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Test Report

Prepared for: **Inovonics**

Address: **397 S. Taylor Ave.**
Louisville, CO 80027

Product: **EN 22XX**

Test Report No: **R20200701-21-E1B DTS**

Approved by:

Nic S. Johnson, NCE
Technical Manager
iNARTE Certified EMC Engineer #EMC-003337-NE

DATE: **2 June 2021**

Total Pages: **37**

ilac-MRA A2LA ACCREDITED TESTING LABORATORY CERTIFICATE NO. 1953.01

REVISION PAGE

Rev. No.	Date	Description
0	10 September 2020	Original – NJohnson Prepared by KVepuri
A	26 April 2021	Bandwidth and unrestricted band edge measurements were updated -KV
B	2 June 2021	Updated table on pg 9 and note #3 on pg 18.

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1.0 SUMMARY OF TEST RESULTS

The worst-case measurements were reported in this report. Summary of test results presented in this report correspond to the following section (Please see the checked box below for the rule part used):

FCC Part 15.247 ☒

The EUT has been tested according to the following specifications:

(1) US Code of Federal Regulations, Title 47, Part 15
(2) ISED RSS-Gen, Issue 5
(3) ISED RSS-247, Issue 2

APPLIED STANDARDS AND REGULATIONS		
Standard Section	**Test Type**	**Result**
FCC Part 15.35 RSS Gen, Issue 5, Section 6.10	Duty Cycle	NA
FCC Part 15.247(a)(1) RSS-247 Issue 2 Section 5.2	Peak output power	Pass
FCC Part 15.247(a)(1) RSS-247 Issue 2 Section 5.2	Bandwidth	Pass
FCC Part 15.209 RSS-Gen Issue 4, Section 7.1	Receiver Radiated Emissions	Pass
FCC Part 15.209 (restricted bands), 15.247 (unrestricted) RSS-247 Issue 2 Section 5.5, RSS-Gen Issue 4, Section 8.9	Transmitter Radiated Emissions	Pass
FCC Part 15.247(a)(1) RSS-247 Issue 2 Section 5.2	Power Spectral Density	Pass
FCC Part 15.209, 15.247(d) RSS-247 Issue 2 Section 11.13	Band Edge Measurement	Pass
FCC Part 15.207 RSS-Gen Issue 4, Section 7.1	Conducted Emissions	NA- Battery powered device

See Section 4 for details on the test methods used for each test.

2.0 EUT DESCRIPTION

2.1 EQUIPMENT UNDER TEST

Summary and Operating Condition:

EUT	EN 22XX
EUT Received	29 July 2020
EUT Tested	29 July 2020- 9 September 2020 23 April 2021 (occupied bandwidth)
Serial No.	0223300 (Used for power and all CW measurements); 0223340 (Used for all other measurements);
Operating Band	2400 – 2483.5 MHz
Device Type	BLE
Power Supply / Voltage	3 VDC (CR 2)

NOTE: For more detailed features description, please refer to the manufacturer's specifications or user's manual.

2.2 DESCRIPTION OF TEST MODES

The operating range of the EUT is dependent on the device type found in section 2.1:

For Bluetooth Transmissions:

Channel	Frequency
Low	2402 MHz
Mid	2426 MHz
High	2480 MHz

These are the only representative channels tested in the frequency range according to FCC Part 15.31 and RSS-Gen Table A1. See the operational description for a list of all channel frequency and designations.

2.3 DESCRIPTION OF SUPPORT UNITS

None

3.0 LABORATORY AND GENERAL TEST DESCRIPTION

3.1 LABORATORY DESCRIPTION

All testing was performed at the following Facility:

The Nebraska Center for Excellence in Electronics (NCEE Labs)
4740 Discovery Drive
Lincoln, NE 68521

A2LA Certificate Number: 1953.01
FCC Accredited Test Site Designation No: US1060
Industry Canada Test Site Registration No: 4294A-1
NCC CAB Identification No: US0177

Environmental conditions varied slightly throughout the tests:
Relative humidity of 35 ± 4%
Temperature of 22 ± 3° Celsius

3.2 TEST PERSONNEL

No.	PERSONNEL	TITLE	ROLE
1	Nic Johnson	Technical Manager	Review/editing
2	Karthik Vepuri	Test Engineer	Testing and report
3	Fox Lane	Test Engineer	Testing and report

Notes:
All personnel are permanent staff members of NCEE Labs. No testing or review was sub-contracted or performed by sub-contracted personnel.

3.3 TEST EQUIPMENT

DESCRIPTION AND MANUFACTURER	MODEL NO.	SERIAL NO.	LAST CALIBRATION DATE	CALIBRATION DUE DATE
Keysight MXE Signal Analyzer (44GHz)	N9038A	MY59050109	April 23, 2019	April 23, 2021
SunAR RF Motion	JB1	A091418	March 6, 2020	March 6, 2022
EMCO Horn Antenna	3115	6415	March 16, 2020	March 16, 2022
EMCO Horn Antenna	3116	2576	March 9, 2020	March 9, 2022
Rohde & Schwarz LISN**	ESH3-Z5	836679/010	July 25, 2019	July 25, 2021
Rohde & Schwarz Preamplifier**	TS-PR18	3545700803	April 14, 2020	April 14, 2022
Trilithic High Pass Filter*	6HC330	23042	April 14, 2020	April 14, 2022
RF Cable (preamplifier to antenna)*	MFR-57500	01-07-002	April 14, 2020	April 14, 2022
RF Cable (antenna to 10m chamber bulkhead)*	FSCM 64639	01E3872	April 14, 2020	April 14, 2022
RF Cable (10m chamber bulkhead to control room bulkhead)*	FSCM 64639	01E3874	April 14, 2020	April 14, 2022
RF Cable (control room bulkhead to test receiver)*	FSCM 64639	01F1206	April 14, 2020	April 14, 2022
N connector bulkhead (10m chamber)*	PE9128	NCEEBH1	April 14, 2020	April 14, 2022
N connector bulkhead (control room)*	PE9128	NCEEBH2	April 14, 2020	April 14, 2022
TDK Emissions Lab Software	V11.25	700307	NA	NA

*Internal Characterization
**2 year calibration cycle

Notes:
All equipment is owned by NCEE Labs and stored permanently at NCEE Labs facilities.

3.4 GENERAL TEST PROCEDURE AND SETUP FOR RADIO MEASUREMNTS

Measurement type presented in this report (Please see the checked box below):

Conducted ☐

The conducted measurements were performed by connecting the output of the transmitter directly into a spectrum analyzer using an impedance matched cable and connector soldered to the EUT in place of the antenna. The information regarding resolution bandwidth, video bandwidth, span and the detector used can be found in the graphs provided in the Appendix C. All the radio measurements were performed using the sections from ANSI C63.10, details about the section used can be found in the spectrum analyzer titles on the graph.

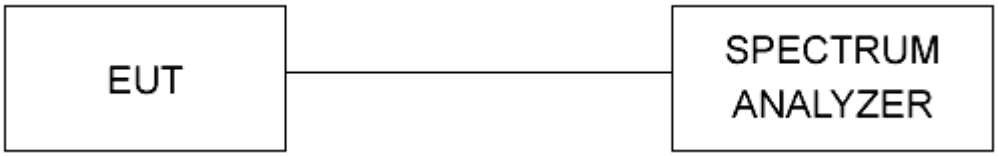


Figure 1 - Bandwidth Measurements Test Setup

Radiated ☒

All the radiated measurements were taken at a distance of 3m from the EUT. The information regarding resolution bandwidth, video bandwidth, span and the detector used can be found in the graphs provided in the Appendix C. All the radio measurements were performed using the sections from ANSI C63.10, details about the section used can be found in the spectrum analyzer titles on the graph.

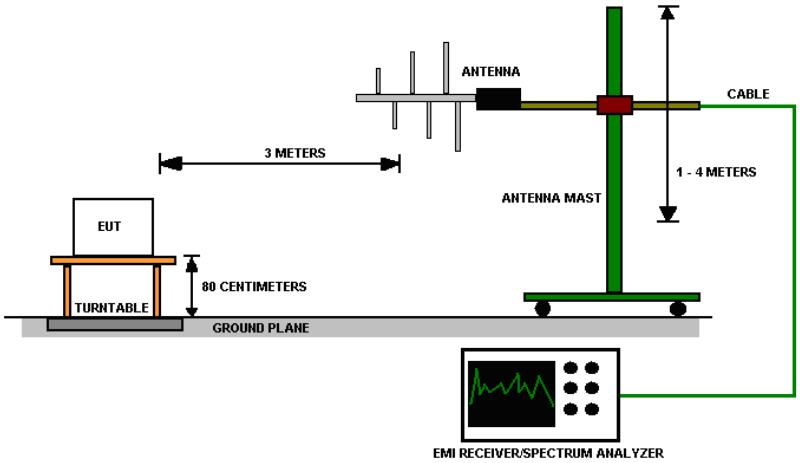


Figure 2 - Radiated Emissions Test Setup

4.0 RESULTS

DTS Radio Measurements							
CHANNEL	**Transmitter**	**Occupied Bandwidth (kHz)**	**6 dB Bandwidth (kHz)**	**PEAK OUTPUT POWER** (dBm)**	**PEAK OUTPUT POWER (mW)**	**PSD (dBm)**	**RESULT**
Low	BLE	1050.10	569.1	8.861	7.693	-24.271	PASS
Mid	BLE	1052.90	609.0	8.546	7.155	-24.872	PASS
High	BLE	1031.30	601.9	7.342	5.423	-27.332	PASS
Occupied Bandwidth = N/A; 6 dB Bandwidth Limit = 500 kHz				Peak Output Power Limit = 30 dBm; PSD Limit = 8 dBm			

Unrestricted Band-Edge							
CHANNEL	**Mode**	**Band edge /Measurement Frequency (MHz)**	**Relative Highest out of band level (dBm)**	**Relative Fundamental (dBm)**	**Delta (dB)**	**Min Delta (dB)**	**Result**
Low	BLE	2400.00	-65.48	-8.375	58.173	20.00	PASS
High	BLE	2483.50	-66.873	-15.518	51.355	20.00	PASS

Restricted Band-Edge							
CHANNEL	**Mode**	**Band edge /Measurement Frequency (MHz)**	**Highest out of band level (dBuV/m @ 3m)****	**Measurement Type**	**Limit (dBuV/m @ 3m)**	**Margin**	**Result**
Low	BLE	2390.00	39.35	Average	53.98	14.64	PASS
High	BLE	2483.50	39.17	Average	53.98	14.81	PASS
Low	BLE	2390.00	51.63	Peak	73.98	22.35	PASS
High	BLE	2483.50	51.22	Peak	73.98	22.76	PASS

*Limit shown is the peak limit taken from FCC Part 15.209; ** Corrections can be found under the graphs in Appendix C; All the power measurements are EIRP measurements.

