Report on the Testing of the

Space Exploration Technologies Corp. (Swarm Technologies)
MODEM-M138

In accordance with:
FCC 47 CFR part 25 Subpart C
ISED RSS-170 Issue 3, July 2015

America

Add value.
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Prepared for: Space Exploration Technologies Corp.(Swarm Technologies)

435 N. Whisman Rd
Mountainview, California 94043 USA

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Kirby Munroe	**Wireless / EMC Technical and Certification Manager, NA TUV SUD America Inc.**	**Authorized Signatory**	1/10/2022

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FCC Accreditation Designation Number US1233
FCC Test Site Registration Number 967699
Innovation, Science, and Economic Development Canada Lab Code 23932

EXECUTIVE SUMMARY

A sample of this product was tested and found to be compliant with the standards listed above.

A2LA Cert. No. 2955.09

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1 Report Summary

1.1 Report Modification Record

Alterations and additions to this report will be issued to the holders of each copy in the form of a complete document.

Table 1.1-1 – Modification Record

Issue	Description of Change	Date of Issue
0	First Issue	1/10/2022

1.2 Introduction

The purpose of this report is to demonstrate compliance with Part 25 Subpart C of the FCC's Code of Federal Regulations and Innovation Science and Economic Development Canada's Radio Standards Specification RSS-170 for the tests documented herein.

Applicant	Mark Bryla
Manufacturer	Space Exploration Technologies Corp.(Swarm Technologies)
Applicant's Email Address	mark@swarm.space
Model Number(s)	MODEM-M138
Serial Number(s)	N/A
FCC ID	2AVE9-M138
ISED Certification Number	25817-M138
Hardware Version(s)	N/A
Software Version(s)	N/A
Number of Samples Tested	1
Test Specification/Issue/Date	US Code of Federal REgulation (CFR): Title 47, Part 25, Subpart C: Satellite Communications, 2021 ISED Canada Radio Standards Specification: RSS-170 – Mobile Earth Stations (MESs) and Ancillary Terrestrial Component (ATC) Equipment Operating in the Mobile-Satellite Service (MSS) Bands, Issue 3, July 2015 Amendment (November 2020)
Order Number	72174891
Date of Receipt of EUT	12/10/2021
Start of Test	12/10/2021
Finish of Test	12/15/2021

Related Document(s)	ANSI C63.26-2015: American National Standard for Compliance Testing of Transmitters Used in Licensed Radio Services US Code of Federal Regulations (CFR): Title 47, Part 2, Subpart J: Equipment Authorization Procedures, 2021. ISED Canada Radio Standards Specification: RSS-GEN – General Requirements for Compliance of Radio Apparatus, Issue 5, Amendment 1 (March 2019), Amendment 2 (February 2021)

1.3 Brief Summary of Results

A brief summary of the tests carried out in accordance with FCC Part 25 Subpart C and ISED Canada's RSS-170 is shown below.

Table 1.3-1: Test Result Summary

Test Parameter	Test Plan (Yes/No)	Test Result	FCC 47 CFR Rule Part	ISED Canada's RSS	Test Report Page No
99% Occupied Bandwidth	Yes	Pass	§2.1049	RSS-GEN 6.7	10
Fundamental Emission Output Power	Yes	Pass	§25.204	RSS-170 Section 5.3.2	13
Spurious Emissions at Antenna Terminals	Yes	Pass	§25.202 (f)	RSS-170 Section 5.4.3	16
Frequency Stability	Yes	Pass	§25.202 (d)	RSS-170 Section 5.2	20
Field Strength of Radiated Spurious Emissions	Yes	Pass	§25.202 (f)	RSS-170 Section 5.4.3	22

1.4 Product Information

1.4.1 Technical Description

The Modem satellite data modem transmits and receives data to and from Swarm's space network and is designed to be embedded into a third-party product. Swarm backend systems can support delivery of customer data via a Swarm REST API to the Swarm cloud or user email, text message, AWS, Slack, etc. Communication can also be point-to-point between Swarm devices (no Internet involvement).

Table 1.4-1 – Wireless Module Technical Information

Detail	Description
Frequency Range	148.0104 – 158.0396 MHz
Transceiver Model #	MODEM-M138
Emission Designator	F1D
Antenna Type / Description:	¼ Wave Whip, 2dBi (PulseLarsen, P/N: 15036A)

A full description and detailed product specification details are available from the manufacturer.

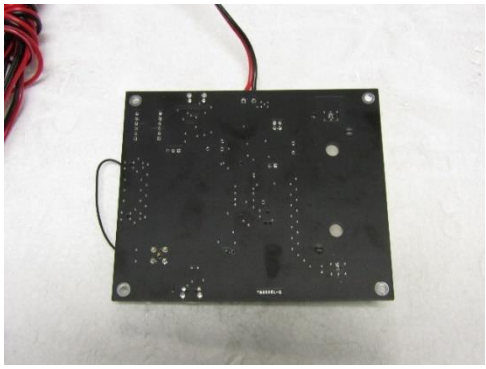

Figure 1.4.1-1 –Front view of the EUT **Figure 1.4.1-2 – Back view of the EUT**

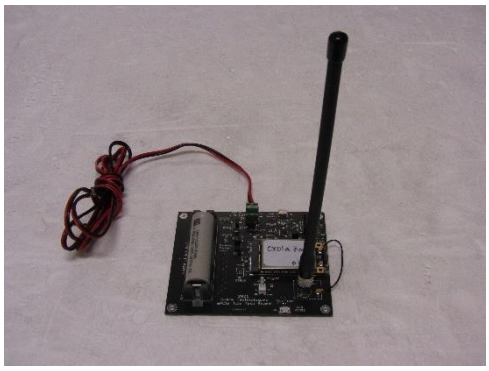

Figure 1.4.1-3 – Radiated sample

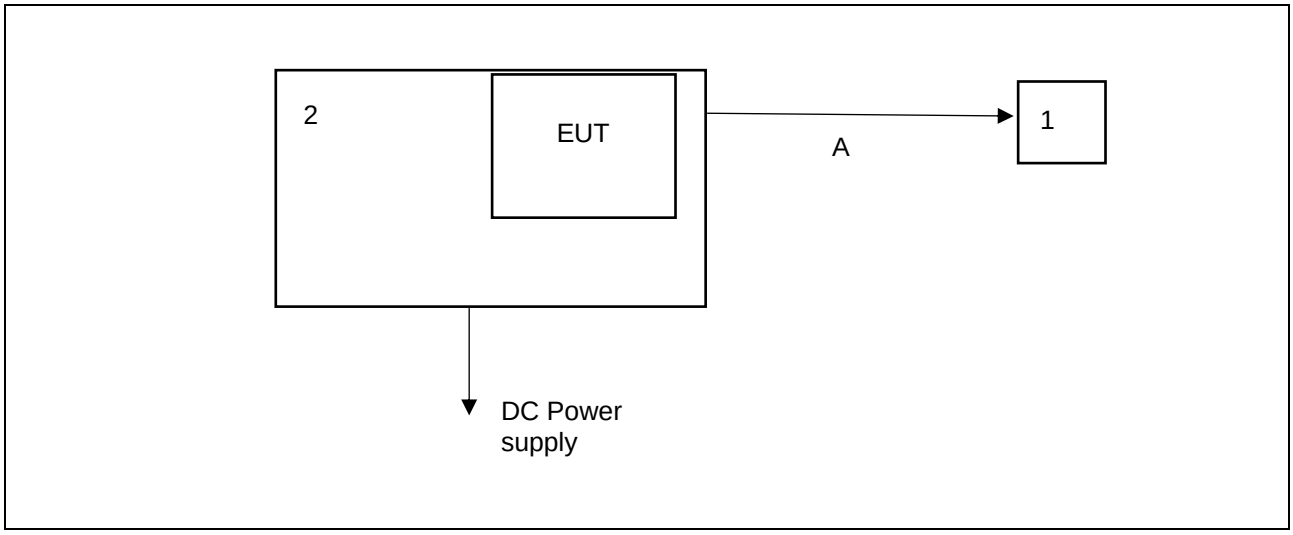

Figure 1.4.1-4 – Test Setup Block Diagram

Table 1.4.1-1 – Cable Descriptions

Item	Cable/Port	Description
A	USB-C Cable	Connected to Laptop for Programming

Table 1.4.1-2 – Support Equipment Descriptions

Item	Make/Model	Description
1	Lenovo	Laptop used for configuring wireless module
2	Swarm Technologies	Programming Board

1.4.2 Modes of Operation

MODEM-M138 supports 5 different bandwidths as outlined below.

Mode of Operation	Bandwidth supported (kHz)	Frequency Range (MHz)	Spreading Factor Supported
1	20.8	148.0104 – 150.0396	SF8
2	31.3	148.0157 – 150.0344	SF8
3	41.7	148.0209 – 150.0292	SF8
4	62.5	148.0313 – 150.0188	SF8

1.4.3 Monitoring of Performance

For radiated emissions, the EUT was evaluated in three orthogonal orientations. The worst-case orientation was X-position. All Bandwidths were evaluated and considered Mode 1 as the worst case. The EUT was programmed to generate a continuously modulated signal on each channel evaluated.

For RF Conducted measurements, the EUT antenna port was directly connected to the test equipment. The EUT was programmed to generate a continuously modulated signal on each channel evaluated.

Mode of Operation	99% Occupied Bandwidth	Fundamental Emission Output Power	Spurious Emissions at Antenna Terminals	Field Strength of Radiated Spurious Emissions	Frequency Stability
	Spreading Factor Tested				
1	SF8	SF8	SF8	SF8*	SF8
2			SF8	**	
3			SF 8	**	
4			SF 8	**	

* : worst case bandwidth evaluated.
**: Addressed by mode 1

Software power setting during test: 12 (30dBm)

1.5 Deviations from the Standard

No deviations from the applicable test standard were made during testing.

