

Report on the Radio Testing
For
Benchmark Electronics
on
NRF51 Module
Report no. TRA-040255-45-00B
02 April 2020

RF915 7.0



Report Number: TRA-040255-45-00B
Issue: B

REPORT ON THE RADIO TESTING OF A
Benchmark Electronics
NRF51 Module
WITH RESPECT TO SPECIFICATION
FCC 47CFR 15.247

TEST DATE: 2020-01-29 to 2020-04-02

Written by: 

Ian Broadwell
Radio Test Engineer

Approved by: 

Date:

02 April 2020

Digitally signed by John Charters
DN: cn=John Charters, o, ou=Element
Materials Technology Ltd.,
email=john.charters@element.com, c=GB
Reason: I am approving this document
Date: 2020.04.17 09:45:20 +01'00'

John Charters
Lab Manager

Disclaimers:

- [1] THIS DOCUMENT MAY BE REPRODUCED ONLY IN ITS ENTIRETY AND WITHOUT CHANGE
[2] THE RESULTS CONTAINED IN THIS DOCUMENT RELATE ONLY TO THE ITEM(S) TESTED

1 Revision Record

<i>Issue Number</i>	<i>Issue Date</i>	<i>Revision History</i>
A	02 April 2020	Original
B		Corrected test date range and operating mode description

2 Summary

TEST REPORT NUMBER:	TRA-040255-45-00B
WORKS ORDER NUMBER	TRA-040255-02
PURPOSE OF TEST:	USA: Testing of radio frequency equipment per the relevant authorization procedure of chapter 47 of CFR (code of federal regulations) Part 2, subpart J.
TEST SPECIFICATION(S):	47CFR15.247
EQUIPMENT UNDER TEST (EUT):	NRF51 Module
FCC IDENTIFIER:	2AVTPNRF
EUT SERIAL NUMBER:	N/A
MANUFACTURER/AGENT:	Benchmark Electronics
ADDRESS:	Brandon Lane Langley Moor Durham DH7 8PE United Kingdom
CLIENT CONTACT:	Gavin Hancock ☎ +44(0)191 3783789 ✉ gavin@benchmark-electronics.co.uk
ORDER NUMBER:	PO19145
TEST DATE:	2020-01-29 to 2020-04-02
TESTED BY:	Ian Broadwell Element

2.1 Test Summary

Test Method and Description		Requirement Clause 47CFR15	Applicable to this equipment	Result / Note
Radiated spurious emissions (restricted bands of operation and cabinet radiation)		15.205	☒	PASS
AC power line conducted emissions		15.207	☐	Note 1
Occupied bandwidth		15.247(a)(2)	☒	PASS
Conducted carrier power	Peak	15.247(b)(3)	☒	PASS
	Max.		☐	
Conducted / radiated RF power out-of-band		15.247(d)	☒	PASS
Power spectral density, conducted		15.247(e)	☒	PASS

Notes:

Note 1: The EUT is a battery powered device that will not be connected to AC power either directly or indirectly through another device.

The results contained in this report relate only to the items tested, in the condition at time of test, and were obtained in the period between the date of initial receipt of samples and the date of issue of the report.

The apparatus was set up and exercised using the configurations, modes of operation and arrangements defined in this report only. Any modifications made are identified in Section 8 of this report.

Particular operating modes, apparatus monitoring methods and performance criteria required by the standards tested to have been performed except where identified in Section 5.2 of this test report (Deviations from Test Standards).

3 Contents

1	Revision Record.....	3
2	Summary.....	4
2.1	Test Summary.....	5
3	Contents.....	6
4	Introduction.....	8
5	Test Specifications.....	9
5.1	Normative References.....	9
5.2	Deviations from Test Standards.....	9
6	Glossary of Terms.....	10
7	Equipment Under Test.....	11
7.1	EUT Identification.....	11
7.2	System Equipment.....	11
7.3	EUT Mode of Operation.....	11
7.3.1	Transmission and Reception.....	11
7.4	EUT Radio Parameters.....	12
7.4.1	General.....	12
7.4.2	Antennas.....	12
7.4.3	Product specific declarations.....	12
7.5	EUT Description.....	12
8	Modifications.....	13
9	EUT Test Setup.....	14
9.1	General Set-up Photograph.....	14
9.2	Measurement software.....	15
10	General Technical Parameters.....	16
10.1	Normal Conditions.....	16
11	Radiated emissions.....	17
11.1	Definitions.....	17
11.2	Test Parameters.....	17
11.3	Test Limit.....	17
11.4	Test Method.....	18
11.5	Test Equipment.....	19
11.6	Test Results.....	20
12	Radiated emissions – unintentional radiation / receiver emissions.....	32
12.1	Definitions.....	32
12.2	Test Parameters.....	32
12.3	Test Limit.....	32
12.4	Test Method.....	33
12.5	Test Equipment.....	33
12.6	Test Results.....	34
13	Occupied Bandwidth.....	36
13.1	Definition.....	36
13.2	Test Parameters.....	36
13.3	Test Limit.....	36
13.4	Test Method.....	37
13.5	Test Equipment.....	37
13.6	Test Results.....	38
14	Maximum peak conducted output power.....	40
14.1	Definition.....	40
14.2	Test Parameters.....	40
14.3	Test Limit.....	40
14.4	Test Method.....	41
14.5	Test Equipment.....	41
14.6	Test Results.....	41
15	Out-of-band and conducted spurious emissions.....	42
15.1	Definition.....	42
15.2	Test Parameters.....	42
15.3	Test Limit.....	42
15.4	Test Method.....	43
15.5	Test Equipment.....	43
15.6	Test Results.....	44
16	Power spectral density.....	47
16.1	Definition.....	47
16.2	Test Parameters.....	47

16.3	Test Limit	47
16.4	Test Method	48
16.5	Test Equipment.....	48
16.6	Test Results	49
17	Measurement Uncertainty	51
18	RF Exposure	52

4 Introduction

This report TRA-040255-45-00B presents the results of the Radio testing on a Benchmark Electronics, NRF51 Module to specification 47CFR15 Radio Frequency Devices.

The testing was carried out for Benchmark Electronics by Element, at the address detailed below:

☒	Element Hull	☐	Element Skelmersdale
	Unit E		Unit 1
	South Orbital Trading Park		Pendle Place
	Hedon Road		Skelmersdale
	Hull		West Lancashire
	HU9 1NJ		WN8 9PN
	UK		UK

This report details the configuration of the equipment, the test methods used and any relevant modifications where appropriate.

All test and measurement equipment under the control of the laboratory and requiring calibration is subject to an established programme and procedures to control and maintain measurement standards. The quality management system meets the principles of ISO 9001, and has quality control procedures for monitoring the validity of tests undertaken. Records and sufficient detail are retained to establish an audit trail of calibration records relating to its test results for a defined period. Under control of the established calibration programme, key quantities or values of the test & measurement instrumentation are within specification and comply with the relevant traceable internationally recognised and appropriate standard specifications, which are UKAS calibrated as such where these properties have a significant effect on results. Participation in inter-laboratory comparisons and proficiency testing ensures satisfactory correlation of results conform to Elements own procedures, as well as statistical techniques for analysis of test data providing the appropriate confidence in measurements.

Throughout this report EUT denotes equipment under test.

FCC Site Listing:

Element is accredited for the above sites under the US-EU MRA, Designation number UK0009.

IC Registration Number(s):

Element Hull	3483A
Element North West	3930B

The test site requirements of ANSI C63.4-2014 are met up to 1GHz.

The test site SVSWR requirements of CISPR 16-1-4:2010 are met over the frequency range 1 GHz to 18 GHz.

5 Test Specifications

5.1 Normative References

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

5.2 Deviations from Test Standards

There were no deviations from the test standard.

6 Glossary of Terms

§	denotes a section reference from the standard, not this document
AC	Alternating Current
ANSI	American National Standards Institute
BW	bandwidth
C	Celsius
CFR	Code of Federal Regulations
CW	Continuous Wave
dB	decibel
dBm	dB relative to 1 milliwatt
DC	Direct Current
DSSS	Direct Sequence Spread Spectrum
EIRP	Equivalent Isotropically Radiated Power
ERP	Effective Radiated Power
EUT	Equipment Under Test
FCC	Federal Communications Commission
FHSS	Frequency Hopping Spread Spectrum
Hz	hertz
IC	Industry Canada
ITU	International Telecommunication Union
LBT	Listen Before Talk
m	metre
max	maximum
MIMO	Multiple Input and Multiple Output
min	minimum
MRA	Mutual Recognition Agreement
N/A	Not Applicable
PCB	Printed Circuit Board
PDF	Portable Document Format
Pt-mpt	Point-to-multipoint
Pt-pt	Point-to-point
RF	Radio Frequency
RH	Relative Humidity
RMS	Root Mean Square
Rx	receiver
s	second
SVSWR	Site Voltage Standing Wave Ratio
Tx	transmitter
UKAS	United Kingdom Accreditation Service
V	volt
W	watt
Ω	ohm

7 Equipment Under Test

7.1 EUT Identification

- Name: NRF51 Module
- Serial Number: N/A
- Model Number: NRF51 Module
- Software Revision: Not Applicable
- Build Level / Revision Number: Not Applicable

7.2 System Equipment

Equipment listed below forms part of the overall test setup and is required for equipment functionality and/or monitoring during testing. The compliance levels achieved in this report relate only to the EUT and not items given in the following list.

Not Applicable – No support/monitoring equipment required.

7.3 EUT Mode of Operation

7.3.1 Transmission and Reception

The EUT transmits in CW or modulated mode immediately when the batteries are plugged in. Similarly it receives on a fixed channel frequency (pre-configured) when batteries are installed. Separate samples were supplied for CW, modulated and receive modes.

7.4 EUT Radio Parameters

7.4.1 General

Frequency of operation:	2.411 GHz to 2.461 GHz
Modulation type:	FSK
Occupied channel bandwidth:	800 kHz
Channel spacing:	10 kHz
Declared output power:	10 dBm
Nominal Supply Voltage:	3 V dc
Location of notice for license exempt use:	Label / user manual / both.
Normal operating Duty cycle:	Less than 0.1%

7.4.2 Antennas

Type:	Integral single trace PCB
Frequency range:	2.411 GHz to 2.461 GHz

7.4.3 Product specific declarations

Sample no:	Tx Frequency (MHz)
1	2411
2	2435
6	2461

7.5 EUT Description

The EUT is a general purpose radio module for use in OEM applications.

8 Modifications

No modifications were performed during this assessment.

9 EUT Test Setup

9.1 General Set-up Photograph

Chamber setup below 1 GHz



Radiated setup above 1 GHz



9.2 Measurement software

Where applicable, the following software was used to perform measurements contained within this report.

Element Emissions R5 (2019.08.15.1)
ETS Lindgren EMPower V1.0.4.2

10 General Technical Parameters

10.1 Normal Conditions

The EUT was tested under the normal environmental conditions of the test laboratory, except where otherwise stated. The normal power source applied was 3 Vdc from alkaline batteries.

11 Radiated emissions

11.1 Definitions

Spurious emissions

Emissions on a frequency or frequencies, which are outside the necessary bandwidth and the level of which may be reduced without affecting the corresponding transmission of information. Spurious emissions include harmonic emissions, parasitic emissions, intermodulation products and frequency conversion products, but exclude out-of-band emissions.

Restricted bands

A frequency band in which intentional radiators are permitted to radiate only spurious emissions but not fundamental signals.

11.2 Test Parameters

Test Location:	Element Hull
Test Chamber:	Wireless Lab2
Test Standard and Clause:	ANSI C63.10-2013, Clause 6.5 and 6.6
EUT Frequencies Measured:	2411 MHz, 2435 MHz, 2461 MHz
EUT Channel Bandwidth:	800 kHz
Deviations From Standard:	None
Measurement BW:	30 MHz to 1 GHz: 120 kHz Above 1 GHz: 1 MHz
Measurement Detector:	Up to 1 GHz: quasi-peak Above 1 GHz: RMS average and Peak

Environmental Conditions (Normal Environment)

Temperature: 23 °C	+15 °C to +35 °C (as declared)
Humidity: 33 % RH	20 % RH to 75 % RH (as declared)
Supply: 3 Vdc	(as declared)

11.3 Test Limit

Unwanted emissions that fall within the restricted frequency bands shall comply with the limits specified:

General Field Strength Limits for License-Exempt Transmitters at Frequencies above 30 MHz

Frequency (MHz)	Field Strength ($\mu\text{V/m}$ at 3 m)
30 to 88	100
88 to 216	150
216 to 960	200
Above 960	500

11.4 Test Method

With the EUT setup as per section 9 of this report and connected as per Figure i, the emissions from the EUT were measured on a spectrum analyzer / EMI receiver.

Radiated electromagnetic emissions from the EUT are checked first by preview scans. Preview scans for all spectrum and modulation characteristics are checked, using a peak detector and where applicable worst-case determined for function, operation, orientation, etc. for both vertical and horizontal polarisations. Pre-scan plots are shown with a peak detector and 100 kHz RBW.

If the EUT connects to auxiliary equipment and is table or floor standing, the configurations prescribed in ANSI C63.10 are followed. Alternatively, a layout closest to normal use (as declared by the provider) is employed, (see EUT setup photographs for more detail).

Emissions between 30 MHz and 1 GHz are measured using calibrated broadband antennas. Emissions above 1 GHz are characterized using standard gain horn antennas. Pre-amplifiers and filters are used where required. Care is taken to ensure that test receiver resolution bandwidth, video bandwidth and detector type(s) meet the regulatory requirements.

For both horizontal and vertical polarizations, the EUT is then rotated through 360 degrees in azimuth until the highest emission is detected. At the previously determined azimuth the test antenna is raised and lowered from 1 to 4 m in height until a maximum emission level is detected, this maximum value is recorded.

Power values measured on the test receiver / analyzer are converted to field strength, FS, in dBμV/m at the regulatory distance, using:

$$FS = PR + CL + AF - PA + DC - CF$$

Where,

PR is the power recorded on the receiver / spectrum analyzer in dBμV;

CL is the cable loss in dB;

AF is the test antenna factor in dB/m;

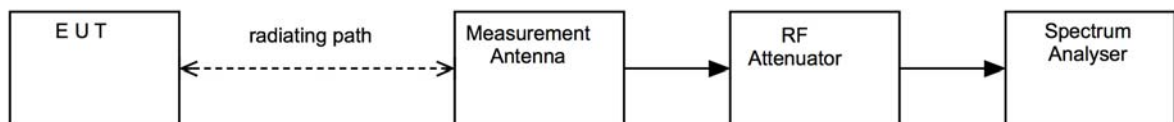
PA is the pre-amplifier gain in dB (where used);

DC is the duty correction factor in dB (where used, e.g. harmonics of pulsed fundamental);

CF is the distance factor in dB (where measurement distance different to limit distance);

This field strength value is then compared with the regulatory limit.

