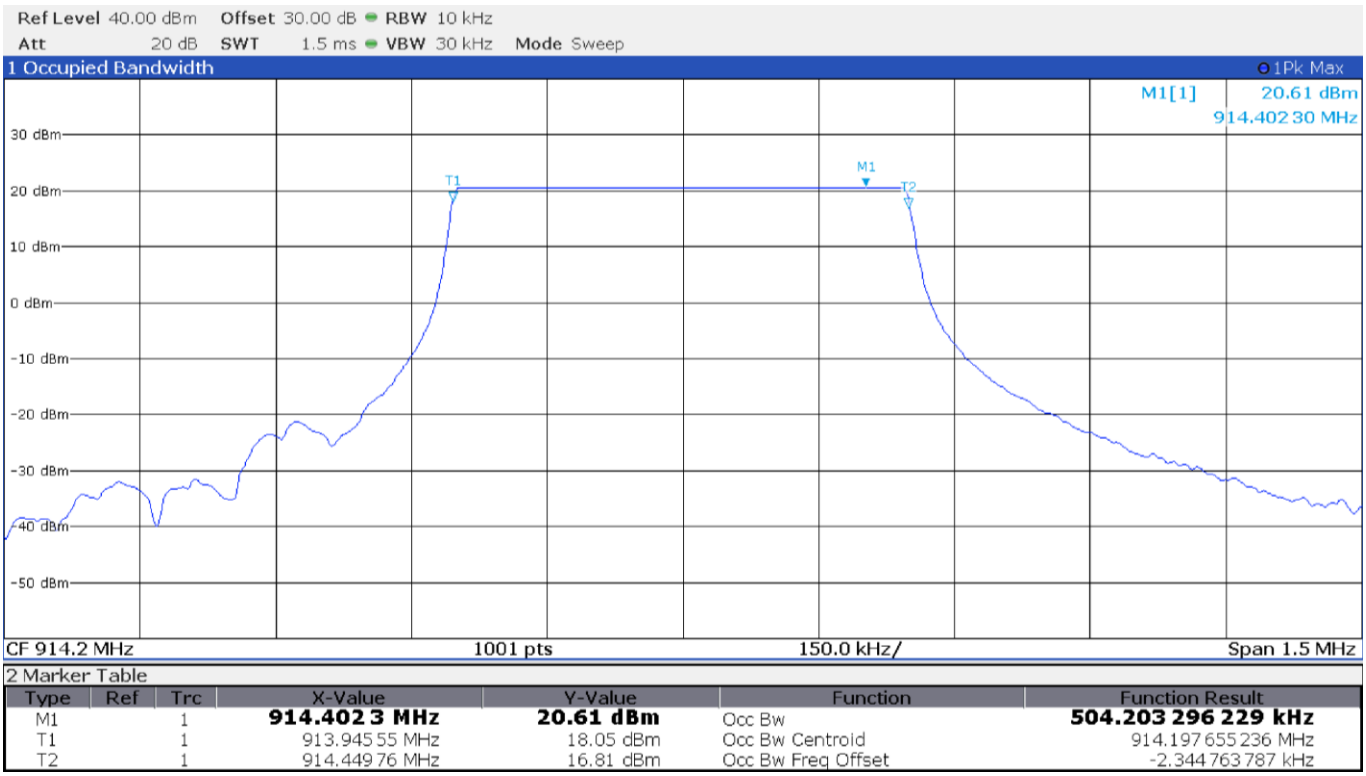


Figure 8.7-9: *99% bandwidth on high channel for LoRa 500 kHz BW*

Test data, continued

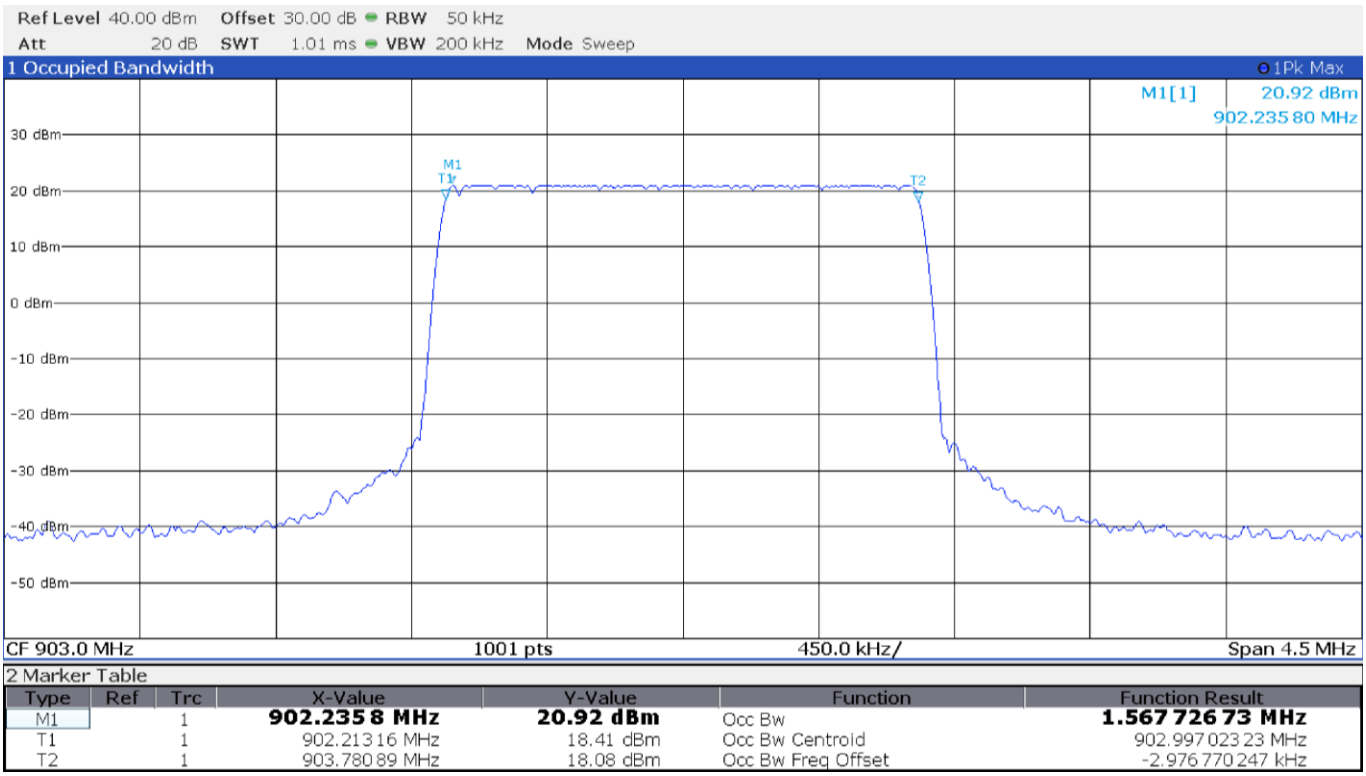


Figure 8.7-10: *99% bandwidth on low channel for LR-FHSS*

Test data, continued

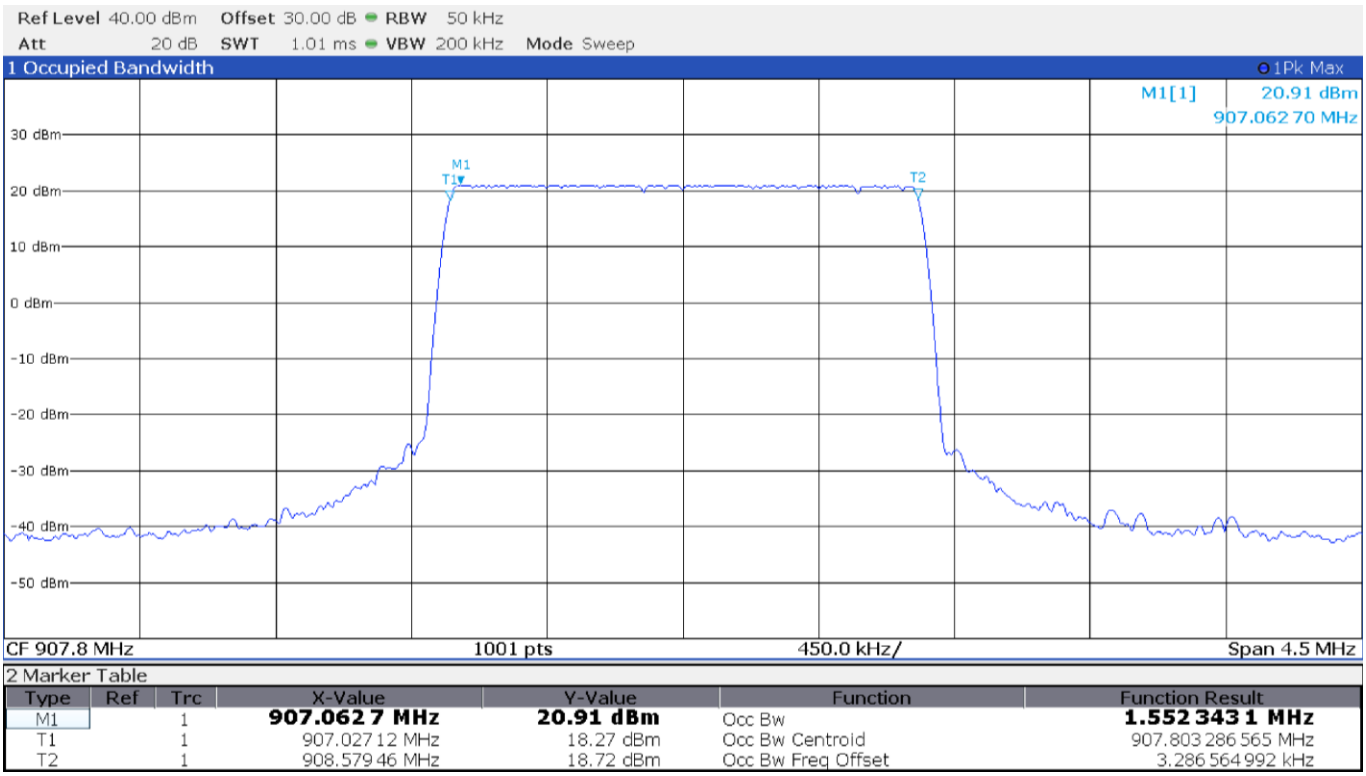


Figure 8.7-11: *99% bandwidth on mid channel for LR-FHSS*

Test data, continued

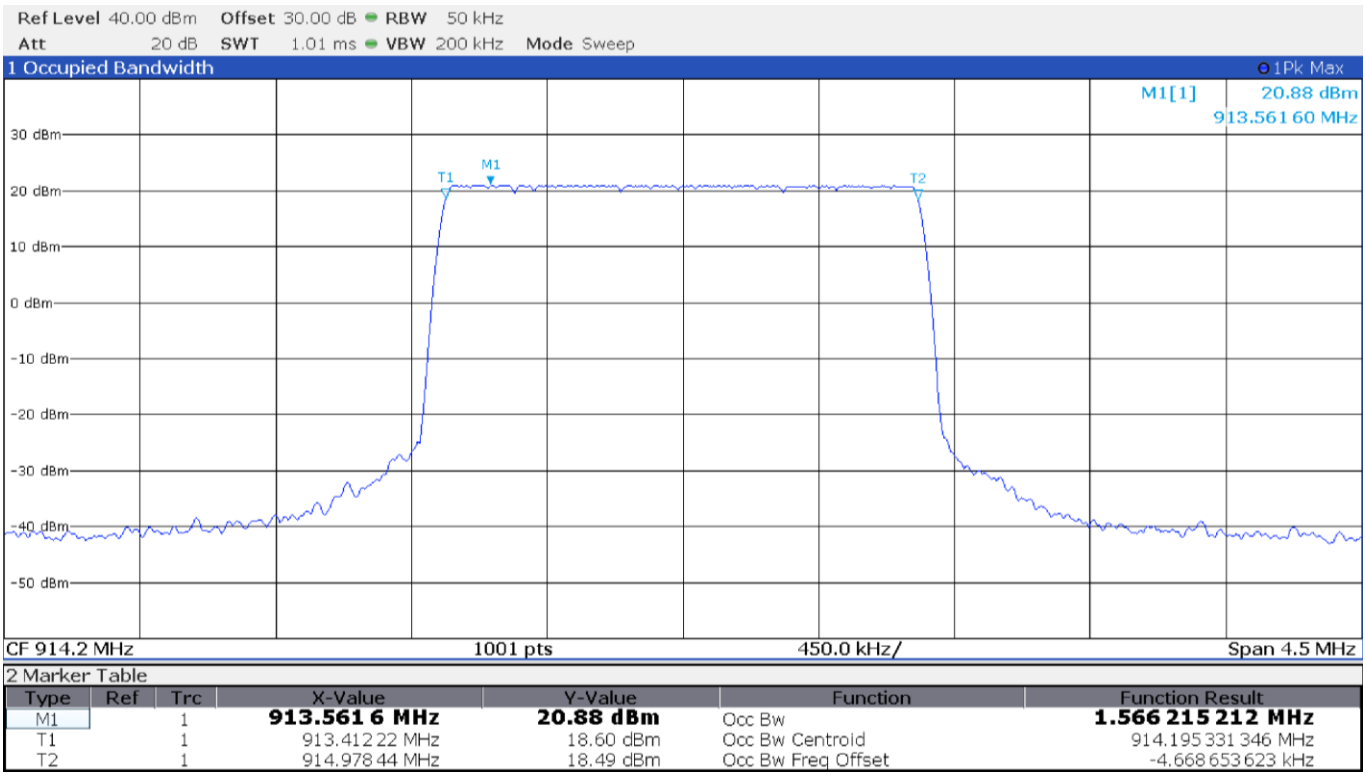


Figure 8.7-12: *99% bandwidth on high channel for LR-FHSS*

8.8 Transmitter output power and e.i.r.p. requirements for DTS in 900 MHz

8.8.1 References, definitions and limits

FCC §15.247:

(b) The maximum peak conducted output power of the intentional radiator shall not exceed the following:

(3) For systems using digital modulation in the 902–928 MHz band: 1 W (30 dBm). As an alternative to a peak power measurement, compliance with the one Watt limit can be based on a measurement of the maximum conducted output power. Maximum Conducted Output Power is defined as the total transmit power delivered to all antennas and antenna elements averaged across all symbols in the signaling alphabet when the transmitter is operating at its maximum power control level. Power must be summed across all antennas and antenna elements. The average must not include any time intervals during which the transmitter is off or is transmitting at a reduced power level. If multiple modes of operation are possible (e.g., alternative modulation methods), the maximum conducted output power is the highest total transmit power occurring in any mode.

(4) The conducted output power limit specified in paragraph (b) of this section is based on the use of antennas with directional gains that do not exceed 6 dBi. Except as shown in paragraph (c) of this section, if transmitting antennas of directional gain greater than 6 dBi are used, the conducted output power from the intentional radiator shall be reduced below the stated values in paragraphs (b)(1), (b)(2), and (b)(3) of this section, as appropriate, by the amount in dB that the directional gain of the antenna exceeds 6 dBi.

(c) Operation with directional antenna gains greater than 6 dBi.

(1) Fixed point-to-point operation:

(iii) Fixed, point-to-point operation, as used in paragraphs (c)(1)(i) and (c)(1)(ii) of this section, excludes the use of point-to-multipoint systems, omnidirectional applications, and multiple co-located intentional radiators transmitting the same information. The operator of the spread spectrum or digitally modulated intentional radiator or, if the equipment is professionally installed, the installer is responsible for ensuring that the system is used exclusively for fixed, point-to-point operations. The instruction manual furnished with the intentional radiator shall contain language in the installation instructions informing the operator and the installer of this responsibility.

