HERMON LABORATORIES

ELECTRICAL TESTING
0839.01

Hermon Laboratories Ltd.
P.O. Box 23, Binyamina 3055001, Israel
Tel. +972 4628 8001
Fax. +972 4628 8277
E-mail: mail@hermonlabs.com

TEST REPORT

ACCORDING TO:

FCC 47CFR part 15 subpart C § 15.247 (Hybrid) and subpart B, Class B

FOR:

Hoopo Systems Ltd.

hoopoSense

Model: 502B1000-1A

FCC ID: 2AVS8-S01

Table of contents

1 Applicant information

Client name:	Hoopo Systems Ltd.
Address:	5 Ayalon St., Ramat Hasharon, 4700225 Israel
Telephone:	052-5192244
E-mail:	menachem@hoopo.tech
Contact name:	Mr. Menachem Tipris

2 Equipment under test attributes

Product name:	hoopoSense
Product type:	IoT Sensor
Model(s):	502B1000-1A
Serial number:	24
Hardware version:	0.0
Software release:	1.3
Receipt date	22-Nov-19

3 Manufacturer information

Manufacturer name:	Hoopo Systems Ltd.
Address:	5 Ayalon St., Ramat Hasharon, 4700225 Israel
Telephone:	052-5192244
E-Mail:	menachem@hoopo.tech
Contact name:	Mr. Menachem Tipris

4 Test details

Project ID:	35117
Location:	Primary: Hermon Laboratories Ltd. P.O. Box 23, Binyamina 3055001, Israel Satellite: Hermon Laboratories Ltd. Hefetz-Haim 10, Tel Aviv 6744124, Israel
Test started:	17-Dec-19
Test completed:	11-Feb-20
Test specification(s):	FCC 47CFR part 15 subpart C § 15.247 (Hybrid) and subpart B, Class B

5 Tests summary

Test	Status
Transmitter characteristics	
Section 15.247(a)1, 20 dB bandwidth	Pass
Section 15.247(a)1, Frequency separation	Pass
Section 15.247(a)1, Number of hopping frequencies	Pass
Section 15.247(a)1, Average time of occupancy	Pass
Section 15.247(b), Peak output power	Pass
Section 15.247(e), Peak spectral density	Pass
Section 15.247(d), Radiated spurious emissions	Pass
Section 15.247(i), RF exposure	Pass*
Section 15.247(d), Emissions at band edges	Pass
Section 15.207(a), Conducted emission	Not required
Section 15.203, Antenna requirements	Pass
Unintentional emissions	
Section 15.107, Class B, Conducted emission at AC power port	Not required
Section 15.109, Class B, Radiated emission	Pass

* - Pass, the exhibit to the application of certification is provided.

Testing was completed against all relevant requirements of the test standard. The results obtained indicate that the product under test complies in full with the requirements tested.
The test results relate only to the items tested. Pass/ fail decision was based on nominal values.

	Name and Title	Date	Signature
Tested by:	Mr. I. Zilberstein, test engineer, EMC & Radio Mrs. E. Pitt, test engineer, EMC & Radio	17-Dec-19 – 11-Feb-20	
Reviewed by:	Mrs. S. Peysahov Sheynin, test engineer, EMC & Radio	03-May-20	
Approved by:	Mr. S. Samokha, technical manager, EMC & Radio	14-June-20	

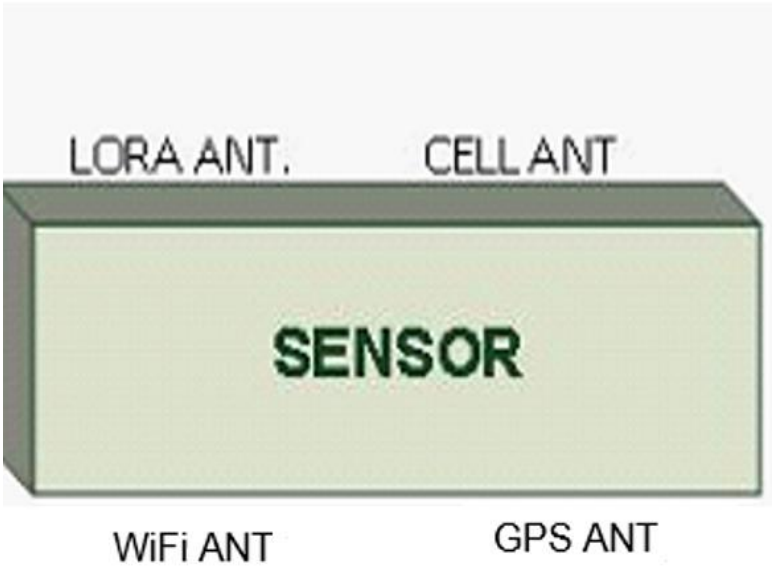
6 EUT description

Note: The following data in this clause is provided by the customer and represents his sole responsibility

6.1 General information

The EUT, a hoopoSense, is a low power device powered by four AA prime batteries. The device is equiped with a LoRa transceiver, an optional cellular modem, a WiFi receiver and a GPS device.

6.2 Test configuration



6.3 Changes made in EUT

No changes were implemented in the EUT during the testing.

6.4 Transmitter characteristics

Type of equipment	
X	Stand-alone (Equipment with or without its own control provisions)
	Combined equipment (Equipment where the radio part is fully integrated within another type of equipment)
	Plug-in card (Equipment intended for a variety of host systems)

Intended use		**Condition of use**
	fixed	Always at a distance more than 2 m from all people
X	mobile	Always at a distance more than 20 cm from all people
	portable	May operate at a distance closer than 20 cm to human body

Assigned frequency ranges	902 – 928 MHz
Operating frequencies	902.5 – 927.5 MHz

Maximum rated output power	At transmitter 50 Ω RF output connector	
	Peak output power	8.20 dBm

Is transmitter output power variable?		No			
	X	Yes		continuous variable	
			X	stepped variable with stepsize	1 dB
				minimum RF power	-1.8dBm
				maximum RF power	+8.2 dBm

Antenna connection			
unique coupling	standard connector	X integral	with temporary RF connector
			X without temporary RF connector

Antenna/s technical characteristics			
Type	Manufacturer	Model number	Gain
Internal	Hoopo systems	part of PCB	2 dBi

Transmitter aggregate data rate/s	980 bps/5470 bps
Type of modulation	LoRa
Modulating test signal (baseband)	PRBS

Transmitter power source						
X	Battery	**Nominal rated voltage**	3 VDC	Battery type	L91 or L6
	DC	**Nominal rated voltage**			
	AC mains	**Nominal rated voltage**		Frequency	

Common power source for transmitter and receiver	X yes	no

Spread spectrum technique used		
		Frequency hopping (FHSS)
		Digital transmission system (DTS)
	X	Hybrid

Spread spectrum parameters for transmitters tested per FCC 15.247 only		
FHSS	Total number of hops	16
	Bandwidth per hop	166.456 kHz
	Max. separation of hops	200 kHz

Test specification:	Section 15.247(a)1, 20 dB bandwidth		
Test procedure:	ANSI C63.10, section 7.8.7		
Test mode:	Compliance	Verdict:	PASS
Date(s):	19-Dec-19		
Temperature: 23 ºC	Relative Humidity: 38 %	Air Pressure: 1008 hPa	Power: 3 VDC
Remarks:			

7 Transmitter tests according to 47CFR part 15 subpart C requirements

7.1 20 dB bandwidth

7.1.1 General

This test was performed to measure 20 dB bandwidth of the transmitter hopping channel. Specification test limits are given in Table 7.1.1.

Table 7.1.1 The 20 dB bandwidth limits

Assigned frequency, MHz	Maximum bandwidth, kHz	Modulation envelope reference points*, dBc
902.0 – 928.0	250	20

* - Modulation envelope reference points provided in terms of attenuation below the peak of modulated carrier.

7.1.2 Test procedure

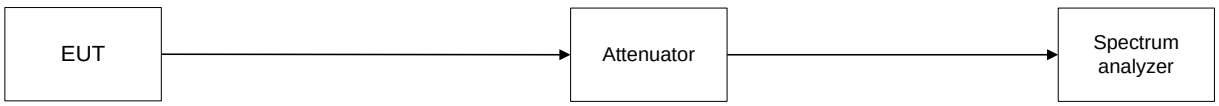
7.1.2.1 The EUT was set up as shown in Figure 7.1.1, energized and its proper operation was checked.

7.1.2.2 The EUT was set to transmit modulated carrier at maximum data rate.

7.1.2.3 The transmitter bandwidth was measured with spectrum analyzer as frequency delta between reference points on modulation envelope and provided in Table 7.1.2 and associated plot.

7.1.2.4 The test was repeated for each data rate and each modulation format.

Figure 7.1.1 The 20 dB bandwidth test setup



Test specification:	**Section 15.247(a)1, 20 dB bandwidth**		
Test procedure:	ANSI C63.10, section 7.8.7		
Test mode:	Compliance	**Verdict:**	PASS
Date(s):	19-Dec-19		
Temperature: 23 ºC	**Relative Humidity:** 38 %	**Air Pressure:** 1008 hPa	**Power:** 3 VDC
Remarks:			

Table 7.1.2 The 20 dB bandwidth test results

ASSIGNED FREQUENCY BAND: 902-928 MHz
DETECTOR USED: Peak
SWEEP TIME: Auto
VIDEO BANDWIDTH: ≥ RBW
MODULATION ENVELOPE REFERENCE POINTS: 20.0 dBc
MODULATING SIGNAL: PRBS
FREQUENCY HOPPING: Disabled

Carrier frequency, MHz	Type of modulation	Data rate, bps	Symbol rate, Msymbols/s	20 dB bandwidth, kHz	Limit, kHz	Margin, kHz	Verdict
902.5	LoRa	980	NA	166.456	250	-83.544	Pass
		5470		162.128	250	-87.872	Pass
915.0	LoRa	980	NA	165.023	250	-84.977	Pass
		5470		161.883	250	-88.117	Pass
927.5	LoRa	980	NA	164.969	250	-85.031	Pass
		5470		162.154	250	-87.846	Pass

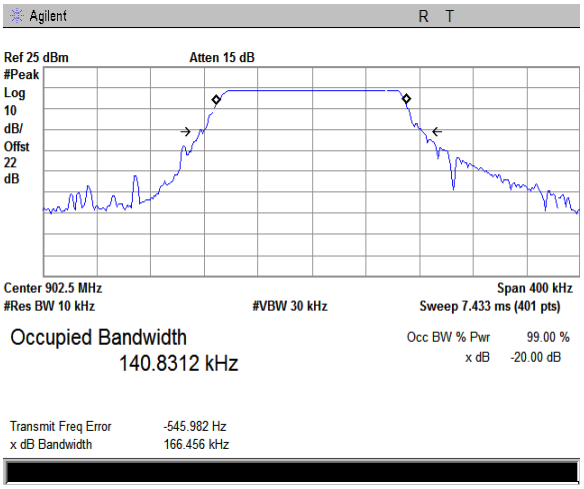
Reference numbers of test equipment used

HL 2909	HL 5111	HL 5612	HL 5606					

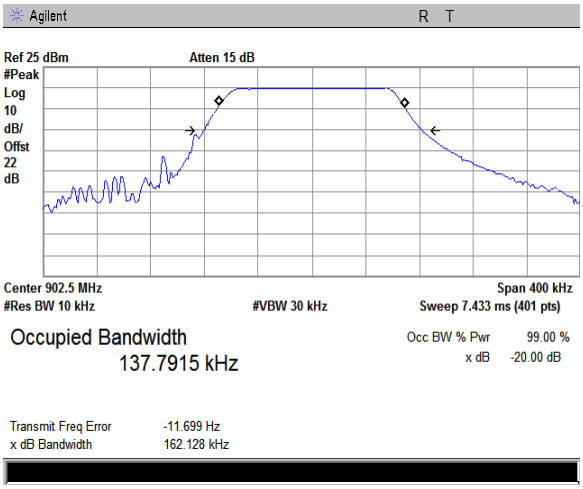
Full description is given in Appendix A.

Test specification:	Section 15.247(a)1, 20 dB bandwidth		
Test procedure:	ANSI C63.10, section 7.8.7		
Test mode:	Compliance	Verdict:	PASS
Date(s):	19-Dec-19		
Temperature: 23 ºC	Relative Humidity: 38 %	Air Pressure: 1008 hPa	Power: 3 VDC
Remarks:			

Plot 7.1.1 The 20 dB bandwidth test result at low frequency

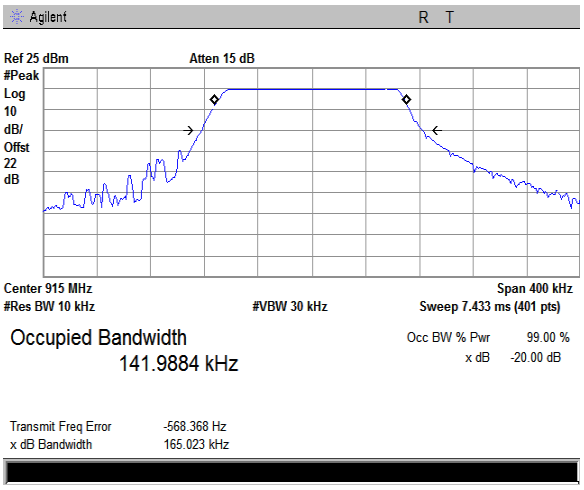


Data rate: 980 bps

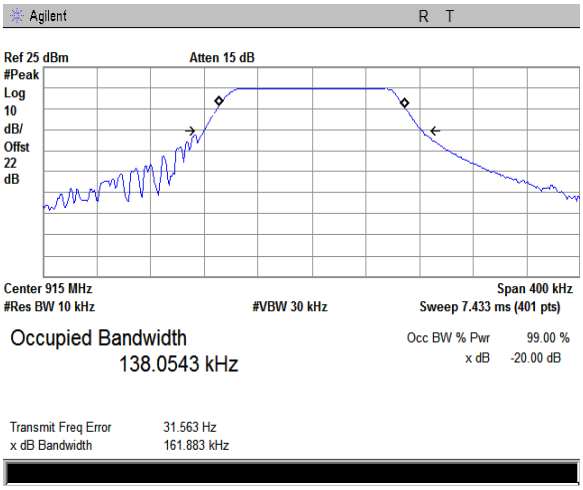


Data rate: 5470 bps

Plot 7.1.2 The 20 dB bandwidth test result at mid frequency



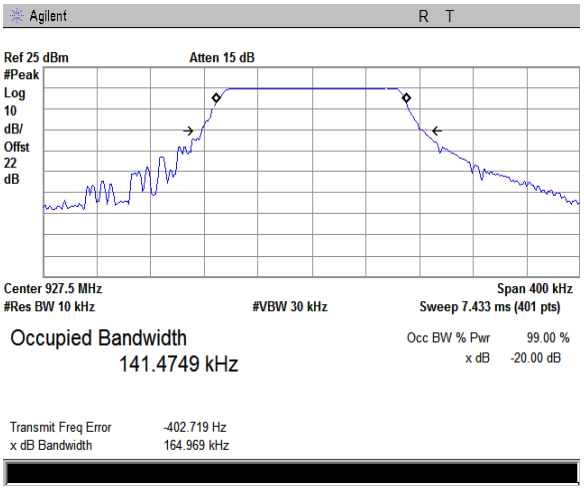
Data rate: 980 bps



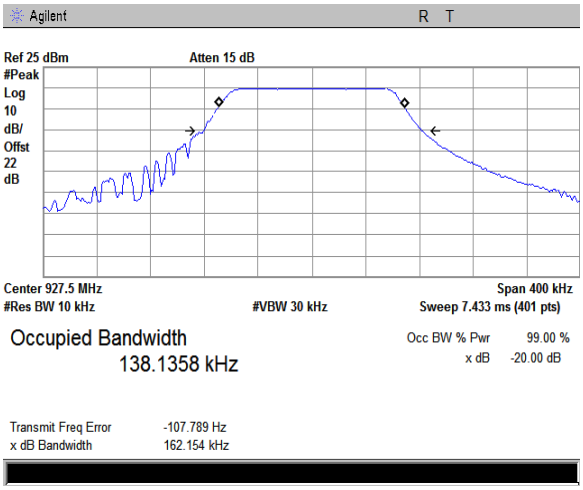
Data rate: 5470 bps

Test specification:	Section 15.247(a)1, 20 dB bandwidth		
Test procedure:	ANSI C63.10, section 7.8.7		
Test mode:	Compliance	Verdict:	PASS
Date(s):	19-Dec-19		
Temperature: 23 ºC	Relative Humidity: 38 %	Air Pressure: 1008 hPa	Power: 3 VDC
Remarks:			

Plot 7.1.3 The 20 dB bandwidth test result at high frequency



Data rate: 980 bps



Data rate: 5470 bps

Test specification:	Section 15.247(a)1, Frequency separation		
Test procedure:	ANSI C63.10, section 7.8.2		
Test mode:	Compliance	Verdict:	PASS
Date(s):	19-Dec-19		
Temperature: 23 ºC	Relative Humidity: 38 %	Air Pressure: 1008 hPa	Power: 3.2 VDC
Remarks:			

7.2 Carrier frequency separation

7.2.1 General

This test was performed to measure frequency separation between the peaks of adjacent channels. Specification test limits are given in Table 7.2.1.

Table 7.2.1 Carrier frequency separation limits

Assigned frequency range, MHz	Carrier frequency separation
902.0 – 928.0	25 kHz or 20 dB bandwidth of the hopping channel, whichever is greater

7.2.2 Test procedure

7.2.2.1 The EUT was set up as shown in Figure 7.2.1, energized with frequency hopping function enabled and its proper operation was checked.