Figure i Test Setup



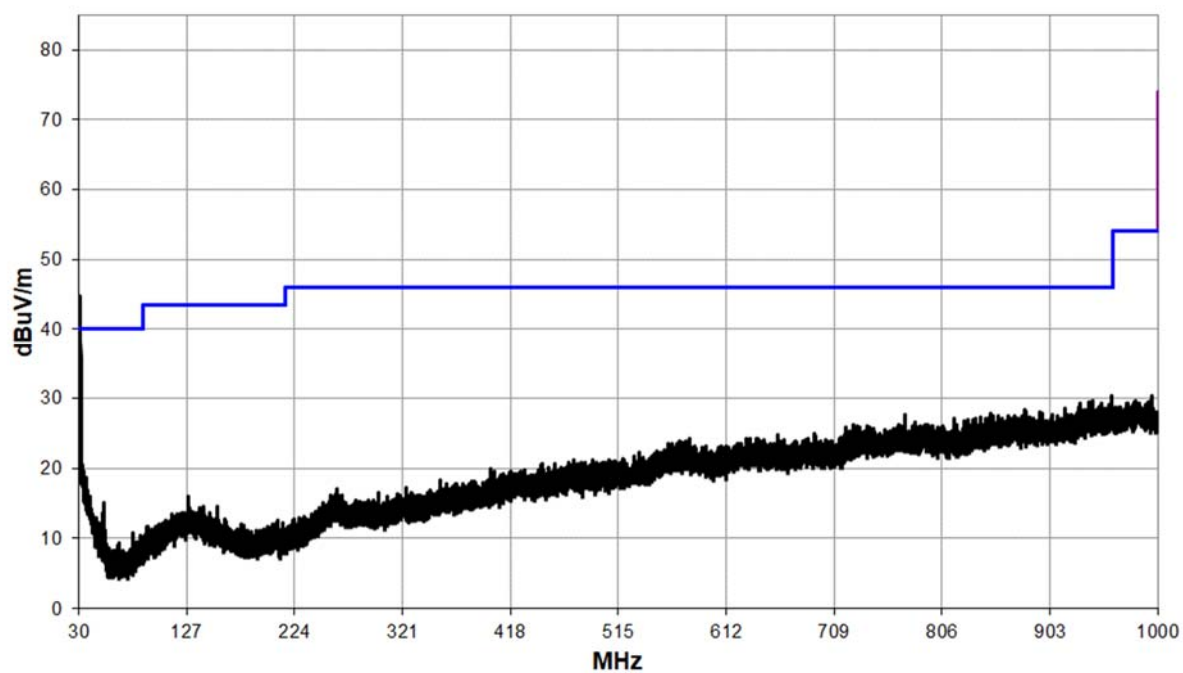
11.5 Test Equipment

Equipment Type	Manufacturer	Equipment Description	Element No	Due For Calibration
ATS	Rainford	Ferrite Lined Chamber	REF886	2020-07-29
CBL6111B	Chase	Bilog Antenna	REF2233	2020-08-17
310	Sonoma	Pre-Amp (9 kHz - 1 GHz)	REF927	2020-05-29
FSU26	R&S	Spectrum Analyser	REF909	2020-06-21
3115	EMCO	Horn Antenna	RFG129	2022-02-14
3115	EMCO	Horn Antenna	L138	2020-04-13
8449B	Agilent	Pre-Amp (1 - 26.5 GHz)	REF913	2021-02-05
QSH20S20S	Q-Par	Horn Antenna	RFG629	2021-10-09
Emissions R5	Element	Radiated Test Software	REF9000	Cal not required

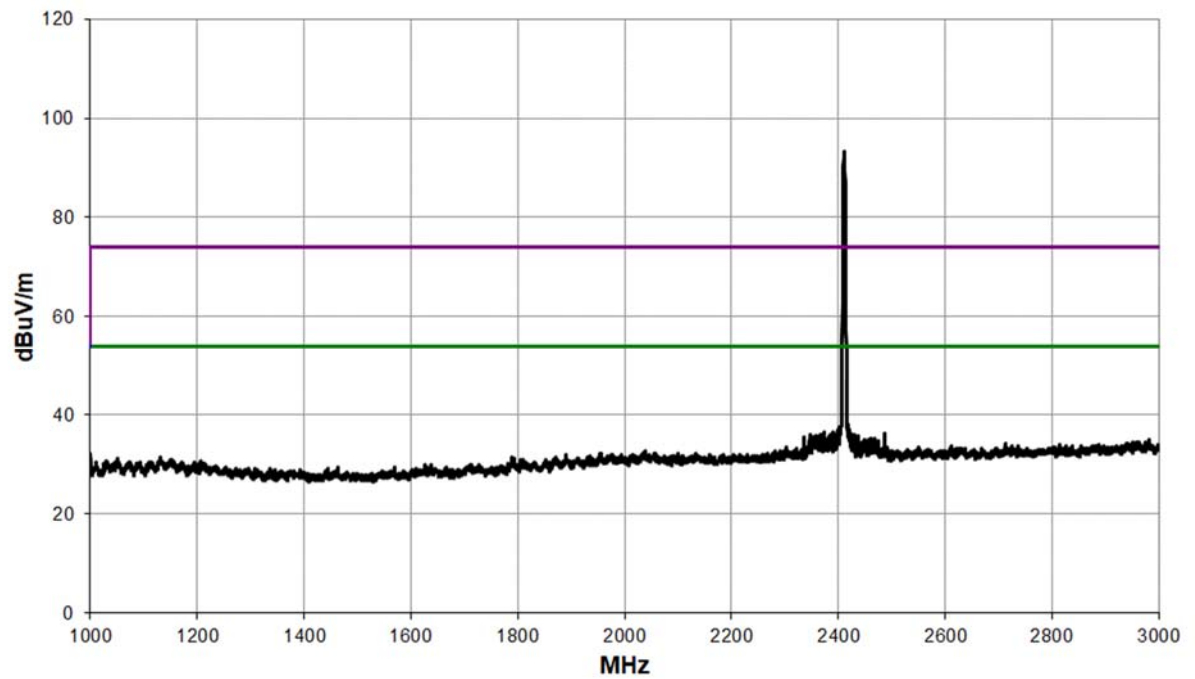
11.6 Test Results

2411MHz										
Detector	Freq. (MHz)	Meas'd Emission (dBμV)	Cable Loss (dB)	Antenna Factor (dB/m)	Pre-amp Gain (dB)	Duty Cycle Corr'n (dB)	Distance Extrap'n Factor (dB)	Field Strength (dBμV/m)	Field Strength (μV/m)	Limit (μV/m)
QP	31	43.5	0.6	24.8	32.6	0.0	0.0	36.3	65.3	100
PK	2335	56.4	3.0	28.5	34.4	0.0	0.0	53.5	473.2	5000
AVE	2335	38	3.0	28.5	34.4	0.0	0.0	35.0	56.2	500
PK	2486	52.5	3.1	28.5	34.4	0.0	0.0	49.7	305.5	5000
AVE	2486	37.8	3.1	28.5	34.4	0.0	0.0	35.0	56.2	500
PK	4822	50.3	4.4	33.0	34.3	0.0	0.0	53.4	467.7	5000
AVE	4822	44.3	4.4	33.0	34.3	0.0	0.0	47.4	234.4	500
PK	7233	16.7	6.8	38.2	0.0	0.0	0.0	61.7	1216.2	5000
AVE	7233	7.6	6.8	38.2	0.0	0.0	0.0	52.6	426.6	500

