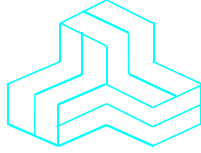


ENGINEERING TEST REPORT



MMB Networks OpenThread Border Router/Mesh Extender
Model(s): BRD21-OTBR, BRD21-OTME
FCC ID: XFF-BRD21

Applicant:

MMB Research Inc.
25 Adelaide Street East, Suite 400
Toronto, ON M5C 3A1
Canada

In Accordance With

Federal Communications Commission (FCC)
Part 15, Subpart C, Section 15.247
Digital Modulation Systems (DTS) Operating in 2400 – 2483.5 MHz Band

UltraTech's File No.: 22MMBN059_FCC15C247

This Test report is Issued under the Authority of
Tri M. Luu
Vice President of Engineering
UltraTech Group of Labs

Date: July 27, 2022

Report Prepared by: Dan Huynh

Tested by: Angus Au

Issued Date: July 27, 2022

Test Dates:
June 2 & 3, 2022
July 7 & 11, 2022

- The results in this Test Report apply only to the sample(s) tested, and the sample tested is randomly selected.
- This report must not be used by the client to claim product endorsement by any agency of the US Government.
- This test report shall not be reproduced, except in full, without a written approval from UltraTech

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APEC TEL CA0001



1309



CA0001-2049



AT-1945



SL2-IN-E-1119R



Korea KCC-RRR

CA0001

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EXHIBIT 1. INTRODUCTION**1.1. SCOPE**

Reference:	FCC Part 15, Subpart C, Section 15.247
Title:	Code of Federal Regulations (CFR), Title 47 – Telecommunication, Part 15 – Radio Frequency Devices
Purpose of Test:	Equipment Certification for Digital Modulation Systems (DTS) Operating Under §15.247
Test Procedures:	▪ ANSI C63.4 ▪ ANSI C63.10 ▪ KDB Publication No. 558074 D01 15.247 Meas Guidance v05r02
Environmental Classification:	☒ Commercial, industrial or business environment ☒ Residential environment

1.2. RELATED SUBMITTAL(S)/GRANT(S)

None.

1.3. NORMATIVE REFERENCES

Publication	Year	Title
47 CFR Parts 0-19	2021	Code of Federal Regulations (CFR), Title 47 – Telecommunication
ANSI C63.4	2014	American National Standard for Methods of Measurement of Radio-Noise Emissions from Low-Voltage Electrical and Electronic Equipment in the Range of 9 KHz to 40 GHz
ANSI C63.10	2013	American National Standard of Procedures for Compliance Testing of Unlicensed Wireless Devices
FCC, KDB Publication No. 558074 D01 15.247 Meas Guidance v05r02	2019	GUIDANCE FOR COMPLIANCE MEASUREMENTS ON DIGITAL TRANSMISSION SYSTEM, FREQUENCY HOPPING SPREAD SPECTRUM SYSTEM, AND HYBRID SYSTEM DEVICES OPERATING UNDER SECTION 15.247 OF THE FCC RULES

EXHIBIT 2. PERFORMANCE ASSESSMENT**2.1. CLIENT INFORMATION**

Applicant	
Name:	MMB Research Inc.
Address:	25 Adelaide Street East, Suite 400 Toronto, ON M5C 3A1 Canada

Manufacturer	
Name:	MMB Research Inc.
Address:	25 Adelaide Street East, Suite 400 Toronto, ON M5C 3A1 Canada

2.2. EQUIPMENT UNDER TEST (EUT) INFORMATION

The following information (with the exception of the Date of Receipt) has been supplied by the applicant.

Brand Name:	MMB Research Inc.
Product Name:	MMB Networks OpenThread Border Router/Mesh Extender
¹Model(s):	BRD21-OTBR (MMB Networks OpenThread Border Router), BRD21-OTME (MMB Networks OpenThread Mesh Extender)
Serial Number:	Test Sample
Type of Equipment:	Digital Transmission System (DTS)
Input Power Supply Type:	5V, 1A DC
Primary User Functions of EUT:	Connect Thread devices to the internet (BRD21-OTBR). Extend range of Thread networks (BRD21-OTME).

¹ The hardware for BRD21-OTBR and BRD21-OTME are identical, they have the same PCBA, RF design, RF performance, antenna type and same plastic enclosure. The differences between the two models are firmware, the Ethernet interface is enabled for BRD21-OTBR and disabled for BRD21-OTME. Since, BRD21-OTBR supports the additional Ethernet interface, it was selected as the worst-case test sample.

2.3. EUT'S TECHNICAL SPECIFICATIONS

Transmitter	
Equipment Type:	Mobile Base station (fixed use)
Intended Operating Environment:	Residential environment Commercial, industrial or business environment
Power Supply Requirement:	5V, 1A DC
RF Output Power Rating:	19.09 dBm Peak
Operating Frequency Range:	2405 - 2480 MHz
RF Output Impedance:	50 Ω
Duty Cycle:	Continuous
Modulation Type:	O-QPSK
Antenna Connector Types:	Integral

2.4. ASSOCIATED ANTENNA DESCRIPTIONS

Antenna Type	Manufacturer	Model	Maximum Gain (dBi)
¹ Printed meandered inverted-F (MIFA)	MMB Research Inc.	ESP ANT B	3.42
² Printed meandered inverted-F (MIFA)	Espressif Systems Ltd.	ESP ANT B	3.42

¹ For Zigbee Radio (Thread)² For WiFi/Bluetooth Module**2.5. LIST OF EUT'S PORTS**

Port Number	EUT's Port Description	Number of Identical Ports	Connector Type	Cable Type (Shielded/Non-shielded)
1	DC Power	1	USB-C	Non-shielded
2	Ethernet	1	RJ45	Non-shielded

2.6. ANCILLARY EQUIPMENT

The EUT was tested while connected to the following representative configuration of ancillary equipment necessary to exercise the ports during tests:

Ancillary Equipment # 1	
Description:	AC Adapter
Brand name:	Ubiquiti
Model Name or Number:	Ubiquiti
Serial Number:	--
Connected to EUT's Port:	Connected to USB-C

Ancillary Equipment # 2	
Description:	Laptop
Brand name:	HP EliteBook
Model Name or Number:	820
Serial Number:	--
Connected to EUT's Port:	UART via test jig cable

EXHIBIT 3. EUT OPERATING CONDITIONS AND CONFIGURATIONS DURING TESTS

3.1. CLIMATE TEST CONDITIONS

The climate conditions of the test environment are as follows:

Temperature:	21 to 23 °C
Humidity:	45 to 58%
Pressure:	102 kPa
Power Input Source:	5V DC

3.2. OPERATIONAL TEST CONDITIONS & ARRANGEMENT FOR TESTS

Operating Modes:	The transmitter was operated in a continuous transmission mode with the carrier modulated as specified in the Test Data.
Special Test Software:	Test software provided by the Applicant to operate the EUT at each channel frequency continuously and in the range of typical modes of operation.
Special Hardware Used:	N/A
Transmitter Test Antenna:	The EUT is tested with the antenna fitted in a manner typical of normal intended use as integral antenna equipment as described with the test results.

Transmitter Test Signals	
Frequency Band(s):	2405 - 2480 MHz
Frequency(ies) Tested:	2405 MHz, 2440 MHz, 2475 MHz, 2480 MHz
RF Power Output: (measured maximum output power at antenna terminals)	19.09 dBm Peak
Normal Test Modulation:	O-QPSK
Modulating Signal Source:	Internal

EXHIBIT 4. SUMMARY OF TEST RESULTS

4.1. LOCATION OF TESTS

All of the measurements described in this report were performed at Ultratech Group of Labs located in the city of Oakville, Province of Ontario, Canada.

- AC Power Line Conducted Emissions were performed in UltraTech's shielded room, 24'(L) by 16'(W) by 8'(H).
- Radiated Emissions were performed at the Ultratech's 3-10 TDK Semi-Anechoic Chamber situated in the Town of Oakville, province of Ontario. This test site been calibrated in accordance with ANSI C63.4, and found to be in compliance with the requirements of Sec. 2.948 of the FCC Rules. The descriptions and site measurement data of the Oakville 3-10 TDK Semi-Anechoic Chamber has been filed with ANAB File No.: AT-1945.

4.2. APPLICABILITY & SUMMARY OF EMC EMISSION TEST RESULTS

FCC Section(s)	Test Requirements	Compliance (Yes/No)
15.203	Antenna requirements	Yes*
15.207(a)	AC Power Line Conducted Emissions	Yes
15.247(a)(2)	6 dB Bandwidth	Yes
15.247(b)(3)	Peak Conducted Output Power	Yes
15.247(d)	Band-Edge and RF Conducted Spurious Emissions at the Transmitter Antenna Terminal	Yes
15.247(d), 15.209 & 15.205	Transmitter Spurious Radiated Emissions	Yes
15.247(e)	Power Spectral Density	Yes
15.247(i), 1.1307, 1.1310, 2.1091	RF Exposure	Yes

* The EUT complies with the requirement; it employs a unique (non-standard) antenna connector or integral antenna.

4.3. MODIFICATIONS INCORPORATED IN THE EUT FOR COMPLIANCE PURPOSES

None.

EXHIBIT 5. TEST DATA

5.1. POWER LINE CONDUCTED EMISSIONS [§15.207(a)]

5.1.1. Limit(s)

The equipment shall meet the limits of the following table:

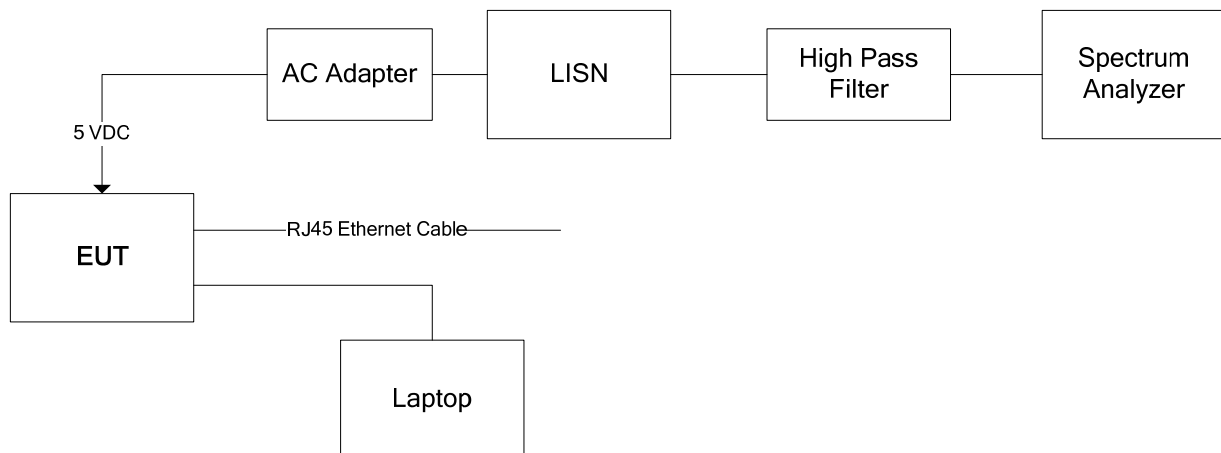
Frequency of emission (MHz)	Conducted Limits (dB μ V)	
	Quasi-peak	Average
0.15–0.5	66 to 56*	56 to 46*
0.5–5	56	46
5–30	60	50

*Decreases linearly with the logarithm of the frequency

5.1.2. Method of Measurements

ANSI C63.4

5.1.3. Test Arrangement

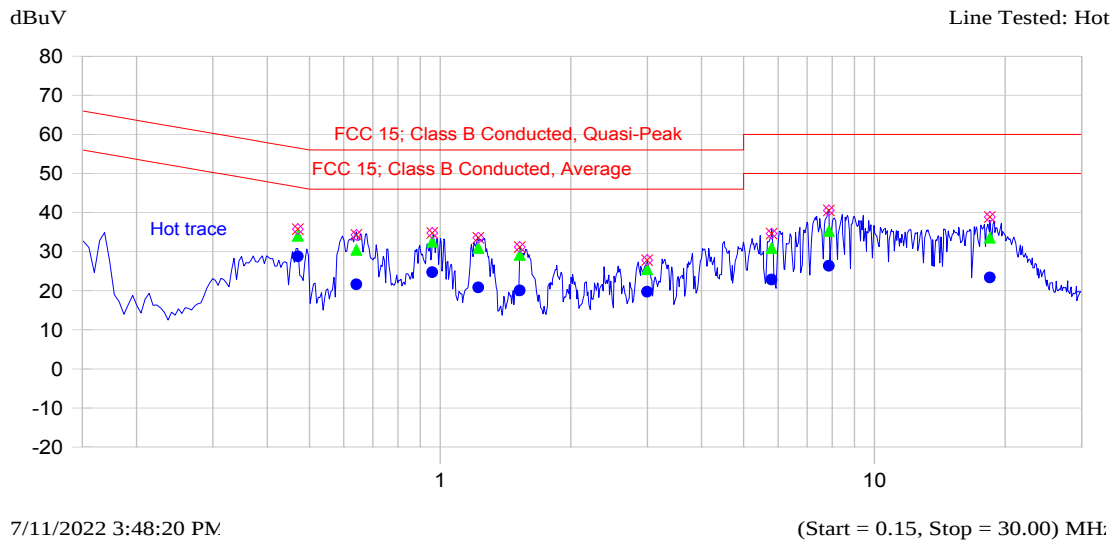


5.1.4. Test Data

Plot 5.1.4.1. Power Line Conducted Emissions (Tx Mode)

Line Voltage: 120 VAC; Line Tested: Hot

Current Graph

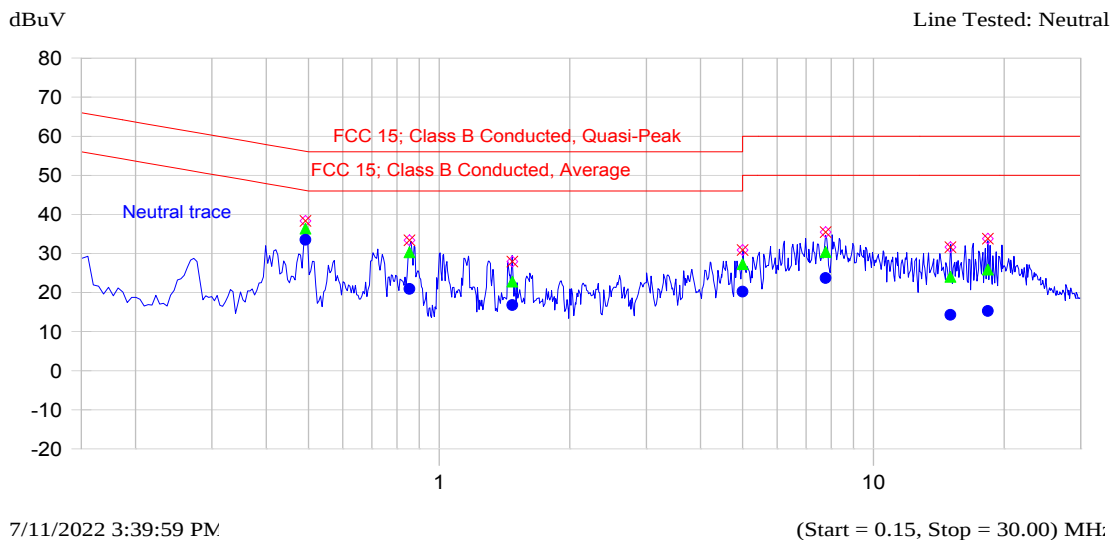


Current List

Frequency MHz	Peak dBuV	QP dBuV	QP-QP Limit dB	Avg dBuV	Avg-Avg Limit dB	Trace Name
0.470	35.7	34.1	-22.4	28.8	-17.7	Hot trace
0.641	34.3	30.5	-25.5	21.6	-24.4	Hot trace
0.959	34.8	32.5	-23.5	24.7	-21.3	Hot trace
1.224	33.5	31.0	-25.0	20.8	-25.2	Hot trace
1.526	31.1	29.2	-26.8	20.1	-25.9	Hot trace
2.996	27.8	25.5	-30.5	19.7	-26.3	Hot trace
5.796	34.6	31.0	-29.0	22.9	-27.1	Hot trace
7.857	40.5	35.3	-24.7	26.4	-23.6	Hot trace
18.430	38.8	33.6	-26.4	23.4	-26.6	Hot trace

