TEST REPORT

Test Report No. : UL-RPT-RP13041774JD08A

Customer	:	Apple Inc.
Model No.	:	A2251
FCC ID	:	BCGA2251
Technology	:	WLAN
Test Standard(s)	:	FCC Parts 15.209(a) & 15.247
Test Laboratory	:	UL VS LTD, Basingstoke, Hampshire, RG24 8AH, United Kingdom

1. This test report shall not be reproduced except in full, without the written approval of UL VS LTD.
2. The results in this report apply only to the sample(s) tested.
3. The sample tested is in compliance with the above standard(s).
4. The test results in this report are traceable to the national or international standards.
5. Version 1.0

Date of Issue: 12 March 2020

Checked by:

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Company Signatory:

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Senior Test Engineer, Radio Laboratory
UL VS LTD

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Customer Information

Company Name:	Apple Inc.
Address:	One Apple Park Way Cupertino, California 95014 U.S.A.
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Report Revision History

Version Number	Issue Date	Revision Details	Revised By
1.0	12/03/2020	Initial Version	Sarah Williams

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1. Attestation of Test Results

1.1. Description of EUT

The Equipment Under Test (EUT) was a Laptop Computer with *Bluetooth, Bluetooth* Low Energy and 802.11 a/b/g/n/ac capabilities in the 2.4 GHz and 5.0 GHz bands.

1.2. General Information

Specification Reference:	47CFR15.247
Specification Title:	Code of Federal Regulations Volume 47 (Telecommunications): Part 15 Subpart C (Intentional Radiators) - Section 15.247
Specification Reference:	47CFR15.209
Specification Title:	Code of Federal Regulations Volume 47 (Telecommunications): Part 15 Subpart C (Intentional Radiators) - Section 15.209
Site Registration:	621311
Location of Testing:	UL VS LTD, Unit 3 Horizon, Wade Road, Kingsland Business Park, Basingstoke, Hampshire, RG24 8AH, United Kingdom
Test Dates:	17 November 2019 to 10 January 2020

1.3. Summary of Test Results

FCC Reference (47CFR)	Measurement	Result
Part 15.35(c)	Transmitter Duty Cycle	Note 1
Part 15.247(a)(2)	Transmitter Minimum 6 dB Bandwidth	Complied
Part 15.247(e)	Transmitter Power Spectral Density	Complied
Part 15.247(b)(3)	Transmitter Maximum (Average) Output Power	Complied
Part 15.247(d) & 15.209(a)	Transmitter Radiated Emissions	Complied
Part 15.247(d) & 15.209(a)	Transmitter Band Edge Radiated Emissions	Complied

Note(s):

1. The measurement was performed to assist in the calculation of the level of maximum conducted output power, power spectral density and emissions. The EUT cannot transmit continuously and sweep triggering/signal gating cannot be implemented.
2. For the data rates declared as worst case and reported in this test report, duty cycle was measured to be greater than 98%. Plots for these measurements are archived on the UL VS LTD IT server and available for inspection upon request.
3. There are two vendors of the WiFi/*Bluetooth* radio modules, Vendor 1 and Vendor 2.

   The WiFi/*Bluetooth* radio modules have the same mechanical outline (i.e. the same packaging dimension and pin layout), use the same on-board antenna matching circuit, have an identical antenna structure and are built and tested to conform to the same specification and to operate within the same tolerances.

   Baseline testing was performed on the two vendors to determine the worst case.

1.4. Deviations from the Test Specification

For the measurements contained within this test report, there were no deviations from, additions to, or

exclusions from the test specification identified above.

2. Summary of Testing

2.1. Facilities and Accreditation

The test site and measurement facilities used to collect data are located at Unit 3 Horizon, Wade Road, Kingsland Business Park, Basingstoke, Hampshire, RG24 8AH, United Kingdom. The following table identifies which facilities were utilised for radiated emission measurements documented in this report. Specific facilities are also identified in the test results sections.

Site 1	X
Site 2	-
Site 17	X

UL VS LTD is accredited by UKAS. The tests reported herein have been performed in accordance with its terms of accreditation.

2.2. Methods and Procedures

Reference:	ANSI C63.10-2013
Title:	American National Standard of Procedures for Compliance Testing of Unlicensed Wireless Devices
Reference:	KDB 558074 D01 15.247 Meas Guidance v05r02, April 2, 2019
Title:	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
Reference:	KDB 662911 D01 Multiple Transmitter Output v02r01 October 31, 2013
Title:	Emissions Testing of Transmitters with Multiple Outputs in the Same Band

2.3. Calibration and Uncertainty

Measuring Instrument Calibration

In accordance with UKAS requirements all the measurement equipment is on a calibration schedule. All equipment was within the calibration period on the date of testing.

Measurement Uncertainty

No measurement or test can ever be perfect and the imperfections give rise to error of measurement in the results. Consequently the result of a measurement is only an approximation to the value measured (the specific quantity subject to measurement) and is only complete when accompanied by a statement of the uncertainty of the approximation.

The expression of uncertainty of a measurement result allows realistic comparison of results with reference values and limits given in specifications and standards.

The uncertainty of the result may need to be taken into account when interpreting the measurement results.

The reported expanded uncertainties below are based on a standard uncertainty multiplied by an appropriate coverage factor such that a confidence level of approximately 95% is maintained. For the purposes of this document “approximately” is interpreted as meaning “effectively” or “for most practical purposes”.

Measurement Type	Range	Confidence Level (%)	Calculated Uncertainty
Duty Cycle	2.4 GHz to 2.4835 GHz	95%	±1.14 %
Minimum 6 dB Bandwidth	2.4 GHz to 2.4835 GHz	95%	±4.59 %
Spectral Power Density	2.4 GHz to 2.4835 GHz	95%	±1.13 dB
Conducted Maximum Output Power	2.4 GHz to 2.4835 GHz	95%	±1.13 dB
Radiated Spurious Emissions	30 MHz to 1 GHz	95%	±3.30 dB
Radiated Spurious Emissions	1 GHz to 25 GHz	95%	±2.94 dB

The methods used to calculate the above uncertainties are in line with those recommended within the various measurement specifications. Where measurement specifications do not include guidelines for the evaluation of measurement uncertainty the published guidance of the appropriate accreditation body is followed.

2.4. Test and Measurement Equipment

Test Equipment Used for Transmitter Conducted Tests (Non-TxBF)

Asset No.	Instrument	Manufacturer	Type No.	Serial No.	Date Calibration Due	Cal. Interval (Months)
M2004	Thermohygrometer	Testo	608-H1	45046425	05 Jan 2021	12
M2033	Signal Analyser	Rohde & Schwarz	FSV13	101667	24 Jul 2020	12
A3027	Attenuator	Broadwave Technologies	351-311-006	#1	Calibrated before use	-
A3028	Attenuator	Broadwave Technologies	351-311-006	#2	Calibrated before use	-
A3029	Attenuator	Broadwave Technologies	351-311-006	#3	Calibrated before use	-
A3004	RF Switch	Pickering Interfaces	64-102-002	XZ363230	Calibrated before use	-
A3180	Attenuator	Pasternack	PE7047-3	Not stated	Calibrated before use	-
G0615	Signal Generator	Rohde & Schwarz	SMBV100A	260473	08 May 2020	36
A3005	Replay Test Rack	N/A	N/A	N/A	Calibration not required	-

Test Equipment Used for Transmitter Conducted Tests (TxBF)

Asset No.	Instrument	Manufacturer	Type No.	Serial No.	Date Calibration Due	Cal. Interval (Months)
M2001	Thermohygrometer	Testo	608-H1	45041824	06 Jan 2020	12
M1996	Signal Analyser	Rohde & Schwarz	FSV13	100975	16 Jan 2020	12
A090	Attenuator	Narda	743-60	01057	Calibrated before use	-
A2505	Directional Coupler	AtlanTecRF	CDC-003060-20	1101230	Calibrated before use	-
A2536	Directional Coupler	AtlanTecRF	CDC-003060-20	14041701720	Calibrated before use	-
A2534	Directional Coupler	AtlanTecRF	CDC-003060-20	14041701718	Calibrated before use	-
A2098	Power Splitter	Mini-Circuits	ZN4PD1-63-S+	SF 210501205	Calibrated before use	-
A2886	Power Splitter	Mini-Circuits	ZN4PD2-63-S+	SUU 47401601#3	Calibrated before use	-
A3160	RF Switch	Pickering Interfaces	60-102B-001	XZ370188	Calibrated before use	-
G0614	Signal Generator	Rohde & Schwarz	SMBV100A	177687	08 May 2020	36

Test Measurement Software/Firmware Used for Transmitter Conducted Tests

Name	Version	Release Date
UL VS LTD Replay	20190208	08 February 2019

Test and Measurement Equipment (continued)

Test Equipment Used for Transmitter Radiated Emissions

Asset No.	Instrument	Manufacturer	Type No.	Serial No.	Date Calibration Due	Cal. Interval (Months)
M2040	Thermohygrometer	Testo	608-H1	45124934	07 Jan 2021	12
K0001	3m RSE Chamber	Rainford	N/A	N/A	16 Oct 2020	12
M2044	Test Receiver	Rohde & Schwarz	ESU26	100122	01 Apr 2020	12
A3083	Low Pass Filter	AtlanTecRF	AFL-01000	18010900076	09 Apr 2020	12
A3154	Pre-Amplifier	Com-Power	PAM-103	18020012	04 Oct 2020	12
A553	Antenna	Chase	CBL6111A	1593	14 Oct 2020	12
A3112	Attenuator	AtlanTecRF	AN18-06	219706#2	14 Oct 2020	12
A3139	Antenna	Schwarzbeck	HWRD750	00027	07 Oct 2020	12
A3141	Pre-Amplifier	Schwarzbeck	BBV 9718 B	00021	08 Oct 2020	12
A3095	High Pass Filter	AtlanTecRF	AFH-07000	18051600012	09 Apr 2020	12
M2003	Thermohygrometer	Testo	608-H1	45046641	07 Jan 2021	12
K0017	3m RSE Chamber	Rainford	N/A	N/A	01 Aug 2020	12
M1630	Test Receiver	Rohde & Schwarz	ESU40	100233	12 Nov 2020	12
A2863	Pre-Amplifier	Agilent	8449B	3008A02100	08 Aug 2020	12
A2896	Pre-Amplifier	Schwarzbeck	BBV 9721	9721 - 023	08 Feb 2020	12
A2889	Antenna	Schwarzbeck	BBHA 9120 B	BBHA 9120 B 653	08 Aug 2020	12
A2895	Antenna	Schwarzbeck	BBHA 9170	9170-728	08 Feb 2020	12
A2916	Attenuator	AtlanTecRF	AN18W5-10	832827#1	20 Feb 2020	12
A2914	High Pass Filter	AtlanTecRF	AFH-03000	2155	20 Feb 2020	12

Test and Measurement Equipment (continued)

Test Equipment Used for Transmitter Band Edge Radiated Emissions

Asset No.	Instrument	Manufacturer	Type No.	Serial No.	Date Calibration Due	Cal. Interval (Months)
M2040	Thermohygrometer	Testo	608-H1	45124934	07 Jan 2021	12
K0001	3m RSE Chamber	Rainford	N/A	N/A	16 Oct 2020	12
M2044	Test Receiver	Rohde & Schwarz	ESU26	100122	01 Apr 2020	12
A3179	Pre Amplifier	Agilent	8449B	3008A00934	09 Oct 2020	12
A3138	Antenna	Schwarzbeck	BBHA 9120 B	00702	04 Oct 2020	12
A2523	Attenuator	AtlanTecRF	AN18W5-10	832827#1	04 Mar 2020	12
M2003	Thermohygrometer	Testo	608-H1	45046641	07 Jan 2021	12
K0017	3m RSE Chamber	Rainford	N/A	N/A	01 Aug 2020	12
M1874	Test Receiver	Rohde & Schwarz	ESU26	100553	04 Feb 2020	12
M1630	Test Receiver	Rohde & Schwarz	ESU40	100233	12 Nov 2020	12
A2863	Pre Amplifier	Agilent	8449B	3008A02100	08 Aug 2020	12
A2889	Antenna	Schwarzbeck	BBHA 9120 B	BBHA 9120 B 653	08 Aug 2020	12
A2916	Attenuator	AtlanTecRF	AN18W5-10	832827#1	20 Feb 2020	12

Test Measurement Software/Firmware Used for Transmitter Radiated Tests

Name	Version	Release Date
UL VS LTD Replay	1	29 November 2018

3. Equipment Under Test (EUT)

3.1. Identification of Equipment Under Test (EUT)

Brand Name:	Apple
Model Name or Number:	A2251
Test Sample Serial Number:	C02ZG00GP22J *(Conducted sample #1)*
Hardware Version:	REV 1.0
Software Version:	19C19
FCC ID:	BCGA2251

Brand Name:	Apple
Model Name or Number:	A2251
Test Sample Serial Number:	C02ZH007P1YX *(Conducted sample #2)*
Hardware Version:	REV 1.0
Software Version:	19C19
FCC ID:	BCGA2251

Brand Name:	Apple
Model Name or Number:	A2251
Test Sample Serial Number:	C02ZG00KP22J *(Radiated sample #1)*
Hardware Version:	REV 1.0
Software Version:	19C19
FCC ID:	BCGA2251

Brand Name:	Apple
Model Name or Number:	A2251
Test Sample Serial Number:	C02ZG00UP22J *(Radiated sample #2)*
Hardware Version:	REV 1.0
Software Version:	19C19
FCC ID:	BCGA2251

Brand Name:	Apple
Model Name or Number:	A2251
Test Sample Serial Number:	C02ZH005P1YX *(Radiated sample #3)*
Hardware Version:	REV 1.0
Software Version:	19C19
FCC ID:	BCGA2251

3.2. Modifications Incorporated in the EUT

No modifications were applied to the EUT during testing.