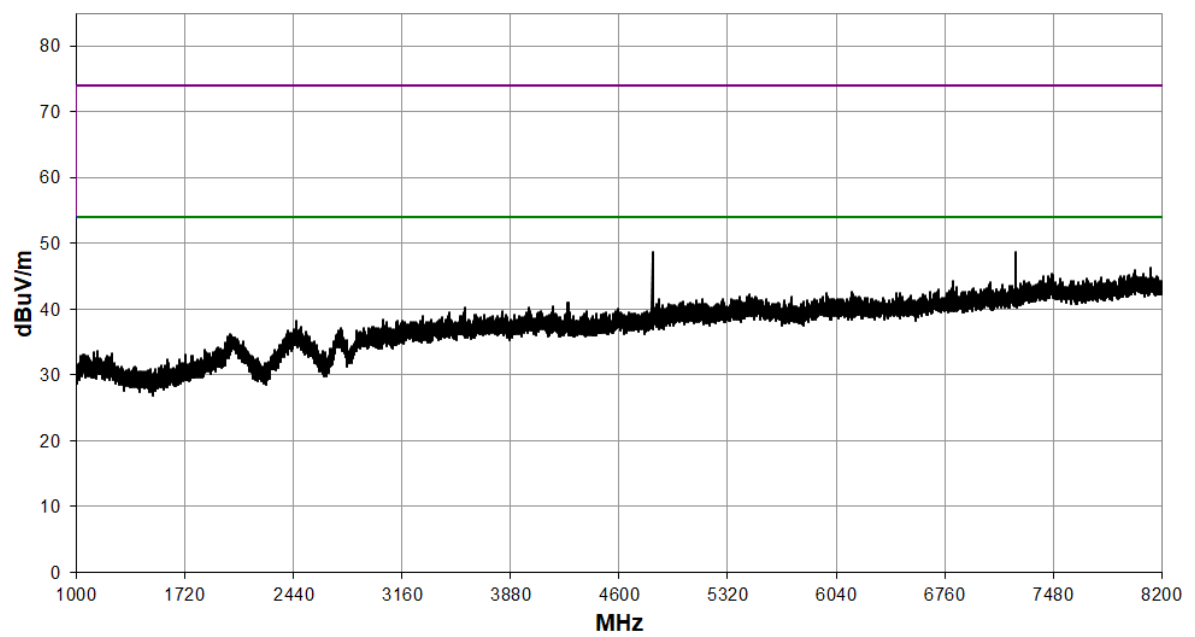
30 MHz to 1 GHz



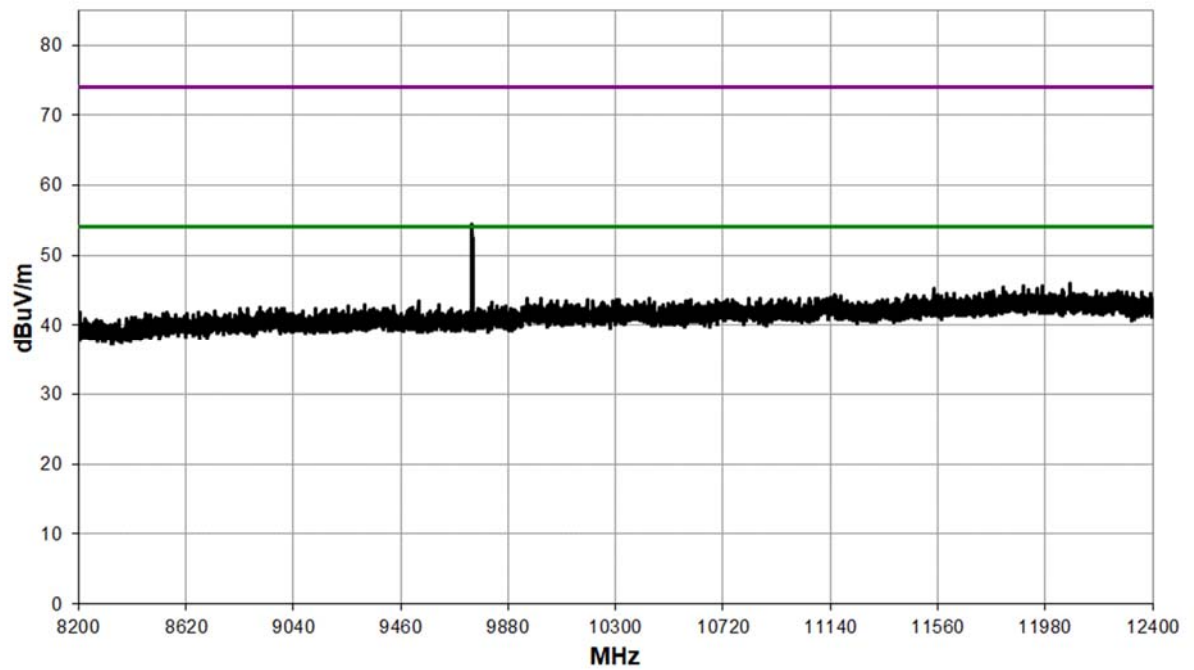
1 GHz to 3 GHz



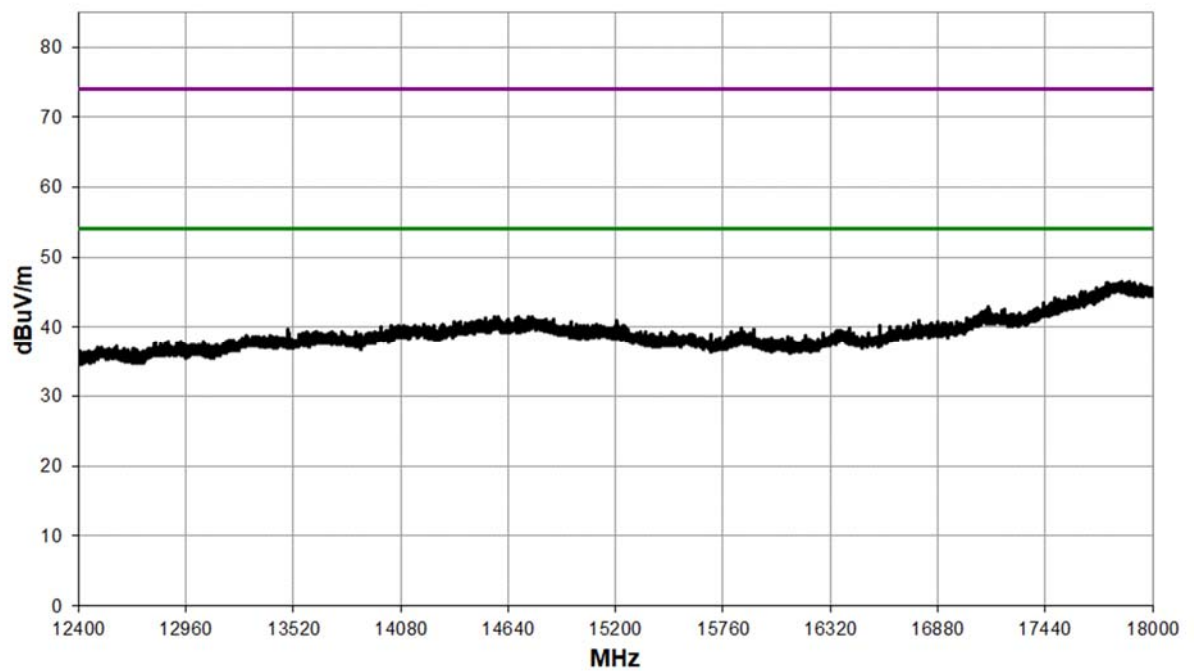
3 GHz to 8.2 GHz



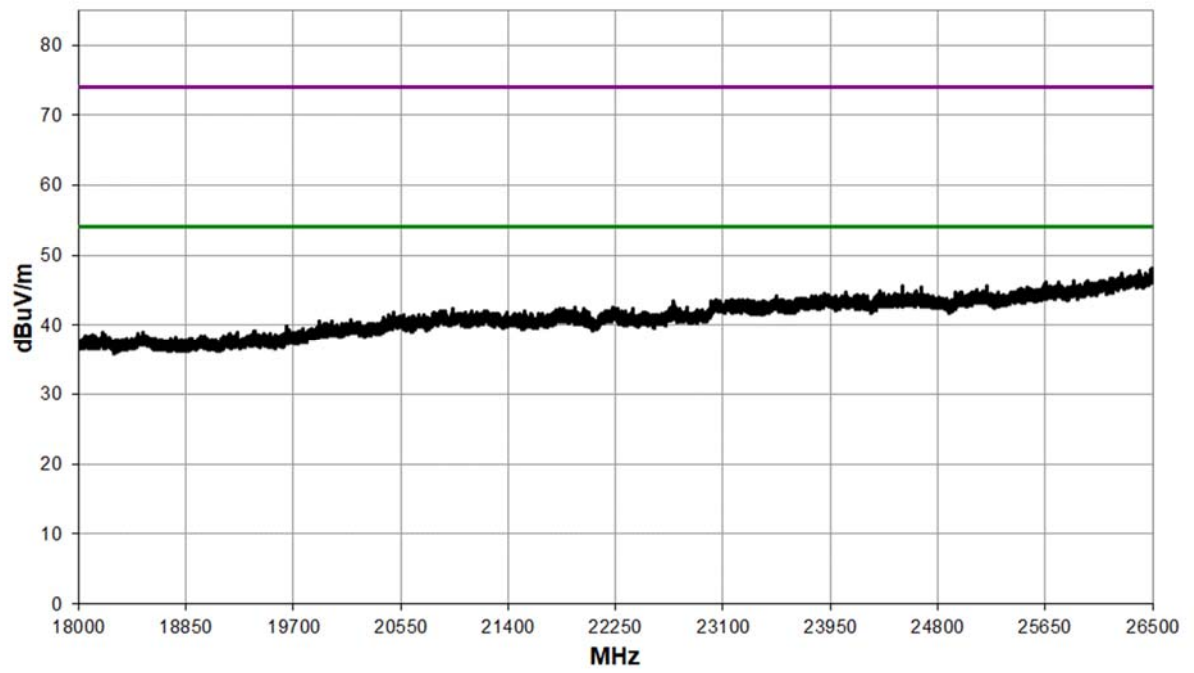
8.2 GHz to 12.4 GHz



12.4 GHz to 18 GHz

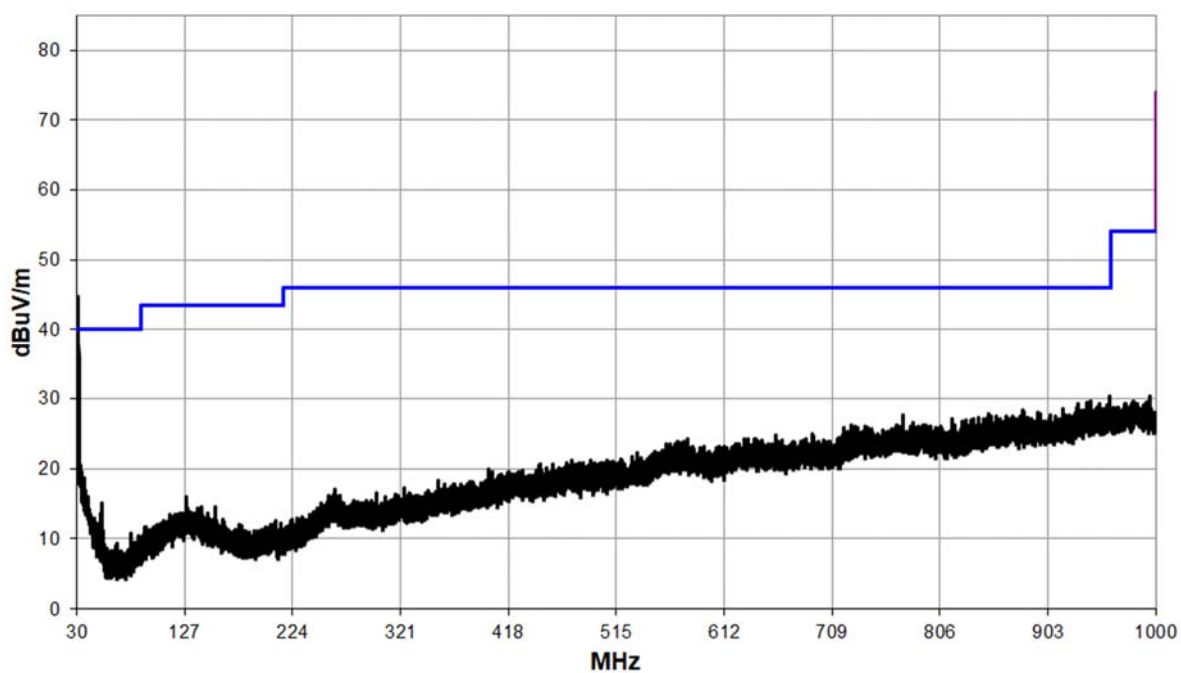


18 GHz to 26.5 GHz

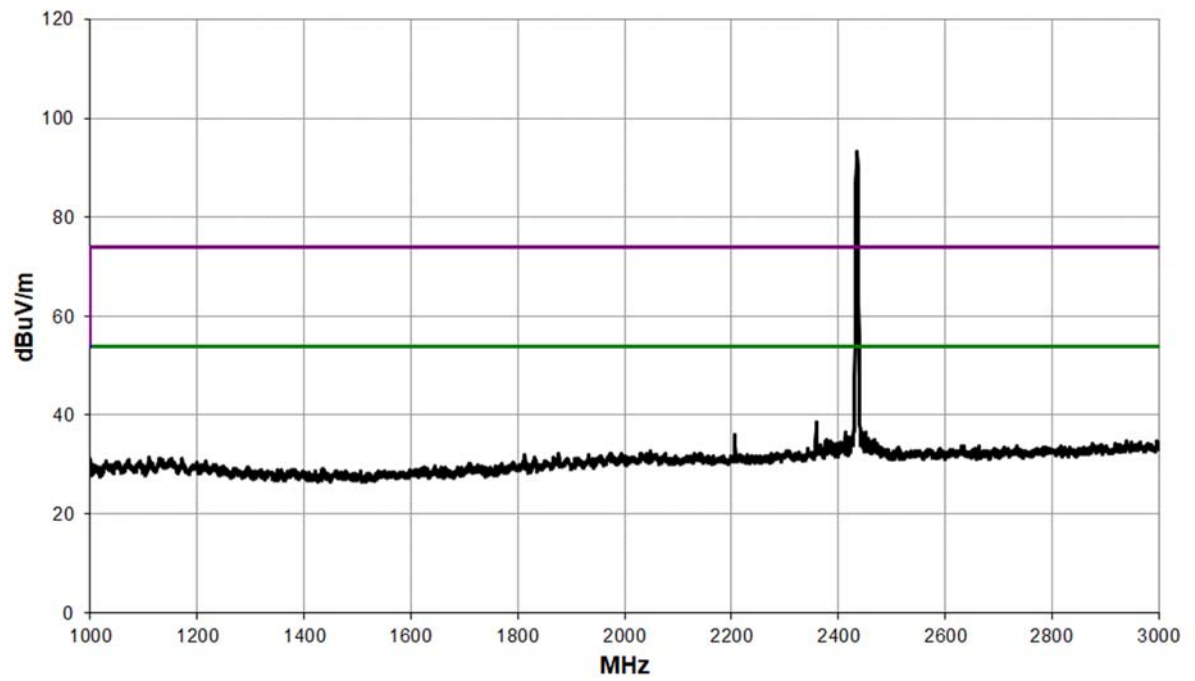


2435 MHz										
Detector	Freq. (MHz)	Meas'd Emission (dBμV)	Cable Loss (dB)	Antenna Factor (dB/m)	Pre-amp Gain (dB)	Duty Cycle Corr'n (dB)	Distance Extrap'n Factor (dB)	Field Strength (dBμV/m)	Field Strength (μV/m)	Limit (μV/m)
QP	31	43.5	0.6	24.8	32.6	0.0	0.0	36.3	65.3	100
PK	2207	49.2	2.9	27.7	34.3	0.0	0.0	45.5	188.4	5000
AVE	2207	42.6	2.9	27.7	34.3	0.0	0.0	38.9	88.1	500
PK	2360	54.7	3.0	28.5	34.4	0.0	0.0	51.8	389.0	5000
AVE	2360	41.9	3.0	28.5	34.4	0.0	0.0	39.0	89.1	500
PK	4870	48.5	4.4	33.1	34.3	0.0	0.0	51.7	384.6	5000
AVE	4870	41.1	4.4	33.1	34.3	0.0	0.0	44.3	164.1	500
PK	7305	15.7	6.8	38.5	0.0	0.0	0.0	61.0	1122.0	5000
AVE	7305	4.9	6.8	38.5	0.0	0.0	0.0	50.2	323.6	500
PK	9740	49.9	6.3	37.6	35.0	0.0	0.0	58.8	871.0	5000
AVE	9740	40.4	6.3	37.6	35.0	0.0	0.0	49.3	291.7	500

