LSR
a Laird Business
ACCREDITED
TESTING CERT #1255.01
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TEST REPORT #: 316054C
LSR Job #: C-2401

Compliance Testing of:
RM191-SM

Test Date(s):
2/17/16 – 3/18/16

Prepared For:
N. Zach Hogya
Laird
11160 Thompson Ave
Lenexa, KS 66219

This Test Report is issued under the Authority of:
Shane Dock, EMC Engineer

Signature: Date: 4-8-16

Test Report Reviewed by:	**Project Engineer:**
Khairul Aidi Zainal, Engineering Manager - Test Services, Connectivity Solutions	Shane Dock, EMC Engineer
Signature: Date: 4-8-16	Signature: Date: 4-8-16

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EXHIBIT 1. INTRODUCTION

1.1 - Scope

References:	FCC Part 15, Section 15.247 RSS GEN issue 4 and RSS 247
Title:	FCC : Telecommunication – Code of Federal Regulations, CFR 47, Part 15. IC : Low-power License-exempt Radio-communication Devices (All Frequency Bands): Category I Equipment
Purpose of Test:	To gain FCC and IC Certification Authorization for Low-Power License-Exempt Transmitters.
Test Procedures:	FCC KDB 558074 D01 DTS Measurement Guidance v03r04
Environmental Classification:	Residential

1.2 – Normative References

Publication	Year	Title
FCC CFR Parts 0-15	2016	Code of Federal Regulations – Telecommunications
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.
RSS-247 Issue 1	2015	Digital Transmission Systems (DTSs), Frequency Hopping Systems (FHSs) and License-Exempt Local Area Network (LE-LAN) Devices
RSS-GEN Issue 4	2014	General Requirements and Information for the Certification of Radio Apparatus
ANSI C63.10	2013	American National Standard for Testing Unlicensed Wireless Devices
FCC KDB 558074 D01 DTS Measurement Guidance v03r04	2016	Guidance for Performing Compliance Measurements on Digital Transmission Systems (DTS) Operating Under §15.247

1.3 - LS Research, LLC Test Facility

LS Research, LLC is accredited by A2LA (American Association for Laboratory Accreditation) as conforming to ISO/IEC 17025, 2005 "General Requirements for the Competence of Calibration and Testing Laboratories".

LS Research, LLC's scope of accreditation includes all test methods listed herein, unless otherwise noted. Accreditation status can be verified at A2LA's web site: www.a2la2.net.

1.4 – Location of Testing

All testing was performed at the following location utilizing the facilities listed below, unless otherwise noted.

LS Research, LLC
W66 N220 Commerce Court
Cedarburg, Wisconsin, 53012 USA,

List of Facilities Located at LS Research, LLC:

Semi-Anechoic Chamber

1.5 – Test Equipment Utilized

A complete list of equipment utilized in testing is provided in Appendix A of this test report. Calibration dates are indicated in Appendix A. All test equipment is calibrated by a calibration laboratory accredited to the requirements of ISO/IEC 17025, and traceable to the SI standard.

1. 6 – Test Report Cover Sheet

The LoRa radio, as described in this report is separated into two sets of modes, which differ in their modulation bandwidths and operating channels. The 500kHz bandwidth channels form a traditional DTS modulation system. The 500kHz channels can have a spreading factor (SF) between 7 and 12, with a higher spreading factor corresponding to a lower data rate. Where data is taken in this report for a 500kHz channel, unless stated otherwise, the measurements were taken with a spreading factor of 12 as this constitutes the worst case scenario for emissions. The given 500kHz channels used were:

Low – 903 MHz
Mid – 907.8 MHz
High – 914.2 MHz

The 125kHz channels form a hybrid DTS and frequency hopping system, which meets part 15.247's requirements for a hybrid system. 125kHz channels can have a spreading factor between 7 and 10, with 10 representing the worst case-emissions. The 125kHz channels used were:

Low – 902.3 MHz
Mid – 908.5 MHz
High – 914.9 MHz

Lastly, the device was supplied with either 3.6 VDC or 1.8 VDC or nominal values. Generally, the lower voltage of the 1.8VDC lowers the power relative to the 3.6VDC supply. In actual products, the minimum allowable voltage is 1.65VDC, while the maximum is 3.58 VDC. Any time the host requests the module to send a packet of data, it reads the supplied voltage and checks to see if it is within the valid operating range. If the Vcc is outside our stated operating range, it will report an error back to the host, and abandon sending the packet.

Data that is laid out in this report reflects the two different types of channels. For each test that has a requirement for either the DTS (500kHz) or hybrid (125kHz) systems, this data is separated as such. Their respective limits need to be applied to the data, and any test that is only required one system is only performed on that system. Where test data is shown, the spreading factor and voltage have automatically been chosen for worst case emissions.

EXHIBIT 2. PERFORMANCE ASSESSMENT

2.1 – Client Information

Manufacturer Name:	Laird Technologies
Address:	11160 Thompson Ave, Lenexa KS 66219
Contact Name:	N. Zach Hogya

2.2 – Equipment Under Test (EUT) Information

The following information has been supplied by the applicant.

Product Name:	RM191-SM
Model Number:	RM191-SM
Serial Number:	LEN DVT 20 (Conducted Testing) LEN DVT 1 (Radiated Testing) LEN DVT 7 (Hopping Unit) LEN DVT 13 (Colocation Testing)

2.3 Associated Antenna Description

All antennas are sleeved dipole antennas.

1. World Products 2 dBi antenna
2. Walsin .9 dBi antenna
3. Nearson 915 MHz. 2dBi antenna.

2.4 – EUT'S Technical Specifications

EUT Frequency Range (in MHz)	902.3-914.9 MHz
RF Power in Watts (Conducted measurement)	
Minimum:	.0067 Watts at 914.9 MHz (125kHz at 1.8V)
Maximum:	.037 Watts at 908.5 MHz (125kHz at 3.6V)
Conducted Output Power, peak(in dBm)	Maximum = 15.7 dBm at 908.5 MHz (125kHz) Minimum = 8.3 dBm at 914.9 MHz (125kHz)
Field Strength at 3 meters (Maximum)	Not Applicable
99% Bandwidth	126.7 kHz (125kHz) / 658.2 kHz (500kHz)
Type of Modulation	Chirp Spread Spectrum
DTS Bandwidth (6dB BW)	757.2 kHz (500kHz only)
Transmitter Spurious (worst case) at 3 meters	49.6 dBµV/m at 7262.4 MHz (500kHz at 3.6V)
Frequency Tolerance %, Hz, ppm	Better than 100 ppm
Microprocessor Model # (if applicable)	None
Antenna Information (Worst case antenna used).	
Detachable/non-detachable	Detachable
Type	Dipole
Gain	2dBi
EUT will be operated under FCC Rule Part(s)	Title 47 part 15.247
EUT will be operated under RSS Rule Part(s)	RSS 247
Modular Filing	☒ Yes ☐ No
Portable or Mobile?	Portable
Emission Designator	127KX1D (125k) / 658KX1D (500k)

2.5 - Product Description

The RM191-SM module is designed to enable OEMs to add a long range LoRa radio link as well as central role Bluetooth Low Energy (BLE) to small, portable, power-conscious devices. The RM191-SM module is enabled with Laird's smart BASIC, an event-driven programming language that enables OEMs to make their product development quicker and simpler, significantly reducing time to market. smartBASIC enables customers to develop a complete embedded application inside the compact RM191 hardware, connecting to a wide array of external sensors via its I2C, SPI, UART, ADC or GPIO interfaces. The module is based on the world-leading Nordic Semiconductor nRF51822 (BLE) and Semtech Sx1272 (LoRa) chipsets, the RM191-SM module provides ultra-low power consumption with outstanding wireless range using the LoRa radio link and local BLE connections.

EXHIBIT 3. EUT OPERATING CONDITIONS & CONFIGURATIONS DURING TESTS

3.1 - Climate Test Conditions

Temperature:	70 -74° F
Humidity:	30-42%
Pressure:	728-741mmHg

3.2 - Applicability & Summary Of EMC Emission Test Results

FCC and IC Paragraph	Test Requirements	Compliance (Yes/No)
FCC : 15.207 IC : RSS GEN sect. 7.2.2	Power Line Conducted Emissions Measurements	Yes
FCC : 15.247 (a)(1) IC : RSS 247 5.1	20 dB Bandwidth	Yes
FCC : 15.247(b) & 1.1310 IC : RSS 247 5.4	Maximum Output Power	Yes
FCC : 15.247(i), 1.1307, 1.1310, 2.1091 & 2.1093 IC : RSS 102	RF Exposure Limit	Yes
FCC :15.247(d) IC : RSS 247 5.5	RF Conducted Spurious Emissions at the Transmitter Antenna Terminal	Yes
FCC:15.247 (a)(2) IC: RSS 247 5.2	6 dB Bandwidth of a Digital Modulation System	Yes
FCC:15.247 (d) IC: RSS 247 5.2	Power Spectral Density of a Digital Modulation System	Yes
FCC : 15.247(c), 15.209 & 15.205 IC : RSS GEN	Transmitter Radiated Emissions	Yes
FCC : 247 (f) IC : RSS 247 5.3	Power Spectral Density of a Hybrid System	Yes
FCC : 247 (f) IC : RSS 247 5.3	Average Time of Occupancy for a Hybrid System	Yes
FCC : 247 (a)(1) IC : RSS 247 5.1	Minimum Channel Separation	Yes
FCC : 247 (a)(1) IC : RSS 247 5.1	Random Hop Sequence	Yes
FCC : 247 (a)(1) IC : RSS 247 5.1	Equal Usage of Channel Frequencies	Yes
FCC : 247 (a)(1) IC : RSS 247 5.1	Receiver Matching Bandwidth and Synchronization	Yes

3.3 - Modifications Incorporated In The EUT For Compliance Purposes

☒ None ☐ Yes (explain below)

3.4 - Deviations & Exclusions From Test Specifications

☒ None ☐ Yes (explain below)

EXHIBIT 4. DECLARATION OF CONFORMITY

The EUT was found to MEET the requirements as described within the specification of FCC Title 47, CFR Part 15.247, and Industry Canada RSS-247, Issue 1 (2015).

Note: If some emissions are seen to be within 3 dB of their respective limits; as these levels are within the tolerances of the test equipment and site employed, there is a possibility that this unit, or a similar unit selected out of production may not meet the required limit specification if tested by another agency.

LS Research, LLC certifies that the data contained herein was taken under conditions that meet or exceed the requirements of the test specifications. The results in this Test Report apply only to the item(s) tested on the above-specified dates. Any modifications made to the EUT subsequent to the indicated test date(s) will invalidate the data herein, and void this certification.

EXHIBIT 5. UNWANTED EMISSIONS INTO THE RESTRICTED FREQUENCY BANDS.

5.1 - Test Setup

The test setup was assembled in accordance with Title 47, CFR FCC Part 15, RSS GEN and ANSI C63.10-2013. The EUT was placed on an 150 cm high non-conductive pedestal, centered on a flush mounted 2-meter diameter turntable inside a 5 meter Semi-Anechoic, FCC listed Chamber. The EUT was operated in continuous transmit mode for final testing using power as provided by an AC to DC power supply that comes with the EUT. The unit has the capability to operate on 3 channels, controllable via proprietary software provided by the manufacturer.

The applicable limits apply at a 3 meter distance. The calculations to determine these limits are detailed in the following pages. Please refer to Appendix A for a complete list of test equipment. The test sample was operated on one of three (3) standard channels to comply with FCC Part 15.31(m).

5.2 - Test Procedure

Radiated RF measurements were performed on the EUT in a 3 meter Semi-Anechoic, FCC listed Chamber. The frequency range from 30 MHz to 10000 MHz was scanned and investigated. The radiated RF emission levels were manually noted at the various fixed degree settings of azimuth on the turntable and antenna height. The EUT was placed on a non-conductive pedestal in the 3 meter Semi-Anechoic Chamber, with the antenna mast placed such that the antenna was 3 meters from the EUT. A Biconical Antenna was used to measure emissions from 30 MHz to 200 MHz, and a Log Periodic Antenna was used to measure emissions from 200 MHz to 1000 MHz. A Double-Ridged Waveguide Horn Antenna was used from 1 GHz to 10 GHz. The maximum radiated RF emissions between 30MHz to 10 GHz were found by raising and lowering the sense antenna between 1 and 4 meters in height, using both horizontal and vertical antenna polarities. A tilt gear was utilized to keep the EUT within the cone of radiation.
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The EUT was positioned in 3 orthogonal orientations.

5.3 - Test Equipment Utilized

A list of the test equipment and antennas utilized for the Radiated Emissions test can be found in Appendix A. This list includes calibration information and equipment descriptions. All equipment is calibrated and used according to the operation manuals supplied by the manufacturers. All calibrations of the antennas used were performed at a calibration laboratory accredited to ISO 17025, and are traceable to the SI standard. In addition, the Connecting Cables were measured for losses using a calibrated Signal Generator and an EMI Receiver. The resulting correction factors and the cable loss factors from these calibrations were entered into the EMI Receiver database. As a result, the data taken from the EMI Receiver accounts for the antenna correction factor as well as cable loss or other corrections, and can therefore be entered into the database as a corrected meter reading. The EMI Receiver was operated with a resolution bandwidth of 120 kHz for measurements below 1 GHz (video bandwidth of 300 kHz), and a resolution bandwidth of 1 MHz for measurements above 1 GHz (video bandwidth of at least 3 MHz).

5.4 - Test Results

The EUT was found to **MEET** the Radiated Emissions requirements of Title 47 CFR, FCC Part 15.247 and Canada RSS-247, Issue 1 for a DTS transmitter (for the 500kHz mode) and Hybrid transmitter (for the 125kHz mode). The frequencies with significant RF signal strength were recorded and plotted as shown in the Data Charts and Graphs.

5.5 - Calculation of Radiated Emissions Limits and reported data.

Reported data:

For both fundamental and spurious emissions measurement, the data reported includes all necessary correction factors. These correction factors are loaded onto the EMI receiver when measurements are performed.

Reported Measurement data = Raw receiver measurement (dBµV/m) + Antenna correction Factor + Cable factor (dB) + Miscellaneous factors when applicable (dB) – amplification factor when applicable (dB).

Generic example of reported data at 200 MHz:

Reported Measurement data = 18.2 (raw receiver measurement) + 15.8 (antenna factor) + 1.45 (cable factor) = 35.45 (dBµV/m).

As specified in 15.247 (d), radiated emissions that fall within the restricted band described in 15.205(c) for FCC, must comply with the general emissions limit.

The following table depicts the general radiated emission limits above 30 MHz. These limits are obtained from Title 47 CFR, Part 15.209, for radiated emissions measurements. These limits were applied to any signals found in the 15.205 restricted bands.

Frequency (MHz)	3 m Limit µV/m	3 m Limit (dBµV/m)	1 m Limit (dBµV/m)
30-88	100	40.0	-
88-216	150	43.5	-
216-960	200	46.0	-
960-10,000	500	54.0	63.5

Sample conversion of field strength (µV/m to dBµV/m):
dBµV/m = 20 log $_{10}$ (100)= 40 dBµV/m (from 30-88 MHz)

5.6 - Data:

Manufacturer:	Laird Technologies					
Date(s) of Test:	2/17/16 – 3/17/16					
Project Engineer(s):	Shane Dock					
Test Engineer(s):	Shane Dock, Kim Bay					
Voltage:	3.6/1.8 VDC					
Operation Mode:	Continuous transmit, modulated					
Environmental Conditions in the Lab:	Temperature: 70-74° F Relative Humidity: 30-42%					
EUT Power:		Single Phase 24VAC		3 Phase ___VAC		
		Battery		Other: Bench DC Supply		
EUT Placement:	X	150 cm non-conductive pedestal		10cm Spacers		
EUT Test Location:	X	3 Meter Semi-Anechoic FCC Listed Chamber		3/10m OATS		
Measurements:		Pre-Compliance		Preliminary	X	Final
Detectors Used:	X	Peak	X	Quasi-Peak	X	Average

Measurements below 1 GHz:

Frequency (MHz)	Height (cm)	Azimuth (degree)	Quasi Peak Reading (dBµV/m)	Quasi Peak Limit B (dBµV/m)	Margin B (dB)	Antenna Polarity	EUT orientation	Channel	Bandwidth Mode
199.9	100.00	285	22.3	43.5	21.2	V	Vertical	Low	125kHz
83.5	100.00	275.3	13.2	40.0	26.8	V	Vertical	Low	125kHz
213.4	137.20	7.6	23.1	43.5	20.4	H	Horizontal	Low	125kHz
213.0	137.20	7.6	21.7	43.5	21.8	V	Horizontal	Low	125kHz
215.5	134.90	13.5	18.7	43.5	24.8	H	Horizontal	Low	500kHz
210.4	134.90	13.5	21.8	43.5	21.7	V	Horizontal	Low	500kHz

Note: Points below 200 MHz are noise-floor measurements. Below 1 GHz, supply voltage was seen to have no noticeable impact on emissions.

Measurements between 1-10 GHz:

Note: Table below shows the emissions from each channel in the restricted band in their worst-case orientations.