RSS-247, Clause 5.4:

Devices shall comply with the following requirements, where applicable:

d. For DTSs employing digital modulation techniques operating in the 902–928 MHz band, the maximum peak conducted output power shall not exceed 1 W. The e.i.r.p. shall not exceed 4 W, except as provided in section 5.4(e).

As an alternative to a peak power measurement, compliance can be based on a measurement of the maximum conducted output power. The maximum conducted output power is the total transmit power delivered to all antennas and antenna elements, averaged across all symbols in the signalling alphabet when the transmitter is operating at its maximum power control level. Power must be summed across all antennas and antenna elements. The average must not include any time intervals during which the transmitter is off or transmitting at a reduced power level. If multiple modes of operation are implemented, the maximum conducted output power is the highest total transmit power occurring in any mode.

8.8.2 Test summary

Verdict	Pass		
Tested by	P. Barbieri	Test date	June 10, 2024

8.8.3 Observations, settings and special notes

The test was performed as per KDB 558074, section 8.3 with reference to ANSI C63.10 subclause 11.9.2 (average power) using method AVGSA-1 (trace averaging with the EUT transmitting at full power throughout each sweep).
Spectrum analyser settings:

Resolution bandwidth	3 kHz
Video bandwidth	≥3 × RBW
Frequency span	≥3 × OBW
Detector mode	RMS
Trace mode	Average with power integration

8.8.4 Test equipment used

Equipment	Manufacturer	Model no.	Asset no.
Spectrum Analyzer	Rohde & Schwarz	FSW43	101767

8.8.5 Test data

Table 8.8-1: *Output power and EIRP results (antenna port measurement) for LoRa 500 kHz BW*

Frequency, MHz	Conducted output power, dBm	Output power limit, dBm	Output power margin, dB	Antenna gain, dBi	EIRP, dBm	EIRP limit, dBm	EIRP margin, dB
903.0	20.7	30.0	-9.3	0	20.7	36.0	-15.3
907.8	20.6	30.0	-9.4	0	20.6	36.0	-15.4
914.2	20.7	30.0	-9.3	0	20.7	36.0	-15.3

Note: EIRP [dBm] = Conducted output power [dBm] + Antenna gain [dBi] (assuming a maximum antenna gain of 0 dBi)

Table 8.8-2: *Output power and EIRP results (antenna port measurement) for LR-FHSS*

Frequency, MHz	Conducted output power, dBm	Output power limit, dBm	Output power margin, dB	Antenna gain, dBi	EIRP, dBm	EIRP limit, dBm	EIRP margin, dB
903.0	20.9	30.0	-9.1	0	20.9	36.0	-15.1
907.8	20.9	30.0	-9.1	0	20.9	36.0	-15.1
914.2	20.8	30.0	-9.2	0	20.8	36.0	-15.2

Note: EIRP [dBm] = Conducted output power [dBm] + Antenna gain [dBi] (assuming a maximum antenna gain of 0 dBi)