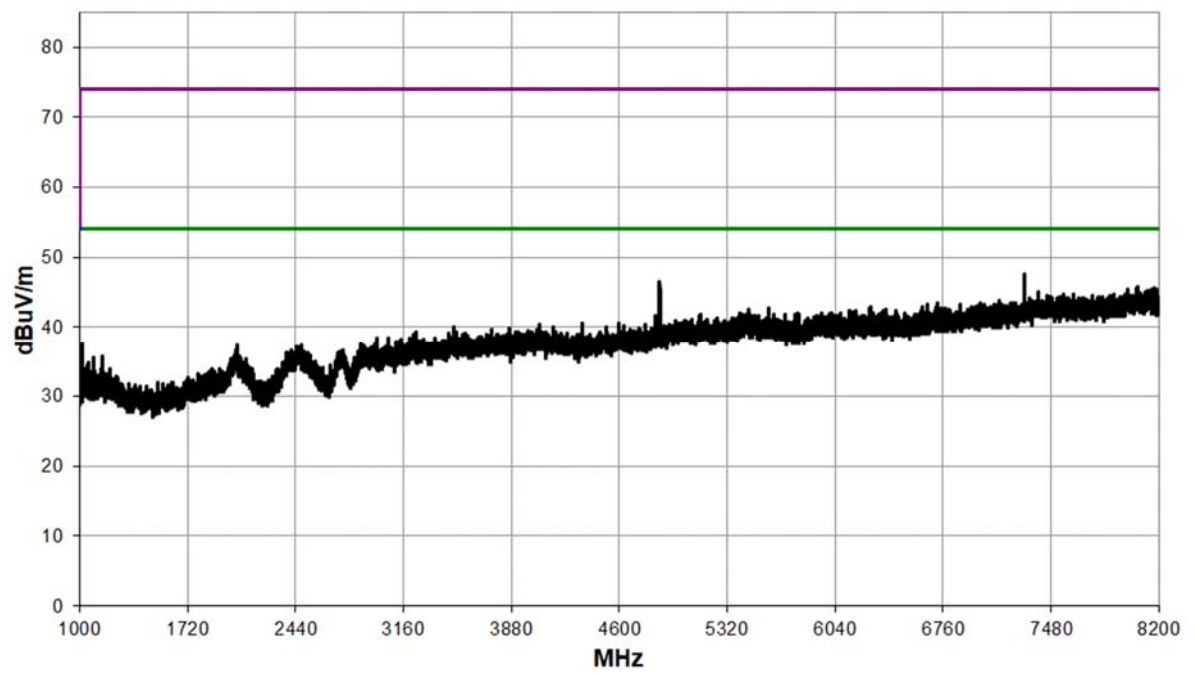
30 MHz to 1 GHz



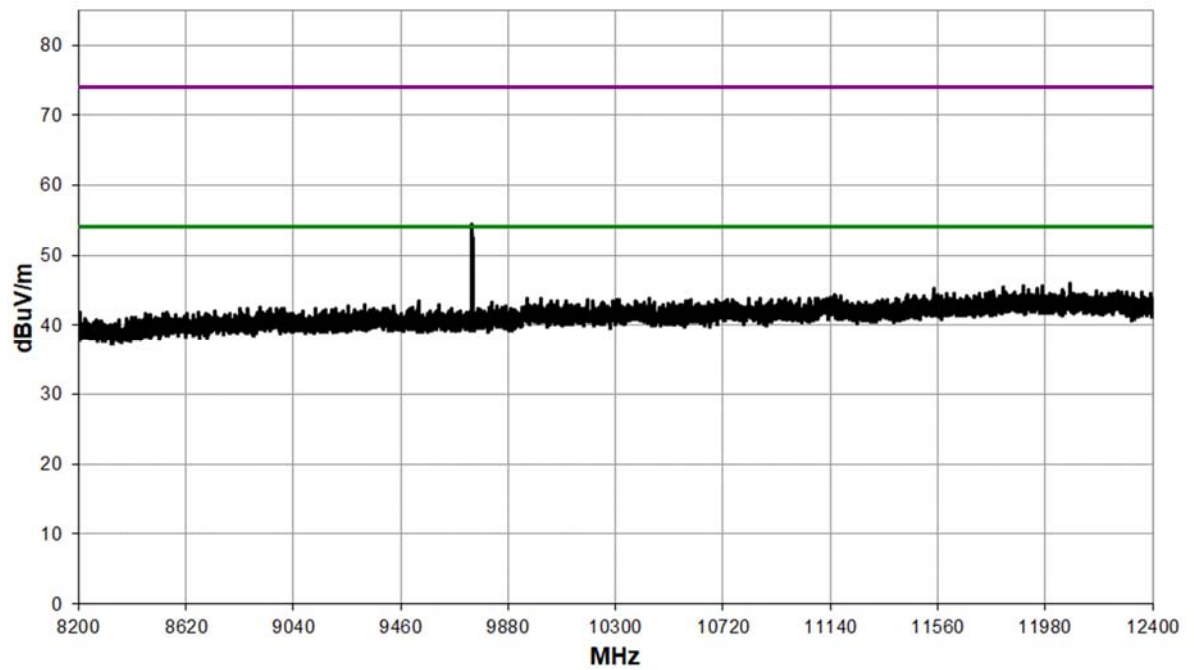
1 GHz to 3 GHz



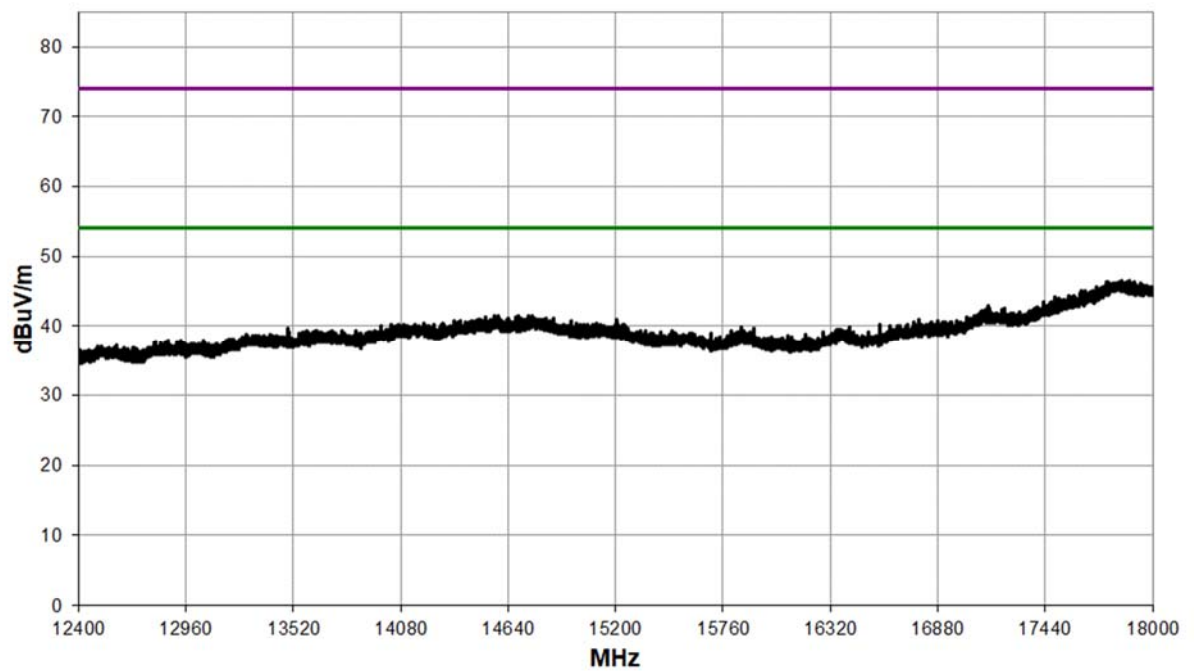
3 GHz to 8.2 GHz



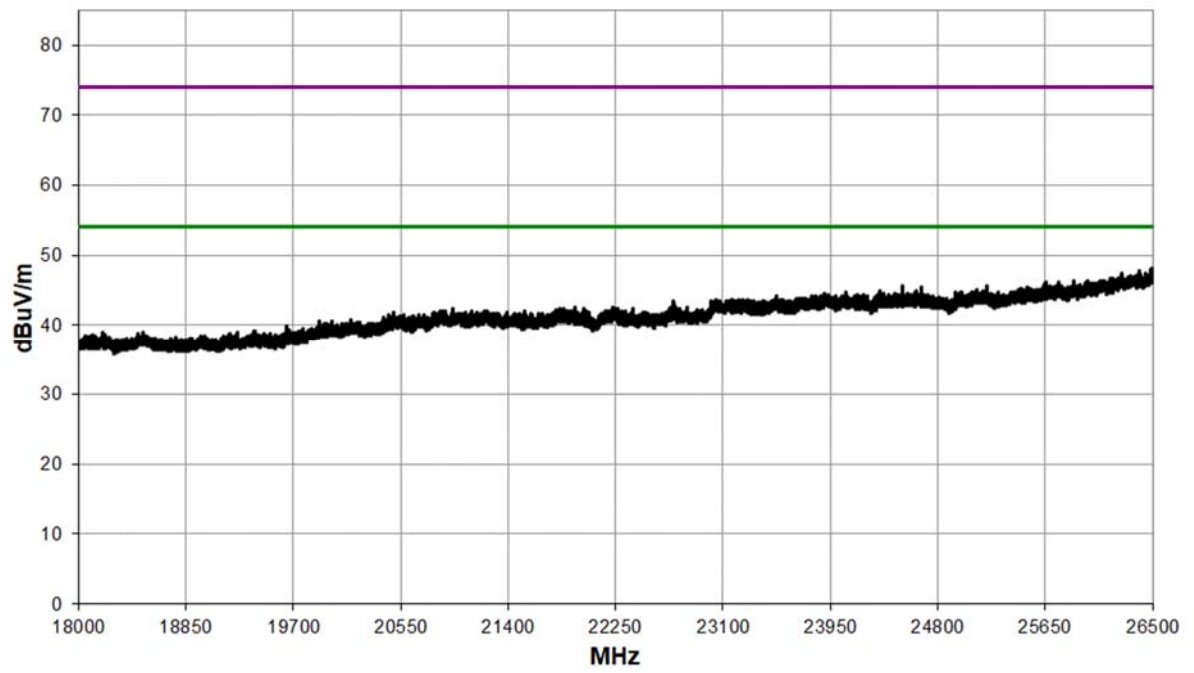
8.2 GHz to 12.4 GHz



12.4 GHz to 18 GHz

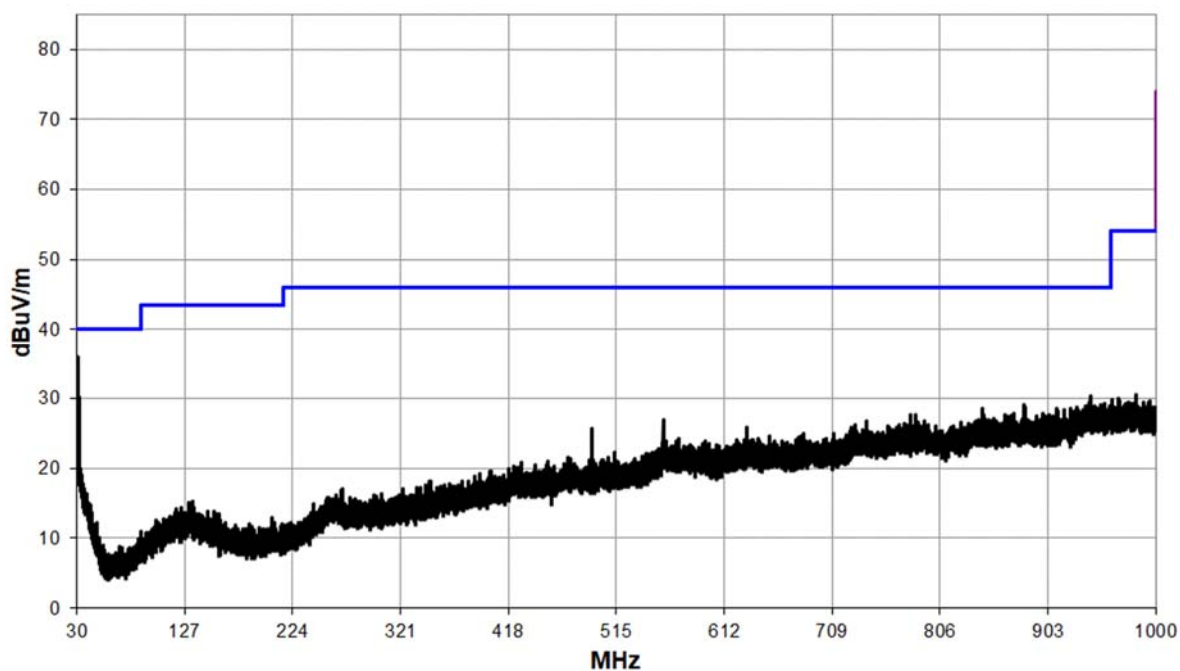


18 GHz to 26.5 GHz

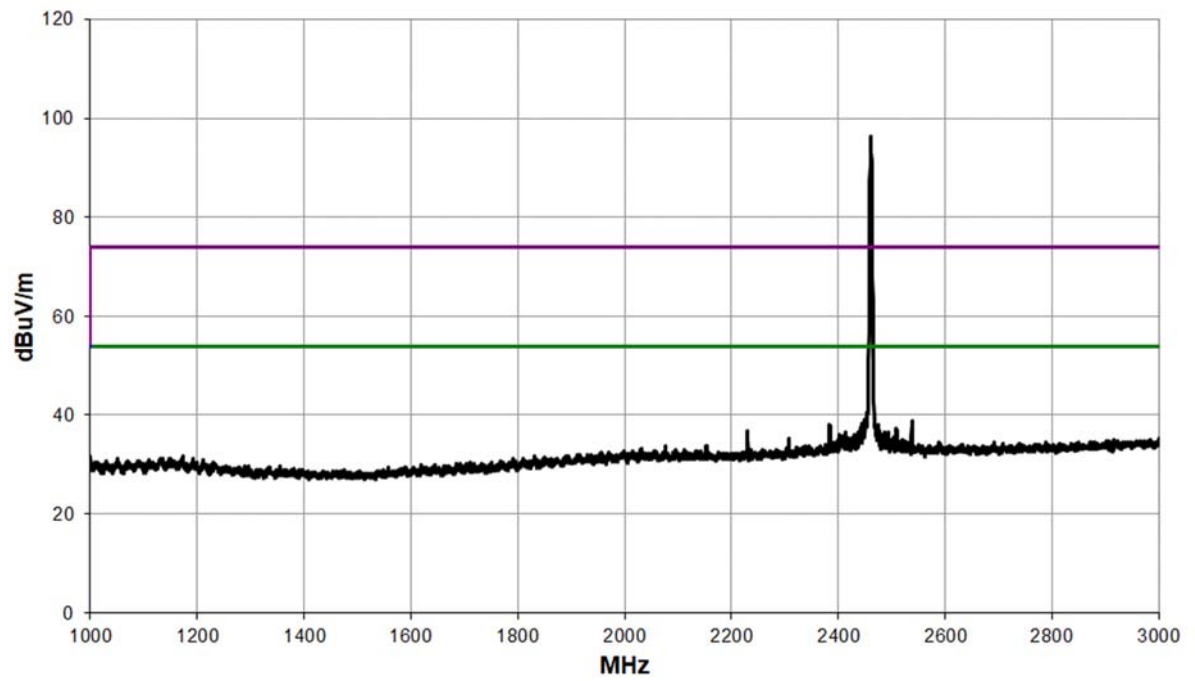


2461 MHz										
Detector	Freq. (MHz)	Meas'd Emission (dBμV)	Cable Loss (dB)	Antenna Factor (dB/m)	Pre-amp Gain (dB)	Duty Cycle Corr'n (dB)	Distance Extrap'n Factor (dB)	Field Strength (dBμV/m)	Field Strength (μV/m)	Limit (μV/m)
QP	31	43.5	0.6	24.8	32.6	0.0	0.0	36.3	65.3	100
PK	2230	50.3	2.9	27.8	34.3	0.0	0.0	46.7	216.3	5000
AVE	2230	43.1	2.9	27.8	34.3	0.0	0.0	39.5	94.4	500
PK	2390	56.3	3.0	28.5	34.4	0.0	0.0	53.4	467.7	5000
AVE	2390	40.9	3.0	28.5	34.4	0.0	0.0	38.0	79.4	500
PK	2538	55.2	3.1	28.6	34.5	0.0	0.0	52.3	412.1	5000
AVE	2538	41.8	3.1	28.6	34.5	0.0	0.0	39.0	89.1	500
PK	4922	51.9	4.5	33.2	34.3	0.0	0.0	55.3	582.1	5000
AVE	4922	46.1	4.5	33.2	34.3	0.0	0.0	49.5	298.5	500
PK	7383	17.4	6.9	38.3	0.0	0.0	0.0	62.6	1349.0	5000
AVE	7383	2.4	6.9	38.3	0.0	0.0	0.0	47.6	239.9	500
PK	12305	48.0	7.2	38.4	34.4	0.0	0.0	59.2	912.0	5000
AVE	12305	36.8	7.2	38.4	34.4	0.0	0.0	48.0	251.2	500