125kHz Bandwidth data:

125k (3.6 V)

Frequency (MHz)	Height (m)	Azimuth (degree)	Peak Reading (dBµV/m)	Avg Reading (dBµV/m)	Avg Limit (dBµV/m)	Margin (dB)	Antenna Polarity	EUT orientation
7268	100.28	303.5	46.9	37.5	54.0	16.5	Horizontal	Side

125k (1.8V)

Frequency (MHz)	Height (m)	Azimuth (degree)	Peak Reading (dBµV/m)	Avg Reading (dBµV/m)	Avg Limit (dBµV/m)	Margin (dB)	Antenna Polarity	EUT orientation
3609.2	1.5052	0	44.7	36.2	54.0	17.8	Vertical	Vertical
8120.7	1.0052	14.75	47.6	35.6	54.0	18.4	Vertical	Vertical
3634	1.5052	0	45.1	35.6	54.0	18.4	Horizontal	Side
3659.6	1.0052	0	44.6	34.5	54.0	19.5	Horizontal	Side

500 kHz Bandwidth data:

500k (3.6 V)

Frequency (MHz)	Height (m)	Azimuth (degree)	Peak Reading (dBµV/m)	Avg Reading (dBµV/m)	Avg Limit (dBµV/m)	Margin (dB)	Antenna Polarity	EUT orientation
2709	2.2027	0	41.8	31.2	54.0	22.8	Horizontal	Side
3612	1.0052	0	45.4	36.4	54.0	17.6	Horizontal	Side
4515	2.3955	0	43.4	31.4	54.0	22.6	Horizontal	Side
5418	2.6556	0	45.0	31.6	54.0	22.4	Horizontal	Side
2723.4	1.3366	245.5	41.2	30.3	54.0	23.7	Horizontal	Side
3631.2	1.3552	0	44.9	36.4	54.0	17.6	Horizontal	Side
4539	2.5053	0	42.8	31.2	54.0	22.8	Horizontal	Side
5446.8	1.8055	0	44.3	31.4	54.0	22.6	Horizontal	Side
7262.4	1.0033	298.75	49.6	37.4	54.0	16.6	Horizontal	Side
9078	1.0033	0	46.9	33.2	54.0	20.8	Horizontal	Side
2742.6	2.7439	0	41.2	30.9	54.0	23.1	Vertical	Vertical
3656.8	2.1235	0	44.6	34.9	54.0	19.1	Vertical	Vertical
4571	1.0033	0	43.4	31.6	54.0	22.4	Vertical	Vertical
7313.6	2.5912	345.5	48.7	35.8	54.0	18.2	Vertical	Vertical

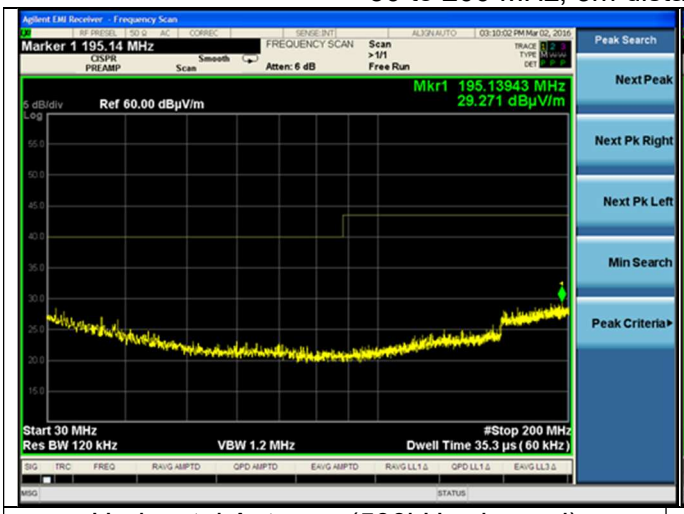
500k (1.8V)

Frequency (MHz)	Height (m)	Azimuth (degree)	Peak Reading (dBµV/m)	Avg Reading (dBµV/m)	Avg Limit (dBµV/m)	Margin (dB)	Antenna Polarity	EUT orientation
3612	2.2056	0	43.8	33.4	54.0	20.6	Vertical	Vertical
4515	1.0052	0	42.6	29.3	54.0	24.7	Vertical	Vertical
8127	1.0052	0	45.6	32.2	54.0	21.8	Vertical	Vertical
3656.8	2.0519	0	43.5	32.9	54.0	21.1	Vertical	Vertical

5.7 – Screen Captures.

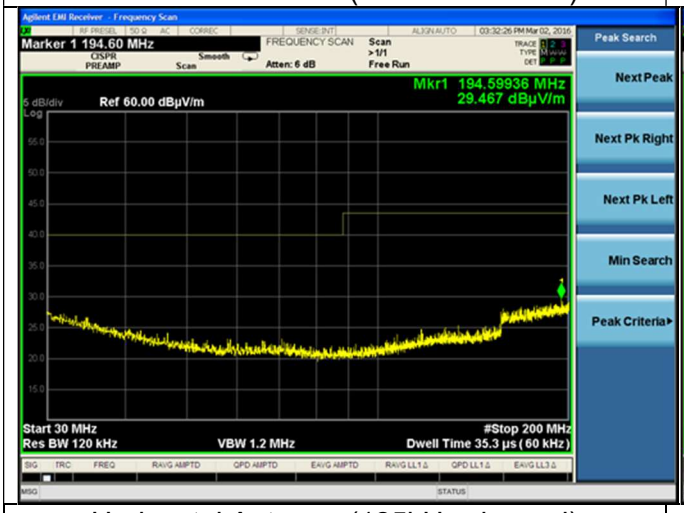
The screen captures below are those using the Peak detector of the analyzer. In addition, the screen captures presented are those which were deemed to be a worst-case representation of the spectrum scan.

30 to 200 MHz, 3m distance (Low Channel)



Horizontal Antenna (500kHz channel)

Vertical Antenna (500kHz channel)



Horizontal Antenna (125kHz channel)

Vertical Antenna (125kHz channel)

200 to 700 MHz, 3m distance (Low Channel, peaked fundamental)

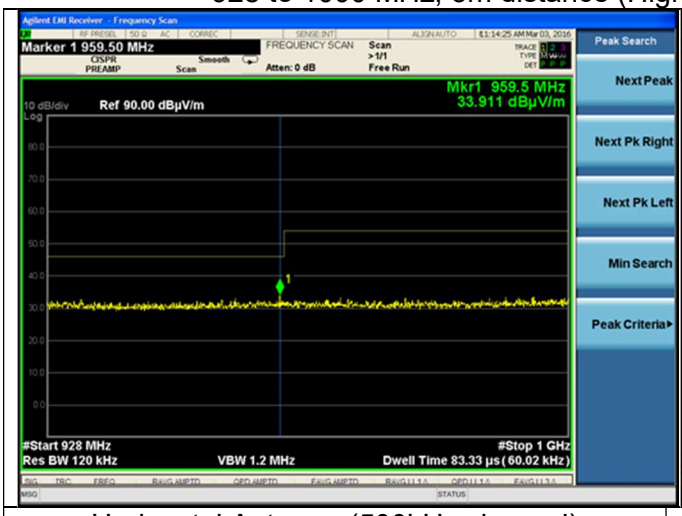
Horizontal Antenna (500kHz channel)

Vertical Antenna (500kHz channel)

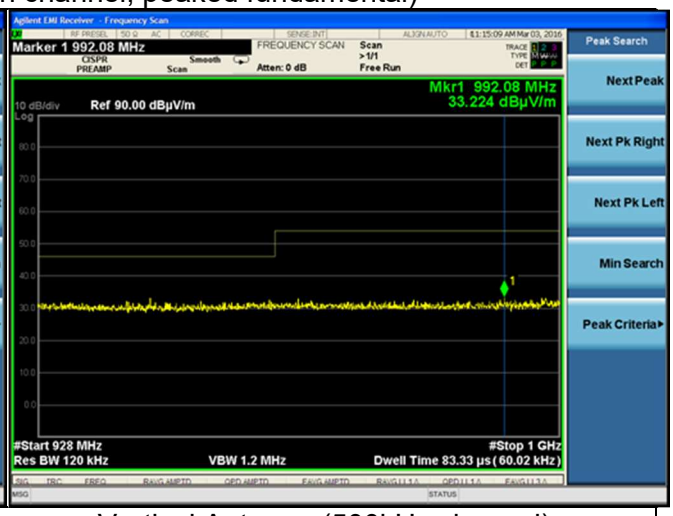
Horizontal Antenna (125kHz channel)

Vertical Antenna (125kHz channel)

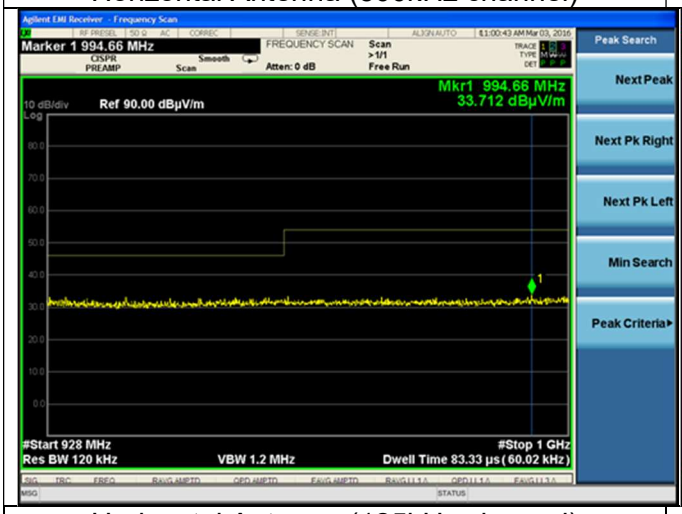
928 to 1000 MHz, 3m distance (High channel, peaked fundamental)



Horizontal Antenna (500kHz channel)



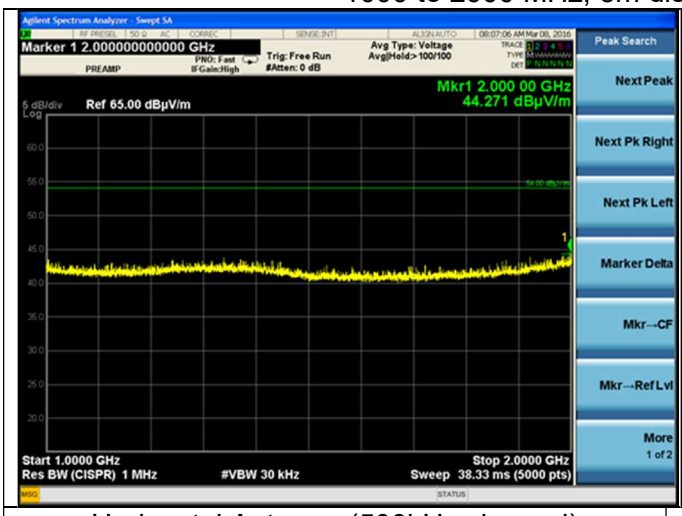
Vertical Antenna (500kHz channel)



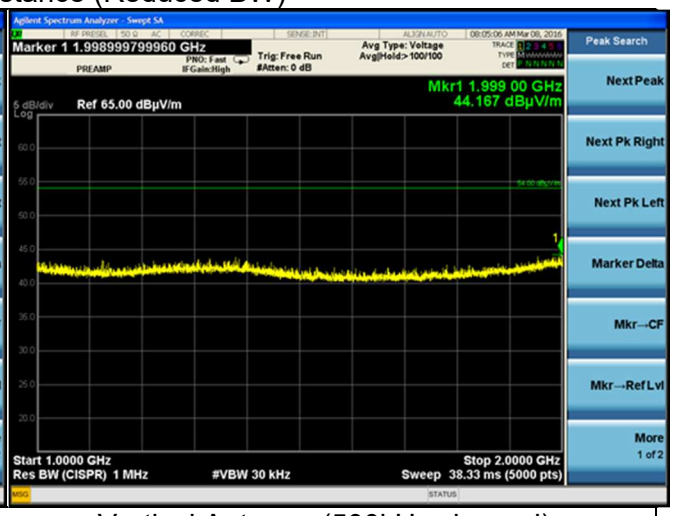
Horizontal Antenna (125kHz channel)

Vertical Antenna (125kHz channel)

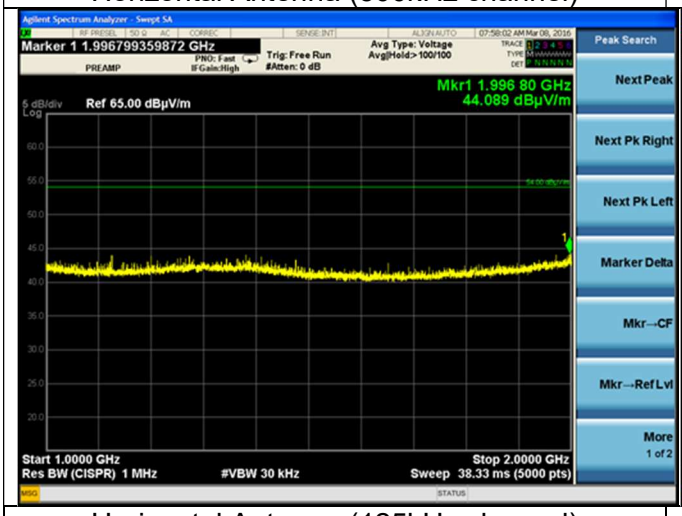
1000 to 2000 MHz, 3m distance (Reduced BW)



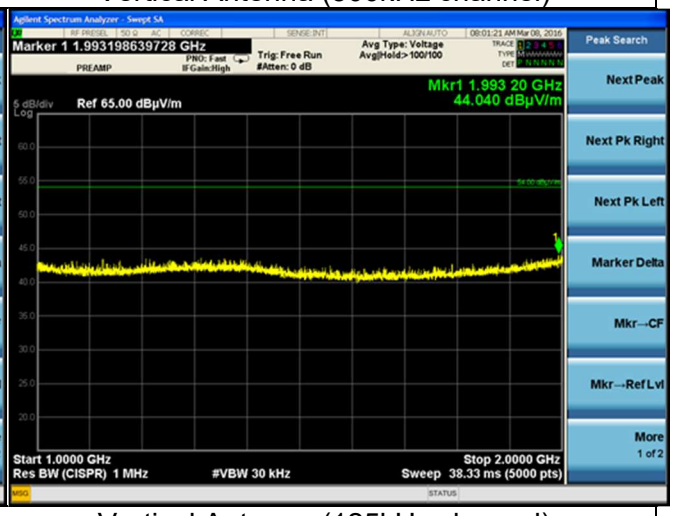
Horizontal Antenna (500kHz channel)



Vertical Antenna (500kHz channel)



Horizontal Antenna (125kHz channel)



Vertical Antenna (125kHz channel)

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2000 to 10000 MHz, 3m distance (Reduced BW) – 500kHz

3.6 V	1.8 V

2000 to 10000 MHz, 3m distance (Reduced BW) – 125kHz

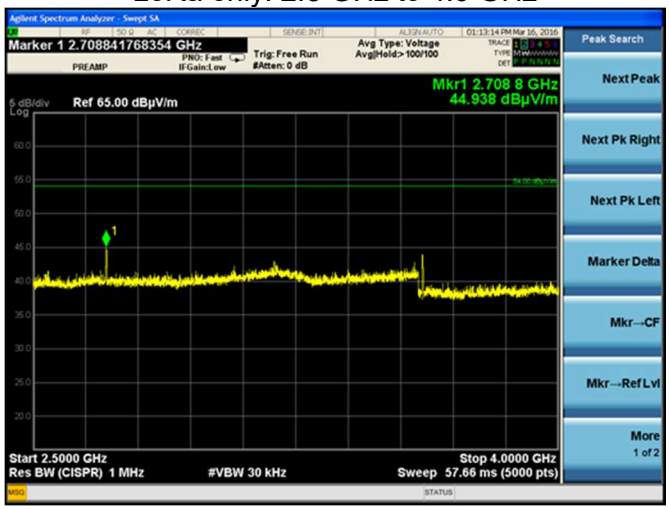
3.6 V	1.8 V

Co-Location

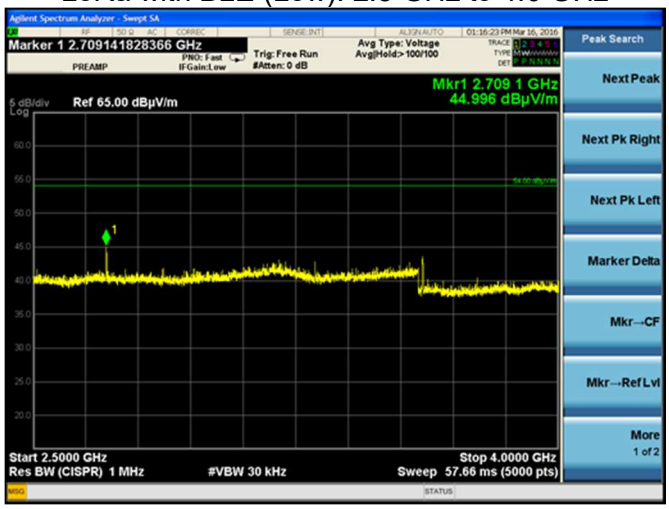
Effects of co-location of the LoRa and BLE transmitters were investigated and were found that the module was still in compliance with requirements. There were no degradation of the emissions associated with the individual transmitters when it is transmitting on its own. Example plots are shown below.