4.1 OUTPUT POWER

Test Method: All the radio measurements were performed using the sections from ANSI C63.10, Section 11.9.1.1.

Limits of power measurements:
For FCC Part 15.247 Device:
The maximum allowed peak output power is 30 dBm.

Test procedures:
Details can be found in section 3.4 of this report.

Deviations from test standard:
No deviation.

Test setup:
Details can be found in section 3.4 of this report.

EUT operating conditions:
Details can be found in section 2.1 of this report.

Test results:
Pass
Comments:

1. All the output power plots can be found in the Appendix C.
2. All the data is presented in the table under the results, section 4.0.
3. All the measurements were found to be compliant.
4. All the measurements were don on a unit without any modulation. As the manufacturer was not able to program the unit to transmit continuously with modulation on these frequencies.

4.2 BANDWIDTH

Test Method: All the radio measurements were performed using the sections from ANSI C63.10, Section 11.8.1.

Limits of bandwidth measurements:

For FCC Part 15.247 Device:
The 99% occupied bandwidth is for informational purpose only. The 6dB bandwidth of the signal must be greater than 500 kHz.

Test procedures:
Details can be found in section 3.4 of this report.

Deviations from test standard:
No deviation.

Test setup:
Test setup details can be found in section 3.4 of this report.

EUT operating conditions:
Details can be found in section 2.1 of this report.

Test results:
Pass
Comments:

1. All the bandwidth plots can be found in the Appendix C.
2. All the data is presented in the table under the results, section 4.0.
3. All the measurements were found to be compliant.
4. Note that the measurements were done, while the EUT was hopping on low, mid and high channels. As the manufacturer was not able to program the unit to transmit continuously with modulation on these frequencies.

4.3 DUTY CYCLE

Test Method: NA

4.4 RADIATED EMISSIONS

Test Method: ANSI C63.10-2013, Section 6.5, 6.6

Limits for radiated emissions measurements:

Emissions radiated outside of the specified bands shall be applied to the limits in 15.209 as followed:

FREQUENCIES (MHz)	FIELD STRENGTH (µV/m)	MEASUREMENT DISTANCE (m)
0.009-0.490	2400/F(kHz)	300
0.490-1.705	24000/F(kHz)	30
1.705-30.0	30	3
30-88	100	3
88-216	150	3
216-960	200	3
Above 960	500	3

NOTE:
1. The lower limit shall apply at the transition frequencies.
2. Emission level (dBuV/m) = 20 * log * Emission level (µV/m).
3. As shown in 15.35(b), for frequencies above 1000MHz, the field strength limits are based on average detector, however, the peak field strength of any emission shall not exceed the maximum permitted average limits by more than 20dB under any condition of modulation.
4. The EUT was tested for spurious emissions while running off of battery power and external USB power. The worse-case emissions were produced while running off of USB power, so results from this mode are presented.

Test procedures:

a. The EUT was placed on the top of a rotating table above the ground plane in a 10 meter semi-anechoic chamber. The table was rotated 360 degrees to determine the position of the highest radiation. The table was 0.8m high for measurements from 30MHz-1Ghz and 1.5m for measurements from 1GHz and higher.

b. The EUT was set 3 meters away from the interference-receiving antenna, which was mounted on the top of a variable-height antenna tower.

c. The antenna was a broadband antenna, and its height is varied from one meter to four meters above the ground to determine the maximum value of the field strength. Both horizontal and vertical polarizations of the antenna are used to make the measurement.

d. For each suspected emission, the EUT was arranged to maximize its emissions and then the antenna height was varied from 1 meter to 4 meters and the rotating table was turned from 0 degrees to 360 degrees to find the maximum emission reading.

e. The test-receiver system was set to use a peak detector with a specified resolution bandwidth. For spectrum analyzer measurements, the composite maximum of several analyzer sweeps was used for final measurements.

f. If the emission level of the EUT in peak mode was 10dB lower than the limit specified, then testing could be stopped and the peak values of the EUT would be reported. Otherwise the emissions that did not have 10 dB margin would be re-tested one by one using peak, quasi-peak or average method as specified and then reported in a data sheet.

g. The EUT was maximized in all 3 orthogonal positions. The results are presented for the axis that had the highest emissions.

Test setup:

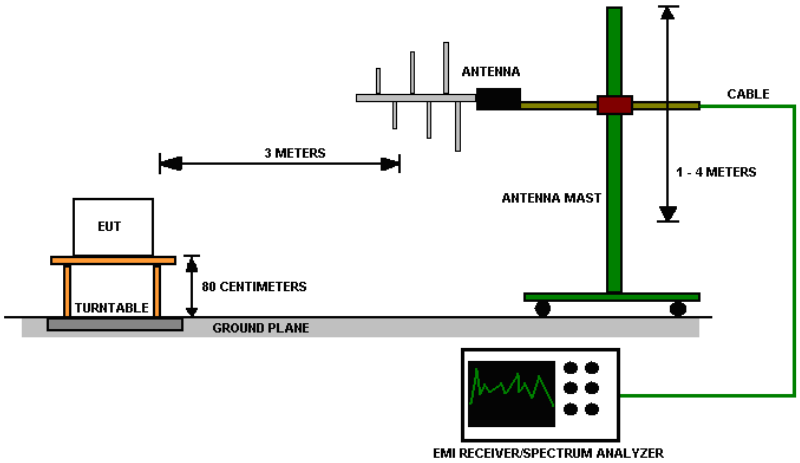


Figure 3 - Radiated Emissions Test Setup

NOTE:
1. The resolution bandwidth and video bandwidth of test receiver/spectrum analyzer is 120kHz for Peak detection (PK) and Quasi-peak detection (QP) at frequencies below 1GHz.

2. The resolution bandwidth 1 MHz for all measurements and at frequencies above 1GHz, A peak detector was used for all measurements above 1GHz. Measurements were made with an EMI Receiver.

Deviations from test standard:

No deviation.

EUT operating conditions
Details can be found in section 2.1 of this report.

Test results:

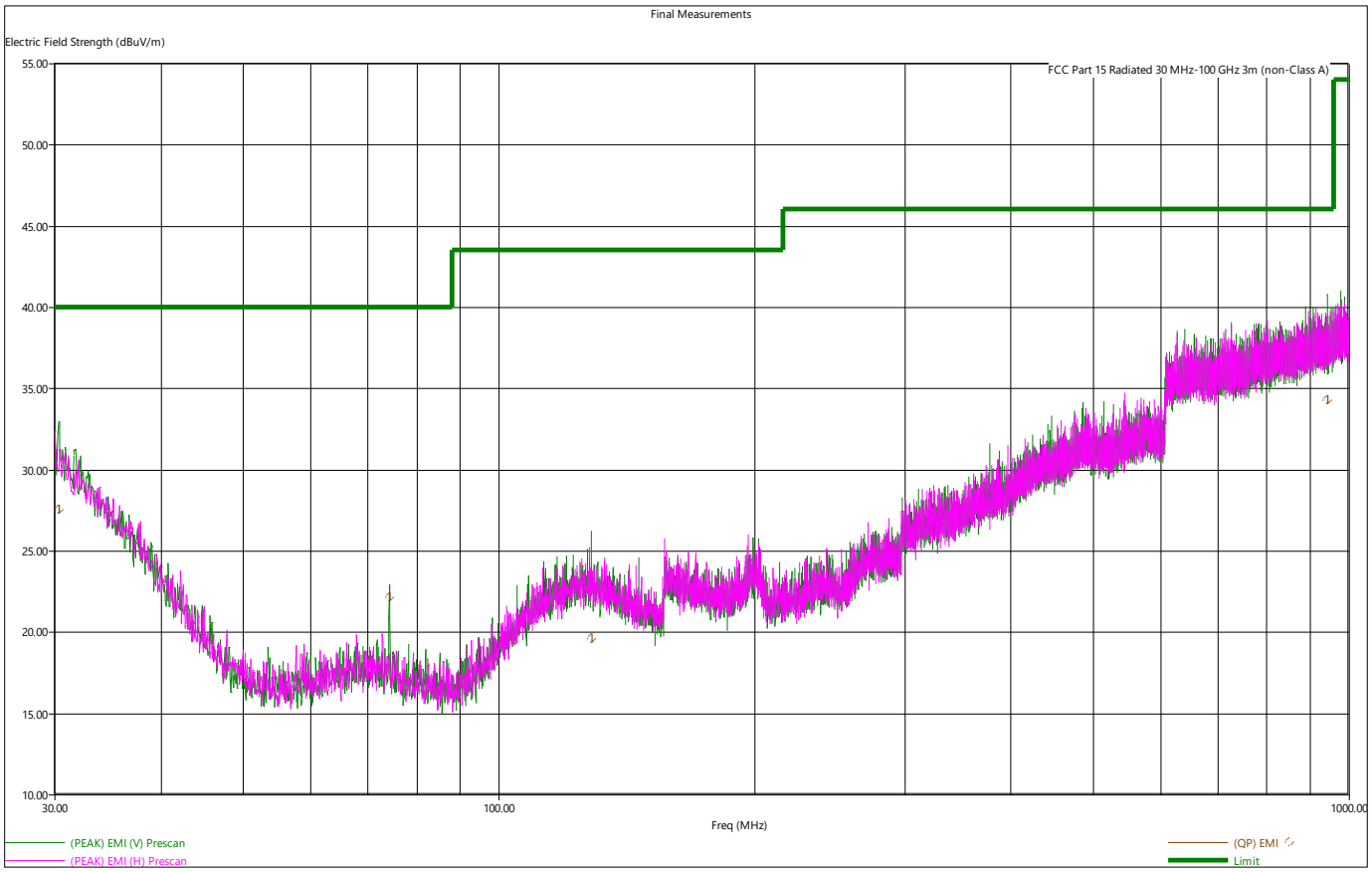


Figure 4 - Radiated Emissions Plot, Receive

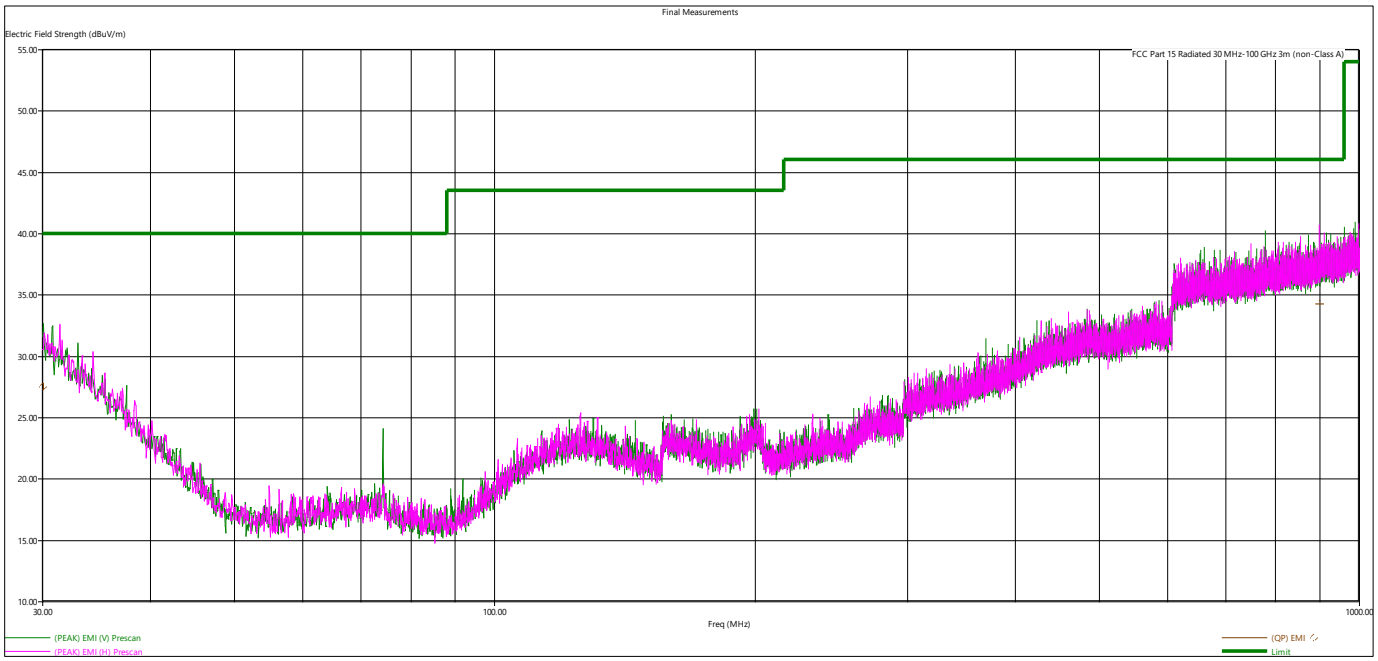


Figure 5 - Radiated Emissions Plot, Low Channel

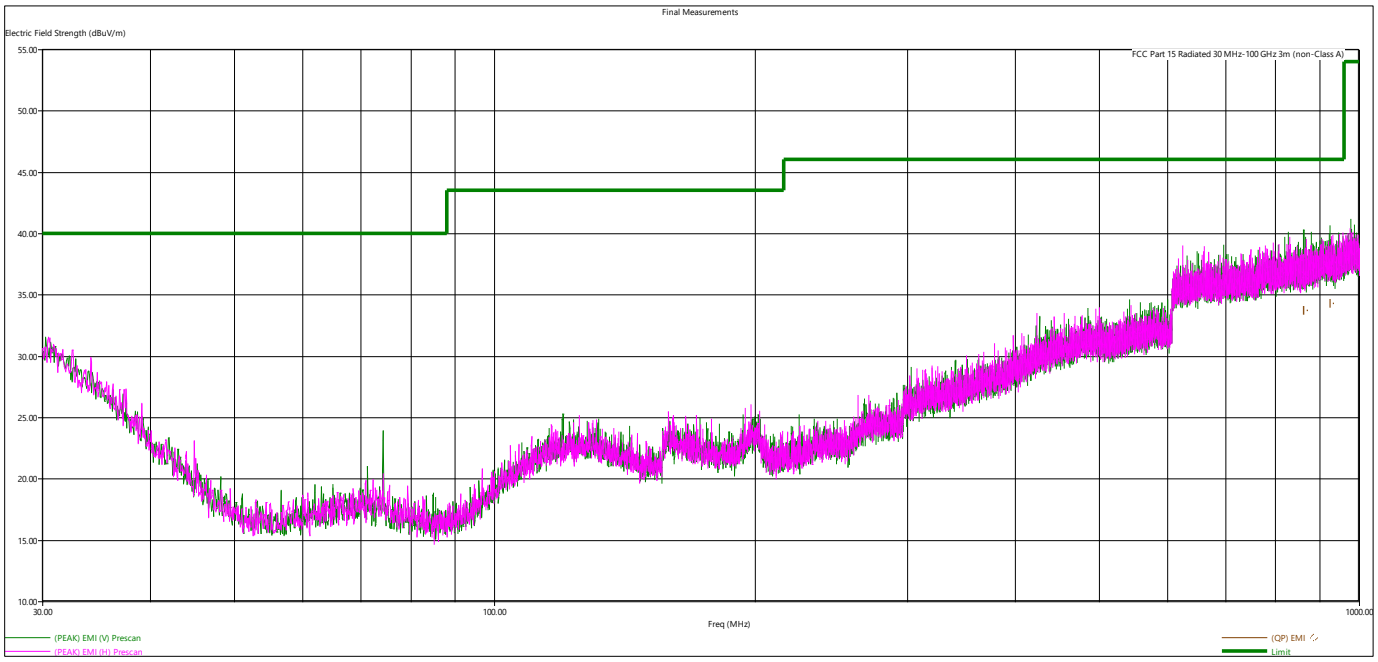


Figure 6 - Radiated Emissions Plot, Mid Channel

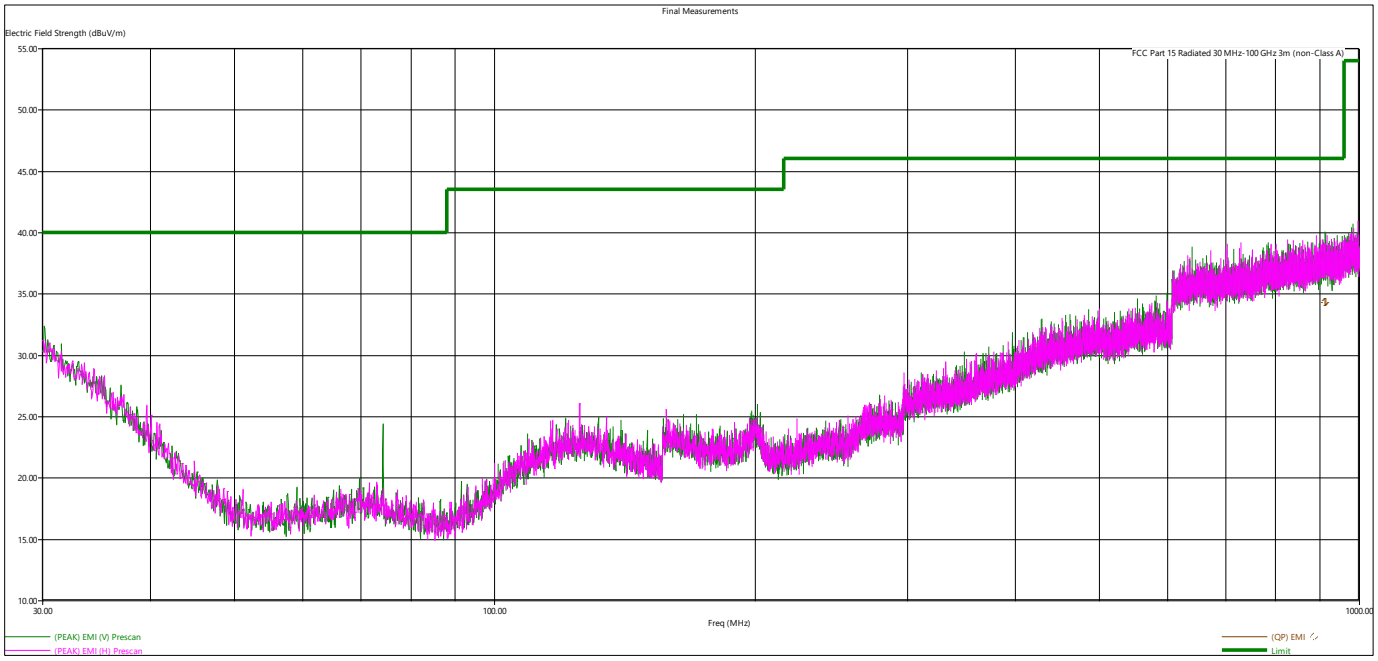


Figure 7 - Radiated Emissions Plot, High Channel

REMARKS:
1. Emission level (dBuV/m) = Raw Value (dBuV) + Correction Factor (dB)
2. Correction Factor (dB/m) = Antenna Factor (dB/m) + Cable Factor (dB)
3. The other emission levels had at least 20 dB of margin
4. Margin value = Emission level – Limit value

Quasi-Peak Measurements								
Frequency	**Level**	**Limit**	**Margin**	**Height**	**Angle**	**Pol**	**Channel**	**Modulation**
MHz	**dBµV/m**	**dBµV/m**	**dB**	**cm.**	**deg.**			
898.966080	34.18	46.02	11.84	226	107	H	Low	CW
30.041492	27.51	40.00	12.49	368	103	V	Low	CW
862.269600	33.69	46.02	12.33	301	360	V	Mid	CW
923.931840	34.26	46.02	11.76	108	347	V	Mid	CW
912.874320	34.31	46.02	11.71	140	218	V	High	CW
914.624880	34.33	46.02	11.69	262	324	V	High	CW
30.184320	27.52	40.00	12.48	201	353	V	Receive	
74.262960	22.11	40.00	17.89	164	184	V	Receive	
128.153760	19.63	43.52	23.89	370	0	V	Receive	
942.070320	34.23	46.02	11.79	393	239	V	Receive	

Peak Measurements								
Frequency	**Level**	**Limit**	**Margin**	**Height**	**Angle**	**Pol**	**Channel**	**Modulation**
MHz	**dBµV/m**	**dBµV/m**	**dB**	**cm.**	**deg.**			
2480.014000	102.26	NA	NA	158	168	H	High	CW
2425.992000	103.96	NA	NA	142	349	H	Mid	CW
2401.982000	103.82	NA	NA	142	355	H	Low	CW

Average Measurements								
Frequency	**Level**	**Limit**	**Margin**	**Height**	**Angle**	**Pol**	**Channel**	**Modulation**
MHz	**dBµV/m**	**dBµV/m**	**dB**	**cm.**	**deg.**			
2480.014000	102.08	NA	NA	158	168	H	High	CW
2425.992000	103.77	NA	NA	142	349	H	Mid	CW
2401.982000	103.61	NA	NA	142	355	H	Low	CW

The EUT was maximized in all 3 orthogonal axis. The worst-case is shown in the plots and tables above. If the measurements were found to be 10 dB below the limit, they were not reported.

4.5 BAND EDGES

Test Method: All the radio measurements were performed using the sections from ANSI C63.10, Section's -6.10.5, 11.13.2.