Test data, continued

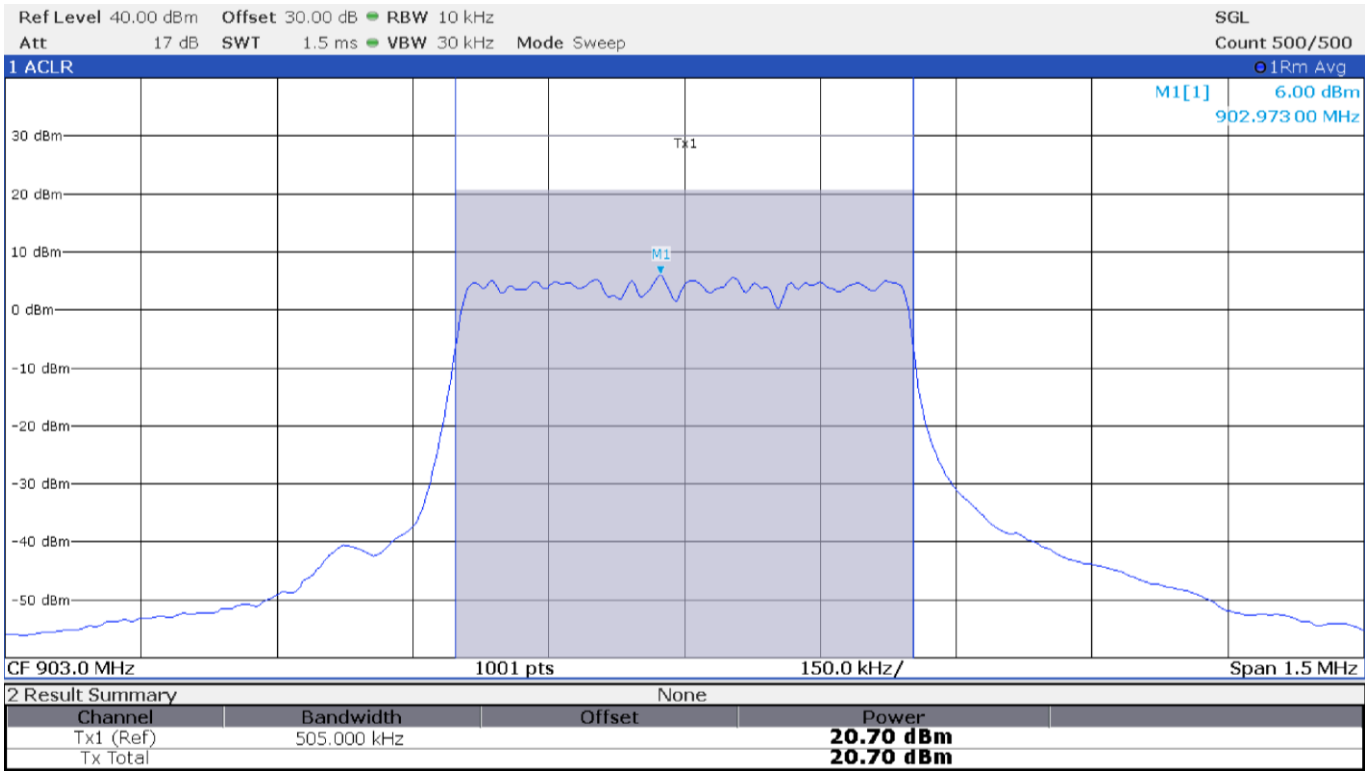


Figure 8.8-1: *Output power on low channel for LoRa 500 kHz BW*

Test data, continued

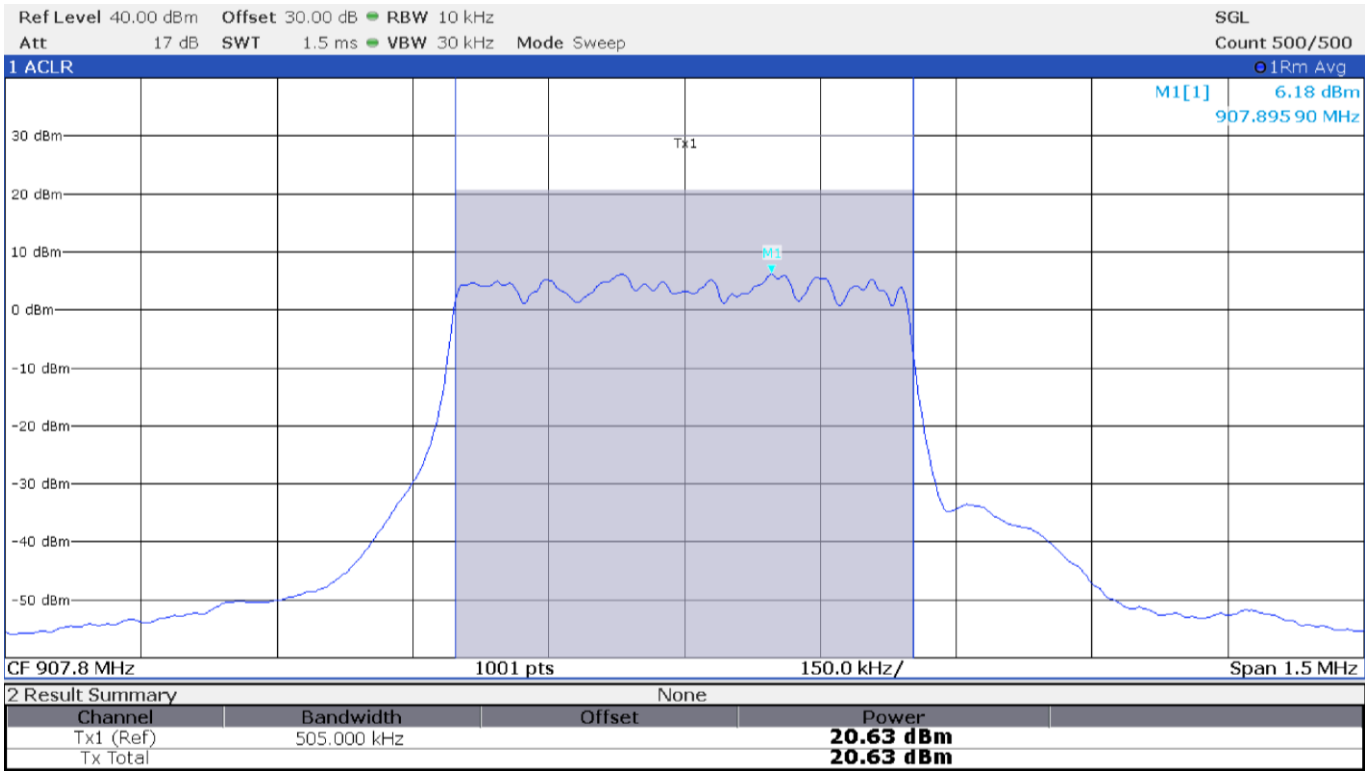


Figure 8.8-2: *Output power on mid channel for LoRa 500 kHz BW*

Test data, continued

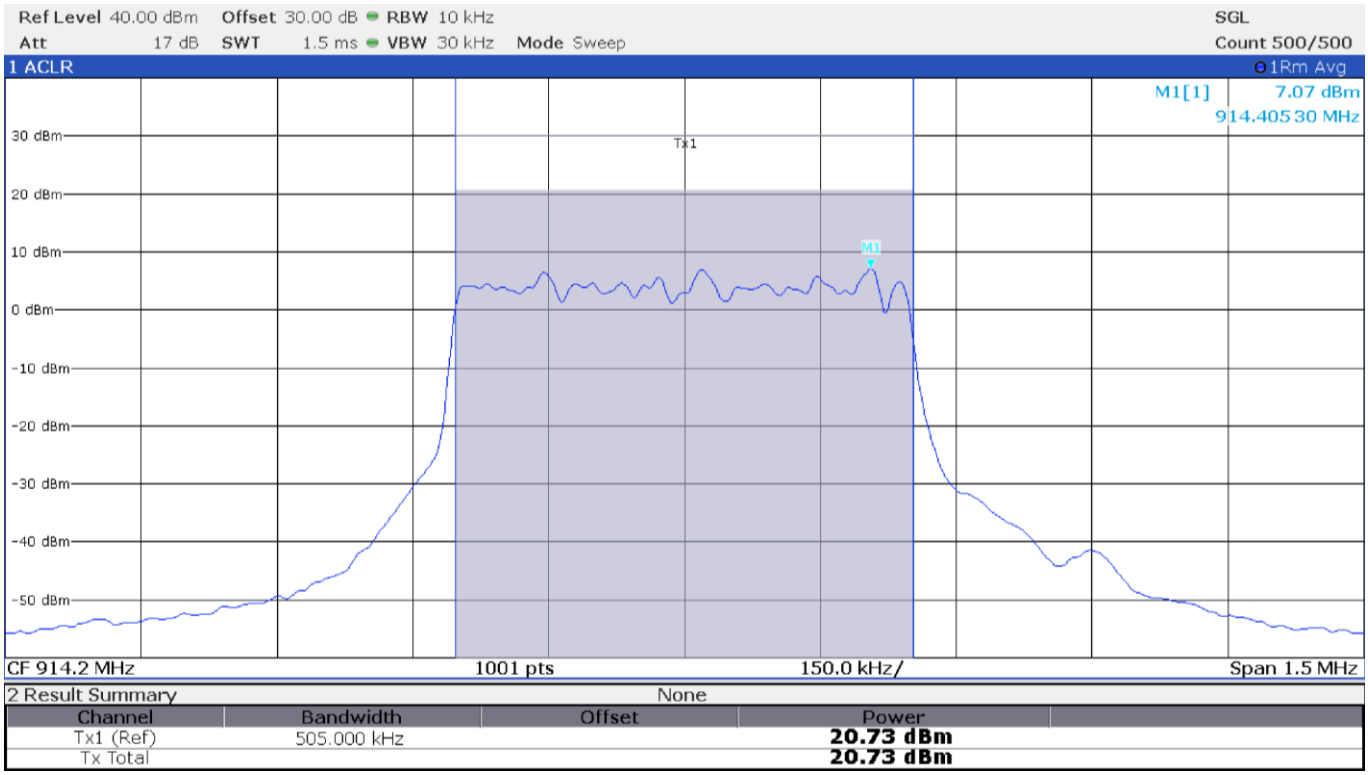


Figure 8.8-3: *Output power on high channel for LoRa 500 kHz BW*

Test data, continued

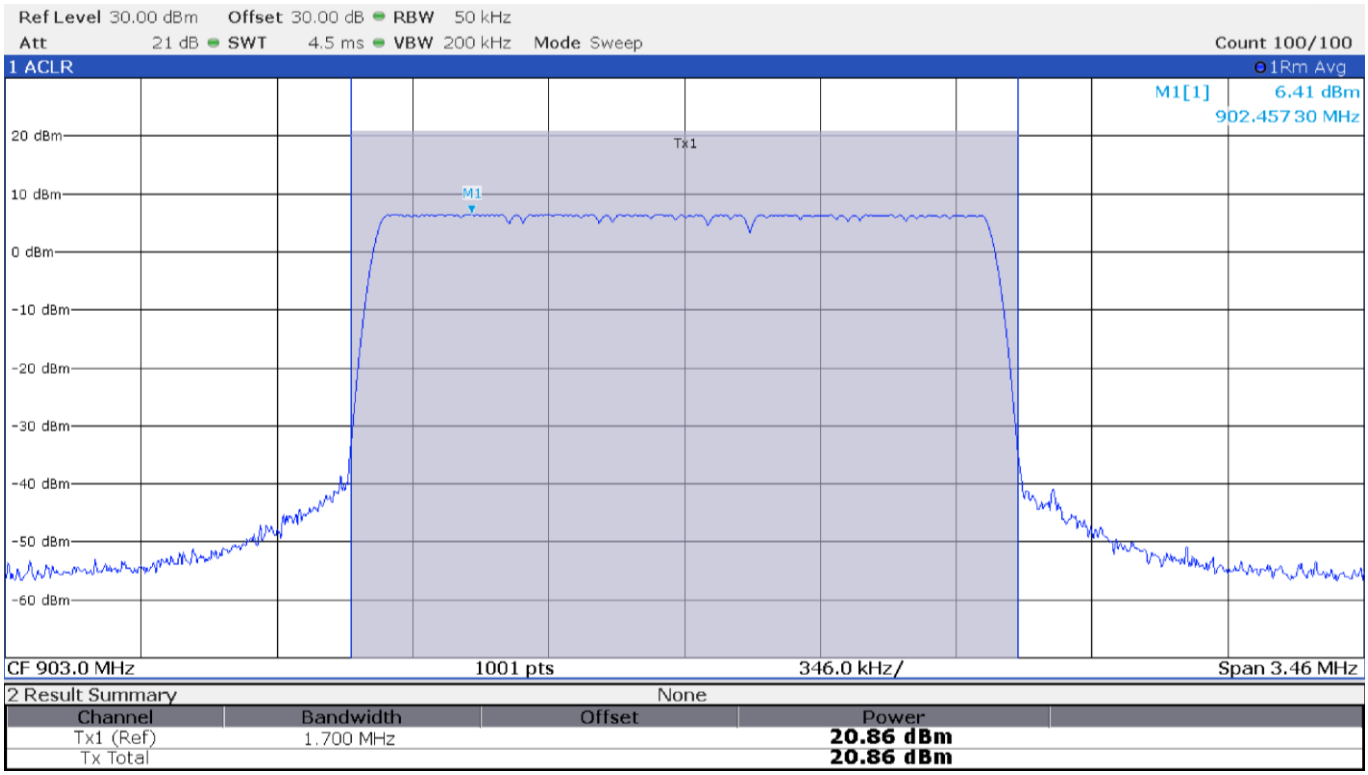


Figure 8.8-4: *Output power on low channel for LR-FHSS*

Test data, continued

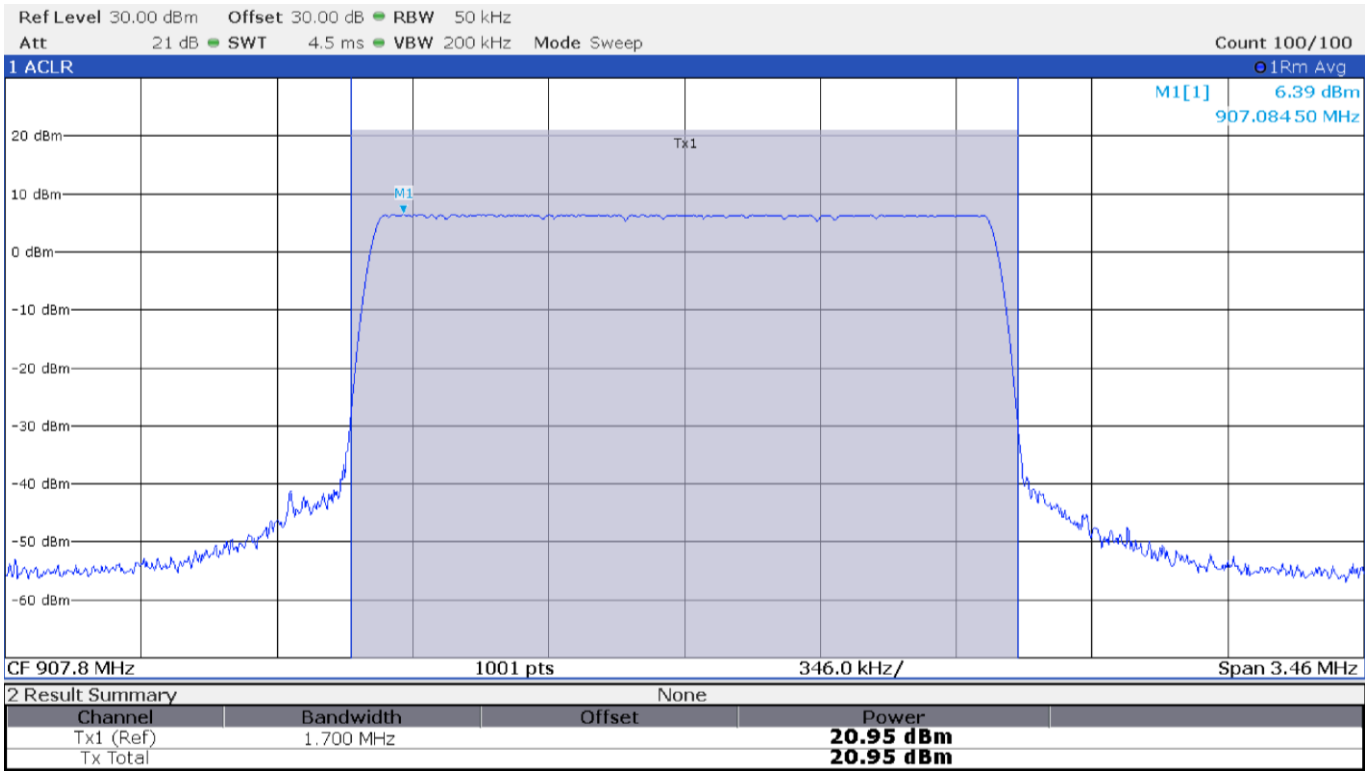


Figure 8.8-5: *Output power on mid channel for LR-FHSS*

Test data, continued

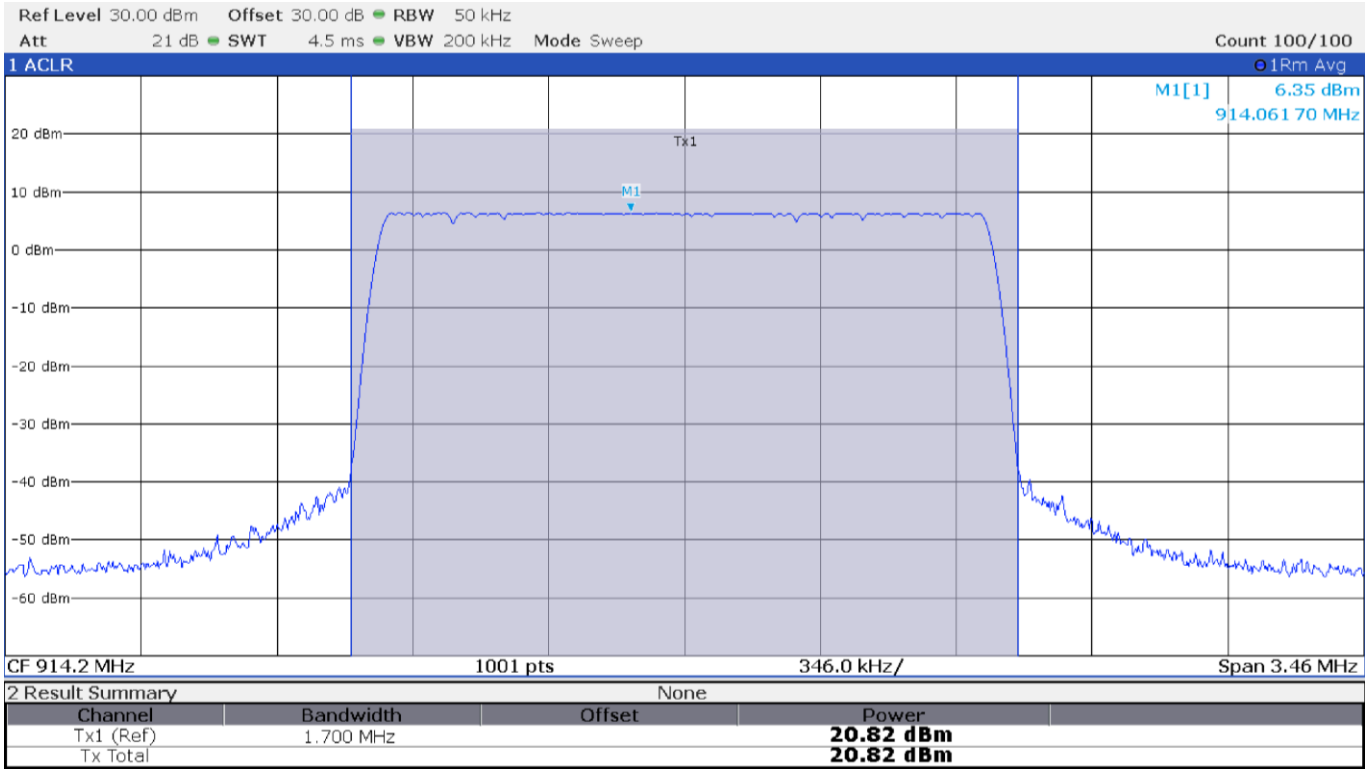


Figure 8.8-6: *Output power on high channel for LR-FHSS*

8.9 Spurious (out-of-band) unwanted emissions

8.9.1 References, definitions and limits

FCC §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 §15.209(a) is not required. In addition, radiated emissions which fall in the restricted bands, as defined in §15.205(a), must also comply with the radiated emission limits specified in §15.209(a) (see §15.205(c)).

RSS-247, Clause 5.5:

In any 100 kHz bandwidth outside the frequency band in which the spread spectrum or digitally modulated device is operating, the RF power that is produced 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 that the transmitter demonstrates compliance with the peak conducted power limits. If the transmitter complies with the conducted power limits based on the use of root-mean-square averaging over a time interval, as permitted under section 5.4(d), the attenuation required shall be 30 dB instead of 20 dB. Attenuation below the general field strength limits specified in RSS-Gen is not required.