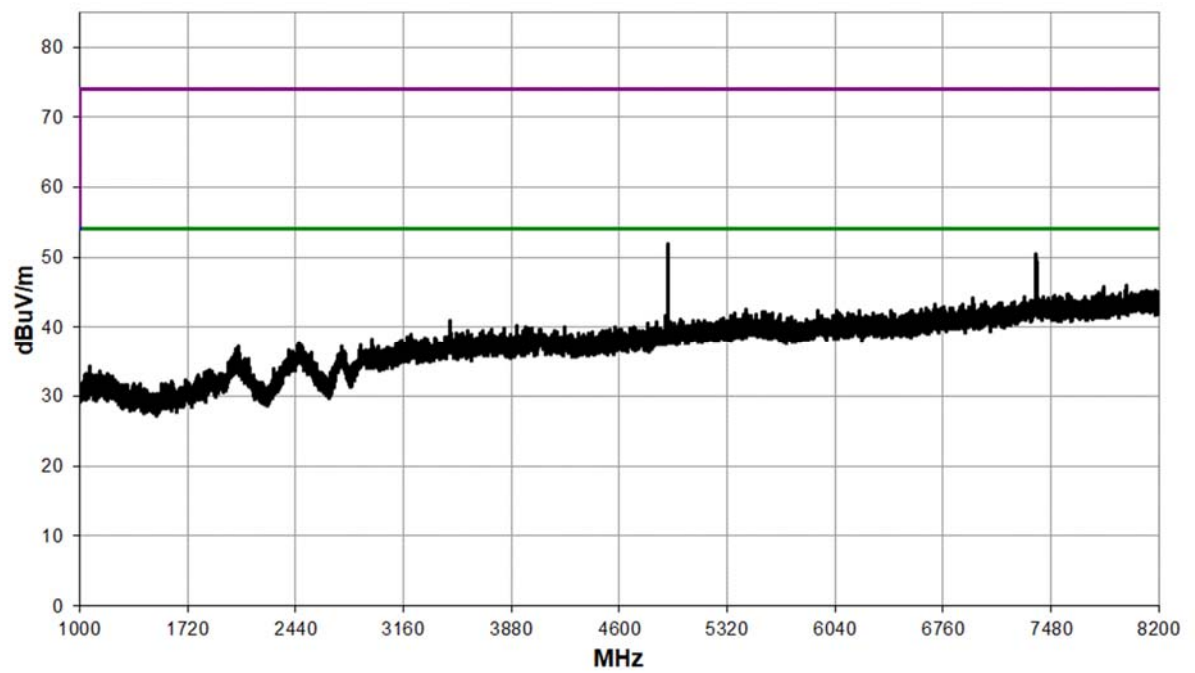
30 MHz to 1 GHz



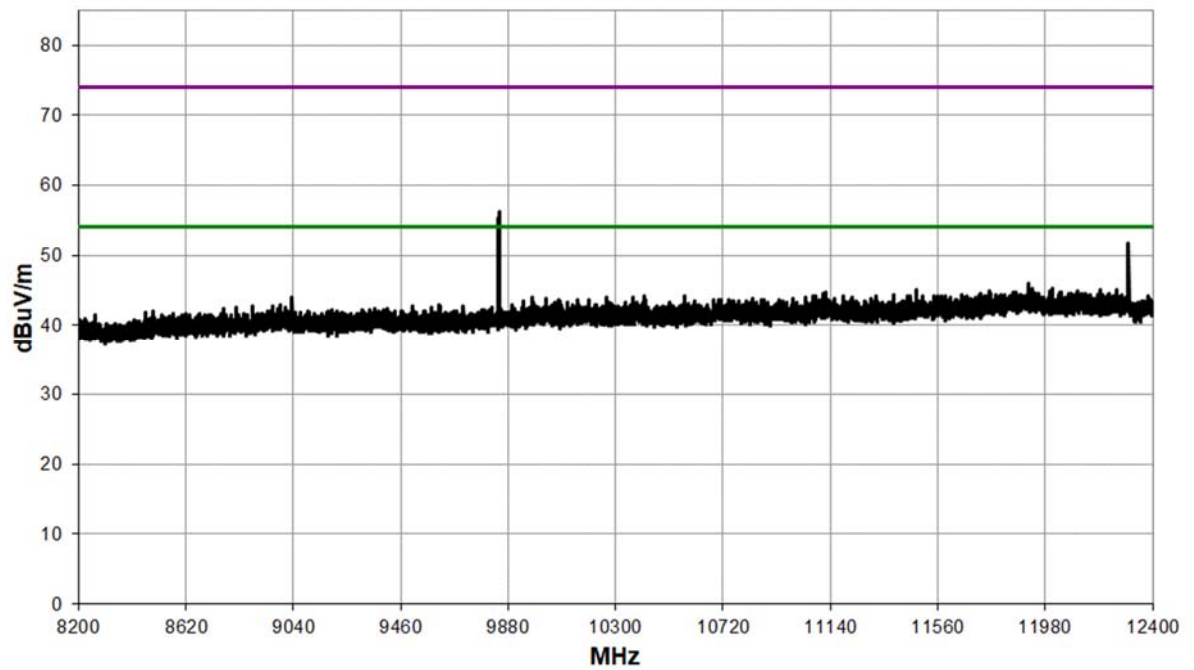
1 GHz to 3 GHz



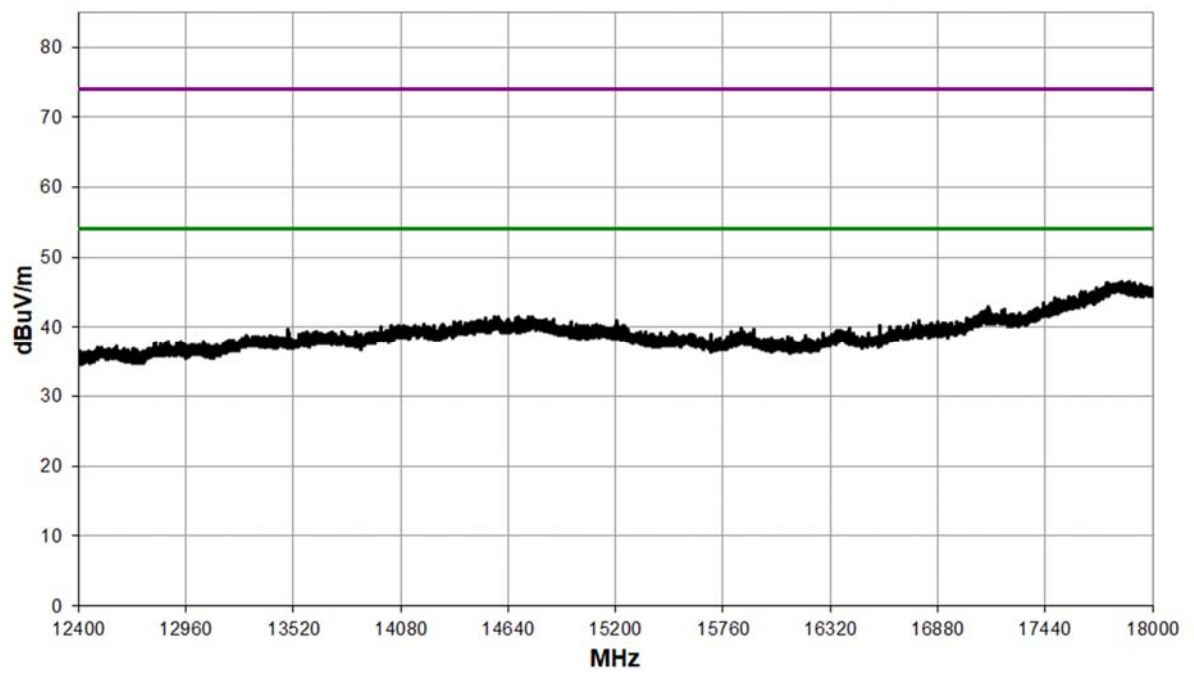
3 GHz to 8.2 GHz



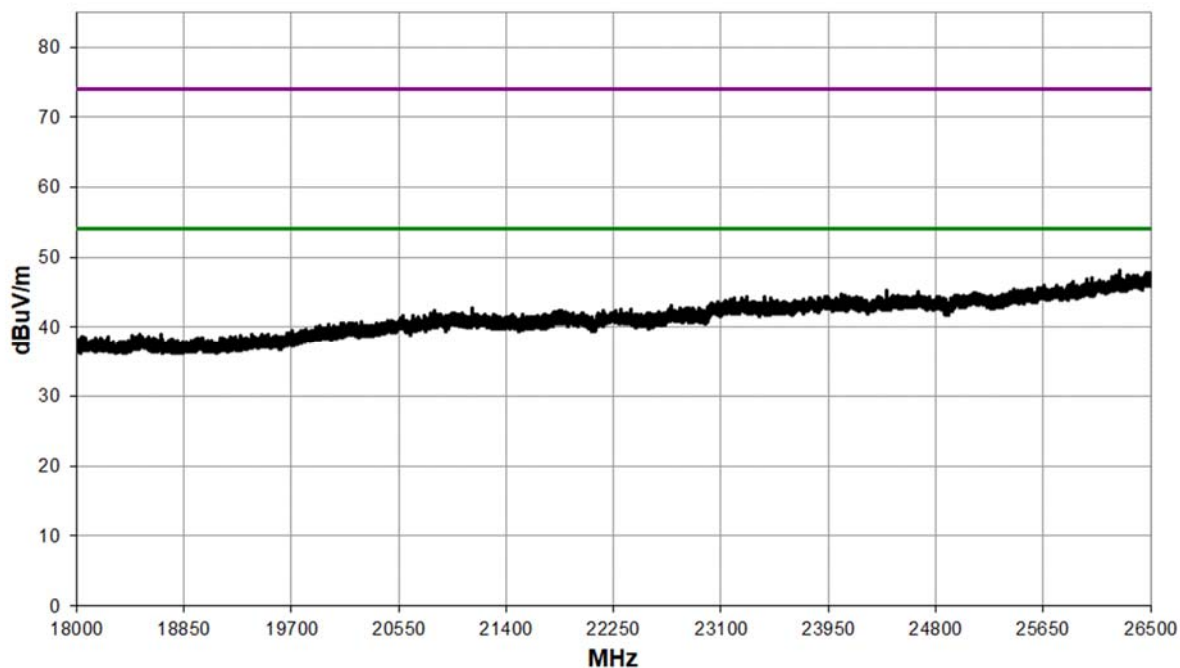
8.2 GHz to 12.4 GHz



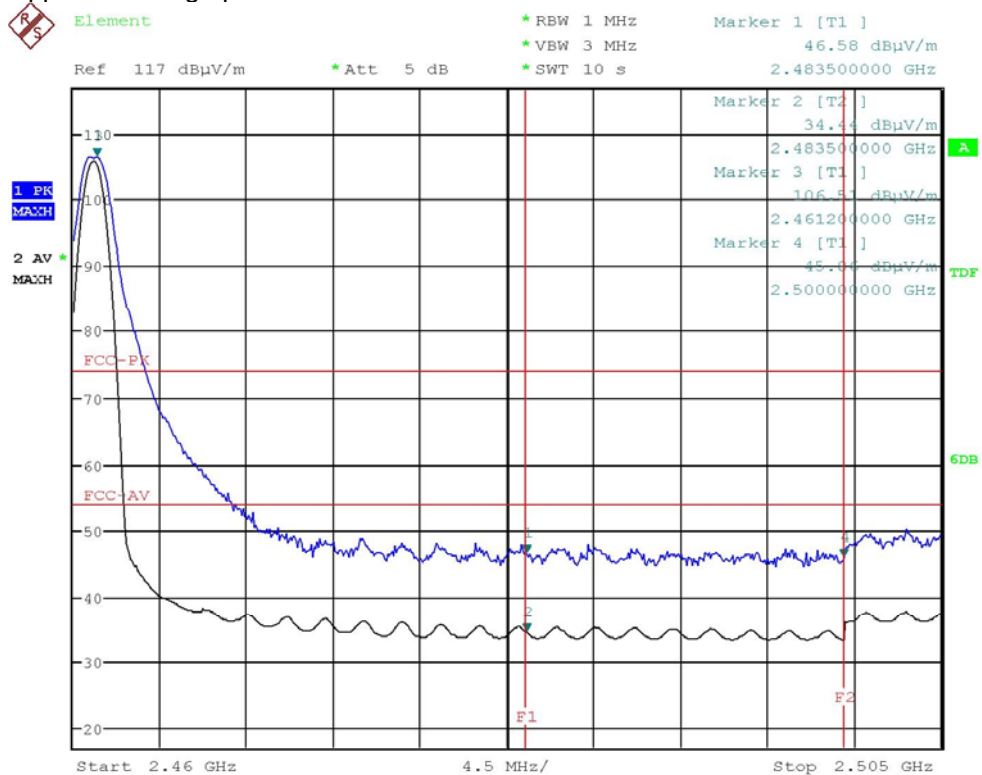
12.4 GHz to 18 GHz



18 GHz to 26.5 GHz



Upper band edge plot



Date: 6.JAN.2003 00:52:19

12 Radiated emissions – unintentional radiation / receiver emissions

12.1 Definitions

Receiver spurious emissions

The radio frequency signals generated within the receiver, which may cause interference to other equipment. This includes the period during which the equipment is scanning or switching channels.

Unintentional radiator

A device that generates RF energy which is not intended to be radiated for reception by a radio receiver.

12.2 Test Parameters

Test Location:	Element Hull
Test Chamber:	Wireless Lab2
Test Standard and Clause:	ANSI C63.10-2013, Clause 6.5 and 6.6
EUT Frequencies Measured:	2411 MHz, 2435 MHz, 2461 MHz
EUT Channel Bandwidth:	800 kHz
Deviations From Standard:	None
Measurement BW:	30 MHz to 1 GHz: 120 kHz Above 1 GHz: 1 MHz
Measurement Detector:	Up to 1 GHz: quasi-peak Above 1 GHz: Peak

Environmental Conditions (Normal Environment)

Temperature: 16 °C	+15 °C to +35 °C (as declared)
Humidity: 37 % RH	20 % RH to 75 % RH (as declared)
Supply: 3 V dc	(as declared)

12.3 Test Limit

Note:

Only radio communication receivers operating in stand-alone mode within the band 30 to 960 MHz, as well as scanner receivers, are subject to requirements, as described above. All other receivers are exempted from any certification, testing, labelling and reporting requirements.

However, all receivers in all frequency bands shall comply with the limits set forth in FCC 47CFR15B / IC RSS-Gen even in cases where testing, reporting and/or certification are not required.

Receiver Radiated Limits

Frequency (MHz)	Field Strength ($\mu\text{V/m}$ at 3 m)
30 to 88	100
88 to 216	150
216 to 960	200
Above 960	500

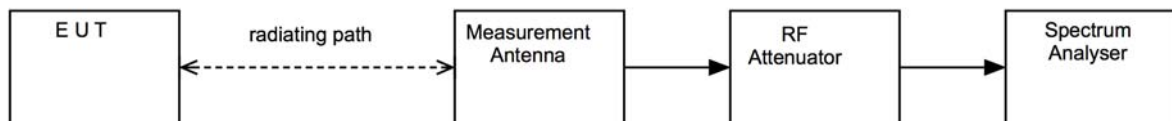
12.4 Test Method

With the EUT setup as per section 9 of this report and connected as per Figure viii, the emissions from the EUT were measured on a spectrum analyzer / EMI receiver. The EUT was rotated in three orthogonal planes and the measurement antenna height scanned (below 1 GHz, from 1 to 4 m; above 1 GHz as necessary) in order to maximise emissions.

The measurements were performed with EUT set at its maximum duty. All modulation schemes, data rates and power settings were used to observe the worst-case configuration at each frequency.

Pre-scan plots are shown with a peak detector and 100 kHz RBW.

Figure viii Test Setup



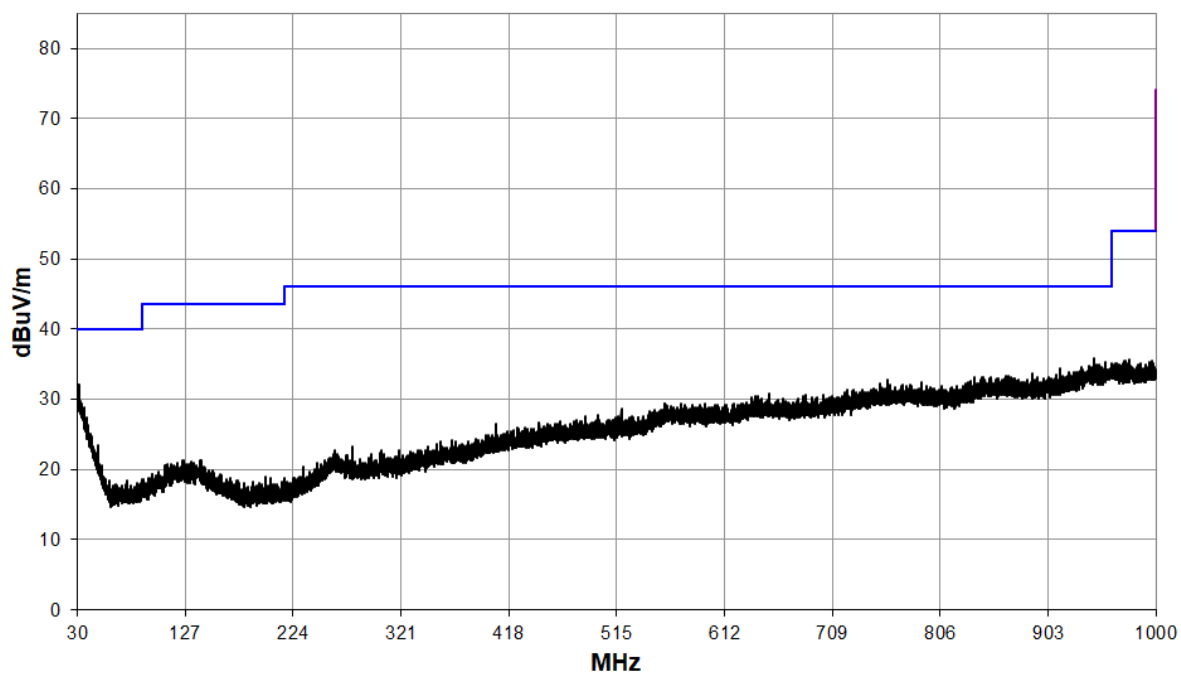
12.5 Test Equipment

Equipment Type	Manufacturer	Equipment Description	Element No	Due For Calibration
-	Rainford	Ferrite Lined Chamber	REF2259	2020-08-03
CBL6111B	Chase	Bilog Antenna	REF2218	2021-10-23
310	Sonoma	Pre-Amp (9 kHz - 1 GHz)	REF927	2020-05-29
ESW26	R&S	EMI Test Receiver	REF2235	2020-07-26
LB-10180-NF	A Info Inc	Horn Antenna	REF2241	2020-07-13
8449B	Agilent	Pre-Amp (1 - 26.5 GHz)	REF913	2021-02-05
QSH20S20S	Q-Par	Horn Antenna	RFG629	2021-10-09
Emissions R5	Element	Radiated Test Software	REF9000	Cal not required

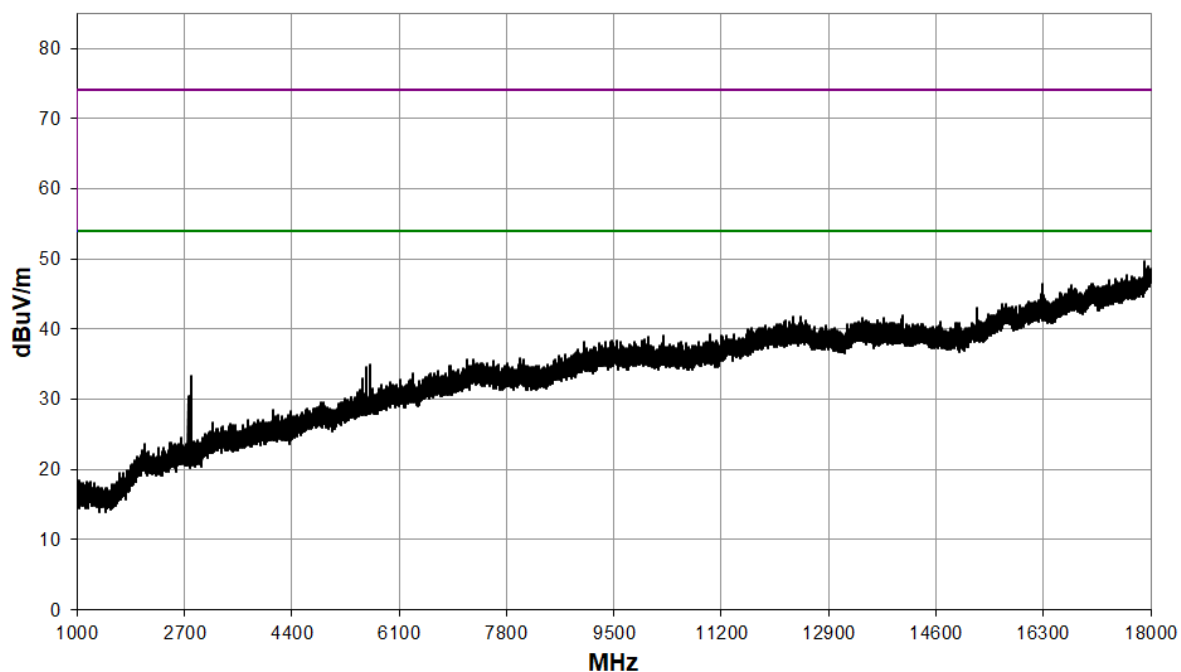
12.6 Test Results

Rx; 2435 MHz									
Detector	Freq. (MHz)	Measured Emission (dB μ V)	Cable Loss (dB)	Antenna Factor (dB/m)	Pre-amp Gain (dB)	Extrap'n Factor (dB)	Field Strength (dB μ V/m)	Field Strength (μ V/m)	Limit (μ V/m)
PK	5630	46.8	6.8	35.0	34.2	-9.5	44.9	175.8	5000
AVE	5630	38.0	6.8	35.0	34.2	-9.5	36.1	63.8	500