Limits of band-edge measurements:

For FCC Part 15.247 Device:
For emissions outside of the allowed band of operation (2400.0MHz – 2480.0MHz), the emission level needs to be 20dB under the maximum fundamental field strength. However, if the emissions fall within one of the restricted bands from 15.205 the field strength levels need to be under that of the limits in 15.209.

Test procedures:

The highest emissions level beyond the band-edge was measured and recorded. All band edge measurements were evaluated to the general limits in Part 15.209. More details can be found in section 3.4 of this report.

Deviations from test standard:
No deviation.

Test setup:
Test setup details can be found in section 3.4 of this report.

EUT operating conditions:
Details can be found in section 2.1 of this report.

Test results:
Pass

Comments:
1. All the band edge plots can be found in the Appendix C.
2. All the data is presented in the table under the results, section 4.0.
3. If the device falls under FCC Part 15.247 (Details can be found in summary of test results), compliance is shown in the unrestricted band edges by showing minimum delta of 20 dB between peak and the band edge.
4. The restricted band edge compliance is shown by comparing to the general limit defined in Part 15.209. The limit shown in the graph accounts for the antenna gain of the device.
5. Note that the measurements were done, while the EUT was hopping on low, mid and high channels. As the manufacturer was not able to program the unit to transmit continuously with modulation on these frequencies.

4.6 POWER SPECTRAL DENSITY

Test Method: All the radio measurements were performed using the sections from ANSI C63.10, Section 11.10.2.

Limits of power measurements:

For FCC Part 15.247 Device:
The maximum PSD allowed is 8 dBm.

Test procedures:
Details can be found in section 3.4 of this report.

Deviations from test standard:
No deviation.

Test setup:
Details can be found in section 3.4 of this report.

EUT operating conditions:
Details can be found in section 2.1 of this report.

Test results:
Pass
Comments:

1. All the Power Spectral Density (PSD) plots can be found in the Appendix C.
2. All the data is presented in the table under the results, section 4.0.
3. All the measurements were found to be compliant.
4. The measurements are reported on the graph.
5. Note that the measurements were done, while the EUT was hopping on low, mid and high channels. As the manufacturer was not able to program the unit to transmit continuously with modulation on these frequencies.

APPENDIX A: SAMPLE CALCULATION

Field Strength Calculation

The field strength is calculated by adding the Antenna Factor and Cable Factor, and subtracting the Amplifier Gain (if any) from the measured reading. The basic equation with a sample calculation is as follows:

FS = RA + AF – (-CF + AG) + AV

where FS = Field Strength

RA = Receiver Amplitude

AF = Antenna Factor

CF = Cable Attenuation Factor

AG = Amplifier Gain

AV = Averaging Factor (if applicable)

Assume a receiver reading of 55 dBμV is obtained. The Antenna Factor of 12 and a Cable Factor of 1.1 is added. The Amplifier Gain of 20 dB is subtracted, giving a field strength of 48.1 dBμV/m.

FS = 55 + 12 – (-1.1 + 20) + 0 = 48.1 dBμV/m

The 48.1 dBμV/m value can be mathematically converted to its corresponding level in μV/m.

Level in μV/m = Common Antilogarithm [(48.1 dBμV/m)/20]= 254.1 μV/m

AV is calculated by the taking the 20*log(T_{on}/100) where T_{on} is the maximum transmission time in any 100ms window.

EIRP Calculations

In cases where direct antenna port measurement is not possible or would be inaccurate, output power is measured in EIRP. The maximum field strength is measured at a specified distance and the EIRP is calculated using the following equation;

EIRP (Watts) = [Field Strength (V/m) x antenna distance (m)]^2 / 30
Power (watts) = 10^[Power (dBm)/10] / 1000
Voltage (dBµV) = Power (dBm) + 107 (for 50Ω measurement systems)
Field Strength (V/m) = 10^[Field Strength (dBµV/m) / 20] / 10^6
Gain = 1 (numeric gain for isotropic radiator)
Conversion from 3m field strength to EIRP (d=3):

EIRP = [FS(V/m) x d^2]/30 = FS [0.3] for d = 3

EIRP(dBm) = FS(dBµV/m) – 10(log 10^9)+ 10log[0.3] = FS(dBµV/m) - 95.23

10log(10^9) is the conversion from micro to milli

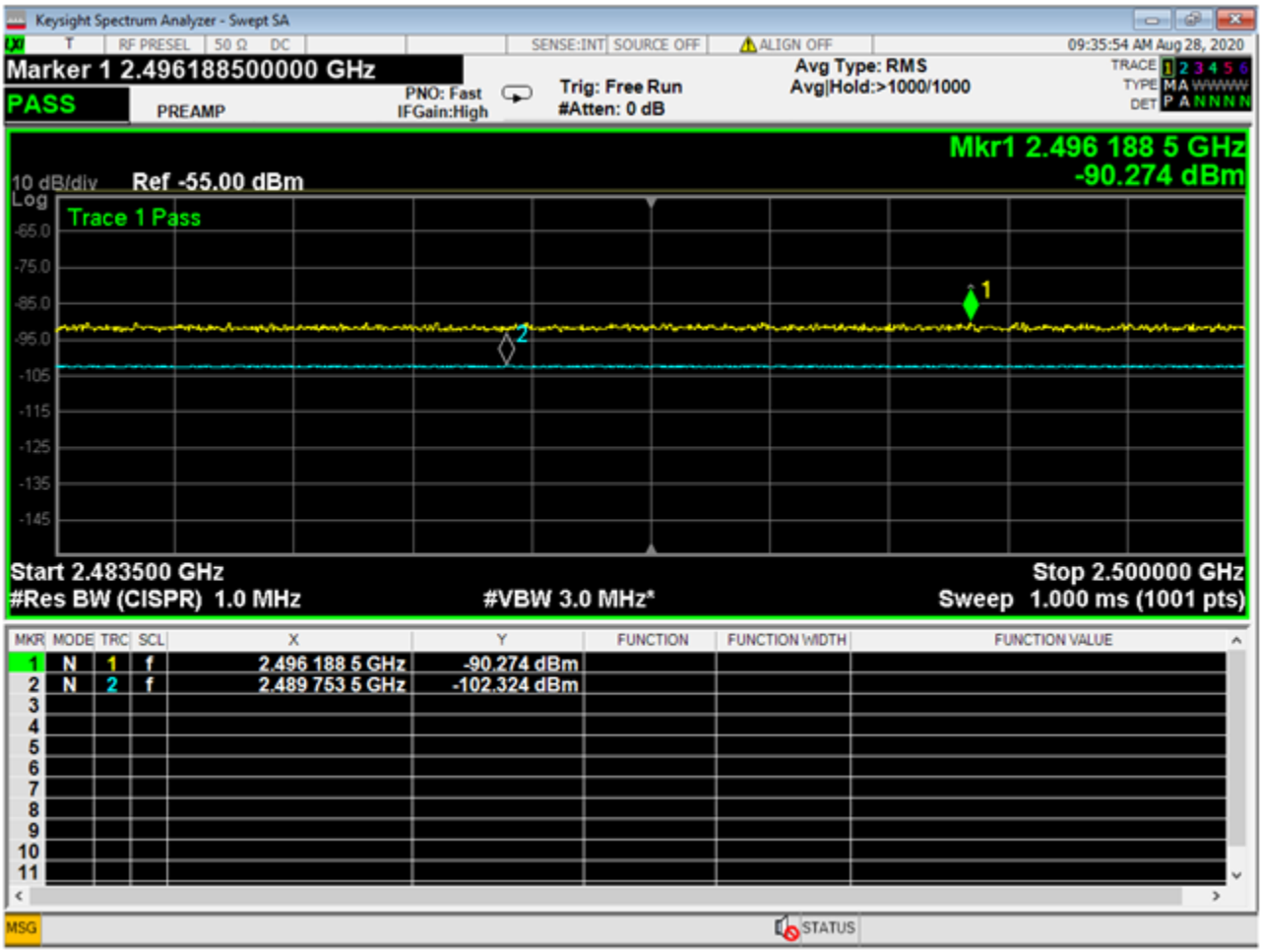
APPENDIX B – MEASUREMENT UNCERTAINTY

Where relevant, the following measurement uncertainty levels have been for tests performed in this test report:

Test	Frequency Range	Uncertainty Value (dB)
Radiated Emissions, 3m	30MHz - 1GHz	3.82
Radiated Emissions, 3m	1GHz - 18GHz	4.44
Emissions limits, conducted	30MHz – 18GHz	±3.30 dB

Expanded uncertainty values are calculated to a confidence level of 95%.

APPENDIX C – GRAPHS AND TABLES



Higher Band Edge_Restricted Hopping

* Corrected measurement at 3m = -102.324 (dBuV)+28.45 (Antenna Factor in dB) +6.04 (Cable Loss in dB) + 107 (conversion from dBm to dBuV)=39.166 (dBuV/m) AV

= -90.274 (dBuV)+28.45 (Antenna Factor in dB) +6.04 (Cable Loss in dB) + 107 (conversion from dBm to dBuV)=51.216 (dBuV/m) PK