All captures have a reduced RBW, and show the 2.5-4 GHz range.

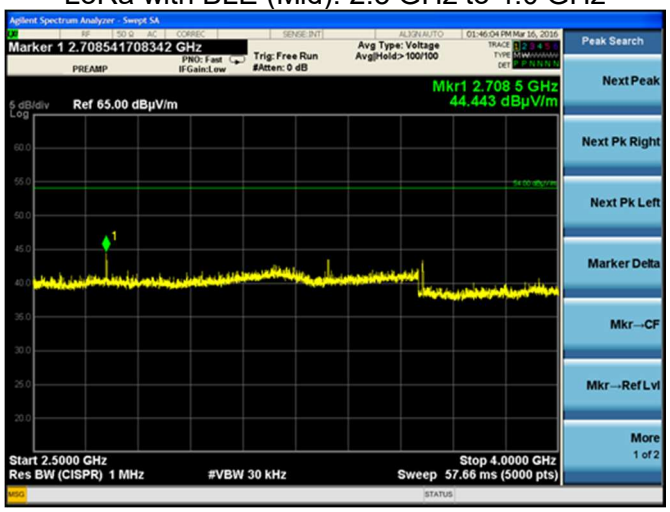
LoRa only: 2.5 GHz to 4.0 GHz



LoRa with BLE (Low): 2.5 GHz to 4.0 GHz



LoRa with BLE (Mid): 2.5 GHz to 4.0 GHz



LoRa with BLE (High) : 2.5 GHz to 4.0 GHz

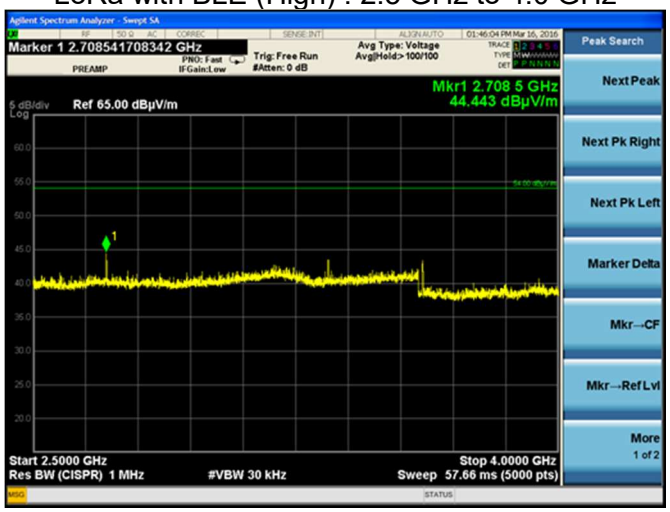


EXHIBIT 6. CONDUCTED EMISSIONS TEST, AC POWER LINE

6.1 Test Setup

The test area and setup are in accordance with ANSI C63.4 and with Title 47 CFR, FCC Part 15, Industry Canada RSS-247 and RSS GEN. The EUT was placed on a non-conductive wooden table, with a height of 80 cm above the reference ground plane. The power supply was then plugged into a 50Ω (ohm) Line Impedance Stabilization Network (LISN). The AC power supply of 120V was provided via an appropriate broadband EMI Filter, and then to the LISN line input. Final readings were then taken and recorded. After the EUT was setup and connected to the LISN, the RF Sampling Port of the LISN was connected to a 10 dB Attenuator-Limiter, and then to EMI receiver System. The EMCO LISN used has the ability to terminate the unused port with a 50Ω (ohm) load when switched to either L1 (line) or L2 (neutral).

6.2 Test Procedure

The EUT was investigated in continuous modulated transmit mode for this portion of the testing. The appropriate frequency range and bandwidths were selected on the EMI Receiver, and measurements were made. The bandwidth used for these measurements is 9 kHz, as specified in CISPR 16-1, Section 1, Table 1, for Quasi-Peak and Average detectors in the frequency range of 150 kHz to 30 MHz. Final readings were then taken and recorded.

6.3 Test Equipment Utilized

A list of the test equipment and accessories utilized for the Conducted Emissions test is provided in Appendix A. This list includes calibration information and equipment descriptions. All equipment is calibrated and used according to the operation manuals supplied by the manufacturers. Calibrations of the LISN and Limiter were performed at an IEC/ISO 17025 accredited calibration laboratory, traceable to the SI standard. All cables are calibrated and checked periodically for conformance. The emissions are measured on the EMI System, which has automatic correction for all factors stored in memory and allows direct readings to be taken.

6.4 Test Results

The EUT was found to **MEET** the Conducted Emission requirements of FCC Part 15.207 and RSS GEN 7.2.4 for Conducted Emissions for an Intentional Radiator. See the Data Charts and Graphs for more details of the test results.

6.5 FCC Limits of Conducted Emissions at the AC Mains Ports

Frequency Range (MHz)	Class B Limits (dBµV)		Measuring Bandwidth
	Quasi-Peak	Average	
0.150 -0.50 *	66-56	56-46	RBW = 9 kHz VBW ≥ 9 kHz for QP VBW = 1 Hz for Average
0.5 – 5.0	56	46	
5.0 – 30	60	50	
* The limit decreases linearly with the Logarithm of the frequency in this range.			

6.6 CONDUCTED EMISSIONS TEST DATA CHART

Frequency Range inspected: 150 KHz to 30 MHz

Manufacturer:	Laird Technologies					
Date(s) of Test:	3/10/16 – 3/11/16					
Project Engineer:	Shane Dock					
Test Engineer:	Shane Dock					
Voltage:	3.6/1.8VDC					
Operation Mode:	Continuous transmit, modulated					
Environmental Conditions in the Lab:	Temperature: 71° F Relative Humidity: 40%					
Test Location:	X	AC Mains Test area				Chamber
EUT Placed On:	X	40cm from Vertical Ground Plane				10cm Spacers
	X	80cm above Ground Plane				Other:
Measurements:		Pre-Compliance		Preliminary	X	Final
Detectors Used:		Peak	X	Quasi-Peak	X	Average

Note: All plots below use the worst case spreading factor (SF 10 for 125k BW, SF 12 for 500k BW).

LoRa 125kHz BW High Channel (3.6V)

Line	Frequency (MHz)	Q-Peak Reading (dBµV)	Q-Peak Limit (dBµV)	Quasi-Peak Margin (dB)	Average Reading (dBµV)	Average Limit (dBµV)	Average Margin (dB)
1	0.190	17.0	64.0	47.0	9.7	54.0	44.4
1	0.231	17.2	62.4	45.2	10.1	52.4	42.3
1	0.258	19.4	61.5	42.1	12.5	51.5	39.0
2	0.163	22.4	65.3	42.9	10.7	55.3	44.6
2	0.218	16.5	62.9	46.4	9.0	52.9	43.9
2	0.227	22.5	62.6	40.1	9.2	52.6	43.4

LoRa 500kHz BW Low Channel (3.6V)

Line	Frequency (MHz)	Q-Peak Reading (dBµV)	Q-Peak Limit (dBµV)	Quasi-Peak Margin (dB)	Average Reading (dBµV)	Average Limit (dBµV)	Average Margin (dB)
1	0.172	22.0	64.8	42.8	11.2	54.8	43.6
1	0.276	19.8	60.9	41.1	11.9	50.9	39.0
1	16.998	23.7	60.0	36.3	9.8	50.0	40.2
2	16.750	23.3	60.0	36.7	9.0	50.0	41.0
2	17.269	20.6	60.0	39.4	7.5	50.0	42.5
2	0.159	22.8	65.5	42.7	10.9	55.5	44.6

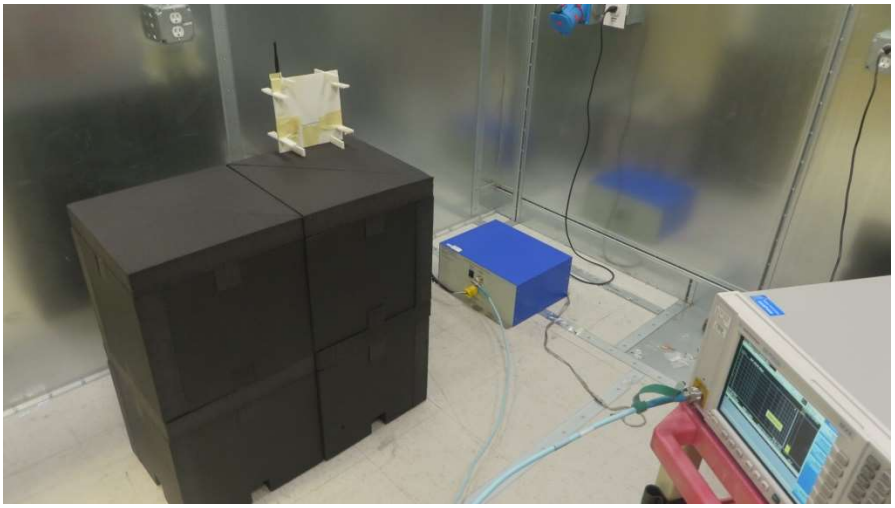
LoRa 500kHz channel High (3.6V)

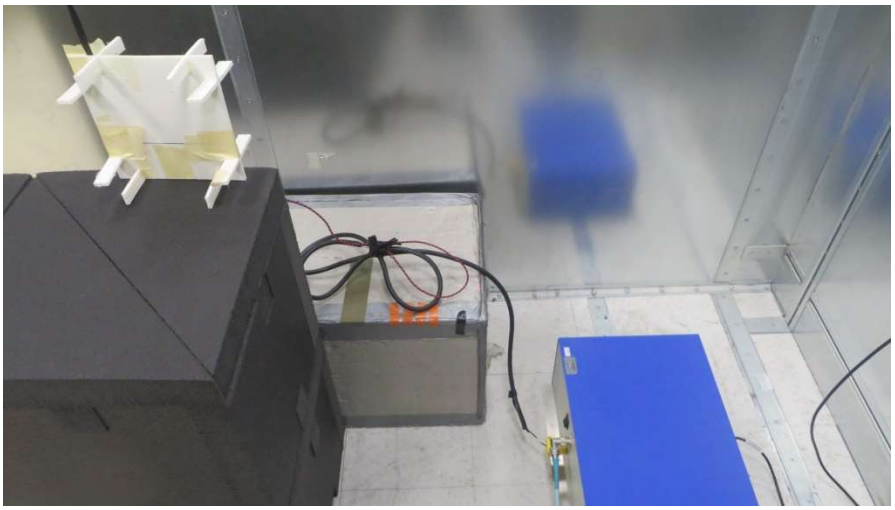
Line	Frequency (MHz)	Q-Peak Reading (dBµV)	Q-Peak Limit (dBµV)	Quasi-Peak Margin (dB)	Average Reading (dBµV)	Average Limit (dBµV)	Average Margin (dB)
1	0.172	22.1	64.8	42.7	10.4	54.8	44.4
1	0.204	20.1	63.5	43.4	9.3	53.5	44.2
1	0.226	22.9	62.6	39.7	9.3	52.6	43.3
2	17.019	21.9	60.0	38.1	8.7	50.0	41.3
2	18.743	19.5	60.0	40.5	8.9	50.0	41.2
2	167.990	22.4	60.0	37.6	10.6	50.0	39.4

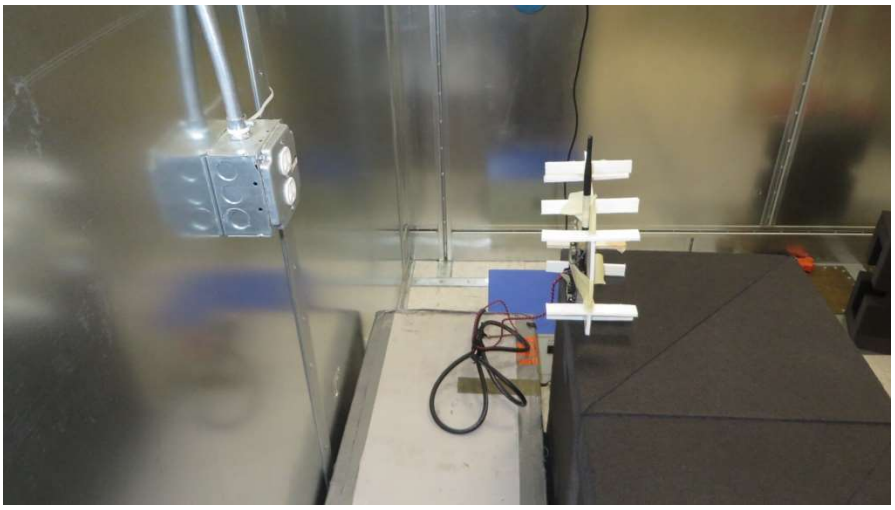
LoRa 500kHz channel High (1.8V Spot-check)

Line	Frequency (MHz)	Q-Peak Reading (dBµV)	Q-Peak Limit (dBµV)	Quasi-Peak Margin (dB)	Average Reading (dBµV)	Average Limit (dBµV)	Average Margin (dB)
1	0.172	22.2	64.8	42.6	10.4	54.8	44.4
1	0.190	21.7	64.0	42.3	9.7	54.0	44.3
1	0.213	20.9	63.1	42.2	9.2	53.1	43.9
2	0.150	23.6	66.0	42.4	11.3	56.0	44.7
2	0.163	22.6	65.3	42.7	10.7	55.3	44.6
2	0.213	21.6	63.1	41.5	9.3	53.1	43.8

6.7 Test Setup Photo(s) – Conducted Emissions Test



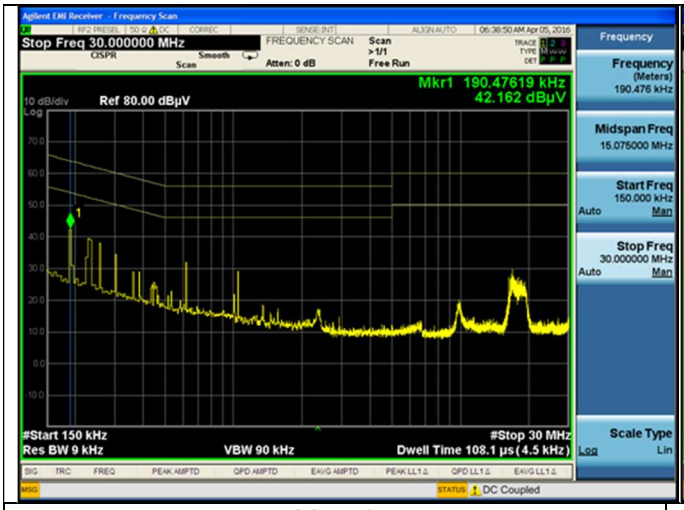




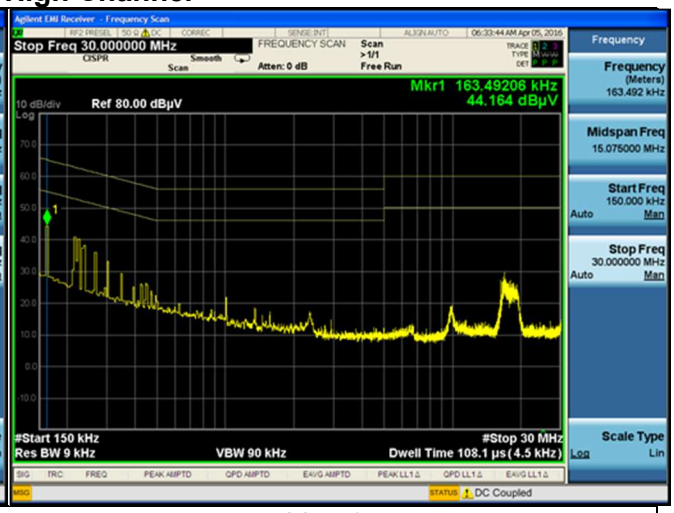
6.8 Screen Captures – Conducted Emissions Test

These screen captures represent the worst-case Peak Emissions. For conducted emission measurements, both a Quasi-Peak detector function and an Average detector function are utilized.