3.3. Additional Information Related to Testing

Technology Tested:	WLAN (IEEE 802.11b,g,n) / Digital Transmission System	
Type of Unit:	Transceiver	
Modulation Type:	DBPSK, DQPSK, BPSK, QPSK, 16QAM & 64QAM	
Data Rates:	802.11b	1, 2, 5.5 & 11 Mbps (SISO, MIMO with CDD)
	802.11g	6, 9, 12, 18, 24, 36, 48 & 54 Mbps (SISO, MIMO with CDD)
	802.11n HT20	MCS0 to MCS7 (1 spatial stream with either SISO or 2/3-chain MIMO CDD/TxBF operation) MCS8 to MCS15 (2 spatial streams on 2 transmit chains with or without TxBF) MCS16 to MCS23 (3 spatial streams on 3 transmit chains with or without TxBF)
Power Supply Requirement(s):	Nominal	Constant 3.8 VDC via 120 VAC 60 Hz AC/DC supply
Maximum Conducted Output Power:	22.6 dBm	
Channel Spacing:	20 MHz	
Transmit Frequency Range:	2412 MHz to 2472 MHz	

Transmit Channels Tested:	**Channel Number**	**Channel Frequency (MHz)**
	1	2412
	2	2417
	3	2422
	6	2437
	7	2442
	11	2462
	12	2467
	13	2472

3.4. Description of Available Antennas

The radio utilizes three integrated antennas, with the following maximum gains:

Frequency Band (MHz)	$G_{Antenna\ 1}$ / Core 0 (dBi)	$G_{Antenna\ 2}$ / Core 1 (dBi)	$G_{Antenna\ 3}$ / Core 2 (dBi)
2400 -2480	1.8	1.1	2.2

Refer to Appendix 1 for directional antenna gain calculations for MIMO modes.

3.5. Description of Test Setup

Support Equipment

The following support equipment was used to exercise the EUT during testing:

Description:	USB-C Power Adapter
Brand Name:	Apple
Model Name or Number:	A1947
Serial Number:	Not marked or stated

Description:	USB-C Cable. Length 2 m.
Brand Name:	Not marked or stated
Model Name or Number:	Not marked or stated
Serial Number:	Not marked or stated

Description:	Personal Hands Free (PHF)
Brand Name:	Apple
Model Name or Number:	Apple EarPods
Serial Number:	Not marked or stated

Description:	USB-C to USB Adapter. Quantity 3.
Brand Name:	Apple
Model Name or Number:	A1632
Serial Number:	Not marked or stated

Description:	USB Cable Type A. Quantity 3. Length 3 m.
Brand Name:	Not marked or stated
Model Name or Number:	Not marked or stated
Serial Number:	Not marked or stated

Brand Name:	Test Laptop
Description:	Apple
Model Name or Number:	MacBook Pro
Serial Number:	C02TF03QHT76

Brand Name:	Test Laptop
Description:	Apple
Model Name or Number:	MacBook Pro
Serial Number:	C02S2007HH5Y

Support Equipment (continued)

Description:	USB Hub
Brand Name:	Belkin
Model Name or Number:	F5U404-BLK
Serial Number:	Not marked or stated

Description:	USB Hub
Brand Name:	Hama
Model Name or Number:	Not marked or stated
Serial Number:	00078498

Operating Modes

The EUT was tested in the following operating mode(s):

- Non-TxBF modes: Continuously transmitting with a modulated carrier at maximum power on the relevant channels as required using the supported data rates/modulation types.
- TxBF modes: Transmitting a modulated carrier with maximum possible duty cycle at maximum power on the relevant channels as required using the supported data rates/modulation types.

Configuration and Peripherals

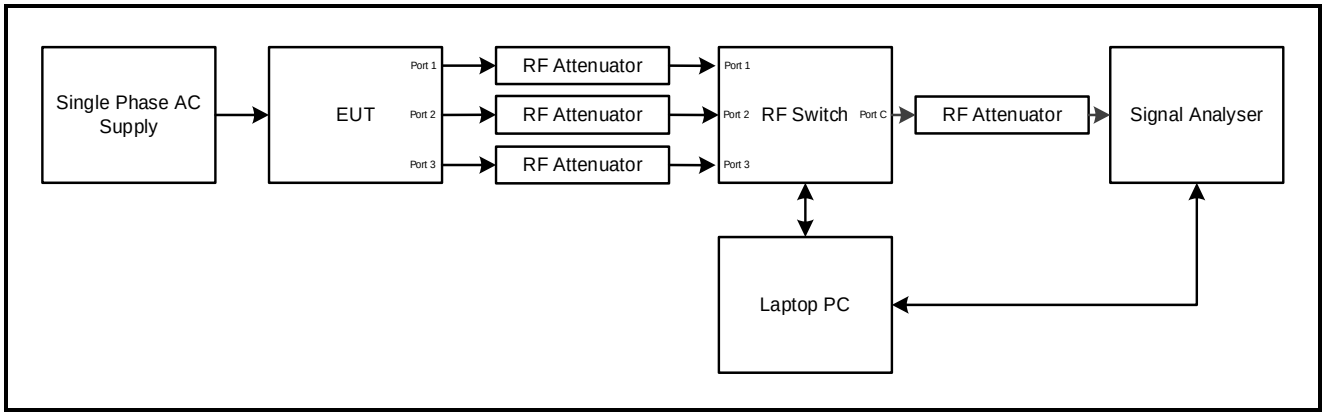
The EUT was tested in the following configuration(s):

- Controlled in test mode using a software application on the EUT supplied by the customer. The application was used to enable a continuous transmission and to select the test channels as required.
- For TxBF modes, the EUT was communicating via a conducted or radiated RF link with an equivalent device. The EUT ran iPerf bandwidth testing application in client mode to produce maximum throughput. The customer supplied a document containing the setup instructions 'EUT_TXBF_operating procedures_v1.pdf'.
- The customer declared the following data rates to be used for all measurements as:
    - 802.11b / SISO – DBPSK / 1 Mbps
    - 802.11g / SISO – BPSK / 6 Mbps
    - 802.11n HT20 / SISO – BPSK / MCS0
    - 802.11b / MIMO / 2Tx CDD – DBPSK / 1 Mbps
    - 802.11b / MIMO / 3Tx CDD – DBPSK / 1 Mbps
    - 802.11n HT20 / MIMO / 2Tx CDD – BPSK / MCS0
    - 802.11n HT20 / MIMO / 3Tx CDD – BPSK / MCS0
    - 802.11n HT20 / MIMO / 2Tx TXBF – BPSK / MCS0
    - 802.11n HT20 / MIMO / 3Tx TXBF – BPSK / MCS0
- The EUT has three separate antennas which correspond to three separate antenna ports. Core 0, Core 1 and Core 2 correspond to antenna 1, antenna 2 and antenna 3 respectively.
- For the Transmitter Minimum 6 dB Bandwidth test, only SISO modes were tested since the bandwidth does not change depending on chains used.
- The customer supplied U.FL RF cables with the EUT in order to perform conducted measurements. The measured additional path loss was included in any path loss calculations.
- Transmitter spurious emissions were performed with the EUT transmitting with a data rate of 802.11b / 1 Mbps / MIMO / 3Tx CDD. This was found to be the worst case modulation scheme with regards to emissions after preliminary investigations and, as this mode emits the highest conducted output power level, it was deemed to be the worst case.
- Transmitter radiated spurious emissions tests were performed with the AC Charger, USB cables and PHF connected to the EUT. The USB-C ports were connected via a USB C-A adaptor and USB cable to a hub. The hub was placed outside the chamber.
- The EUT was powered from a 120 VAC 60 Hz single phase mains supply.
- Additional testing on channels near the upper band edge was requested.

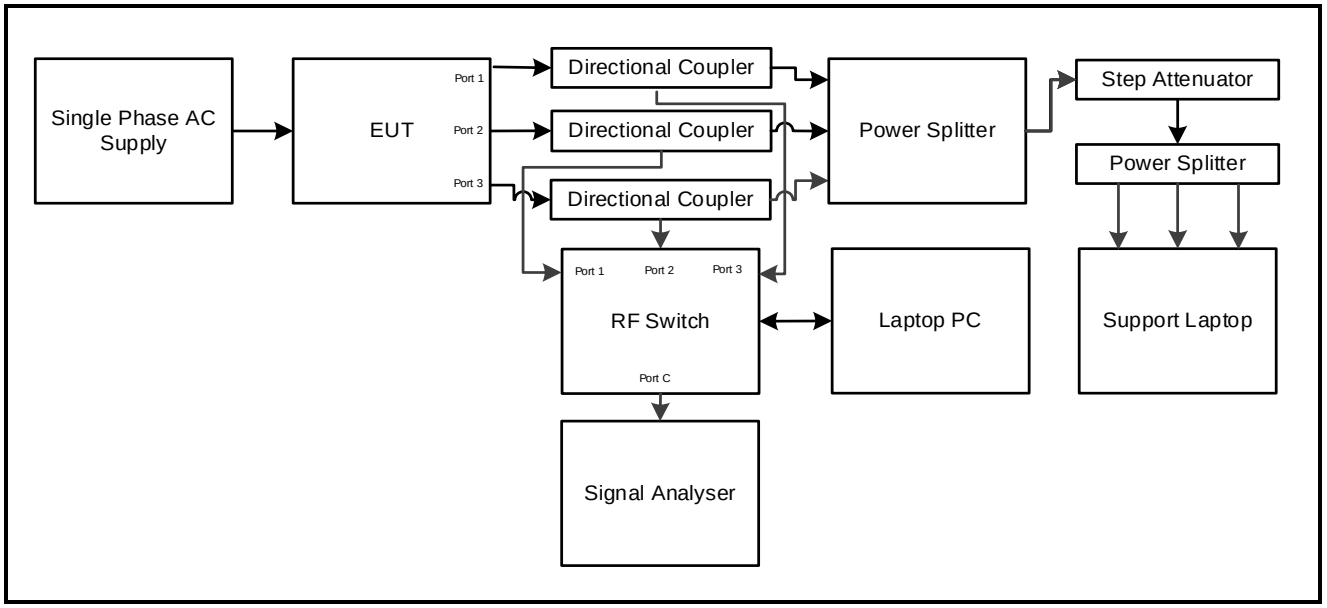
Test Setup Diagrams

Conducted Tests:

Test Setup for Transmitter Conducted Tests (non-TXBF)