1.6 EUT Modification Record

The table below details modifications made to the EUT during the test program. The modifications incorporated during each test are recorded on the appropriate test pages.

Modification State	Description of Modification still fitted to EUT	Modification Fitted By	Date Modification Fitted
0	Initial State		

The equipment was tested as provided without any modifications.

1.7 Test Location

TÜV SÜD conducted the following tests at our Alpharetta, GA test laboratory.

Test Name	Name of Engineer(s)	Accreditation
99% Occupied Bandwidth	Divya Adusumilli	A2LA
Fundamental Emission Output Power	Divya Adusumilli	A2LA
Spurious Emissions at Antenna Terminals	Divya Adusumilli	A2LA
Frequency Stability	Divya Adusumilli	A2LA
Field Strength of Radiated Spurious Emissions	Divya Adusumilli	A2LA

Office address:
TÜV SÜD America
5945 Cabot Parkway, Suite 100
Alpharetta, GA 30005, USA

2 Test Details

2.1 99% Occupied Bandwidth

2.1.1 Specification Reference

FCC Sections: §2.1049
ISED Canada: RSS-GEN 6.7

2.1.2 Equipment Under Test and Modification State

As shown in §1.4 with modification state “0”, as noted in §1.6.

2.1.3 Date of Test

12/10/2021

2.1.4 Test Method

The occupied bandwidth measurement function of the spectrum analyzer was used to measure the 99% bandwidth. The span of the analyzer was set to capture all products of the modulation process, including the emission sidebands. The resolution bandwidth was set from 1% to 5% of the occupied bandwidth and the video bandwidth set to at least 3 times the resolution bandwidth. A peak detector was used.

2.1.5 Environmental Conditions

The EUT was evaluated within the temperature, humidity and pressure range of the EUT as specified by the standard. The laboratory shall have an ambient temperature range of 15°C to 35°C and relative humidity range of 30% to 60%.

Ambient Temperature	22.3 °C
Relative Humidity	53.8 %

2.1.6 Test Results

Test Summary: EUT was set to transmit mode.

Test Results: Pass

See data below for detailed results.

Table 2.1.6-1: 99% Occupied Bandwidth

Mode	Frequency (MHz)	99% Bandwidth (kHz)
1	148.0104	20.965
	150.0396	20.767
2	148.0157	31.404
	150.0344	31.549
3	148.0209	41.534
	150.0292	41.389
4	148.0313	62.084
	150.0188	61.867

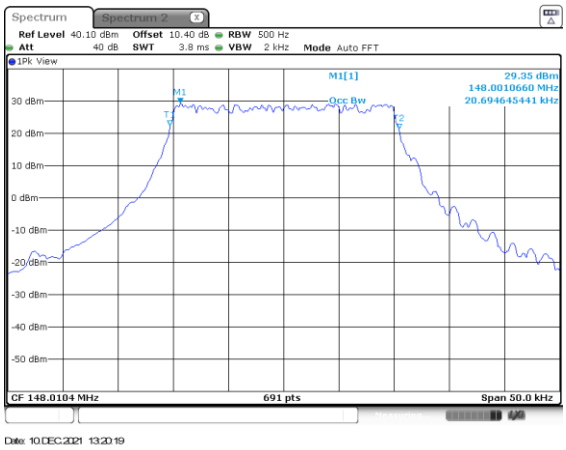

Figure 2.1.6-1: 99% BW – Mode 1 – LCH

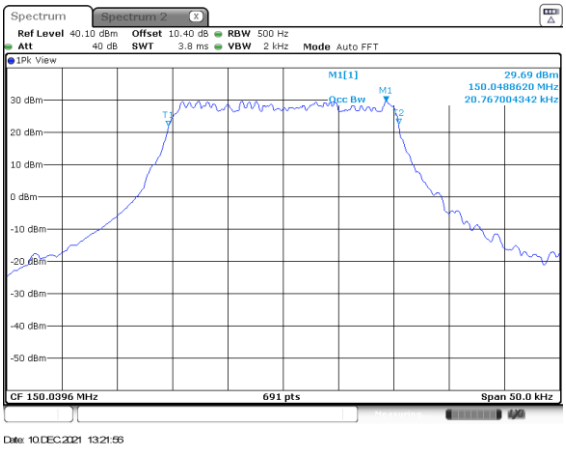

Figure 2.1.6-2: 99% BW – Mode 1 – HCH

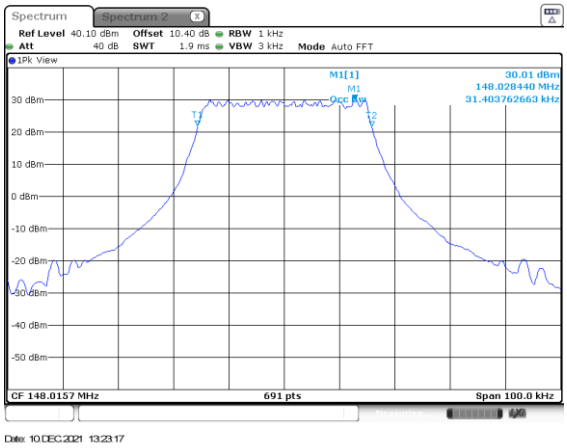

Figure 2.1.6-3: 99% BW – Mode 2 – LCH

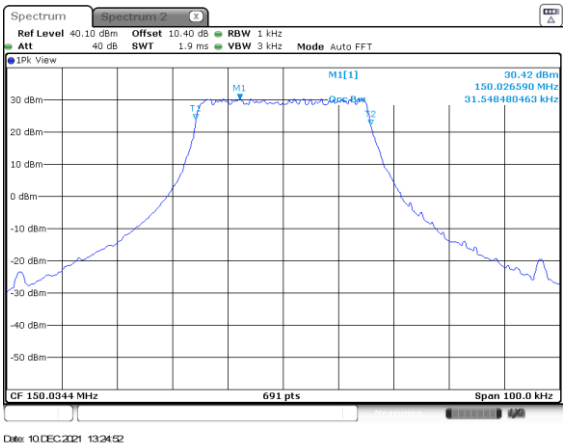

Figure 2.1.6-4: 99% BW – Mode 2– HCH

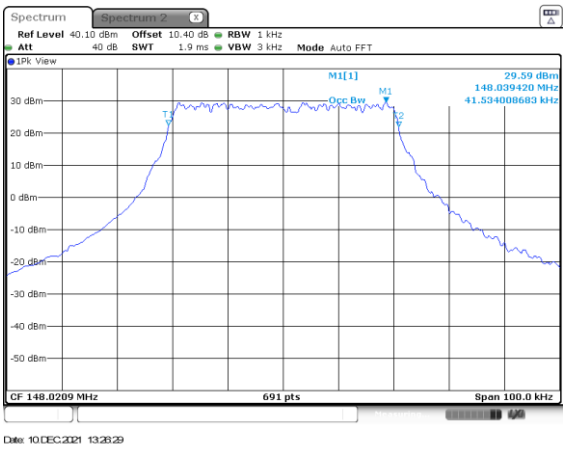

Figure 2.1.6-5: 99% BW – Mode 3 – LCH

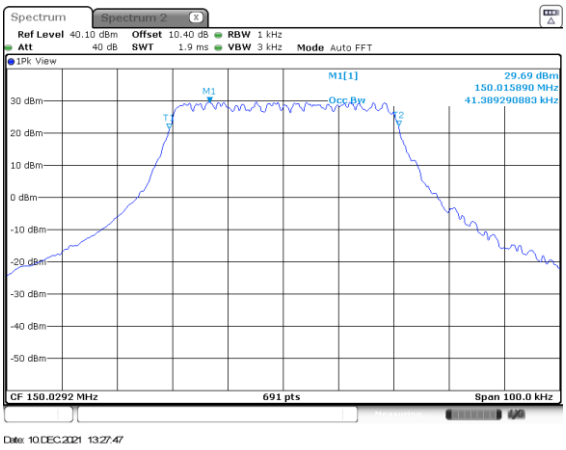

Figure 2.1.6-6: 99% BW – Mode 3 – HCH

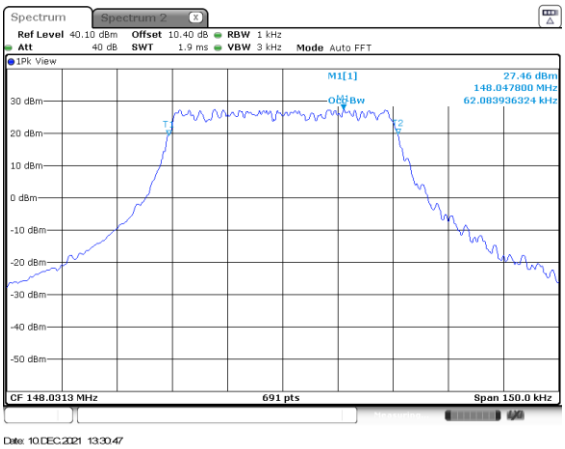

Figure 2.1.6-7: 99% BW – Mode 4 – LCH

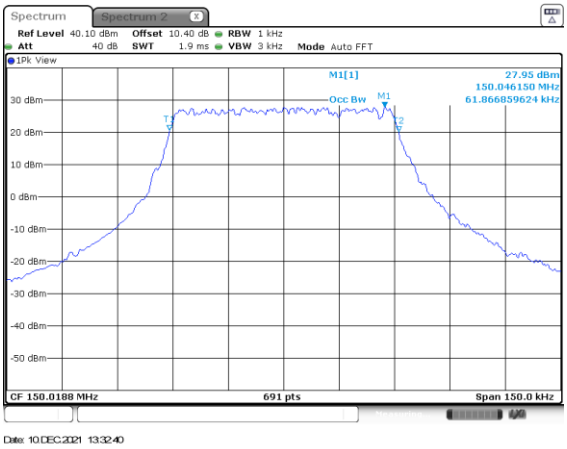

Figure 2.1.6-8: 99% BW – Mode 4– HCH

2.2 Fundamental Emission Output Power

2.2.1 Specification Reference

FCC Sections: §25.204
ISED Canada: RSS-170 Section 5.3.2

2.2.2 Equipment Under Test and Modification State

As shown in §1.4 with modification state “0”, as noted in §1.6.