Table 8.9-1: *FCC §15.209 and RSS-Gen – Radiated emission limits*

	Field strength of emissions		
Frequency, MHz	**µV/m**	**dBµV/m**	**Measurement distance, m**
0.009–0.490	2400/F	$67.6 - 20 \times \log_{10}(F)$	300
0.490–1.705	24000/F	$87.6 - 20 \times \log_{10}(F)$	30
1.705–30.0	30	29.5	30
30–88	100	40.0	3
88–216	150	43.5	3
216–960	200	46.0	3
above 960	500	54.0	3

Notes: In the emission table above, the tighter limit applies at the band edges.
For frequencies above 1 GHz the limit on peak RF emissions is 20 dB above the maximum permitted average emission limit applicable to the equipment under test.

References, definitions and limits, continued

Table 8.9-2: *ISED restricted frequency bands*

MHz	MHz	MHz	GHz
0.090–0.110	12.57675–12.57725	399.9–410	7.25–7.75
0.495–0.505	13.36–13.41	608–614	8.025–8.5
2.1735–2.1905	16.42–16.423	960–1427	9.0–9.2
3.020–3.026	16.69475–16.69525	1435–1626.5	9.3–9.5
4.125–4.128	16.80425–16.80475	1645.5–1646.5	10.6–12.7
4.17725–4.17775	25.5–25.67	1660–1710	13.25–13.4
4.20725–4.20775	37.5–38.25	1718.8–1722.2	14.47–14.5
5.677–5.683	73–74.6	2200–2300	15.35–16.2
6.215–6.218	74.8–75.2	2310–2390	17.7–21.4
6.26775–6.26825	108–138	2483.5–2500	22.01–23.12
6.31175–6.31225	149.9–150.05	2655–2900	23.6–24.0
8.291–8.294	156.52475–156.52525	3260–3267	31.2–31.8
8.362–8.366	156.7–156.9	3332–3339	36.43–36.5
8.37625–8.38675	162.0125–167.17	3345.8–3358	
8.41425–8.41475	167.72–173.2	3500–4400	Above 38.6
12.29–12.293	240–285	4500–5150	
12.51975–12.52025	322–335.4	5350–5460	

Note: Certain frequency bands listed in Table 8.9-2 and above 38.6 GHz are designated for licence-exempt applications. These frequency bands and the requirements that apply to related devices are set out in the 200 and 300 series of RSSs.