Lora 125kHz BW High Channel

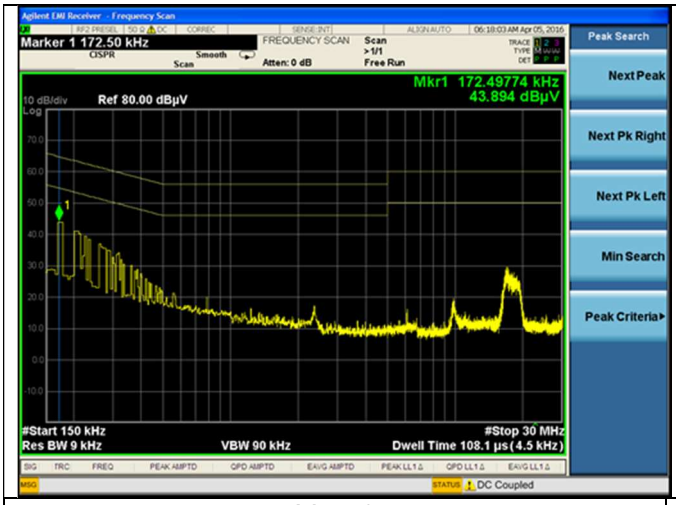


Line 1

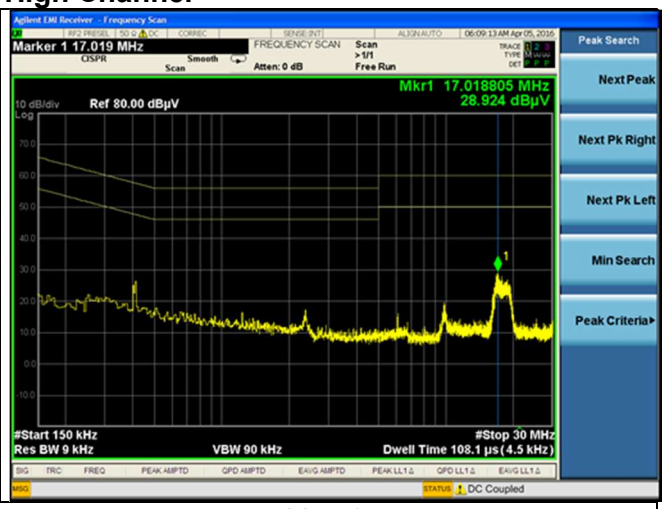


Line 2

Lora 500kHz BW High Channel

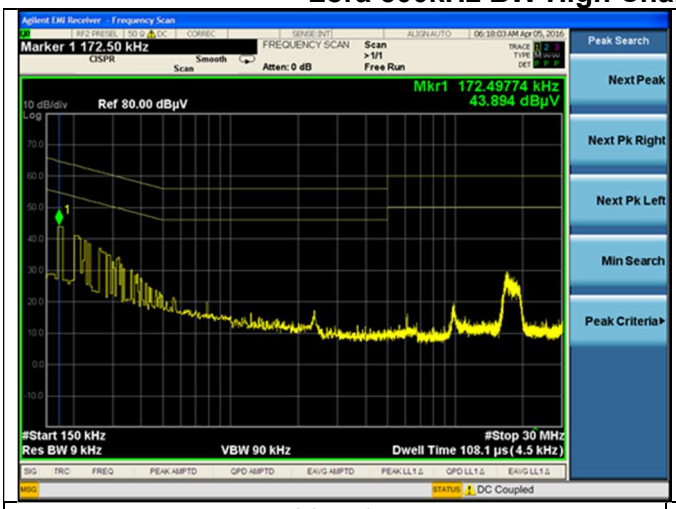


Line 1

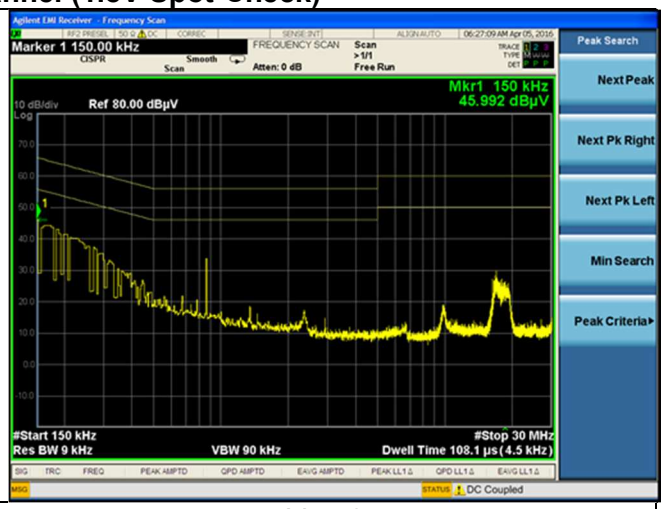


Line 2

Lora 500kHz BW High Channel (1.8V Spot-Check)



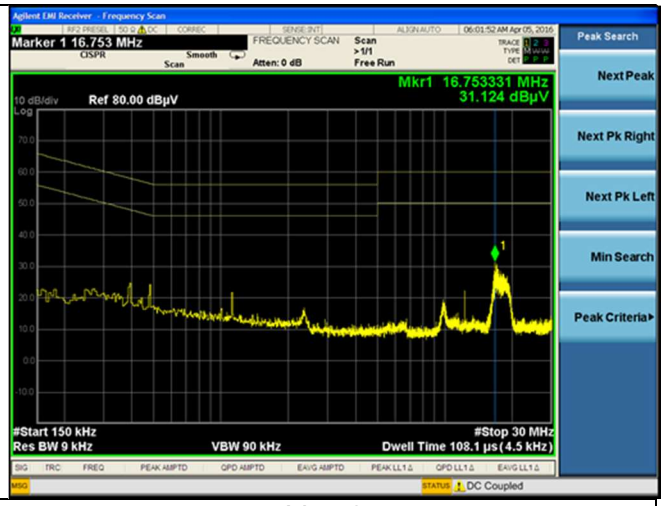
Line 1



Line 2

Lora 500kHz BW Low Channel

Line 1



Line 2

Note: The display lines in the plot above represent the limit lines for Class B, Quasi-Peak (Upper) and Average (Lower).

EXHIBIT 7. OCCUPIED/DTS BANDWIDTH

Test Engineer(s): Shane Dock

7.1 - Limits

For a DTS system the 6dB emission bandwidth limit is 500 kHz.

For the hybrid system there is no limit for the 20 dB or 99% bandwidth.

7.2 - Method of Measurements

For this portion of the tests, a direct measurement of the transmitted signal was performed at the antenna port of the EUT, via a cable connection to a spectrum analyzer. An attenuator was placed in series with the cable to protect the spectrum analyzer. The loss from the cable and the attenuator were added on the analyzer as gain offset settings there by allowing direct measurements, without the need for any further corrections. The EUT was configured to run in a continuous transmit mode, while being supplied with typical data as a modulation source. A bandwidth measurement function that is built into the spectrum analyzer was used to measure the 20dB/emission bandwidth while the 6dB bandwidth was measured using **FCC OET KDB 558074 section 8 option 2.**

7.3 - Test Data

125 kHz channel

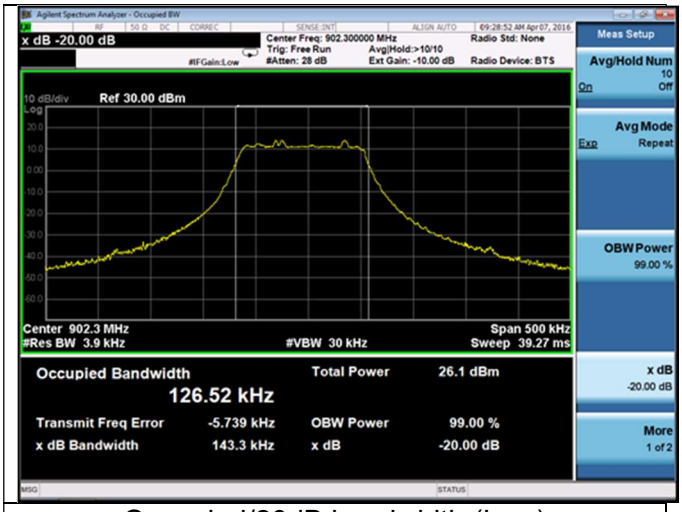
Channel	Frequency (MHz)	20dB EBW (kHz)	99% EBW (kHz)
Low	902.3	143.3	126.5
Mid	908.5	142.5	126.2
High	914.9	144.3	126.7

500 kHz channel

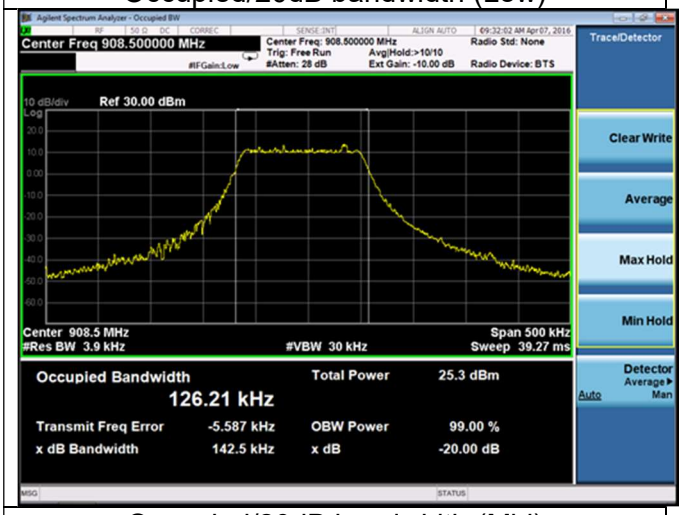
Channel	Frequency (MHz)	6dB BW (kHz)	99% EBW (kHz)
Low	903	749.6	658.2
Mid	907.8	744.3	655.6
High	914.2	757.0	654.7

7.4 – Screen Captures

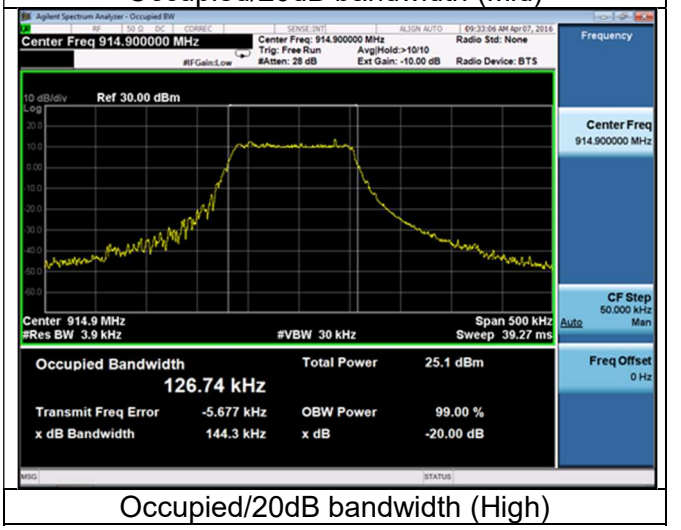
125kHz Channel



Occupied/20dB bandwidth (Low)

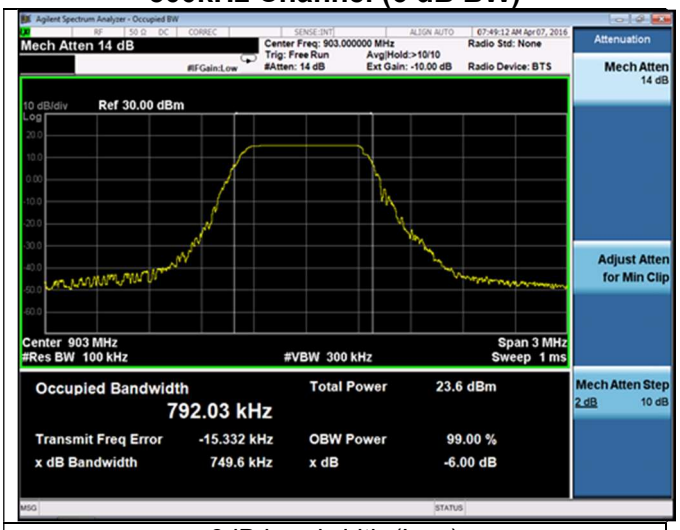


Occupied/20dB bandwidth (Mid)

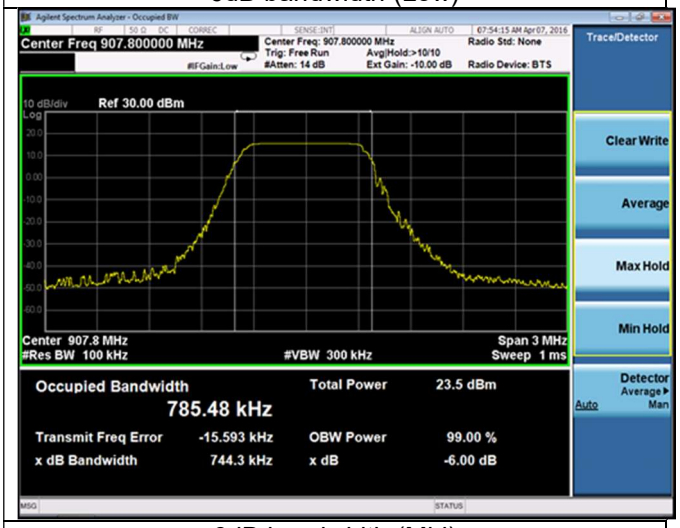


Occupied/20dB bandwidth (High)

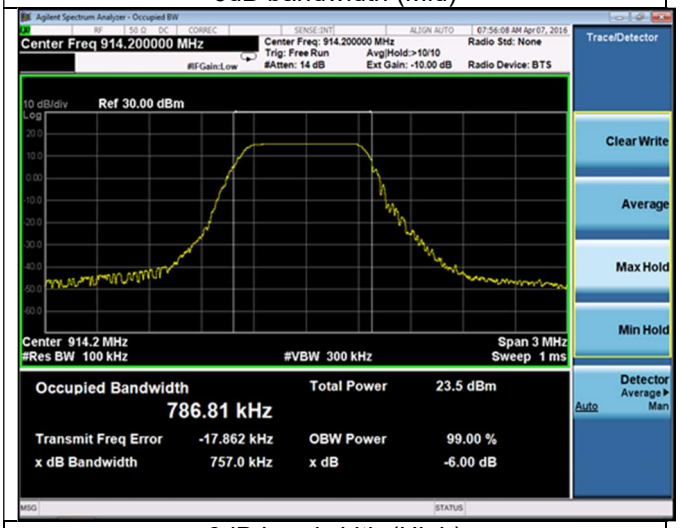
500kHz Channel (6 dB BW)



6dB bandwidth (Low)

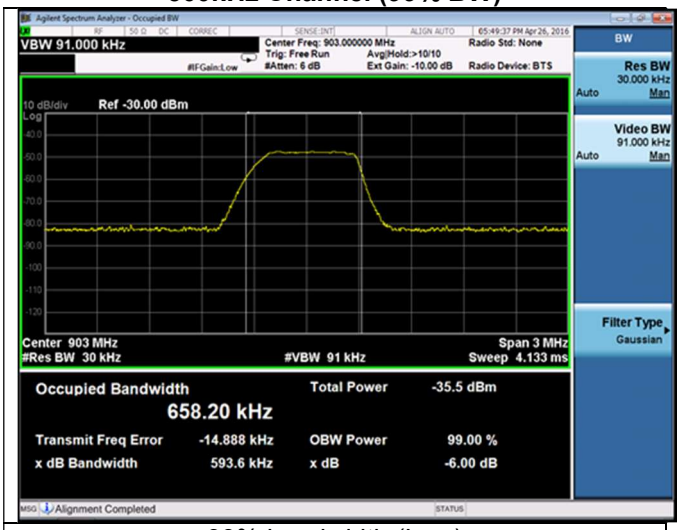


6dB bandwidth (Mid)

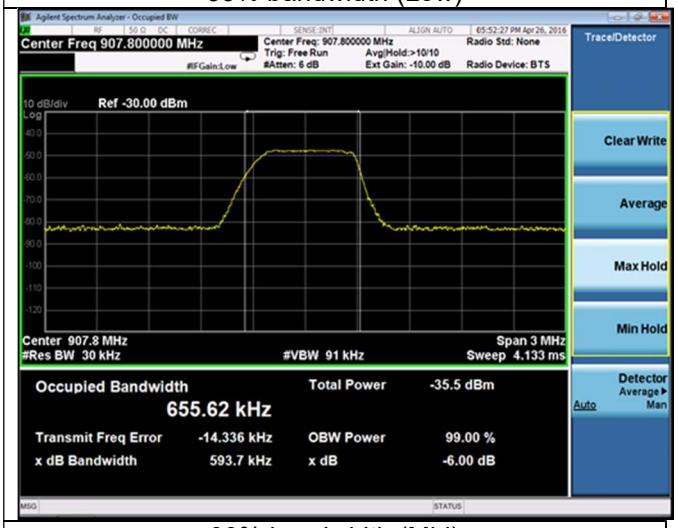


6dB bandwidth (High)

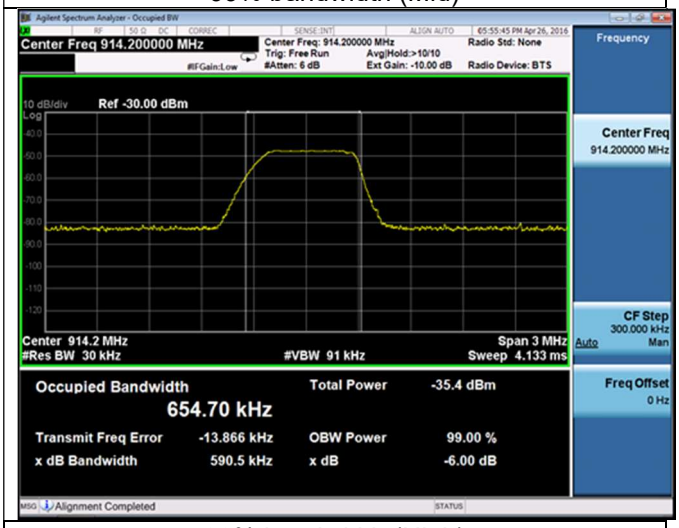
500kHz Channel (99% BW)



99% bandwidth (Low)



99% bandwidth (Mid)



99% bandwidth (High)

EXHIBIT 8. BAND EDGE MEASUREMENTS

Test Engineer(s): Shane Dock

8.1 - Method of Measurements

FCC 15.247 require a measurement of spurious emission levels at the restricted band to be compliant to the general emissions limit, in particular at the Band-Edges where the intentional radiator operates. Also, RSS 247 requires that unwanted emissions meet limits listed in RSS GEN and also to the limits in the applicable annex. The EUT was operated in continuous transmit mode with continuous modulation, with internally generated data as the modulating source. The EUT was operated at the lowest channel for the investigation of the lower Band-Edge, and at the highest channel for the investigation of the higher Band-Edge.