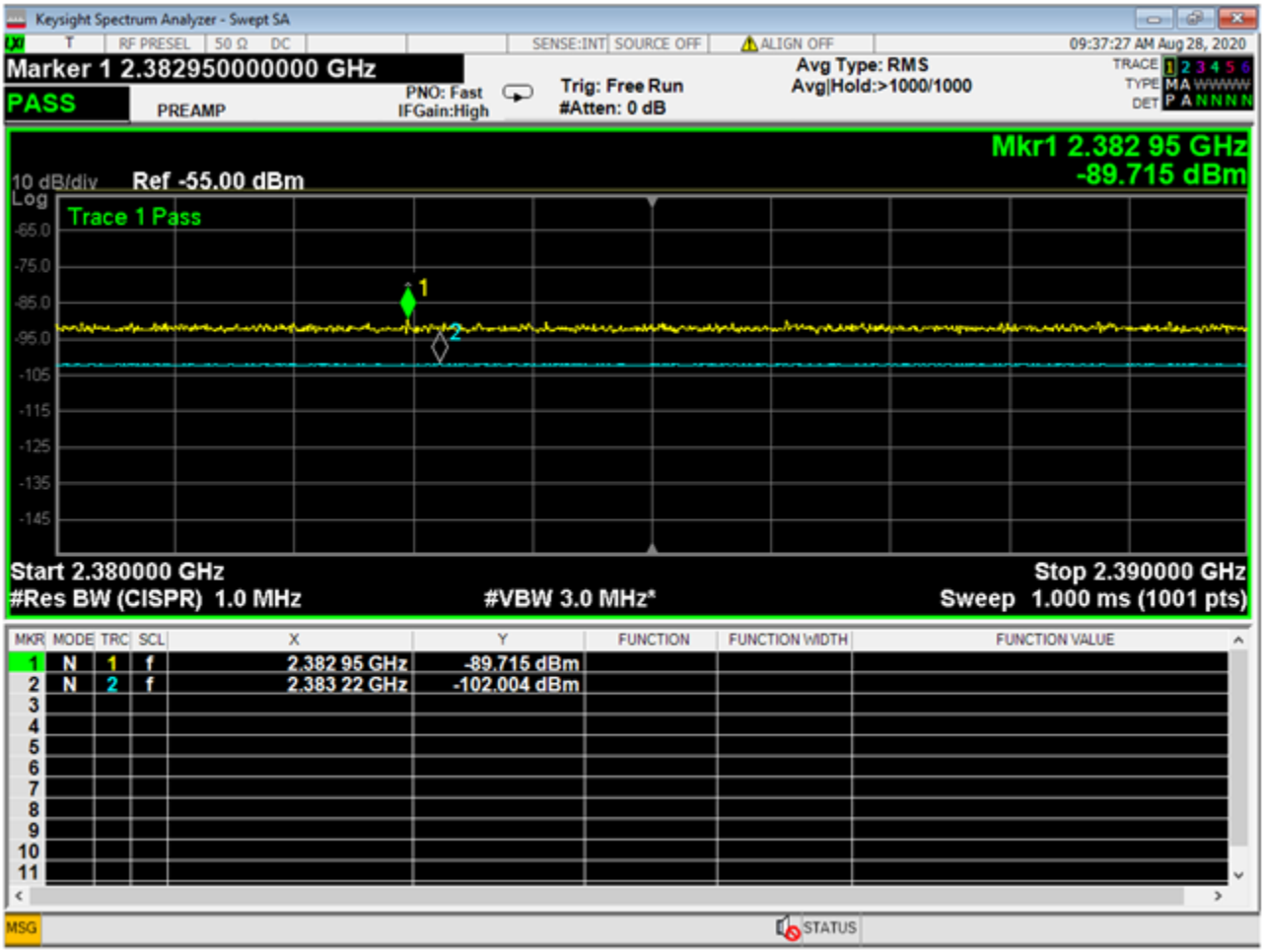
Higher Band Edge_Unrestricted Hopping

*Note that the plot shows the measurement in dBuV and the table in section 4 shows the values in dBm so they were coverted by the following equation:

dBm=dBuV-107;

-15.518 dBm= 91.482 dBuV

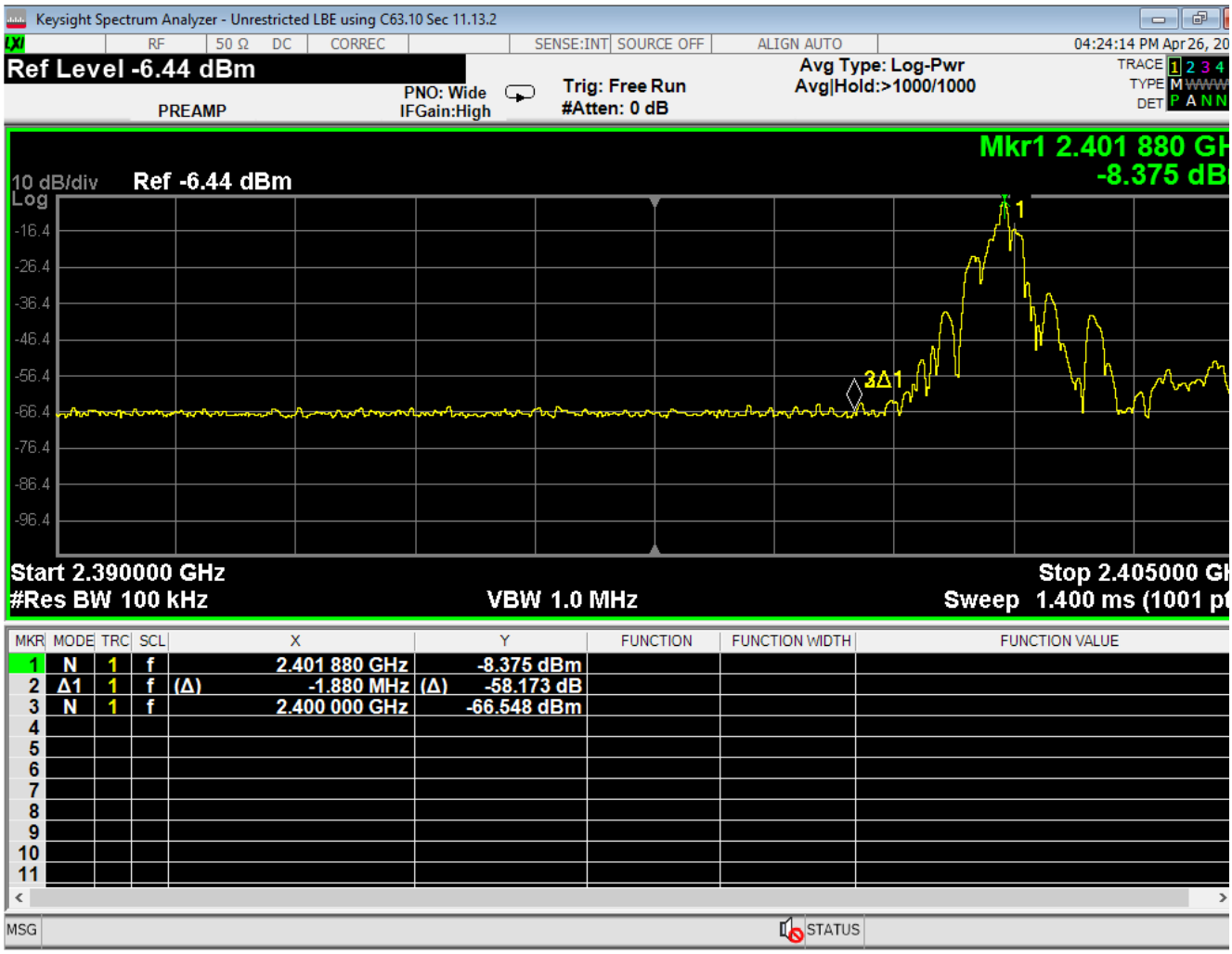
-66.873 dBm = 40.127 dBuV



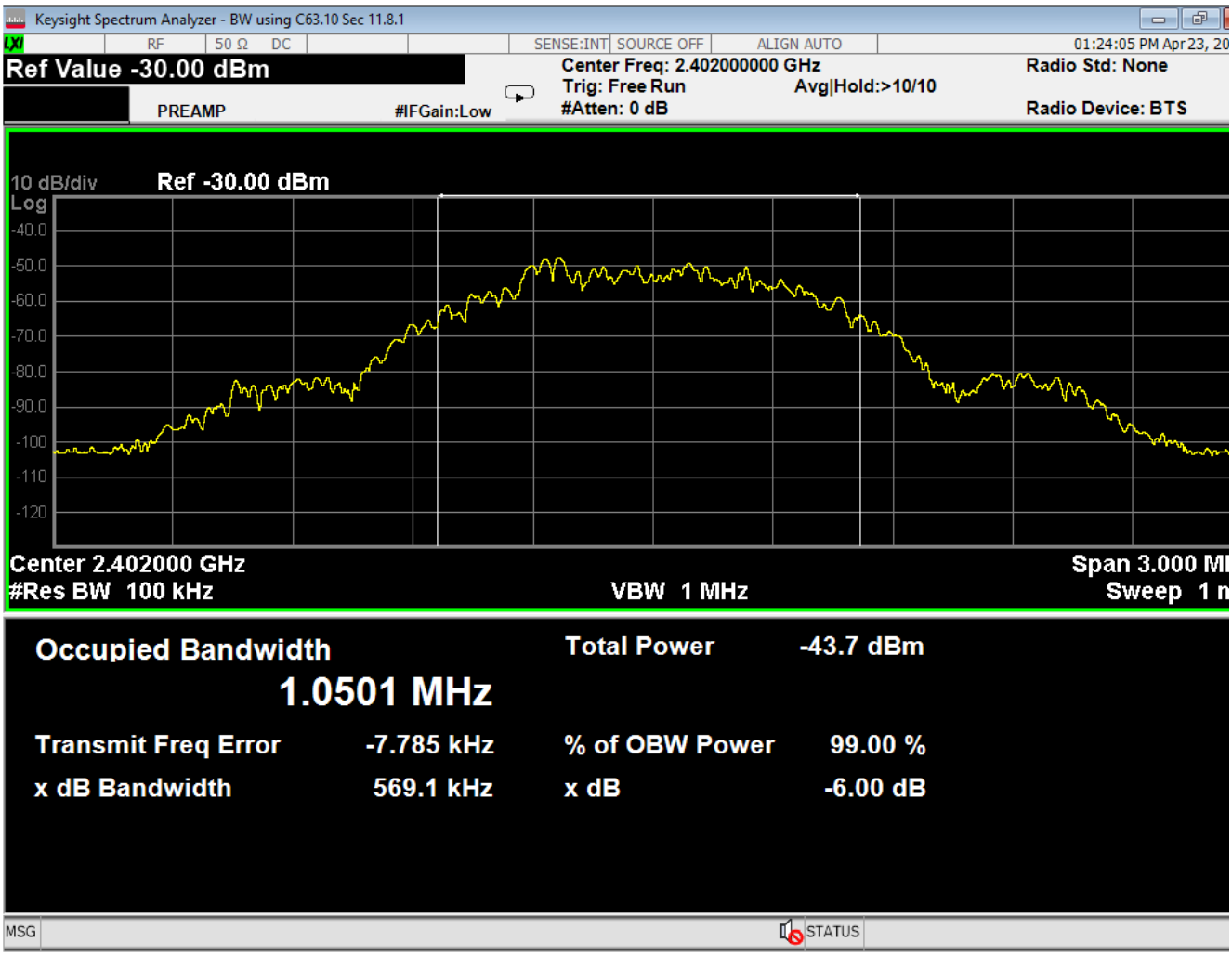
Lower Band Edge_Restricted Hopping

* Corrected measurement at 3m = -102.004 (dBuV)+28.45 (Antenna Factor in dB) +6.04 (Cable loss in dB) +107 (conversion from dBm to dBuV)=39.345 (dBuV/m) AV