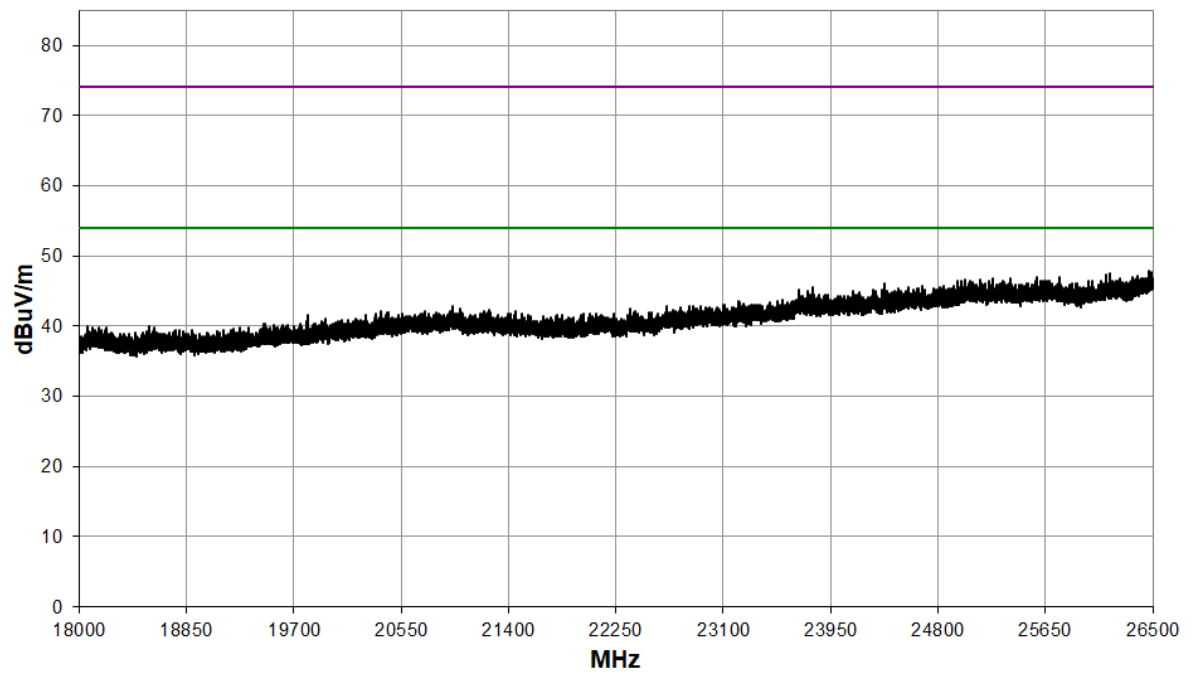
30 MHz to 1GHz



1 GHz to 18 GHz



18 GHz to 26.5 GHz



13 Occupied Bandwidth

13.1 Definition

The emission bandwidth (x dB) is defined as the frequency range between two points, one above and one below the carrier frequency, at which the spectral density of the emission is attenuated x dB below the maximum in-band spectral density of the modulated signal.

13.2 Test Parameters

Test Location:	Element Hull
Test Chamber:	Wireless Laboratory 1
Test Standard and Clause:	FCC: ANSI C63.10-2013, Clause 11.8
EUT Frequencies Measured:	2411 MHz / 2435 MHz / 2461 MHz
EUT Channel Bandwidth:	800 kHz
EUT Test Modulations:	FSK
Deviations From Standard:	None
Measurement BW:	100 kHz
FCC requirement: 100 kHz)	
Spectrum Analyzer Video BW:	300 kHz
(requirement at least 3x RBW)	
Measurement Span:	2 MHz
(requirement 2 to 5 times OBW)	
Measurement Detector:	Peak

Environmental Conditions (Normal Environment)

Temperature: 21 °C	+15 °C to +35 °C (as declared)
Humidity: 40 % RH	20 % RH to 75 % RH (as declared)
Supply: 3 V dc	(as declared)

13.3 Test Limit

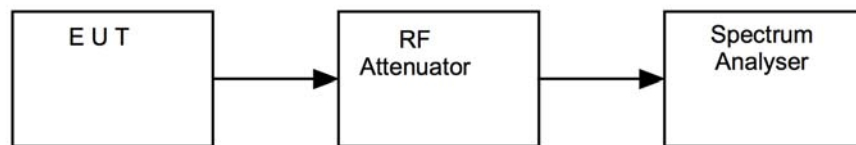
The minimum -6 dB bandwidth shall be at least 500 kHz.

13.4 Test Method

With the EUT setup as per section 9 of this report and connected as per Figure iii, the bandwidth of the EUT was measured on a spectrum analyser.

The measurements were performed with EUT set at its maximum duty. All modulation schemes, data rates and power settings were used to observe the worst-case configuration in each bandwidth.

Figure iii Test Setup

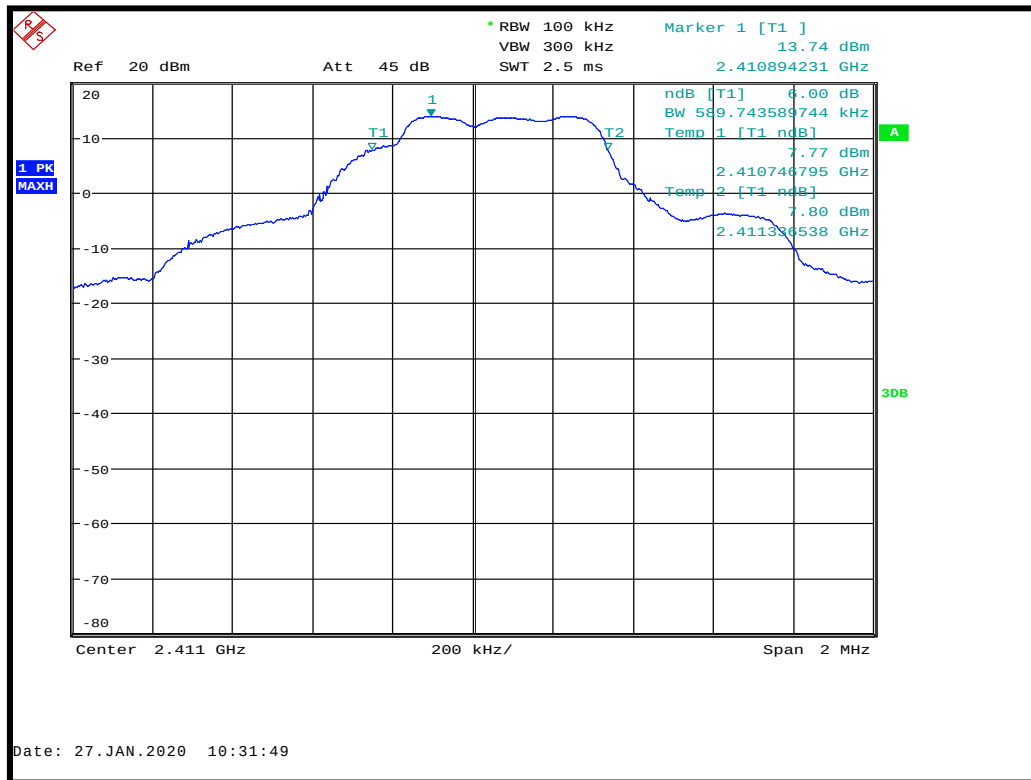


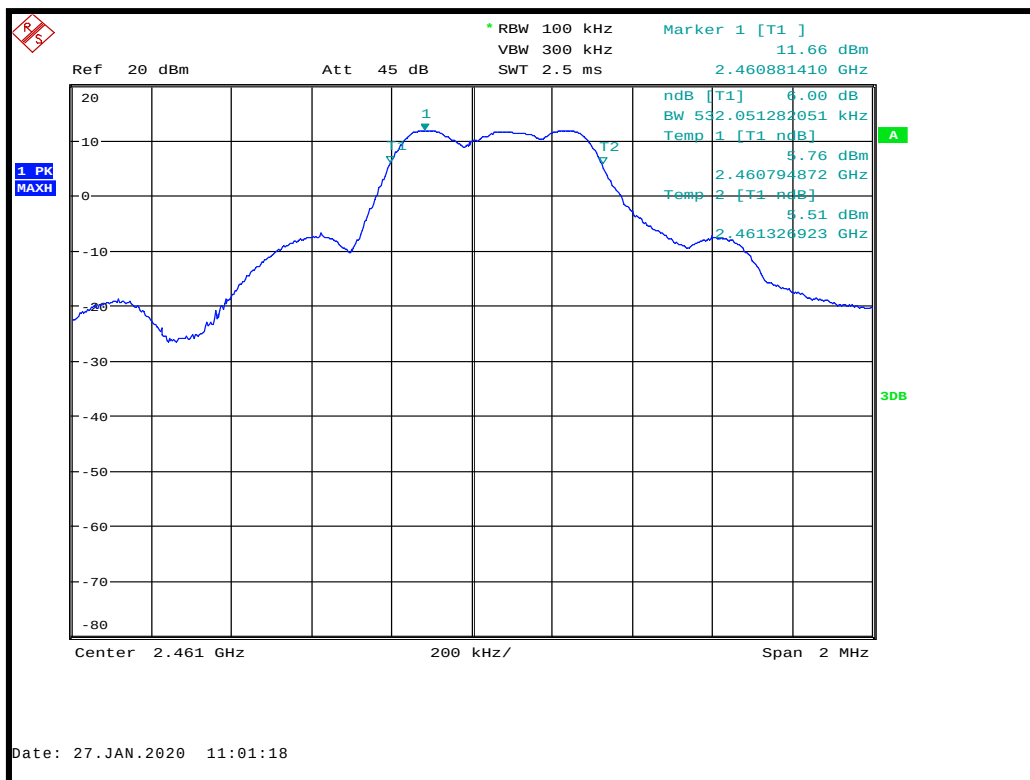
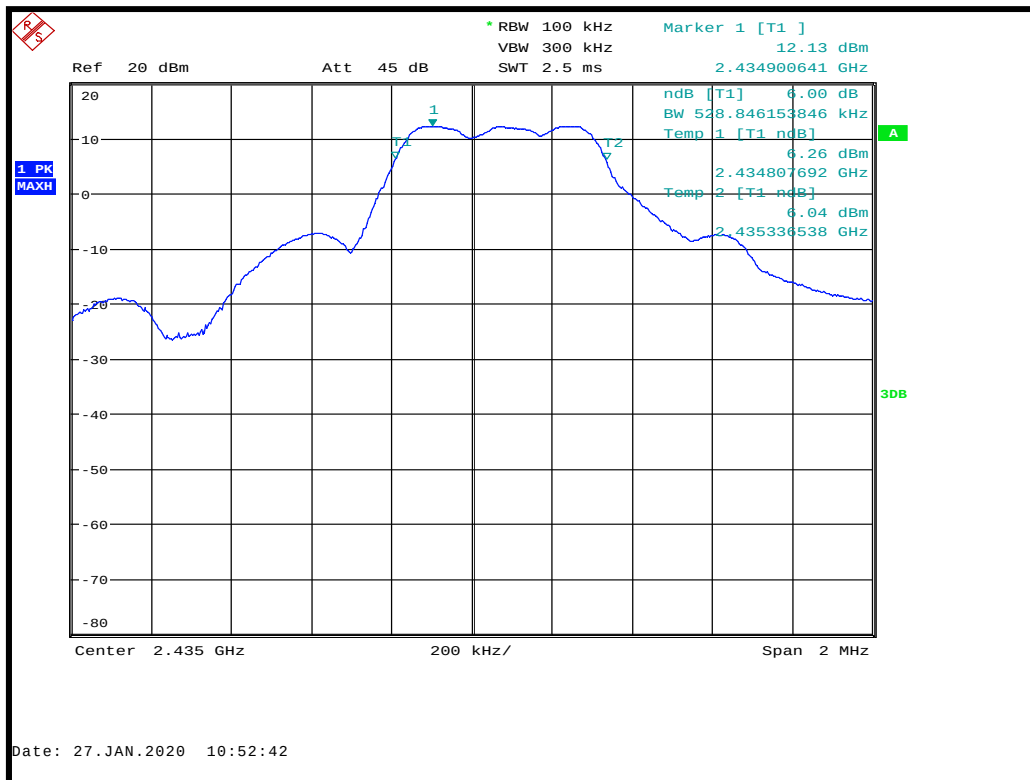
13.5 Test Equipment

Equipment Type	Manufacturer	Equipment Description	Element No	Due For Calibration
FSU50	R&S	Spectrum Analyser	U544	2020-06-05

13.6 Test Results

FCC 15.247. Modulation: FSK; Power setting: As Supplied				
Channel Frequency (MHz)	F_L (MHz)	F_H (MHz)	6dB Bandwidth (kHz)	Result
2411	2410.746795	2411.336538	589.743589744	PASS
2435	2434.807692	2435.336538	528.846153846	PASS
2461	2460.794872	2461.326923	532.051282051	PASS





14 Maximum peak conducted output power

14.1 Definition

The maximum peak conducted output power is defined as the maximum power level measured with a peak detector using a filter with width and shape of which is sufficient to accept the signal bandwidth.

The 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.

14.2 Test Parameters

Test Location:	Element Hull
Test Chamber:	Wireless Laboratory 1
Test Standard and Clause:	ANSI C63.10-2013, Clause 11.9.1
EUT Frequencies Measured:	2411 MHz / 2435 MHz / 2461 MHz
EUT Channel Bandwidth:	800 kHz
Deviations From Standard:	None
Measurement BW:	1 MHz
Spectrum Analyzer Video BW: (requirement at least 3x RBW)	3 MHz
Measurement Detector:	Peak
Voltage Extreme Environment Test Range:	Battery Power = new battery.

Environmental Conditions (Normal Environment)

Temperature: 21 °C	+15 °C to +35 °C (as declared)
Humidity: 40 % RH	20 % RH to 75 % RH (as declared)

14.3 Test Limit

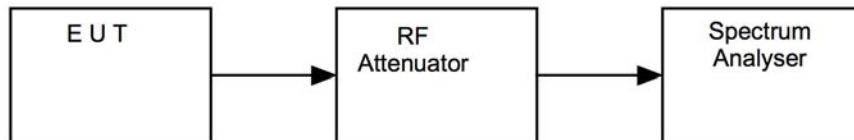
For systems employing digital modulation techniques operating in the bands 902 to 928 MHz, 2400 to 2483.5 MHz and 5725 to 5850 MHz, the maximum peak conducted output power shall not exceed 1 W.