Plot 5.1.4.2. Power Line Conducted Emissions (Tx Mode)

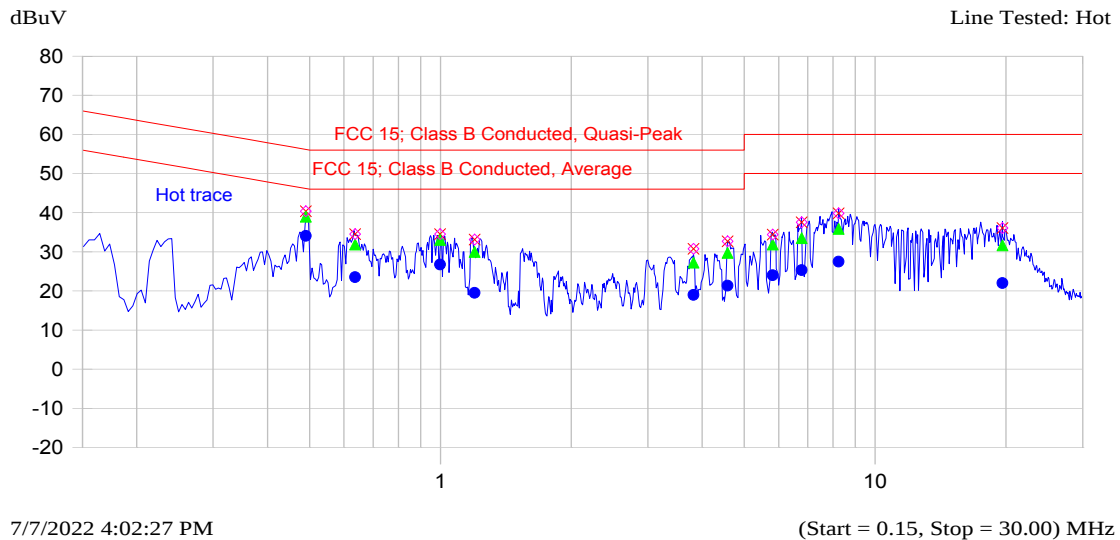
Line Voltage: 120 VAC Line Tested: Neutral

Current Graph**Current List**

Frequency MHz	Peak dBuV	QP dBuV	QP-QP Limit dB	Avg dBuV	Avg-Avg Limit dB	Trace Name
0.492	38.3	36.4	-19.8	33.5	-12.6	Neutral trace
0.855	33.4	30.3	-25.7	20.9	-25.1	Neutral trace
1.474	27.9	22.8	-33.2	16.8	-29.2	Neutral trace
5.001	30.9	27.3	-32.7	20.2	-29.8	Neutral trace
7.759	35.5	30.4	-29.6	23.7	-26.3	Neutral trace
15.052	31.6	24.1	-35.9	14.3	-35.7	Neutral trace
18.343	33.8	25.9	-34.1	15.3	-34.7	Neutral trace

Plot 5.1.4.3. Power Line Conducted Emissions (Rx Mode)

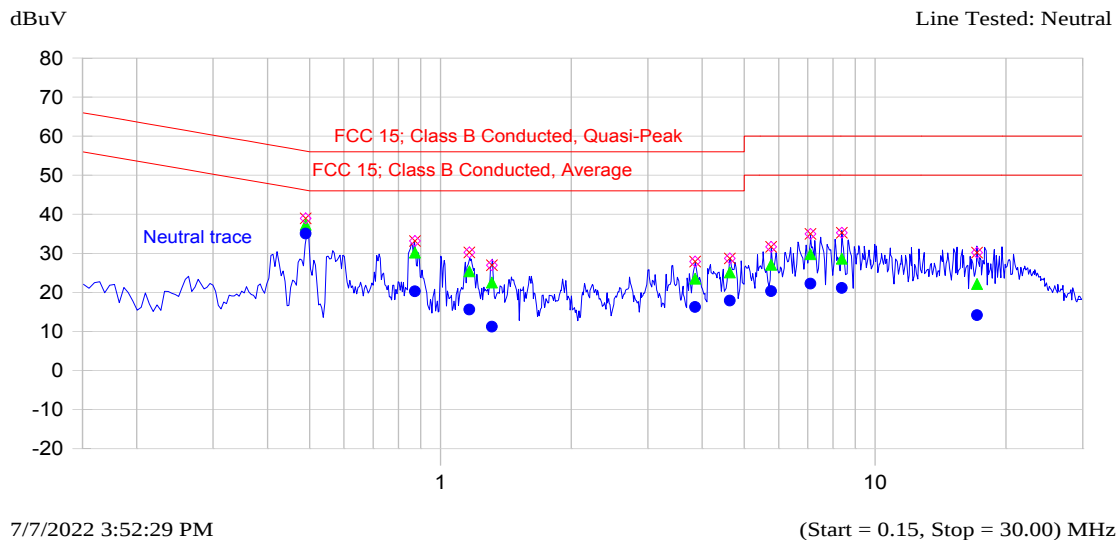
Line Voltage: 120 VAC; Line Tested: Hot

Current Graph**Current List**

Frequency MHz	Peak dBuV	QP dBuV	QP-QP Limit dB	Avg dBuV	Avg-Avg Limit dB	Trace Name
0.490	40.4	39.0	-17.2	34.1	-12.1	Hot trace
0.636	34.5	31.8	-24.2	23.5	-22.5	Hot trace
0.999	34.5	33.0	-23.0	26.7	-19.3	Hot trace
1.197	33.1	30.0	-26.0	19.5	-26.5	Hot trace
3.820	30.7	27.2	-28.8	19.0	-27.0	Hot trace
4.572	32.7	29.7	-26.3	21.3	-24.7	Hot trace
5.809	34.4	31.8	-28.2	24.0	-26.0	Hot trace
6.774	37.5	33.5	-26.5	25.3	-24.7	Hot trace
8.242	39.8	35.8	-24.2	27.5	-22.5	Hot trace
19.626	36.1	31.6	-28.4	22.0	-28.0	Hot trace

Plot 5.1.4.4. Power Line Conducted Emissions (Rx Mode)

Line Voltage: 120 VAC; Line Tested: Neutral

Current Graph**Current List**

Frequency MHz	Peak dBuV	QP dBuV	QP-QP Limit dB	Avg dBuV	Avg-Avg Limit dB	Trace Name
0.490	38.9	37.3	-18.9	35.1	-11.1	Neutral trace
0.873	33.2	30.2	-25.8	20.3	-25.7	Neutral trace
1.165	30.2	25.4	-30.6	15.6	-30.4	Neutral trace
1.312	26.9	22.5	-33.5	11.2	-34.8	Neutral trace
3.853	27.9	23.5	-32.5	16.3	-29.7	Neutral trace
4.630	28.7	25.1	-30.9	17.9	-28.1	Neutral trace
5.762	31.7	27.1	-32.9	20.3	-29.7	Neutral trace
7.097	35.0	29.7	-30.3	22.2	-27.8	Neutral trace
8.383	35.3	28.6	-31.4	21.1	-28.9	Neutral trace
17.149	30.2	22.1	-37.9	14.2	-35.8	Neutral trace

5.2. OCCUPIED BANDWIDTH [§ 15.247(a)(2)]

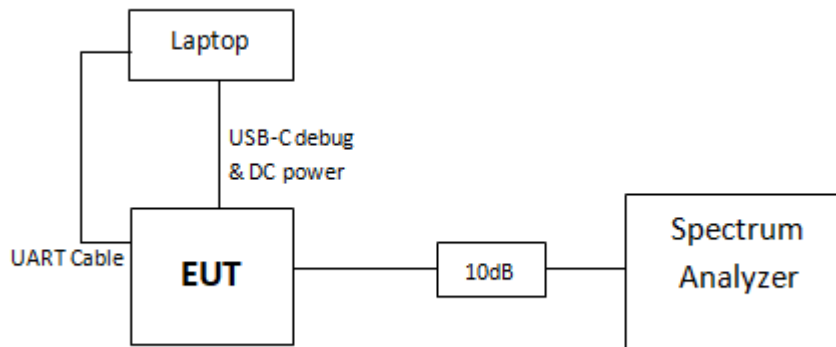
5.2.1. Limit(s)

The minimum 6 dB bandwidth shall be at least 500 kHz.

5.2.2. Method of Measurements

FCC KDB 558074 D01 15.247 Meas Guidance V05r02, Section 8.2 , ANSI C63.10, 11.8.2 Option 2

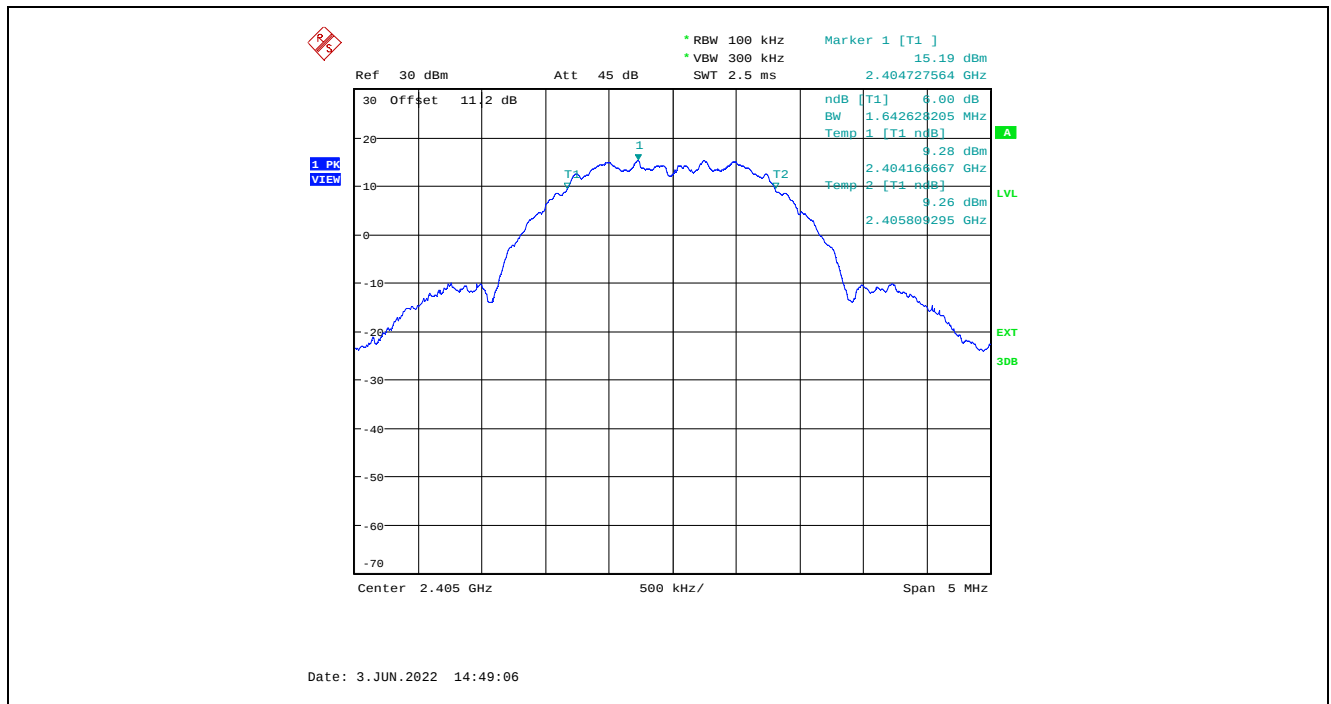
5.2.3. Test Arrangement



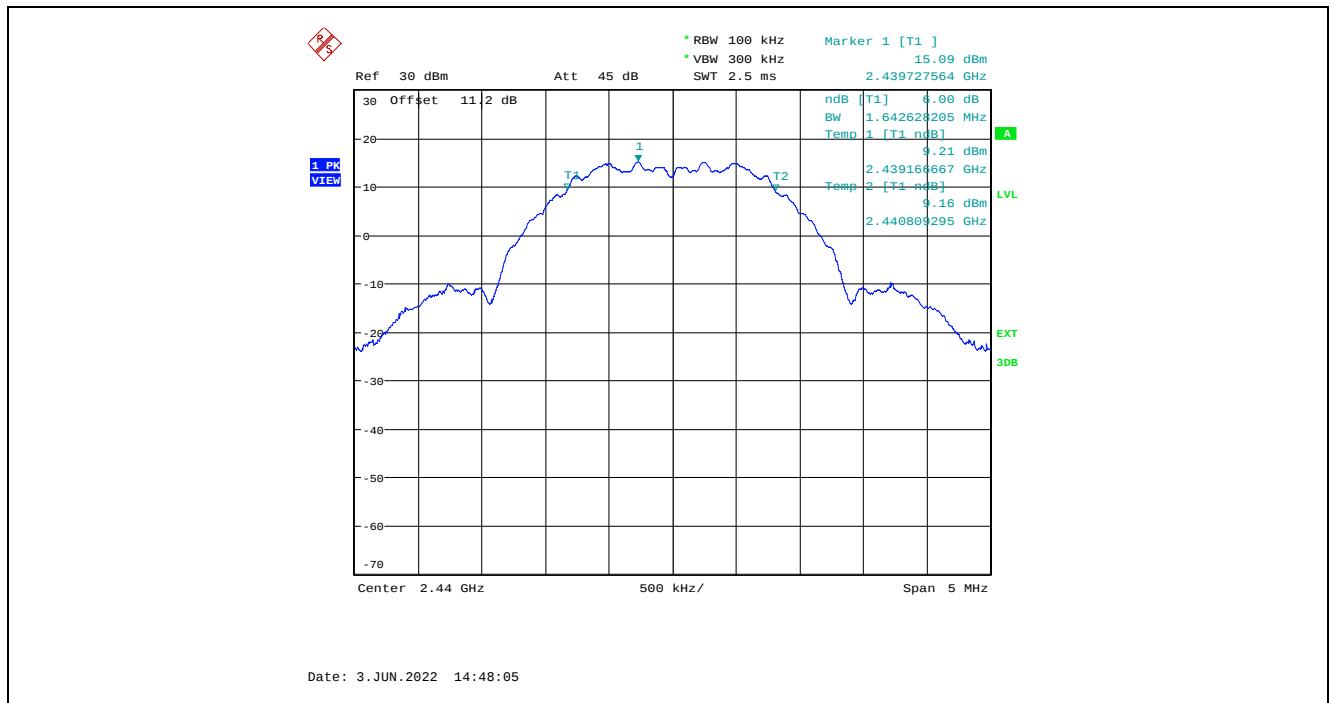
5.2.4. Test Data

Modulation	Power Setting	Frequency (MHz)	6dB BW (MHz)	Min. Limit (kHz)
O-QPSK	200	2405	1.643	500
	200	2440	1.643	500
	200	2475	1.643	500
	106	2480	1.651	500