7.2.2.2 The spectrum analyzer span was set to capture the carrier frequency and both of adjacent channels, the lower and the higher. The resolution bandwidth was set wider than 1 % of the frequency span.

7.2.2.3 The spectrum analyzer was set in max hold mode and allowed trace to stabilize.

7.2.2.4 The frequency separation between the peaks of adjacent channels was measured as provided in Table 7.2.2 and associated plots.

Figure 7.2.1 Carrier frequency separation test setup

Test specification:	Section 15.247(a)1, Frequency separation		
Test procedure:	ANSI C63.10, section 7.8.2		
Test mode:	Compliance	Verdict:	PASS
Date(s):	19-Dec-19		
Temperature: 23 ºC	Relative Humidity: 38 %	Air Pressure: 1008 hPa	Power: 3.2 VDC
Remarks:			

Table 7.2.2 Carrier frequency separation test results

ASSIGNED FREQUENCY: 902-928 MHz
MODULATION: LoRa
DETECTOR USED: Peak
RESOLUTION BANDWIDTH: ≥ 1% of the span
VIDEO BANDWIDTH: ≥ RBW
FREQUENCY HOPPING: Enabled
20 dB BANDWIDTH: 166.456 kHz

Carrier frequency separation, kHz	Limit, kHz	Margin*	Verdict
200.0	166.456	33.544	Pass

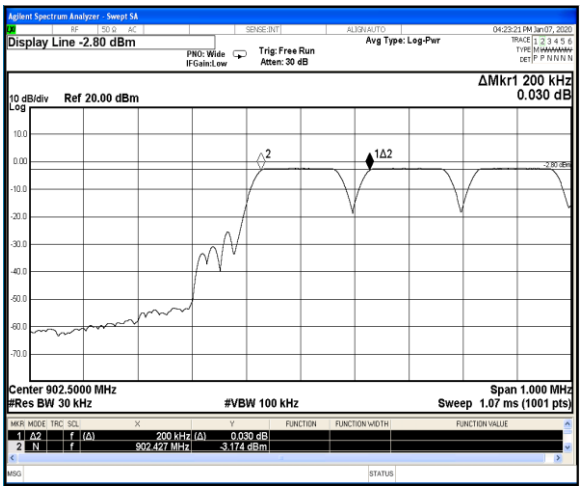
* - Margin = Carrier frequency separation – specification limit.

Reference numbers of test equipment used

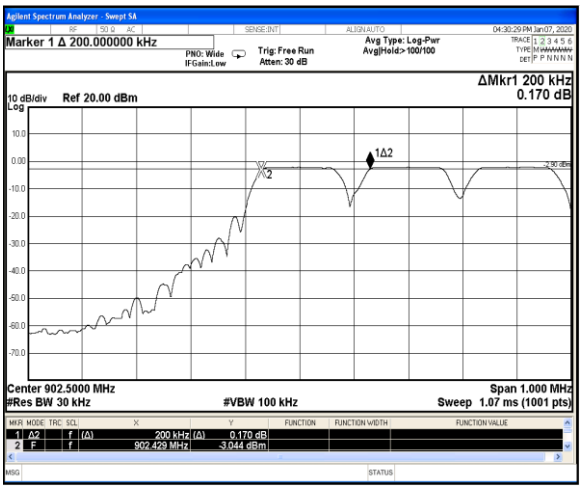
HL 2909	HL 5111	HL 5612	HL 5606				

Full description is given in Appendix A.

Plot 7.2.1 Carrier frequency separation



980 bps



5470 bps

Test specification:	Section 15.247(a)1, Number of hopping frequencies		
Test procedure:	ANSI C63.10, section 7.8.3		
Test mode:	Compliance	Verdict:	PASS
Date(s):	19-Dec-19		
Temperature: 23 ºC	Relative Humidity: 38 %	Air Pressure: 1008 hPa	Power: 3.2 VDC
Remarks:			

7.3 Number of hopping frequencies

7.3.1 General

This test was performed to calculate the number of hopping frequencies used by the EUT. Specification test limits are given in Table 7.3.1.

Table 7.3.1 Minimum number of hopping frequencies

Assigned frequency range, MHz	Number of hopping frequencies
902.0 – 928.0	50 (if the 20 dB bandwidth is less than 250 kHz)

7.3.2 Test procedure

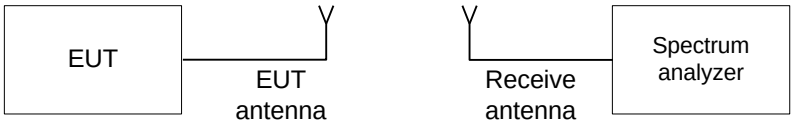
7.3.2.1 The EUT was set up as shown in Figure 7.3.1, energized with frequency hopping function enabled and its proper operation was checked.

7.3.2.2 Initially the spectrum analyzer span was set equal to frequency band of operation and the resolution bandwidth was set wider than 1 % of the frequency span. If the separate hopping channels were not clearly resolved the frequency band of operation was broken to sections and the resolution bandwidth was set wider than 1 % of the frequency span of each section.

7.3.2.3 The spectrum analyzer was set in max hold mode and allowed trace to stabilize.

7.3.2.4 The number of frequency hopping channels was calculated as provided in Table 7.3.2 and associated plots.

Figure 7.3.1 Hopping frequencies test setup



Test specification:	**Section 15.247(a)1, Number of hopping frequencies**		
Test procedure:	ANSI C63.10, section 7.8.3		
Test mode:	Compliance	**Verdict:**	PASS
Date(s):	19-Dec-19		
Temperature: 23 ºC	**Relative Humidity:** 38 %	**Air Pressure:** 1008 hPa	**Power:** 3.2 VDC
Remarks:			

Table 7.3.2 Hopping frequencies test results

ASSIGNED FREQUENCY:	902-928 MHz
MODULATION:	LoRa
DETECTOR USED:	Peak
VIDEO BANDWIDTH:	≥ RBW
FREQUENCY HOPPING:	Enabled

Number of hopping frequencies	Minimum number of hopping frequencies	Margin*	Verdict
16	NA for hybrid mode	NA	Pass

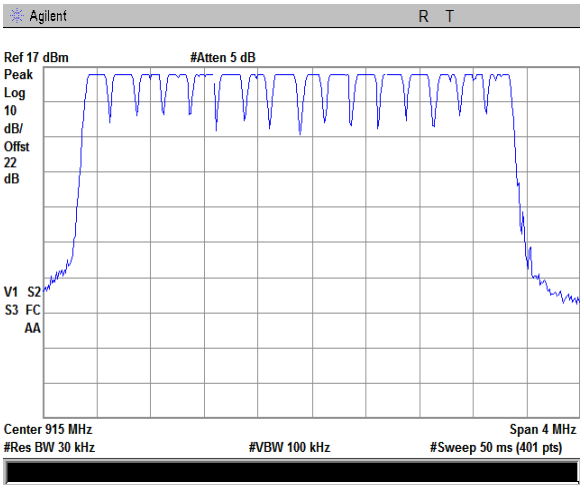
* - Margin = Number of hopping frequencies – Minimum number of hopping frequencies.

Reference numbers of test equipment used

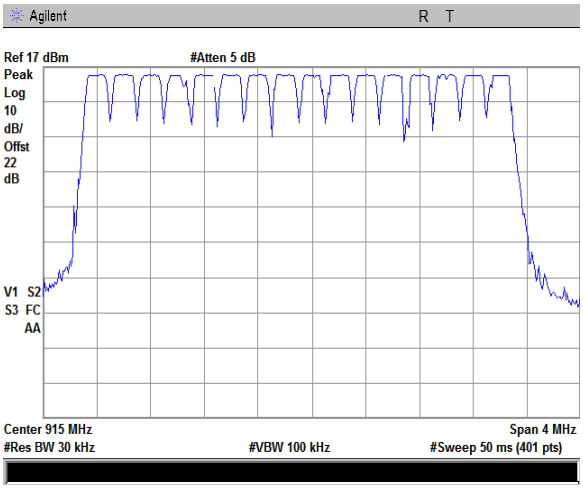
HL 2909	HL 5111	HL 5612	HL 5606				

Full description is given in Appendix A.

Plot 7.3.1 Number of hopping frequencies



980 bps



5470 bps

Test specification:	Section 15.247(a)1, Average time of occupancy		
Test procedure:	ANSI C63.10, section 7.8.4		
Test mode:	Compliance	Verdict:	PASS
Date(s):	20-Dec-19		
Temperature: 23 ºC	Relative Humidity: 40 %	Air Pressure: 1009 hPa	Power: 3 VDC
Remarks:			

7.4 Average time of occupancy

7.4.1 General

This test was performed to calculate the average time of occupancy (dwell time) on any frequency channel of the EUT. Specification test limits are given in Table 7.4.1.

Table 7.4.1 Average time of occupancy limits

Assigned frequency range, MHz	Maximum average time of occupancy, s	Investigated period, s	Number of hopping frequencies
902.0 – 928.0	0.4	20.0	≥ 50
902.0 – 928.0	0.4	10.0	< 50
902.0 – 928.0	**0.4**	**0.4 × N**	**N = 16**

7.4.2 Test procedure

7.4.2.1 The EUT was set up as shown in Figure 7.4.1, energized with frequency hopping function enabled and its proper operation was checked.

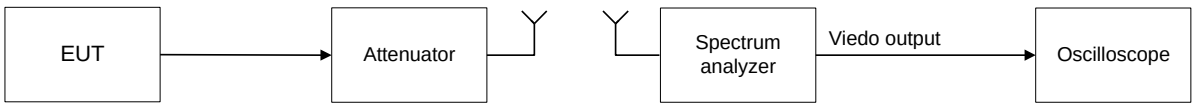
7.4.2.2 The spectrum analyzer span was set to zero centered on a hopping channel.

7.4.2.3 The single transmission duration and period were measured with oscilloscope.

7.4.2.4 The average time of occupancy was calculated as the single transmission time multiplied by the investigated period and divided by the single transmission period.

7.4.2.5 The test was repeated at each data rate and modulation type as provided in Table 7.4.2 and associated plots.

Figure 7.4.1 Average time of occupancy test setup



Test specification:	**Section 15.247(a)1, Average time of occupancy**		
Test procedure:	ANSI C63.10, section 7.8.4		
Test mode:	Compliance	**Verdict:**	PASS
Date(s):	20-Dec-19		
Temperature: 23 ºC	**Relative Humidity:** 40 %	**Air Pressure:** 1009 hPa	**Power:** 3 VDC
Remarks:			

Table 7.4.2 Average time of occupancy test results

ASSIGNED FREQUENCY: 902-928 MHz
MODULATION: LoRa
DETECTOR USED: Peak
NUMBER OF HOPPING FREQUENCIES: 16
INVESTIGATED PERIOD: 6.4 s
FREQUENCY HOPPING: Enabled

Carrier frequency, MHz	Single transmission duration, ms	Single transmission period, s	Average time of occupancy*, s	Bit rate, bps	Symbol rate, Msymbol/s	Limit, s	Margin, s**	Verdict
915	327	> 6.4	0.3270	980	NA	0.4	0.0730	Pass
915	51.25	> 6.4	0.0513	5470	NA	0.4	0.3487	Pass

* - Average time of occupancy = the transmit time per hop × the number of hops in the investigated period.

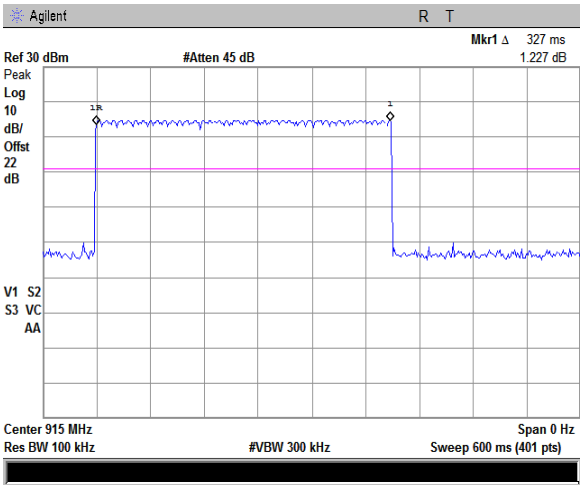
Reference numbers of test equipment used

HL 2909	HL	HL					

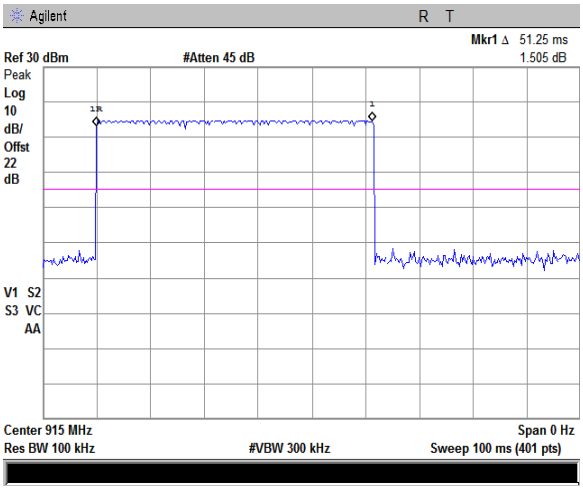
Full description is given in Appendix A.

Test specification:	Section 15.247(a)1, Average time of occupancy		
Test procedure:	ANSI C63.10, section 7.8.4		
Test mode:	Compliance	Verdict:	PASS
Date(s):	20-Dec-19		
Temperature: 23 ºC	Relative Humidity: 40 %	Air Pressure: 1009 hPa	Power: 3 VDC
Remarks:			

Plot 7.4.1 Single transmission duration at mid frequency

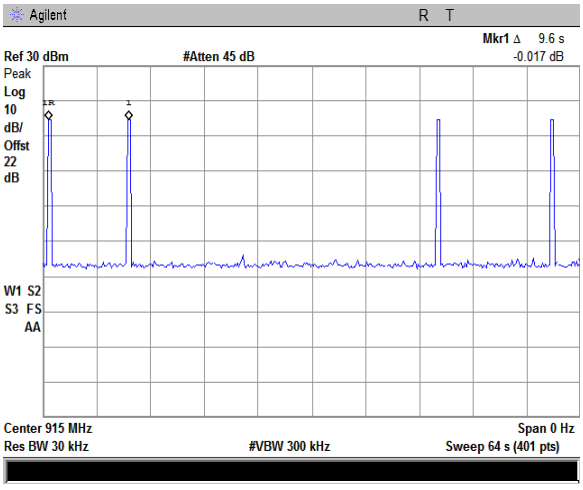


980 bps

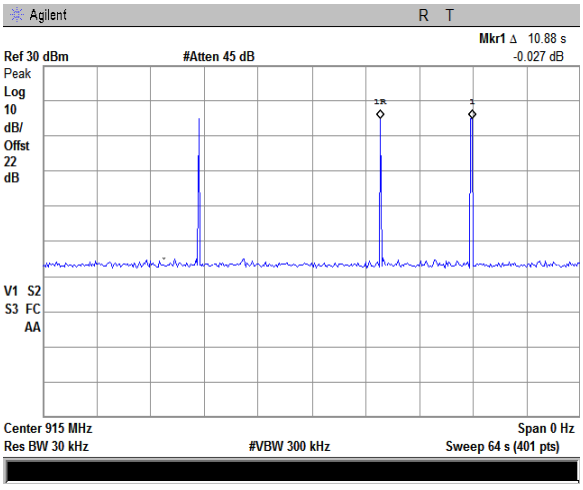


5470 bps

Plot 7.4.2 Single transmission period



980 bps



5470 bps

Test specification:	Section 15.247(b), Peak output power		
Test procedure:	ANSI C63.10, section 11.9.2.2.4		
Test mode:	Compliance	Verdict:	PASS
Date(s):	18-Dec-19		
Temperature: 23 ºC	Relative Humidity: 45 %	Air Pressure: 1027 hPa	Power: 3 VDC
Remarks:			

7.5 Peak output power

7.5.1 General

This test was performed to measure the maximum peak output power radiated by transmitter. Specification test limits are given in Table 7.5.1.

Table 7.5.1 Peak output power limits

Assigned frequency range, MHz	Peak output power*		Equivalent field strength limit @ 3m, dB(μV/m)*	Maximum antenna gain, dBi
	W	dBm		
902.0 – 928.0	0.25 (<50 hopping channels)	24.0(<50 hopping channels)	125.2 (<50 hopping channels)	6.0*

*- Equivalent field strength limit was calculated from the peak output power as follows: E=sqrt(30×P×G)/r, where P is peak output power in Watts, r is antenna to EUT distance in meters and G is transmitter antenna gain in dBi.
**- The limit is provided in terms of conducted RF power at the antenna connector. If transmitting antennas of directional gain greater than 6 dBi are used, the peak output power limit shall be reduced below the stated value as follows:

- by 1 dB for every 3 dB that the directional gain of antenna exceeds 6 dBi for fixed point-to-point transmitters operate in 2400-2483.5 MHz band;
- without any corresponding reduction for fixed point-to-point transmitters operate in 5725-5850 MHz band;
- by the amount in dB that the directional gain of antenna exceeds 6 dBi for the rest of transmitters.

7.5.2 Test procedure

7.5.2.1 The EUT was set up as shown in Figure 7.5.1, energized and its proper operation was checked.

7.5.2.2 The EUT was adjusted to produce maximum available to end user RF output power.

7.5.2.3 The frequency span of spectrum analyzer was set approximately 5 times wider than 20 dB bandwidth of the EUT and the resolution bandwidth was set wider than 20 dB bandwidth of the EUT. To find maximum radiation the turntable was rotated 360^0 and the measuring antenna height was swept in both vertical and horizontal polarizations.

7.5.2.4 The maximum field strength of the EUT carrier frequency was measured as provided in Table 7.5.2 and associated plots.