14.4 Test Method

With the EUT setup as per section 9 of this report and connected as per Figure iv, the resolution bandwidth of the spectrum analyser was increased above the EUT occupied bandwidth and the peak emission data noted.

The measurements were performed with EUT set at its maximum duty. All modulation schemes, data rates and power settings were used to observe the worst-case configuration in each bandwidth.

Figure iv Test Setup



14.5 Test Equipment

Equipment Type	Manufacturer	Equipment Description	Element No	Due For Calibration
FSU50	R&S	Spectrum Analyser	U544	2020-06-05

14.6 Test Results

<i>Modulation: FSK; Power setting: As Supplied</i>				
<i>Channel Frequency (MHz)</i>	<i>Analyzer Level (dBm)</i>	<i>Cable loss (dB)</i>	<i>Power (mW)</i>	<i>Result</i>
2411	13.5	0	22.4	PASS
2435	12.7	0	18.6	PASS
2461	11.9	0	15.5	PASS

15 Out-of-band and conducted spurious emissions

15.1 Definition

Out-of-band emission.

Emission on a frequency or frequencies immediately outside the necessary bandwidth that results from the modulation process but excluding spurious emissions.

Spurious emission.

Emission on a frequency or frequencies that are outside the necessary bandwidth and the level of which may be reduced without affecting the corresponding transmission of information. Spurious emissions include harmonic emissions, parasitic emissions, intermodulation products, and frequency conversion products, but exclude out-of-band emissions.

15.2 Test Parameters

Test Location:	Element Hull
Test Chamber:	Wireless Laboratory 1
Test Standard and Clause:	ANSI C63.10-2013, Clause 11.11
EUT Frequencies Measured:	2411 MHz / 2435 MHz / 2461 MHz
EUT Channel Bandwidth:	800 kHz
Deviations From Standard:	None
Measurement BW:	100 kHz
Spectrum Analyzer Video BW: (requirement at least 3x RBW)	300 kHz
Measurement Detector:	Peak
Measurement Range:	9 kHz to 25 GHz

Environmental Conditions (Normal Environment)

Temperature: 21 °C	+15 °C to +35 °C (as declared)
Humidity: 40 % RH	20 % RH to 75 % RH (as declared)
Supply: 3 Vdc	(as declared)

15.3 Test Limit

In any 100 kHz bandwidth outside the frequency band in which the spread spectrum or digitally modulated device is operating, the RF power that is produced 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 that the transmitter demonstrates compliance with the peak conducted power limits. If the transmitter complies with the conducted power limits based on the use of root-mean-square averaging over a time interval, the attenuation required shall be 30 dB instead of 20 dB. Attenuation below the general field strength limits specified in FCC 47CFR15.209(a) is not required.

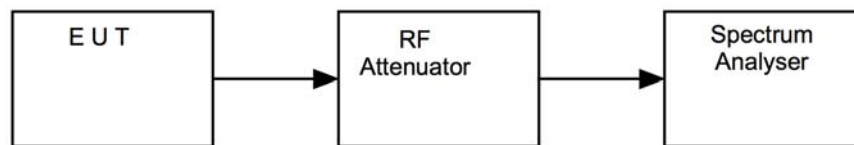
Reference measurement in band :	13.4 dBm
20 dBc limit :	-6.6 dBm

15.4 Test Method

With the EUT setup as per section 9 of this report and connected as per Figure v, the emissions from the EUT were measured on a spectrum analyser.

The measurements were performed with EUT set at its maximum duty. All modulation schemes, data rates and power settings were used to observe the worst case configuration in each bandwidth.

Figure v Test Setup

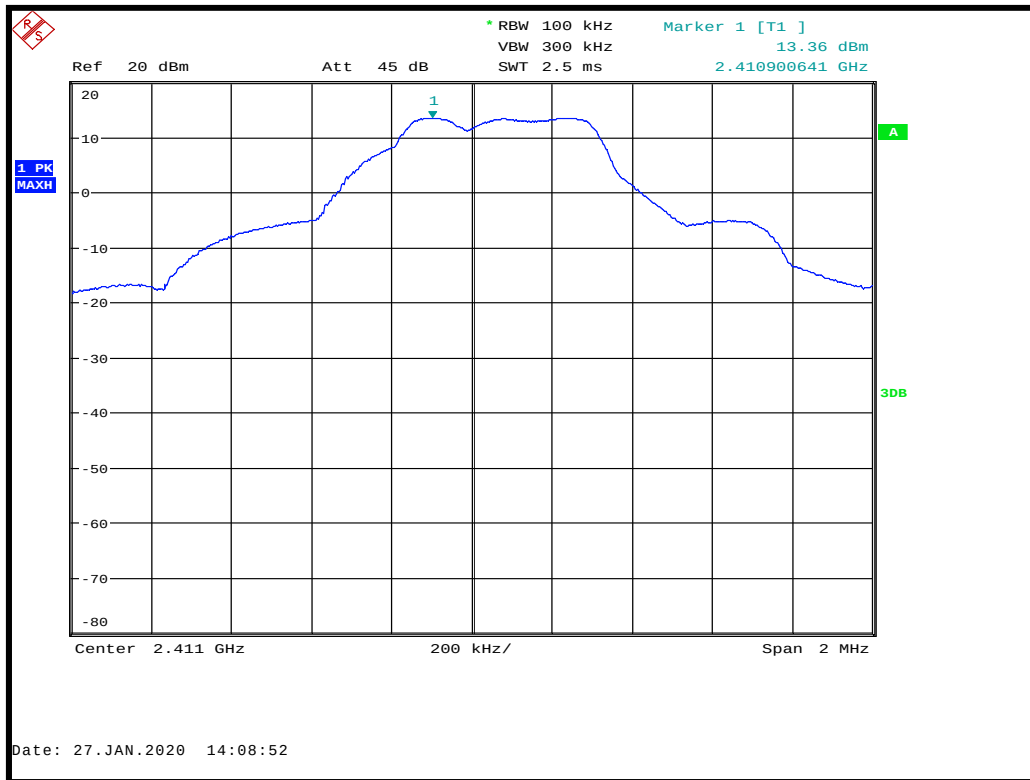


15.5 Test Equipment

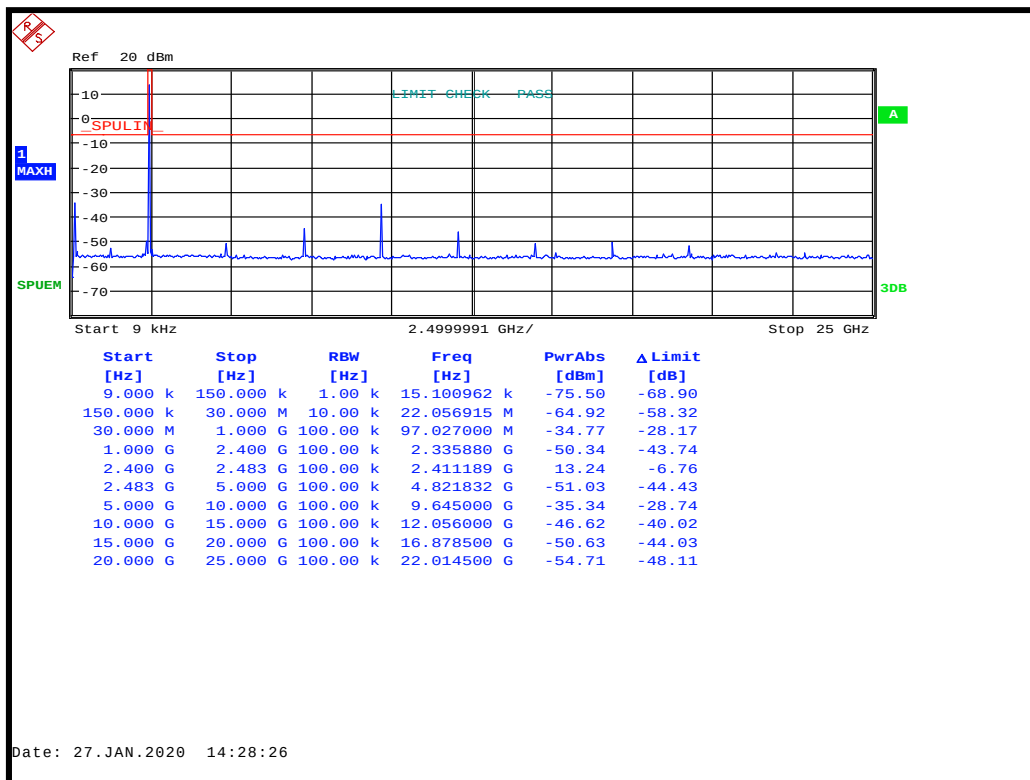
Equipment Type	Manufacturer	Equipment Description	Element No	Due For Calibration
FSU50	R&S	Spectrum Analyser	U544	2020-06-05

15.6 Test Results

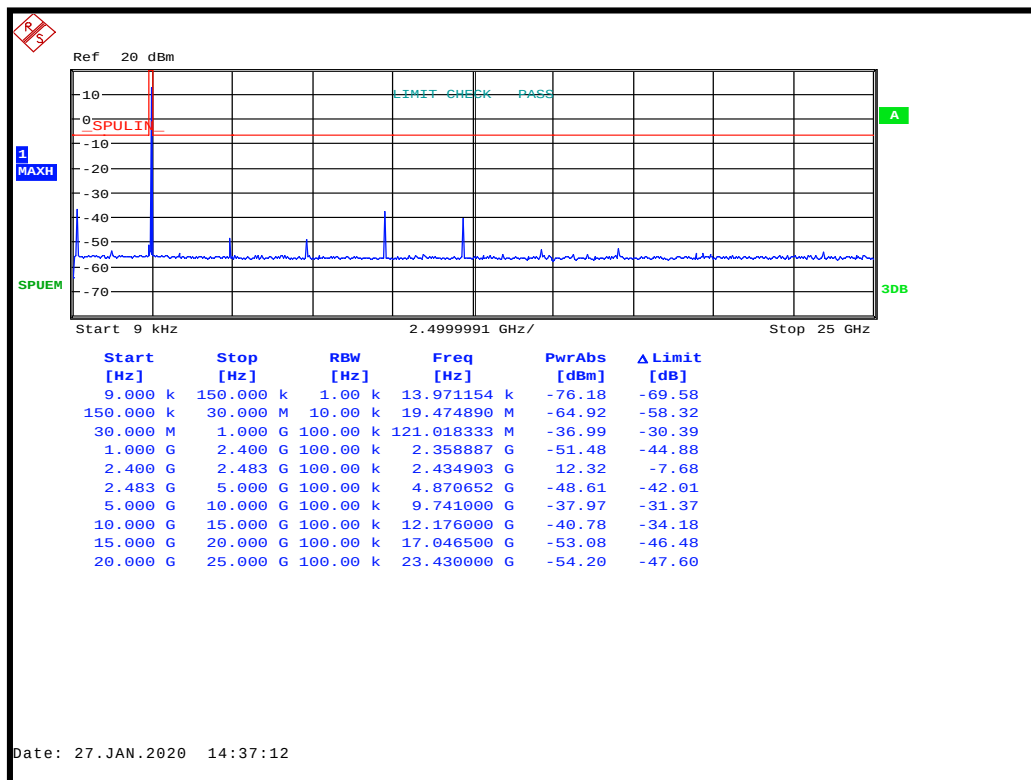
Reference measurement (taken on 2411 MHz channel as it provided worst case PSD results):



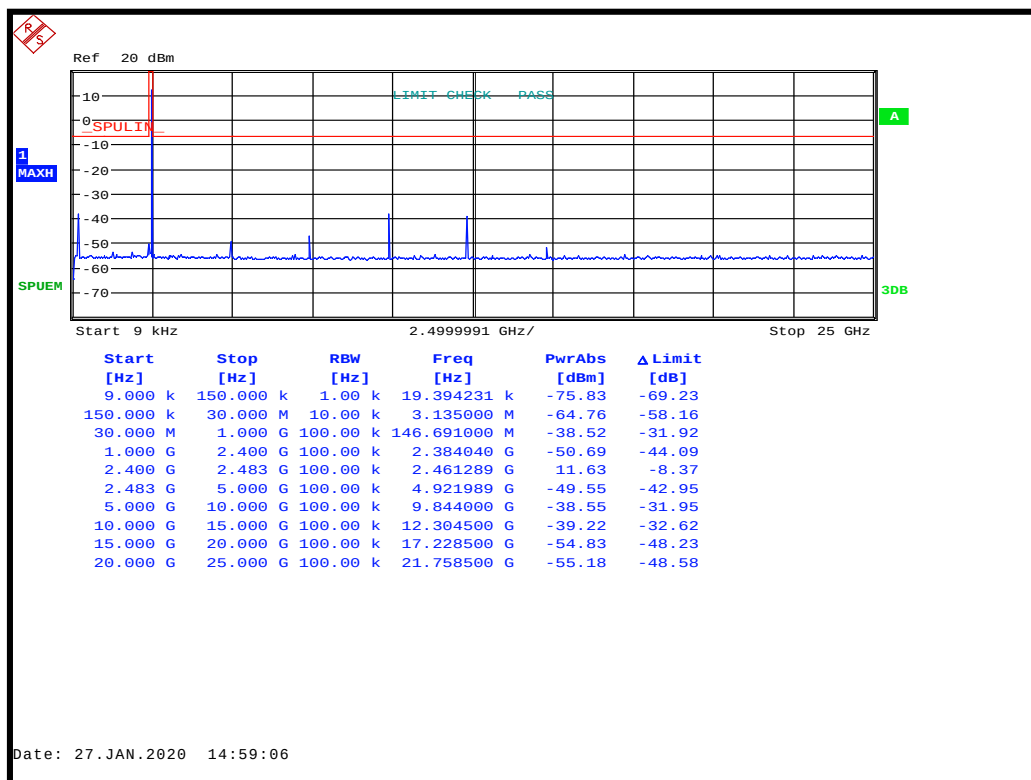
Bottom Channel 2411 MHz:



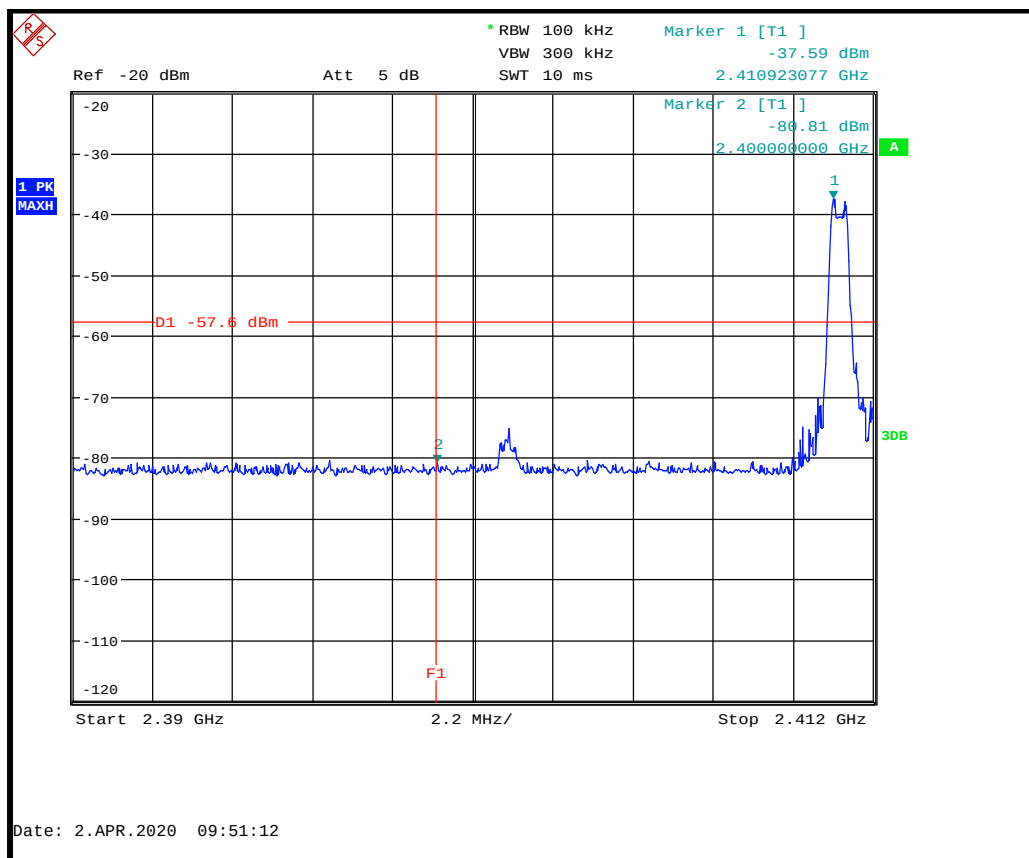
Middle Channel 2435 MHz:



Top Channel 2461 MHz:



Bottom Channel 2411 MHz : Lower Band Edge



16 Power spectral density

16.1 Definition

The power per unit bandwidth.