2.2.3 Date of Test

12/10/2021

2.2.4 Test Method

The antenna port conducted power was measured with the output of the equipment under test directly connected to the input of the spectrum analyzer through suitable attenuation.

No maximum RF peak power limit exists for this band (148-150.05MHz) per Part 25.

2.2.5 Environmental Conditions

The EUT was evaluated within the temperature, humidity and pressure range of the EUT as specified by the standard. The laboratory shall have an ambient temperature range of 15°C to 35°C and relative humidity range of 30% to 60%.

Ambient Temperature	22.3 °C
Relative Humidity	53.8 %

2.2.6 Test Results

Test Summary: EUT was set to transmit mode.

Test Results: Pass

See data below for detailed results.

Table 2.2.6-1: RF Output Power

Mode	Frequency (MHz)	Peak Power (dBm)
1	148.0104	30.68
	150.0396	31.02
2	148.0157	30.79
	150.0344	31.02
3	148.0209	30.81
	150.0292	30.98
4	148.0313	30.75
	150.0188	31.01

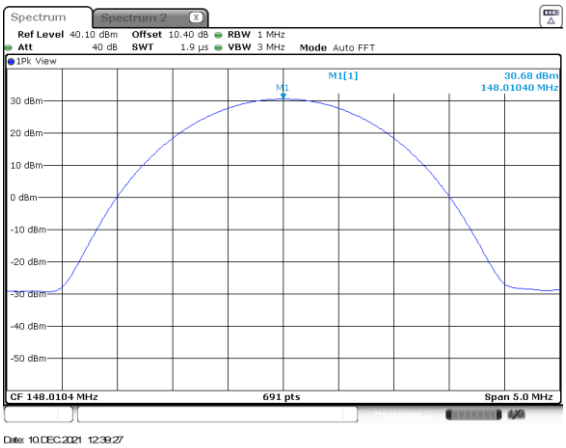

Figure 2.2.6-1: Output Power– Mode 1 – LCH

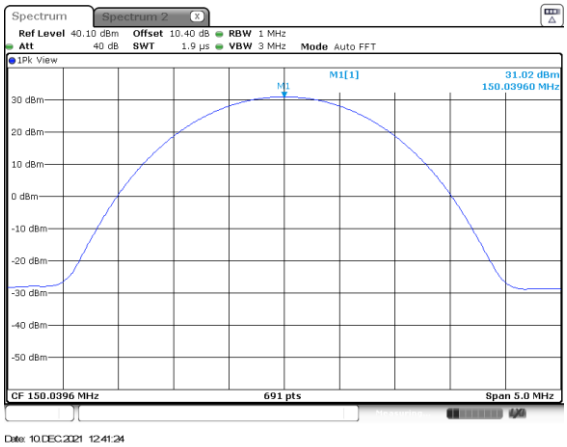

Figure 2.2.6-2: Output Power– Mode 1 – HCH

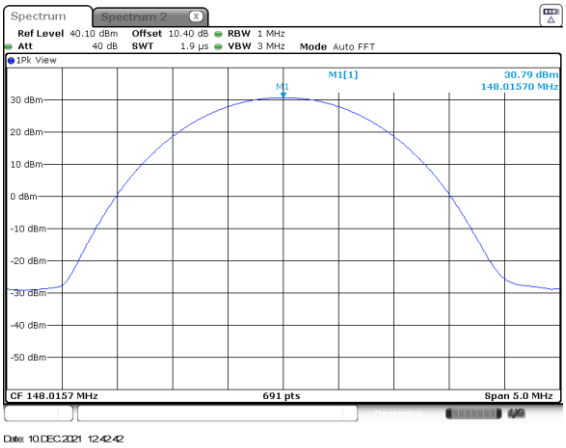

Figure 2.2.6-3: Output Power– Mode 2 – LCH

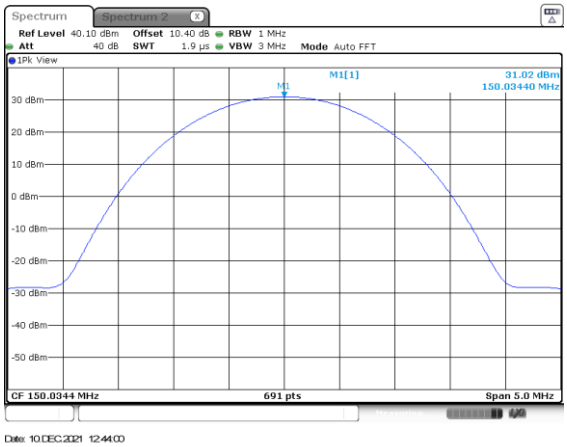

Figure 2.2.6-4: Output Power– Mode 2 – HCH

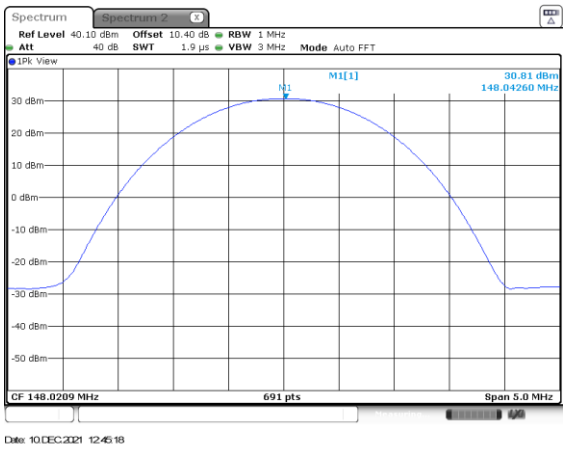

Figure 2.2.6-5: Output Power– Mode 3 – LCH

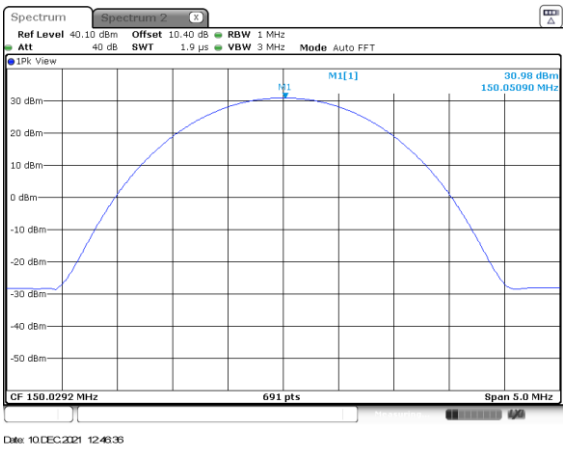

Figure 2.2.6-6: Output Power– Mode 3 – HCH

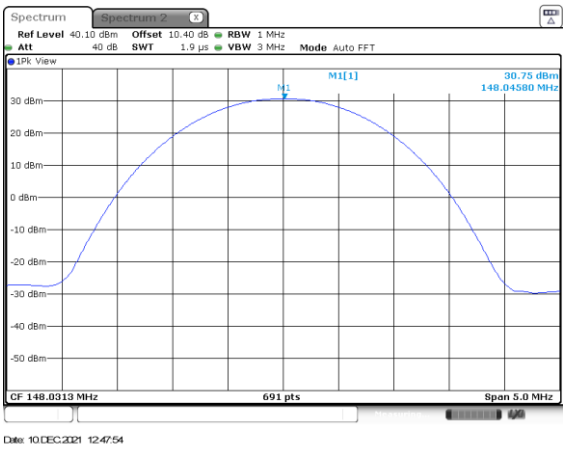

Figure 2.2.6-7: Output Power– Mode 4 – LCH

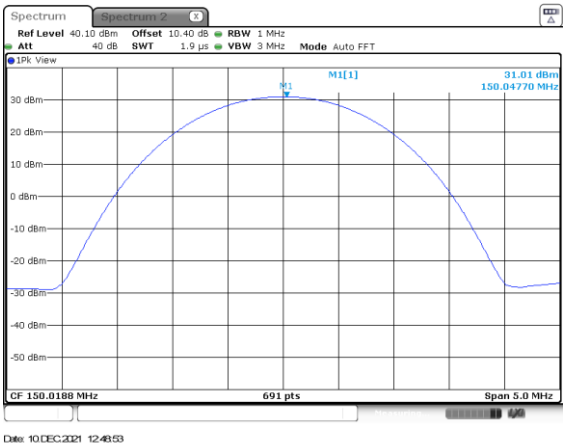

Figure 2.2.6-8: Output Power– Mode 4 – HCH

2.3 Spurious Emissions at Antenna Terminals

2.3.1 Specification Reference

FCC Sections: §25.202 (f)
ISED Canada: RSS-170 Section 5.4.3

2.3.2 Equipment Under Test and Modification State

As shown in §1.4 with modification state “0”, as noted in §1.6 for mode 1 & 2.
For Mode 3 & 4, Frequency offsets were adjusted in the software and client will be implementing it in the final software of the product.

2.3.3 Date of Test

12/10/2021 to 12/15/2021

2.3.4 Test Method

The antenna port emissions were measured with the output of the equipment under test directly connected to the input of the spectrum analyzer applying suitable attenuation.

Compliance was determined using the following guidance from the specifications:

FCC CFR Part 25, Section 25.202(f):
(f) Emission limitations. Except for SDARS terrestrial repeaters, the mean power of emissions shall be attenuated below the mean output power of the transmitter in accordance with the schedule set forth in paragraphs (f)(1) through (f)(4) of this section. The out-of-band emissions of SDARS terrestrial repeaters shall be attenuated in accordance with the schedule set forth in paragraph (h) of this section.