7.5.2.5 The maximum peak output power was calculated from the field strength of carrier as follows:

$$P = (E \times d)^2 / (30 \times G),$$

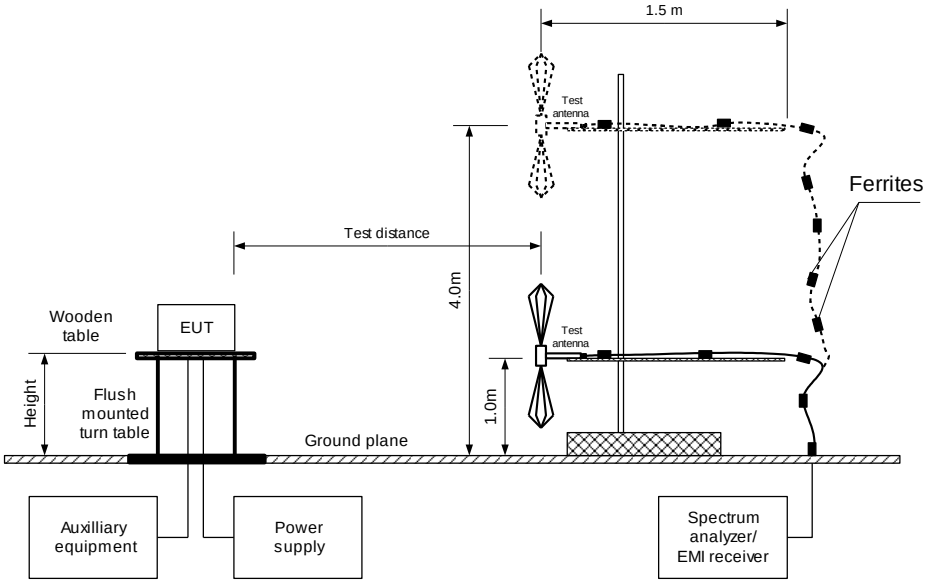
where P is the peak output power in W, E is the field strength in V/m, d is the test distance and G is the transmitter numeric antenna gain over an isotropic radiator.
The above equation was converted in logarithmic units for 3 m test distance:

Peak output power in dBm = Field strength in dB(μV/m) - Transmitter antenna gain in dBi – 95.2 dB

7.5.2.6 The worst test results (the lowest margins) were recorded in Table 7.5.2.

Test specification:	Section 15.247(b), Peak output power		
Test procedure:	ANSI C63.10, section 11.9.2.2.4		
Test mode:	Compliance	Verdict:	PASS
Date(s):	18-Dec-19		
Temperature: 23 ºC	Relative Humidity: 45 %	Air Pressure: 1027 hPa	Power: 3 VDC
Remarks:			

Figure 7.5.1 Setup for carrier field strength measurements



Test specification:	**Section 15.247(b), Peak output power**		
Test procedure:	ANSI C63.10, section 11.9.2.2.4		
Test mode:	Compliance	**Verdict:**	PASS
Date(s):	18-Dec-19		
Temperature: 23 ºC	**Relative Humidity:** 45 %	**Air Pressure:** 1027 hPa	**Power:** 3 VDC
Remarks:			

Table 7.5.2 Peak output power test results

ASSIGNED FREQUENCY: 902.0 – 928.0 MHz
TEST DISTANCE: 3 m
TEST SITE: Semi anechoic chamber
EUT HEIGHT: 0.8 m
DETECTOR USED: Peak
TEST ANTENNA TYPE: Biconilog (30 MHz – 1000 MHz)
Double ridged guide (above 1000 MHz)
MODULATION: LoRa
MODULATING SIGNAL: PRBS

TRANSMITTER OUTPUT POWER SETTINGS: Maximum
DETECTOR USED: Peak
RESOLUTION BANDWIDTH: 1 MHz
VIDEO BANDWIDTH: 10 MHz

BIT RATE: 980 bps

Frequency, MHz	Field strength, dB(μV/m)	Antenna polarization	Antenna height, m	Azimuth, degrees*	EUT antenna gain, dBi	Peak output power, dBm**	Limit, dBm	Margin, dB***	Verdict
902.5	105.40	Horizontal	1.40	33	2.0	8.20	24.0	-15.80	Pass
915.0	103.15	Horizontal	1.40	42	2.0	5.95	24.0	-18.05	Pass
927.5	99.70	Horizontal	1.40	35	2.0	2.50	24.0	-21.50	Pass

BIT RATE: 5470 bps

Frequency, MHz	Field strength, dB(μV/m)	Antenna polarization	Antenna height, m	Azimuth, degrees*	EUT antenna gain, dBi	Peak output power, dBm**	Limit, dBm	Margin, dB***	Verdict
902.5	105.06	Horizontal	1.40	33	2.0	7.86	24.0	-16.14	Pass
915.0	102.22	Horizontal	1.40	42	2.0	5.02	24.0	-18.98	Pass
927.5	98.99	Horizontal	1.40	35	2.0	1.79	24.0	-22.21	Pass

*****- EUT front panel refer to 0 degrees position of turntable.
******- Peak output power was calculated from the field strength of carrier as follows: $P = (E \times d)^2 / (30 \times G)$,
where P is the peak output power in W, E is the field strength in V/m, d is the test distance in meters and G is the transmitter numeric antenna gain over an isotropic radiator. The above equation was converted in logarithmic units for 3 m test distance: *Peak output power in dBm = Field strength in dB(μV/m) - Transmitter antenna gain in dBi – 95.2 dB*
***- Margin = Peak output power – specification limit.
Note: Maximum peak output power was obtained at U_{nom} ($115\%U_{nom}$, $85\%U_{nom}$) input power voltage.

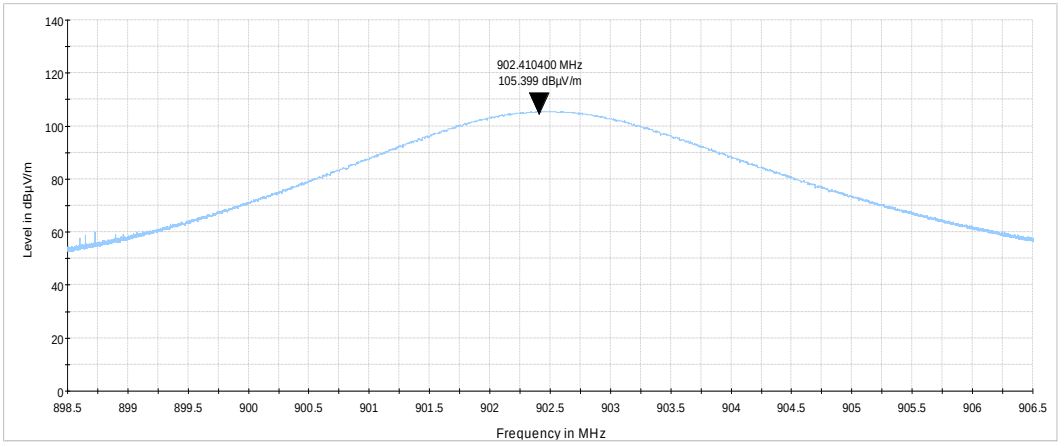
Reference numbers of test equipment used

HL 3903	HL 4360	HL 5288	HL 5665				

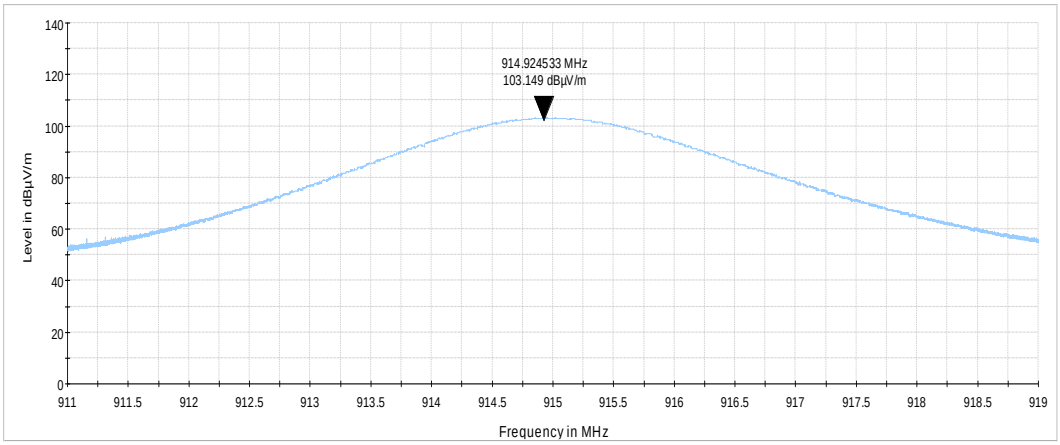
Full description is given in Appendix A.

Test specification:	Section 15.247(b), Peak output power		
Test procedure:	ANSI C63.10, section 11.9.2.2.4		
Test mode:	Compliance	Verdict:	PASS
Date(s):	18-Dec-19		
Temperature: 23 ºC	Relative Humidity: 45 %	Air Pressure: 1027 hPa	Power: 3 VDC
Remarks:			

Plot 7.5.1 Field strength of carrier at low frequency and bitrate 980 bps

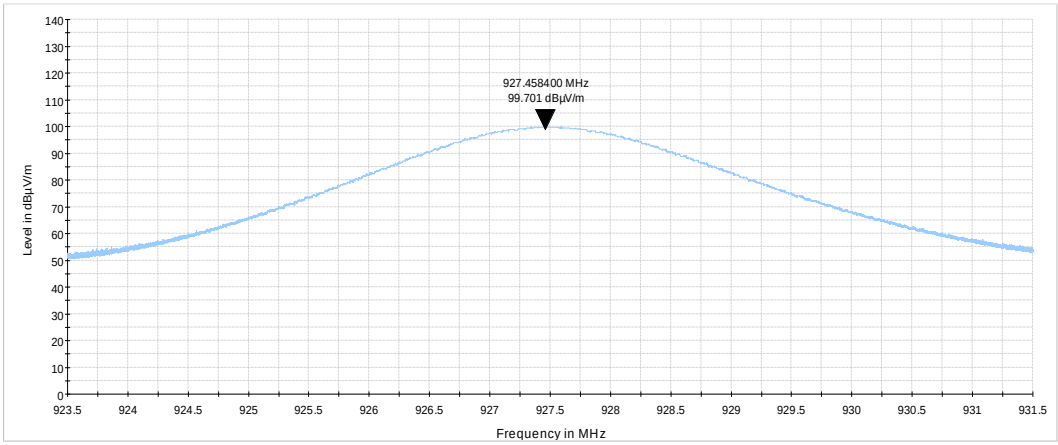


Plot 7.5.2 Field strength of carrier at mid frequency and bitrate 980 bps



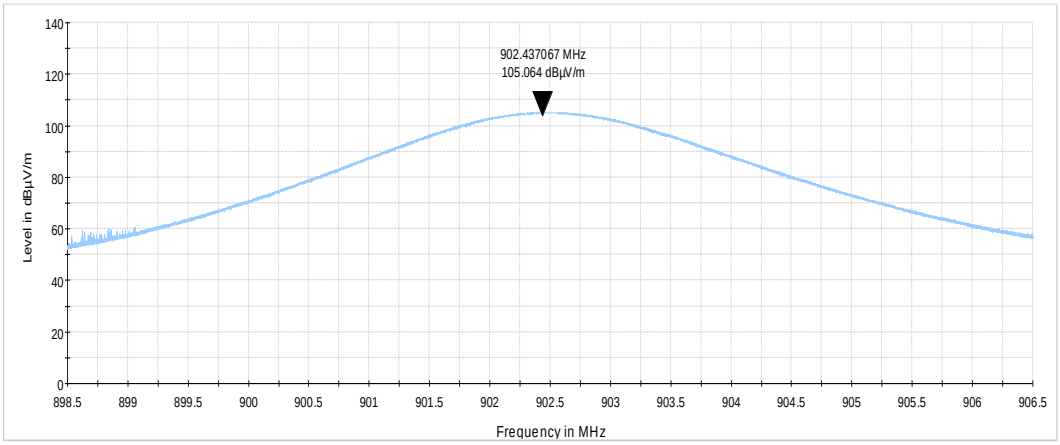
Test specification:	Section 15.247(b), Peak output power		
Test procedure:	ANSI C63.10, section 11.9.2.2.4		
Test mode:	Compliance	Verdict:	PASS
Date(s):	18-Dec-19		
Temperature: 23 ºC	Relative Humidity: 45 %	Air Pressure: 1027 hPa	Power: 3 VDC
Remarks:			

Plot 7.5.3 Field strength of carrier at high frequency and bitrate 980 bps

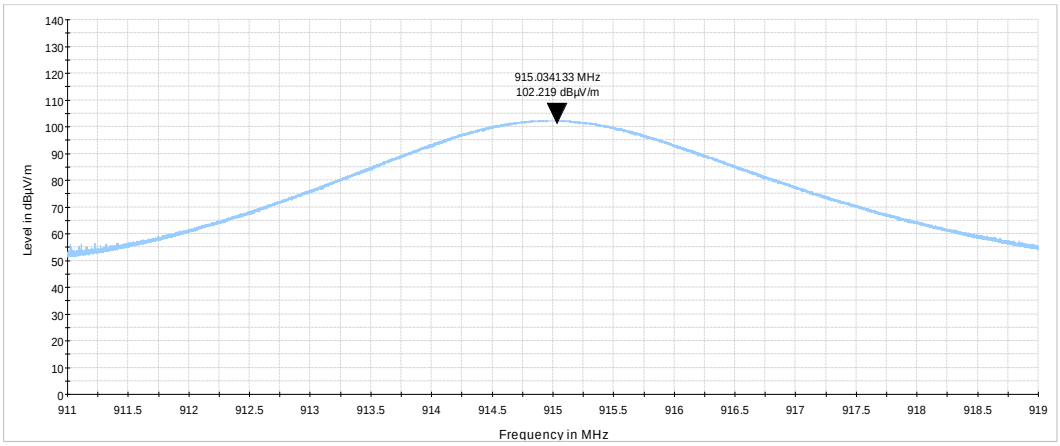


Test specification:	Section 15.247(b), Peak output power		
Test procedure:	ANSI C63.10, section 11.9.2.2.4		
Test mode:	Compliance	Verdict:	PASS
Date(s):	18-Dec-19		
Temperature: 23 ºC	Relative Humidity: 45 %	Air Pressure: 1027 hPa	Power: 3 VDC
Remarks:			

Plot 7.5.4 Field strength of carrier at low frequency and bitrate 5470 bps

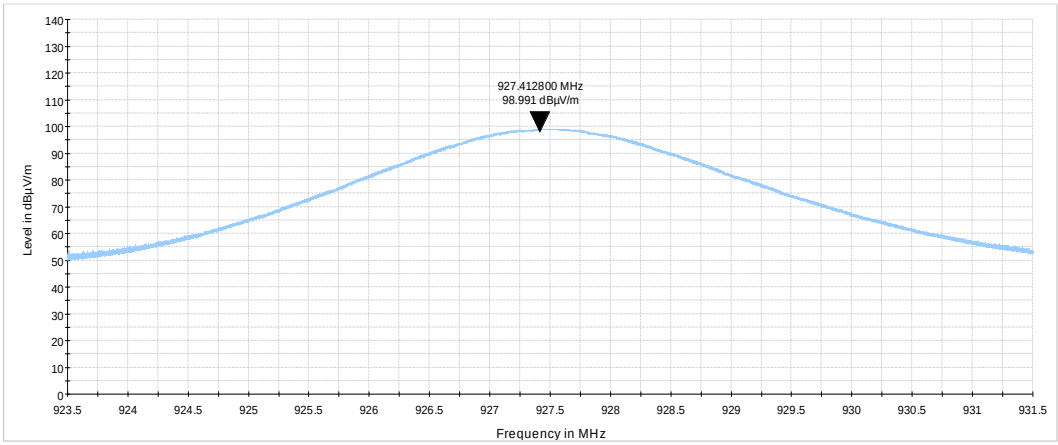


Plot 7.5.5 Field strength of carrier at mid frequency and bitrate 5470 bps



Test specification:	Section 15.247(b), Peak output power		
Test procedure:	ANSI C63.10, section 11.9.2.2.4		
Test mode:	Compliance	Verdict:	PASS
Date(s):	18-Dec-19		
Temperature: 23 ºC	Relative Humidity: 45 %	Air Pressure: 1027 hPa	Power: 3 VDC
Remarks:			

Plot 7.5.6 Field strength of carrier at high frequency and bitrate 5470 bps



Test specification:	**Section 15.247(d), Peak power density**		
Test procedure:	ANSI C63.10, section 11.10.5		
Test mode:	Compliance	**Verdict:**	PASS
Date(s):	20-Dec-19		
Temperature: 23 ºC	**Relative Humidity:** 40 %	**Air Pressure:** 1010 hPa	**Power:** 3 VDC
Remarks:			

7.6 Peak spectral power density

7.6.1 General

This test was performed to measure the peak spectral power density radiated by the transmitter RF antenna. Specification test limits are given in Table 7.6.1.

Table 7.6.1 Peak spectral power density limits

Assigned frequency range, MHz	Measurement bandwidth, kHz	Peak spectral power density, dBm	Equivalent field strength limit @ 3m, dB(μV/m)*
902.0 – 928.0	3.0	8.0	103.2

* - Equivalent field strength limit was calculated from the peak spectral power density as follows: E=sqrt(30×P)/r, where P is peak spectral power density and r is antenna to EUT distance in meters.