Table 8.9-3: *FCC restricted frequency bands*

MHz	MHz	MHz	GHz
0.090–0.110	16.42–16.423	399.9–410	4.5–5.15
0.495–0.505	16.69475–16.69525	608–614	5.35–5.46
2.1735–2.1905	16.80425–16.80475	960–1240	7.25–7.75
4.125–4.128	25.5–25.67	1300–1427	8.025–8.5
4.17725–4.17775	37.5–38.25	1435–1626.5	9.0–9.2
4.20725–4.20775	73–74.6	1645.5–1646.5	9.3–9.5
6.215–6.218	74.8–75.2	1660–1710	10.6–12.7
6.26775–6.26825	108–121.94	1718.8–1722.2	13.25–13.4
6.31175–6.31225	123–138	2200–2300	14.47–14.5
8.291–8.294	149.9–150.05	2310–2390	15.35–16.2
8.362–8.366	156.52475–156.52525	2483.5–2500	17.7–21.4
8.37625–8.38675	156.7–156.9	2690–2900	22.01–23.12
8.41425–8.41475	162.0125–167.17	3260–3267	23.6–24.0
12.29–12.293	167.72–173.2	3332–3339	31.2–31.8
12.51975–12.52025	240–285	3345.8–3358	36.43–36.5
12.57675–12.57725	322–335.4	3600–4400	Above 38.6
13.36–13.41			

8.9.2 Test summary

Verdict	Pass		
Tested by	P. Barbieri	Test date	June 11, 2024

8.9.3 Observations, settings and special notes

- As part of the current assessment, the test range of 9 kHz to 10th harmonic has been fully considered and compared to the actual frequencies utilized within the EUT. Since the EUT contains a transmitter in the GHz range, the EUT has been deemed compliant without formal testing in the 9 kHz to 30 MHz test range, therefore formal test results (tabular data and/or plots) are not provided within this test report.
- EUT was set to transmit with 100 % duty cycle.
- Radiated measurements were performed at a distance of 3 m.
- DTS emissions in non-restricted frequency bands test was performed as per KDB 558074, section 8.5 with reference to ANSI C63.10 subclause 11.11.
- For the LoRa 125 kHz BW, since fundamental power was tested using the maximum peak conducted output power procedure to demonstrate compliance, the spurious emissions limit is −20 dBc/100 kHz. For the other modulations, since fundamental power was tested using maximum conducted (average) output power procedure to demonstrate compliance, the spurious emissions limit is −30 dBc/100 kHz.
- DTS emissions in restricted frequency bands test was performed as per KDB 558074, section 8.6 with reference to ANSI C63.10 subclause 11.12.
- DTS band-edge emission measurements test was performed as per KDB 558074, section 8.7 with reference to ANSI C63.10 subclause 11.13.
- Limit outside the restricted frequency bands is 20.8 – 20 +95.22 = 96 dBµV/m for LoRa 125 kHz BW modulation and 20.8 – 30 + 95.22 = 86 dBµV/m for the other modulations.

Spectrum analyser settings for radiated measurements within restricted bands below 1 GHz:

Resolution bandwidth:	100 kHz
Video bandwidth:	300 kHz
Detector mode:	Peak
Trace mode:	Max Hold

Spectrum analyser settings for peak radiated measurements within restricted bands above 1 GHz:

Resolution bandwidth:	1 MHz
Video bandwidth:	3 MHz
Detector mode:	Peak
Trace mode:	Max Hold

Spectrum analyser settings for average radiated measurements within restricted bands above 1 GHz:

Resolution bandwidth:	1 MHz
Video bandwidth:	10 Hz
Detector mode:	Peak
Trace mode:	Max Hold

Spectrum analyser settings for conducted spurious emissions measurements:

Resolution bandwidth:	100 kHz
Video bandwidth:	300 kHz
Detector mode:	Peak
Trace mode:	Max Hold

8.9.4 Test equipment used

Equipment	Manufacturer	Model no.	Asset no.
EMI Receiver	Rohde & Schwarz	ESW44	101620
Antenna Trilog 25MHz - 8GHz	Schwarzbeck Mess-Elektronik	VULB9162	9162-025
Antenna 1 - 18 GHz	Schwarzbeck Mess-Elektronik	STLP9148	STLP 9148-152
Double Ridge Horn Antenna	RFSpin	DRH40	061106A40
Broadband Amplifier	Schwarzbeck Mess-Elektronik	BBV9718C	00121
Broadband Bench Top Amplifier	Sage	STB-1834034030-KFKF-L1	18490-01
Controller	Maturo	FCU3.0	10041
Tilt antenna mast	Maturo	TAM4.0-E	10042
Turntable	Maturo	TT4.0-5T	2.527
Semi-anechoic chamber	Nemko S.p.a.	10m semi-anechoic chamber	530
Cable set	Rosenberger	ST.ALO-02	1.650
Software turntable and mast	Maturo	mcApp	8.1.0.5410

8.9.5 Test data

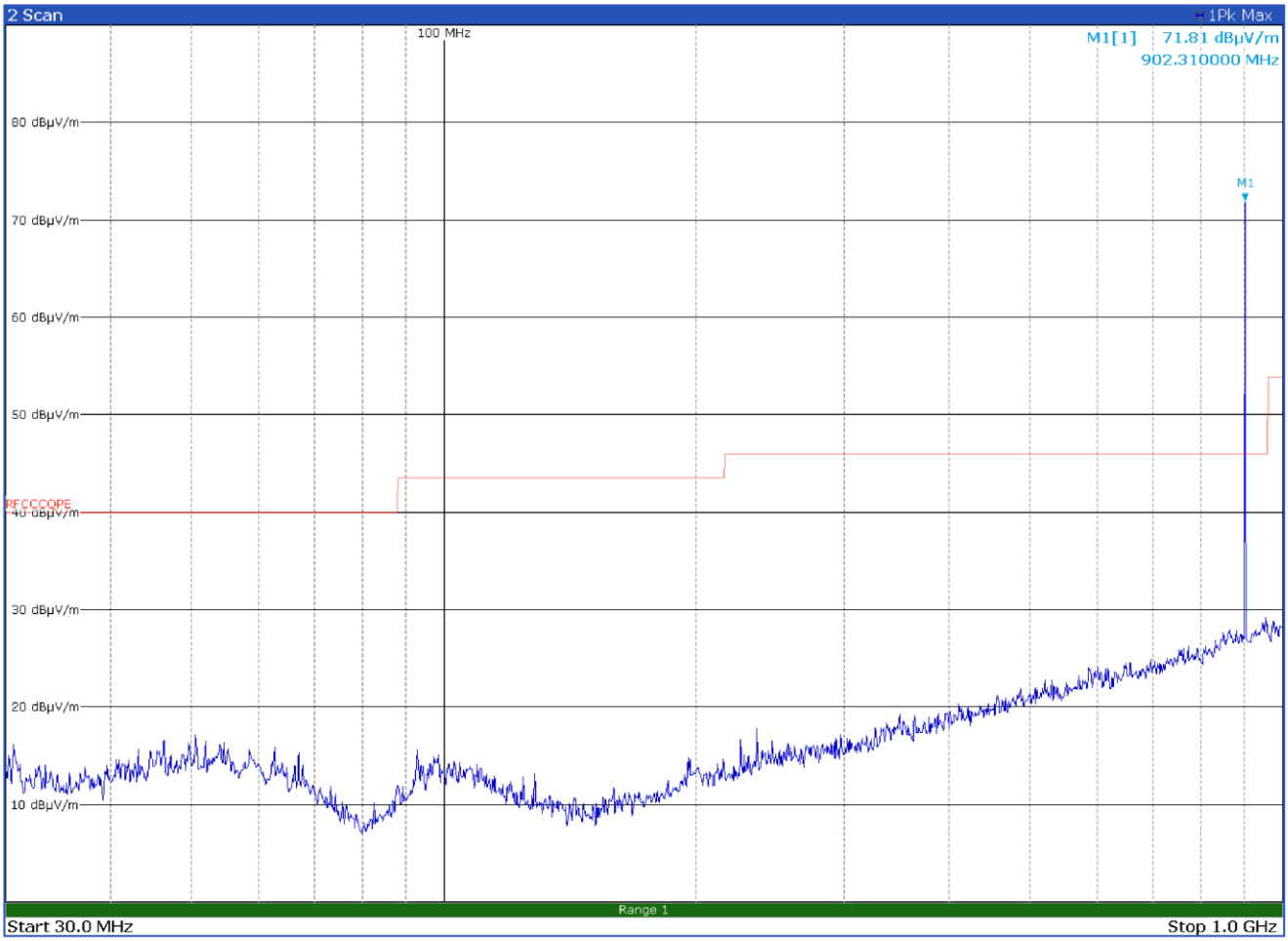


Figure 8.9-1: *Radiated spurious emissions on low channel - LoRa 125 kHz BW – Antenna in horizontal polarization*