> (1) In any 4 kHz band, the center frequency of which is removed from the assigned frequency by more than 50 percent up to and including 100 percent of the authorized bandwidth: 25 dB;
> (2) In any 4 kHz band, the center frequency of which is removed from the assigned frequency by more than 100 percent up to and including 250 percent of the authorized bandwidth: 35 dB;
> (3) In any 4 kHz band, the center frequency of which is removed from the assigned frequency by more than 250 percent of the authorized bandwidth: An amount equal to 43 dB plus 10 times the logarithm (to the base 10) of the transmitter power in watts;
> (4) In any event, when an emission outside of the authorized bandwidth causes harmful interference, the Commission may, at its discretion, require greater attenuation than specified in paragraphs (f) (1), (2) and (3) of this section.

RSS-170 issue 3, Section 5.4.3:
The average power of unwanted emissions shall be attenuated below the average output power, P (dBW), of the transmitter, as specified below:

> (1) 25 dB in any 4 kHz band, the centre frequency of which is offset from the channel frequency by more than 50%, up to and including 100% of the occupied bandwidth or necessary bandwidth, whichever is greater;
> (2) 35 dB in any 4 kHz band, the centre frequency of which is offset from the channel frequency by more than 100%, up to and including 250% of the occupied bandwidth or necessary bandwidth, whichever is greater; and

(3) 43 + 10 log p (watts) in any 4 kHz band, the centre frequency of which is offset from the channel frequency by more than 250% of the occupied bandwidth or necessary bandwidth, whichever is greater.

Note: Since a 4kHz resolution bandwidth was not available, a 3kHz RBW was applied and adjusted by 1.2dB.

2.3.5 Environmental Conditions

The EUT was evaluated within the temperature, humidity and pressure range of the EUT as specified by the standard. The laboratory shall have an ambient temperature range of 15°C to 35°C and relative humidity range of 30% to 60%.

Ambient Temperature	22.3 °C
Relative Humidity	53.8 %

2.3.6 Test Results

Test Summary: EUT was set to transmit mode.

Test Results: Pass

See below plots for detailed results.