7.6.2 Test procedure for field strength measurements

7.6.2.1 The EUT was set up as shown in Figure 7.6.1, energized and its proper operation was checked.

7.6.2.2 The EUT was adjusted to produce maximum available to end user RF output power.

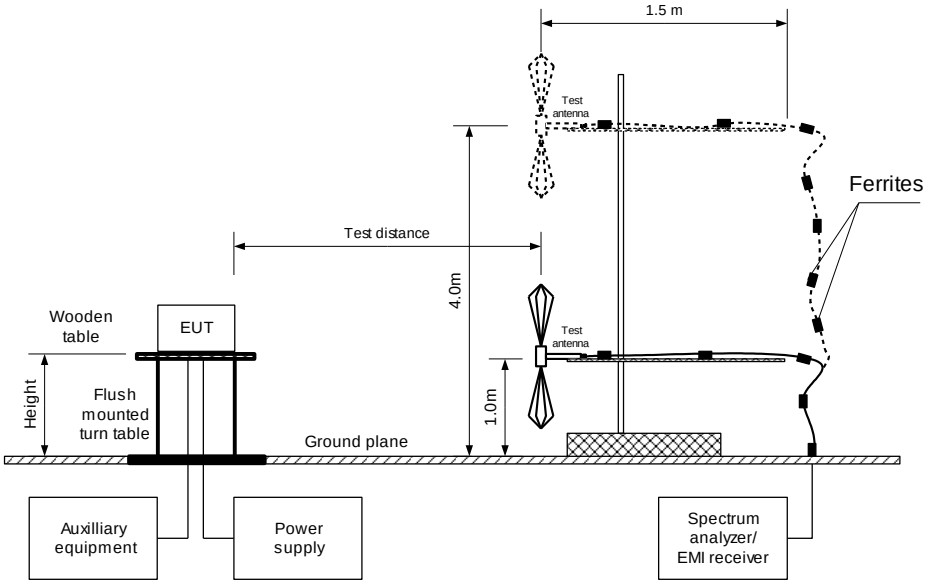
7.6.2.3 The field strength of the EUT carrier frequency was measured with antenna connected to spectrum analyzer/ EMI receiver. To find maximum radiation the turntable was rotated 360^0 and the measuring antenna height was swept in both vertical and horizontal polarizations.

7.6.2.4 The frequency span of spectrum analyzer was set to capture the entire 6 dB band of the transmitter, in peak hold mode with resolution bandwidth set to 3.0 kHz, video bandwidth wider than resolution bandwidth, auto sweep time and sufficient number of sweeps was allowed for trace stabilization. The spectrum lines spacing was verified to be wider than 3 kHz. Otherwise the resolution bandwidth was reduced until individual spectrum lines were resolved and the power of individual spectrum lines was integrated over 3 kHz band.

7.6.2.5 The peak of emission was zoomed with span set just wide enough to capture the emission peak area and sweep time was set equal to span width divided by resolution bandwidth. Spectrum analyzer was set in peak hold mode, sufficient number of sweeps was allowed for trace stabilization and peak spectral power density was measured as provided in Table 7.6.2 and associated plots.

Test specification:	Section 15.247(d), Peak power density		
Test procedure:	ANSI C63.10, section 11.10.5		
Test mode:	Compliance	Verdict:	PASS
Date(s):	20-Dec-19		
Temperature: 23 ºC	Relative Humidity: 40 %	Air Pressure: 1010 hPa	Power: 3 VDC
Remarks:			

Figure 7.6.1 Setup for carrier field strength measurements



Test specification:	**Section 15.247(d), Peak power density**		
Test procedure:	ANSI C63.10, section 11.10.5		
Test mode:	Compliance	**Verdict:**	PASS
Date(s):	20-Dec-19		
Temperature: 23 ºC	**Relative Humidity:** 40 %	**Air Pressure:** 1010 hPa	**Power:** 3 VDC
Remarks:			

Table 7.6.2 Field strength measurement of peak spectral power density

ASSIGNED FREQUENCY: 902.0 – 928.0 MHz
TEST DISTANCE: 3 m
TEST SITE: Semi anechoic chamber
EUT HEIGHT: 0.8 m
DETECTOR USED: Peak
RESOLUTION BANDWIDTH: 3 kHz
VIDEO BANDWIDTH: 10 kHz
TEST ANTENNA TYPE: Biconilog (30 MHz – 1000 MHz)
MODULATION: LoRa
MODULATING SIGNAL: PRBS
TRANSMITTER OUTPUT POWER SETTINGS: Maximum

BIT RATE: 980 bps

Frequency, MHz	Field strength, dB(μV/m)	EUT antenna gain, dBi	Limit, dB(μV/m)	Margin, dB*	Antenna polarization	Antenna height, m	Turn-table position**, degrees
902.5	104.53	2.0	8.0	-0.67	Horizontal	1.4	33
915.0	102.31	2.0	8.0	-2.89	Horizontal	1.4	42
927.5	98.63	2.0	8.0	-6.57	Horizontal	1.4	35

BIT RATE: 5470 bps

Frequency, MHz	Field strength, dB(μV/m)	EUT antenna gain, dBi	Limit, dB(μV/m)	Margin, dB*	Antenna polarization	Antenna height, m	Turn-table position**, degrees
902.5	102.23	2.0	8.0	-2.97	Horizontal	1.4	33
915.0	99.10	2.0	8.0	-6.10	Horizontal	1.4	42
927.5	95.33	2.0	8.0	-9.87	Horizontal	1.4	35

*****- Margin = Field strength - EUT antenna gain - calculated field strength limit.
******- EUT front panel refer to 0 degrees position of turntable.

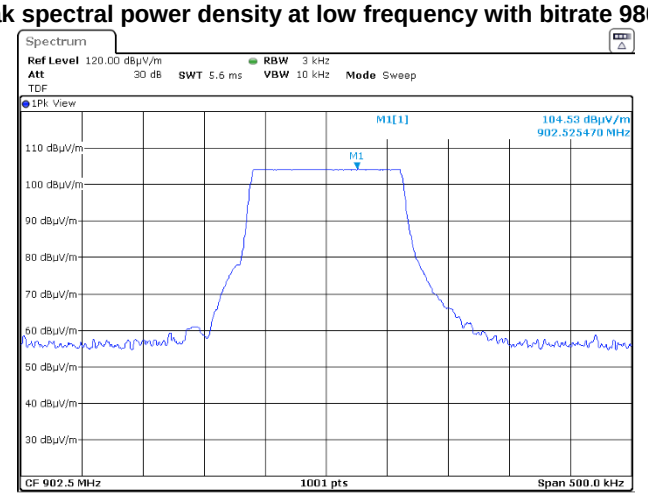
Reference numbers of test equipment used

HL 3903	HL 4355	HL 5288	HL 5665				

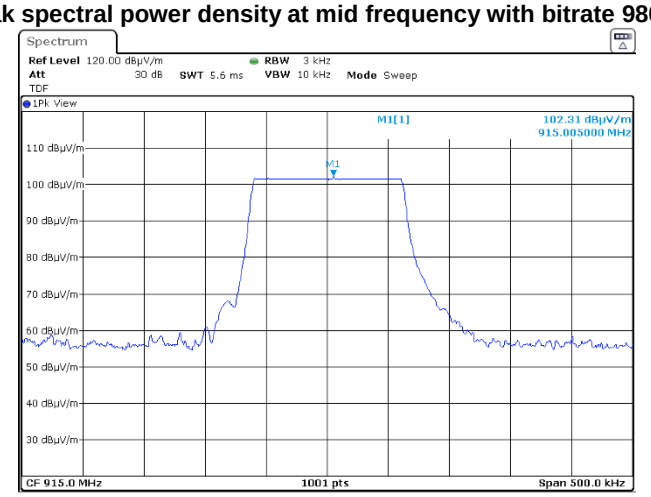
Full description is given in Appendix A.

Test specification:	Section 15.247(d), Peak power density		
Test procedure:	ANSI C63.10, section 11.10.5		
Test mode:	Compliance	Verdict:	PASS
Date(s):	20-Dec-19		
Temperature: 23 ºC	Relative Humidity: 40 %	Air Pressure: 1010 hPa	Power: 3 VDC
Remarks:			

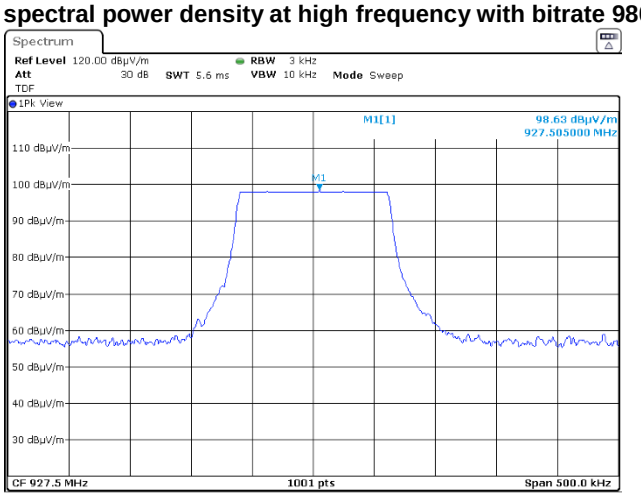
Plot 7.6.1 Peak spectral power density at low frequency with bitrate 980 bps



Plot 7.6.2 Peak spectral power density at mid frequency with bitrate 980 bps

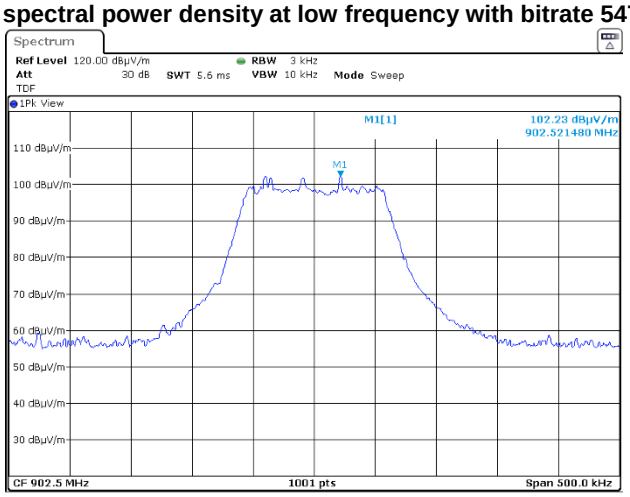


Plot 7.6.3 Peak spectral power density at high frequency with bitrate 980 bps

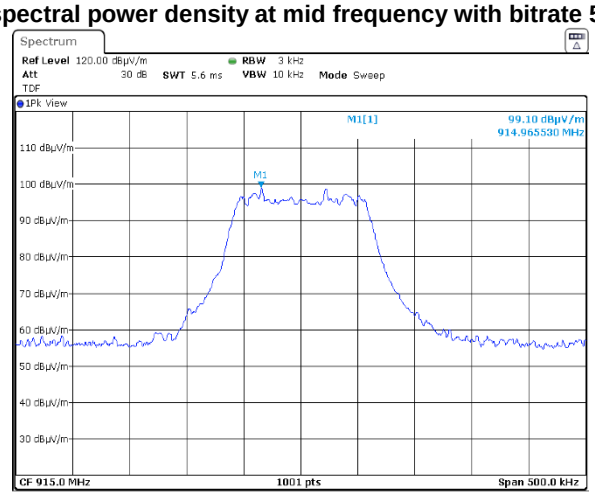


Test specification:	Section 15.247(d), Peak power density		
Test procedure:	ANSI C63.10, section 11.10.5		
Test mode:	Compliance	Verdict:	PASS
Date(s):	20-Dec-19		
Temperature: 23 ºC	Relative Humidity: 40 %	Air Pressure: 1010 hPa	Power: 3 VDC
Remarks:			

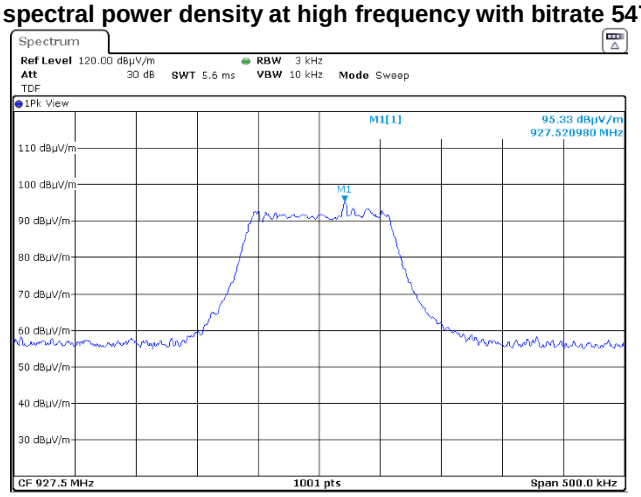
Plot 7.6.4 Peak spectral power density at low frequency with bitrate 5470 bps



Plot 7.6.5 Peak spectral power density at mid frequency with bitrate 5470 bps



Plot 7.6.6 Peak spectral power density at high frequency with bitrate 5470 bps



Test specification:	**Section 15.247(c), Radiated spurious emissions**		
Test procedure:	ANSI C63.10, sections 6.5, 6.6		
Test mode:	Compliance	**Verdict:**	PASS
Date(s):	20-Dec-19		
Temperature: 23 ºC	**Relative Humidity:** 40 %	**Air Pressure:** 1010 hPa	**Power:** 3 VDC
Remarks:			

7.7 Field strength of spurious emissions

7.7.1 General

This test was performed to measure field strength of spurious emissions from the EUT. Specification test limits are given in Table 7.7.1.

Table 7.7.1 Radiated spurious emissions limits

Frequency, MHz	Field strength at 3 m within restricted bands, dB(μV/m)*			Attenuation of field strength of spurious versus carrier outside restricted bands, dBc***
	Peak	Quasi Peak	Average	
0.009 – 0.090	148.5 – 128.5	NA	128.5 – 108.5**	20.0
0.090 – 0.110	NA	108.5 – 106.8**	NA	
0.110 – 0.490	126.8 – 113.8	NA	106.8 – 93.8**	
0.490 – 1.705	NA	73.8 – 63.0**	NA	
1.705 – 30.0*		69.5		
30 – 88		40.0		
88 – 216		43.5		
216 – 960		46.0		
960 - 1000		54.0		
1000 – 10th harmonic	74.0	NA	54.0	

*- The limit for 3 m test distance was calculated using the inverse square distance extrapolation factor as follows:

$$Lim_{S2} = Lim_{S1} + 40 \log (S_1/S_2),$$

where S_1 and S_2 – standard defined and test distance respectively in meters.

**- The limit decreases linearly with the logarithm of frequency.

*** - The field strength limits applied from the lowest radio frequency generated in the device, without going below 9 kHz up to the tenth harmonic of the highest fundamental frequency.

7.7.2 Test procedure for spurious emission field strength measurements in 9 kHz to 30 MHz band

7.7.2.1 The EUT was set up as shown in Figure 7.7.1, energized and the performance check was conducted.

7.7.2.2 The specified frequency range was investigated with antenna connected to spectrum analyzer/ EMI receiver. To find maximum radiation the turntable was rotated 360^0 and the measuring antenna was rotated around its vertical axis.

7.7.2.3 The worst test results (the lowest margins) were recorded and shown in the associated plots.

7.7.3 Test procedure for spurious emission field strength measurements above 30 MHz

The EUT was set up as shown in Figure 7.7.2, Figure 7.7.3 energized and the performance check was conducted.

7.7.3.1 The specified frequency range was investigated with antenna connected to spectrum analyzer/ EMI receiver. To find maximum radiation the turntable was rotated 360^0, the measuring antenna height was changed from 1 to 4 m, its polarization was switched from vertical to horizontal.