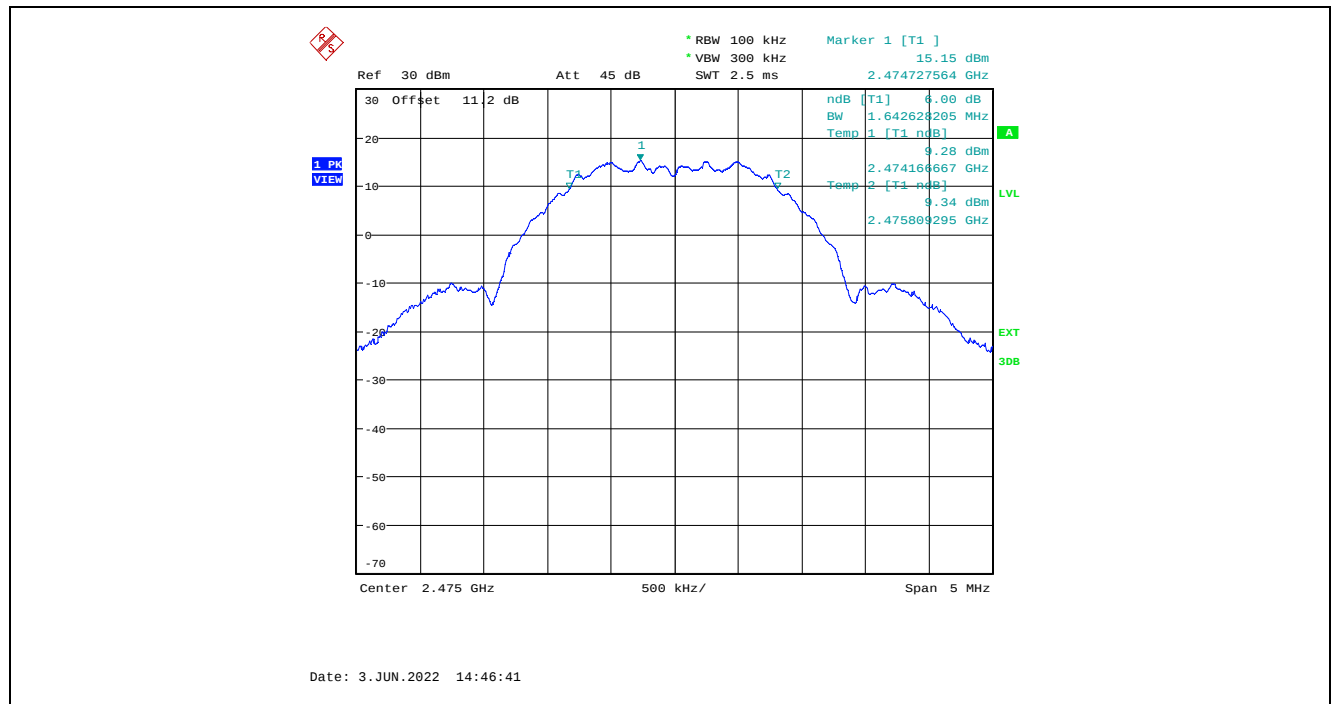
Plot 5.2.4.1. 6 dB Bandwidth, O-QPSK Modulation, Power Setting at 200, 2405 MHz



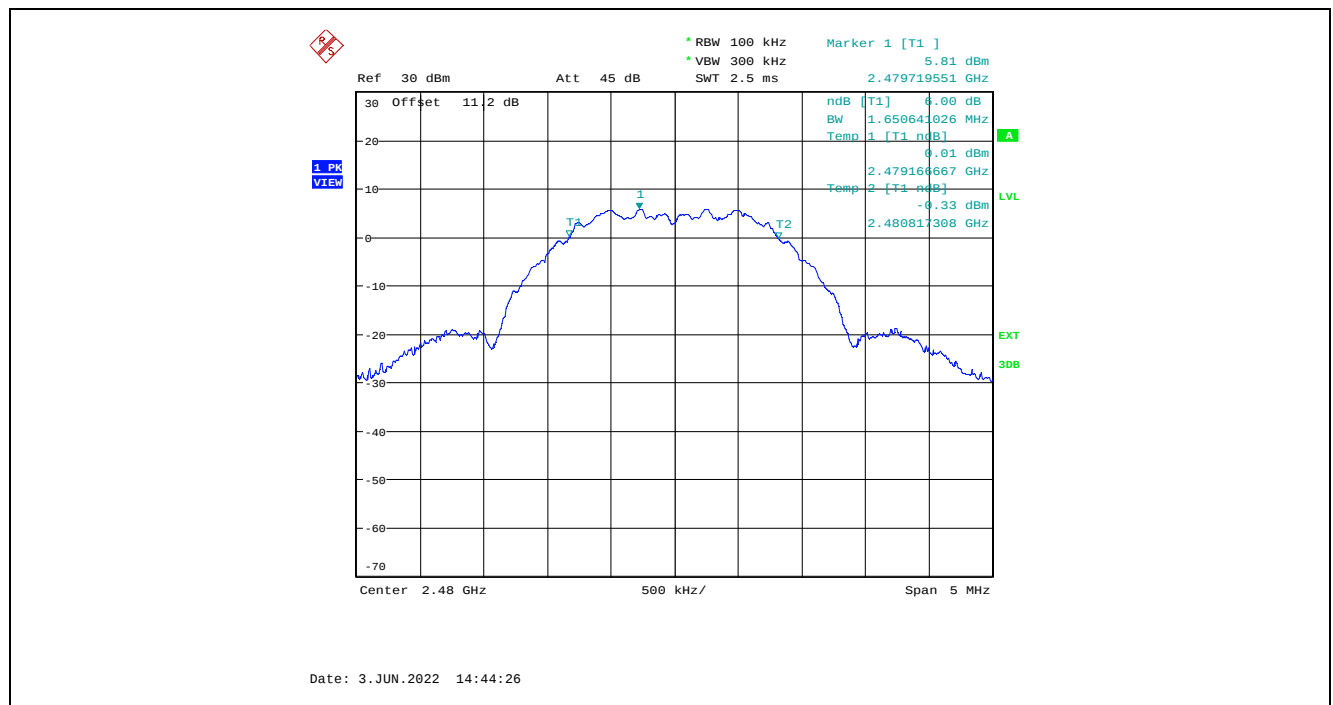
Plot 5.2.4.2. 6 dB Bandwidth, O-QPSK Modulation, Power Setting at 200, 2440 MHz



Plot 5.2.4.3. 6 dB Bandwidth, O-QPSK Modulation, Power Setting at 200, 2475 MHz



Plot 5.2.4.4. 6 dB Bandwidth, O-QPSK Modulation, Power Setting at 106, 2480 MHz



5.3. PEAK CONDUCTED OUTPUT POWER - DTS [§ 15.247(b)(3)]

5.3.1. Limit(s)

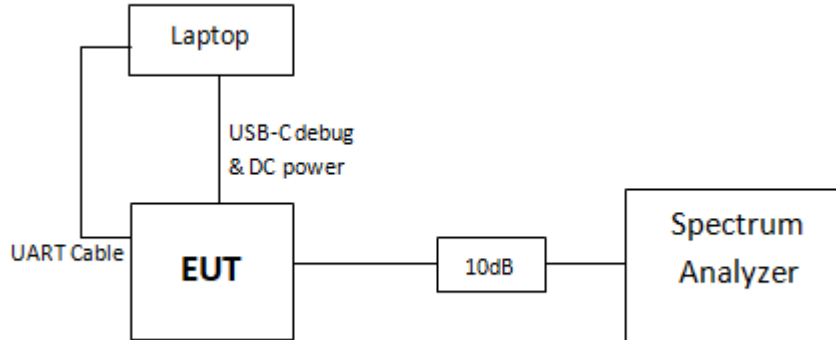
§ 15.247(b)(3): For systems using digital modulation in the 902-928 MHz, 2400-2483.5 MHz, and 5725-5850 MHz bands: 1 Watt. As an alternative to a peak power measurement, compliance with the one Watt limit can be based on a measurement of the maximum conducted output power. Maximum Conducted Output Power is defined as the total transmit power delivered to all antennas and antenna elements averaged across all symbols in the signaling alphabet when the transmitter is operating at its maximum power control level. Power must be summed across all antennas and antenna elements. The average must not include any time intervals during which the transmitter is off or is transmitting at a reduced power level. If multiple modes of operation are possible (e.g., alternative modulation methods), the *maximum conducted output power* is the highest total transmit power occurring in any mode.

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

5.3.2. Method of Measurements & Test Arrangement

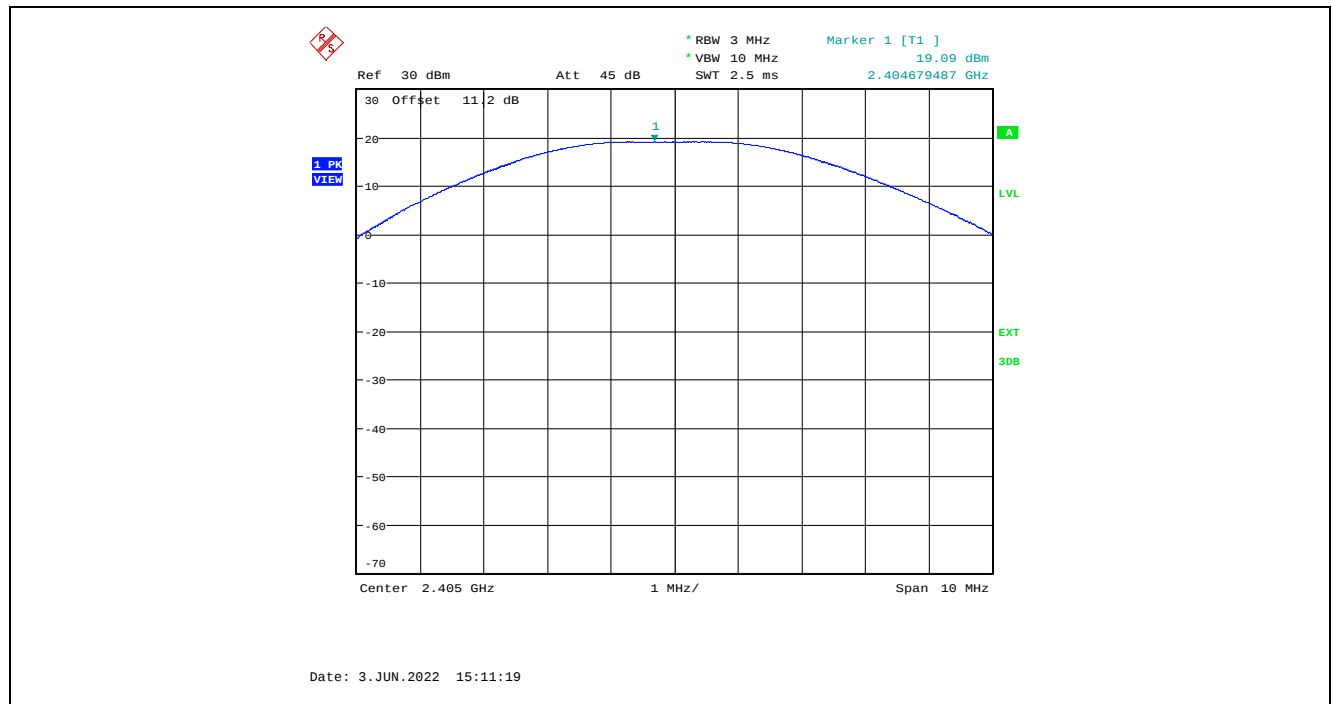
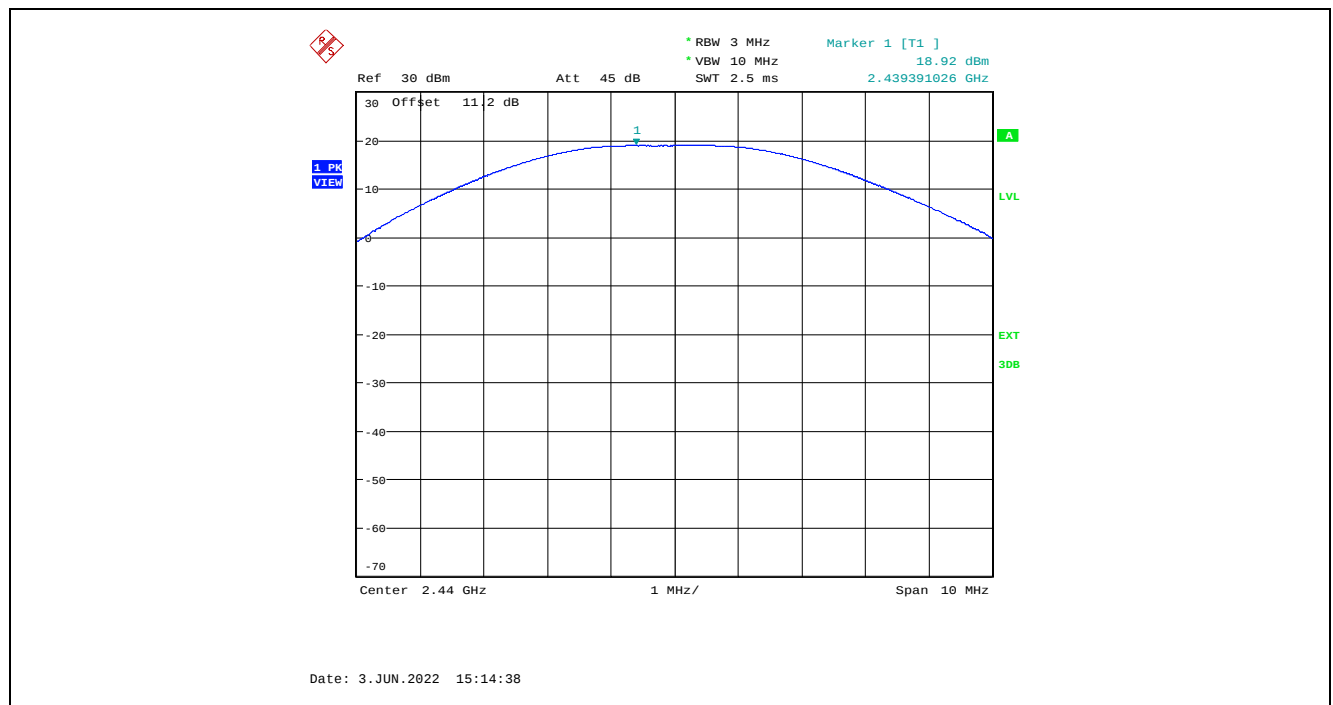
FCC KDB 558074 D01 15.247 Meas Guidance v05r01, Section 8.3.1.1 RBW $\geq$ DTS bandwidth or Subclause 11.9.1.1 of ANSI C63.10