Limit exceeded by the carrier

Test data, continued

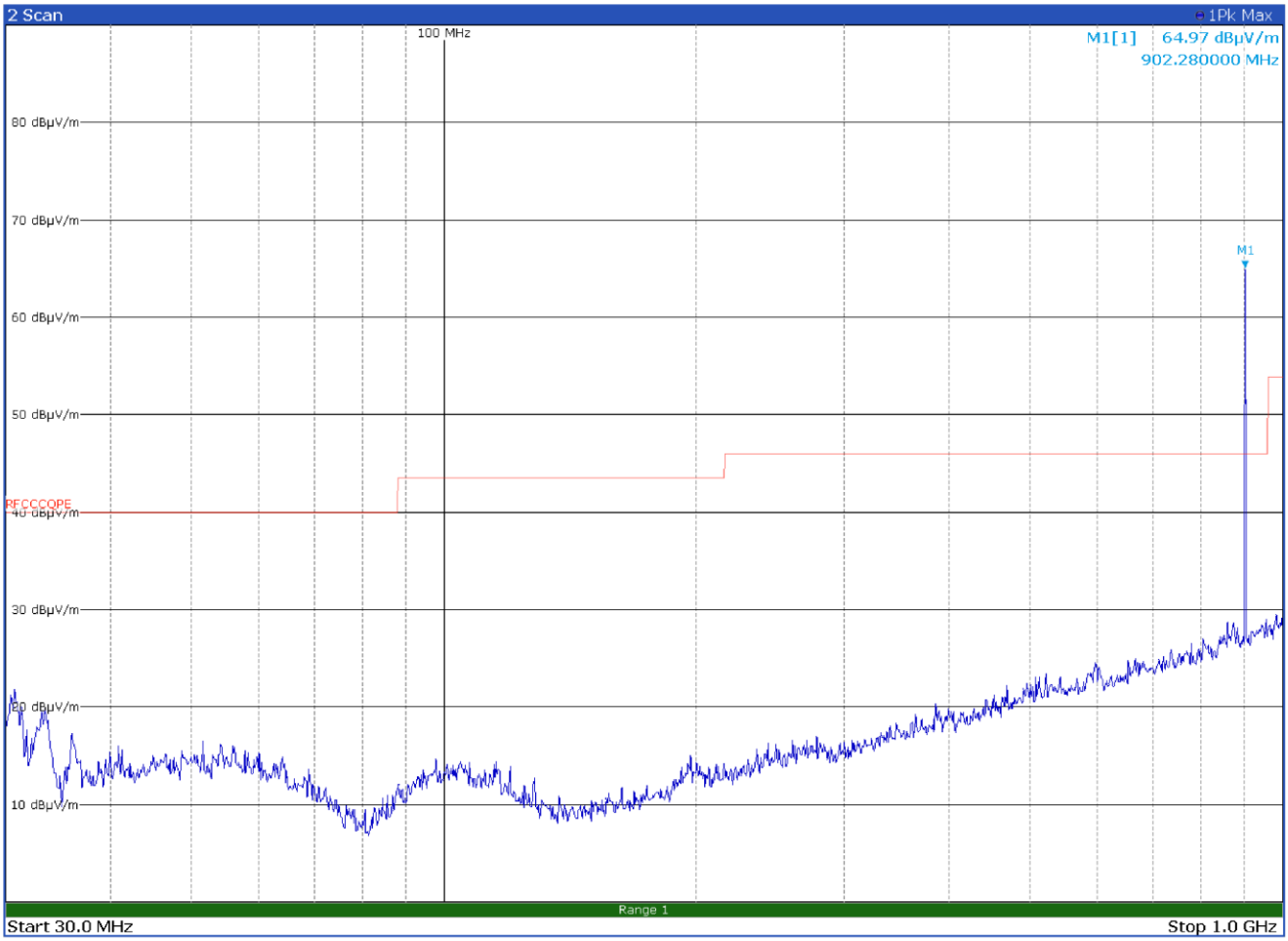


Figure 8.9-2: *Radiated spurious emissions on low channel - LoRa 125 kHz BW – Antenna in vertical polarization*

Limit exceeded by the carrier

Test data, continued

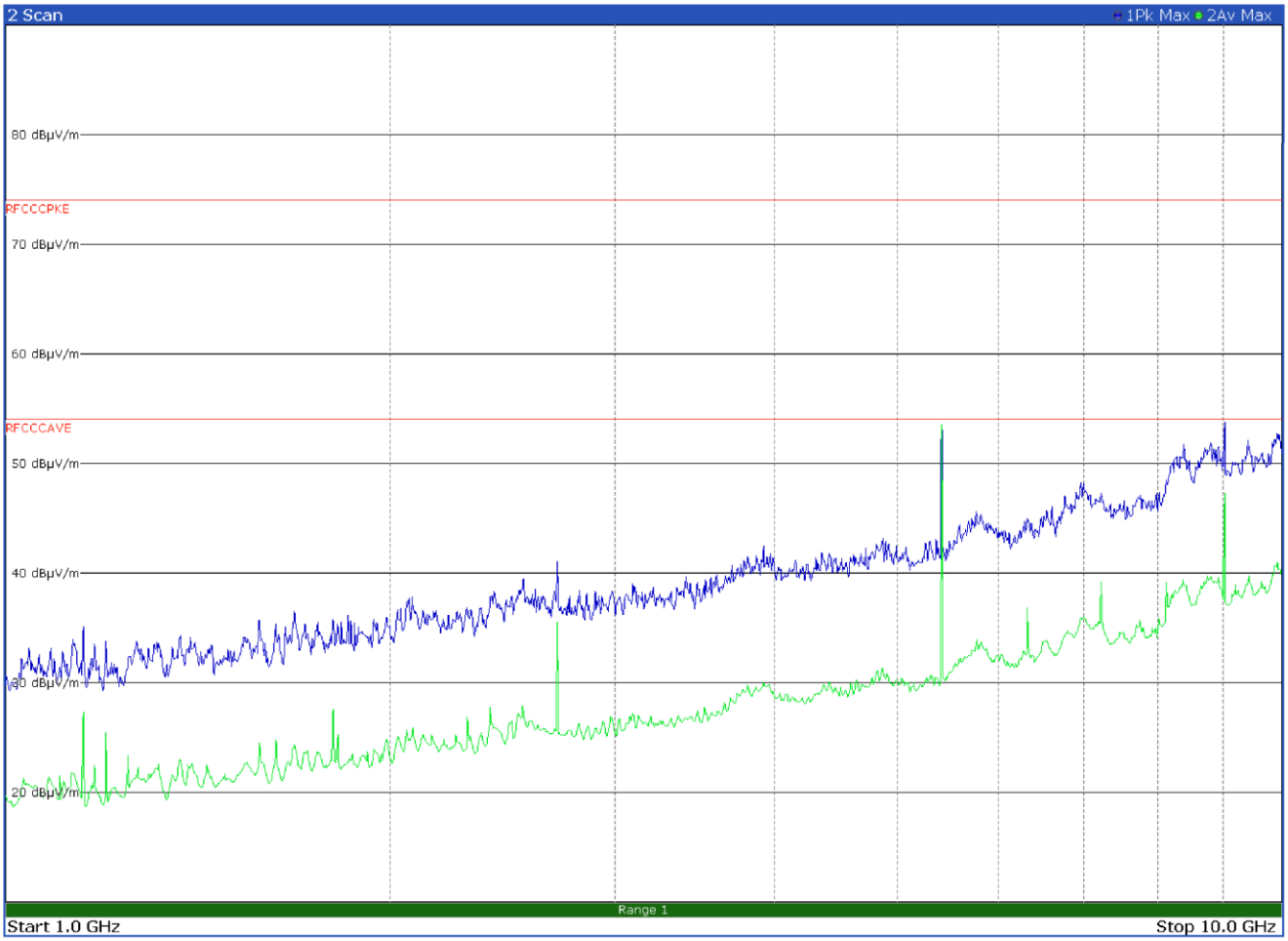


Figure 8.9-3: *Radiated spurious emissions on low channel - LoRa 125 kHz BW – Antenna in horizontal polarization*

Frequency (MHz)	Level (dBµV/m)	Limit (dBµV/m)	Margin (dB)	Detector
2706.7500	40.3	54.0	-13.7	Av
5413.5000	53.5	54.0	-0.5	Av
7218.5000	47.2	96.0	-48.8	Av
9022.7500	53.6	96.0	-42.4	Av

Test data, continued

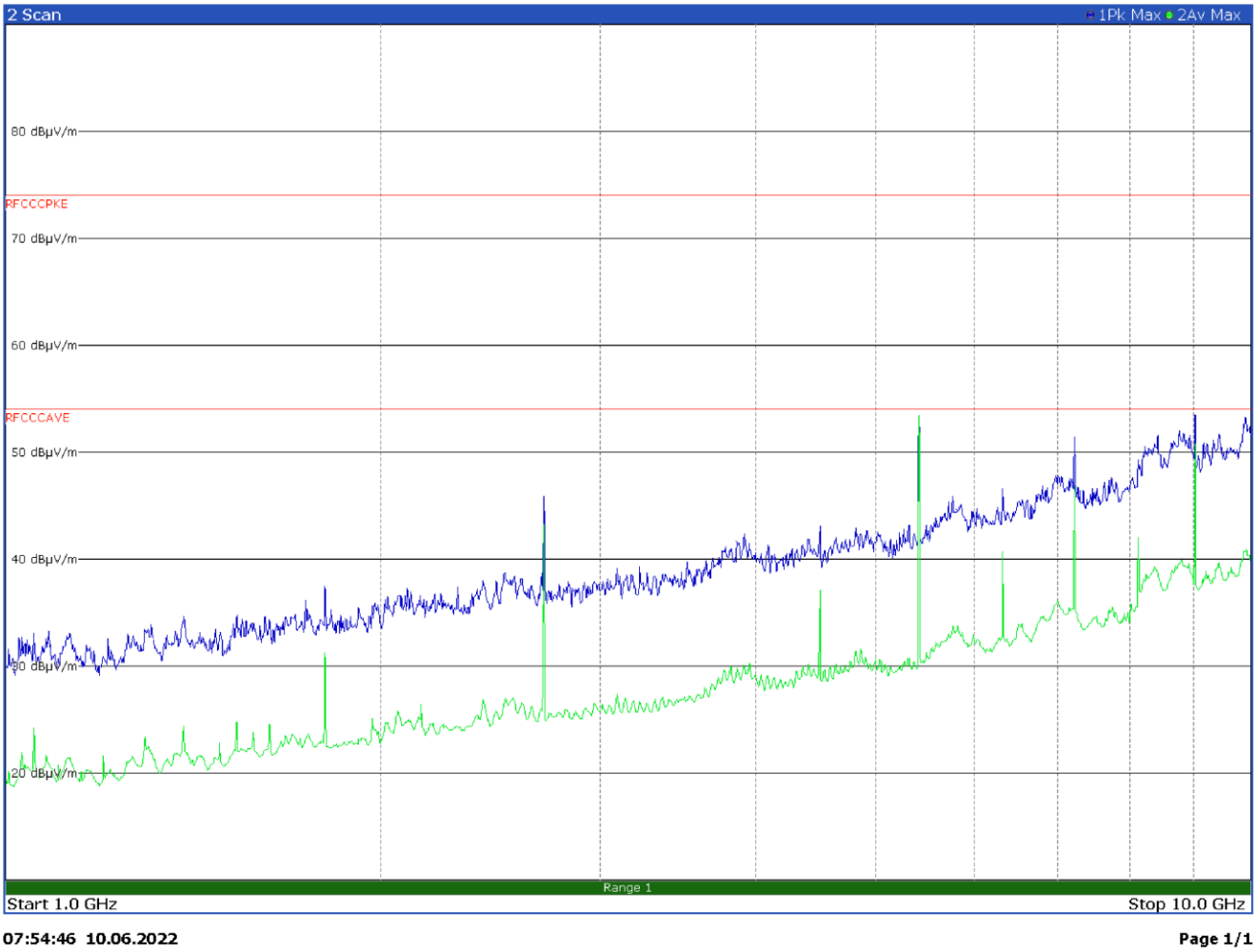


Figure 8.9-4: *Radiated spurious emissions on low channel - LoRa 125 kHz BW – Antenna in vertical polarization*