7.7.3.2 The worst test results (the lowest margins) were recorded and shown in the associated plots.

Test specification:	Section 15.247(c), Radiated spurious emissions		
Test procedure:	ANSI C63.10, sections 6.5, 6.6		
Test mode:	Compliance	Verdict:	PASS
Date(s):	20-Dec-19		
Temperature: 23 ºC	Relative Humidity: 40 %	Air Pressure: 1010 hPa	Power: 3 VDC
Remarks:			

Figure 7.7.1 Setup for spurious emission field strength measurements below 30 MHz

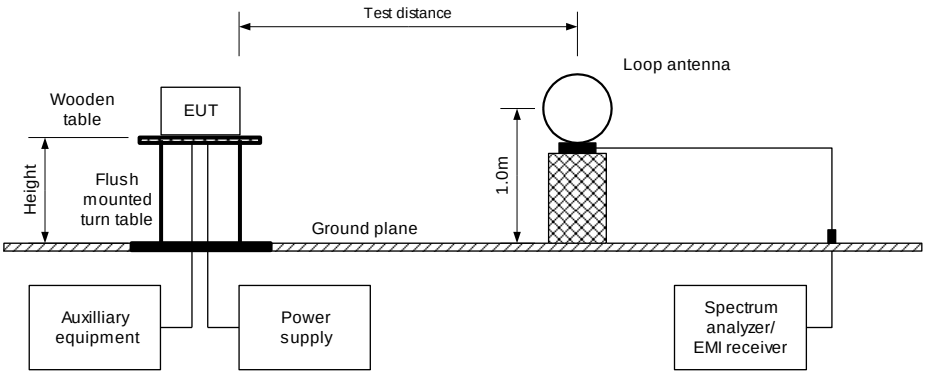
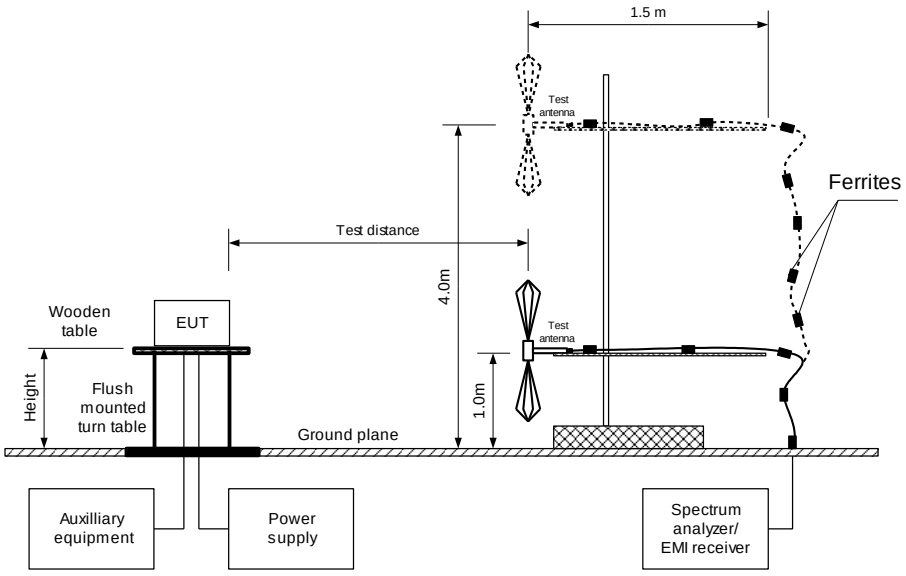
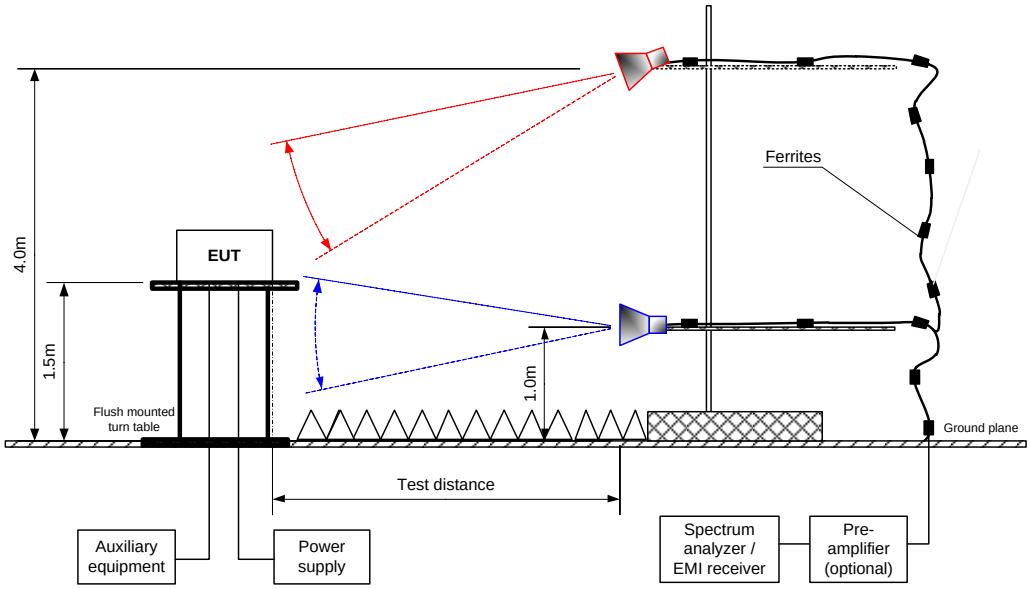


Figure 7.7.2 Setup for spurious emission field strength measurements in 30 – 1000 MHz



Test specification:	Section 15.247(c), Radiated spurious emissions		
Test procedure:	ANSI C63.10, sections 6.5, 6.6		
Test mode:	Compliance	Verdict:	PASS
Date(s):	20-Dec-19		
Temperature: 23 ºC	Relative Humidity: 40 %	Air Pressure: 1010 hPa	Power: 3 VDC
Remarks:			

Figure 7.7.3 Setup for spurious emission field strength measurements above1000 MHz



Test specification:	Section 15.247(c), Radiated spurious emissions		
Test procedure:	ANSI C63.10, sections 6.5, 6.6		
Test mode:	Compliance	Verdict:	PASS
Date(s):	20-Dec-19		
Temperature: 23 ºC	Relative Humidity: 40 %	Air Pressure: 1010 hPa	Power: 3 VDC
Remarks:			

Table 7.7.2 Field strength of emissions outside restricted bands

ASSIGNED FREQUENCY:	902.0 – 928.0 MHz
INVESTIGATED FREQUENCY RANGE:	0.009 – 9500 MHz
TEST DISTANCE:	3 m
MODULATION:	LoRa
MODULATING SIGNAL:	PRBS
DUTY CYCLE:	100 %
TRANSMITTER OUTPUT POWER SETTINGS:	Maximum
DETECTOR USED:	Peak
RESOLUTION BANDWIDTH:	100 kHz
VIDEO BANDWIDTH:	300 kHz
TEST ANTENNA TYPE:	Active loop (9 kHz – 30 MHz) Biconilog (30 MHz – 1000 MHz) Double ridged guide (above 1000 MHz)

Frequency, MHz	Field strength of spurious, dB(μV/m)	Antenna polarization	Antenna height, m	Azimuth, degrees*	Field strength of carrier, dB(μV/m)	Attenuation below carrier, dBc	Limit, dBc	Margin, dB**	Verdict
Low carrier frequency 902.5 MHz									
1805.0	45.6	Horizontal	1.7	-130	104.99	59.39	20.0	39.39	Pass
6317.5	56.8	Vertical	1.3	-90		48.19		28.19	
7220.0	49.2	Vertical	1.7	-44		55.79		35.79	
Mid carrier frequency 915.0 MHz									
1830.0	49.5	Horizontal	1.8	-132	102.93	53.43	20.0	33.43	Pass
5490.0	49.4	Vertical	1.3	-76		53.53		33.53	
6405.0	51.2	Vertical	1.8	-48		51.73		31.73	
High carrier frequency 927.5 MHz									
1855.0	55.2	Horizontal	1.8	-125	99.52	44.32	20.0	24.32	Pass
5565.0	49.8	Vertical	1.3	-95		49.72		29.72	
6492.5	52.6	Vertical	1.7	-50		46.92		26.92	

*****- EUT front panel refers to 0 degrees position of turntable.
******- Margin = Attenuation below carrier – specification limit.

Test specification:	**Section 15.247(c), Radiated spurious emissions**		
Test procedure:	ANSI C63.10, sections 6.5, 6.6		
Test mode:	Compliance	**Verdict:**	PASS
Date(s):	20-Dec-19		
Temperature: 23 ºC	**Relative Humidity:** 40 %	**Air Pressure:** 1010 hPa	**Power:** 3 VDC
Remarks:			

Table 7.7.3 Field strength of spurious emissions above 1 GHz within restricted bands

ASSIGNED FREQUENCY:	902.0 – 928.0 MHz
INVESTIGATED FREQUENCY RANGE:	1000 - 9500 MHz
TEST DISTANCE:	3 m
MODULATION:	LoRa
MODULATING SIGNAL:	PRBS
DUTY CYCLE:	100 %
TRANSMITTER OUTPUT POWER SETTINGS:	Maximum
DETECTOR USED:	Peak
RESOLUTION BANDWIDTH:	1000 kHz
TEST ANTENNA TYPE:	Double ridged guide

Frequency, MHz	Antenna		Azimuth, degrees*	Peak field strength(VBW=3 MHz)			Average field strength(VBW=10 Hz)				Verdict
	Polarization	Height, m		Measured, dB(μV/m)	Limit, dB(μV/m)	Margin, dB**	Measured, dB(μV/m)	Calculated, dB(μV/m)	Limit, dB(μV/m)	Margin, dB**	
Low carrier frequency 902.5 MHz											
2707.5	Horizontal	1.4	60	56.9	74	-17.1	53.2	NA	54	-0.8	Pass
3610.0	Vertical	1.5	102	49.1	74	-24.9	44.5	NA	54	-9.5	
4512.5	Vertical	1.5	-76	54.3	74	-19.7	49.2	NA	54	-4.8	
5415.0	Vertical	1.4	-140	53.4	74	-20.6	48.3	NA	54	-5.7	
8122.5	Horizontal	1.6	-137	49.4	74	-24.6	44.1	NA	54	-9.9	
9025.0	Horizontal	1.6	-130	49.1	74	-24.9	43.9	NA	54	-10.1	
Mid carrier frequency 915.0 MHz											
2745.0	Horizontal	1.4	56	55.7	74	-18.3	52.7	NA	54	-1.3	Pass
3660.0	Vertical	1.5	-100	46.5	74	-27.5	41.0	NA	54	-13	
4086.0	Vertical	1.5	-76	48.7	74	-25.3	43.5	NA	54	-10.5	
High carrier frequency 927.5 MHz											
2782.5	Horizontal	1.4	55	54.8	74	-19.2	51.2	NA	54	-2.8	Pass
3710.0	Vertical	1.5	-98	40.7	74	-33.3	35.3	NA	54	-18.7	
4637.5	Vertical	1.5	-80	49.8	74	-24.2	43.7	NA	54	-10.3	

*****- EUT front panel refers to 0 degrees position of turntable.
******- Margin = Measured field strength - specification limit.

Test specification:	**Section 15.247(c), Radiated spurious emissions**		
Test procedure:	ANSI C63.10, sections 6.5, 6.6		
Test mode:	Compliance	**Verdict:**	PASS
Date(s):	20-Dec-19		
Temperature: 23 ºC	**Relative Humidity:** 40 %	**Air Pressure:** 1010 hPa	**Power:** 3 VDC
Remarks:			

Table 7.7.4 Field strength of spurious emissions below 1 GHz within restricted bands

ASSIGNED FREQUENCY:	902.0 MHz
INVESTIGATED FREQUENCY RANGE:	0.009 – 1000 MHz
TEST DISTANCE:	3 m
MODULATION:	LoRa
MODULATING SIGNAL:	PRBS
BIT RATE:	3.9 kbps
DUTY CYCLE:	100 %
TRANSMITTER OUTPUT POWER SETTINGS:	Maximum
RESOLUTION BANDWIDTH:	0.2 kHz (9 kHz – 150 kHz) 9.0 kHz (150 kHz – 30 MHz) 120 kHz (30 MHz – 1000 MHz)
VIDEO BANDWIDTH:	> Resolution bandwidth
TEST ANTENNA TYPE:	Active loop (9 kHz – 30 MHz) Biconilog (30 MHz – 1000 MHz)

Frequency, MHz	**Peak emission, dB(μV/m)**	**Quasi-peak**			**Antenna polarization**	**Antenna height, m**	**Turn-table position**, degrees**	**Verdict**
		Measured emission, dB(μV/m)	**Limit, dB(μV/m)**	**Margin, dB***				
Low carrier frequency 902.5 MHz								
All emissions are more than 20 dB below the limit								Pass
Mid carrier frequency 915.0 MHz								
All emissions are more than 20 dB below the limit								Pass
High carrier frequency 927.5 MHz								
All emissions are more than 20 dB below the limit limit								Pass

*****- Margin = Measured emission - specification limit.
******- EUT front panel refer to 0 degrees position of turntable.

Table 7.7.5 Restricted bands

MHz	**MHz**	**MHz**	**MHz**	**MHz**	**GHz**
0.09 - 0.11	8.37625 - 8.38675	73 - 74.6	399.9 - 410	2690 - 2900	10.6 - 12.7
0.495 - 0.505	8.41425 - 8.41475	74.8 - 75.2	608 - 614	3260 - 3267	13.25 - 13.4
2.1735 - 2.1905	12.29 - 12.293	108 - 121.94	960 - 1240	3332 - 3339	14.47 - 14.5
4.125 - 4.128	12.51975 - 12.52025	123 - 138	1300 - 1427	3345.8 - 3358	15.35 - 16.2
4.17725 - 4.17775	12.57675 - 12.57725	149.9 - 150.05	1435 - 1626.5	3600 - 4400	17.7 - 21.4
4.20725 - 4.20775	13.36 - 13.41	156.52475 - 156.52525	1645.5 - 1646.5	4500 - 5150	22.01 - 23.12
6.215 - 6.218	16.42 - 16.423	156.7 - 156.9	1660 - 1710	5350 – 5460	23.6 - 24
6.26775 - 6.26825	16.69475 - 16.69525	162.0125 - 167.17	1718.8 - 1722.2	7250 - 7750	31.2 - 31.8
6.31175 - 6.31225	16.80425 - 16.80475	167.72 - 173.2	2200 - 2300	8025 – 8500	36.43 - 36.5
8.291 - 8.294	25.5 - 25.67	240 - 285	2310 - 2390	9000 - 9200	Above 38.6
8.362 - 8.366	37.5 - 38.25	322 - 335.4	2483.5 - 2500	9300 - 9500	

Reference numbers of test equipment used

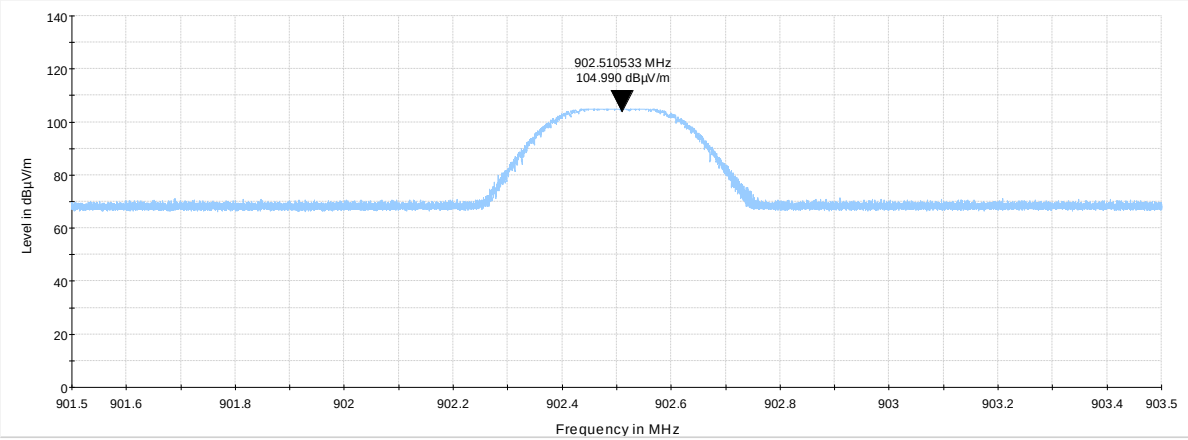
HL 3903	HL 4360	HL 4933	HL 5288	HL 5665	HL 446	HL 5404	HL 4338

Full description is given in Appendix A.

Test specification:	Section 15.247(c), Radiated spurious emissions		
Test procedure:	ANSI C63.10, sections 6.5, 6.6		
Test mode:	Compliance	Verdict:	PASS
Date(s):	20-Dec-19		
Temperature: 23 ºC	Relative Humidity: 40 %	Air Pressure: 1010 hPa	Power: 3 VDC
Remarks:			

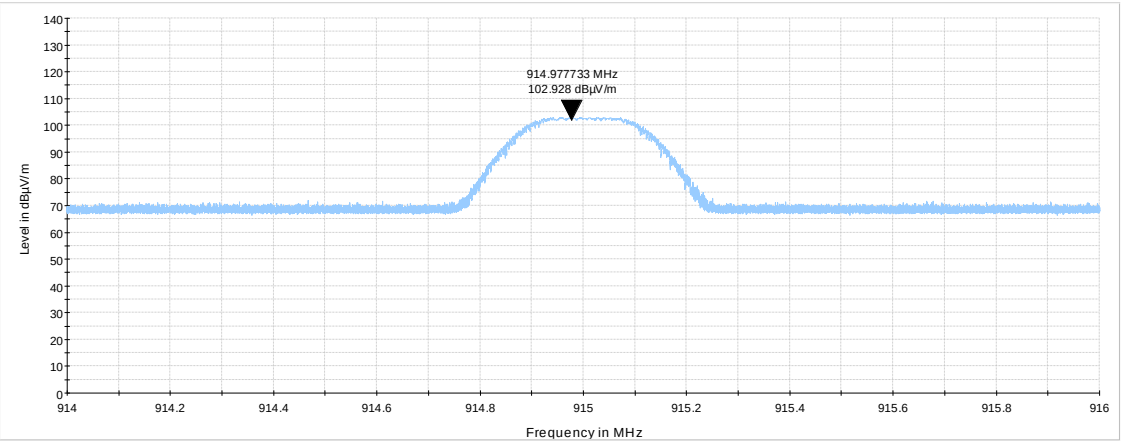
Plot 7.7.1 Radiated emission measurements at the low carrier frequency

TEST SITE: Semi anechoic chamber
TEST DISTANCE: 3 m
ANTENNA POLARIZATION: Vertical and horizontal



Plot 7.7.2 Radiated emission measurements at the mid carrier frequency

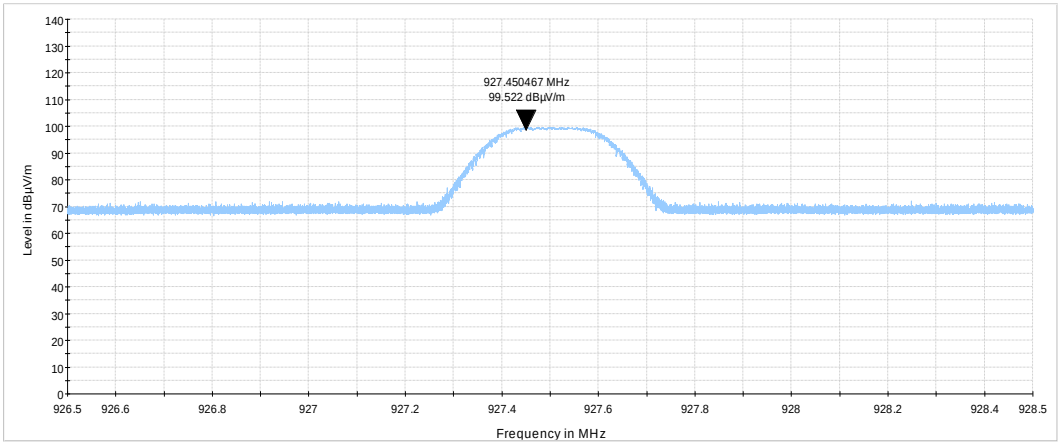
TEST SITE: Semi anechoic chamber
TEST DISTANCE: 3 m
ANTENNA POLARIZATION: Vertical and horizontal