16.2 Test Parameters

Test Location:	Element Hull
Test Chamber:	Wireless Laboratory 1
Test Standard and Clause:	ANSI C63.10-2013, Clause 11.10
EUT Frequencies Measured:	2411 MHz / 2435 MHz / 2461 MHz
EUT Channel Bandwidth:	800 kHz
Deviations From Standard:	None
Measurement BW:	3 kHz
Spectrum Analyzer Video BW: (requirement at least 3x RBW)	10 kHz
Measurement Span: (requirement 1.5 times Channel BW)	1.6 MHz
Measurement Detector:	Peak

Environmental Conditions (Normal Environment)

Temperature: 21 °C	+15 °C to +35 °C (as declared)
Humidity: 40 % RH	20 % RH to 75 % RH (as declared)
Supply: 3 V dc	(as declared)

16.3 Test Limit

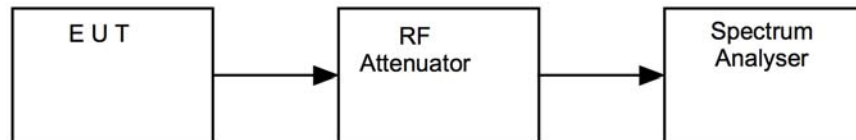
The transmitter power spectral density conducted from the transmitter to the antenna shall not be greater than 8 dBm in any 3 kHz band during any time interval of continuous transmission.

16.4 Test Method

With the EUT setup as per section 9 of this report and connected as per Figure vi, the peak emission of the EUT was measured on a spectrum analyser, with path losses taken into account.

The measurements were performed with EUT set at its maximum duty. All modulation schemes, data rates and power settings were used to observe the worst case configuration in each bandwidth.

Figure vi Test Setup



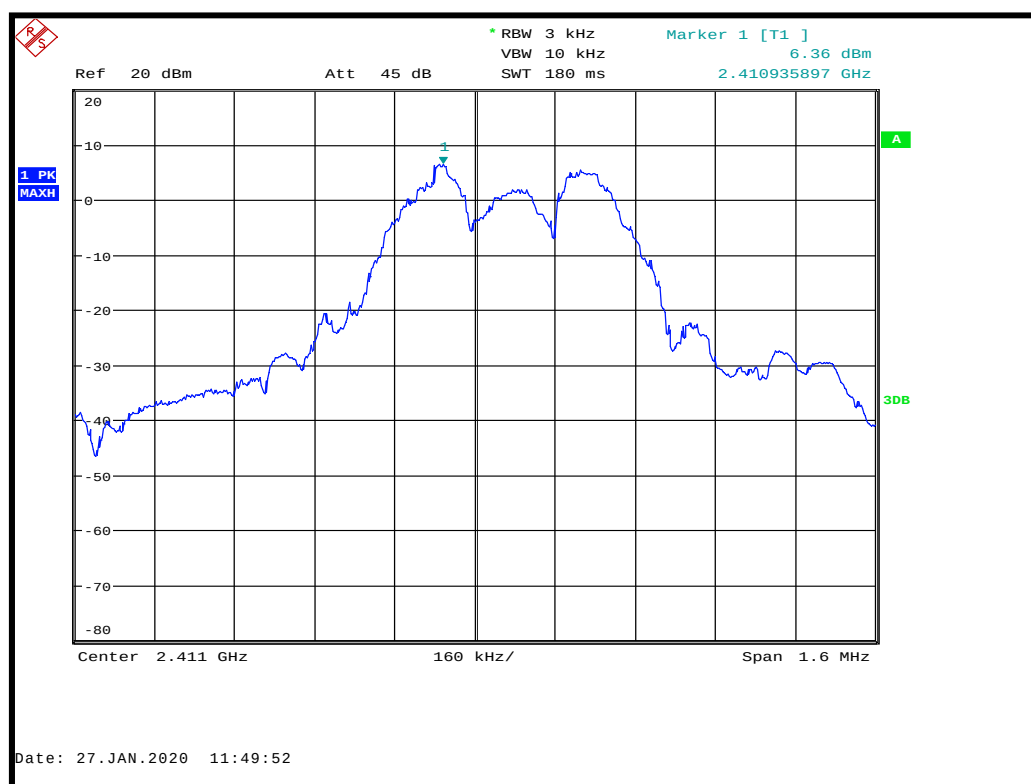
16.5 Test Equipment

Equipment Type	Manufacturer	Equipment Description	Element No	Due For Calibration
FSU50	R&S	Spectrum Analyser	U544	2020-06-05

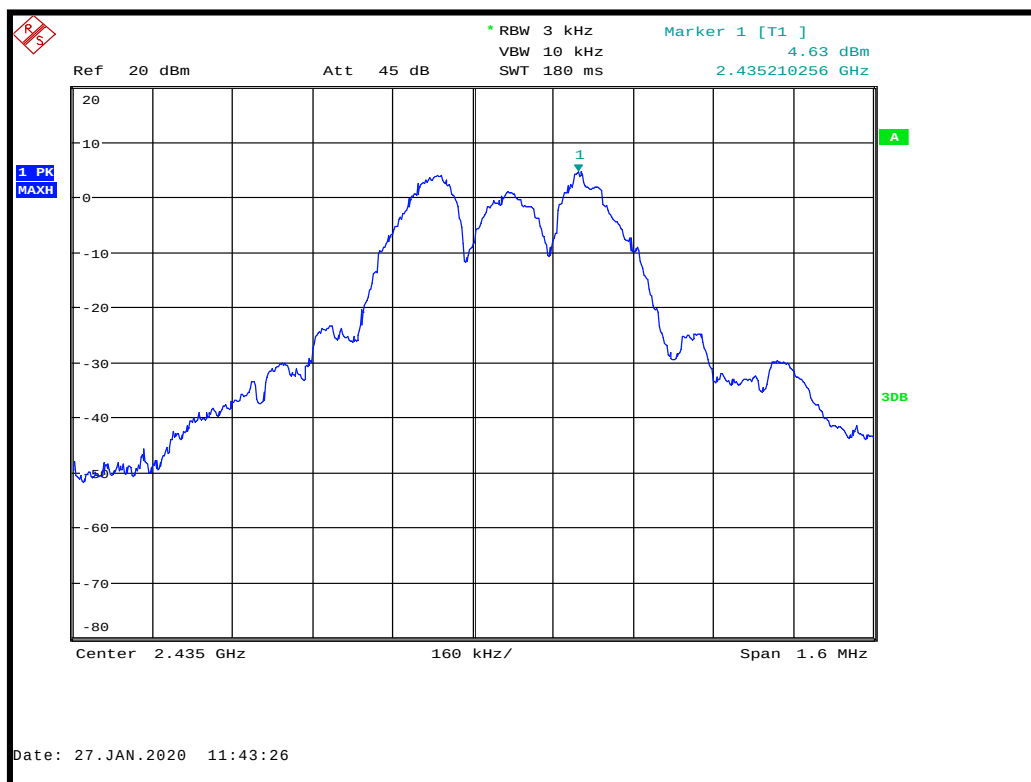
16.6 Test Results

Modulation: FSK; Power setting: As Supplied				
Channel Frequency (MHz)	Analyzer Level (dBm)	Cable loss (dB)	Power (dBm)	Result
2411	6.4	0	6.4	PASS
2435	4.6	0	4.6	PASS
2461	3.1	0	3.1	PASS

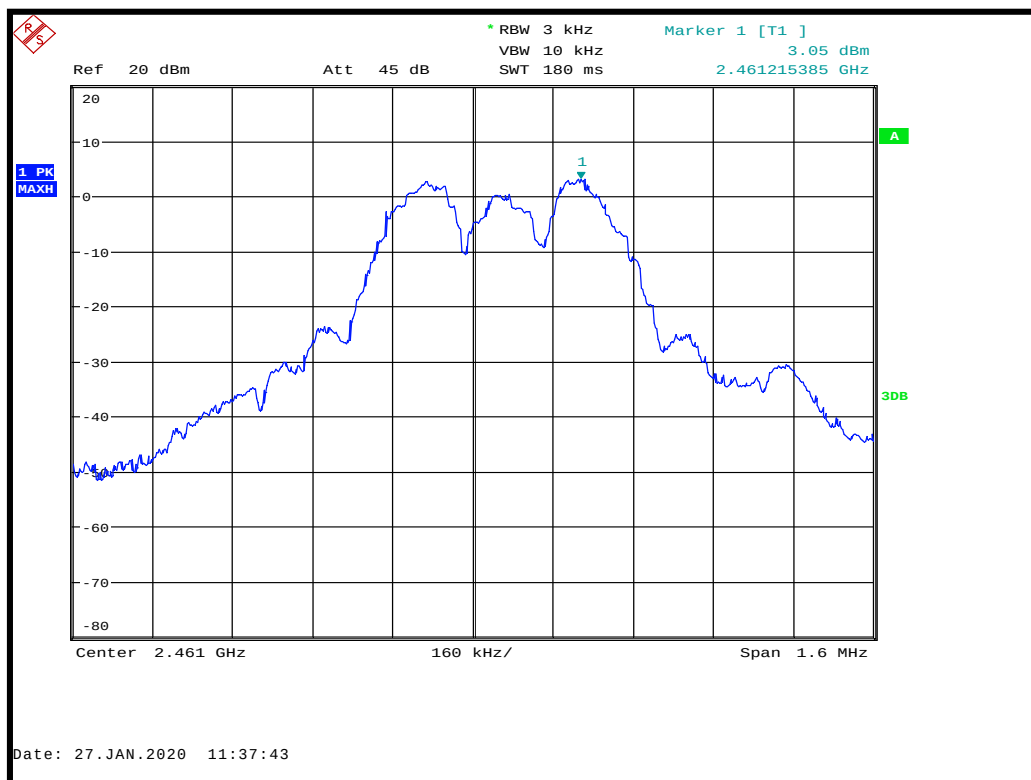
Bottom Channel 2411 MHz:



Middle Channel 2435 MHz:



Top Channel 2461 MHz



17 Measurement Uncertainty

Calculated Measurement Uncertainties

All statements of uncertainty are expanded standard uncertainty using a coverage factor of 1.96 to give a 95 % confidence:

[1] Radiated spurious emissions

Uncertainty in test result (30 MHz to 1 GHz) = **4.75 dB**

Uncertainty in test result (1 GHz to 18 GHz) = **4.46 dB**

[2] AC power line conducted emissions

Uncertainty in test result = **3.2 dB**

[3] Occupied bandwidth

Uncertainty in test result = **15.58 %**

[4] Conducted carrier power

Uncertainty in test result (Power Meter) = **0.93 dB**

[5] Conducted RF power out-of-band

Uncertainty in test result – up to 8.1 GHz = **3.31 dB**

Uncertainty in test result – 8.1 GHz to 15.3 GHz = **4.43 dB**

[6] Radiated RF power out-of-band

Uncertainty in test result (30 MHz to 1 GHz) = **4.75 dB**

Uncertainty in test result (1 GHz to 18 GHz) = **4.46 dB**

[7] Power spectral density

Uncertainty in test result (Spectrum Analyser) = **3.11 dB**

[8] ERP / EIRP

Uncertainty in test result (Laboratory) = **4.71 dB**

Uncertainty in test result (Pershore OATS) = **4.26 dB**

18 RF Exposure

Section 4.3 General SAR test reduction and exclusion guidance

For Standalone SAR exclusion consideration, when SAR Exclusion Threshold requirement in KDB 447498 is satisfied, standalone SAR evaluation for general population exposure conditions by measurement or numerical simulation is not required.

In the frequency range below 100 MHz to 6 GHz and test separation distance of 50 mm, the SAR Test Exclusion Threshold will be determined as follows

$$\text{SAR Exclusion Threshold (SARET)} = \text{Step 1} + \text{Step 2}$$

Step 1

$$\begin{aligned} \text{NT} &= \left[\left(\text{MP} / \text{TSD}^A \right) * \sqrt{f_{\text{GHz}}} \right] \\ \text{NT} &= \text{Numeric Threshold (3.0 for 1-g SAR and 7.5 for 10-g SAR)} \\ \text{MP} &= \text{Max Power of channel (mW) (inc tune up)} \\ \text{TSD}^A &= \text{Min Test separation Distance or 50mm (whichever is lower)} = 50 \end{aligned}$$

We can transpose this formula to allow us to find the maximum power of a channel allowed and compare this to the measured maximum power.

$$= \left[(\text{NT} * \text{TSD}^A) / \sqrt{f_{\text{GHz}}} \right]$$

For Distances Greater than 50 mm Step 2 applies

Step 2

$$(\text{TSD}^B - 50\text{mm}) * 10\}$$

Where:

$$\text{TSD}^B = \text{Min Test separation Distance (mm)} = 50$$

Operating Frequency 2.411 GHz

$$\begin{aligned} \text{SARET} &= \left[(3.0 * 50) / \sqrt{2.411} \right] + \{ (50 - 50) * 10 \} \\ \text{SARET} &= [150 / 1.55] + (0 * 10) \\ \text{SARET} &= 96.77 \text{ mW} \end{aligned}$$

Operating Frequency 2.435 GHz

$$\begin{aligned} \text{SARET} &= \left[(3.0 * 50) / \sqrt{2.435} \right] + \{ (50 - 50) * 10 \} \\ \text{SARET} &= [150 / 1.56] + (0 * 10) \\ \text{SARET} &= 96.15 \text{ mW} \end{aligned}$$

Operating Frequency 2.461 GHz

$$\begin{aligned} \text{SARET} &= \left[(3.0 * 50) / \sqrt{2.461} \right] + \{ (50 - 50) * 10 \} \\ \text{SARET} &= [150 / 1.57] + (0 * 10) \\ \text{SARET} &= 95.54 \text{ mW} \end{aligned}$$

Channel Frequency (MHz)	Max. Peak Conducted Power (mW)	SAR Exclusion Threshold (mW)	SAR Exclusion Threshold (W)
2411	22.4	96.77	Not Required
2435	18.6	96.15	Not Required
2461	15.5	95.54	Not Required

Therefore standalone SAR evaluation for general population exposure conditions by measurement or numerical simulation is not required.