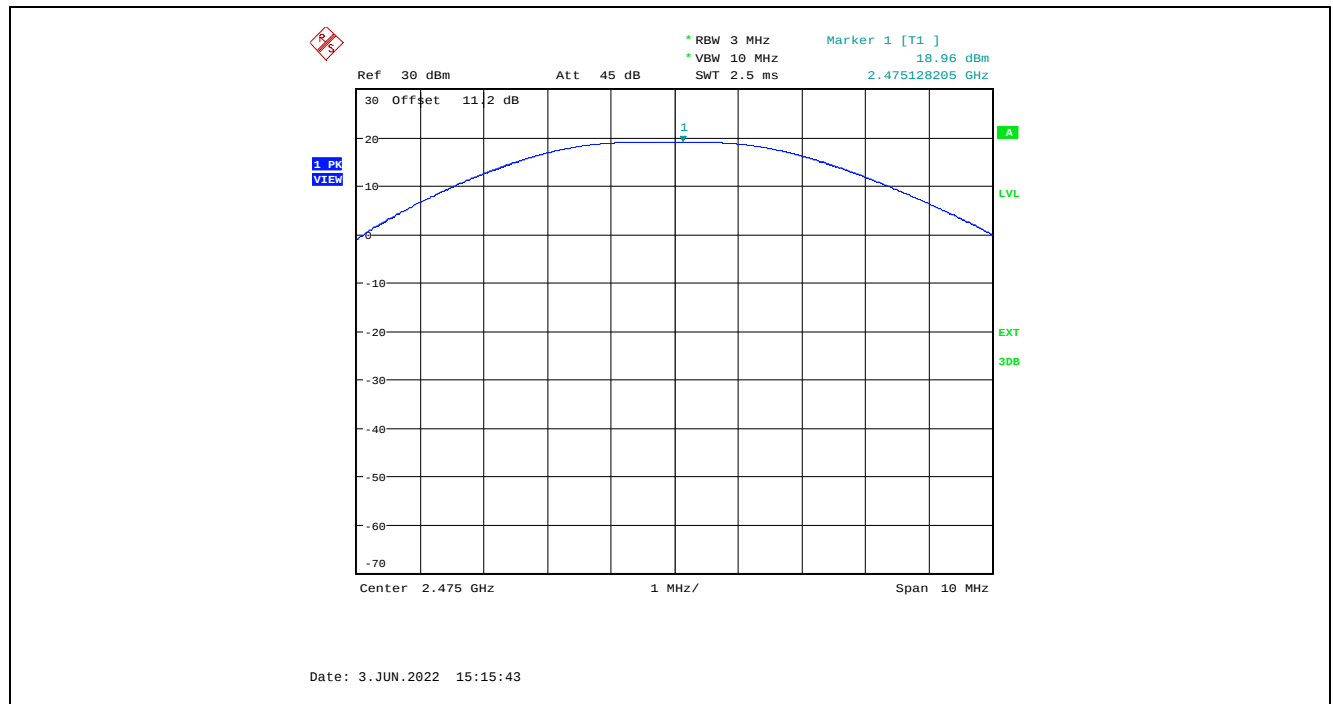
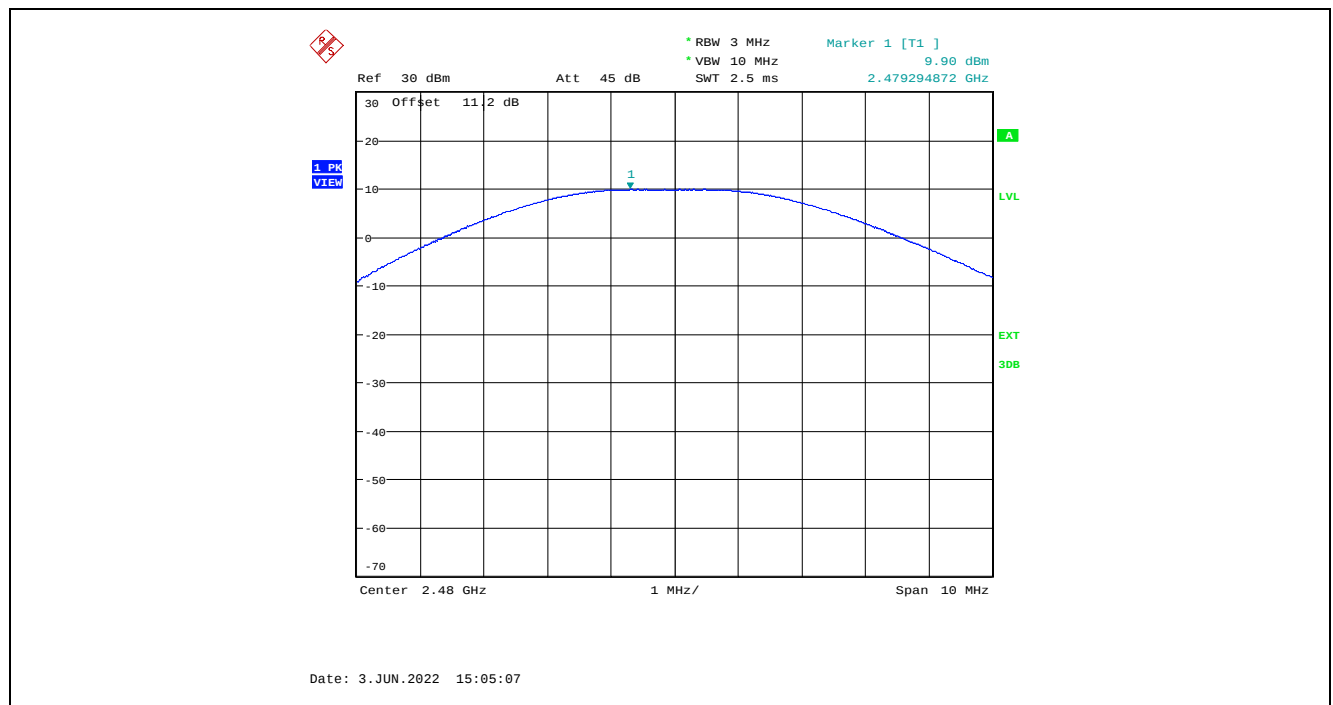
5.3.3. Test Arrangement



5.3.4. Test Data

Peak Conducted Power and Power Settings for EUT with 3.42 dBi PCB Trace Antenna					
Modulation	Power Setting	Frequency (MHz)	Peak Power (dBm)	Assembly Gain (dB)	EIRP (dBm)
O-QPSK	200	2405	19.09	3.42	22.51
		2440	18.92	3.42	22.34
		2475	18.96	3.42	22.38
	106	2480	9.90	3.42	13.32

Plot 5.3.4.1. Maximum Peak Conducted Output Power, O-QPSK Modulation, Power Setting 200, 2405 MHz**Plot 5.3.4.2.** Maximum Peak Conducted Output Power, O-QPSK Modulation, Power Setting 200, 2440 MHz

Plot 5.3.4.3. Maximum Peak Conducted Output Power, O-QPSK Modulation, Power Setting 200, 2475 MHz**Plot 5.3.4.4.** Maximum Peak Conducted Output Power, O-QPSK Modulation, Power Setting 106, 2480 MHz

5.4. TRANSMITTER SPURIOUS RADIATED EMISSIONS AT 3 METERS [§§ 15.247(d), 15.209 & 15.205]**5.4.1. Limit(s)**

§ 15.247 (d): In any 100 kHz bandwidth outside the frequency band in which the spread spectrum or digitally modulated intentional radiator is operating, the radio frequency power that is produced by the intentional radiator shall be at least 20 dB below that in the 100 kHz bandwidth within the band that contains the highest level of the desired power, based on either an RF conducted or a radiated measurement, provided the transmitter demonstrates compliance with the peak conducted power limits. If the transmitter complies with the conducted power limits based on the use of RMS averaging over a time interval, as permitted under paragraph (b)(3) of this section, the attenuation required under this paragraph shall be 30 dB instead of 20 dB. Attenuation below the general limits specified in Section 15.209(a) is not required. In addition, radiated emissions which fall in the restricted bands, as defined in Section 15.205(a), must also comply with the radiated emission limits specified in Section 15.209(a) (see Section 15.205(c)).

Section 15.205(a) - Restricted Bands of Operation

MHz	MHz	MHz	GHz
0.090–0.110	16.42–16.423	399.9–410	4.5–5.15
¹ 0.495–0.505	16.69475–16.69525	608–614	5.35–5.46
2.1735–2.1905	16.80425–16.80475	960–1240	7.25–7.75
4.125–4.128	25.5–25.67	1300–1427	8.025–8.5
4.17725–4.17775	37.5–38.25	1435–1626.5	9.0–9.2
4.20725–4.20775	73–74.6	1645.5–1646.5	9.3–9.5
6.215–6.218	74.8–75.2	1660–1710	10.6–12.7
6.26775–6.26825	108–121.94	1718.8–1722.2	13.25–13.4
6.31175–6.31225	123–138	2200–2300	14.47–14.5
8.291–8.294	149.9–150.05	2310–2390	15.35–16.2
8.362–8.366	156.52475–156.52525	2483.5–2500	17.7–21.4
8.37625–8.38675	156.7–156.9	2655–2900	22.01–23.12
8.41425–8.41475	162.0125–167.17	3260–3267	23.6–24.0
12.29–12.293	167.72–173.2	3332–3339	31.2–31.8
12.51975–12.52025	240–285	3345.8–3358	36.43–36.5
12.57675–12.57725	322–335.4	3600–4400	(²)
13.36–13.41			

¹ Until February 1, 1999, this restricted band shall be 0.490–0.510 MHz.

² Above 38.6

Section 15.209(a) - Field Strength Limits within Restricted Frequency Bands

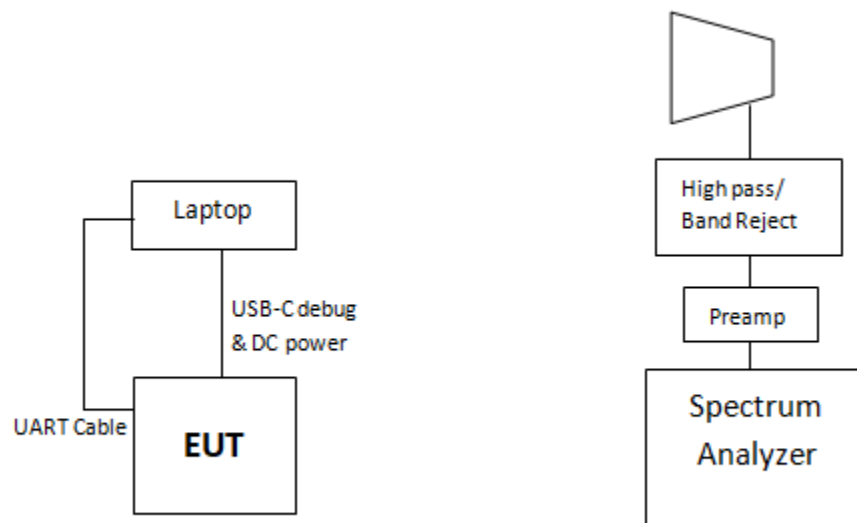
Frequency (MHz)	Field Strength (microvolts/meter)	Measurement Distance (meters)
0.009 - 0.490	2,400 / F (kHz)	300
0.490 - 1.705	24,000 / F (kHz)	30
1.705 - 30.0	30	30
30 - 88	100	3
88 - 216	150	3
216 - 960	200	3
Above 960	500	3

5.4.2. Method of Measurements

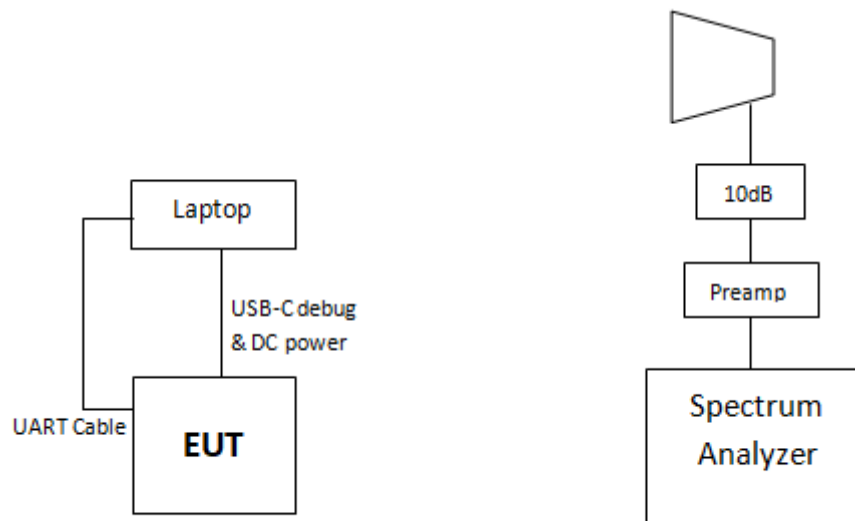
FCC KDB 558074 D01 15.247 Meas Guidance v05r01, Sections 8.5, 8.6 and 8.7 / Subclauses 6.10.6.2, 11.11 and 11.12. of ANSI C63.10.

5.4.3. Test Arrangement

Radiated Emissions



Band-Edge Radiated Emissions



5.4.4. Test Data**5.4.4.1. Transmitter Spurious Radiated Emissions****Remark(s):**

- All spurious emissions that are in excess of 20 dB below the specified limit shall be recorded.
- EUT shall be tested in three orthogonal positions.

Fundamental Frequency:		2405 MHz					
Frequency Test Range:		30 MHz – 25 GHz					
Power Setting:		200					
Frequency (MHz)	RF Peak Level (dBμV/m)	RF Avg Level (dBμV/m)	Antenna Plane (H/V)	Limit 15.209 (dBμV/m)	Limit 15.247 (dBμV/m)	Margin (dB)	Pass/Fail
2405	113.43	--	V	--	--	--	--
2405	113.00	--	H	--	--	--	--
4810	51.48	39.10	V	54.0	93.4	-14.9	Pass*
4810	50.81	38.68	H	54.0	93.4	-15.3	Pass*

*Field strength of emissions appearing within restricted frequency bands shall not exceed the limits in § 15.209.

Fundamental Frequency:		2440 MHz					
Frequency Test Range:		30 MHz – 25 GHz					
Power Setting:		200					
Frequency (MHz)	RF Peak Level (dBμV/m)	RF Avg Level (dBμV/m)	Antenna Plane (H/V)	Limit 15.209 (dBμV/m)	Limit 15.247 (dBμV/m)	Margin (dB)	Pass/Fail
2440	112.47	--	V	--	--	--	--
2440	113.27	--	H	--	--	--	--
4880	49.51	36.73	V	54.0	93.3	-17.3	Pass*
4880	49.55	36.86	H	54.0	93.3	-17.1	Pass*
7320	52.89	47.99	V	54.0	93.3	-6.0	Pass*
7320	55.74	51.01	H	54.0	93.3	-3.0	Pass*

*Field strength of emissions appearing within restricted frequency bands shall not exceed the limits in § 15.209.