Test specification:	Section 15.247(c), Radiated spurious emissions		
Test procedure:	ANSI C63.10, sections 6.5, 6.6		
Test mode:	Compliance	Verdict:	PASS
Date(s):	20-Dec-19		
Temperature: 23 ºC	Relative Humidity: 40 %	Air Pressure: 1010 hPa	Power: 3 VDC
Remarks:			

Plot 7.7.3 Radiated emission measurements at the high carrier frequency

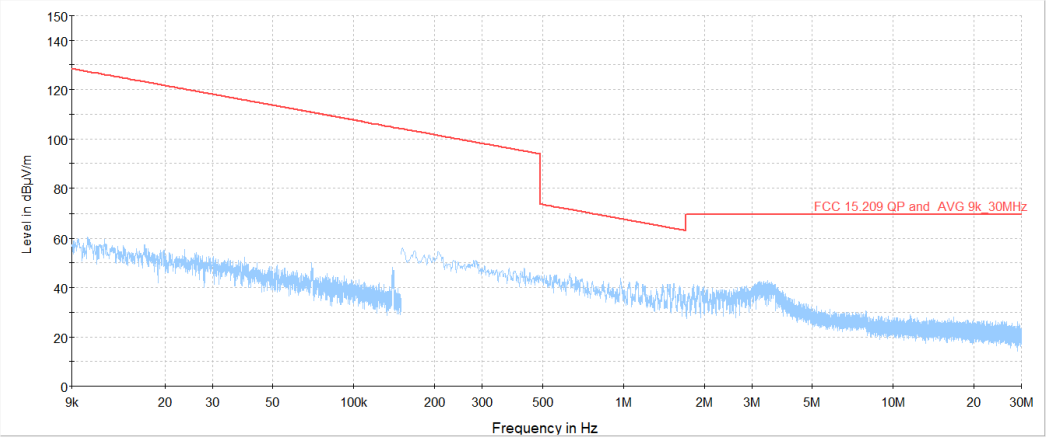
TEST SITE: Semi anechoic chamber
TEST DISTANCE: 3 m
ANTENNA POLARIZATION: Vertical and horizontal



Test specification:	Section 15.247(c), Radiated spurious emissions		
Test procedure:	ANSI C63.10, sections 6.5, 6.6		
Test mode:	Compliance	Verdict:	PASS
Date(s):	20-Dec-19		
Temperature: 23 ºC	Relative Humidity: 40 %	Air Pressure: 1010 hPa	Power: 3 VDC
Remarks:			

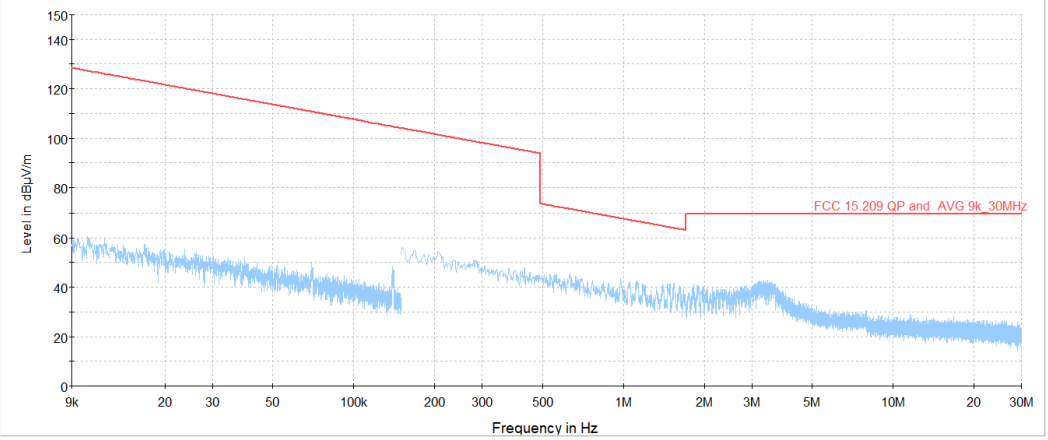
Plot 7.7.4 Radiated emission measurements from 9 kHz to 30 MHz at the low carrier frequency

TEST SITE: Semi anechoic chamber
TEST DISTANCE: 3 m
ANTENNA POLARIZATION: Vertical



Plot 7.7.5 Radiated emission measurements from 9 kHz to 30 MHz at the high carrier frequency

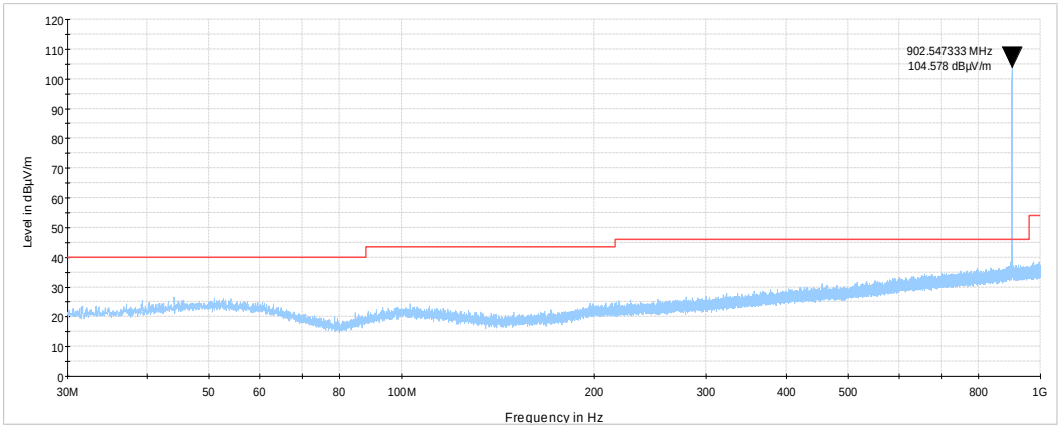
TEST SITE: Semi anechoic chamber
TEST DISTANCE: 3 m
ANTENNA POLARIZATION: Vertical



Test specification:	Section 15.247(c), Radiated spurious emissions		
Test procedure:	ANSI C63.10, sections 6.5, 6.6		
Test mode:	Compliance	Verdict:	PASS
Date(s):	20-Dec-19		
Temperature: 23 ºC	Relative Humidity: 40 %	Air Pressure: 1010 hPa	Power: 3 VDC
Remarks:			

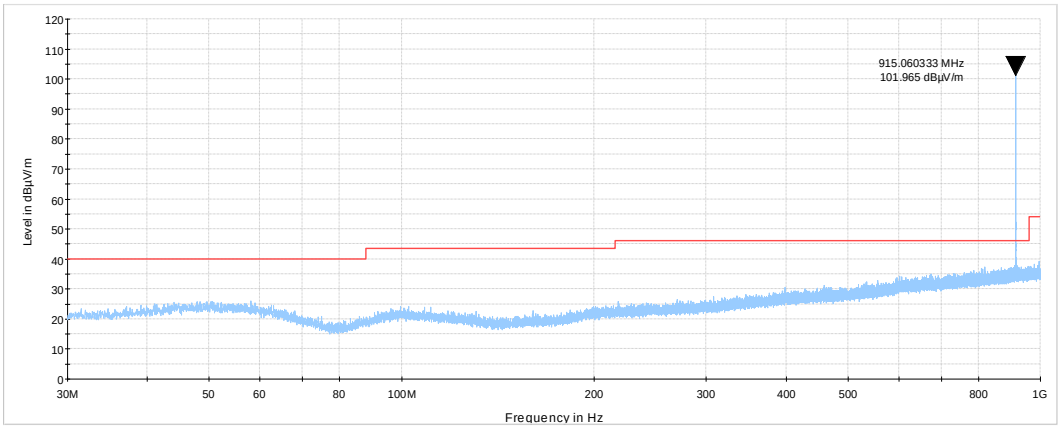
Plot 7.7.6 Radiated emission measurements from 30 to 1000 MHz at the low carrier frequency

TEST SITE: Semi anechoic chamber
TEST DISTANCE: 3 m
ANTENNA POLARIZATION: Vertical and Horizontal



Plot 7.7.7 Radiated emission measurements from 30 to 1000 MHz at the mid carrier frequency

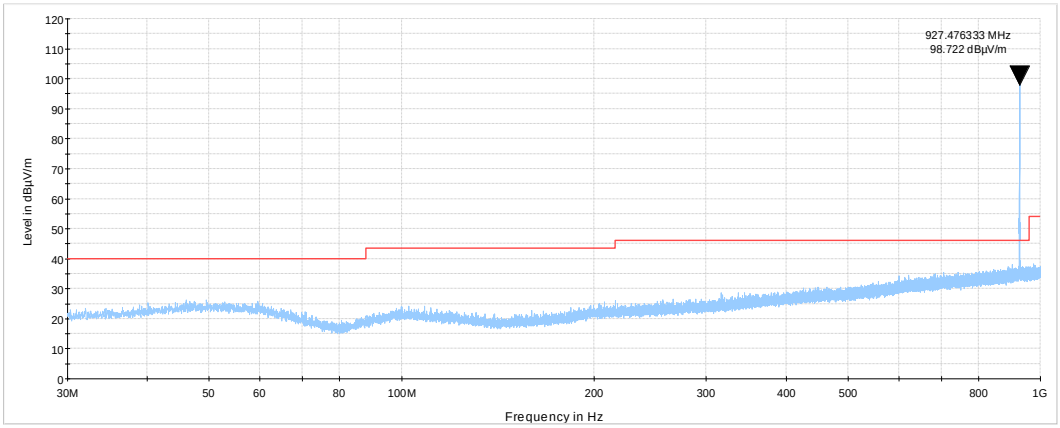
TEST SITE: Semi anechoic chamber
TEST DISTANCE: 3 m
ANTENNA POLARIZATION: Vertical and Horizontal



Test specification:	Section 15.247(c), Radiated spurious emissions		
Test procedure:	ANSI C63.10, sections 6.5, 6.6		
Test mode:	Compliance	Verdict:	PASS
Date(s):	20-Dec-19		
Temperature: 23 ºC	Relative Humidity: 40 %	Air Pressure: 1010 hPa	Power: 3 VDC
Remarks:			

Plot 7.7.8 Radiated emission measurements from 30 to 1000 MHz at the high carrier frequency

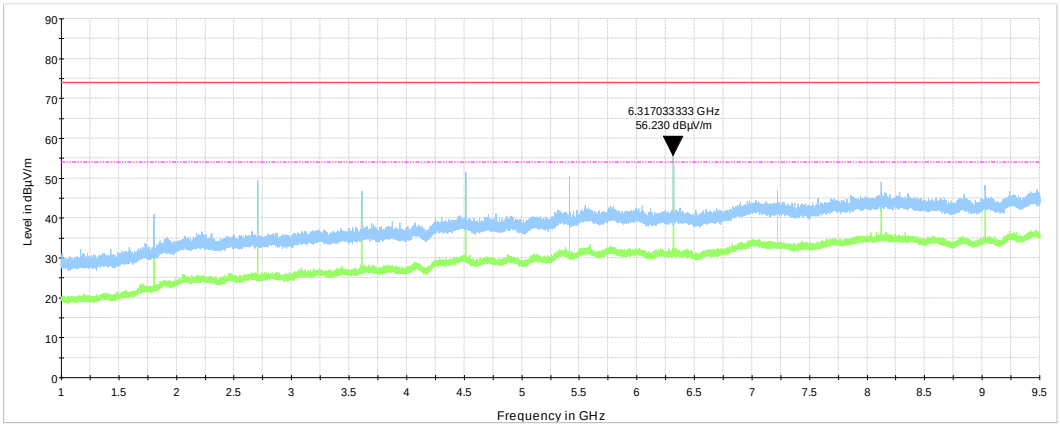
TEST SITE: Semi anechoic chamber
TEST DISTANCE: 3 m
ANTENNA POLARIZATION: Vertical and Horizontal



Test specification:	Section 15.247(c), Radiated spurious emissions		
Test procedure:	ANSI C63.10, sections 6.5, 6.6		
Test mode:	Compliance	Verdict:	PASS
Date(s):	20-Dec-19		
Temperature: 23 ºC	Relative Humidity: 40 %	Air Pressure: 1010 hPa	Power: 3 VDC
Remarks:			

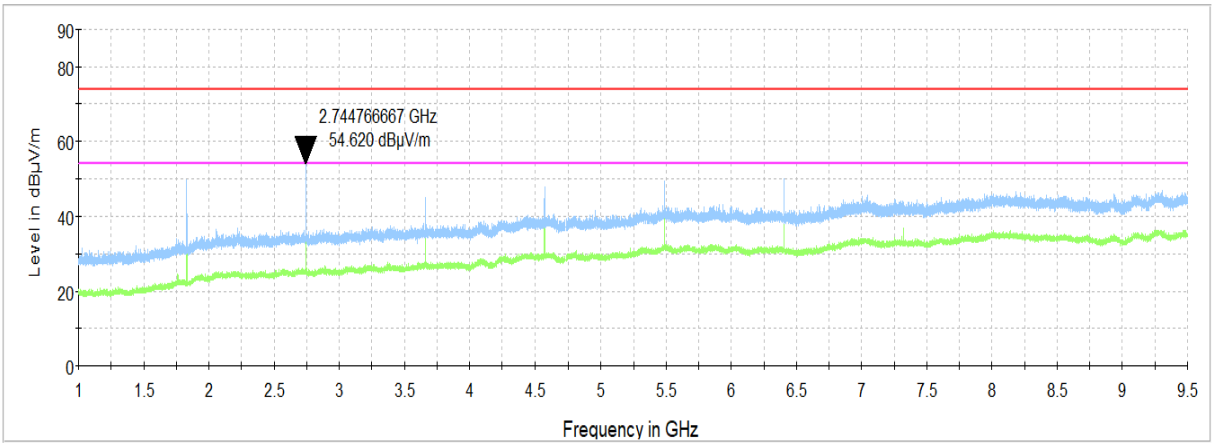
Plot 7.7.9 Radiated emission measurements from 1000 to 9500 MHz at the low carrier frequency

TEST SITE: Semi anechoic chamber
TEST DISTANCE: 3 m
ANTENNA POLARIZATION: Vertical and Horizontal



Plot 7.7.10 Radiated emission measurements from 1000 to 9500 MHz at the mid carrier frequency

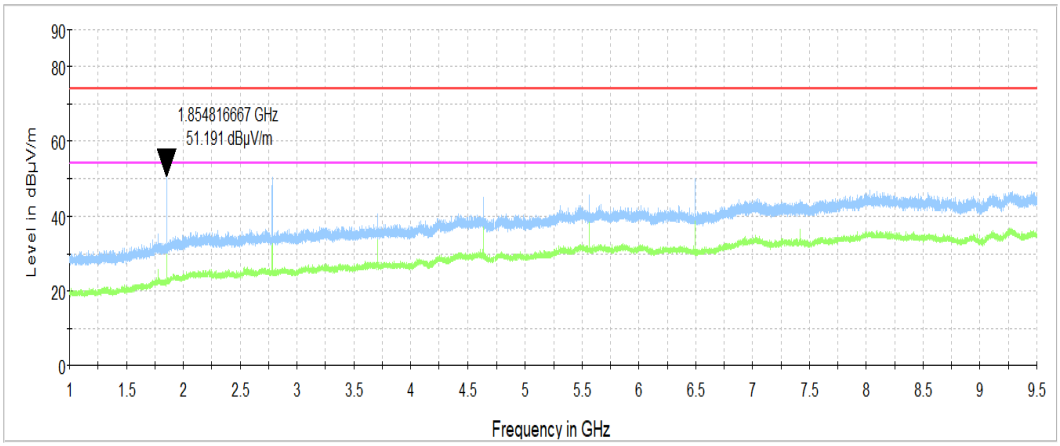
TEST SITE: Semi anechoic chamber
TEST DISTANCE: 3 m
ANTENNA POLARIZATION: Vertical and Horizontal



Test specification:	**Section 15.247(c), Radiated spurious emissions**		
Test procedure:	ANSI C63.10, sections 6.5, 6.6		
Test mode:	Compliance	**Verdict:**	PASS
Date(s):	20-Dec-19		
Temperature: 23 ºC	**Relative Humidity:** 40 %	**Air Pressure:** 1010 hPa	**Power:** 3 VDC
Remarks:			

Plot 7.7.11 Radiated emission measurements from 1000 to 9500 MHz at the high carrier frequency

TEST SITE: Semi anechoic chamber
TEST DISTANCE: 3 m
ANTENNA POLARIZATION: Vertical and Horizontal



Test specification:	Section 15.247(d), Emissions at band edges		
Test procedure:	ANSI C63.10, Section 6.10		
Test mode:	Compliance	Verdict:	PASS
Date(s):	26-Dec-19		
Temperature: 23 ºC	Relative Humidity: 45 %	Air Pressure: 1008 hPa	Power: 3 VDC
Remarks:			

7.8 Band edge radiated emissions

7.8.1 General

This test was performed to measure emissions, radiated from the EUT at the assigned frequency band edges. Specification test limits are given in Table 7.8.1.