Frequency (MHz)	Level (dBµV/m)	Limit (dBµV/m)	Margin (dB)	Detector
2707.0000	45.3	54.0	-8.7	Av
4511.2500	41.9	54.0	-12.1	Av
5413.5000	53.7	54.0	-0.3	Av
6316.0000	45.8	96.0	-50.2	Av
7218.7500	51.3	96.0	-44.7	Av
8121.0000	49.9	54.0	-4.1	Av
9022.5000	53.6	54.0	-0.4	Av

Test data, continued

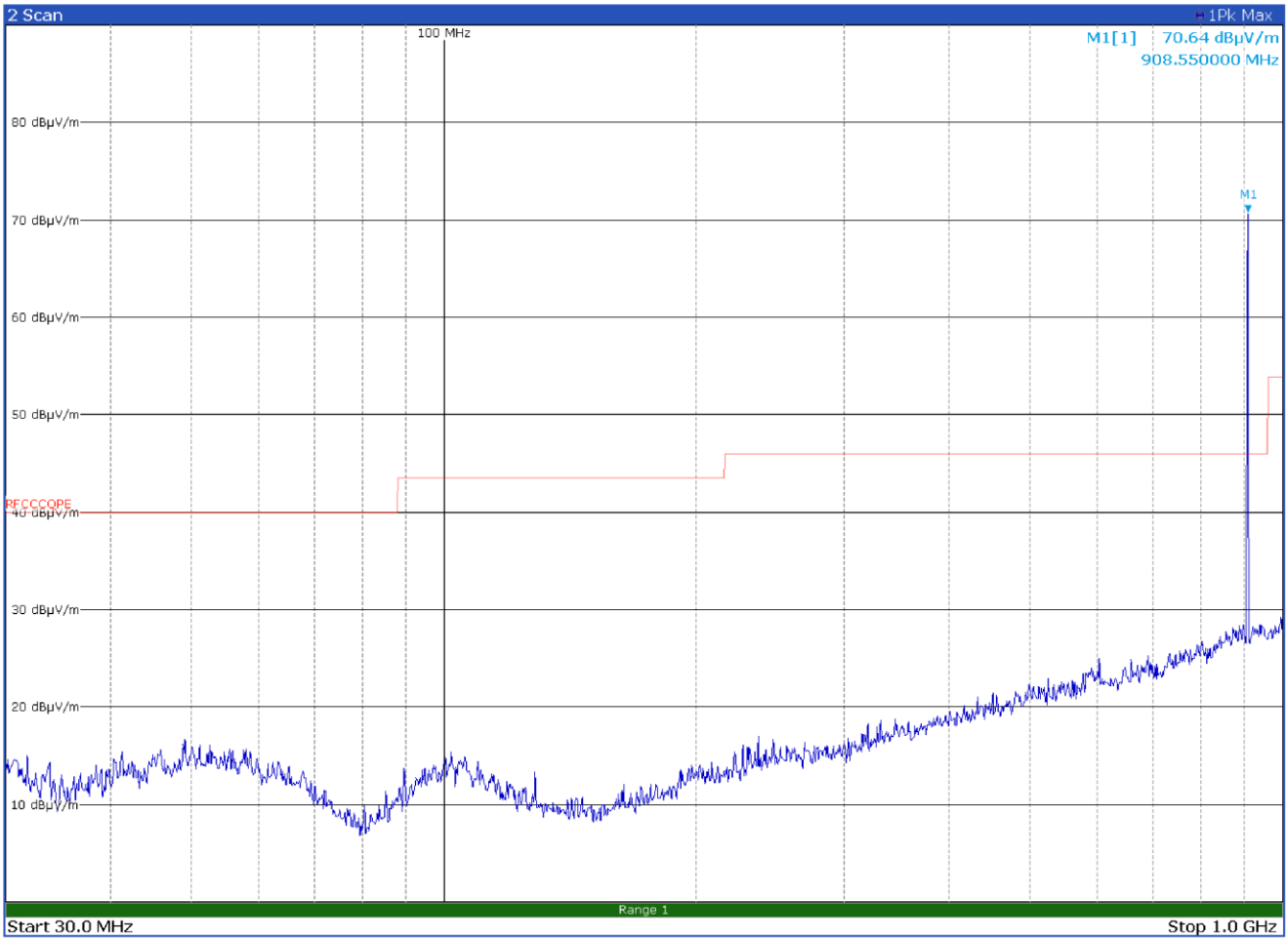


Figure 8.9-5: *Radiated spurious emissions on mid channel - LoRa 125 kHz BW – Antenna in horizontal polarization*

Limit exceeded by the carrier

Test data, continued

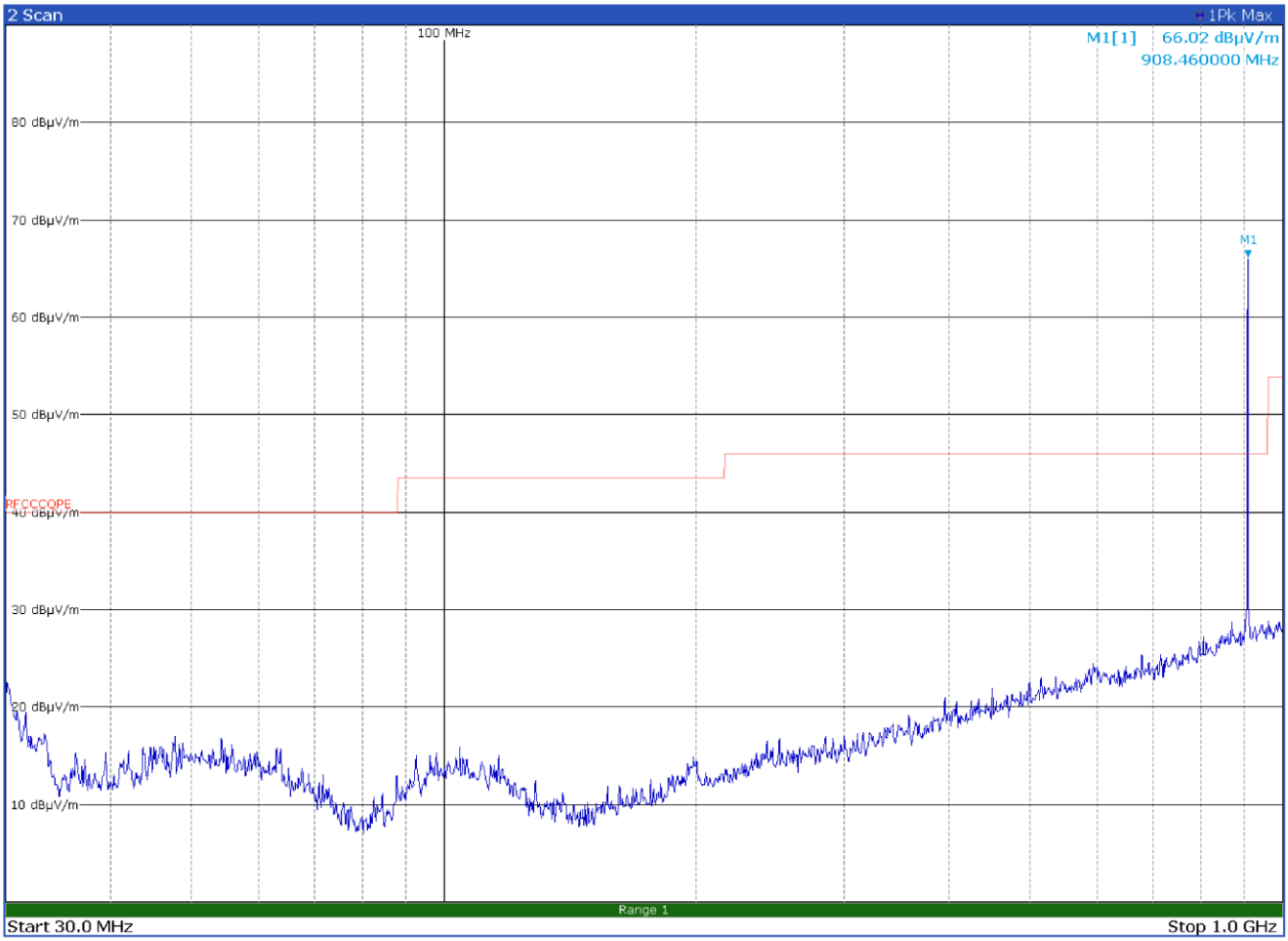


Figure 8.9-6: *Radiated spurious emissions on mid channel - LoRa 125 kHz BW – Antenna in vertical polarization*