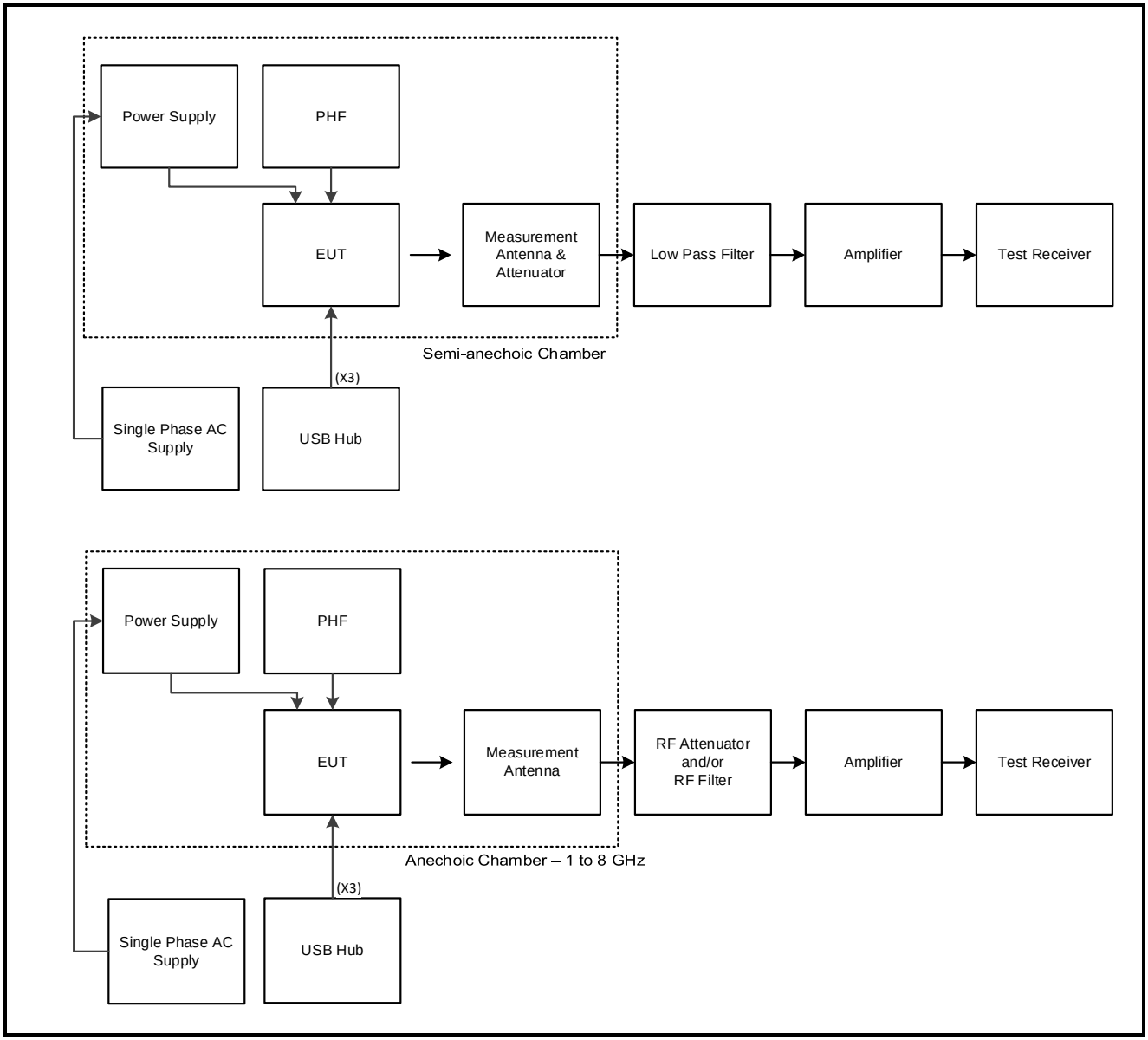
Test Setup for Transmitter Conducted Tests (TXBF)



Test Setup Diagrams (continued)

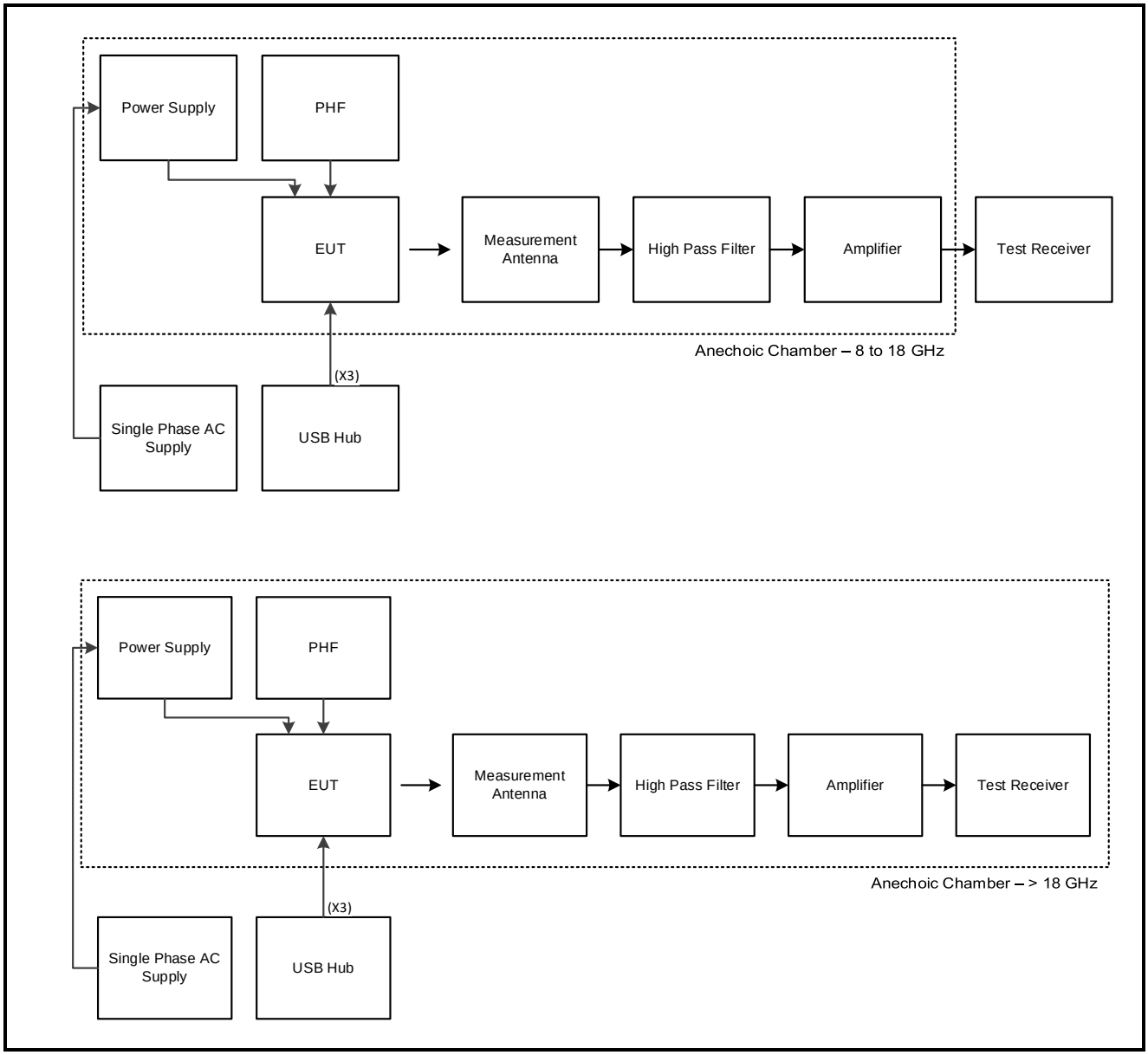
Radiated Tests:

Test Setup for Transmitter Radiated Emissions



Test Setup Diagrams (continued)

Test Setup for Transmitter Radiated Emissions



4. Antenna Port Test Results

4.1. Transmitter Duty Cycle

Test Summary:

Test Engineer:	Matthew Botfield	**Test Date:**	17 December 2019
Test Sample Serial Number:	C02ZG00GP22J		

FCC Reference:	Part 15.35(c)
Test Method Used:	FCC KDB 558074 Section 6 referencing ANSI C63.10 Section 11.6

Environmental Conditions:

Temperature (°C):	23
Relative Humidity (%):	42

Note(s):

1. In order to assist with the determination of the average level of fundamental and spurious emissions field strength, measurements were made of duty cycle to determine the transmission duration and the silent period time of the transmitter. The transmitter duty cycle was measured using a spectrum analyser in the time domain and calculated by using the following calculation:

   10 log (1 / (On Time / [Period or 100 ms whichever is the lesser])).

   802.11n / HT20 / MCS0 / MIMO / 2 Tx TXBF / Core 0 duty cycle: 10 log (1 / (3.83/3.96)) = 0.1 dB

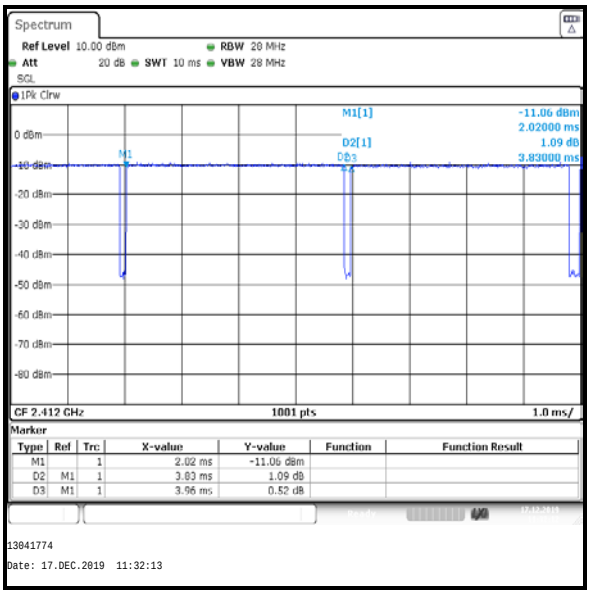
   802.11n / HT20 / MCS0 / MIMO / 3 Tx TXBF / Core 0 duty cycle: 10 log (1 / (3.83/3.95)) = 0.1 dB

2. For all other modes, the duty cycle was measured and found to be greater than 98%. Plots for these measurements are archived on the UL VS LTD IT server and available for inspection upon request.

Transmitter Duty Cycle (continued)

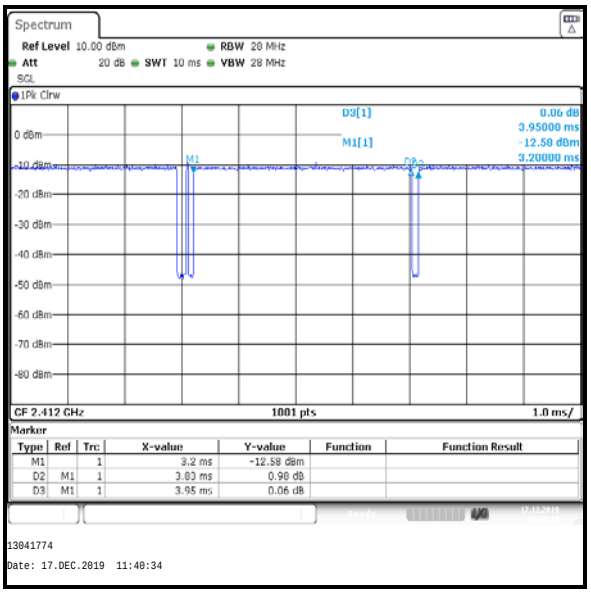
Results: 802.11n / HT20 / MIMO / 2Tx TxBF / MCS0 / Core 0

Pulse Duration (ms)	Period (ms)	Duty Cycle (dB)
3.83	3.96	0.1



Results: 802.11n / HT20 / MIMO / 3TxBF / MCS0 / Core 0

Pulse Duration (ms)	Period (ms)	Duty Cycle (dB)
3.83	3.95	0.1



4.2. Transmitter Minimum 6 dB Bandwidth

Test Summary:

Test Engineer:	Max Passell	**Test Date:**	02 January 2020
Test Sample Serial Number:	C02ZH007P1YX		

FCC Reference:	Part 15.247(a)(2)
Test Method Used:	FCC KDB 558074 Section 8.2 referencing ANSI C63.10 Section 11.8.1

Environmental Conditions:

Temperature (°C):	23
Relative Humidity (%):	31

Note(s):

1. The customer declared the following data rates to be used for all measurements as:
    - 802.11b – DBPSK / 1 Mbps / Core 2
    - 802.11g – BPSK / 6 Mbps / Core 2
    - 802.11n HT20 – BPSK / MCS0 / Core 2

    Only SISO modes are reported since the bandwidth does not change depending on chains used.
2. Final measurements were performed using the above configurations on the relevant channels in accordance with ANSI C63.10 Section 11.8.1 Option 1 measurement procedure. Additional channels were tested as requested by the customer. The test receiver resolution bandwidth was set to 100 kHz and video bandwidth 300 kHz. A peak detector was used, sweep time was set to auto and the trace mode was Max Hold. The span was set to 40 MHz. The DTS bandwidth was measured at 6 dB down from the peak of the signal.
3. The signal analyser was connected to the RF port on the EUT using an RF switch, suitable attenuation and RF cables. An RF offset was entered on the signal analyser to compensate for the loss of the switch, attenuator and RF cables.