Table 7.8.1 Band edge emission limits

Assigned frequency, MHz	Attenuation below carrier*, dBc	Field strength at 3 m within restricted bands, dB(μV/m)	
		Peak	Average
902.0 – 928.0	20.0	74.0	54.0

* - Band edge emission limit is provided in terms of attenuation below the peak of modulated carrier measured with the same resolution bandwidth.

7.8.2 Test procedure

7.8.2.1 The EUT was set up as shown in Figure 7.8.1, energized normally modulated at the maximum data rate with its hopping function disabled and its proper operation was checked.

7.8.2.2 The EUT was adjusted to produce maximum available to end user RF output power at the lowest carrier frequency.

7.8.2.3 The spectrum analyzer span was set to capture the carrier frequency and associated modulation products. The resolution bandwidth was set wider than 1 % of the frequency span.

7.8.2.4 The spectrum analyzer was set in max hold mode and allowed trace to stabilize. The highest emission level within the authorized band was measured.

7.8.2.5 The maximum band edge emission and modulation product outside of the band were measured as provided in Table 7.8.2 and associated plots and referenced to the highest emission level measured within the authorized band.

7.8.2.6 The above procedure was repeated with the EUT adjusted to produce maximum RF output power at the highest carrier frequency.

7.8.2.7 The above procedure was repeated with the frequency hopping function enabled.

Figure 7.8.1 Band edge emission test setup

Test specification:	**Section 15.247(d), Emissions at band edges**		
Test procedure:	ANSI C63.10, Section 6.10		
Test mode:	Compliance	**Verdict:**	PASS
Date(s):	26-Dec-19		
Temperature: 23 ºC	**Relative Humidity:** 45 %	**Air Pressure:** 1008 hPa	**Power:** 3 VDC
Remarks:			

Table 7.8.2 Band edge emission test results

ASSIGNED FREQUENCY RANGE: 902-928 MHz
DETECTOR USED: Peak
MODULATION: LoRa
RESOLUTION BANDWIDTH: 100 kHz
VIDEO BANDWIDTH: 300 kHz

BIT RATE: 980bps

Frequency, MHz	Band edge emission, dBm	Emission at carrier, dBm	Attenuation below carrier, dBc	Limit, dBc	Margin, dB*	Verdict
Frequency hopping disabled						
902	-34.00	14.05	48.05	20.0	28.05	Pass
928	-27.41	13.94	41.38		21.38	
Frequency hopping enabled						
902	-34.04	13.98	48.02	20.0	28.02	Pass
928	-26.92	13.96	40.88		20.88	

BIT RATE: 5470 bps

Frequency, MHz	Band edge emission, dBm	Emission at carrier, dBm	Attenuation below carrier, dBc	Limit, dBc	Margin, dB*	Verdict
Frequency hopping disabled						
902	-33.70	14.08	47.78	20.0	27.78	Pass
928	-26.97	14.03	41.00		21.00	
Frequency hopping enabled						
902	-34.86	13.81	47.87	20.0	27.87	Pass
928	-28.63	13.95	42.58		22.58	

*****- Margin = Attenuation below carrier – specification limit.

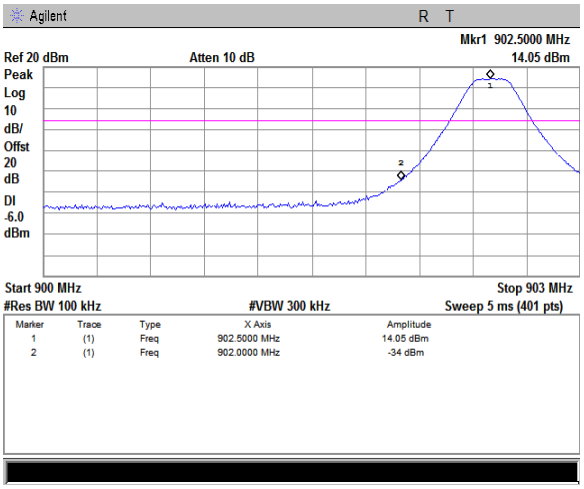
Reference numbers of test equipment used

HL 2909	HL 5606	HL 5612					

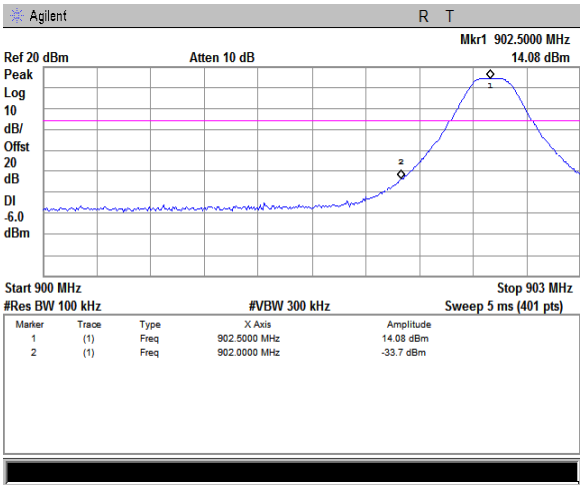
Full description is given in Appendix A.

Test specification:	Section 15.247(d), Emissions at band edges		
Test procedure:	ANSI C63.10, Section 6.10		
Test mode:	Compliance	Verdict:	PASS
Date(s):	26-Dec-19		
Temperature: 23 ºC	Relative Humidity: 45 %	Air Pressure: 1008 hPa	Power: 3 VDC
Remarks:			

Plot 7.8.1 The band edge emission at low carrier frequency with hopping function disabled

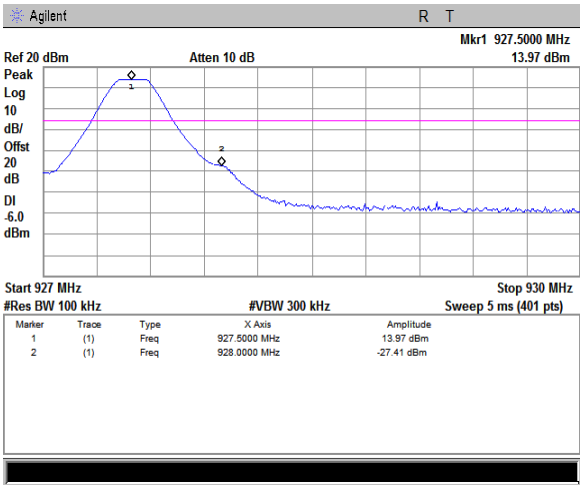


980 bps

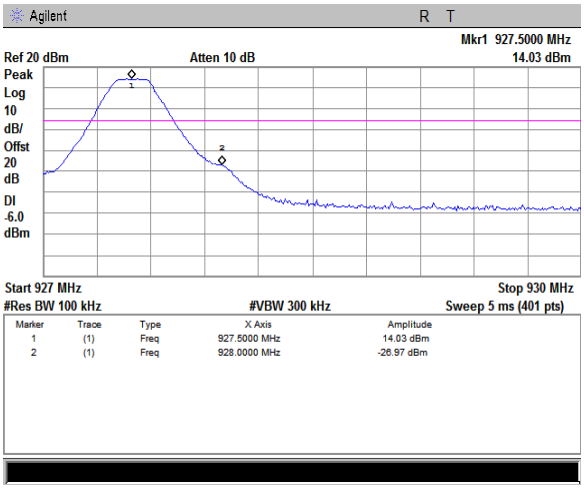


5470 bps

Plot 7.8.2 The band edge emission at high carrier frequency with hopping function disabled



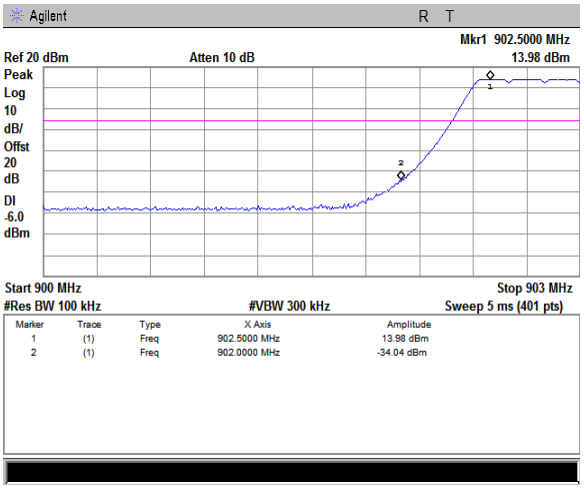
980 bps



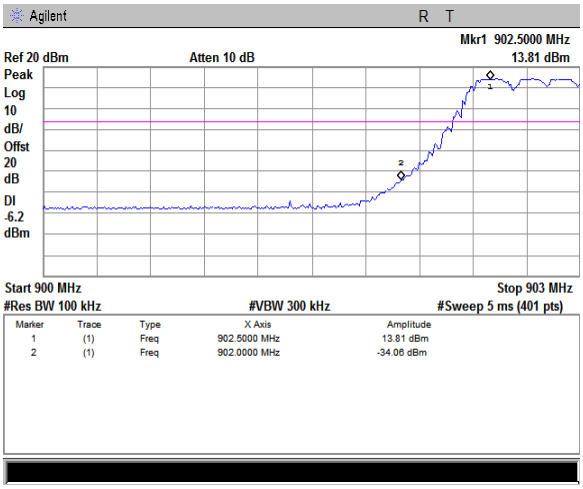
5470 bps

Test specification:	Section 15.247(d), Emissions at band edges		
Test procedure:	ANSI C63.10, Section 6.10		
Test mode:	Compliance	Verdict:	PASS
Date(s):	26-Dec-19		
Temperature: 23 ºC	Relative Humidity: 45 %	Air Pressure: 1008 hPa	Power: 3 VDC
Remarks:			

Plot 7.8.3 The band edge emission at low carrier frequency with hopping function enabled

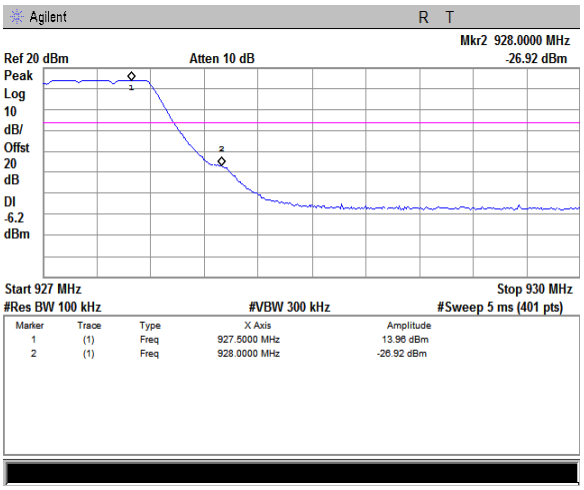


980 bps

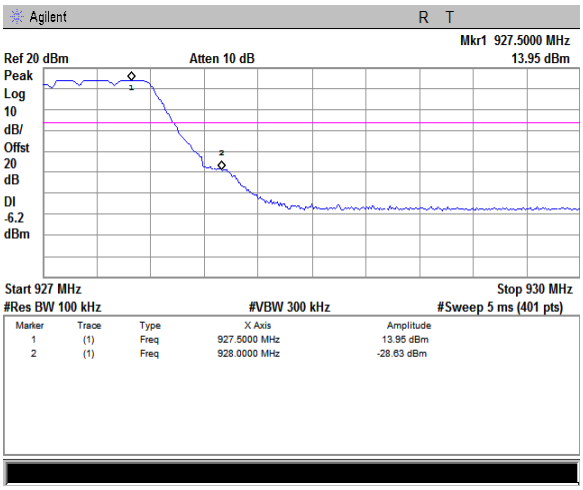


5470 bps

Plot 7.8.4 The band edge emission at high carrier frequency with hopping function enabled



980 bps



5470 bps

Test specification:	**Section 15.203, Antenna requirements**		
Test procedure:	Visual inspection		
Test mode:	Compliance	**Verdict:**	PASS
Date(s):	26-Dec-19		
Temperature: 23 ºC	**Relative Humidity:** 45 %	**Air Pressure:** 1008 hPa	**Power:** 3 VDC
Remarks:			

7.9 Antenna requirements

The EUT was verified for compliance with antenna requirements. A transmitter shall be designed to ensure that no antenna other than that furnished by the responsible party will be used with the device. It may be either permanently attached or employs a unique antenna connector for every antenna proposed for use with the EUT. This requirement does not apply to professionally installed transmitters.
The rationale for compliance with the above requirements was either visual inspection results or supplier declaration. The summary of results is provided in Table 7.9.1.

Table 7.9.1 Antenna requirements

Requirement	Rationale	Verdict
The transmitter antenna is permanently attached	Visual inspection	Comply
The transmitter employs a unique antenna connector	NA	
The transmitter requires professional installation	NA	

Test specification:	Section 15.109, Radiated emission		
Test procedure:	ANSI C63.4, Sections 11.6 and 12.1.4		
Test mode:	Compliance	Verdict:	PASS
Date(s):	17-Dec-19		
Temperature: 22 ºC	Relative Humidity: 47 %	Air Pressure: 1020 hPa	Power: 3 VDC
Remarks:			

8 Emission tests according to 47CFR part 15 subpart B requirements

8.1 Radiated emission measurements

8.1.1 General

This test was performed to measure radiated emissions from the EUT enclosure. Specification test limits are given in Table 8.1.1.

Table 8.1.1 Radiated emission test limits

Frequency, MHz	Class B limit, dB(μV/m)		Class A limit, dB(μV/m)	
	10 m distance	3 m distance	10 m distance	3 m distance
30 - 88	29.5*	40.0	39.0	49.5*
88 - 216	33.0*	43.5	43.5	54.0*
216 - 960	35.5*	46.0	46.4	56.9*
Above 960	43.5*	54.0	49.5	60.0*

* The limit for test distance other than specified was calculated using the inverse linear distance extrapolation factor as follows: $Lim_{S2} = Lim_{S1} + 20 \log (S_1/S_2)$,
where S_1 and S_2 – standard defined and test distance respectively in meters.

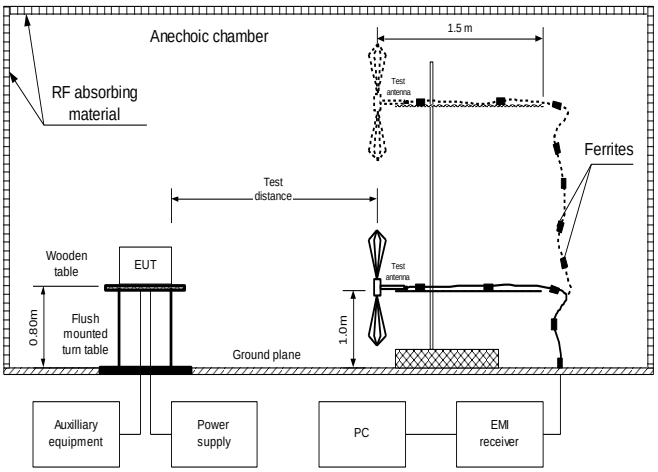
8.1.2 Test procedure for measurements in semi-anechoic chamber

8.1.2.1 The EUT was set up as shown in Figure 8.1.1 and associated photograph/s, energized and the performance check was conducted.

8.1.2.2 The specified frequency range was investigated with biconilog antenna connected to EMI receiver. To find maximum radiation the turntable was rotated 360^0, the measuring antenna height was changed from 1 to 4 m, its polarization was switched from vertical to horizontal and the EUT cables position was varied.

8.1.2.3 The worst test results (the lowest margins) were recorded in Table 8.1.2 and shown in the associated plots.

Figure 8.1.1 Setup for radiated emission measurements in anechoic chamber, table-top equipment



Test specification:	**Section 15.109, Radiated emission**		
Test procedure:	ANSI C63.4, Sections 11.6 and 12.1.4		
Test mode:	Compliance	**Verdict:**	PASS
Date(s):	17-Dec-19		
Temperature: 22 ºC	**Relative Humidity:** 47 %	**Air Pressure:** 1020 hPa	**Power:** 3 VDC
Remarks:			

Table 8.1.2 Radiated emission test results

EUT SET UP: TABLE-TOP
LIMIT: Class B
EUT OPERATING MODE: Receive
TEST SITE: SEMI ANECHOIC CHAMBER
TEST DISTANCE: 3 m
DETECTORS USED: PEAK / QUASI-PEAK
FREQUENCY RANGE: 30 MHz – 1000 MHz
RESOLUTION BANDWIDTH: 120 kHz

Frequency, MHz	**Peak emission, dB(μV/m)**	**Quasi-peak**			**Antenna polarization**	**Antenna height, m**	**Turn-table position**, degrees**	**Verdict**
		Measured emission, dB(μV/m)	**Limit, dB(μV/m)**	**Margin, dB***				
All emissions are more than 20 dB below the limit								Pass

TEST SITE: SEMI ANECHOIC CHAMBER
TEST DISTANCE: 3 m
DETECTORS USED: PEAK / AVERAGE
FREQUENCY RANGE: 1000 MHz – 5000 MHz
RESOLUTION BANDWIDTH: 1000 kHz

Frequency, MHz	**Peak**			**Average**			**Antenna polarization**	**Antenna height, m**	**Turn-table position**, degrees**	**Verdict**
	Measured emission, dB(μV/m)	**Limit, dB(μV/m)**	**Margin, dB***	**Measured emission, dB(μV/m)**	**Limit, dB(μV/m)**	**Margin, dB***				
All emissions are more than 20 dB below the limit										Pass

*- Margin = Measured emission - specification limit.
**- EUT front panel refer to 0 degrees position of turntable.