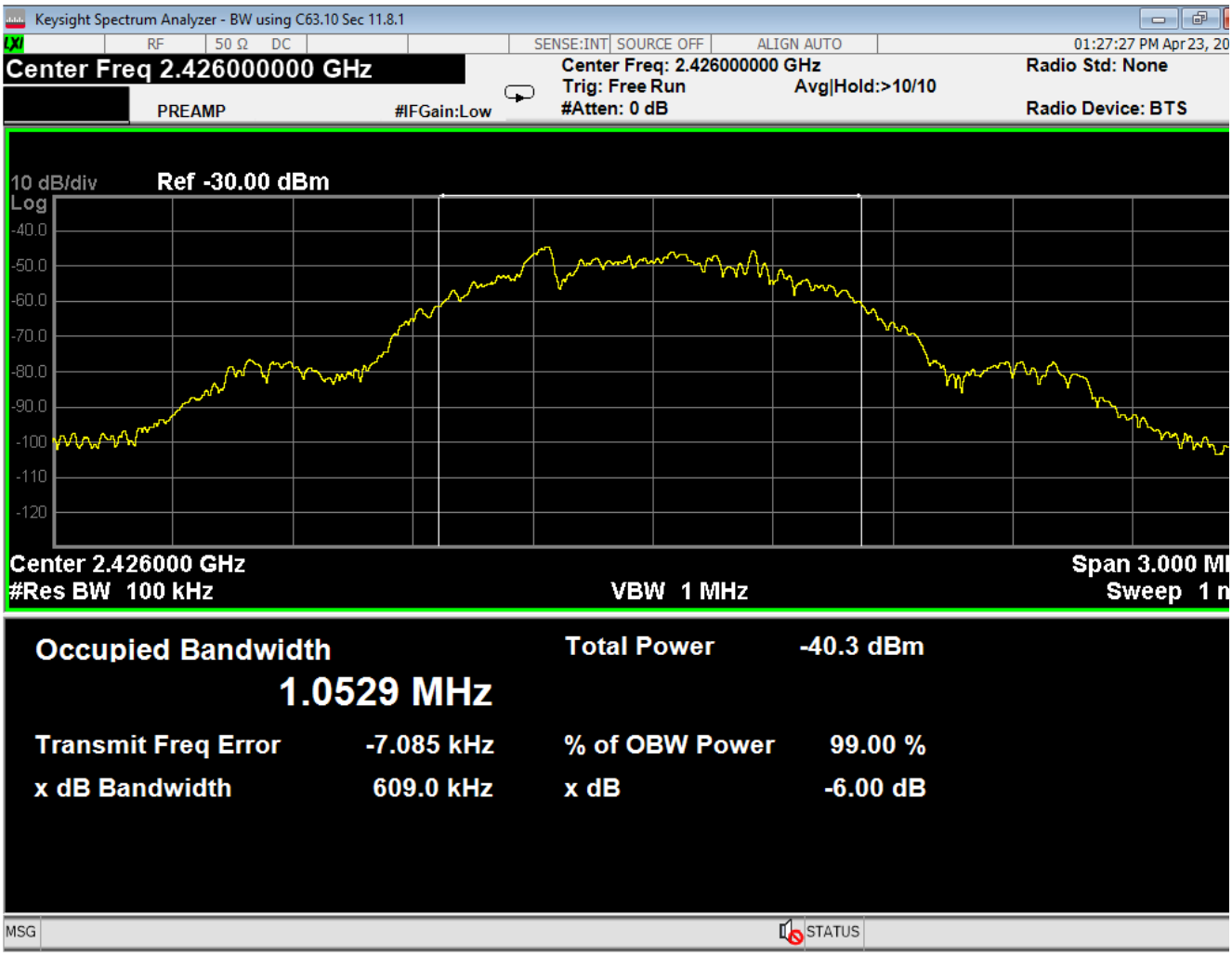
* Corrected measurement at 3m = -89.715 (dBuV)+28.45 (Antenna Factor in dB) +6.04 (Cable loss in dB) +107 (conversion from dBm to dBuV)=51.634 (dBuV/m) PK