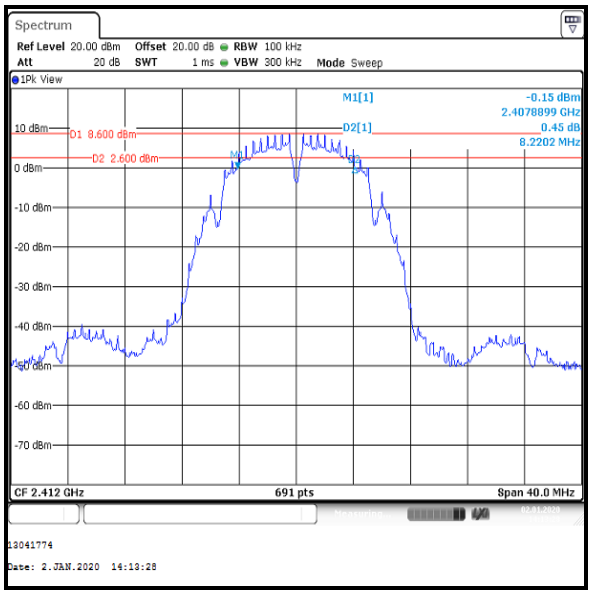
Transmitter Minimum 6 dB Bandwidth (continued)

Results: 802.11b / 20 MHz / DBPSK / 1 Mbps / Core 2

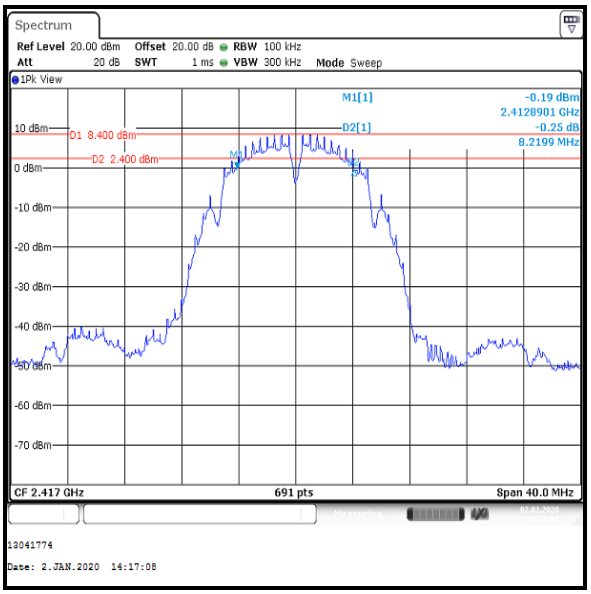
Channel	6 dB Bandwidth (kHz)	Limit (kHz)	Margin (kHz)	Result
1	8220	≥500	7720	Complied
2	8220	≥500	7720	Complied
3	8683	≥500	8183	Complied
6	8683	≥500	8183	Complied
7	8220	≥500	7720	Complied
11	8683	≥500	8183	Complied
12	8220	≥500	7720	Complied
13	8683	≥500	8183	Complied

Transmitter Minimum 6 dB Bandwidth (continued)

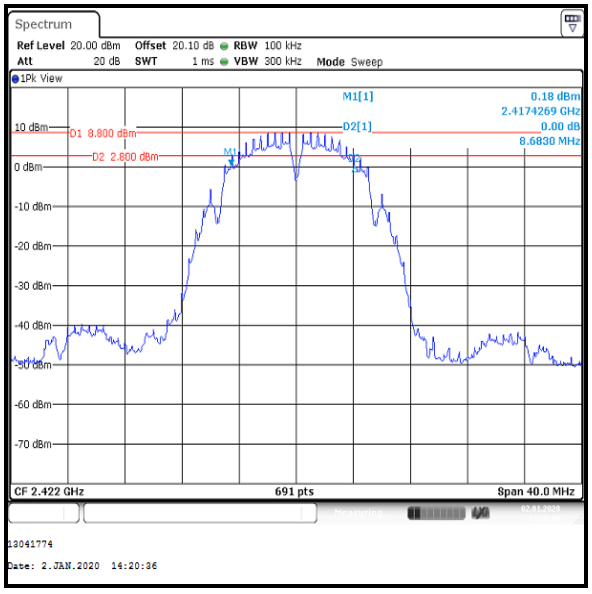
Results: 802.11b / 20 MHz / DBPSK / 1 Mbps / Core 2



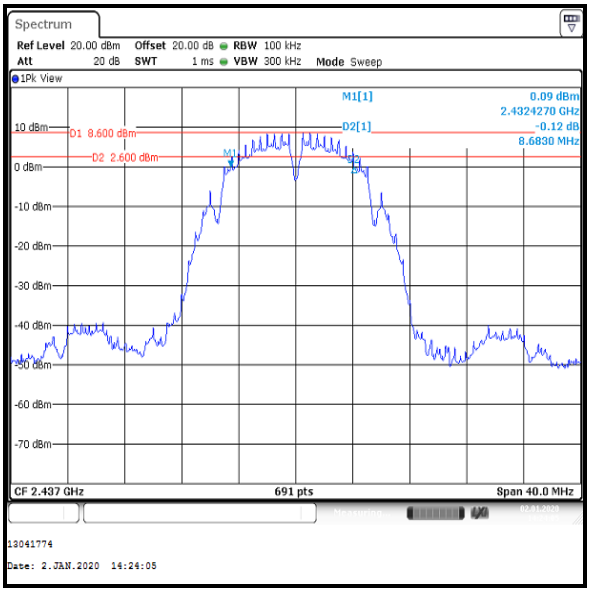
Channel 1



Channel 2



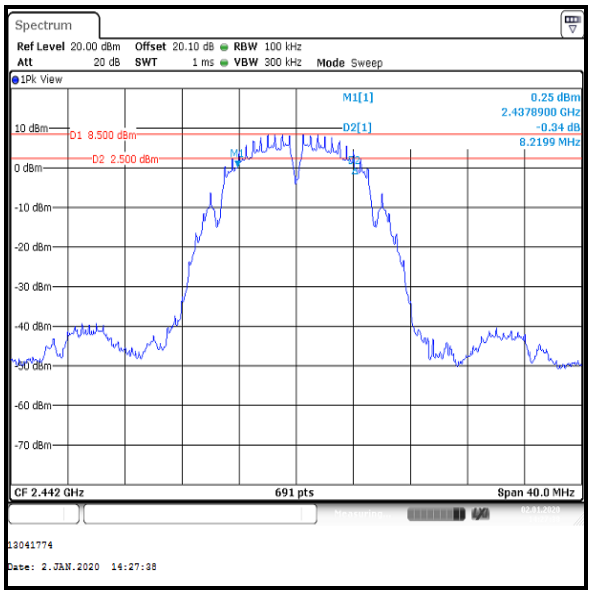
Channel 3



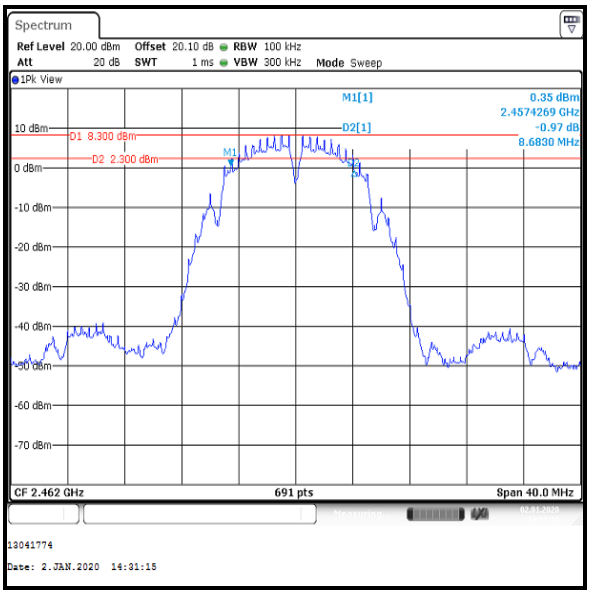
Channel 6

Transmitter Minimum 6 dB Bandwidth (continued)

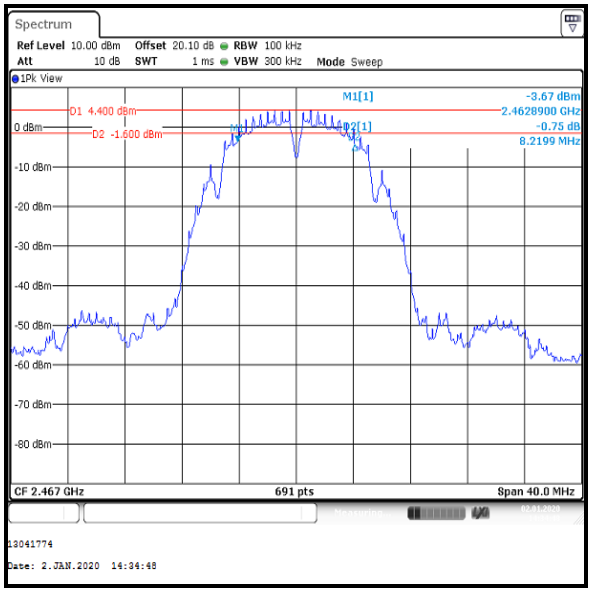
Results: 802.11b / 20 MHz / DBPSK / 1 Mbps / Core 2



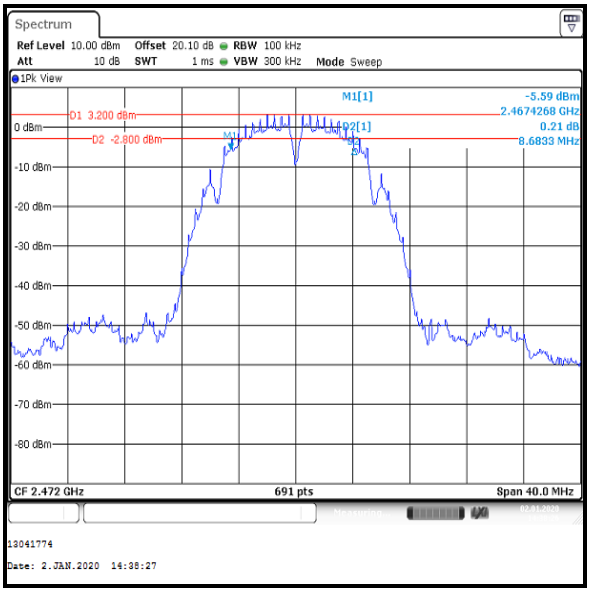
Channel 7



Channel 11



Channel 12



Channel 13

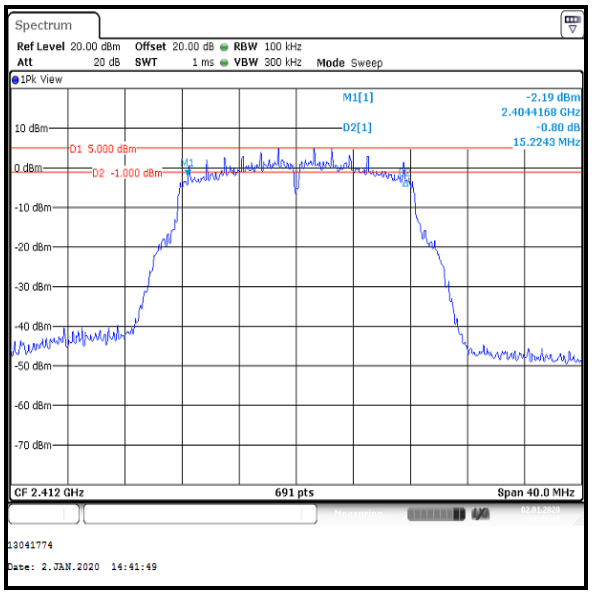
Transmitter Minimum 6 dB Bandwidth (continued)

Results: 802.11g / 20 MHz / BPSK / 6 Mbps / Core 2

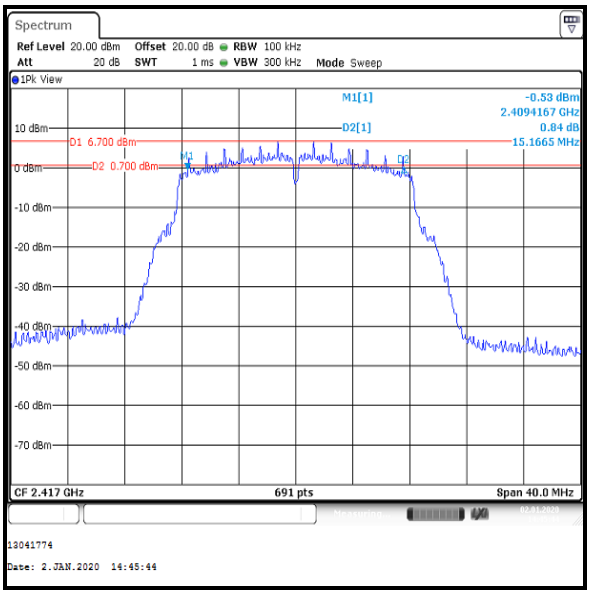
Channel	6 dB Bandwidth (kHz)	Limit (kHz)	Margin (kHz)	Result
1	15224	≥500	14724	Complied
2	15167	≥500	14666	Complied
3	15166	≥500	14666	Complied
6	15224	≥500	14724	Complied
7	15224	≥500	14724	Complied
11	15166	≥500	14666	Complied
12	15224	≥500	14724	Complied
13	15167	≥500	14667	Complied