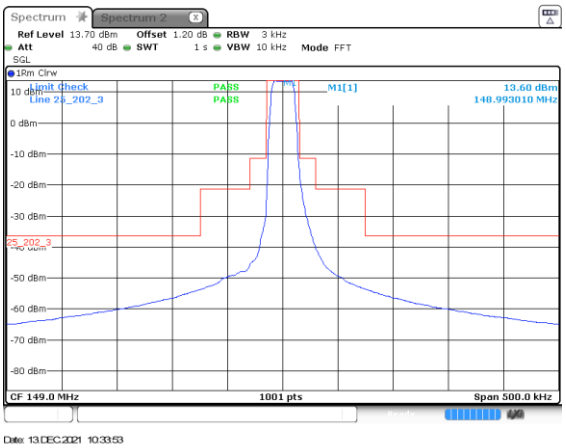

Figure 2.3.6-1: Emission Mask – Mode 1

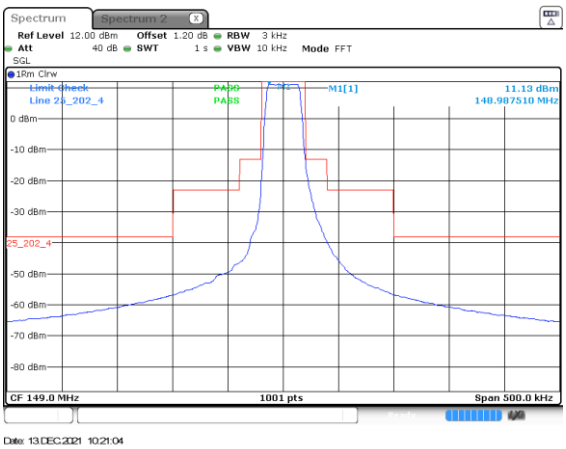

Figure 2.3.6-2: Emission Mask – Mode 2

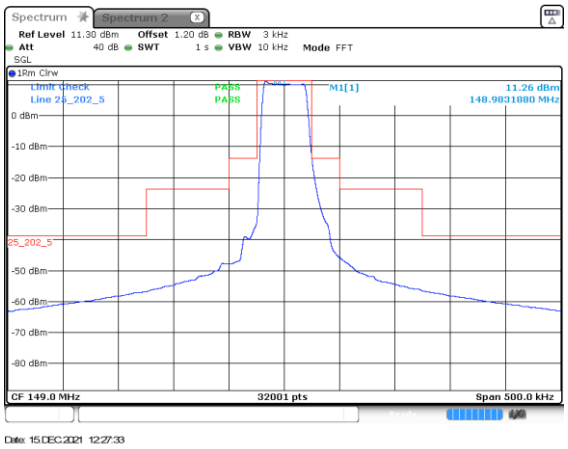

Figure 2.3.6-3: Emission Mask – Mode 3

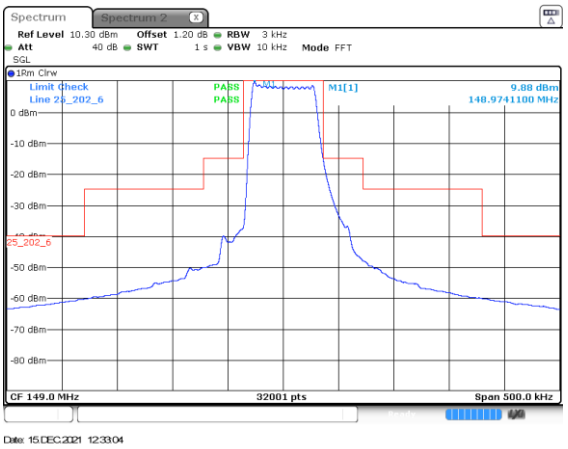

Figure 2.3.6-4: Emission Mask – Mode 4

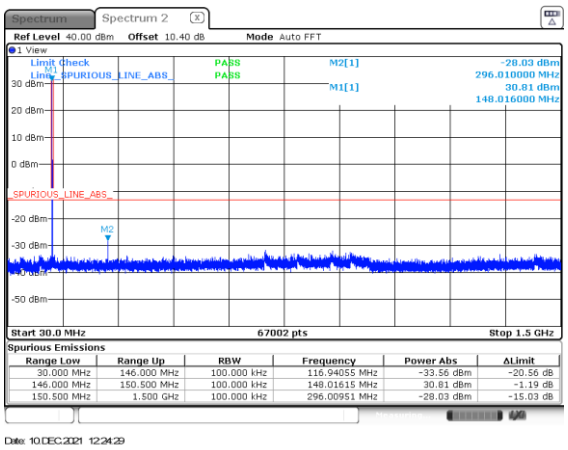

Figure 2.3.6-5: Spurious Emission – Mode 1 - LCH

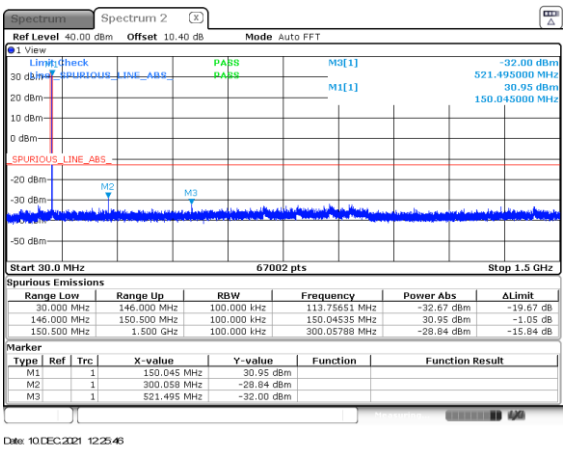

Figure 2.3.6-6: Spurious Emission – Mode 1 - HCH

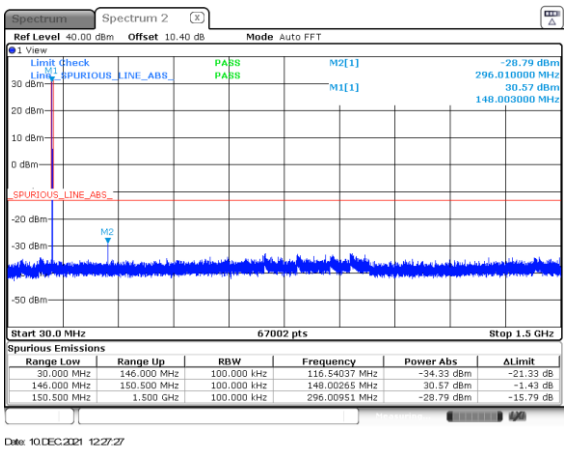

Figure 2.3.6-7: Spurious Emission – Mode 2 - LCH

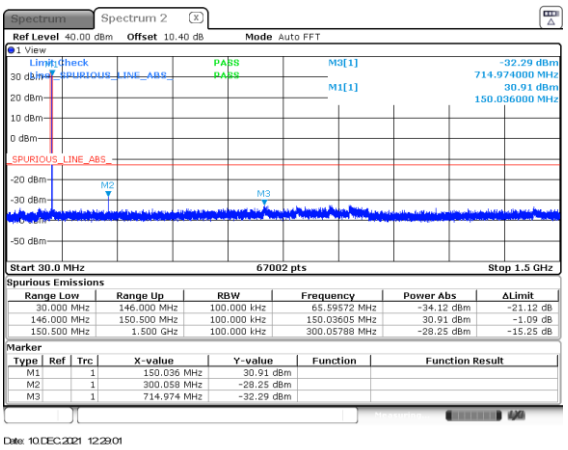

Figure 2.3.6-8: Spurious Emission – Mode 2 - HCH

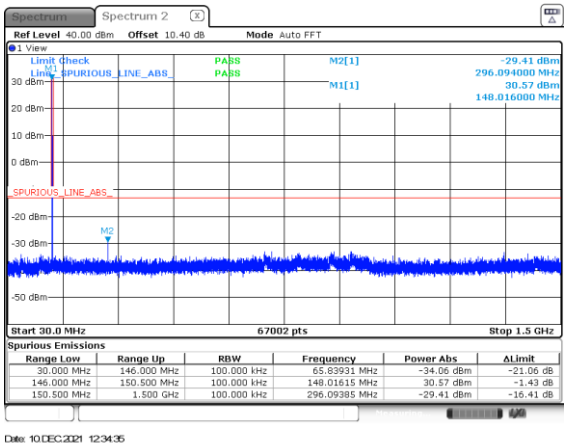

Figure 2.3.6-9: Spurious Emission – Mode 3 - LCH

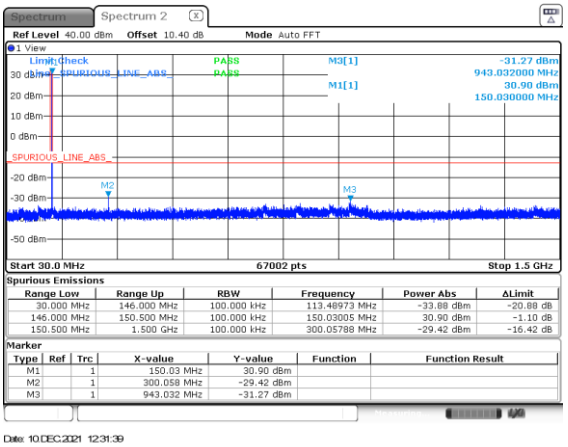

Figure 2.3.6-10: Spurious Emission – Mode 3 - HCH

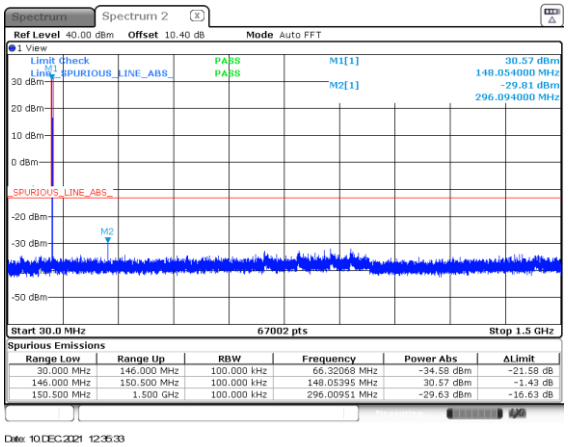

Figure 2.3.6-11: Spurious Emission – Mode 4 - LCH

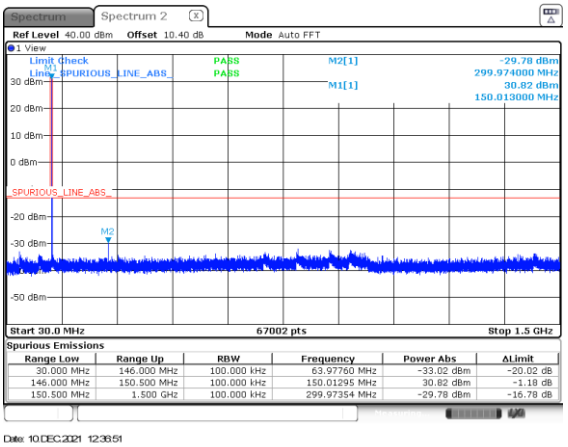

Figure 2.3.6-12: Spurious Emission – Mode 4 - HCH

2.4 Frequency Stability

2.4.1 Specification Reference

FCC Sections: §25.202 (d)
ISED: RSS-170 Section 5.2

2.4.2 Equipment Under Test and Modification State

As shown in §1.4with modification state “0”, as noted in §1.6.

2.4.3 Date of Test

12/13/2021

2.4.4 Test Method

N/A

2.4.5 Environmental Conditions

The EUT was evaluated within the temperature, humidity and pressure range of the EUT as specified by the standard. The laboratory shall have an ambient temperature range of 15°C to 35°C and relative humidity range of 30% to 60%.

Ambient Temperature	22.3 °C
Relative Humidity	53.8 %

2.4.6 Test Results

Test Summary: EUT was set to transmit mode.

Test Results: Pass

See below plots for detailed results.

Table 2.4.6-1: Frequency Stability Tabulated data

Nominal Voltage		3.3Vdc	Nominal Frequency (MHz)	149
Voltage (VDC)	**Temperature (°C)**	**Frequency Center (MHz)**		**Deviation (ppm)**
3.3	-55	149.000055		0.37
	-50	149.000036		0.24
	-40	149.000017		0.11
	-30	148.999993		-0.05
	-20	149.000056		0.38
	-10	149.000042		0.28
	0	149.000022		0.15
	+10	149.000045		0.30
	+20	149.000012		0.08
	+30	149.000002		0.01
	+40	149.000033		0.22
	+50	148.999978		-0.15
	+60	148.999997		-0.02
	+70	149.000027		0.18
	+80	149.000008		0.05
	+85	149.000025		0.17
3.00	+20	149.000012		0.08
5.50	+20	149.000002		0.01

2.5 Field Strength of Radiated Spurious Emissions

2.5.1 Specification Reference

FCC Sections: 25.202(f)
ISED Canada: RSS 170 5.4.3

2.5.2 Equipment Under Test and Modification State

As shown in §1.4 with modification state “0”, as noted in §1.6.

2.5.3 Date of Test

12/15/2021

2.5.4 Test Method

The unwanted emissions were measured radiated over the frequency range of 30 MHz to 1.6 GHz, more than 10 times the highest fundamental frequency using the methods defined in ANSI C63.26.

The EUT was rotated through 360° and the receive antenna height was varied from 1 meter to 4 meters so that the maximum radiated emissions level would be detected. For frequencies below 1000 MHz, peak measurements were made using a resolution bandwidth (RBW) of 100 kHz and a video bandwidth VBW of 300 kHz. For frequencies above 1000 MHz, peak and average measurements were made with RBW and VBW of 1 MHz and 3 MHz respectively.

Compliance was determined using the following guidance from the specifications:
FCC CFR Part 25, Section 25.202(f):

> (3) In any 4 kHz band, the center frequency of which is removed from the assigned frequency by more than 250 percent of the authorized bandwidth: An amount equal to 43 dB plus 10 times the logarithm (to the base 10) of the transmitter power in watts;

RSS-170 issue 3, Section 5.4.3:

> (3) 43 + 10 log p (watts) in any 4 kHz band, the centre frequency of which is offset from the channel frequency by more than 250% of the occupied bandwidth or necessary bandwidth, whichever is greater.

Note: Although a 4kHz resolution bandwidth is stated in the specification, the higher bandwidth settings mentioned above were applied to facilitate testing.

2.5.5 Environmental Conditions

The EUT was evaluated within the temperature, humidity and pressure range of the EUT as specified by the standard. The laboratory shall have an ambient temperature range of 15°C to 35°C and relative humidity range of 30% to 60%.

Ambient Temperature	22.3 °C
Relative Humidity	53.8 %

2.5.6 Test Results

Test Summary: EUT was set to transmit mode.

Test Results: Pass

See below plots for detailed results.

Table 2.5.6-1: Radiated Spurious Emissions Tabulated Data

Frequency (MHz)	Level (dBuV)	Antenna Polarity	Correction Factors	Corrected Leve (dBuV/m)	Limit (dBuV/m)	Margin (dB)
	pk	(H/V)	(dB)	pk	RMS	
LCH						
222	54.90	H	-20.40	34.50	82.2	47.7
222	54.70	V	-20.40	34.30	82.2	47.9
296	95.60	H	-16.28	79.32	82.2	2.9
296	97.70	V	-16.28	81.42	82.2	0.8
444	87.20	H	-11.90	75.30	82.2	6.9
444	84.40	V	-11.90	72.50	82.2	9.7
592	79.00	H	-8.70	70.30	82.2	11.9
592	76.70	V	-8.70	68.00	82.2	14.2
740	73.50	H	-7.10	66.40	82.2	15.8
740	70.00	V	-7.10	62.90	82.2	19.3
888.1	60.80	H	-5.36	55.44	82.2	26.8
888.1	64.50	V	-5.36	59.14	82.2	23.1
HCH						
225	46.80	H	-20.10	26.70	82.2	55.5
225	48.10	V	-20.10	28.00	82.2	54.2
300.1	91.90	H	-16.19	75.71	82.2	6.5
300.1	97.60	V	-16.19	81.41	82.2	0.8
450.1	84.50	H	-11.90	72.60	82.2	9.6
450.1	86.00	V	-11.90	74.10	82.2	8.1
600.1	76.70	H	-8.70	68.00	82.2	14.2
600.1	75.10	V	-8.70	66.40	82.2	15.8
750.3	67.50	H	-7.20	60.30	82.2	21.9
750.3	64.10	V	-7.20	56.90	82.2	25.3
900.3	62.00	H	-5.00	57.00	82.2	25.2
900.3	63.7	V	-5.00	58.70	82.2	23.5

Note: Peak measurements were compared to the RMS limit.