Fundamental Frequency:		2475 MHz					
Frequency Test Range:		30 MHz – 25 GHz					
Power Setting:		200					
Frequency (MHz)	RF Peak Level (dBμV/m)	RF Avg Level (dBμV/m)	Antenna Plane (H/V)	Limit 15.209 (dBμV/m)	Limit 15.247 (dBμV/m)	Margin (dB)	Pass/Fail
2475	112.34	--	V	--	--	--	--
2475	115.12	--	H	--	--	--	--
4950	49.34	36.25	V	54.0	95.1	-17.8	Pass*
4950	48.78	35.66	H	54.0	95.1	-18.3	Pass*
7425	53.59	48.47	V	54.0	95.1	-5.5	Pass*
7425	55.57	51.08	H	54.0	95.1	-2.9	Pass*

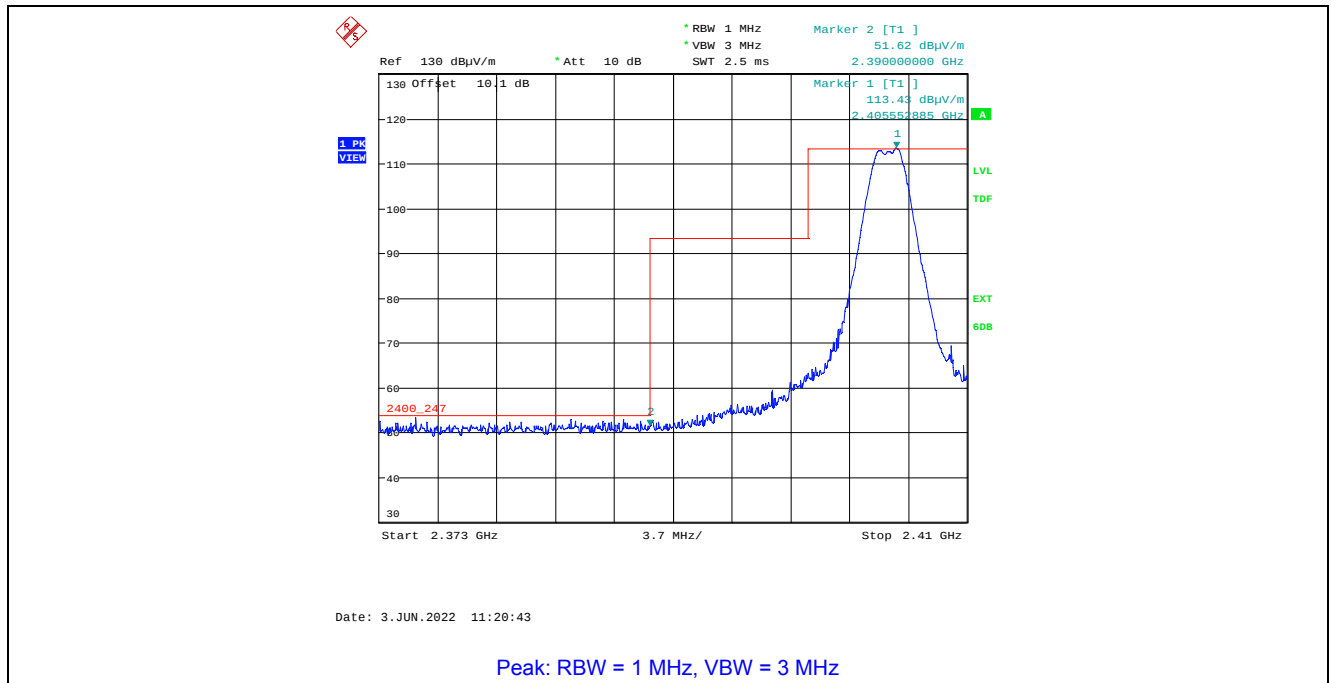
*Field strength of emissions appearing within restricted frequency bands shall not exceed the limits in § 15.209.

Fundamental Frequency:		2480 MHz					
Frequency Test Range:		30 MHz – 25 GHz					
Power Setting:		106					
Frequency (MHz)	RF Peak Level (dBμV/m)	RF Avg Level (dBμV/m)	Antenna Plane (H/V)	Limit 15.209 (dBμV/m)	Limit 15.247 (dBμV/m)	Margin (dB)	Pass/Fail
2480	102.77	--	V	--	--	--	--
2480	105.01	--	H	--	--	--	--
4960	50.60	39.50	V	54.0	85.0	-14.5	Pass*
4960	55.58	45.65	H	54.0	85.0	-8.4	Pass*
7440	55.41	42.79	V	54.0	85.0	-11.2	Pass*
7440	54.84	42.78	H	54.0	85.0	-11.2	Pass*

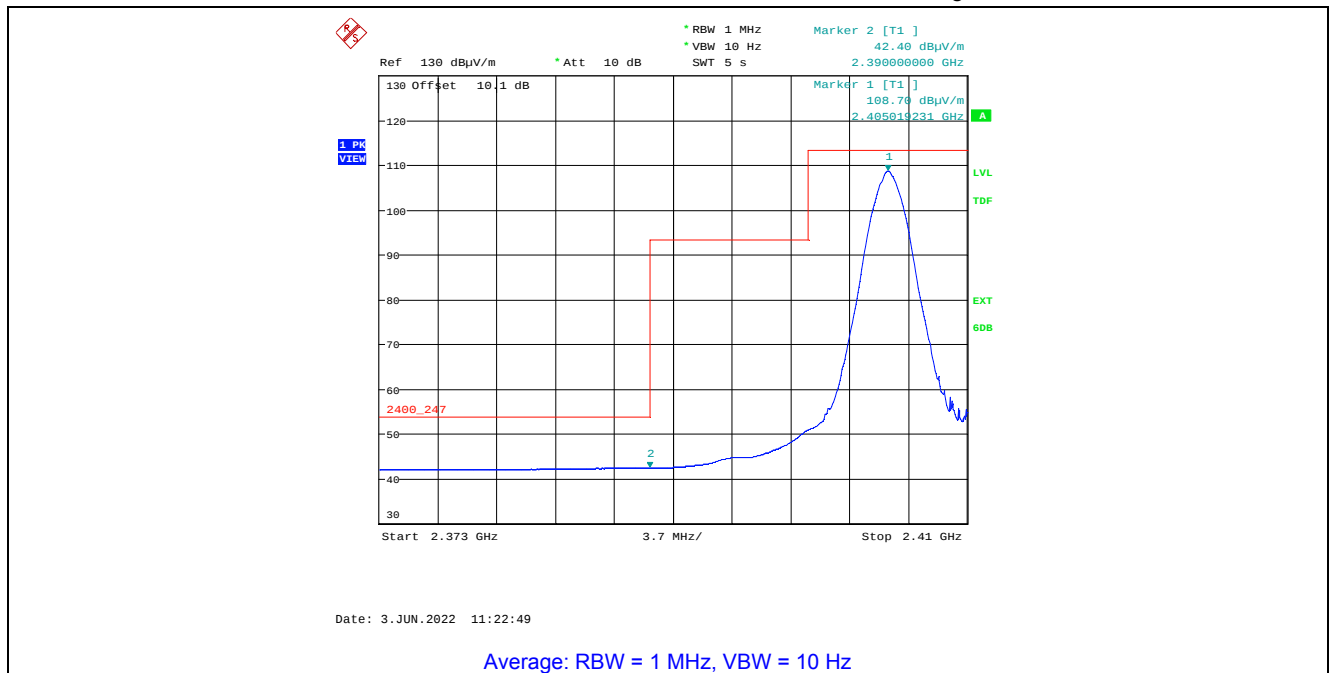
*Field strength of emissions appearing within restricted frequency bands shall not exceed the limits in § 15.209.

5.4.4.2. Band-Edge Radiated Emissions

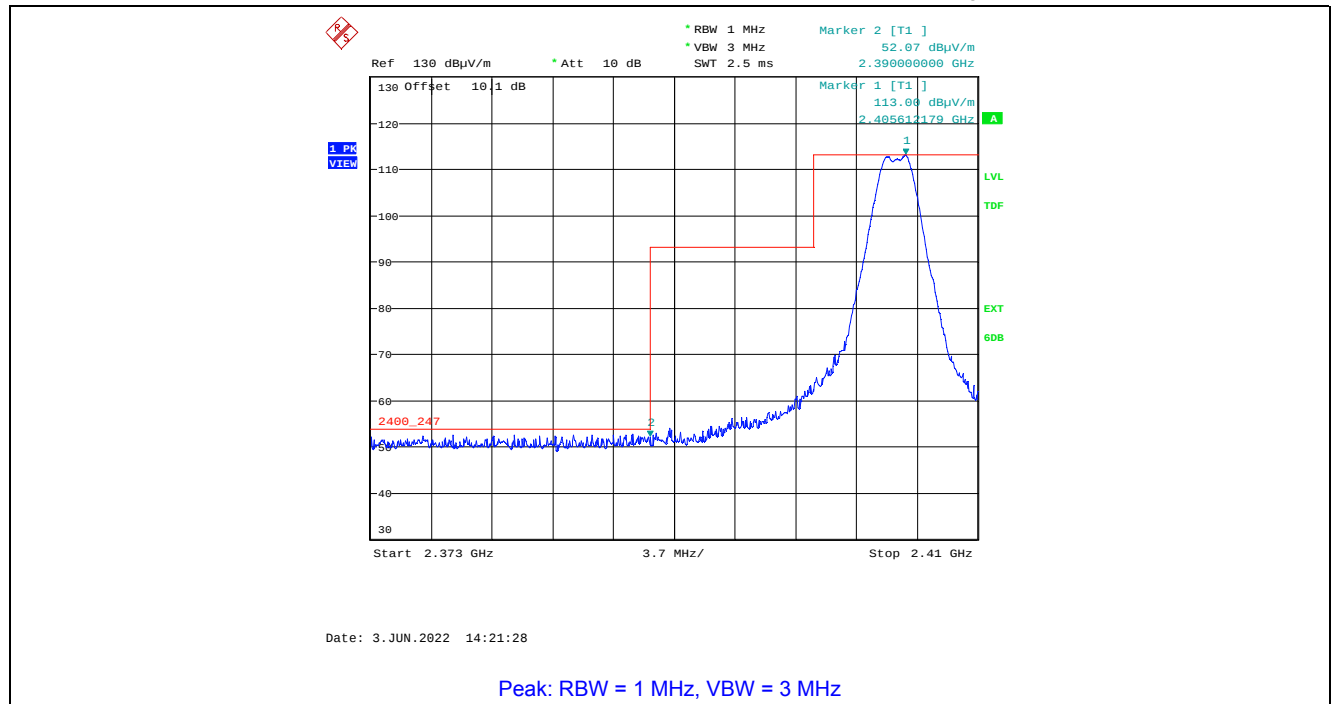
Plot 5.4.4.2.1. Band-Edge Radiated Emissions, Lower Band-edge
Rx Antenna in Vertical Polarization, O-QPSK Modulation, Power Setting 200, 2405 MHz



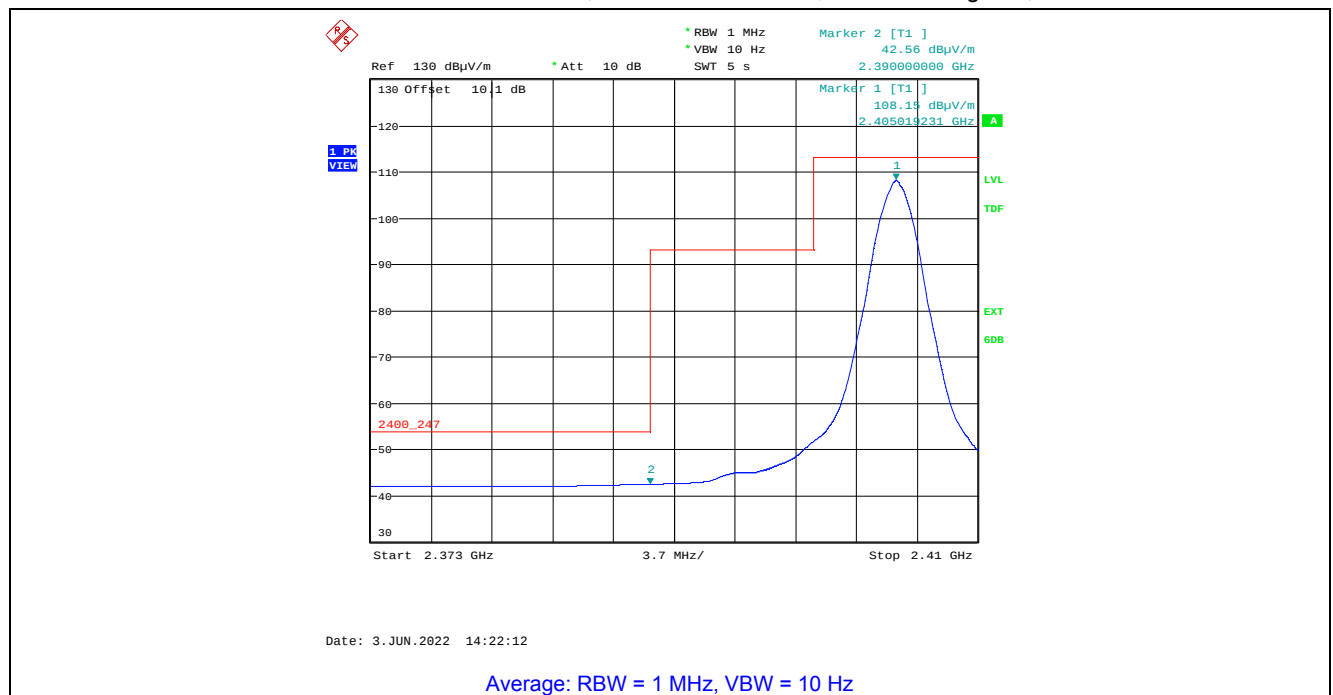
Plot 5.4.4.2.2. Band-Edge Radiated Emissions, Lower Band- edge
Rx Antenna in Vertical Polarization, O-QPSK Modulation, Power Setting 200, 2405 MHz