Reference numbers of test equipment used

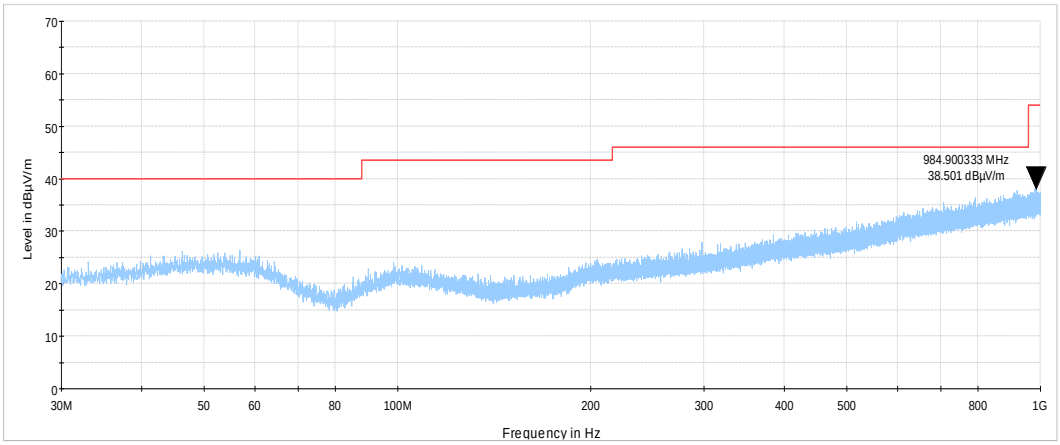
HL 3903	HL 4360	HL 4933	HL 5288	HL 5665			

Full description is given in Appendix A.

Test specification:	**Section 15.109, Radiated emission**		
Test procedure:	ANSI C63.4, Sections 11.6 and 12.1.4		
Test mode:	Compliance	**Verdict:**	PASS
Date(s):	17-Dec-19		
Temperature: 22 ºC	**Relative Humidity:** 47 %	**Air Pressure:** 1020 hPa	**Power:** 3 VDC
Remarks:			

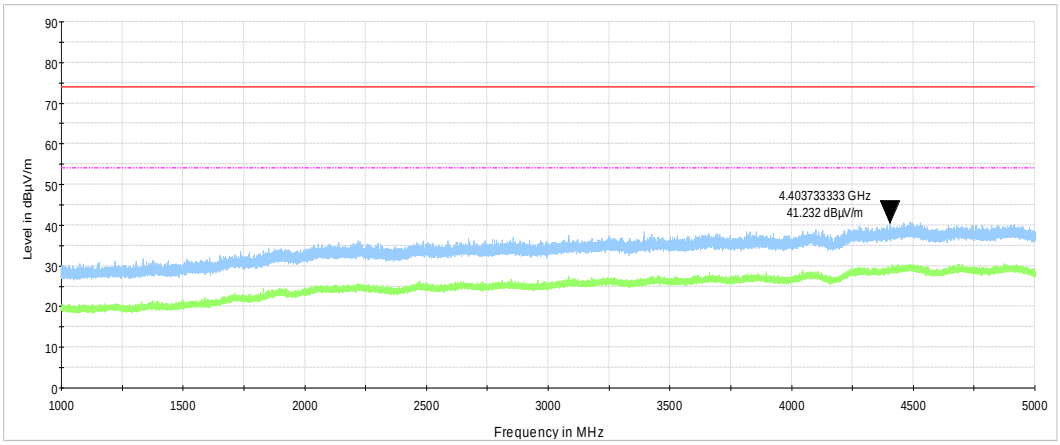
Plot 8.1.1 Radiated emission measurements in 30 - 1000 MHz range, vertical and horizontal antenna polarization

TEST SITE: Semi anechoic chamber
LIMIT: Class B
TEST DISTANCE: 3 m
EUT OPERATING MODE: Receive



Plot 8.1.2 Radiated emission measurements above 1000 MHz, vertical and horizontal antenna polarization

TEST SITE: Semi anechoic chamber
LIMIT: Class B
TEST DISTANCE: 3 m
EUT OPERATING MODE: Receive



9 APPENDIX A Test equipment and ancillaries used for tests

HL No	Description	Manufacturer	Model	Ser. No.	Last Cal./ Check	Due Cal./ Check
0446	Antenna, Loop, Active, 10 (9) kHz - 30 MHz	EMCO	6502	2857	24-Feb-20	24-Feb-21
2909	Spectrum analyzer, ESA-E, 100 Hz to 26.5 GHz	Agilent Technologies	E4407B	MY41444762	04-Apr-19	04-Apr-20
3903	Microwave Cable Assembly, 40.0 GHz, 1.5 m, SMA/SMA	Huber-Suhner	SUCOFLEX 102A	1226/2A	07-Apr-19	07-Apr-20
4338	Reject Band Filter, 50 Ohm, 0 to 2170 and 3000 to 18000 MHz,SMA-FM / SMA-M	Micro-Tronics	BRM 50702-02	023	05-Jun-19	05-Jun-20
4355	Signal and Spectrum Analyzer, 9 kHz to 7 GHz	Rohde & Schwarz	FSV 7	101630	04-Aug-19	04-Aug-20
4360	EMI Test Receiver, 20 Hz to 40 GHz.	Rohde & Schwarz	ESU40	100322	20-Jan-20	20-Jan-21
4933	Active Horn Antenna, 1 GHz to 18 GHz	COM-POWER CORPORATION	AHA-118	701046	06-Jan-20	06-Jan-21
5111	RF cable, 40 GHz, 5.5 m, K-type	Huber-Suhner	SF102EA/11SK/11SK/5500MM	502493/2EA	14-Aug-19	14-Aug-20
5288	Trilog Antenna, 25 MHz - 8 GHz, 100W	Frankonia	ALX-8000E	00809	08-Feb-19	08-Feb-22
5404	RF cable, 18 GHz, N-N, 6 m	Huber-Suhner	SF118/11N(x2)	500024/18	11-Aug-19	11-Aug-20
5606	Precision Fixed Attenuator, 50 Ohm, 5 W, 10 dB, DC to 18000 MHz	Mini Circuits	BW-N10W5+	NA	24-Sep-19	24-Sep-20
5612	Precision Fixed Attenuator, 50 Ohm, 5 W, 10 dB, DC to 18 GHz	Mini Circuits	BW-S10W5+	NA	24-Sep-19	24-Sep-20
5665	Cable SF118/11N(x2)/6M, 18 GHz, 11N/11N	Huber-Suhner	SF118	501644/118	23-Oct-19	23-Oct-20

10 APPENDIX B Test equipment correction factors

HL 0446: Active Loop Antenna
EMCO, model: 6502, s/n 2857

Frequency,	Measured antenna factor, dBS/m	Measurement uncertainty, dB
10	-33.4	±1.0
20	-37.8	±1.0
50	-40.5	±1.0
75	-41.0	±1.0
100	-41.2	±1.0
150	-41.2	±1.0
250	-41.1	±1.0
500	-41.2	±1.0
750	-41.3	±1.0
1000	-41.3	±1.0

Frequency,	Measured antenna factor, dBS/m	Measurement uncertainty, dB
2000	-41.4	±1.0
3000	-41.4	±1.0
4000	-41.5	±1.0
5000	-41.5	±1.0
10000	-41.7	±1.0
15000	-42.1	±1.0
20000	-42.7	±1.0
25000	-44.2	±1.0
30000	-45.8	±1.0

The antenna factor shall be added to receiver reading in dBμV to obtain field strength in dBμA/m.

HL 4933: Active Horn Antenna
COM-POWER CORPORATION, model: AHA-118, s/n 701046

Frequency, MHz	Measured antenna factor (with preamplifier), dB/m
1000	-16.1
1500	-15.1
2000	-10.9
2500	-11.9
3000	-11.1
3500	-10.6
4000	-8.6
4500	-8.3
5000	-5.9
5500	-5.7
6000	-3.3
6500	-4.0
7000	-2.2
7500	-1.7
8000	1.1
8500	-0.8
9000	-1.5
9500	-0.2

Frequency, MHz	Measured antenna factor (with preamplifier), dB/m
10000	1.8
10500	1.0
11000	0.3
11500	-0.5
12000	3.1
12500	1.4
13000	-0.3
13500	-0.4
14000	2.5
14500	2.2
15000	1.9
15500	0.5
16000	2.1
16500	1.2
17000	0.6
17500	3.1
18000	4.2

The antenna factor shall be added to receiver reading in dBμV to obtain field strength in dBμV/m.

HL 5288: Trilog Antenna
Frankonia, model: ALX-8000E, s/n: 00809
30-1000 MHz

Frequency, MHz	Antenna factor, dB/m	Frequency, MHz	Antenna factor, dB/m
30	14.96	160	12.67
35	15.33	180	13.34
40	16.37	200	15.40
45	17.56	250	16.42
50	17.95	300	17.28
60	16.87	400	19.98
70	13.22	500	21.11
80	10.56	600	22.90
90	13.61	700	24.13
100	15.46	800	25.25
120	14.03	900	26.35
140	12.23	1000	27.18

The antenna factor shall be added to receiver reading in dBμV to obtain field strength in dBμV/m.

above 1000 MHz

Frequency, MHz	Antenna factor, dB/m	Frequency, MHz	Antenna factor, dB/m
1000	26.9	3600	38.9
1100	28.1	3700	39.4
1200	28.4	3800	39.4
1300	29.6	3900	39.6
1400	29.1	4000	39.7
1500	30.4	4100	39.8
1600	30.7	4200	40.5
1700	31.5	4300	40.9
1800	32.3	4400	41.1
1900	32.6	4500	41.4
2000	32.5	4600	41.3
2100	32.9	4700	41.6
2200	33.5	4800	41.9
2300	33.2	4900	42.3
2400	33.7	5000	42.7
2500	34.6	5100	43.0
2600	34.7	5200	42.9
2700	34.6	5300	43.5
2800	35.0	5400	43.6
2900	35.5	5500	44.3
3000	36.2	5600	44.7
3100	36.8	5700	45.0
3200	36.8	5800	45.0
3300	37.0	5900	45.3
3400	37.5	6000	45.9
3500	38.2		

The antenna factor shall be added to receiver reading in dBμV to obtain field strength in dBμV/m.

HL 5111: RF cable

Huber-Suhner, SF102EA/11SK/11SK/5500MM, s/n 502493/2EA

Set / Applied, MHz	Measured, dB	Uncertainty, dB
100	0.70	±0.07
200	0.99	±0.08
300	1.21	±0.08
500	1.56	±0.08
1000	2.20	±0.08
1500	2.69	±0.08
2000	3.11	±0.08
2500	3.50	±0.10
3000	3.85	±0.10
3500	4.16	±0.10
4000	4.47	±0.10
4500	4.74	±0.10
5000	5.03	±0.10
5500	5.30	±0.10
6000	5.57	±0.10
6500	5.76	±0.10
7000	6.00	±0.10
7500	6.20	±0.10
8000	6.44	±0.10
8500	6.67	±0.10
9000	6.82	±0.10
9500	7.04	±0.10
10000	7.18	±0.10
10500	7.36	±0.10
11000	7.55	±0.10
11500	7.75	±0.10
12000	7.90	±0.10
12500	8.08	±0.13
13000	8.19	±0.13
13500	8.39	±0.13
14000	8.58	±0.13
14500	8.76	±0.18
15000	8.92	±0.18
15500	9.03	±0.18
16000	9.18	±0.18
16500	9.34	±0.18
17000	9.51	±0.18
17500	9.66	±0.18
18000	9.80	±0.18
18500	9.94	±0.23
19000	10.05	±0.23
19500	10.22	±0.23
20000	10.32	±0.23
20500	10.48	±0.23
21000	10.60	±0.23
21500	10.73	±0.23
22000	10.87	±0.23
22500	10.97	±0.29
23000	11.09	±0.29
23500	11.26	±0.29
24000	11.37	±0.29
24500	11.50	±0.29
25000	11.61	±0.23
25500	11.72	±0.23
26000	11.87	±0.23
26500	11.99	±0.23
27000	12.09	±0.33
27500	12.24	±0.33
28000	12.34	±0.40
28500	12.47	±0.40
29000	12.61	±0.40
29500	12.70	±0.40
30000	12.86	±0.40
30500	12.92	±0.33
31000	13.09	±0.33
31500	13.16	±0.33
32000	13.33	±0.33
32500	13.40	±0.33
33000	13.62	±0.33
33500	13.70	±0.33
34000	13.88	±0.33
34500	13.97	±0.40
35000	14.05	±0.40
35500	14.23	±0.40
36000	14.25	±0.40
36500	14.46	±0.40
37000	14.49	±0.33
37500	14.72	±0.33
38000	14.77	±0.33
38500	14.97	±0.33
39000	15.04	±0.33
39500	15.22	±0.33
40000	15.63	±0.47

11 APPENDIX C Measurement uncertainties

Expanded uncertainty at 95% confidence in Hermon Labs EMC measurements

Test description	Expanded uncertainty
Conducted carrier power at RF antenna connector	Below 12.4 GHz: ± 1.7 dB 12.4 GHz to 40 GHz: ± 2.3 dB
Conducted emissions at RF antenna connector	9 kHz to 2.9 GHz: ± 2.6 dB 2.9 GHz to 6.46 GHz: ± 3.5 dB 6.46 GHz to 13.2 GHz: ± 4.3 dB 13.2 GHz to 22.0 GHz: ± 5.0 dB 22.0 GHz to 26.8 GHz: ± 5.5 dB 26.8 GHz to 40.0 GHz: ± 4.8 dB
Occupied bandwidth	± 8.0 %
Duty cycle, timing (Tx ON / OFF) and average factor measurements	± 1.0 %
Conducted emissions with LISN	9 kHz to 150 kHz: ± 3.9 dB 150 kHz to 30 MHz: ± 3.8 dB
Radiated emissions at 3 m measuring distance Horizontal polarization Vertical polarization	 Biconilog antenna: ± 5.3 dB Biconical antenna: ± 5.0 dB Log periodic antenna: ± 5.3 dB Double ridged horn antenna: ± 5.3 dB Biconilog antenna: ± 6.0 dB Biconical antenna: ± 5.7 dB Log periodic antenna: ± 6.0 dB Double ridged horn antenna: ± 6.0 dB

Hermon Laboratories is accredited by A2LA for calibration according to present requirements of ISO/IEC 17025 and NCSL Z540-1. The accreditation is granted to perform calibration of parameters that are listed in the Scope of Hermon Laboratories Accreditation.

Hermon Laboratories calibrates its reference and transfer standards by calibration laboratories accredited to ISO/IEC 17025 by a mutually recognized Accreditation Body or by a recognized national metrology institute. All reference and transfer standards used in the calibration system are traceable to national or international standards.

In-house calibration of all test and measurement equipment is performed on a regular basis according to Hermon Laboratories calibration procedures, manufacturer calibration/verification procedures or procedures defined in the relevant standards. The Hermon Laboratories test and measurement equipment is calibrated within the tolerances specified by the manufacturers and/or by the relevant standards.

12 APPENDIX D Test laboratory description

Tests were performed at Hermon Laboratories Ltd., which is a fully independent, private, EMC, Radio, Safety, Environmental and Telecommunication testing facility.
Hermon Laboratories is recognized and accredited by the Federal Communications Commission (USA) for 1, 2, 15, 18 parts of Code of Federal Regulations 47 (CFR 47), Test Firm Registration Number is 927748, Designation Number is IL1001; registered by Industry Canada for electromagnetic emissions, file number IC 2186A-1 for OATS, certified by VCCI, Japan (the registration numbers are R-10808 for OATS, R-1082 for anechoic chamber, G-10869 for RE measurements above 1 GHz, C-10845 for conducted emissions site and T-11606 for conducted emissions at telecommunication ports).
The laboratory is accredited by American Association for Laboratory Accreditation (USA) according to ISO/IEC 17025 for electromagnetic compatibility, product safety, telecommunications testing, environmental simulation and calibration (for exact scope please refer to Certificate No. 839.01, 839.03 and 839.04).

Address: P.O. Box 23, Binyamina 3055001, Israel
Telephone: +972 4628 8001
Fax: +972 4628 8277
e-mail: mail@hermonlabs.com
website: www.hermonlabs.com

Person for contact: Mr. Michael Nikishin, EMC and radio group manager

13 APPENDIX E Specification references

FCC 47CFR part 15:2019	Radio Frequency Devices.
ANSI C63.4:2014	American National Standard for Methods of Measurement of Radio-Noise Emissions from Low-Voltage Electrical and Electronic Equipment in the Range of 9 kHz to 40 GHz.
ANSI C63.10:2013	American National Standard of Procedures for Compliance Testing of Unlicensed Wireless Devices

14 APPENDIX F Abbreviations and acronyms

A	ampere
AC	alternating current
A/m	ampere per meter
AM	amplitude modulation
AVRG	average (detector)
cm	centimeter
dB	decibel
dBm	decibel referred to one milliwatt
dB(μV)	decibel referred to one microvolt
dB(μV/m)	decibel referred to one microvolt per meter
dB(μA)	decibel referred to one microampere
DC	direct current
EIRP	equivalent isotropically radiated power
ERP	effective radiated power
EUT	equipment under test
F	frequency
GHz	gigahertz
GND	ground
H	height
HL	Hermon laboratories
Hz	hertz
k	kilo
kHz	kilohertz
LO	local oscillator
m	meter
MHz	megahertz
min	minute
mm	millimeter
ms	millisecond
μs	microsecond
NA	not applicable
NB	narrow band
OATS	open area test site
Ω	Ohm
PM	pulse modulation
PS	power supply
ppm	part per million (10^{-6})
QP	quasi-peak
RE	radiated emission
RF	radio frequency
rms	root mean square
Rx	receive
s	second
T	temperature
Tx	transmit
V	volt
WB	wideband

END OF DOCUMENT