Sample Calculation:

$R_C = R_U + CF_T$

Where:

CF_T = Total Correction Factor (AF+CA+AG)-DC (Average Measurements Only)
R_U = Uncorrected Reading
R_C = Corrected Level
AF = Antenna Factor
CA = Cable Attenuation
AG = Amplifier Gain
DC = Duty Cycle Correction Factor

Example Calculation: Peak

Corrected Level: 97.70 + -16.28 = 81.42dBµV/m
Margin: 82.2dBµV/m – 81.42dBµV/m = 0.8dB

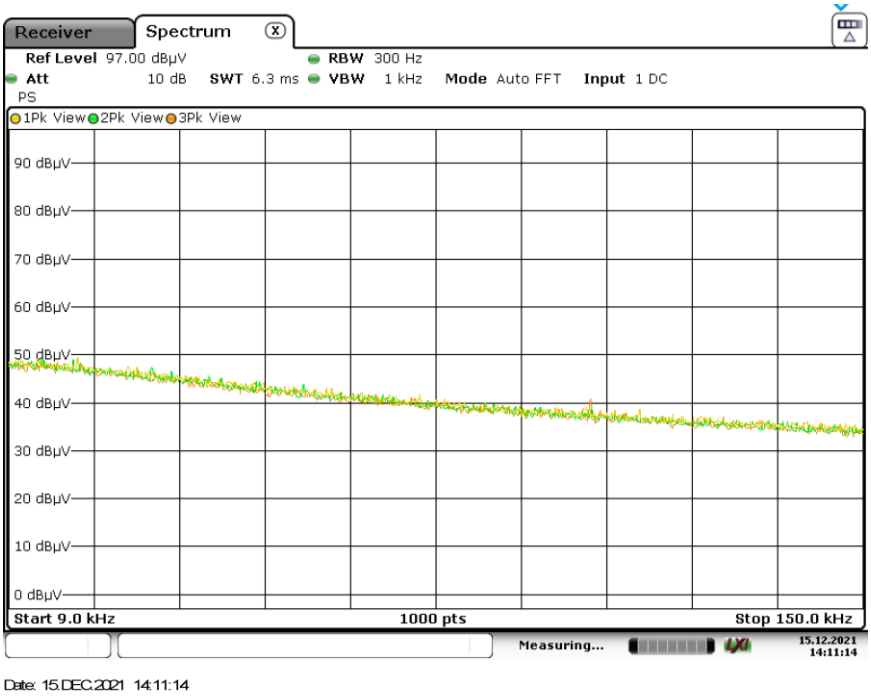

Figure 1: Reference plot for Radiated Spurious Emissions – 9 kHz – 150 kHz

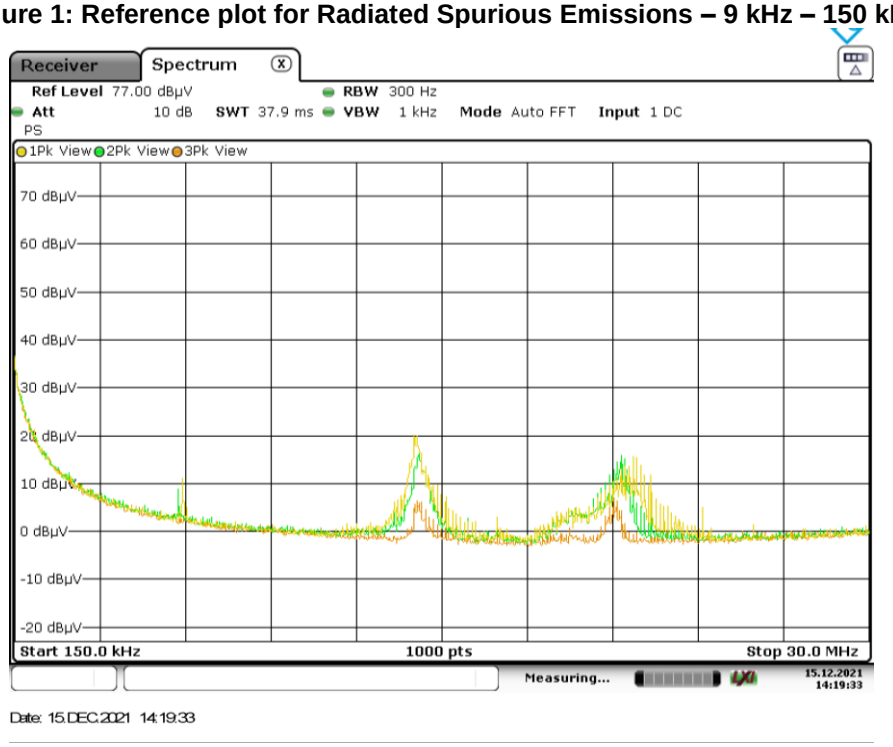

Figure 2: Reference plot for Radiated Spurious Emissions– 150 kHz – 30 kHz

Note: Emissions above the noise floor are ambient not associated with the EUT.

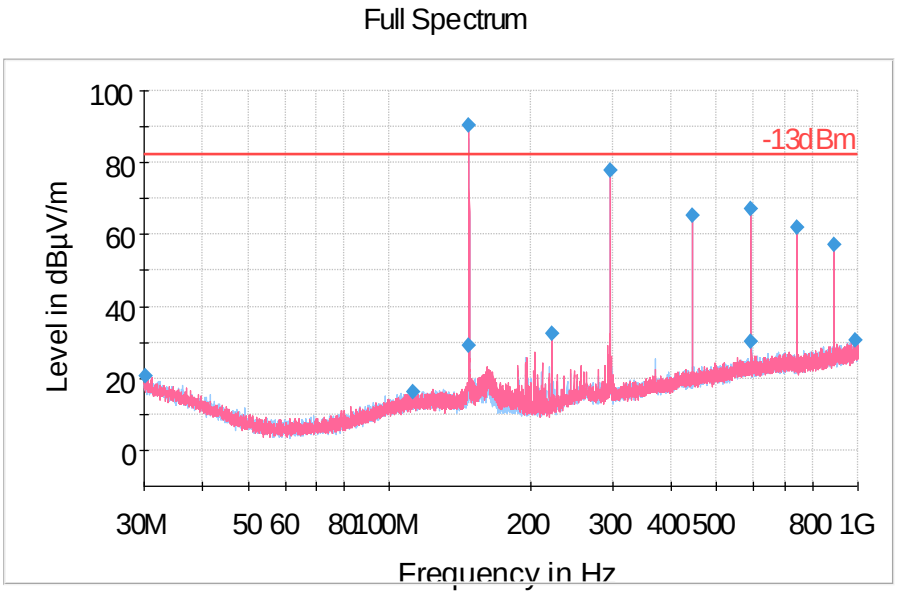

Figure 3: Reference plot for Radiated Spurious Emissions – 30 MHz – 1 GHz
Note: Emissions exceeding the limit is the fundamental emission

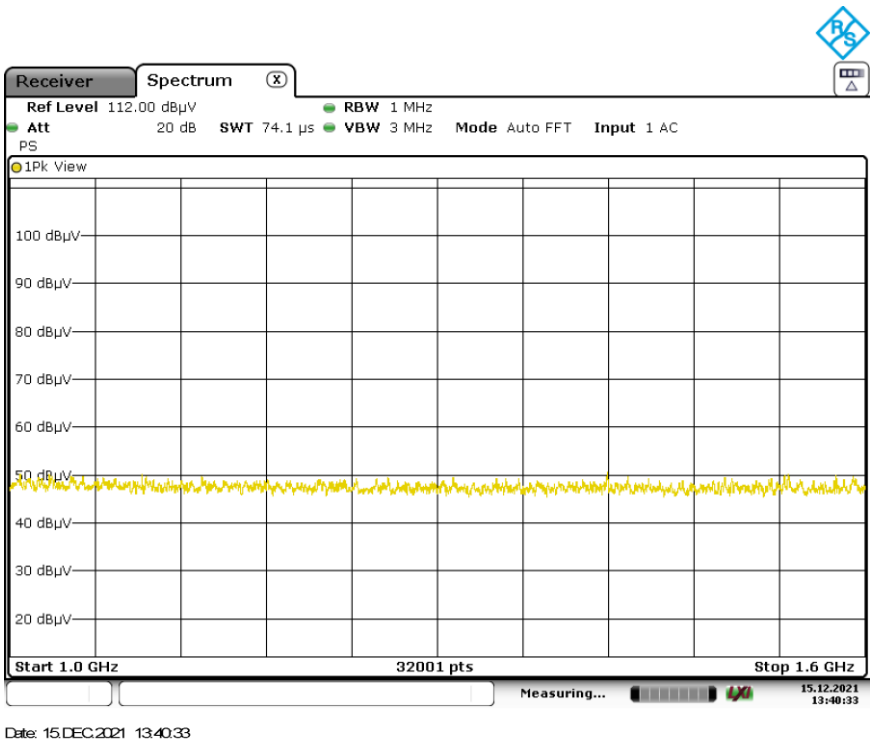

Figure 4: Reference plot for Radiated Spurious Emissions – 1 GHz – 1.6 GHz

2.6 Test Equipment Used

Table 2.6-1 –Equipment List

Asset ID	Manufacturer	Model	Equipment Type	Serial Number	Last Calibration Date	Calibration Due Date
852	Teseq	CBL 6112D	Bilog Antenna; Attenuator	51617	10/13/2020	10/13/2022
1956	Fei Teng Wireless Technology	HA-07M18G-NF	Horn Antenna	2013120203	5/12/2021	5/12/2022
888	Com Power	PAM-103	Pre-Amp	18020214	9/27/2021	9/27/2022
338	Hewlett Packard	8449B	High Frequency Pre-Amp	3008A01111	6/22/2021	6/22/2023
17	EMCO	1060	Positioner	1728	NCR	NCR
18	EMCO	1051-12	Positioner	9203-1657	NCR	NCR
819	Rohde & Schwarz	ESR26	EMI Test Receiver	101345	4/7/2021	4/7/2022
836	ETS Lindgren	SAC Cable Set	SAC Cable Set includes 620, 837, 838	N/A	5/11/2021	5/11/2022
622	Rohde & Schwarz	FSV40 (v3.40)	FSV Signal Analyzer 10Hz to 40GHz	101338	9/22/2021	9/22/2022
827	(-)	TS8997 Rack Cable Set	TS8997 Rack Cable Set	N/A	12/4/2021	12/20/2022
267	Hewlett Packard	N1911A	Power Meter	MY45100129	7/27/2021	7/27/2023
881	Fluke	52 II	Thermocouple Thermometer	49390196WS	8/2/2021	8/2/2022
694	Thermotron	S-1.2C	Temperature chamber	19753	NCR	NCR