The Band-edge measurements were performed conducted (100kHz bandwidth) and radiated. The measurement of band-edge was performed to satisfy FCC 15.247(d).

Per FCC KDB 558074 D01 Measurement Guidance v03r04 (Section 11 for DTS) and ANSI 63.10, conducted measurements were performed with 100 kHz bandwidth for all emissions outside of the band of operation for the 500kHz mode. For the 125kHz mode, The measurements were carried out in accordance with ANSI 6310 Section 6.

For both conducted and radiated measurements, correction factors and the cable loss factors were entered into the EMI Receiver database. **As a result, the plots taken from the EMI Receiver accounts for all applicable correction factor as well as cable loss, and can therefore be entered into the database as a corrected meter reading.**

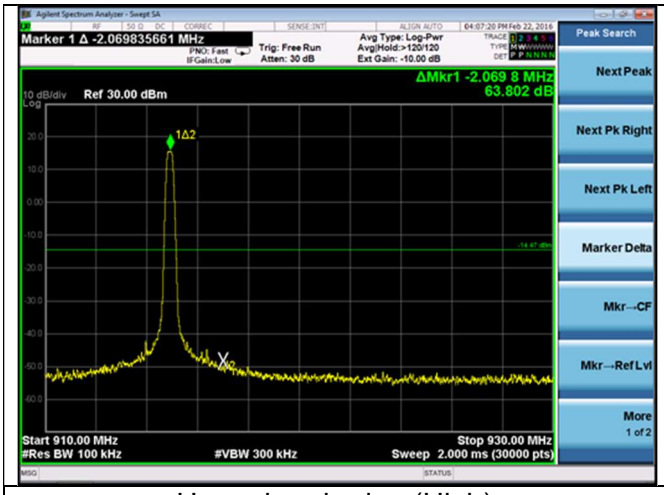
8.2. Band edge screen captures.

The data presented below are samples selected from the various data rates and channels tested.

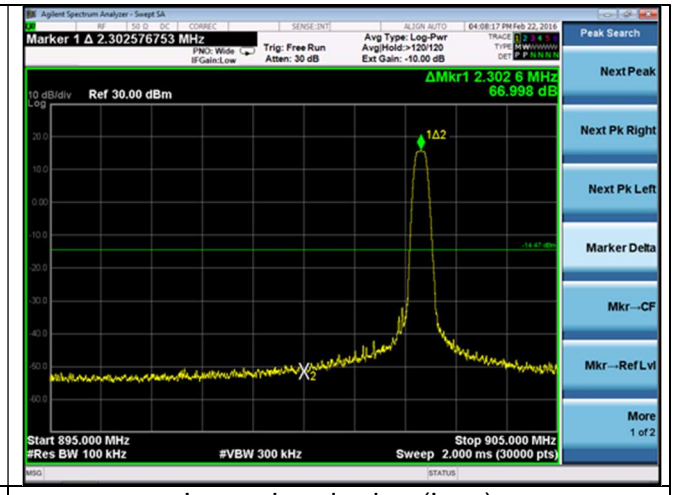
Note: Radiated Band-Edge measurements can be found in Exhibit 5.

Band-edge in 100kHz bandwidth (Conducted Band Edge)

125kHz channel

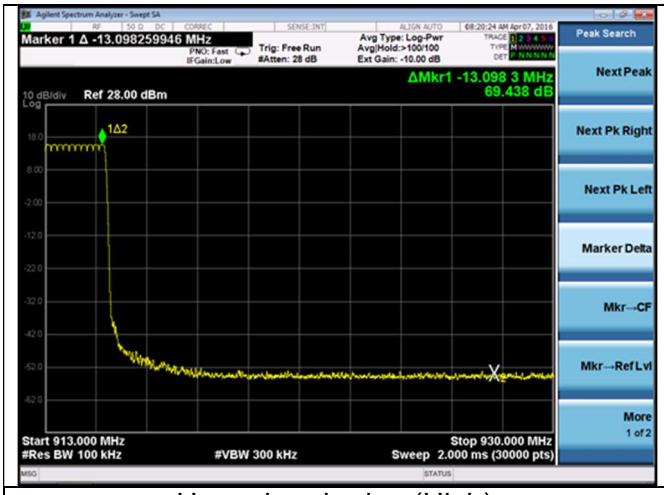


Upper band-edge (High)

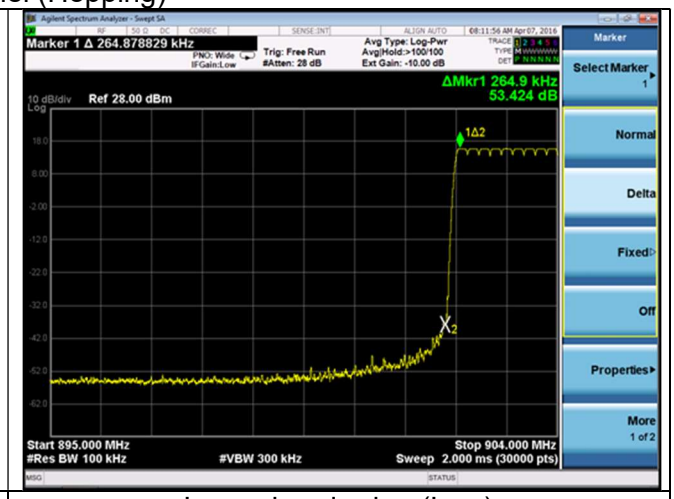


Lower band-edge (Low)

125kHz channel (Hopping)



Upper band-edge (High)



Lower band-edge (Low)

500kHz channel

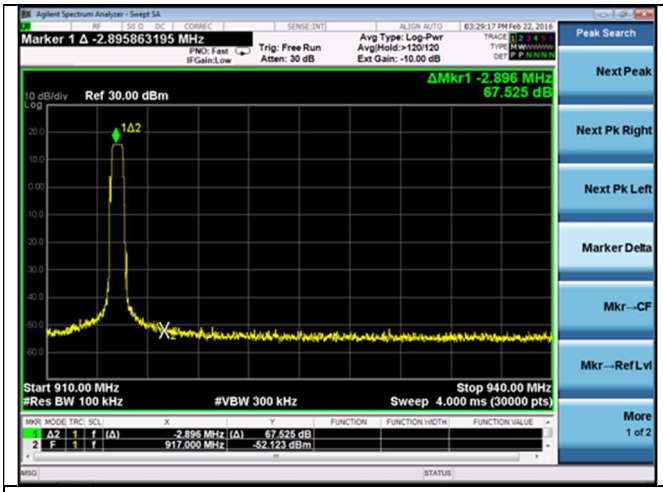
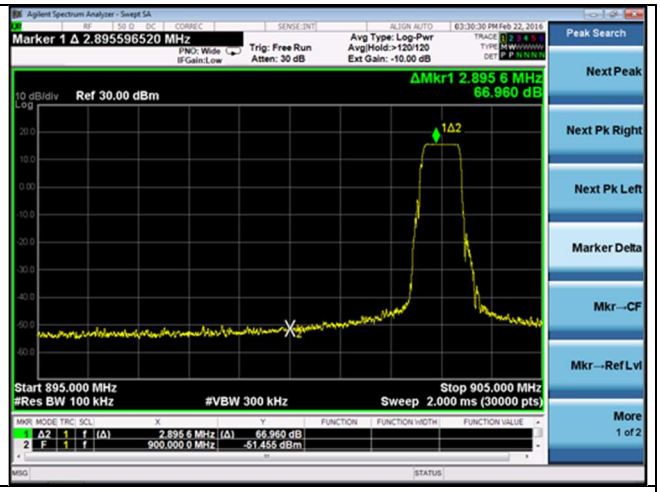
	
Upper band-edge (High)	Lower band-edge (Low)

EXHIBIT 9. POWER OUTPUT (CONDUCTED): 15.247(b)

Test Engineer(s): Shane Dock

9.1 - Method of Measurements

The conducted RF output power of the EUT was measured at the antenna port using a short RF cable along with an attenuator as protection for the spectrum analyzer. The loss from the cable and the attenuator were added on the analyzer as gain offset settings there by allowing direct measurements without the need for any further corrections. The unit was configured to run in a continuous transmit mode, while being supplied with typical data as a modulation source.

Measurement procedure used was FCC OET KDB 558074 D01 Measurement Guidance v03r04 section 9.2.2.4.

9.2 - Test Data

The data reported includes all necessary correction factors. These correction factors are loaded onto the EMI receiver when measurements are performed.

Reported Measurement data = Raw receiver measurement (dBm) + Cable factor (dB) + Miscellaneous factors when applicable (dB).

Generic example of reported data at 2440 MHz:

Reported Measurement data = 8.55 (raw receiver measurement in dBm) + 0.85 (cable factor in dB) = 9.4 (dBm).

9.2.1. Maximum conducted power:

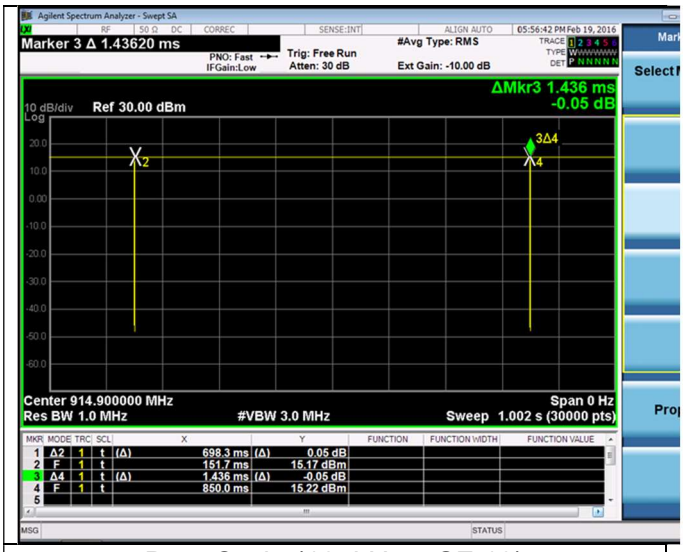
9.2.1.1 Duty cycle:

Measurement procedure: **FCC OET KDB 558074 D01 Measurement Guidance v03r04. Duty Cycle was found to be >99%, except for SF 07 – 500kHz which has a duty cycle of 95.45%. Both output power and PSD measurements for the 500kHz set with a spreading factor of 7 feature a .2dB correction for duty cycle.**

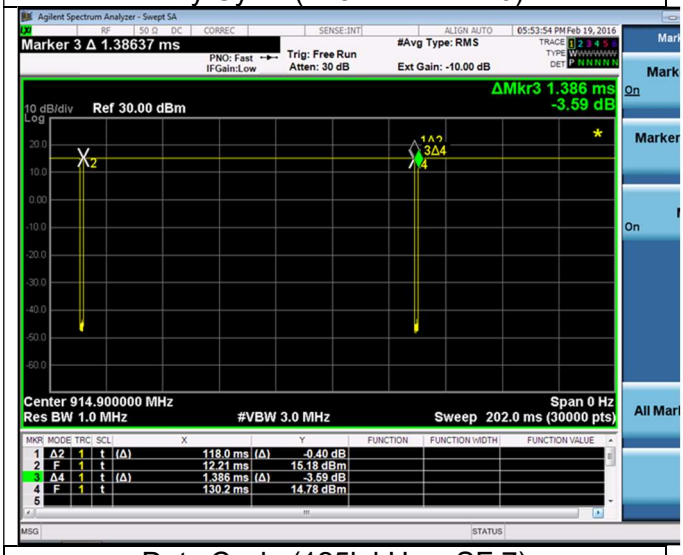
Note:

SF: spreading factor

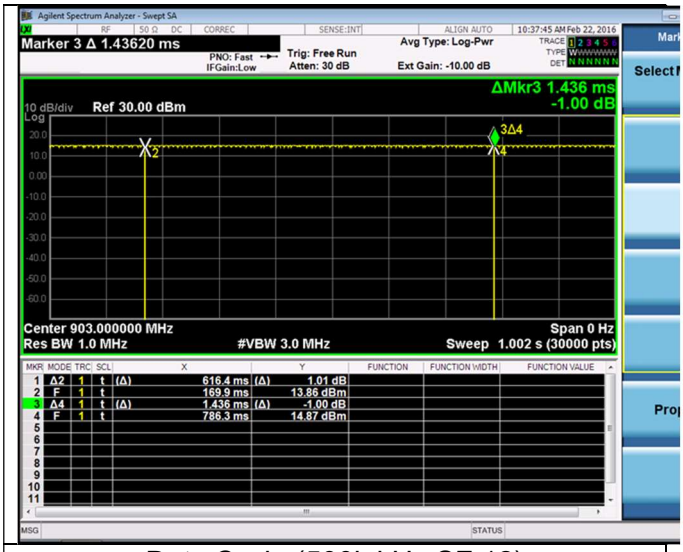
Screen captures:



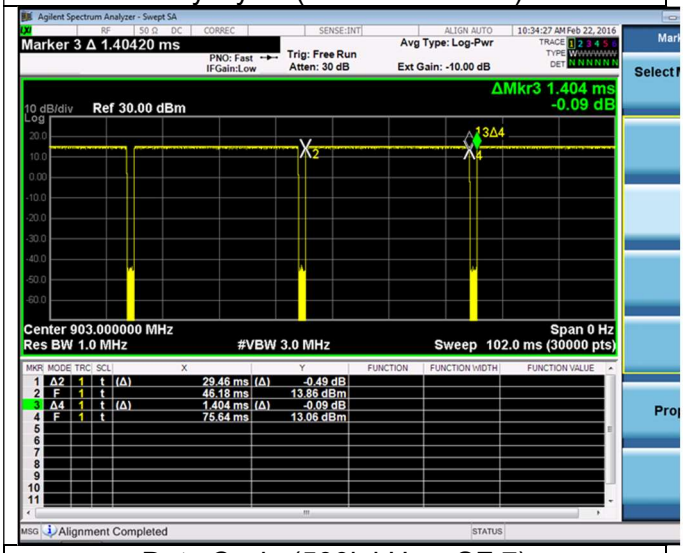
Duty Cycle (125kHz – SF 10)



Duty Cycle (125k kHz – SF 7)



Duty Cycle (500k kHz SF 12)



Duty Cycle (500k kHz – SF 7)

Note:

SF: spreading factor

9.2.1.2 Maximum conducted output power:
Note: Where SF is mentioned below, it refers to the spreading factor (between 7-12 for 500k, and 7-10 for 125k). A higher SF yields a lower data rate.

500kHz channels

Packet Type	Channel	Frequency (MHz)	Output Power (dBm)	Output power limit (dBm)	Margin (dB)
3.6V 7 SF	Low	903	15.2	30.0	14.8
	Mid	907.8	15.0	30.0	15.0
	High	914.2	14.8	30.0	15.2

Note: Above power includes .2 dBm correction for duty cycle.

Packet Type	Channel	Frequency (MHz)	Output Power (dBm)	Output power limit (dBm)	Margin (dB)
1.8V 7 SF	Low	903	8.5	30.0	21.5
	Mid	907.8	8.8	30.0	21.2
	High	914.2	8.6	30.0	21.4

Note: Above power includes .2 dBm correction for duty cycle.

Packet Type	Channel	Frequency (MHz)	Output Power (dBm)	Output power limit (dBm)	Margin (dB)
3.6V 12 SF	Low	903	14.9	30.0	15.1
	Mid	907.8	14.9	30.0	15.1
	High	914.2	15.0	30.0	15.0
Packet Type	Channel	Frequency (MHz)	Output Power (dBm)	Output power limit (dBm)	Margin (dB)
1.8V 12 SF	Low	903	8.6	30.0	21.4
	Mid	907.8	8.9	30.0	21.1
	High	914.2	8.8	30.0	21.2

Notes:
1. 3.6V and 1.8V in the tables above refer to the supply voltage (DC) to the module.