Transmitter Minimum 6 dB Bandwidth (continued)

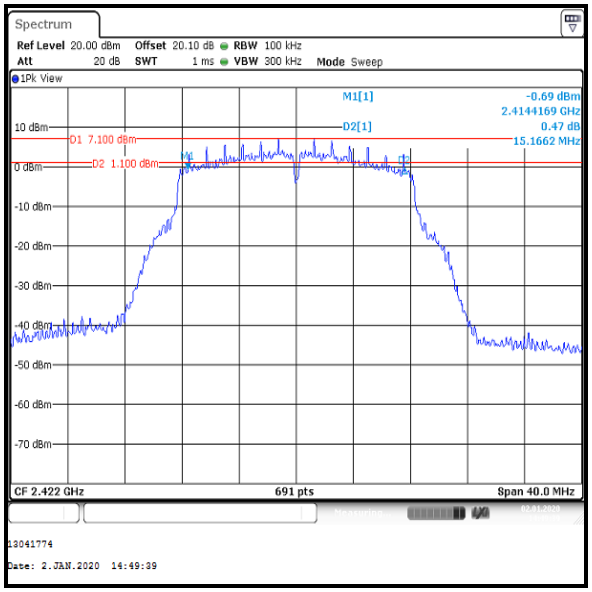
Results: 802.11g / 20 MHz / BPSK / 6 Mbps / Core 2



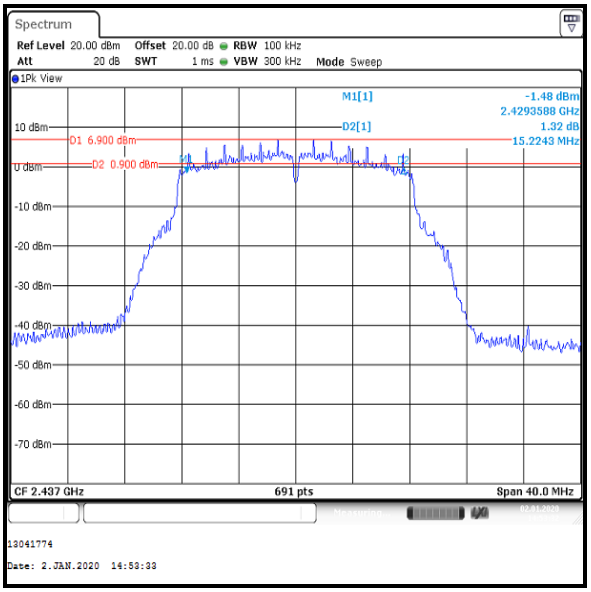
Channel 1



Channel 2



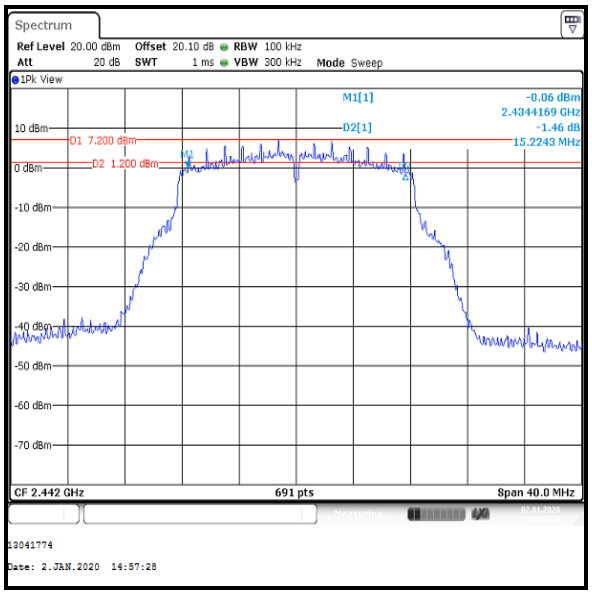
Channel 3



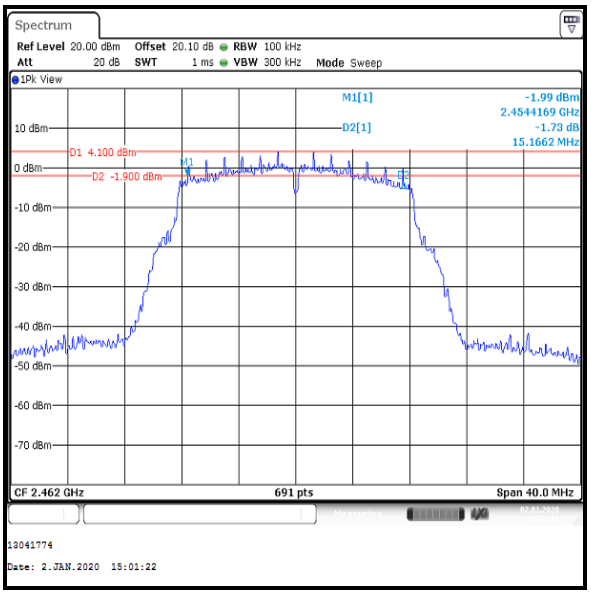
Channel 6

Transmitter Minimum 6 dB Bandwidth (continued)

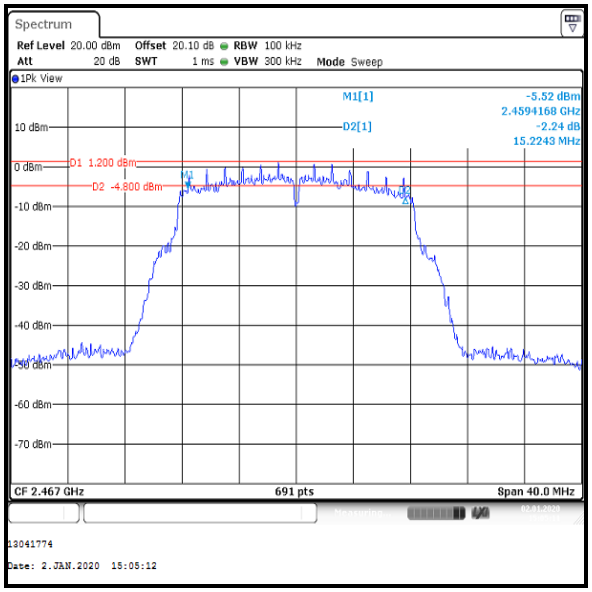
Results: 802.11g / 20 MHz / BPSK / 6 Mbps / Core 2



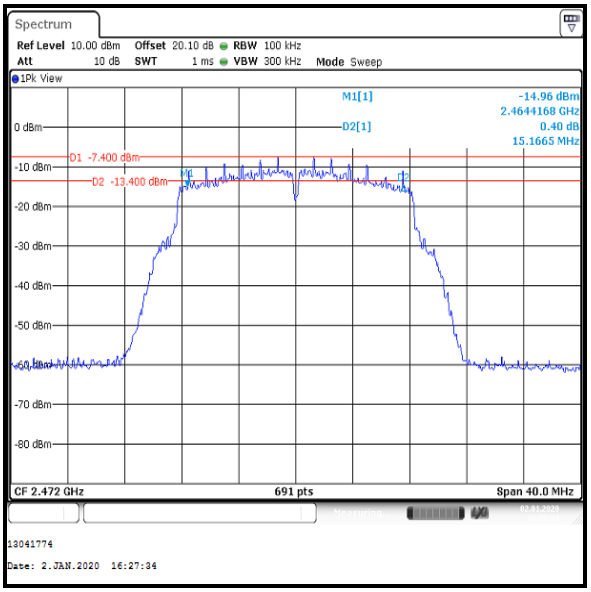
Channel 7



Channel 11



Channel 12



Channel 13

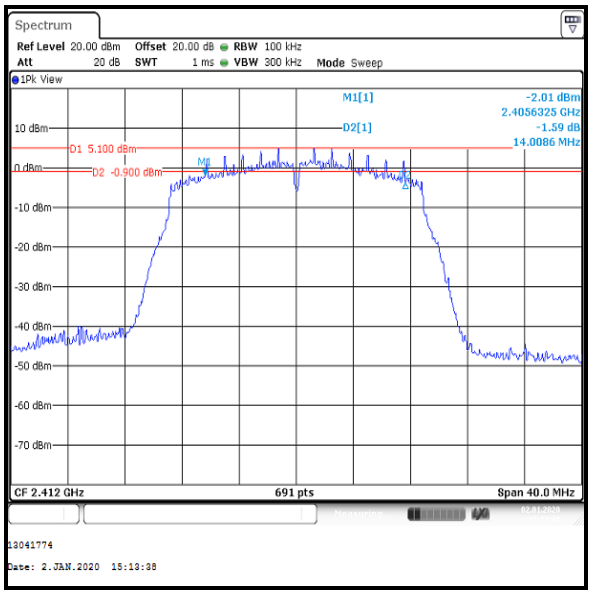
Transmitter Minimum 6 dB Bandwidth (continued)

Results: 802.11n / HT20 / BPSK / MCS0 / Core 2

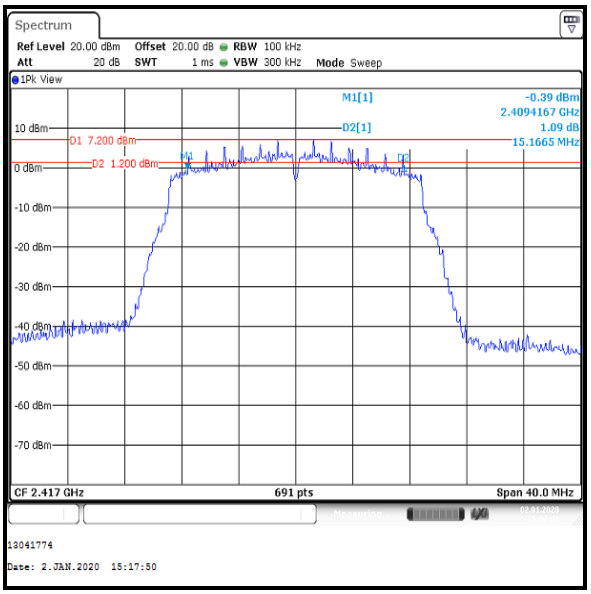
Channel	6 dB Bandwidth (kHz)	Limit (kHz)	Margin (kHz)	Result
1	14009	≥500	13509	Complied
2	15167	≥500	14666	Complied
3	15166	≥500	14666	Complied
6	15167	≥500	14666	Complied
7	15166	≥500	14666	Complied
11	15166	≥500	14666	Complied
12	15167	≥500	14666	Complied
13	15224	≥500	14724	Complied

Transmitter Minimum 6 dB Bandwidth (continued)

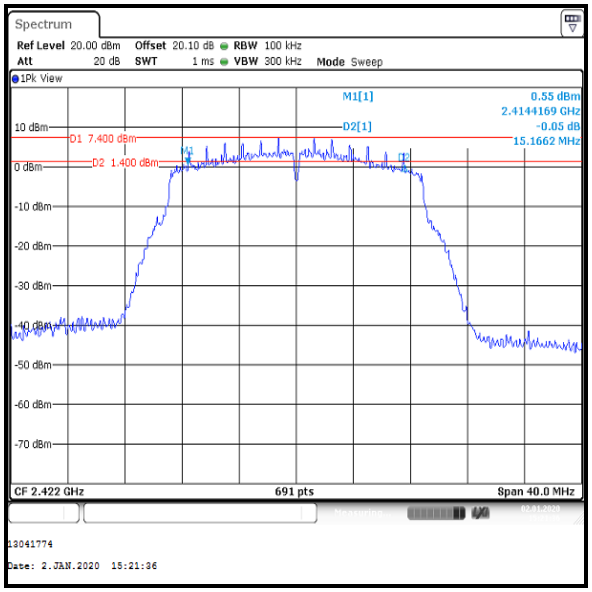
Results: 802.11n / HT20 / BPSK / MCS0 / Core 2