N/A – Not Applicable
NCR – No Calibration Required

3 Diagram of Test Set-ups

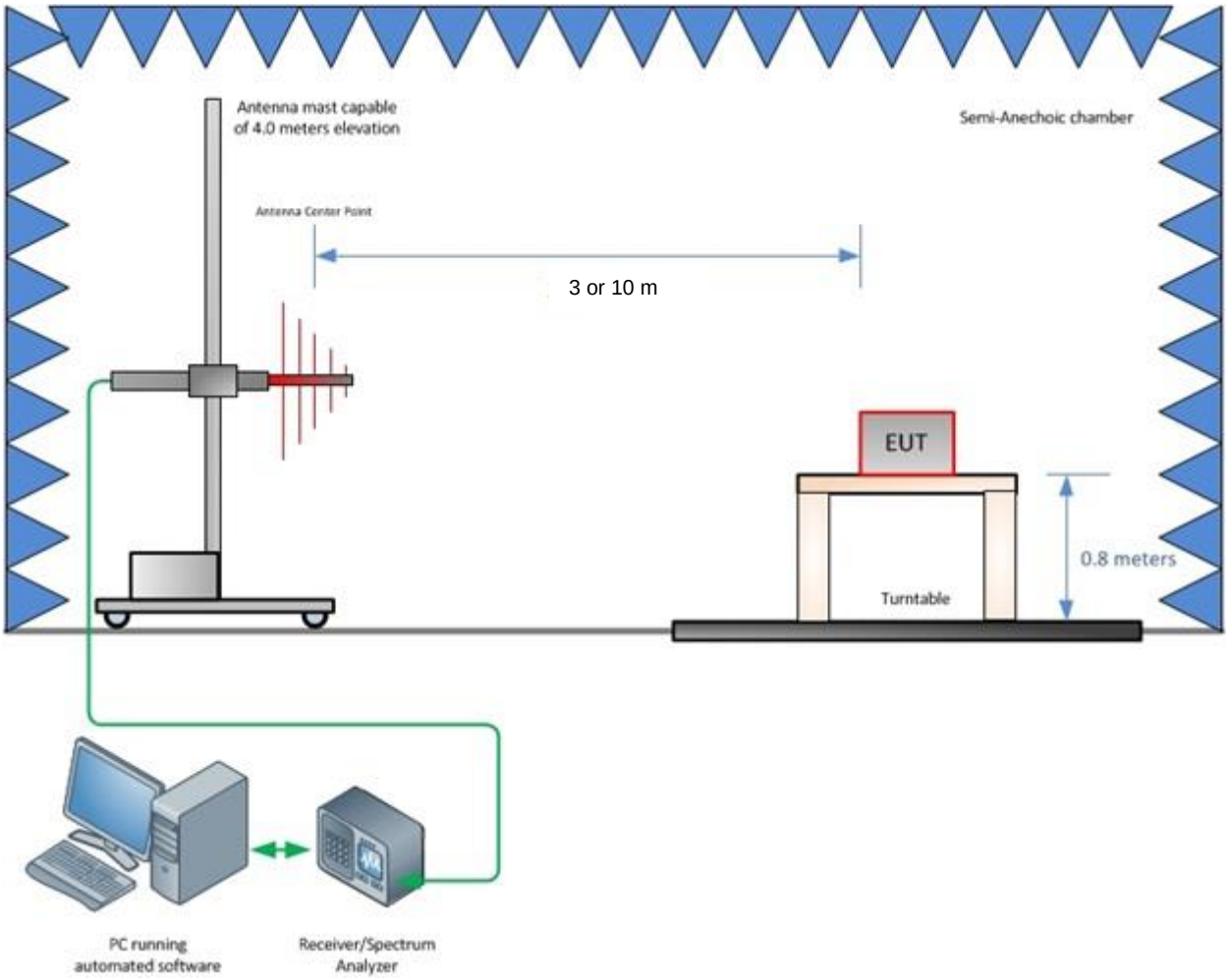

Figure 3-1 – Radiated Emissions Test Setup up to 1 GHz

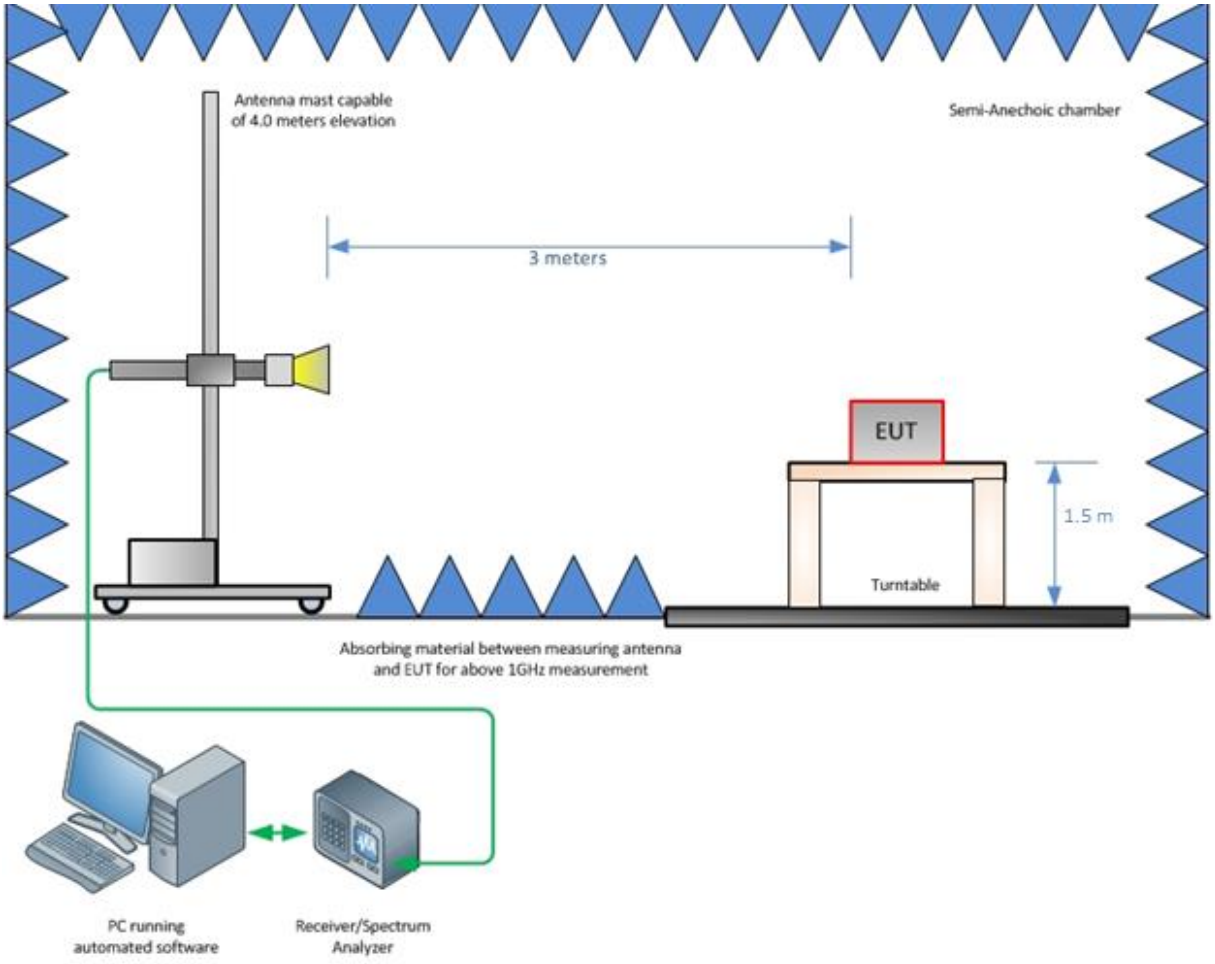

Figure 3-2 – Radiated Emissions Test Setup above 1 GHz

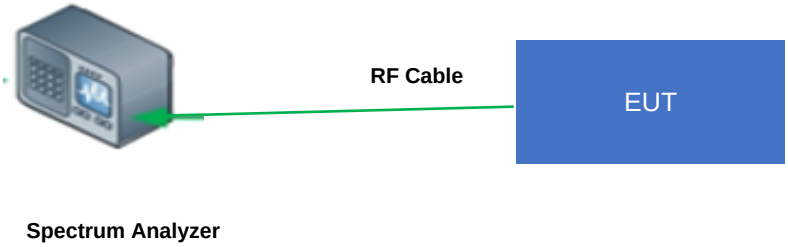

Figure 3-3 – Conducted Test Setup: Antenna Port measurement

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STATEMENT OF MEASUREMENT UNCERTAINTY

The expanded laboratory measurement uncertainty figures (U_{Lab}) provided below correspond to an expansion factor (coverage factor) k = 1.96 which provide confidence levels of 95%.