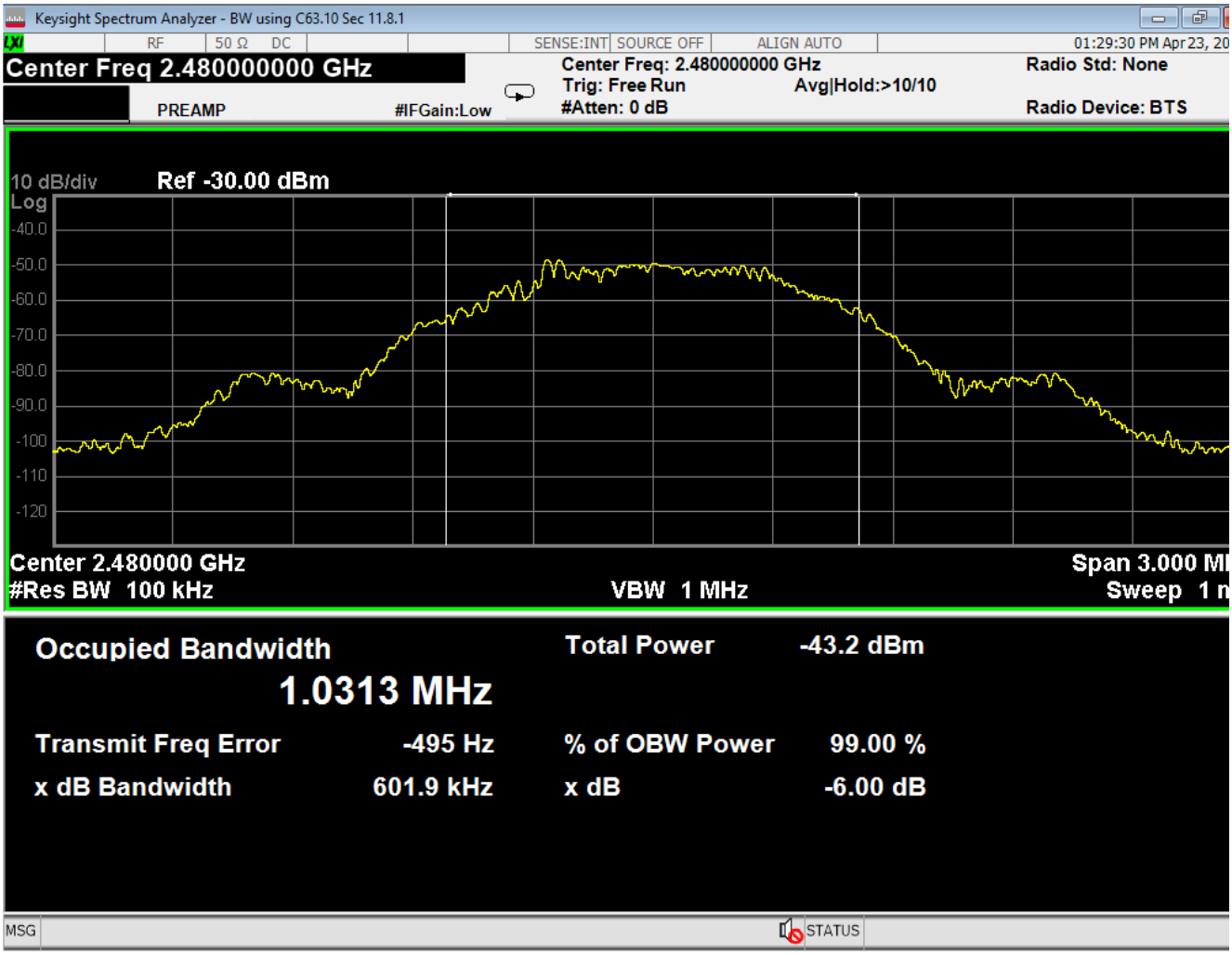
Lower Band Edge_Unrestricted Hopping



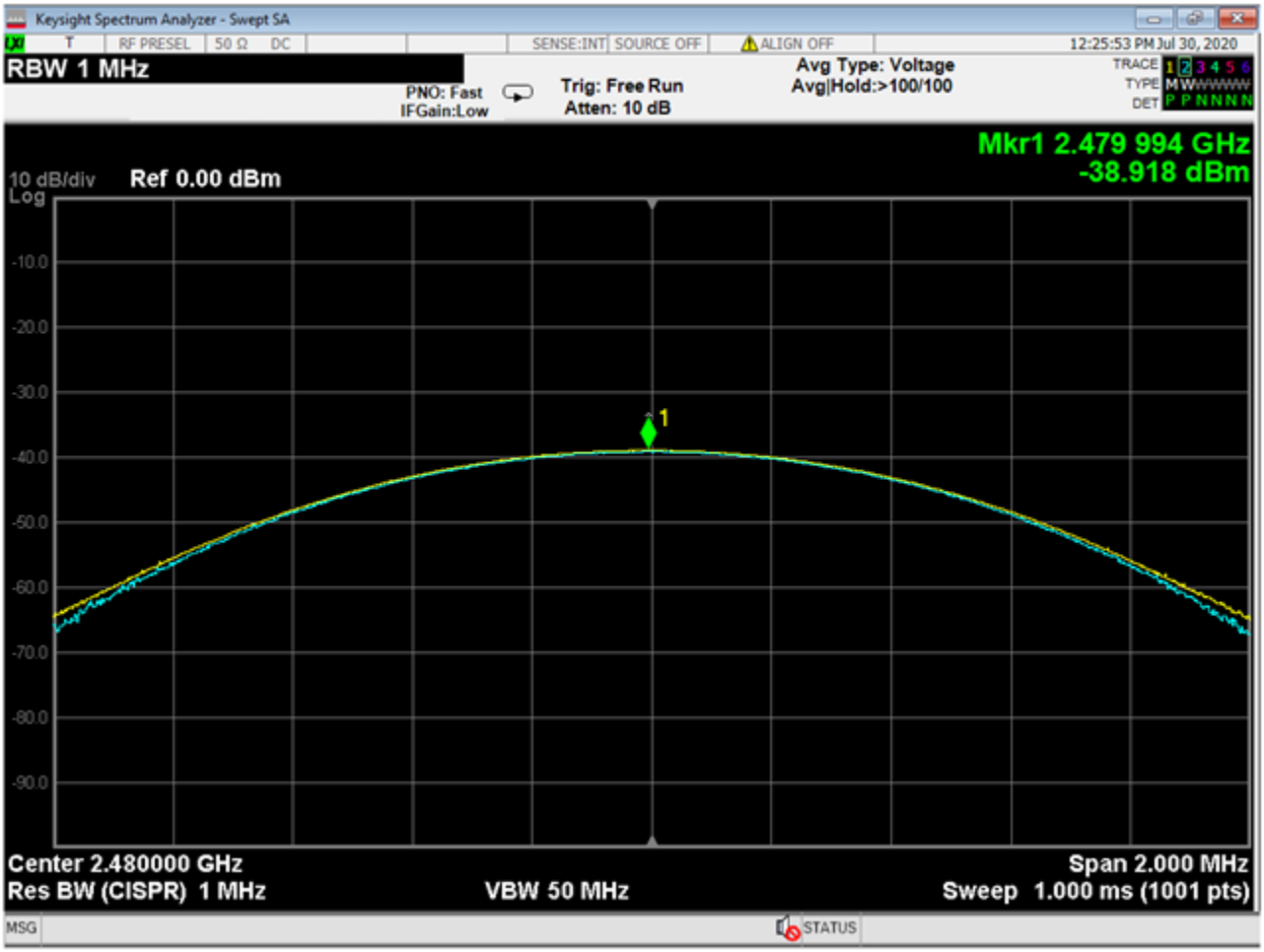
Occupied Bandwidth Low Channel



Occupied Bandwidth Mid Channel

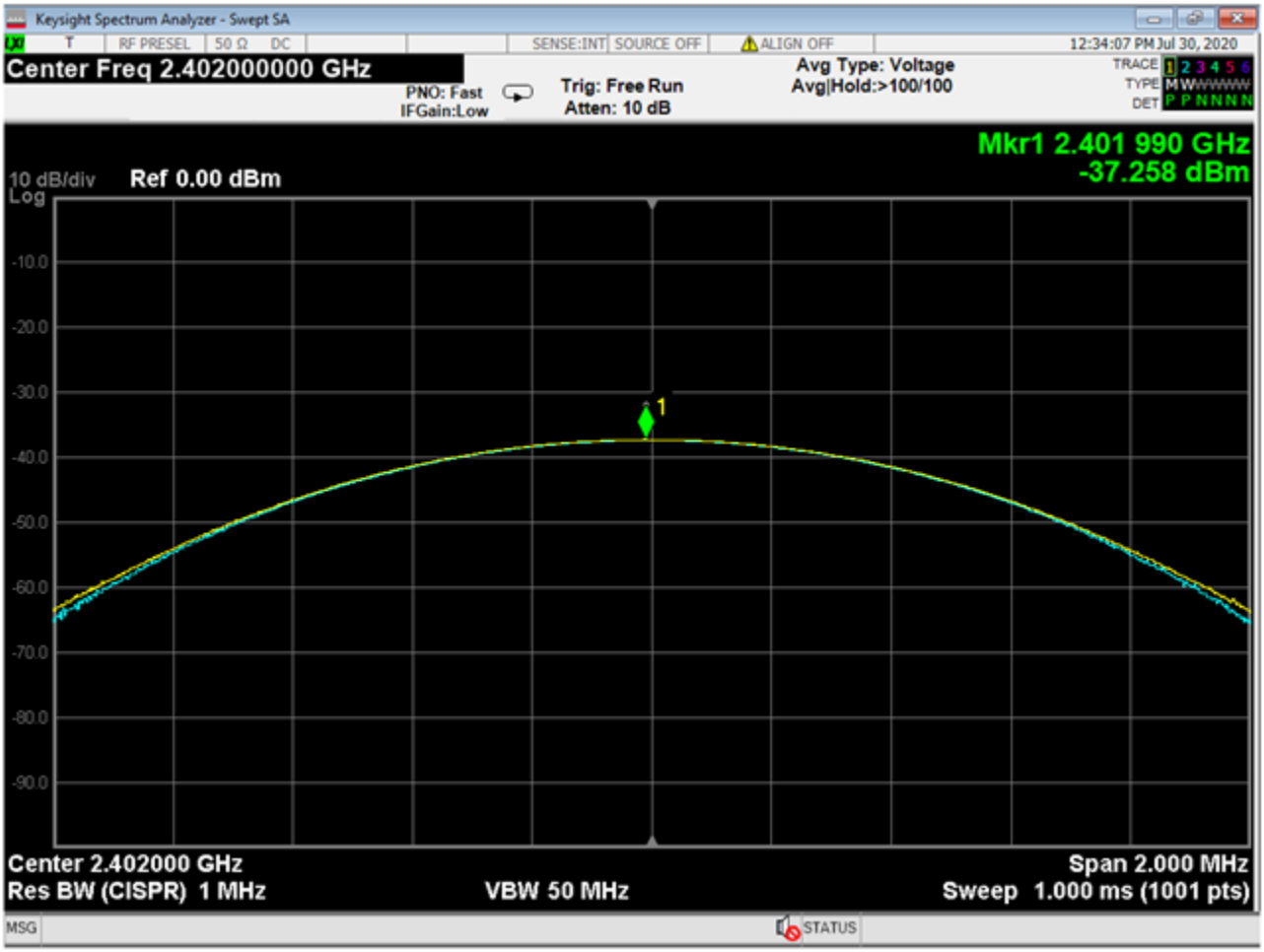


Occupied Bandwidth High Channel



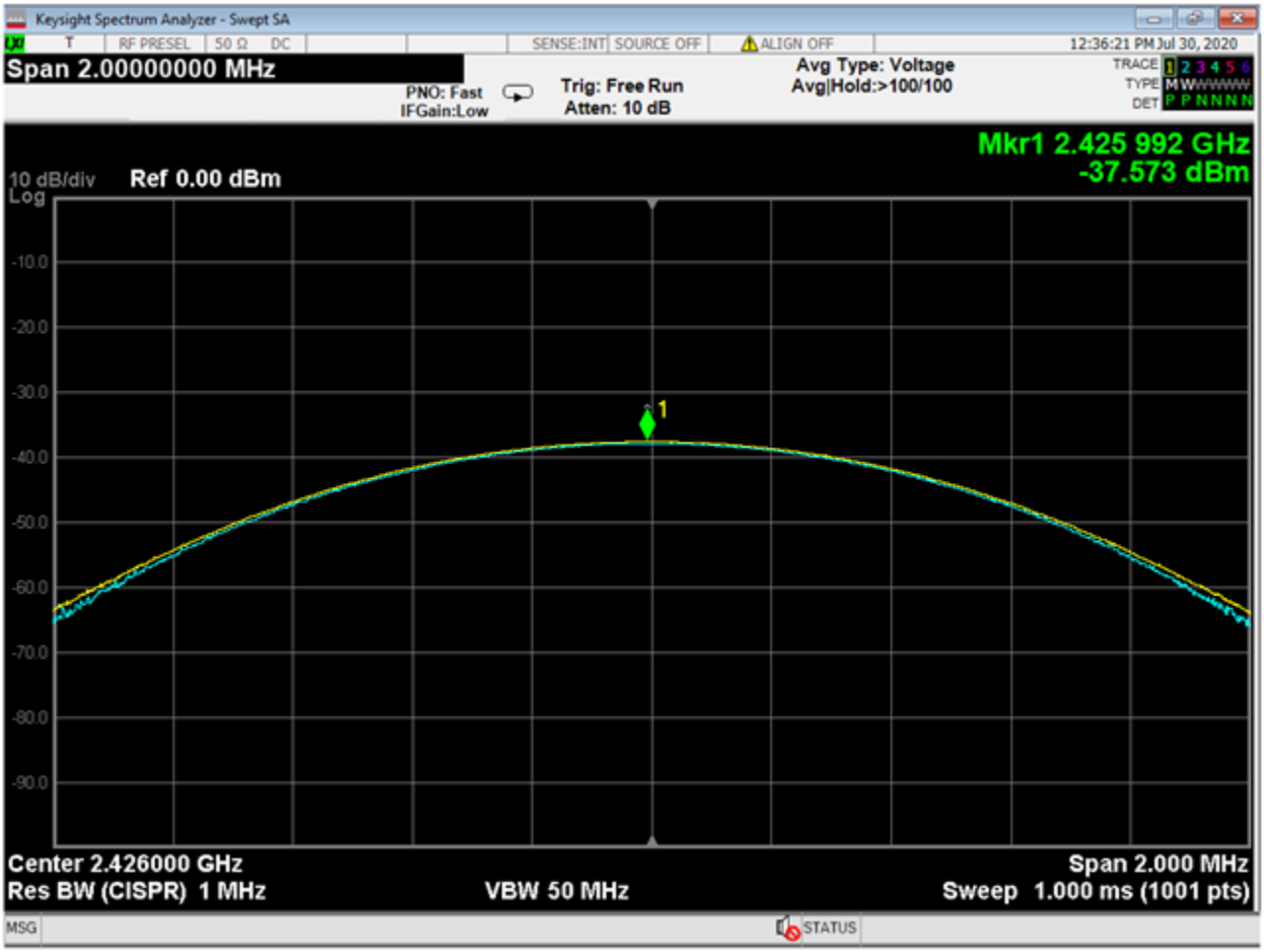
Output Power _High Channel

* Corrected EIRP Measurement = -38.918 (dBuV)+28.45 (Transducer in dB) +6.04 (Cable loss in dB) +107 (conversion from dBm to dBuV) -95.23 (EIRP conversion from 3m) = 7.342 dBm