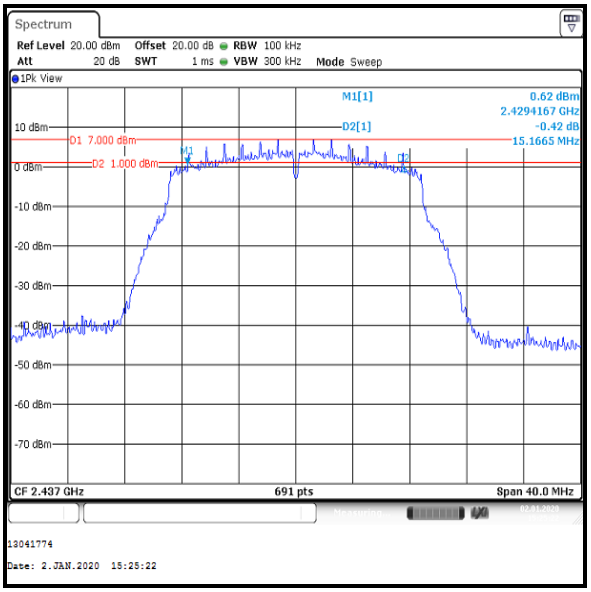
Channel 1



Channel 2



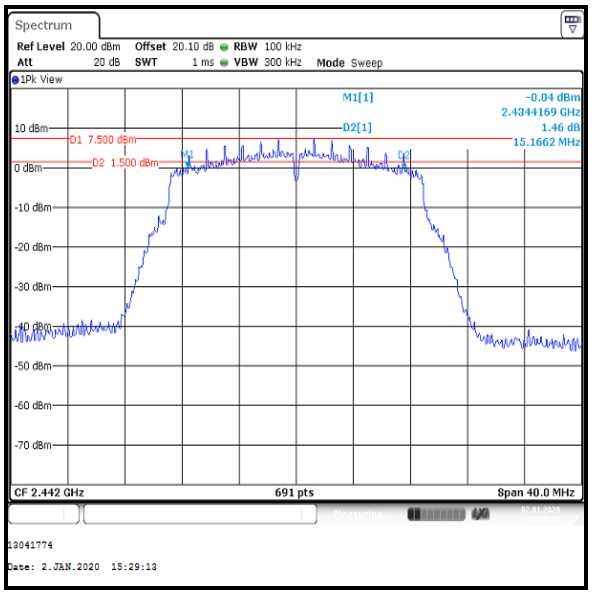
Channel 3



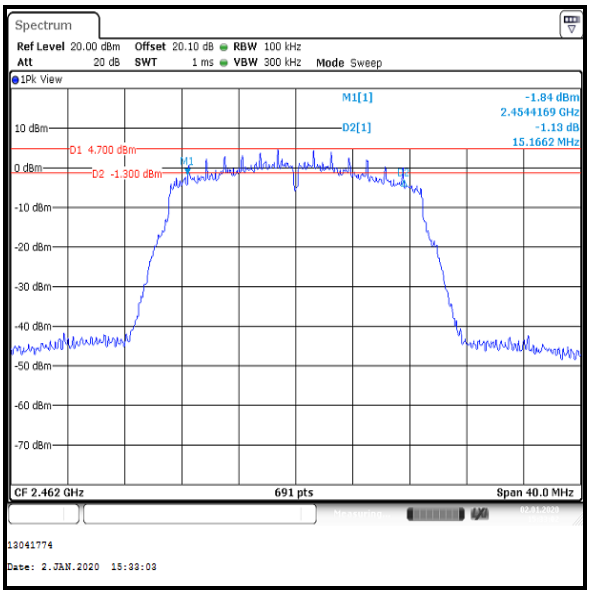
Channel 6

Transmitter Minimum 6 dB Bandwidth (continued)

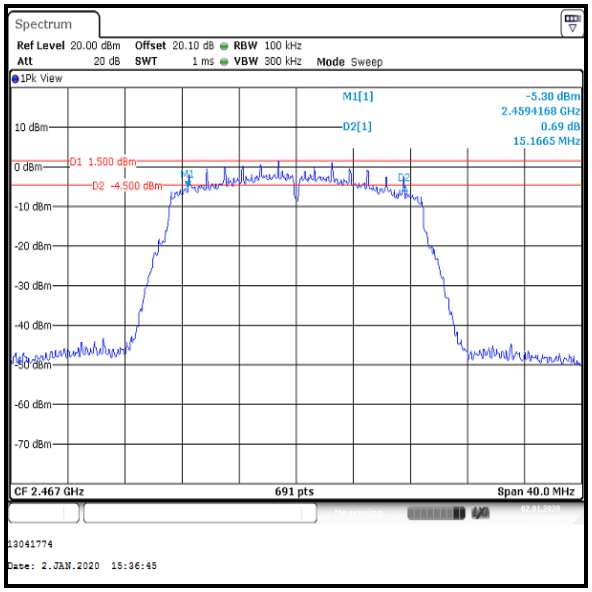
Results: 802.11n / HT20 / BPSK / MCS0 / Core 2



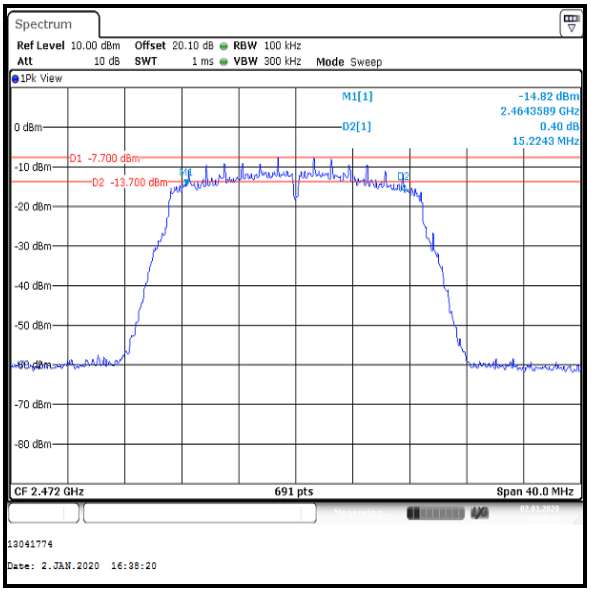
Channel 7



Channel 11



Channel 12



Channel 13

4.3. Transmitter Power Spectral Density

Test Summary:

Test Engineers:	Matthew Botfield & Max Passell	**Test Dates:**	18 December 2019 to 09 January 2020
Test Sample Serial Numbers:	C02ZH007P1YX & C02ZG00GP22J		

FCC Reference:	Part 15.247(e)
Test Method Used:	FCC KDB 558074 Section 8.4 referencing ANSI C63.10 Sections 11.10.3 & 11.10.5

Environmental Conditions:

Temperature (°C):	21 to 23
Relative Humidity (%):	31 to 44

Transmitter Power Spectral Density (continued)

Note(s):

1. The customer declared the following data rates to be used for all measurements as:
    - 802.11b / DBPSK / 1 Mbps / SISO / Core 2
    - 802.11g / BPSK / 1 Mbps / SISO / Core 2
    - 802.11n HT20 / BPSK / MCS0 / SISO / Core 2
    - 802.11b / DBPSK / 1 Mbps / MIMO / 2Tx CDD / Core 0 & Core 2
    - 802.11b / DBPSK / 1 Mbps / MIMO / 3Tx CDD / Core 0, Core 1 & Core 2
    - 802.11n HT20 / BPSK / MCS0 / MIMO / 2Tx CDD / Core 0 & Core 2
    - 802.11n HT20 / BPSK / MCS0 / MIMO / 3Tx CDD / Core 0, Core 1 & Core 2
    - 802.11n HT20 / BPSK / MCS0 / MIMO / 2Tx TxBF / Core 0 & Core 2
    - 802.11n HT20 / BPSK / MCS0 / MIMO / 3Tx TxBF / Core 0, Core 1 & Core 2
2. Final measurements were performed using the above configurations on the relevant channels. Additional channels were tested as requested by the customer.
3. For non-TxBF modes, the EUT was transmitting at >98% duty cycle and testing was performed in accordance with ANSI C63.10 Section 11.10.3 Method AVGPSD-1. The signal analyser resolution bandwidth was set to 3 kHz and video bandwidth 10 kHz. An RMS detector was used and sweep time set manually to perform trace averaging over 200 traces. The span was set greater than 1.5 times the 99% emission bandwidth. The highest peak of the measured signal was recorded.
4. For TxBF modes, the EUT was transmitting at <98% duty cycle and testing was performed in accordance with ANSI C63.10 Section 11.10.5 Method AVGPSD-2. The signal analyser resolution bandwidth was set to 100 kHz and video bandwidth 300 kHz. An RMS detector was used and sweep time set manually to perform trace averaging over 200 traces. The span was set greater than 1.5 times the 99% emission bandwidth. The highest peak of the measured signal was recorded. The calculated duty cycle in section 4.1 was added to the measured average power spectral density in order to compute the average power spectral density during the actual transmission time.
5. For 802.11b & 802.11n MIMO CDD, PSD was measured on all ports and then combined using the *measure and sum the spectra across the outputs* technique, stated in FCC KDB 662911 D01 Section E)2)a).
6. For 802.11n MIMO TxBF, PSD was measured on all ports and then combined using the *measure and sum spectral maxima across the outputs* technique, stated in FCC KDB 662911 D01 Section E)2)b).
7. The signal analyser was connected to the RF port on the EUT using an RF switch, suitable attenuation and RF cables. An RF offset was entered on the signal analyser to compensate for the loss of the switch, attenuator and RF cables.
8. The EUT with serial number C02ZH007P1YX was used for non-TxBF tests, the EUT with serial number C02ZG00GP22J was used for TxBF tests.

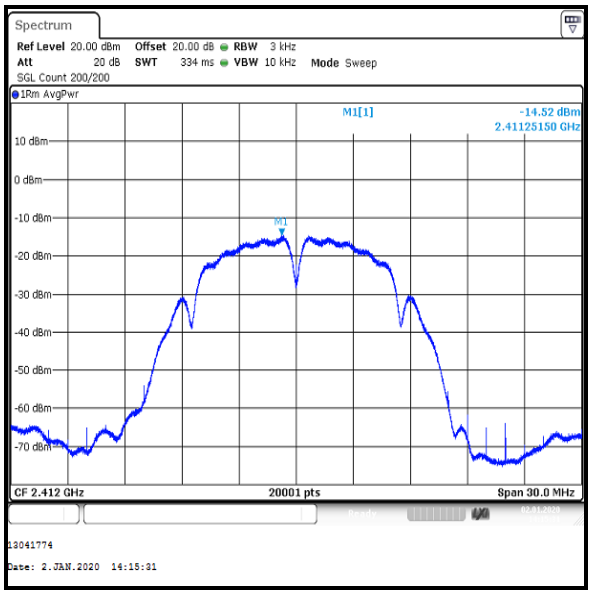
Transmitter Power Spectral Density (continued)

Results: 802.11b / 20 MHz / SISO / DBPSK / 1 Mbps / Core 2

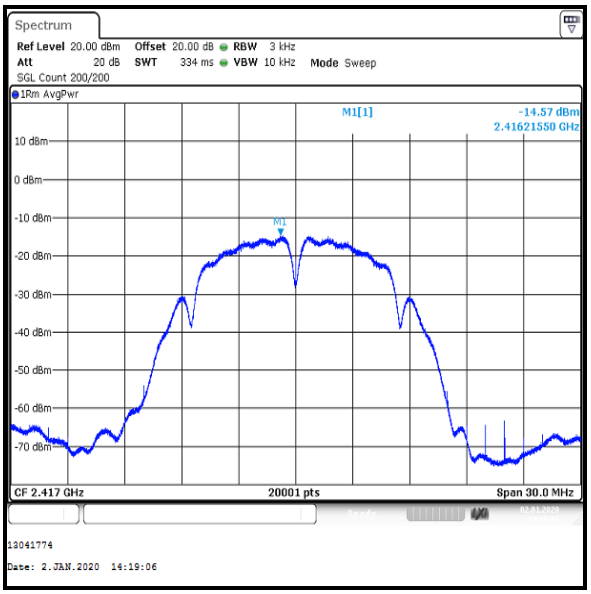
Channel	PSD (dBm/3 kHz)	Limit (dBm/3kHz)	Margin (dB)	Result
1	-14.5	8.0	22.5	Complied
2	-14.6	8.0	22.6	Complied
3	-14.5	8.0	22.5	Complied
6	-14.6	8.0	22.6	Complied
7	-14.3	8.0	22.3	Complied
11	-15.0	8.0	23.0	Complied
12	-18.9	8.0	26.9	Complied
13	-19.9	8.0	27.9	Complied

Transmitter Power Spectral Density (continued)