Table 4-1: Estimation of Measurement Uncertainty

Parameter	U_{lab}
Occupied Channel Bandwidth	± 0.009 %
RF Conducted Output Power	± 0.349 dB
Antenna Port Conducted Emissions	± 1.264 dB
Radiated Emissions ≤ 1 GHz	± 5.814 dB
Radiated Emissions > 1 GHz	± 4.318 dB
Temperature	± 0.860 °C
Radio Frequency	± 2.832 x 10^{-8}

TEST EQUIPMENT

All measurement instrumentation is traceable to the National Institute of Standards and Technology and is calibrated to meet test method standard requirements and/or manufacturer's specifications

Appendix A: Test Setup Photos

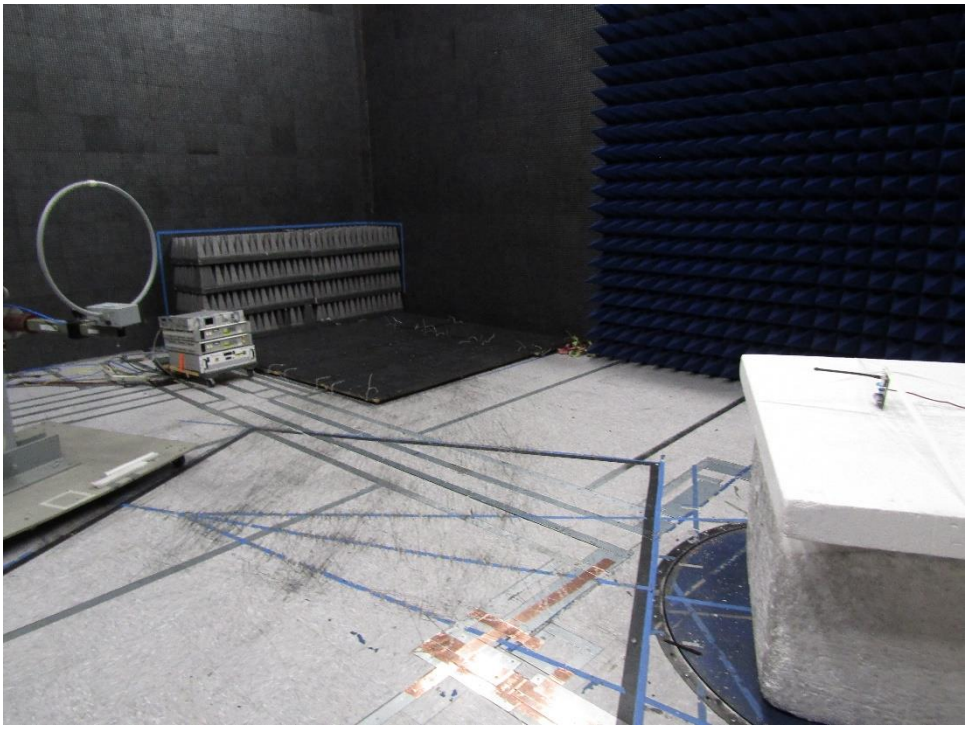

Figure A-1 – Test Set up - Radiated Emissions <30 MHz

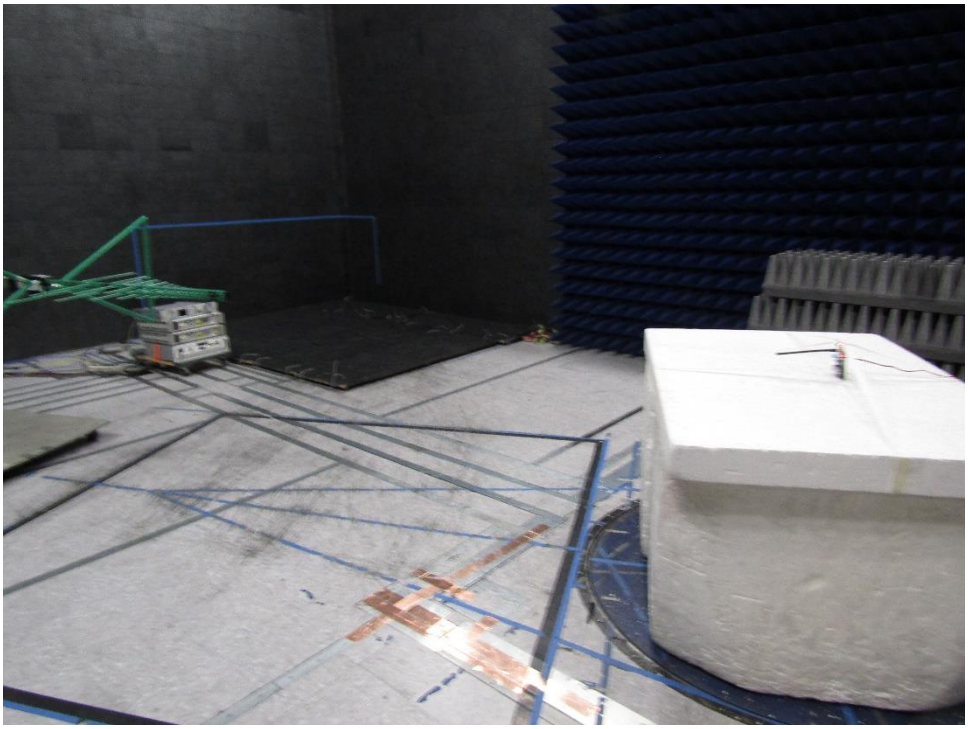

Figure A-2 – Test Set up - Radiated Emissions <1 GHz

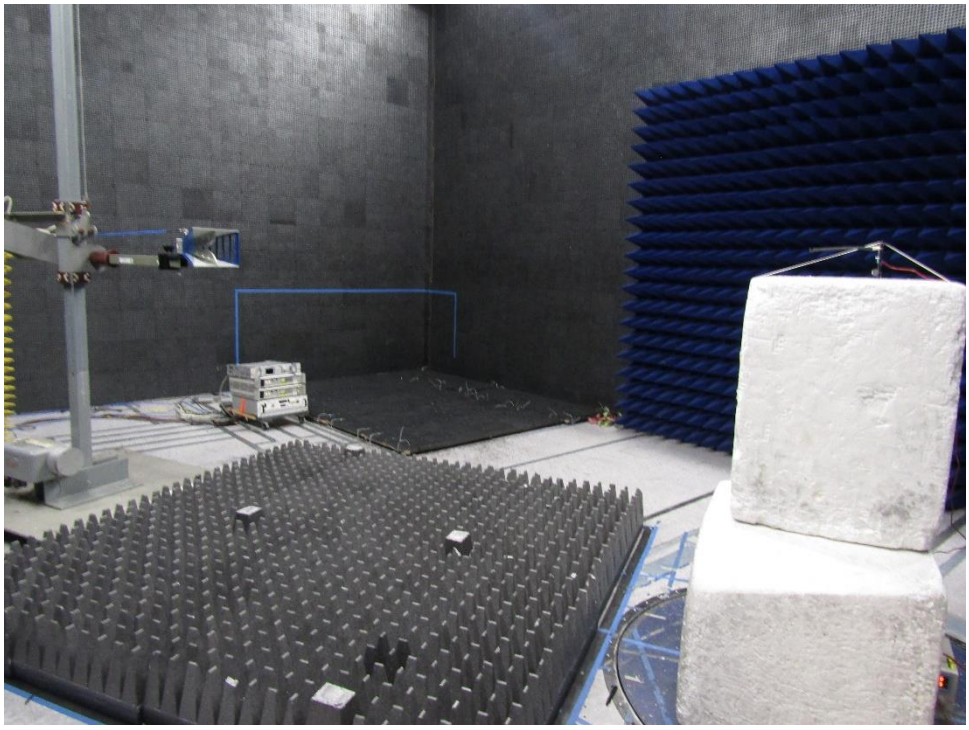

Figure A-3 – Test Set up - Radiated Emissions <10 GHz

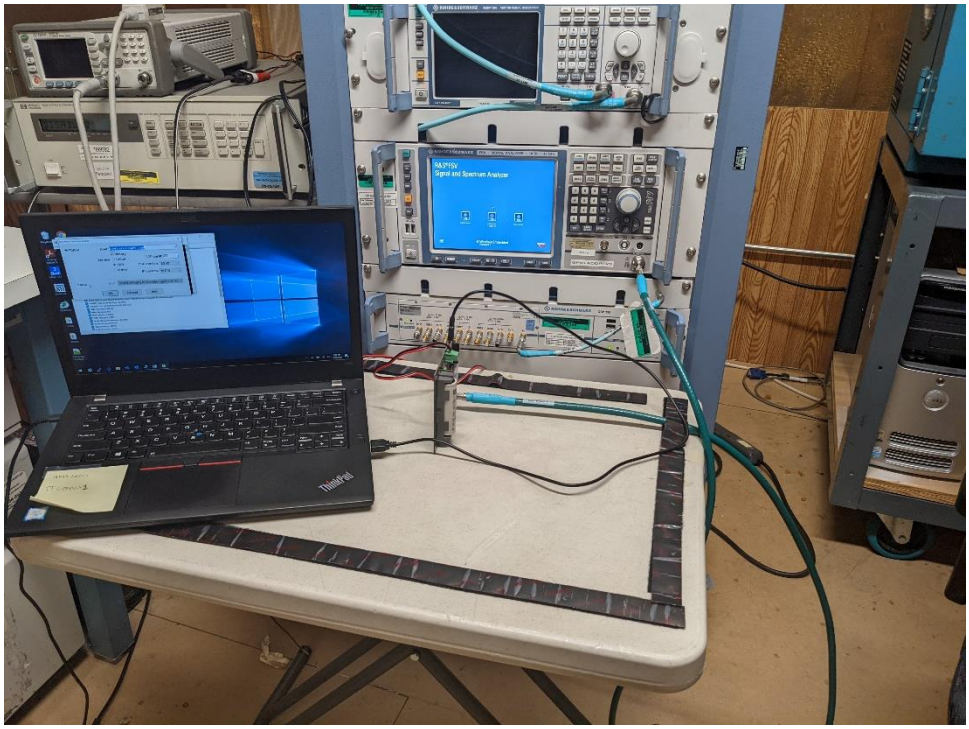

Figure A-4 – Test Set up – Antenna Port measurements