125kHz channels

Packet Type	Channel	Frequency (MHz)	Output Power (dBm)	Output power limit (dBm)	Margin (dB)
3.6V 7 SF	Low	902.3	15.3	30.0	14.7
	Mid	908.5	15.2	30.0	14.8
	High	914.9	15.0	30.0	15.0
Packet Type	Channel	Frequency (MHz)	Output Power (dBm)	Output power limit (dBm)	Margin (dB)
1.8V 7 SF	Low	902.3	8.5	30.0	21.5
	Mid	908.5	8.5	30.0	21.5
	High	914.9	8.6	30.0	21.4

Packet Type	Channel	Frequency (MHz)	Output Power (dBm)	Output power limit (dBm)	Margin (dB)
3.6V 10 SF	Low	902.3	15.3	30.0	14.7
	Mid	908.5	15.7	30.0	14.3
	High	914.9	15.0	30.0	15.0
Packet Type	Channel	Frequency (MHz)	Output Power (dBm)	Output power limit (dBm)	Margin (dB)
1.8V 10 SF	Low	902.3	8.4	30.0	21.6
	Mid	908.5	8.6	30.0	21.4
	High	914.9	8.3	30.0	21.7

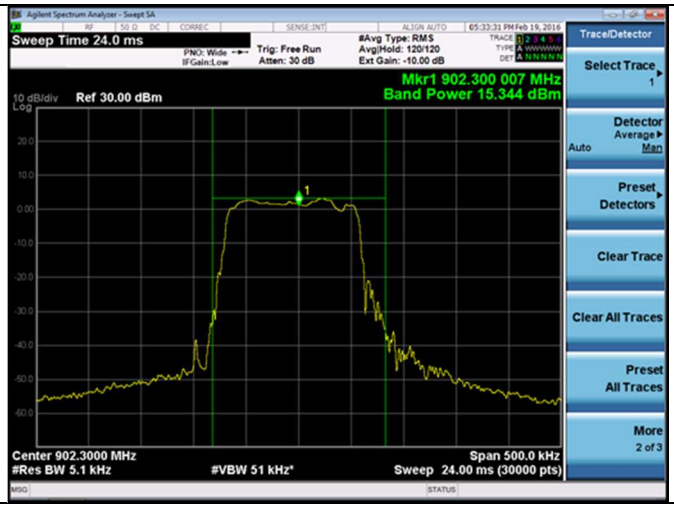
Notes:

1. 3.6V and 1.8V in the tables above refer to the supply voltage (DC) to the module.

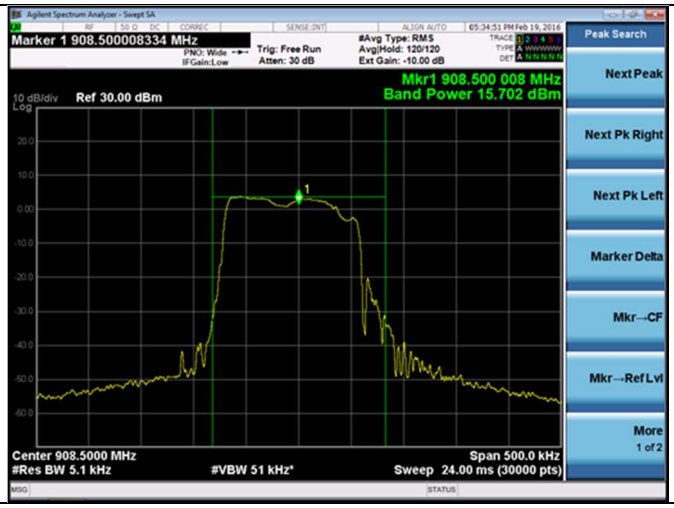
9.3 – Screen Captures.

Note: Plots shown below are those of the 3.6 VDC EUT.

125kHz channel



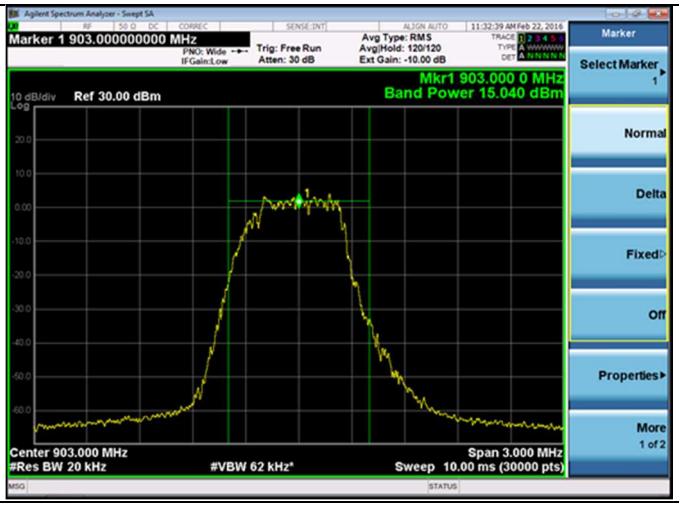
Low



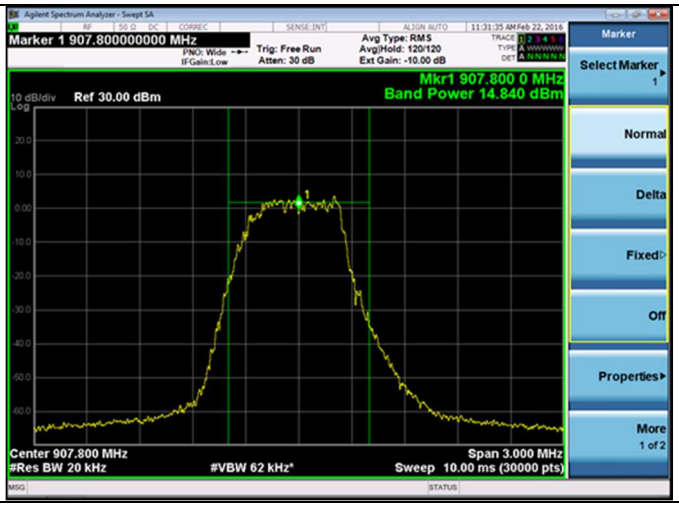
Mid

High

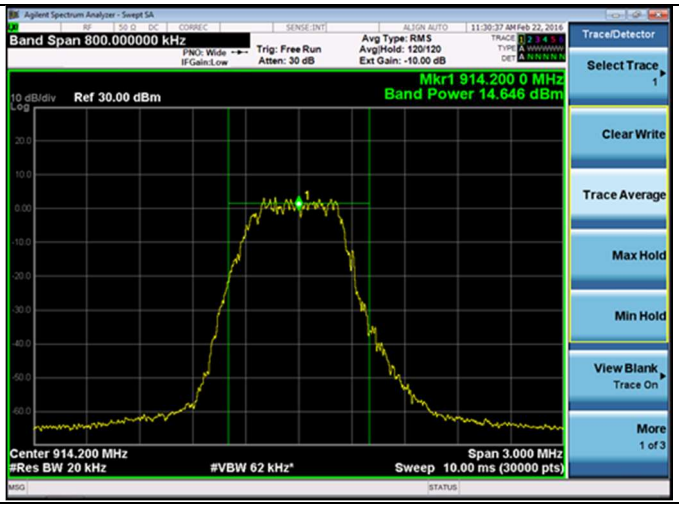
500kHz channel



Low



Mid


Agilent Spectrum Analyzer - Swept SA
Band Span 800.000000 kHz
PNO: Wide
IFGain:Low
Trig: Free Run
Atten: 30 dB
Avg Type: RMS
Avg|Hold: 120/120
Ext Gain: -10.00 dB
11:30:37 AM Feb 22, 2016
Mkr1 914.200 0 MHz
Band Power 14.646 dBm
10 dB/div
Log
Ref 30.00 dBm
Center 914.200 MHz
#Res BW 20 kHz
#VBW 62 kHz*
Span 3.000 MHz
Sweep 10.00 ms (30000 pts)
Trace/Detector
Select Trace
1
Clear Write
Trace Average
Max Hold
Min Hold
View Blank
Trace On
More
1 of 3

High

EXHIBIT 10. CONDUCTED SPURIOUS EMISSIONS: 15.247(d)

Test Engineer(s): Shane Dock

10.1 - Limits

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 30 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.

10.2 – Conducted Harmonic And Spurious RF Measurements

FCC Part 15.247(d) and IC RSS 247 both require a measurement of conducted harmonic and spurious RF emission levels, as reference to the carrier level when measured in a 100 kHz bandwidth. For this test, the spurious and harmonic RF emissions from the EUT were measured at the EUT antenna port using a short RF cable along with an attenuator as protection for the spectrum analyzer. The loss from the cable and the attenuator were added on the analyzer as gain offset settings, thereby allowing direct readings of the measurements made without the need for any further corrections. A spectrum analyzer was used with the resolution bandwidth set to 100 kHz for this portion of the tests. The unit was configured to run in a continuous transmit mode, while being supplied with typical data as a modulation source. The spectrum analyzer was used with measurements from a peak detector presented in the chart below. Screen captures were acquired and any noticeable spurious and harmonic signals were identified and measured.

Measurement procedure used was FCC OET KDB 558074 D01 Measurement Guidance v03r04 section 11 for DTS and ANSI 63.10 Section 7.8.8 was used for the hybrid system.

The data reported includes all necessary correction factors. These correction factors are loaded onto the EMI receiver when measurements are performed.

Reported Measurement data = Raw receiver measurement (dBm) + Cable factor (dB) + Miscellaneous factors when applicable (dB).

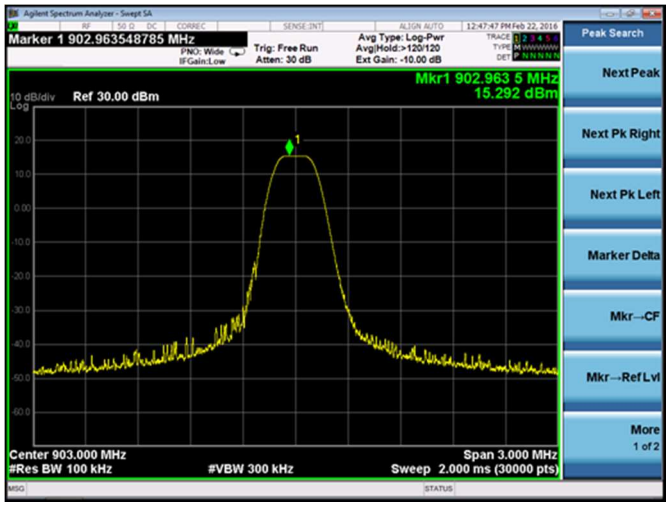
Generic example of reported data at 2440 MHz:

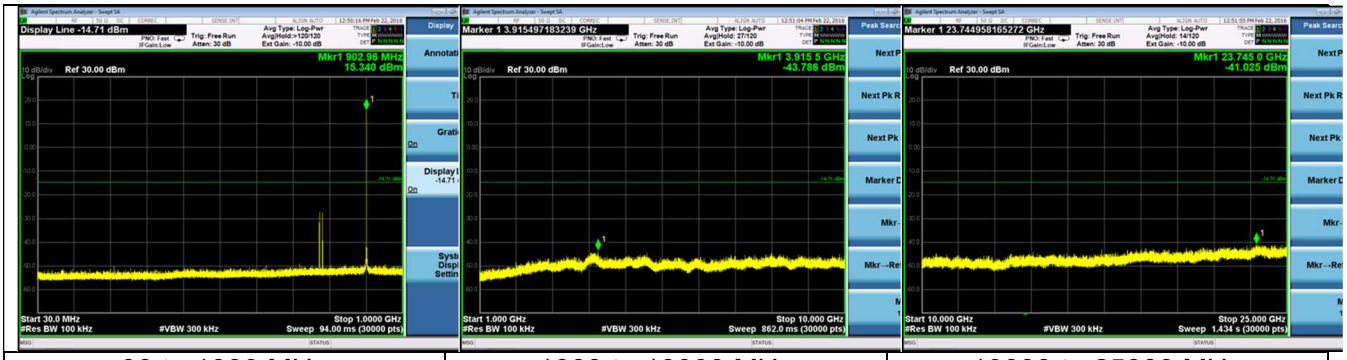
Reported Measurement data = 8.55 (raw receiver measurement in dBm) + 0.85 (cable factor in dB) = 9.4 (dBm).

10.3 - Test Data

The data presented below are samples selected from the various data rates and channels tested.

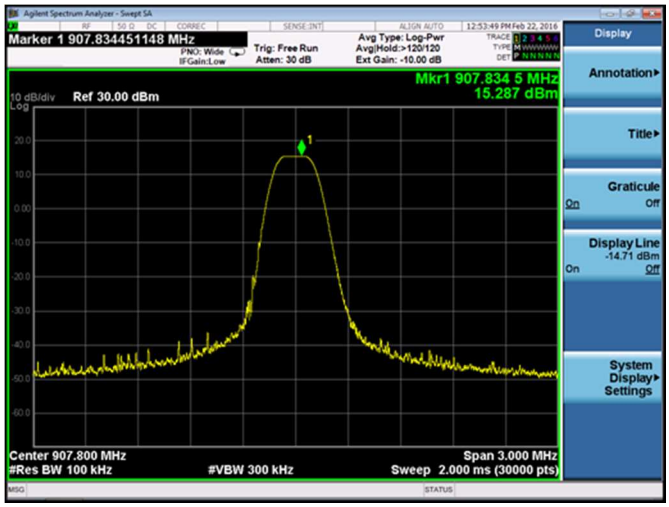
Low fundamental in 100 kHz: 500kHz channel

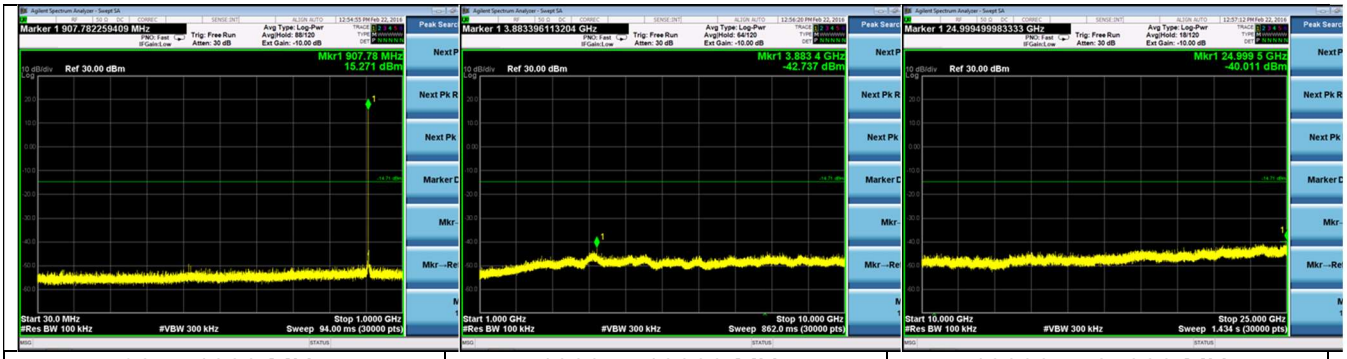




30 to 1000 MHz	1000 to 10000 MHz	10000 to 25000 MHz

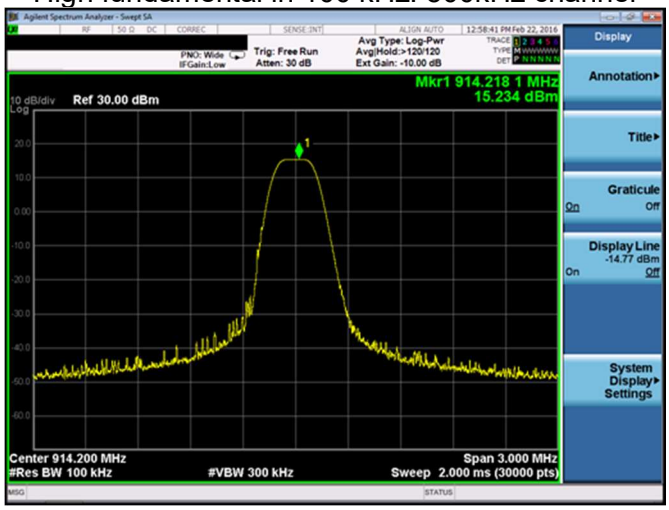
Mid fundamental in 100 kHz: 500kHz channel