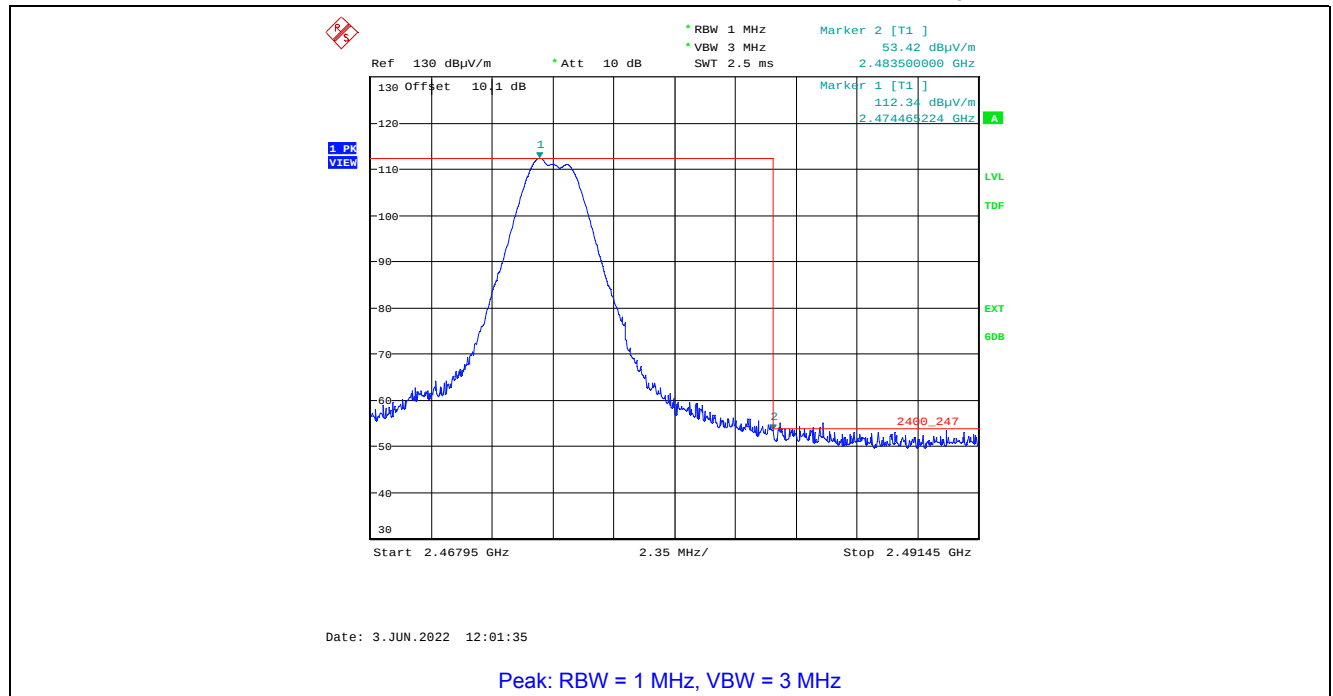
Plot 5.4.4.2.3. Band-Edge Radiated Emissions, Lower Band-edge
Rx Antenna in Horizontal Polarization, O-QPSK Modulation, Power Setting 200, 2405 MHz



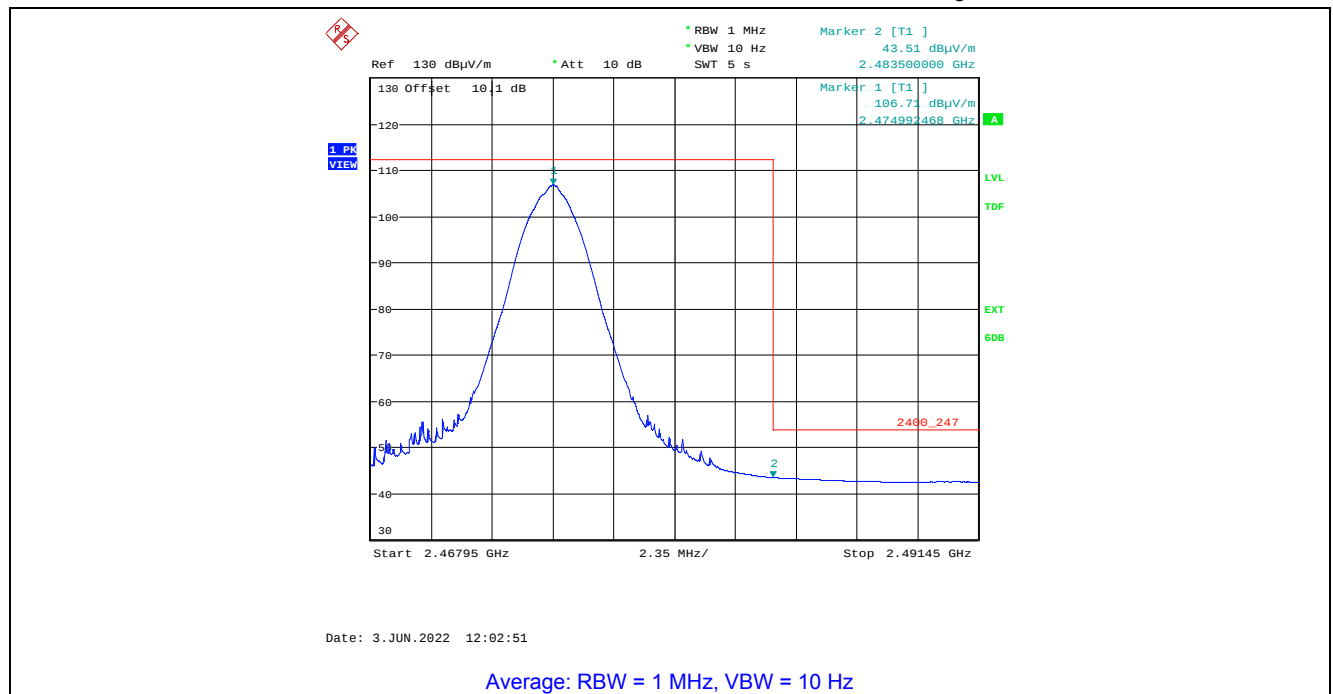
Plot 5.4.4.2.4. Band-Edge Radiated Emissions, Lower Band-edge
Rx Antenna in Horizontal Polarization, O-QPSK Modulation, Power Setting 200, 2405 MHz



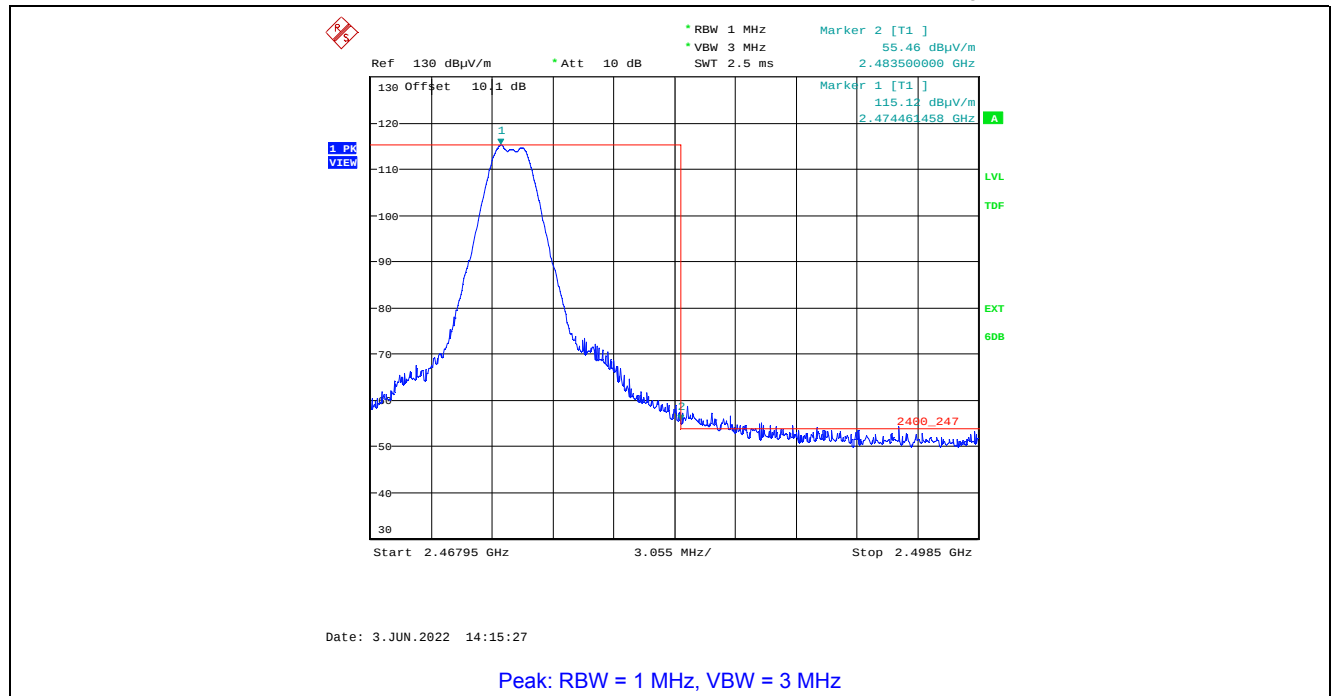
Plot 5.4.4.2.5. Band-Edge Radiated Emissions, Higher Band-edge
 Rx Antenna in Vertical Polarization, O-QPSK Modulation, Power Setting 200, 2475 MHz



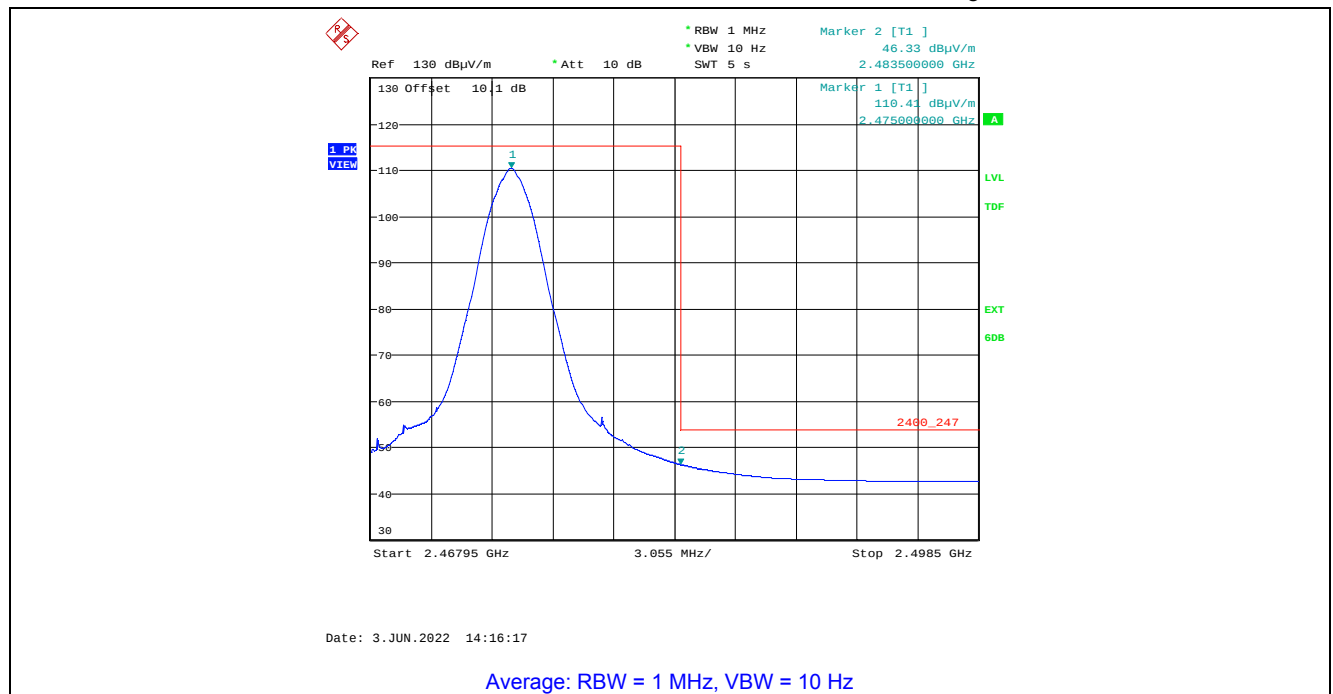
Plot 5.4.4.2.6. Band-Edge Radiated Emissions, Higher Band-edge
 Rx Antenna in Vertical Polarization, O-QPSK Modulation, Power Setting 200, 2475 MHz



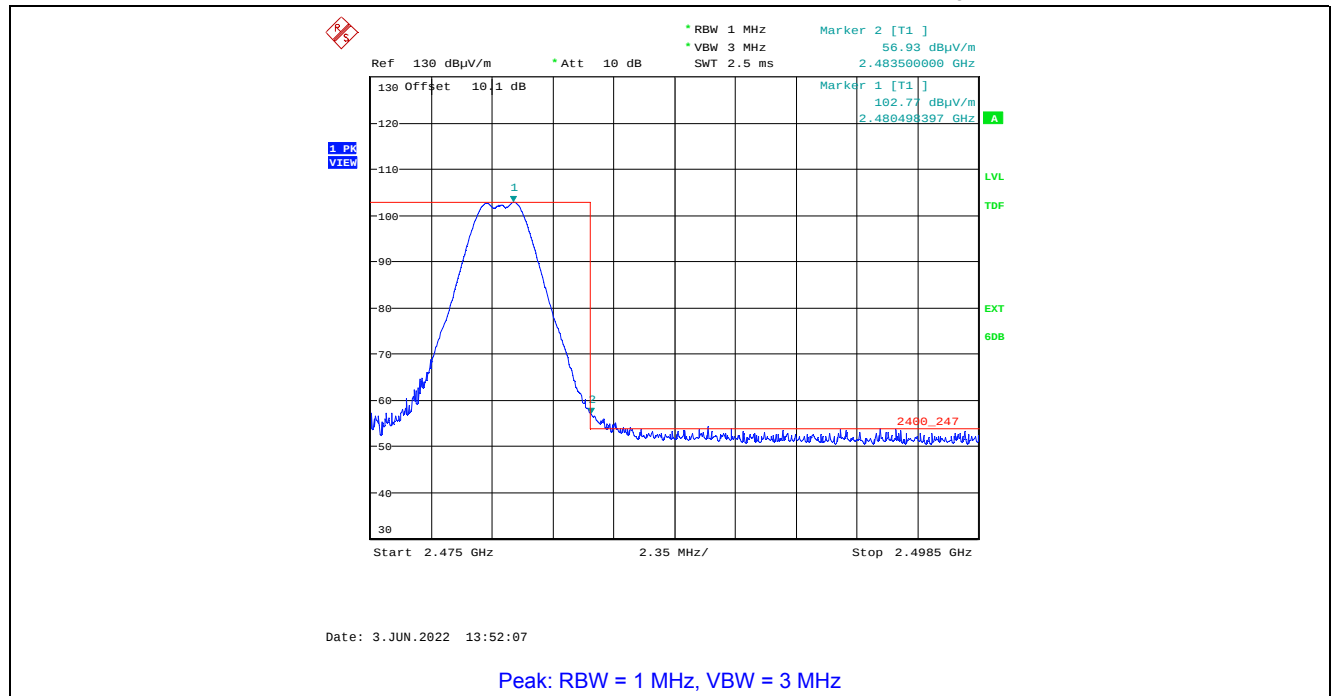
Plot 5.4.4.2.7. Band-Edge Radiated Emissions, Higher Band-edge
Rx Antenna in Horizontal Polarization, O-QPSK Modulation, Power Setting 200, 2475 MHz