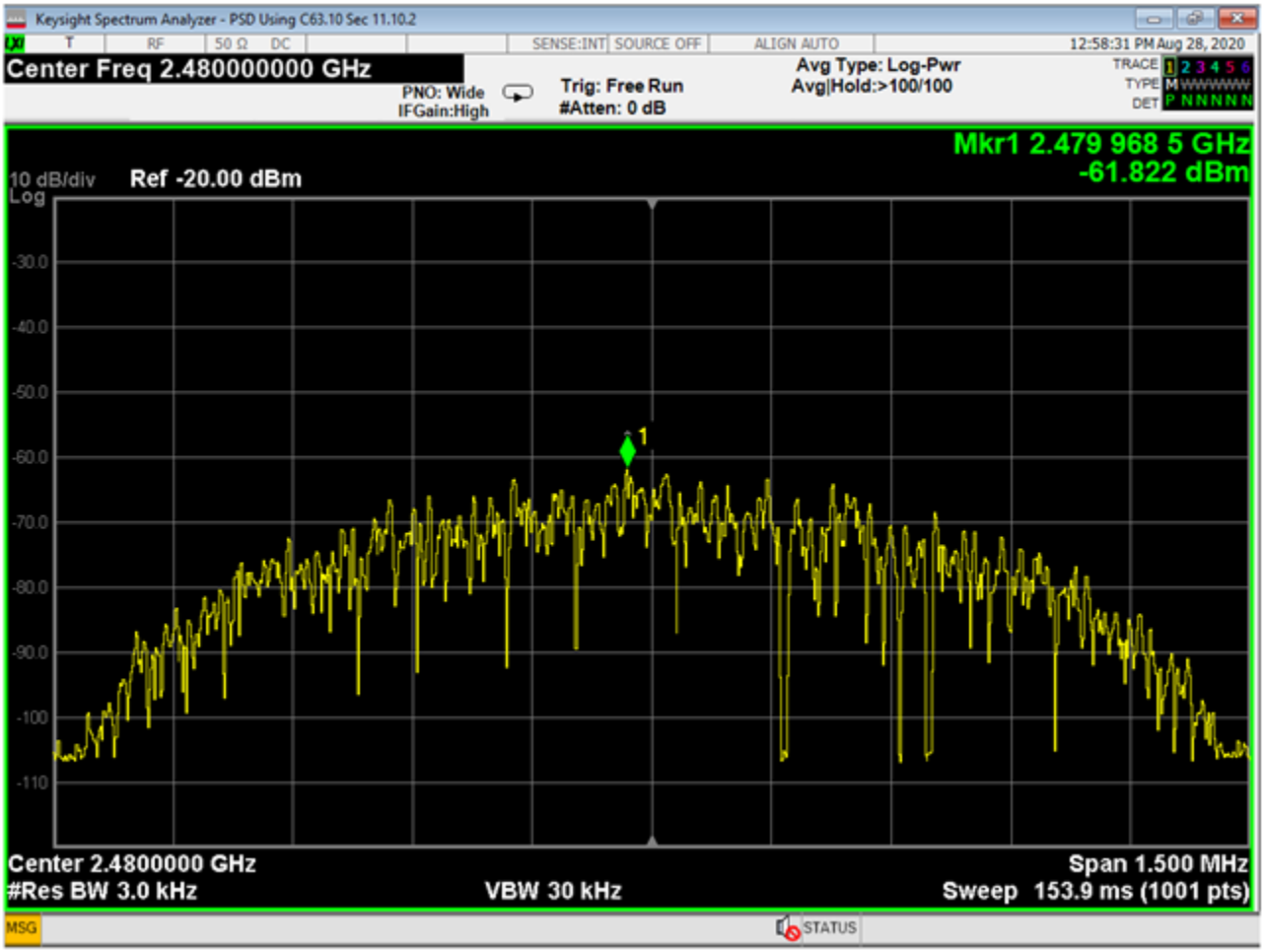
Output Power _Low Channel

* Corrected EIRP = -37.258 (dBuV)+28.389 (Transducer in dB) +5.96 (Cable loss in dB) +107 (conversion from dBm to dBuV) -95.23 (EIRP conversion from 3m) = 8.861 dBm



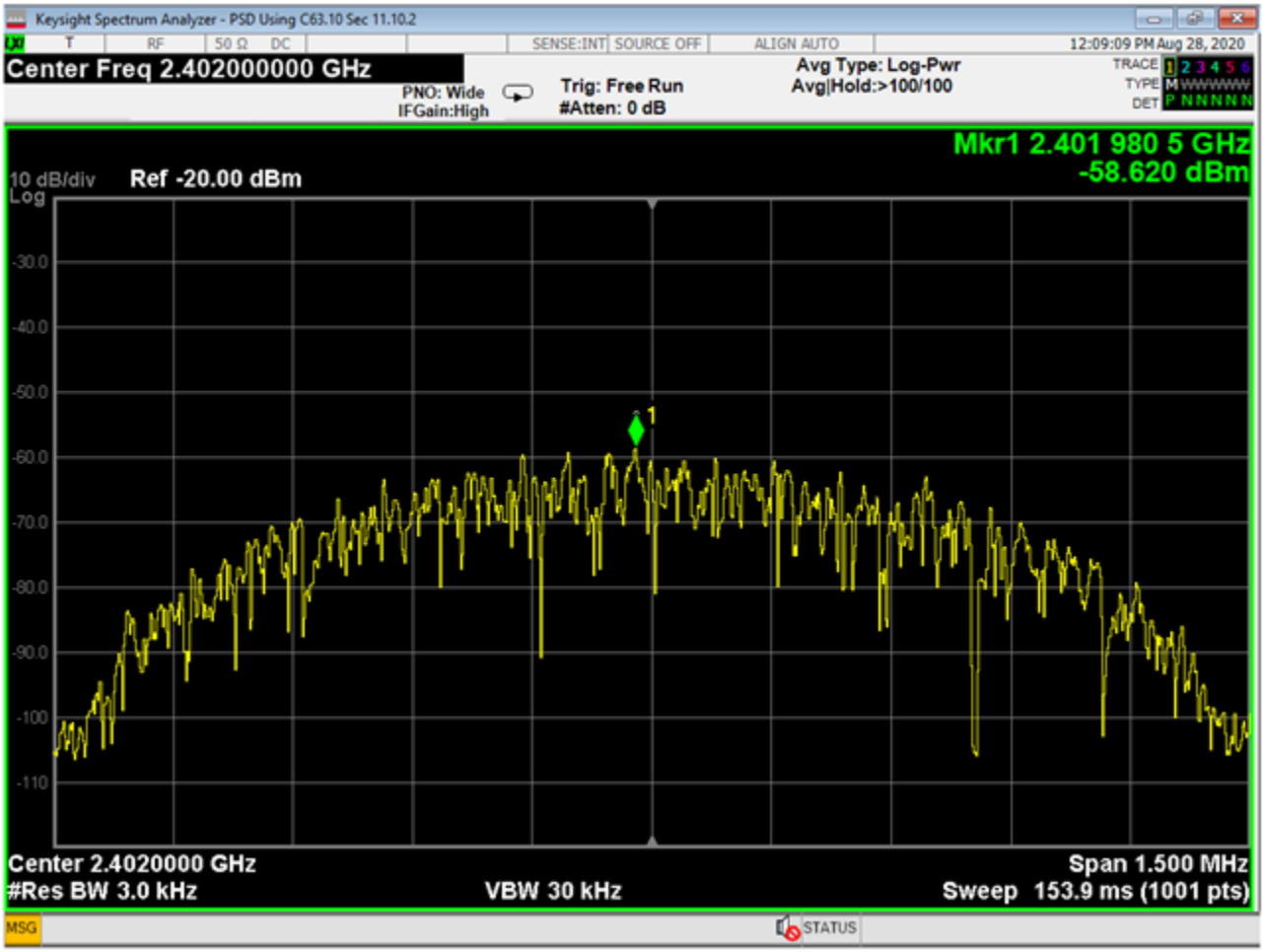
Output Power _Mid Channel

* Corrected EIRP = -37.573 (dBuV)+28.389 (Transducer in dB) +5.96 (Cable loss in dB) +107 (conversion from dBm to dBuV) -95.23 (EIRP conversion from 3m) = 8.546 dBm



PSD _High Channel

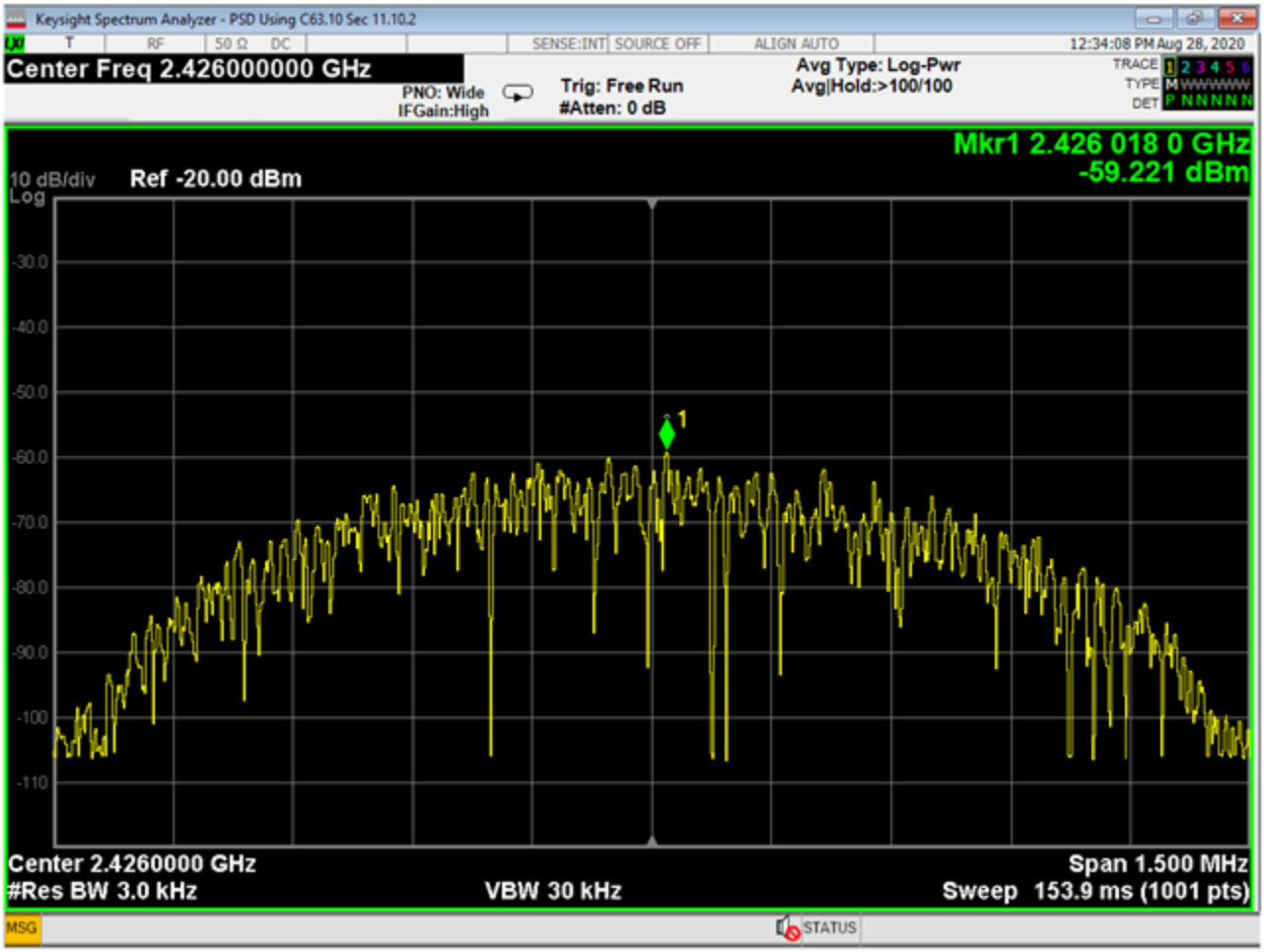
* Corrected EIRP = -61.822 (dBuV)+28.45 (Transducer in dB) +6.04 (Cable loss in dB) +107 (conversion from dBm to dBuV) -95.23 (EIRP conversion from 3m) = -27.332 dBm



PSD _Low Channel

* Corrected EIRP = -58.980 (dBuV)+28.389 (Transducer in dB) +5.96 (Cable loss in dB) +107 (conversion from dBm to dBuV) -95.23 (EIRP conversion from 3m) = -24.271 dBm

**Note that, measurement was made while the EUT was hopping in low, mid and High channels. The analyzer was placed in max hold mode till the spectrum filled up.



PSD _Mid Channel

* Corrected EIRP = -59.221 (dBuV)+28.389 (Transducer in dB) +5.96 (Cable loss in dB) +107 (conversion from dBm to dBuV) -95.23 (EIRP conversion from 3m) = -24.872 dBm

**Note that, measurement was made while the EUT was hopping in low, mid and High channels. The analyzer was placed in max hold mode till the spectrum filled up.

REPORT END