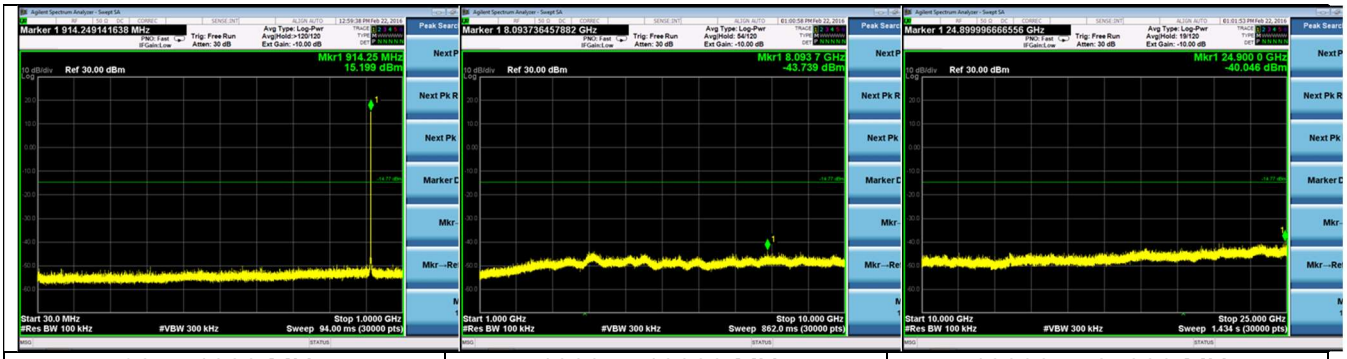




30 to 1000 MHz	1000 to 10000 MHz	10000 to 25000 MHz

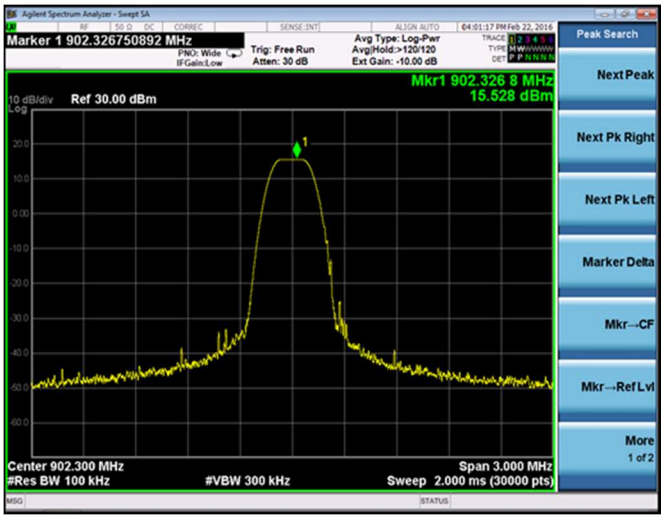
High fundamental in 100 kHz: 500kHz channel

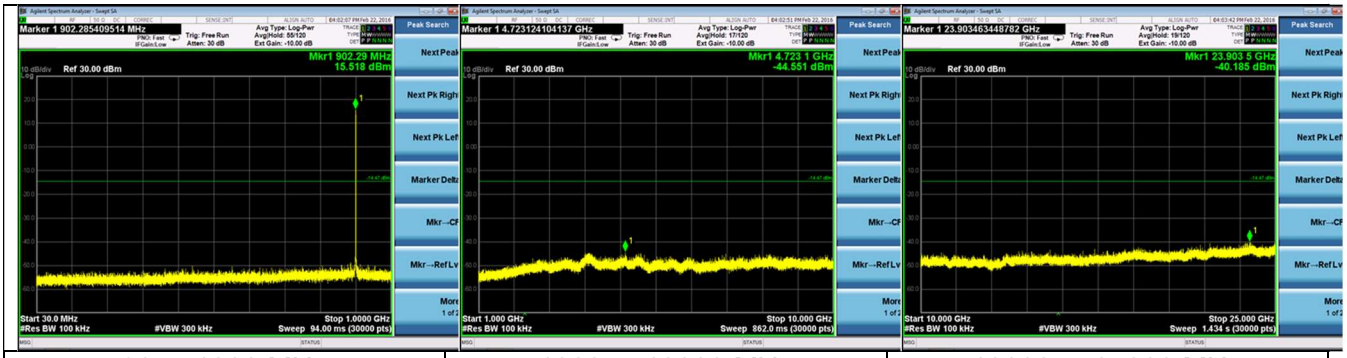




30 to 1000 MHz	1000 to 10000 MHz	10000 to 25000 MHz

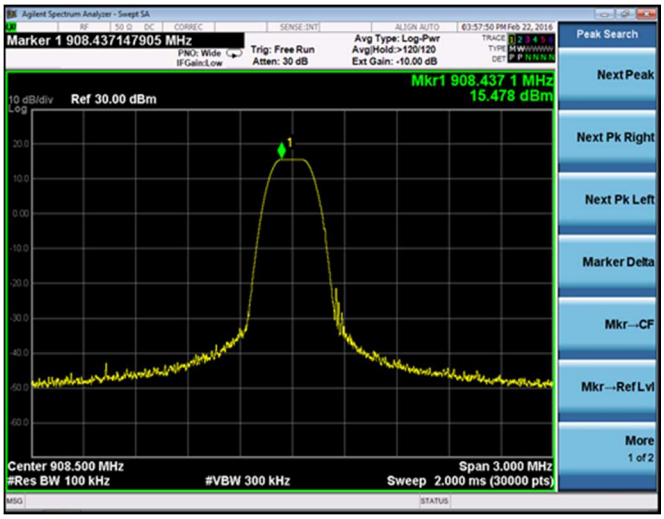
Low fundamental in 100 kHz: 125kHz channel

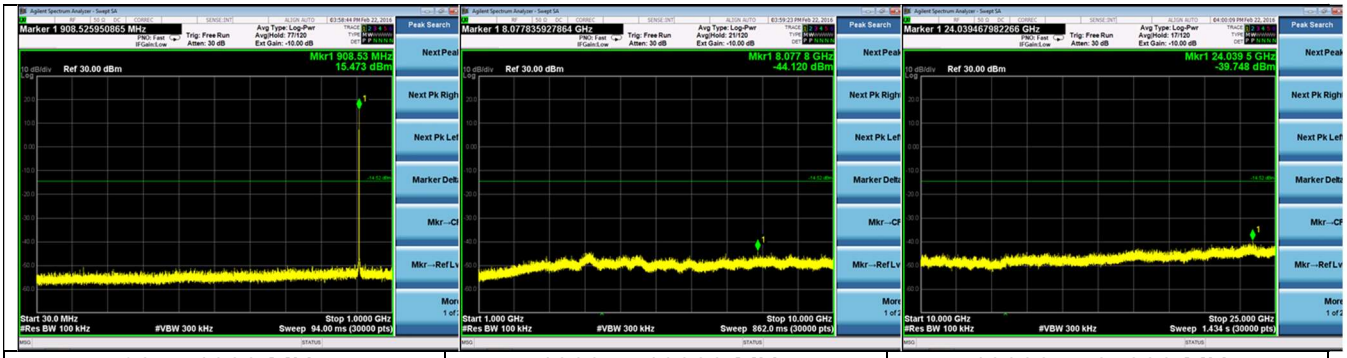




30 to 1000 MHz	1000 to 10000 MHz	10000 to 25000 MHz

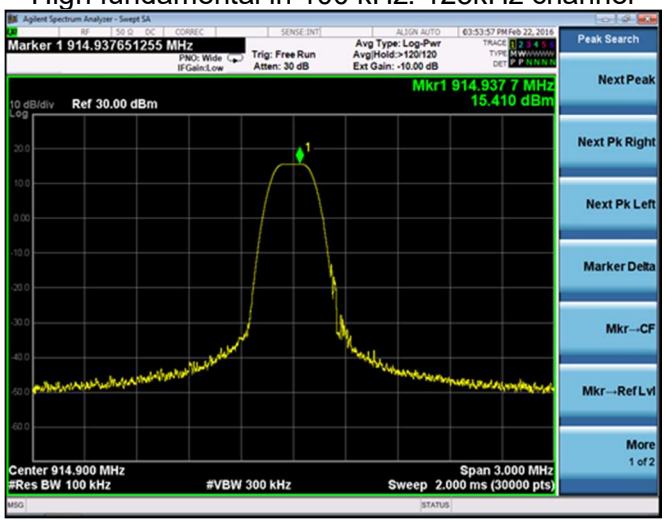
Mid fundamental in 100 kHz: 125kHz channel

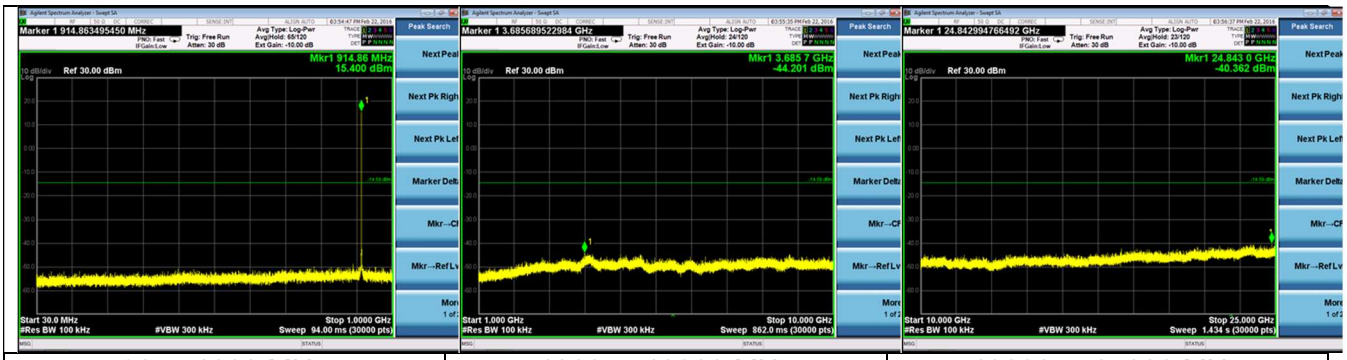




30 to 1000 MHz	1000 to 10000 MHz	10000 to 25000 MHz

High fundamental in 100 kHz: 125kHz channel





30 to 1000 MHz	1000 to 10000 MHz	10000 to 25000 MHz

EXHIBIT 11. POWER SPECTRAL DENSITIES: 15.247(e)

This section is applicable to both the 500 kHz channels (DTS) and 125 kHz channels (Hybrid).

11.1 Limits

For digitally modulated systems and hybrid systems, the power spectral density conducted from the intentional radiator
to the antenna shall not be greater than 8 dBm in any 3 kHz band during any time interval of continuous transmission.

In accordance with FCC Part 15.247(e/f) and RSS 247, the peak power spectral density should not exceed +8 dBm in any 3 kHz band. This measurement was performed along with the conducted power output readings performed as described in previous sections. The peak output frequency for each representative frequency was scanned, with a narrow bandwidth, and reduced sweep, and a power density measurement was performed.

Measurement procedure used was FCC OET KDB 558074 D01 Measurement Guidance v03r04 section 10.5.

The data reported includes all necessary correction factors, including any necessary duty cycle corrections. These correction factors are loaded onto the EMI receiver when measurements are performed.

Reported Measurement data = Raw receiver measurement (dBm) + Cable factor (dB) + Miscellaneous factors when applicable (dB).

Generic example of reported data at 2440 MHz:

Reported Measurement data = 8.55 (raw receiver measurement in dBm) + 0.85 (cable factor in dB) = 9.4 (dBm).

11.2 Test Data

125kHz channel

Packet Type	Channel	Frequency (MHz)	PSD (dBm)
3.6V 10 SF	Low	902.3	4.1
	Mid	908.5	2.7
	High	914.9	1.5

Packet Type	Channel	Frequency (MHz)	PSD (dBm)
3.6V 7 SF	Low	902.3	2.4
	Mid	908.5	1.9
	High	914.9	1.8

500kHz channel

Packet Type	Channel	Frequency (MHz)	PSD (dBm)
3.6V 12 SF	Low	903	-2.2
	Mid	907.8	-1.7
	High	914.2	-1.6

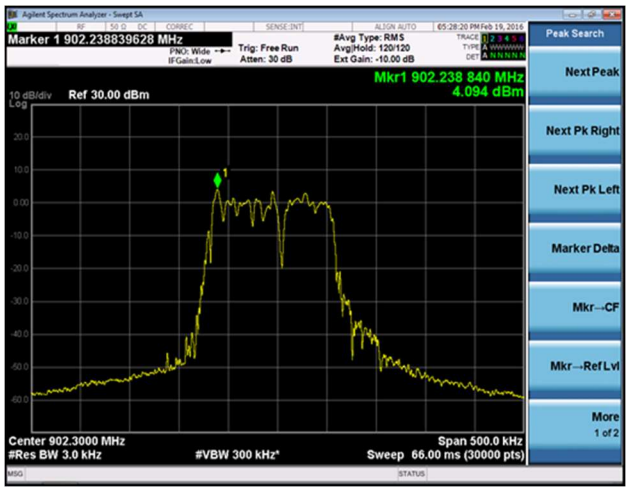
Packet Type	Channel	Frequency (MHz)	PSD (dBm)
3.6V 7 SF	Low	903	-4.5
	Mid	907.8	-4.8
	High	914.2	-5.0

PSD values for 3.6V 7 SF feature a .2 dB correction. See section 9.2.1 for a breakdown of the duty cycle.

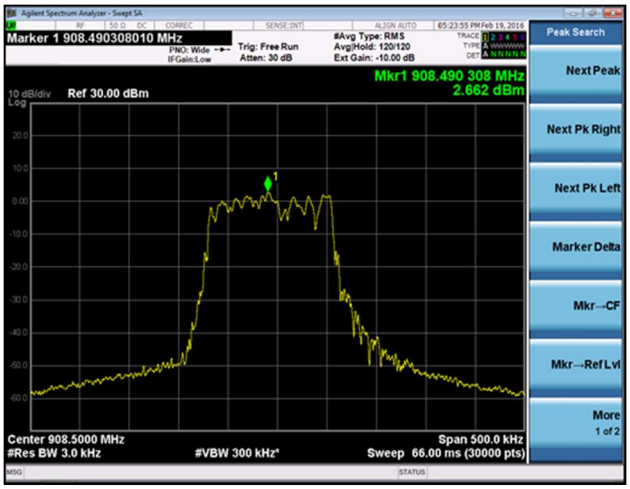
Note: Values above in dBm. Only 3.6V values shown as they are the worst case scenario.

11.3 Screen Captures – Power Spectral Density

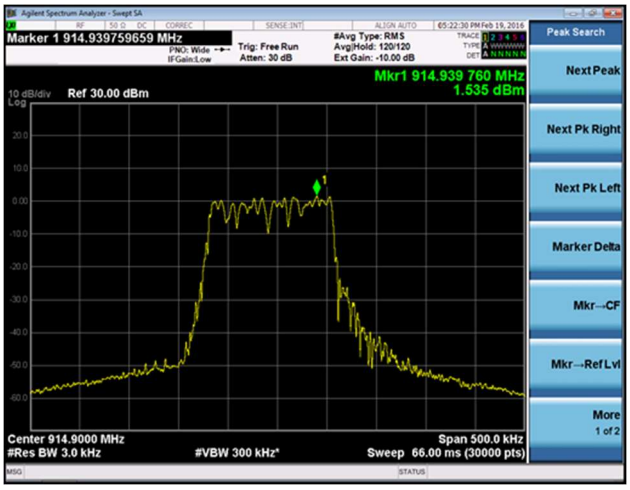
125kHz channel



Low

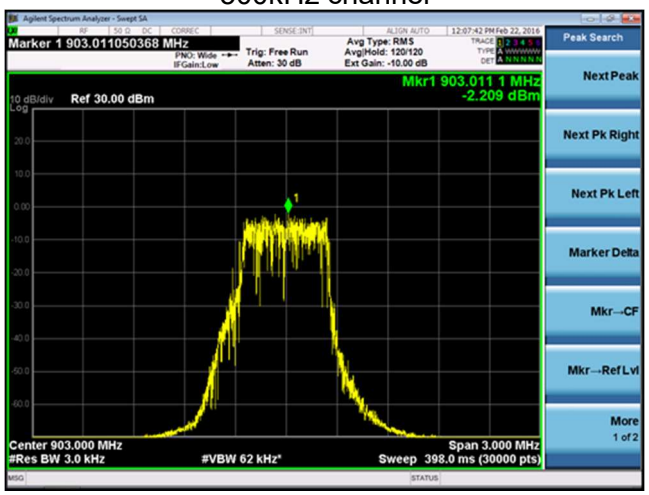


Mid

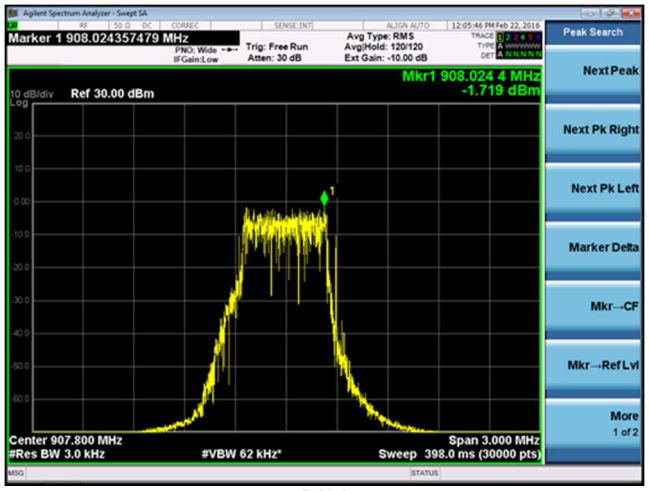


High

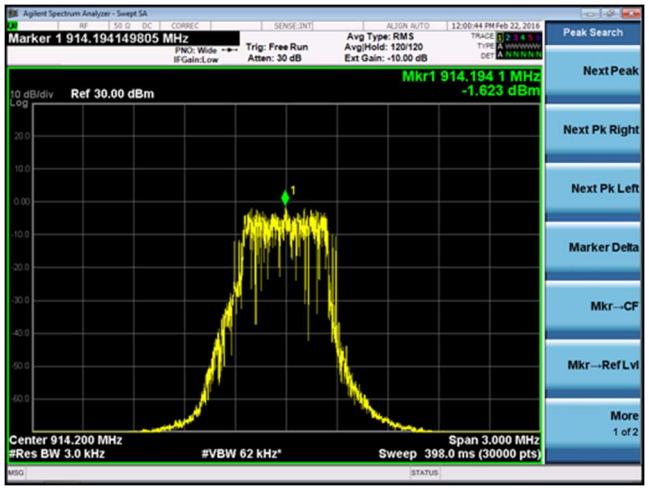
500kHz channel



Low



Mid



High

Note: All captures shown above use the worst case spreading factor (10 for 125kHz, 12 for 500kHz).