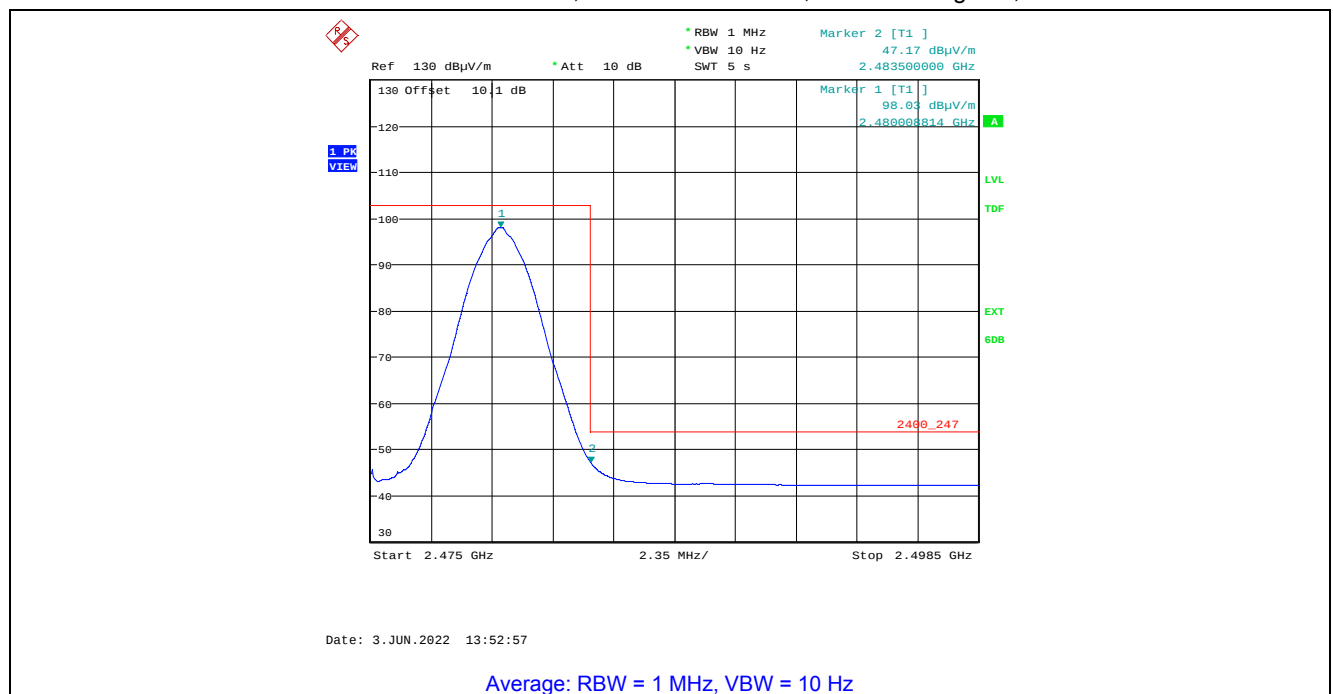
Plot 5.4.4.2.8. Band-Edge Radiated Emissions, Higher Band-edge
Rx Antenna in Horizontal Polarization, O-QPSK Modulation, Power Setting 200, 2475 MHz



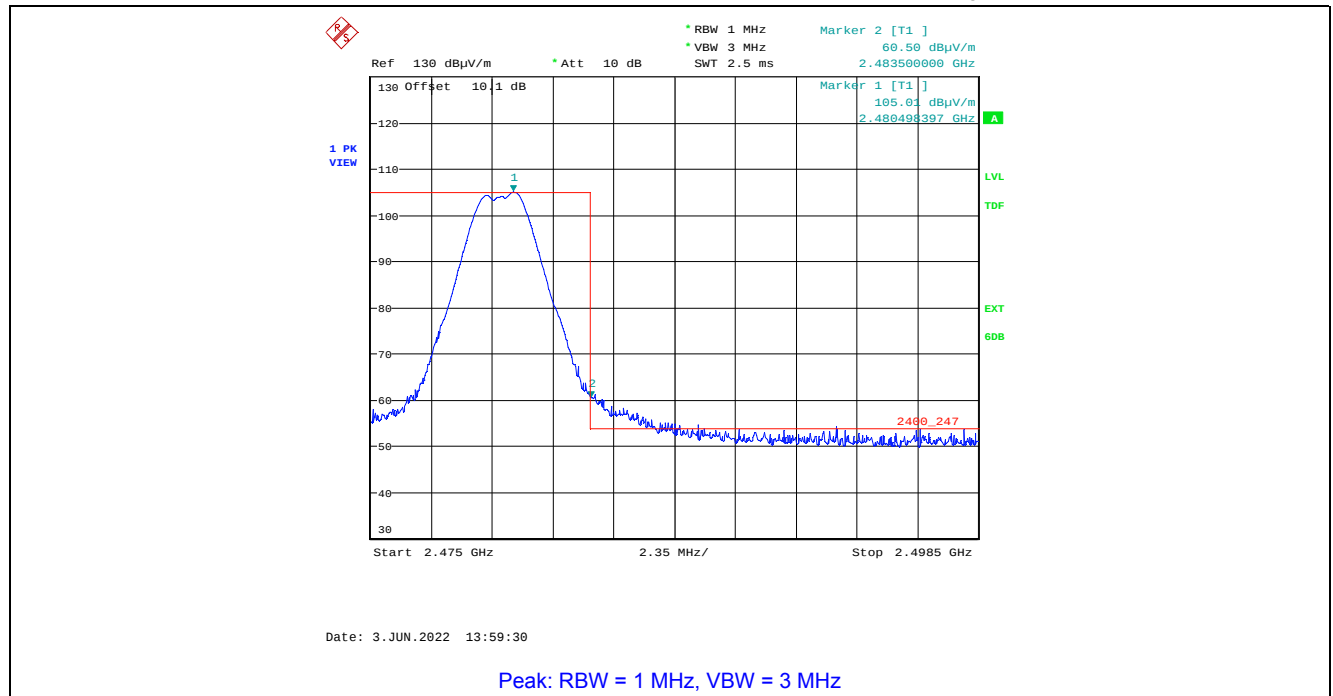
Plot 5.4.4.2.9. Band-Edge Radiated Emissions, Higher Band-edge
Rx Antenna in Vertical Polarization, O-QPSK Modulation, Power Setting 106, 2480 MHz



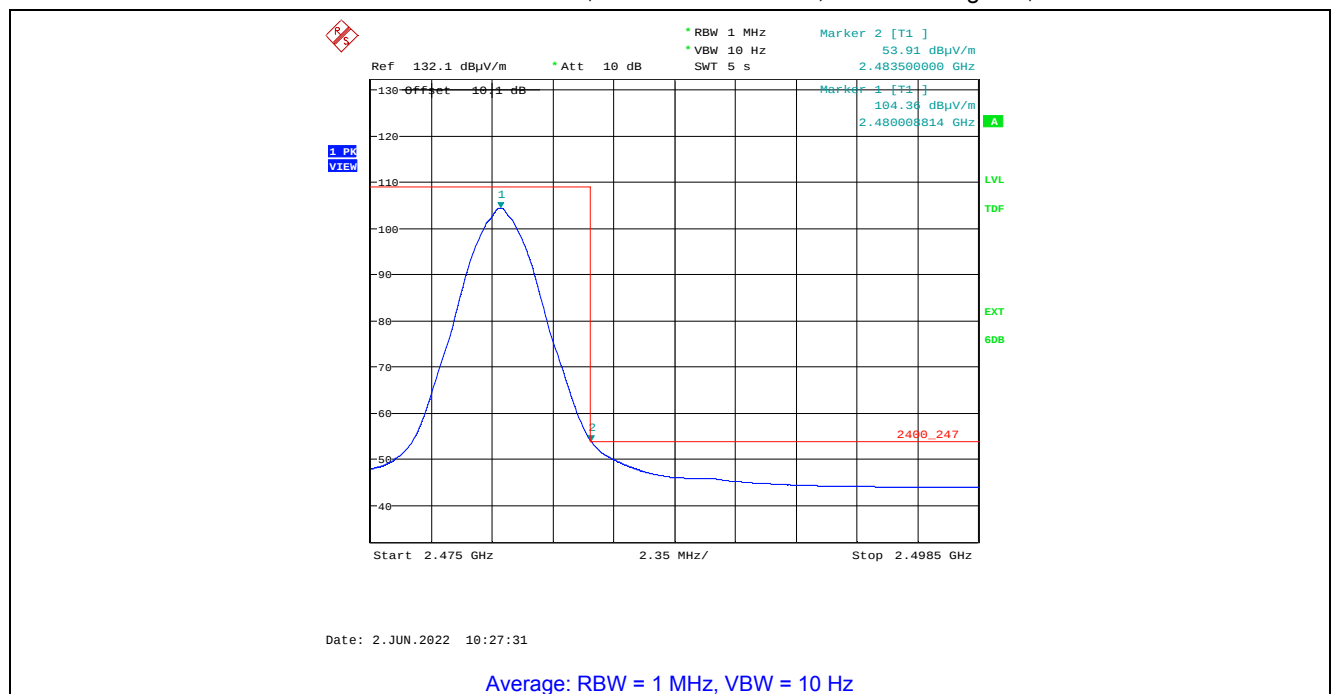
Plot 5.4.4.2.10. Band-Edge Radiated Emissions, Higher Band-edge
Rx Antenna in Vertical Polarization, O-QPSK Modulation, Power Setting 106, 2480 MHz



Plot 5.4.4.2.11. Band-Edge Radiated Emissions, Higher Band-edge
Rx Antenna in Horizontal Polarization, O-QPSK Modulation, Power Setting 106, 2480 MHz



Plot 5.4.4.2.12. Band-Edge Radiated Emissions, Higher Band-edge
Rx Antenna in Horizontal Polarization, O-QPSK Modulation, Power Setting 106, 2480 MHz



5.5. POWER SPECTRAL DENSITY [§ 15.247(e)]

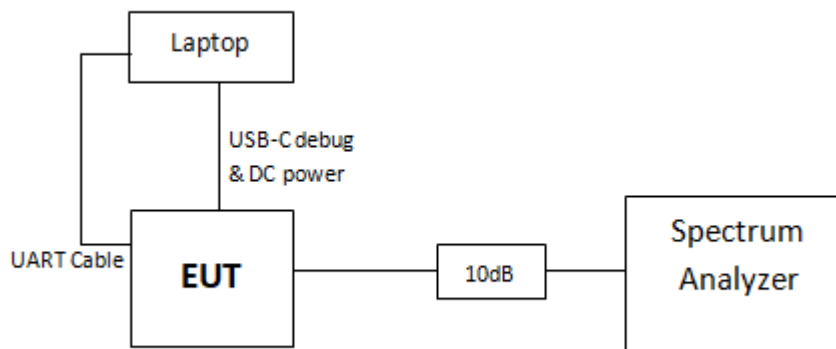
5.5.1. Limit(s)

For digitally modulated 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.

5.5.2. Method of Measurements

KDB 558074 D01 15.247 Meas Guidance v05r01, Section 8.4 / ANSI C63.10 Subclause 11.10.2 Method PKPSD (peak PSD).

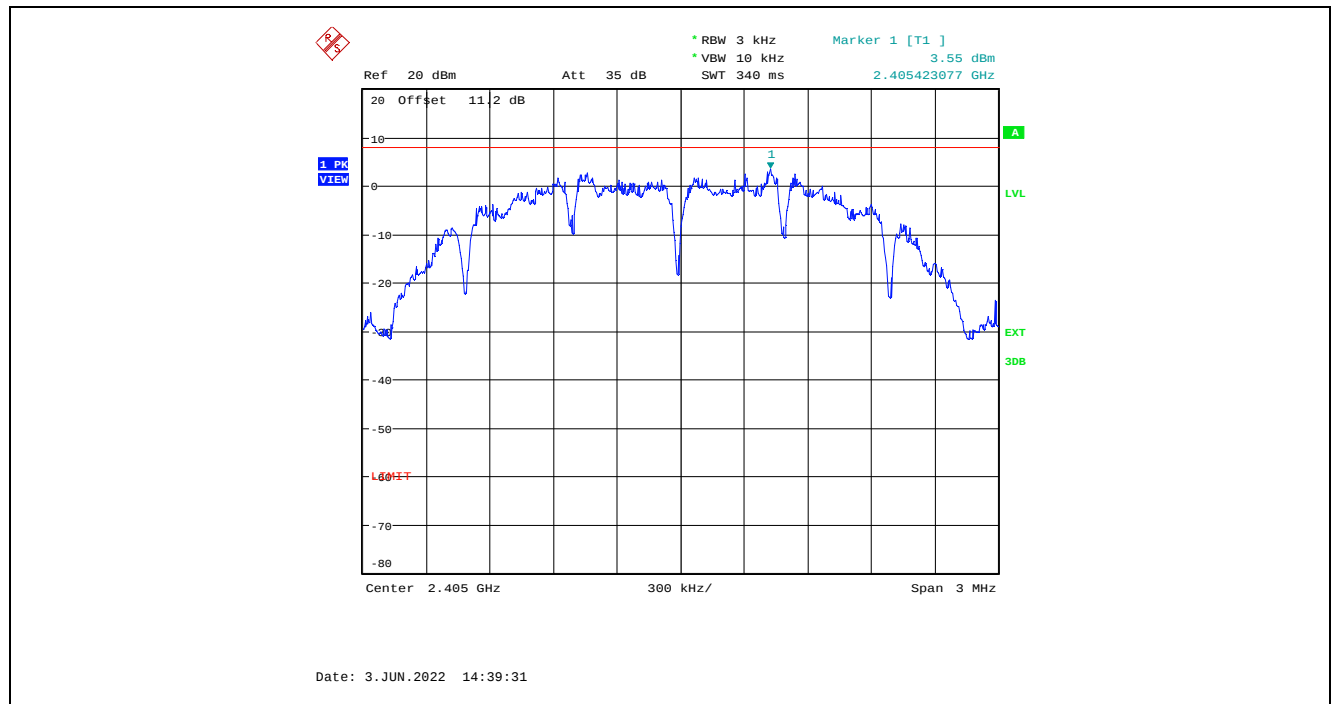
5.5.3. Test Arrangement



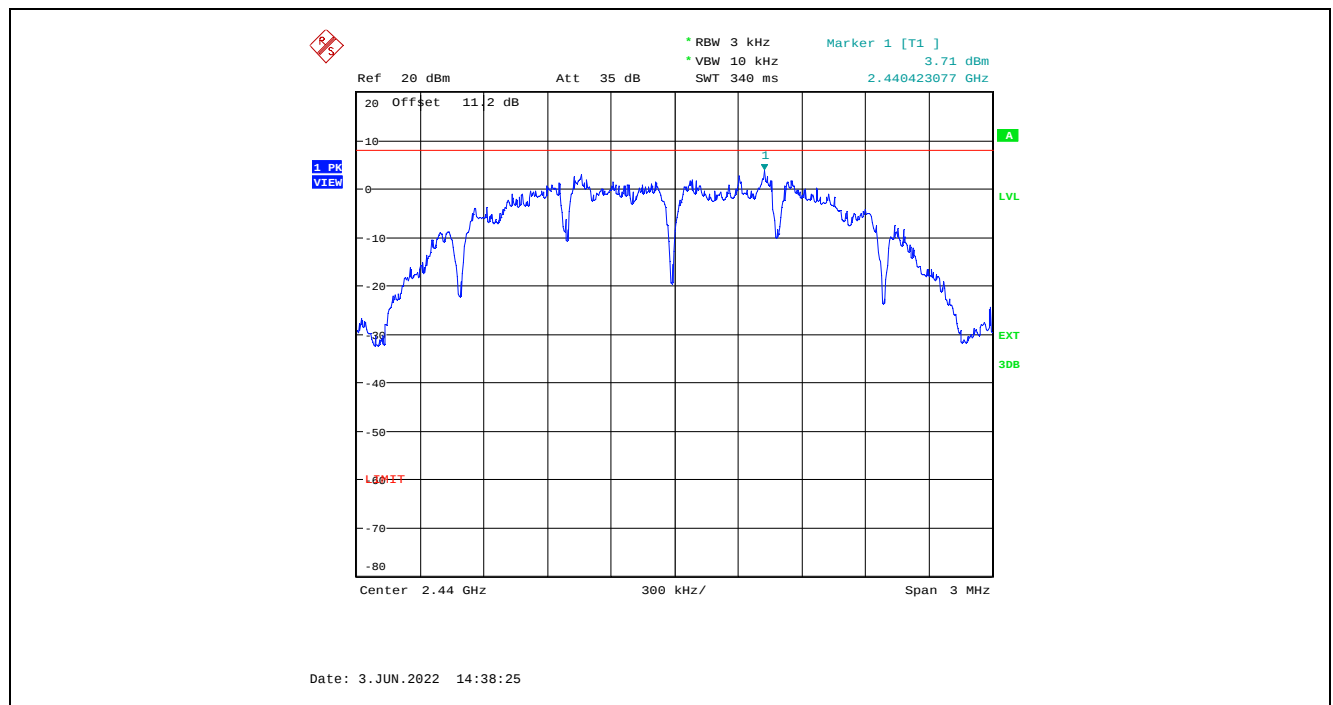
5.5.4. Test Data

Modulation	Power Setting	Frequency (MHz)	PSD (dBm)	Max. Limit (dBm)	Margin (dBm)
O-QPSK	200	2405	3.55	8	-4.45
		2440	3.71	8	-4.29
		2475	3.66	8	-4.34
	106	2480	-5.63	8	-13.63