Limit exceeded by the carrier

Test data, continued

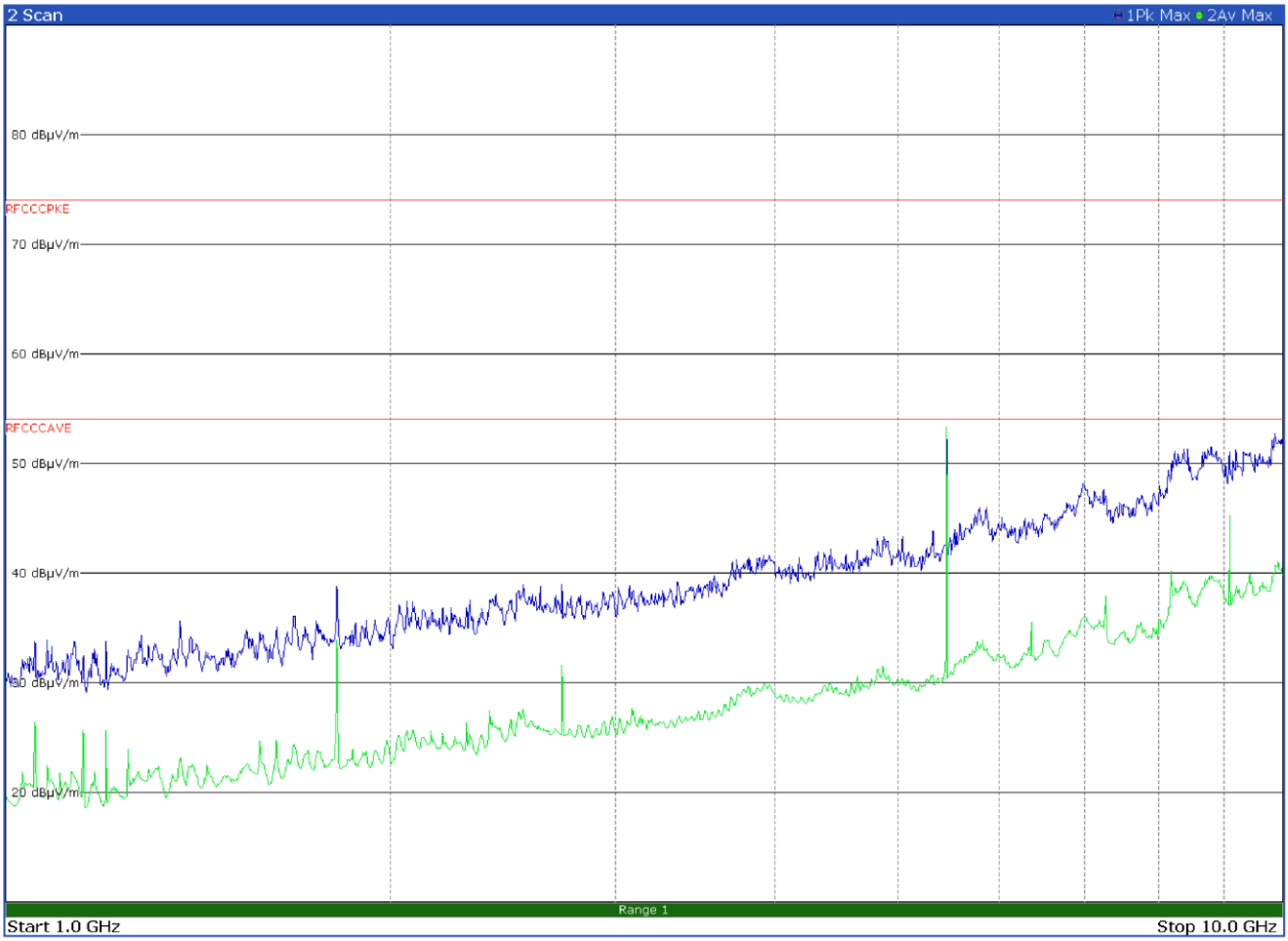


Figure 8.9-7: *Radiated spurious emissions on mid channel - LoRa 125 kHz BW – Antenna in horizontal polarization*

Frequency (MHz)	Level (dBµV/m)	Limit (dBµV/m)	Margin (dB)	Detector
5451.2500	53.3	54.0	-0.7	Av
9085.0000	50.3	54.0	-3.7	Av

Test data, continued

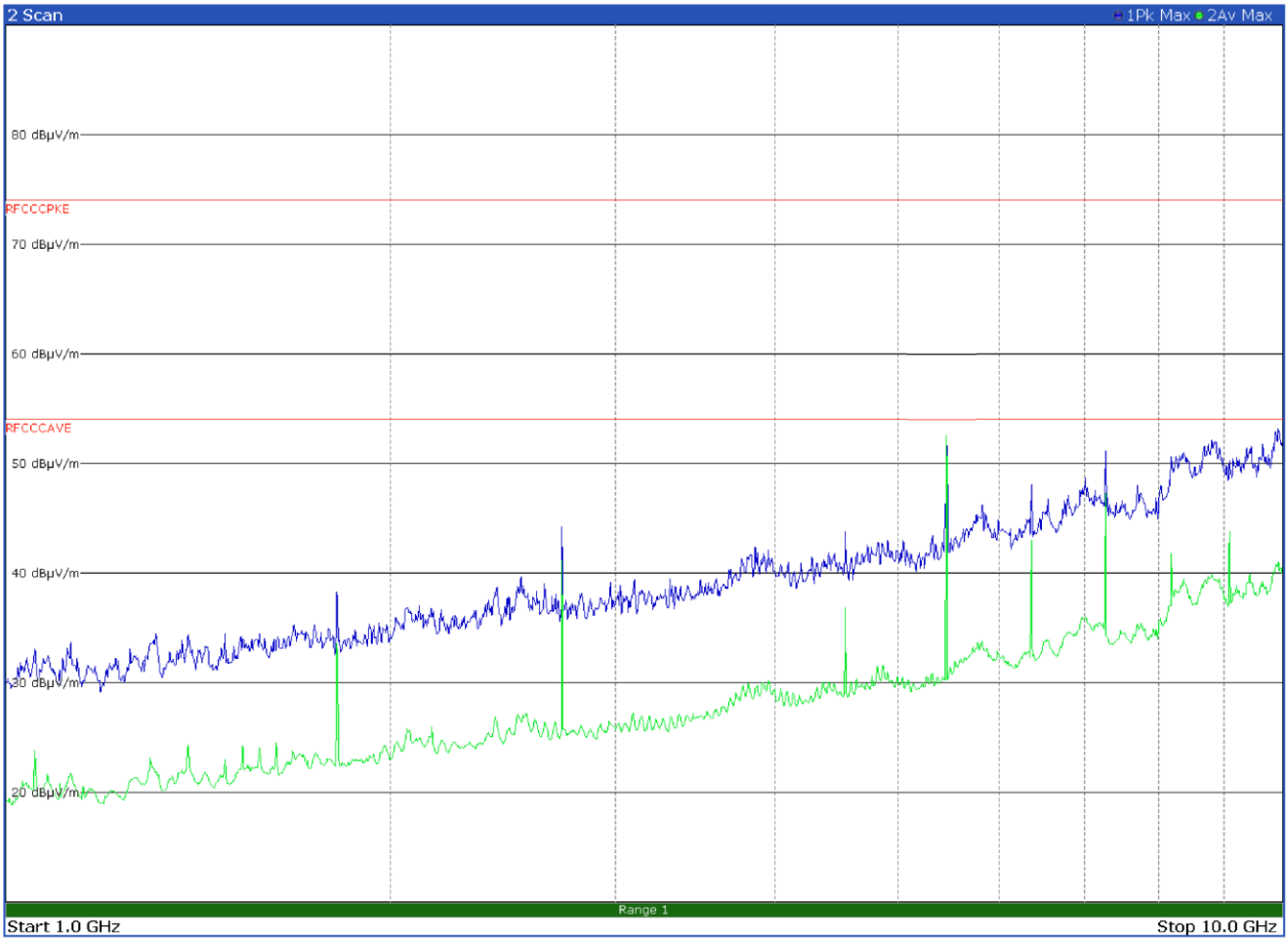


Figure 8.9-8: *Radiated spurious emissions on mid channel - LoRa 125 kHz BW – Antenna in vertical polarization*

Frequency (MHz)	Level (dBµV/m)	Limit (dBµV/m)	Margin (dB)	Detector
2725.5000	43.2	54.0	-10.8	Av
4542.7500	42.9	54.0	-11.1	Av
5451.2500	52.8	54.0	-1.2	Av
6359.7500	48.0	96.0	-48.0	Av
7268.5000	51.3	54.0	-2.7	Av
9085.5000	50.8	54.0	-3.2	Av

Test data, continued

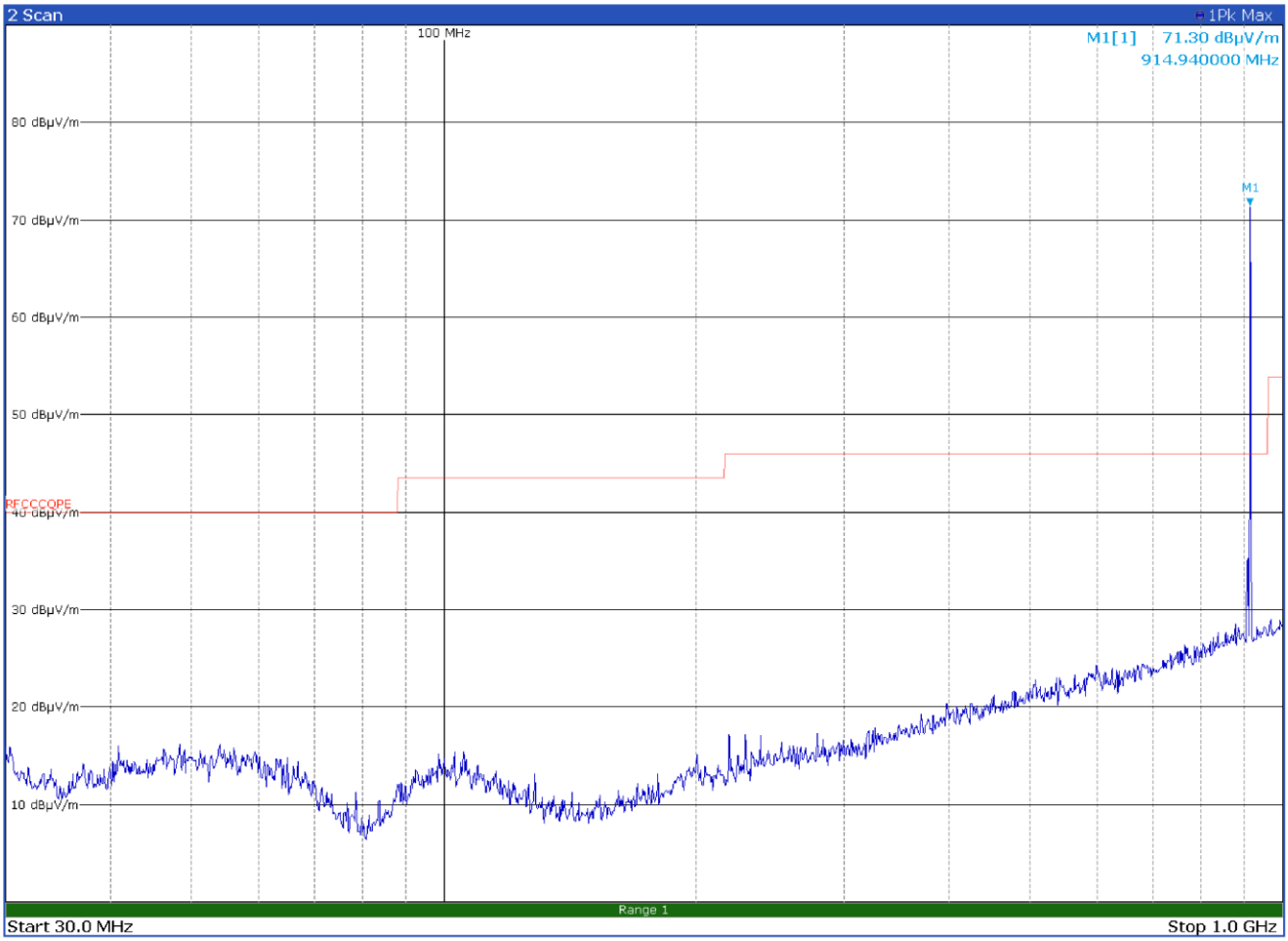


Figure 8.9-9: *Radiated spurious emissions on high channel - LoRa 125 kHz BW – Antenna in horizontal polarization*

Limit exceeded by the carrier