EXHIBIT 12. FREQUENCY STABILITY OVER VOLTAGE VARIATIONS

Test Engineer(s): Shane Dock

The frequency stability of the device was examined as a function of the input voltage available to the EUT. A Spectrum Analyzer was used to measure the RF output power and frequency at the appropriate frequency markers. Power was supplied by an external bench-type DC power supply and was varied ±15% from the nominal.

The power was then cycled On/Off to observe system response. No unusual response was observed, the emission characteristics were well behaved, and the system returned to the same state of operation as before the power cycle.

Measurement procedure used was ANSI C63.10 section 6.8

125kHz

Spread 7	1.8 VDC	3.3 VDC	3.6 VDC		Spread 10	1.8 VDC	3.3 VDC	3.6 VDC	
Channel	Frequency (Hz)	Frequency (Hz)	Frequency (Hz)	Frequency Drift (Hz)	Channel	Frequency (Hz)	Frequency (Hz)	Frequency (Hz)	Frequency Drift (Hz)
902.3	902294420	902294420	902294250	170	902.3	902294580	902294250	902294920	670
908.5	908494580	908494720	908494250	470	908.5	908493750	908494420	908494420	670
914.9	914894580	914894580	914894750	170	914.9	914894080	914894580	914894920	840

500kHz

Spread 7	1.8 VDC	3.3 VDC	3.6 VDC		Spread 12	1.8 VDC	3.3 VDC	3.6 VDC	
Channel	Frequency (Hz)	Frequency (Hz)	Frequency (Hz)	Frequency Drift (Hz)	Channel	Frequency (Hz)	Frequency (Hz)	Frequency (Hz)	Frequency Drift (Hz)
903	902994250	902994580	902995250	1000	903	902994920	902994580	902993750	1170
907.8	907794750	907794420	907794920	500	907.8	907794580	907794750	907794750	170
914.2	914194080	914194250	914195250	1170	914.2	914194750	914194580	914194080	670

EXHIBIT 13. CHANNEL PLAN AND SEPARATION

A spectrum analyzer was used with a resolution bandwidth of 1% of the span to measure the channel separation of the EUT.

Measurement procedure: ANSI C63.10 section 7.8.2

The channel separation measured for this device is **200.0 kHz.** The following plots describe this spacing, and also establish the channel separation and plan.

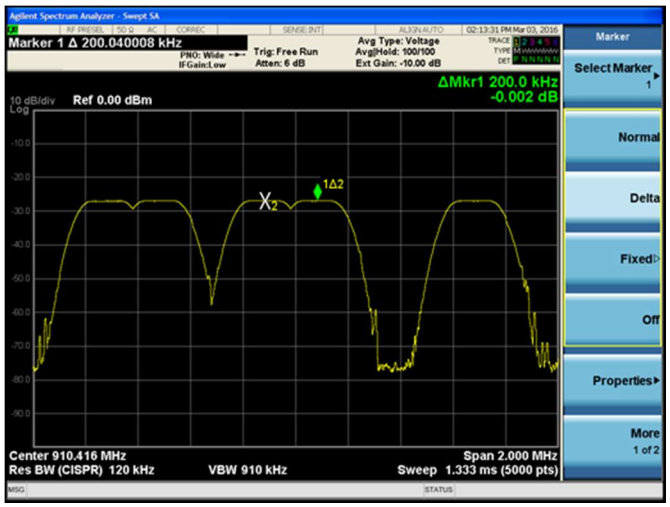
This EUT carries a total of 64 channels (however, there is no minimum number of channels for hybrid systems.

Span	Number of channels
902.3 – 914.9 MHz	64

Total Number of channels	64

13.1 - Screen Captures

Channel Separation
125kHz -3.6V



125kHz – 1.8V

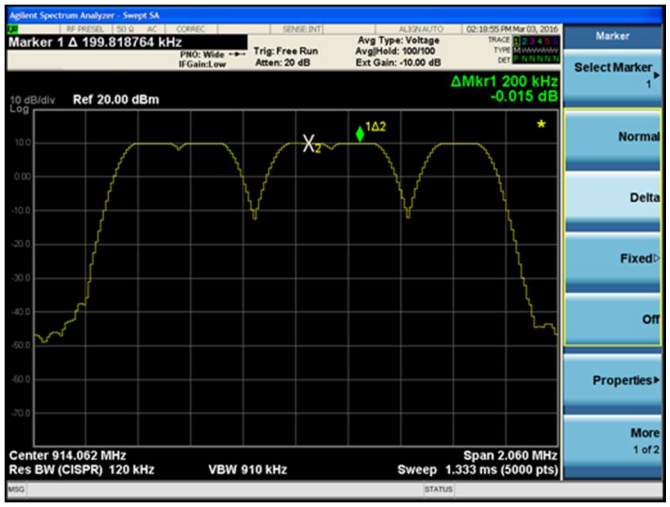


EXHIBIT 14. CHANNEL OCCUPANCY.

Measurement procedure: ANSI C63.10 section 7.8.4

Part 15.247(f) requires an average channel occupancy, for this device, of no more than 400 milliseconds in a 25.6 second window .The channel occupancy for this EUT was measured using a spectrum analyzer, set to zero-span at the frequency of interest. With the analyzer in peak-hold mode, the transmission lengths can be measured by adjusting the sweep rate of the analyzer. A suitable sweep rate was used to measure the channel occupancy at the low, mid and high channels. A single transmission will occur on a single channel for **399.3 ms**. In a 25.6 seconds window, there will be 1 occurrences. Therefore the total time occupancy in a 25.6 seconds window is

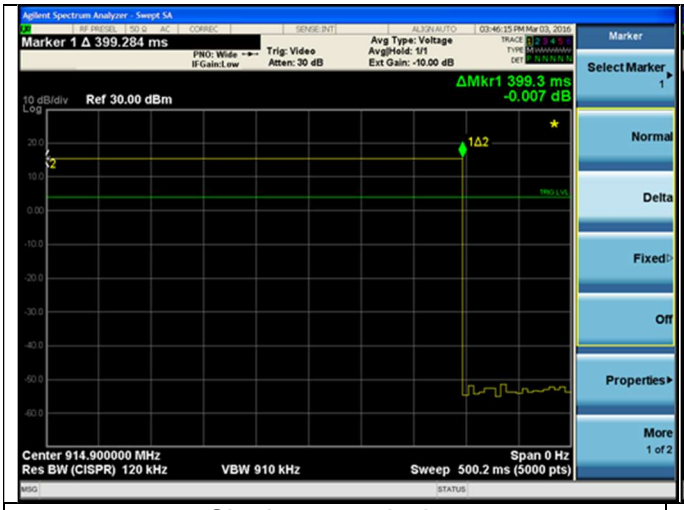
1 x 399.3ms = **399.3ms**

The window of measurement is equal to the number of hopping channels multiplied by 400ms. So,

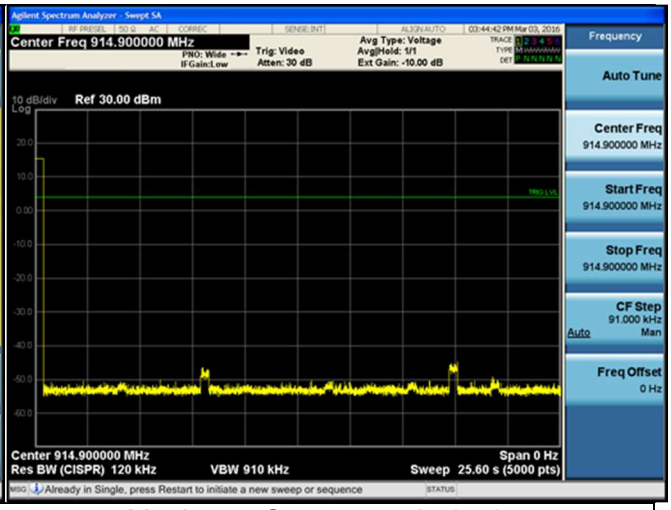
.4 seconds x 64 channels = 25.6 seconds.

14.1 Time occupancy captures.

Note: The captures shown are from 125kHz mode which is frequency hopping. Images below are from the high channel, but the transmission length is the same for all three channels measured.



Single transmission



Maximum Occupancy in 25.6s

EXHIBIT 15. HOP SEQUENCE/EQUAL CHANNEL USE

As provided by manufacturer:

Each transmission to the gateway will occur at a randomly selected channel. The transmit channel is selected by first performing an in-band RSSI measurement, and then using this RSSI value as the seed to a random number generator. Math is then preformed on the resulting random number to generate a channel number. If the indicated channel number has already been used (this time around the hopping sequence), the next sequential channel in the list (that has not already been used) will be selected, and then marked off the list. After all channels have been used, the entire sequence will start over. Each time around the hopping sequence, all channels will be used for transmissions.

Below is a screenshot of a hopping sequence generated:

LoRa 125kHz Hoppping Sequency Example

Hop #	Bin#	Frequency	Hop #	Bin#	Frequency	Hop #	Bin#	Frequency	Hop #	Bin#	Frequency
0	15	905.3	16	14	905.1	32	31	908.5	48	61	914.5
1	63	914.9	17	23	906.9	33	38	909.9	49	10	904.3
2	55	913.3	18	49	912.1	34	48	911.9	50	44	911.1
3	32	908.7	19	16	905.5	35	20	906.3	51	0	902.3
4	13	904.9	20	30	908.3	36	21	906.5	52	60	914.3
5	4	903.1	21	7	903.7	37	9	904.1	53	56	913.5
6	53	912.9	22	40	910.3	38	26	907.5	54	1	902.5
7	6	903.5	23	34	909.1	39	59	914.1	55	45	911.3
8	12	904.7	24	43	910.9	40	36	909.5	56	11	904.5
9	52	912.7	25	8	903.9	41	22	906.7	57	2	902.7
10	33	908.9	26	18	905.9	42	57	913.7	58	54	913.1
11	5	903.3	27	51	912.5	43	3	902.9	59	37	909.7
12	47	911.7	28	35	909.3	44	24	907.1	60	27	907.7
13	28	907.9	29	17	905.7	45	25	907.3	61	29	908.1
14	58	913.9	30	42	910.7	46	50	912.3	62	41	910.5
15	62	914.7	31	19	906.1	47	39	910.1	63	46	911.5

EXHIBIT 16. RECEIVER MATCHING BANDWIDTH AND SYNCHRONIZATION

The Semtech Sx1272 RF transceiver chip has an adjustable receive filter that is controlled by the LoRa stack implemented in firmware. Whenever the Sx1272 transmits to the gateway, the gateway responds with a transmission where the bandwidth is a function of our transmitted signal. The SX1272 receive filter will be adjusted to the exact bandwidth of the signal expected to be received back from the gateway. This is all controlled by the software stack and it optimizes the receiver sensitivity of the SX1272 by matching the receiver bandwidth exactly to the expected incoming signal.

APPENDIX A – Test Equipment List

LSR
a Laird Business

Date : 18-Feb-2016 Type Test : Radiated Emissions Job # : C-2401

Prepared By: Shane Dock Customer : Laird Quote #: 316054

No.	Asset #	Description	Manufacturer	Model #	Serial #	Cal Date	Cal Due Date	Equipment Status
1	EE 960088	8GHz MXE Spectrum Analyzer	Agilent	N9038A	MY51210138	2/24/2016	2/24/2017	Active Calibration
2	AA 960005	Biconical Antenna	EMCO	93110B	9601-2280	1/14/2016	1/14/2017	Active Calibration
3	AA 960004	Log Periodic Antenna (NSA)	EMCO	93146	9512-4276	4/15/2014	4/15/2016	Active Calibration
4	AA 960007	Double Ridge Horn Antenna	EMCO	3115	9311-4138	8/4/2015	8/4/2016	Active Calibration
5	EE 960160	0.8-21GHz LNA	Mini-Circuits	ZVA-213X-S+	977711030	8/4/2015	8/4/2016	Active Calibration
6	AA 960158	Double Ridge Horn Antenna	ETS Lindgren	3117	109300	2/4/2016	2/4/2017	Active Calibration
7	EE 960159	0.8 - 21GHz LNA	Mini-Circuits	ZVA-213X-S+	40201429	2/4/2016	2/4/2017	Active Calibration
8	EE 960085	N9038A MXE 26.5GHz Receiver	Agilent	N9038A	MY51210148	5/6/2015	5/6/2016	Active Calibration
9	EE 960125	SMA Cable	MegaPhase	NC19-S1S1-236	1GVT4 14032106 001	3/6/2015	3/6/2016	Active Verification
10	AA 960162	EM Series Cable	MegaPhase	EM26-S1S1-120	12024301 001	6/30/2015	6/30/2016	Active Calibration
11	EE 960085	N9038A MXE 26.5GHz Receiver	Agilent	N9038A	MY51210148	5/6/2015	5/6/2016	Active Calibration

LSR
a Laird Business

Date : 18-Feb-2016 Type Test : Conducted Radio Job # : C-2401

Prepared By: Shane Dock Customer : Laird Quote #: 316054

No.	Asset #	Description	Manufacturer	Model #	Serial #	Cal Date	Cal Due Date	Equipment Status
1	AA 960144	Phaseflex	Gore	EKD01D010720	5800373	Verification	Verification	System
2	EE 960087	44GHz EXA Spectrum Analyzer	Agilent	N9010A	MY53400296	12/18/2015	12/18/2016	Active Calibration
3	AA 960156	900MHz High Pass Filter	KWM	HPF-L-14185	unknown	8/4/2015	8/4/2016	Active Calibration

LSR
a Laird Business

Date : 18-Feb-2016 Type Test : Conducted Emissions Job # : C-2401

Prepared By: Shane Dock Customer : Laird Quote #: 316054

No.	Asset #	Description	Manufacturer	Model #	Serial #	Cal Date	Cal Due Date	Equipment Status
1	EE 960085	N9038A MXE 26.5GHz Receiver	Agilent	N9038A	MY51210148	5/6/2015	5/6/2016	Active Calibration
2	EE 960162	LISN - 15A	COM-POWER	LI-215A	191969	7/24/2015	7/24/2016	Active Calibration
3	EE 960088	8GHz MXE Spectrum Analyzer	Agilent	N9038A	MY51210138	2/24/2016	2/24/2017	Active Calibration

Project Engineer: Shane Dock Quality Assurance:

APPENDIX B – Test Standards: CURRENT PUBLICATION DATES RADIO

STANDARD #	DATE	Am. 1	Am. 2
ANSI C63.4	2014		
ANSI C63.10	2013		
FCC 47 CFR, Parts 0-15, 18, 90, 95	2016		
RSS GEN	2014		
RSS 247	2015		

APPENDIX C - Uncertainty Statement

Table of Expanded Uncertainty Values, (K=2) for Specified Measurements

Measurement Type	*Particular Configuration*	*Uncertainty Values*
Radiated Emissions	*3 – Meter chamber, Biconical Antenna*	*4.82 dB*
Radiated Emissions	*3-Meter Chamber, Log Periodic Antenna*	*4.88 dB*
Radiated Emissions	*3-Meter Chamber, Horn Antenna*	*4.85 dB*
Radiated Emissions	*10-Meter OATS, Biconical Antenna*	*4.32 dB*
Radiated Emissions	*10-Meter OATS, Log Periodic Antenna*	*3.63 dB*
Absolute Conducted Emissions	*Agilent PSA/ESA Series*	*1.38 dB*
AC Line Conducted Emissions	*Shielded Room/EMCO LISN*	*3.20 dB*
Radiated Immunity	*3 Volts/Meter in 3-Meter Chamber*	*2.05 Volts/Meter*
Conducted Immunity	*3 Volts level*	*2.33 V*
EFT Burst, Surge, VDI	*230 VAC*	*54.4 V*
ESD Immunity	*Discharge at 15kV*	*3200 V*
Temperature/Humidity	*Thermo-hygrometer*	*0.64° / 2.88 %RH*