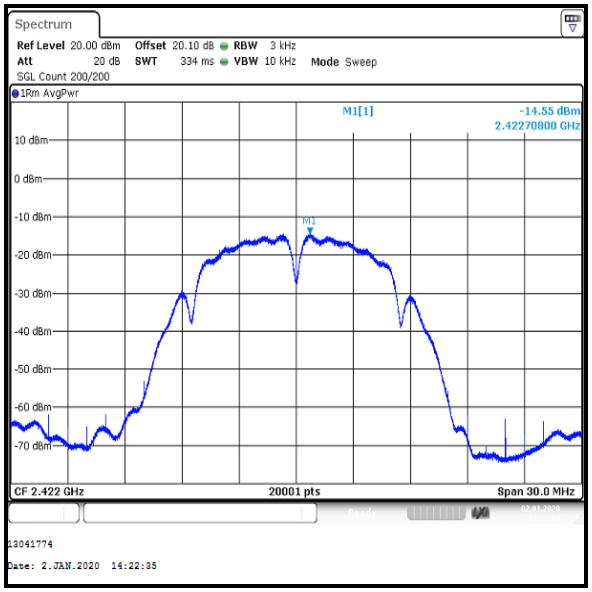
Results: 802.11b / 20 MHz / SISO / DBPSK / 1 Mbps / Core 2



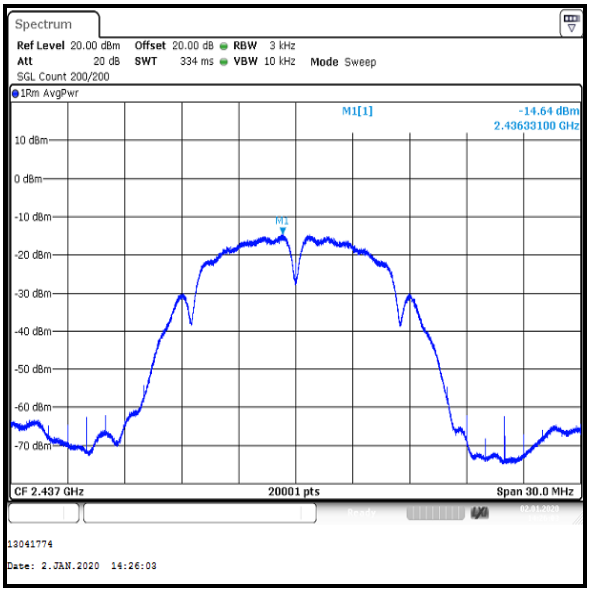
Channel 1



Channel 2



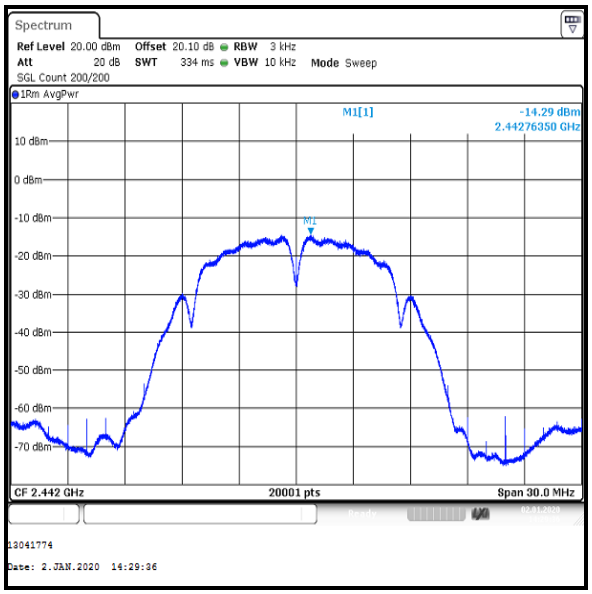
Channel 3



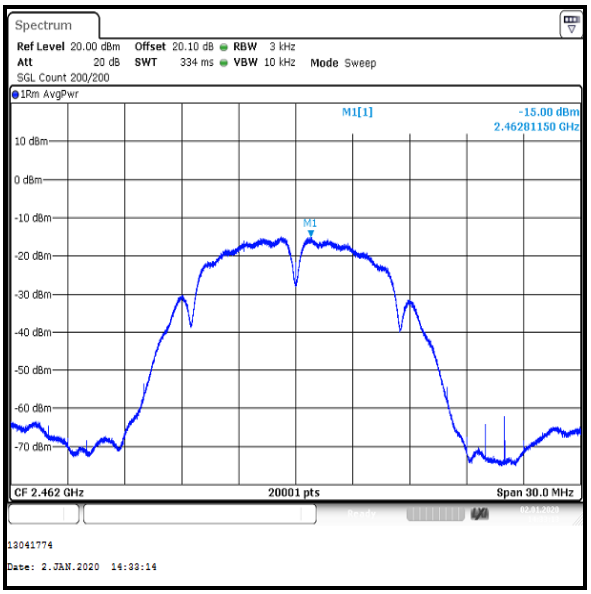
Channel 6

Transmitter Power Spectral Density (continued)

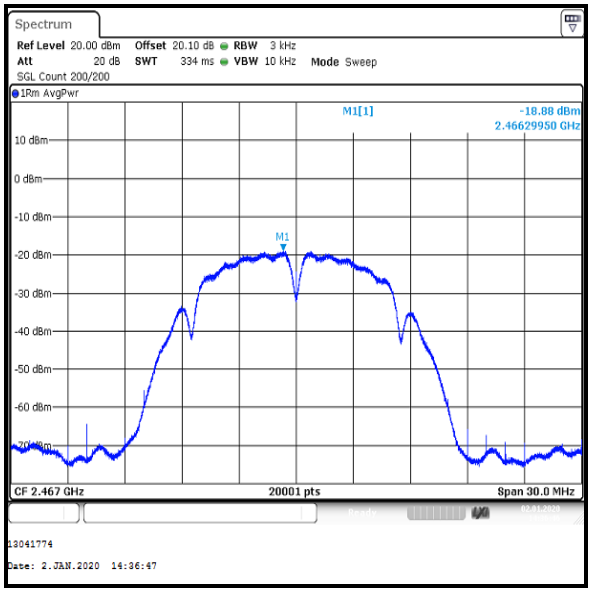
Results: 802.11b / 20 MHz / SISO / DBPSK / 1 Mbps / Core 2



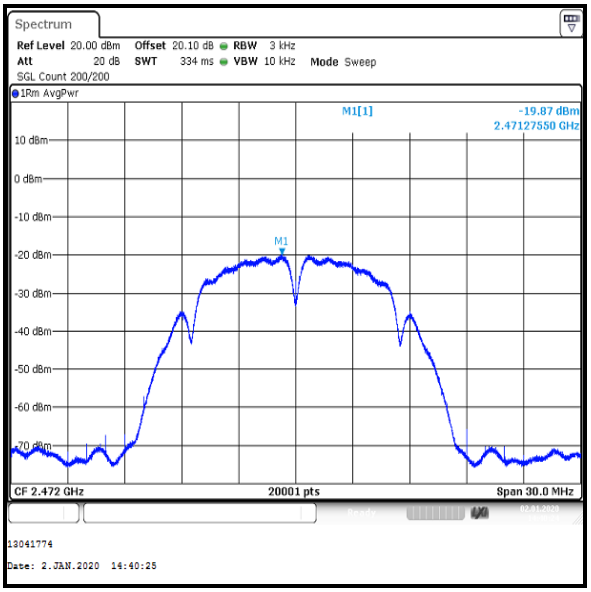
Channel 7



Channel 11



Channel 12



Channel 13

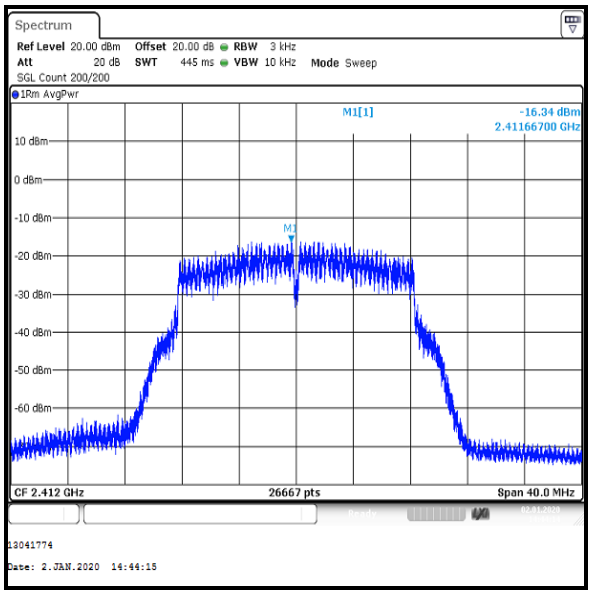
Transmitter Power Spectral Density (continued)

Results: 802.11g / 20 MHz / SISO / BPSK / 6 Mbps / Core 2

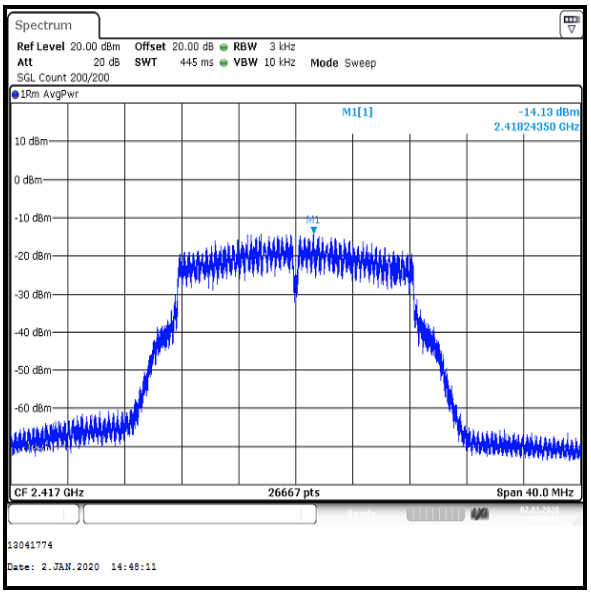
Channel	PSD (dBm/3 kHz)	Limit (dBm/3 kHz)	Margin (dB)	Result
1	-16.3	8.0	24.3	Complied
2	-14.1	8.0	22.1	Complied
3	-14.0	8.0	22.0	Complied
6	-14.4	8.0	22.4	Complied
7	-14.0	8.0	22.0	Complied
11	-16.8	8.0	24.8	Complied
12	-19.8	8.0	27.8	Complied
13	-28.4	8.0	36.4	Complied

Transmitter Power Spectral Density (continued)

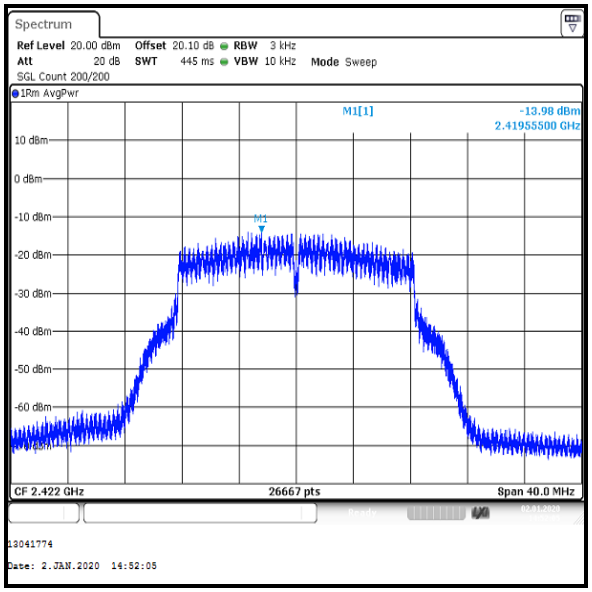
Results: 802.11g / 20 MHz / SISO / BPSK / 6 Mbps / Core 2