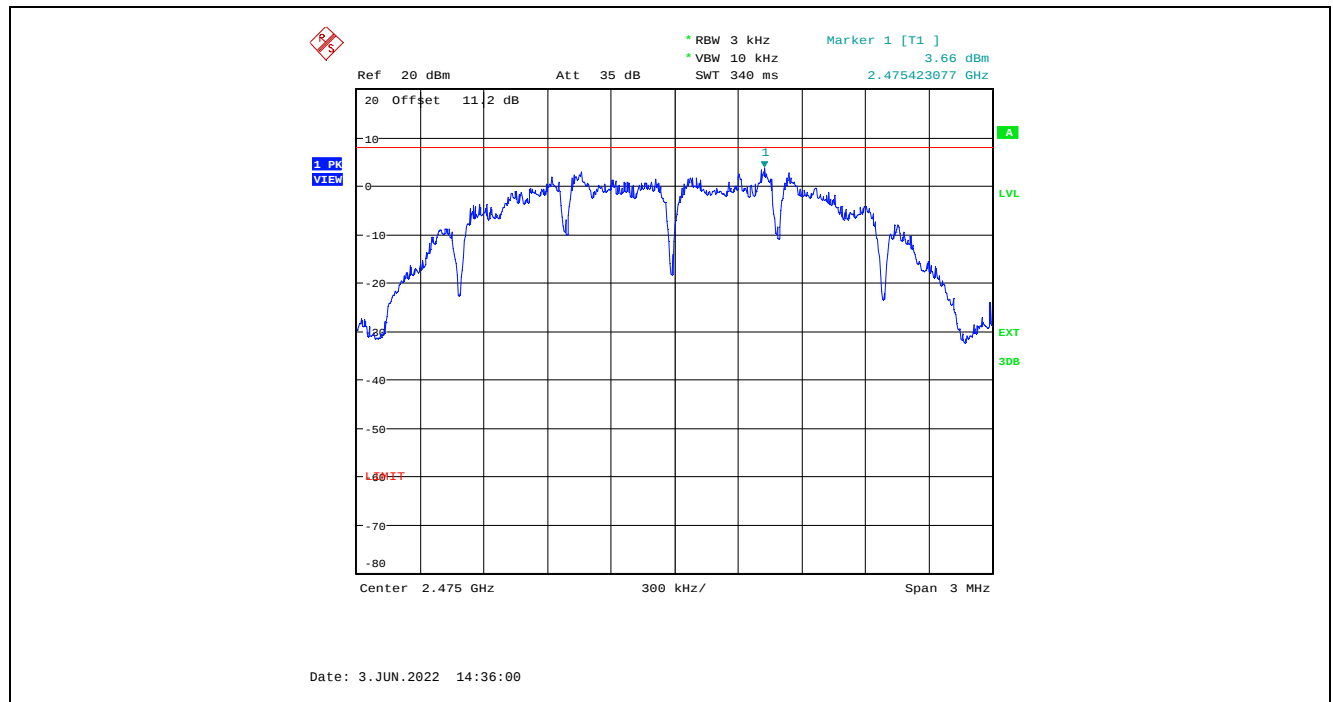
Plot 5.5.4.1. Power Spectral Density, O-QPSK Modulation, Power Setting 200, 2405 MHz



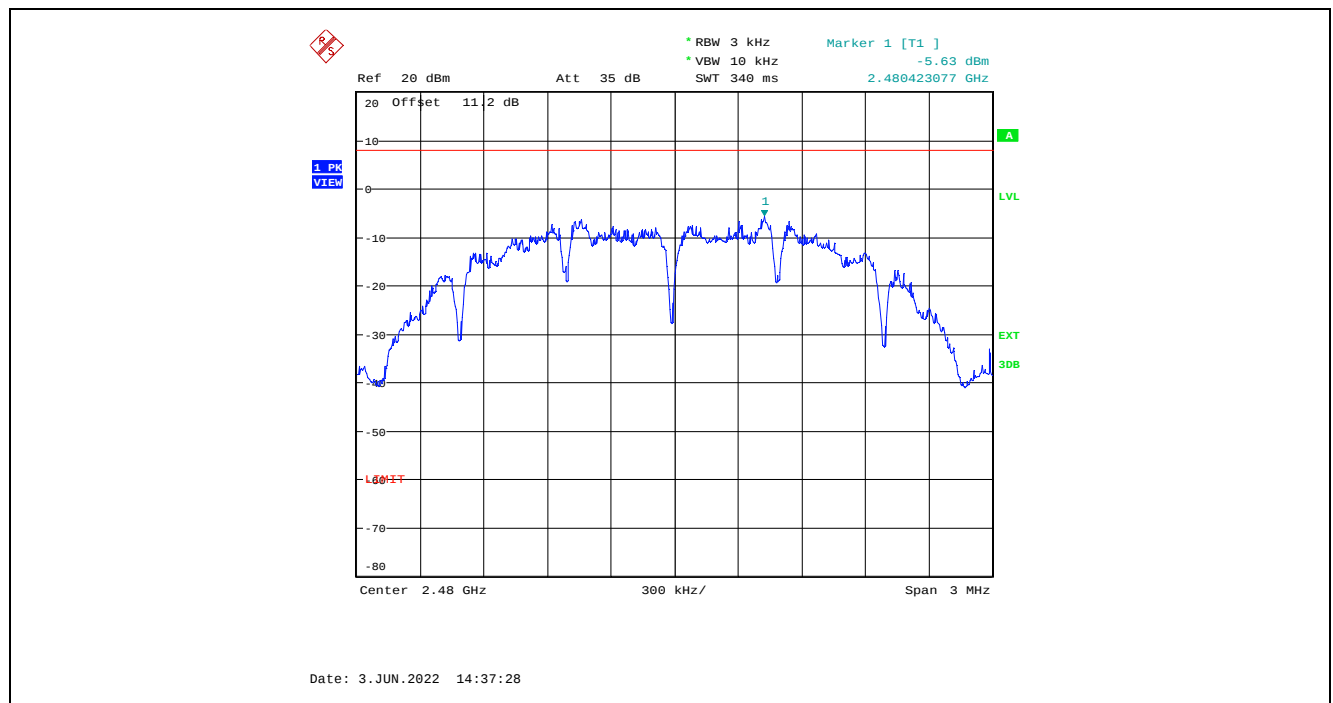
Plot 5.5.4.2. Power Spectral Density, O-QPSK Modulation, Power Setting 200, 2440 MHz



Plot 5.5.4.3. Power Spectral Density, O-QPSK Modulation, Power Setting 200, 2475 MHz



Plot 5.5.4.4. Power Spectral Density, O-QPSK Modulation, Power Setting 106, 2480 MHz



5.6. RF EXPOSURE REQUIREMENTS [§§ 15.247(i), 1.1310 & 2.1091]**5.6.1. Limits**

§ 1.1310: The criteria listed in the following table shall be used to evaluate the environmental impact of human exposure to radio-frequency (RF) radiation as specified in 1.1307(b).

Limits for Maximum Permissible Exposure (MPE)

Frequency range (MHz)	Electric field strength (V/m)	Magnetic field strength (A/m)	Power density (mW/cm ²)	Averaging time (minutes)
(A) Limits for Occupational/Controlled Exposures				
0.3-3.0	614	1.63	*(100)	6
3.0-30	1842/f	4.89/f	*(900/f ²)	6
30-300	61.4	0.163	1.0	6
300-1500			f/300	6
1500-100,000			5	6
(B) Limits for General Population/Uncontrolled Exposure				
0.3-1.34	614	1.63	*(100)	30
1.34-30	824/f	2.19/f	*(180/f ²)	30
30-300	27.5	0.073	0.2	30
300-1500			f/1500	30
1500-100,000			1.0	30

f = frequency in MHz

* = Plane-wave equivalent power density

Note 1: Occupational/controlled limits apply in situations in which persons are exposed as a consequence of their employment provided those persons are fully aware of the potential for exposure and can exercise control over their exposure. Limits for occupational/controlled exposure also apply in situations when an individual is transient through a location where occupational/controlled limits apply provided he or she is made aware of the potential for exposure.

Note 2: General population/uncontrolled exposures apply in situations in which the general public may be exposed, or in which persons that are exposed as a consequence of their employment may not be fully aware of the potential for exposure or cannot exercise control over their exposure.

5.6.2. Method of Measurements

Calculation Method of Power Density/RF Safety Distance:

$$S = \frac{PG}{4\pi \cdot r^2} = \frac{EIRP}{4\pi \cdot r^2}$$

Where,

- P: power input to the antenna in mW
- EIRP: Equivalent (effective) isotropic radiated power.
- S: power density mW/cm²
- G: numeric gain of antenna relative to isotropic radiator
- r: distance to centre of radiation in cm

5.6.3. RF Evaluation

Pursuant to KDB 447498 D01 General RF Exposure Guidance v06, Section 7.2:

Simultaneous transmission MPE test exclusion applies when the sum of the MPE ratios for all simultaneously transmitting antennas incorporated in a host device is ≤ 1.0, according to calculated/estimated, numerically modeled, or measured field strengths or power density.

The EUT contained a ZigBee radio and a certified ESPRESSIF SYSTEMS (SHANGHAI) CO., LTD Wi-Fi & Bluetooth IoT module, the table below is the calculated sum of the MPE ratios from all sources for co-located MPE evaluation at 20 cm distance.

Source	Maximum MPE Ratio
EUT, MMB Networks Zigbee Radio	0.0576
ESPRESSIF SYSTEMS (SHANGHAI) CO., LTD Wi-Fi & Bluetooth IoT Module (FCC ID: 2AC7Z-ESP32WROVERE)	0.2183
Sum of the MPE ratios from all sources:	0.2759

The sum of the MPE ratios from all sources is < 1. Thus, in compliant with the general public (uncontrolled environment) MPE limit.

For detailed MPE ratios calculation, refer to the following tables.

Calculated MPE Ratio for EUT Zigbee Radio							
Frequency Band (MHz)	Frequency (MHz)	¹ Max. EIRP (dBm)	Max. EIRP (mW)	Evaluation Distance (cm)	Power Density (mW/cm ²)	MPE Limit (mW/cm ²)	MPE Ratio
2405-2480	2405	24.62	289.734	20	0.0576	1.0	0.0576

¹ Maximum EIRP = Tune-up conducted power of 21.2 dBm + maximum antenna gain of 3.42 dBi

Calculated MPE Ratio for Espressif Systems (Shanghai) Co., Ltd Wi-Fi & Bluetooth IoT Module (FCC ID: 2AC7Z-ESP32WROVERE)									
Mode	Frequency Range (MHz)	¹ Antenna Gain		¹ Tune up Conducted Power		Evaluation Distance (cm)	¹ Power Density (mW/cm ²)	MPE Limit (mW/cm ²)	MPE Ratio
		(dBi)	(numeric)	(dBm)	(mW)				
802.11b	2412-2462	3.40	2.19	27.00	501.19	20	0.2183	1.0	0.2183
802.11g		3.40	2.19	26.00	398.11	20	0.1734	1.0	0.1734
802.11n HT20		3.40	2.19	26.00	398.11	20	0.1734	1.0	0.1734
802.11n HT40	2422-2452	3.40	2.19	27.00	501.19	20	0.2183	1.0	0.2183
BLE	2402-2480	3.40	2.19	7.00	5.01	20	0.0022	1.0	0.0022
BT	2402-2480	3.40	2.19	9.00	7.94	20	0.0035	1.0	0.0035

¹ Test data derived from ESPRESSIF SYSTEMS (SHANGHAI) CO., LTD Wi-Fi & Bluetooth Internet of Things Module test report, Test Report No. RSHS200116001-00A (FCC ID: 2AC7Z-ESP32WROVERE).

EXHIBIT 6. TEST EQUIPMENT LIST

Test Instruments	Manufacturer	Model No.	Serial No.	Frequency Range	Cal. Due Date
Spectrum Analyzer	Rohde & Schwarz	FSU26	200946	20Hz–26.5 GHz	11 Mar 2024
Attenuator	Pasternack Enterprises	PE 7024-10	4	DC–26.5 GHz	See Note 1
Horn Antenna	ETS	3115	9701-5061	1-18GHz	30 Jun 2022*
Preamp	Hewlett Packard	8449B	3003A00764	1GHz-26.5GHz	02 May 2023
EMI Receiver	Rohde & Schwarz	ESU40	100037	20Hz–40 GHz	01 Sep 2022
Biconilog Antenna	ETS	3142C	00026873	26 – 3000 MHz	16 Dec 2023
Horn Antenna	ETS	3160-09	00118385	18-26GHz	22 Jan 2023
Band Reject Filter	Microtronics	BRM50701	105	Cut off 2.170-3 GHz	See Note 1
High Pass Filter	K & L	11SH-10- 4000/T 12000	4	Cut off 2.4GHz	See Note 1
Spectrum Analyzer	Agilent	E7401A	US40240432	9 kHz–22 GHz	01 Oct 2022
High Pass filter	Rohde & Schwarz	EZ-25	100064	Cut off 150kHz	06 Aug 2022
LISN Used	EMCO	3825-2	8907-1531	9 kHz–30 MHz	17 Feb 2023
Note 1: Internal Verification/Calibration check					

*Equipment used before calibration due date.

EXHIBIT 7. MEASUREMENT UNCERTAINTY

The measurement uncertainties stated were calculated in accordance with the requirements of CISPR 16-4-2 @ IEC:2003 and JCGM 100:2008 (GUM 1995) – Guide to the Expression of Uncertainty in Measurement.

Test Description	Expanded Uncertainty, K=2 for 95% Confidence Level
Power Line Conducted Emissions	± 2.62
Conducted Output Power	± 0.63 dB
Power Spectral Density	± 0.20 Hz / ± 0.63 dB
Occupied Bandwidth	± 0.20 Hz / ± 0.63 dB
Transmitter Band-edge Radiated Emissions	± 2.76 dB (1 – 18 GHz)
Transmitter Spurious Radiated Emissions	± 4.20 dB (30 MHz – 1 GHz)
	± 2.70 dB (1 – 18 GHz)
	± 3.11 dB (18 – 26.5 GHz)