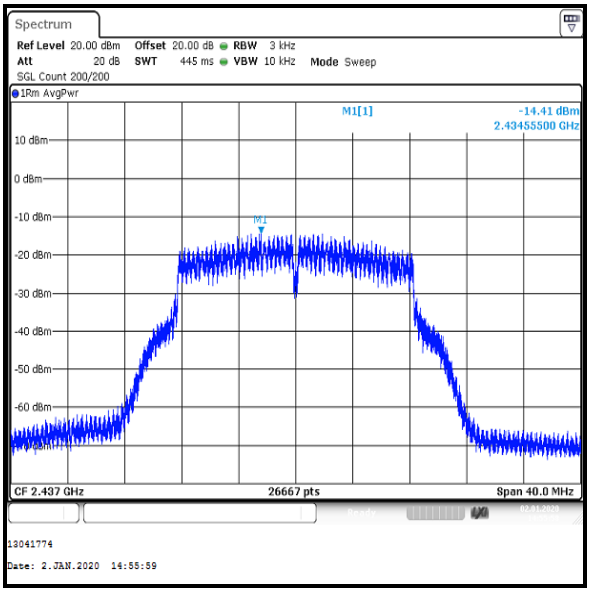
Channel 1



Channel 2



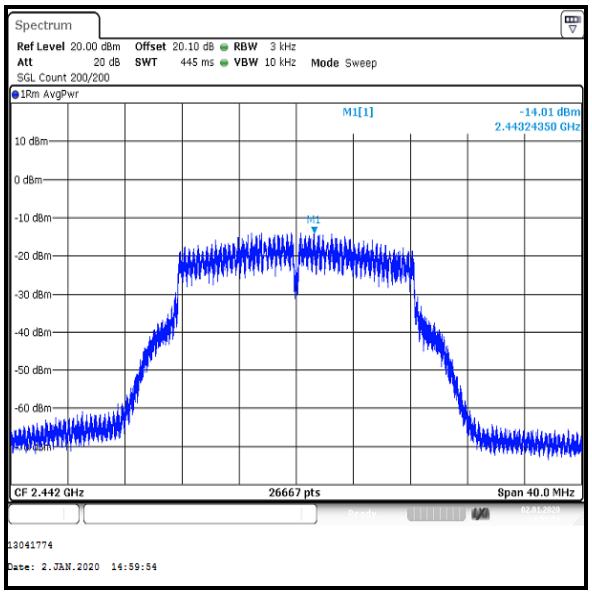
Channel 3



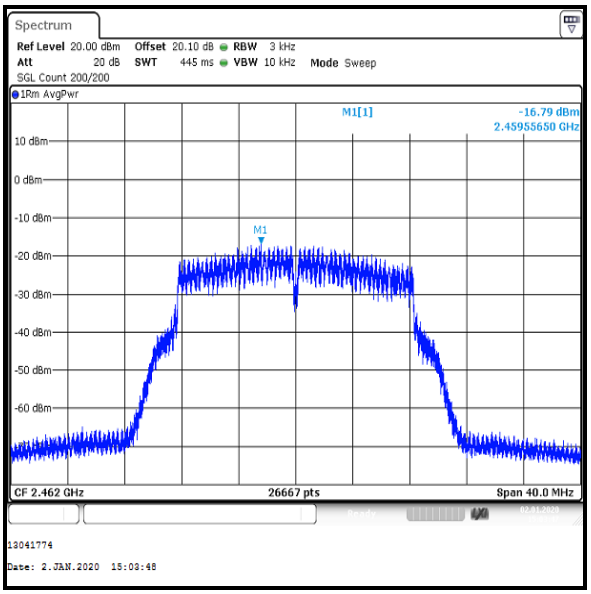
Channel 6

Transmitter Power Spectral Density (continued)

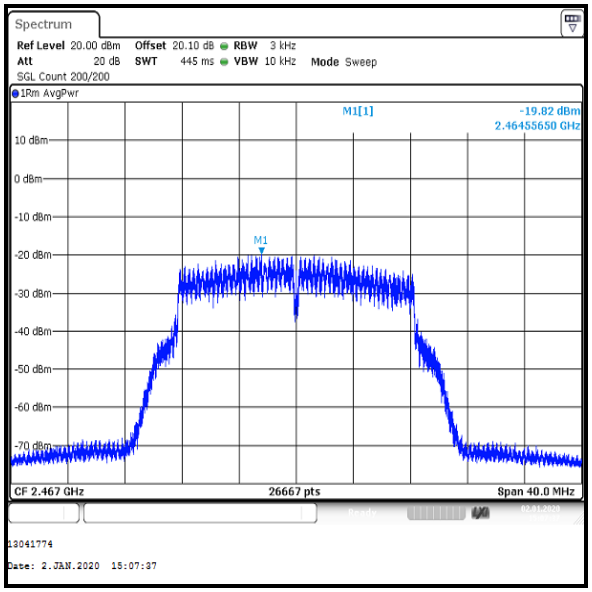
Results: 802.11g / 20 MHz / SISO / BPSK / 6 Mbps / Core 2



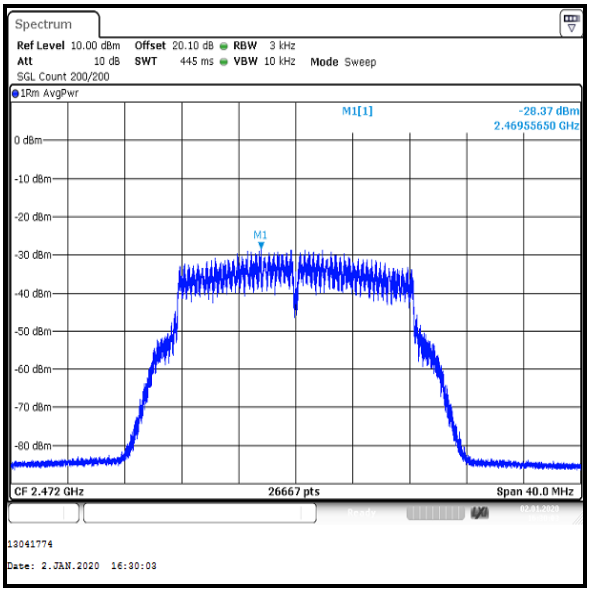
Channel 7



Channel 11



Channel 12



Channel 13

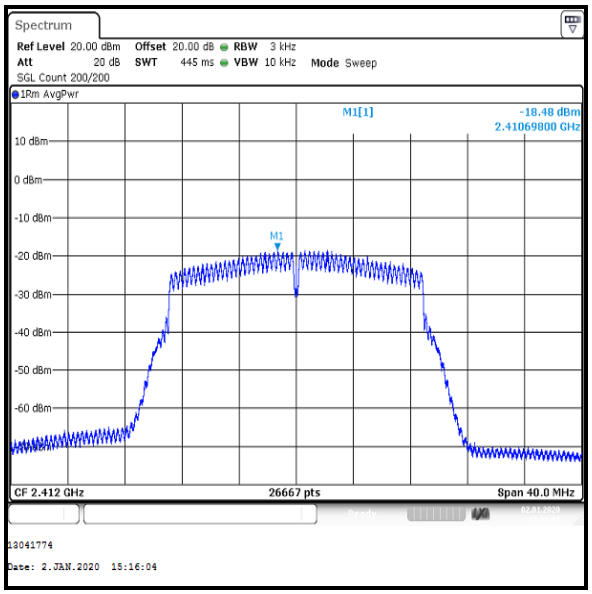
Transmitter Power Spectral Density (continued)

Results: 802.11n / HT20 / SISO / BPSK / MCS0 / Core 2

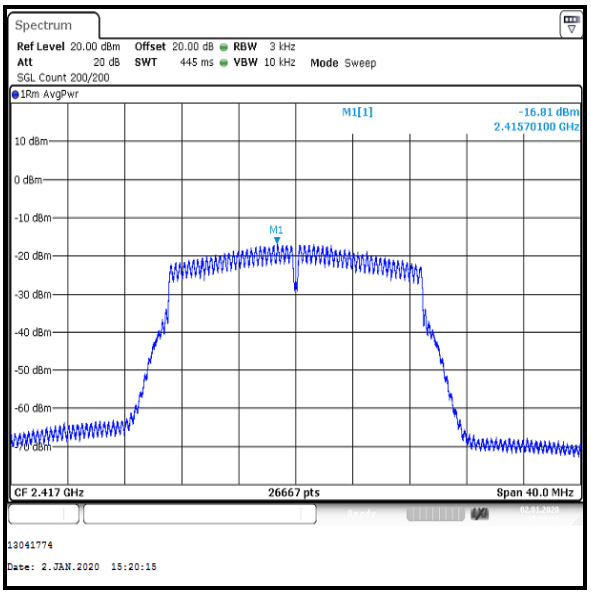
Channel	PSD (dBm/3 kHz)	Limit (dBm/3 kHz)	Margin (dB)	Result
1	-18.5	8.0	26.5	Complied
2	-16.8	8.0	24.8	Complied
3	-16.1	8.0	24.1	Complied
6	-16.7	8.0	24.7	Complied
7	-16.2	8.0	24.3	Complied
11	-19.0	8.0	27.0	Complied
12	-22.0	8.0	30.0	Complied
13	-31.5	8.0	39.5	Complied

Transmitter Power Spectral Density (continued)

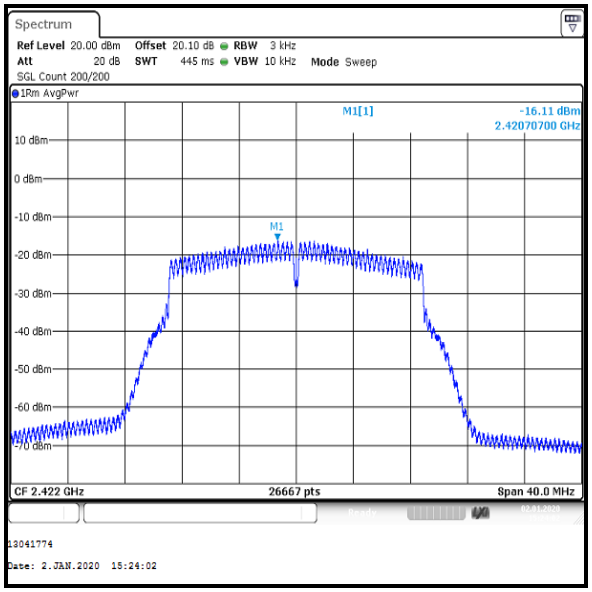
Results: 802.11n / HT20 / SISO / BPSK / MCS0 / Core 2



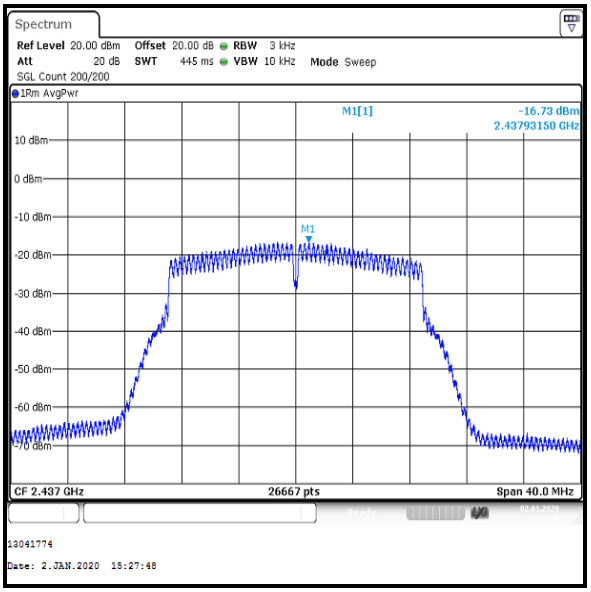
Channel 1



Channel 2



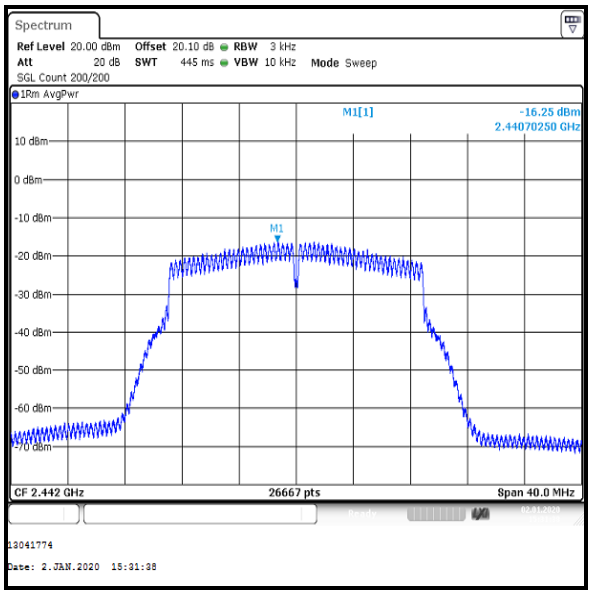
Channel 3



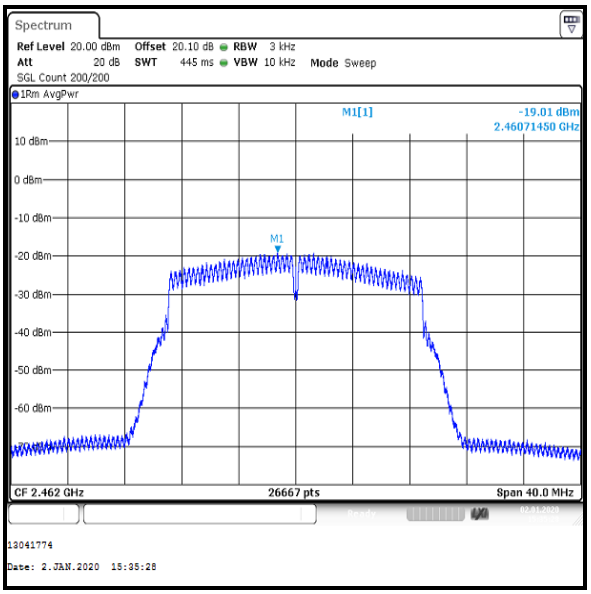
Channel 6

Transmitter Power Spectral Density (continued)

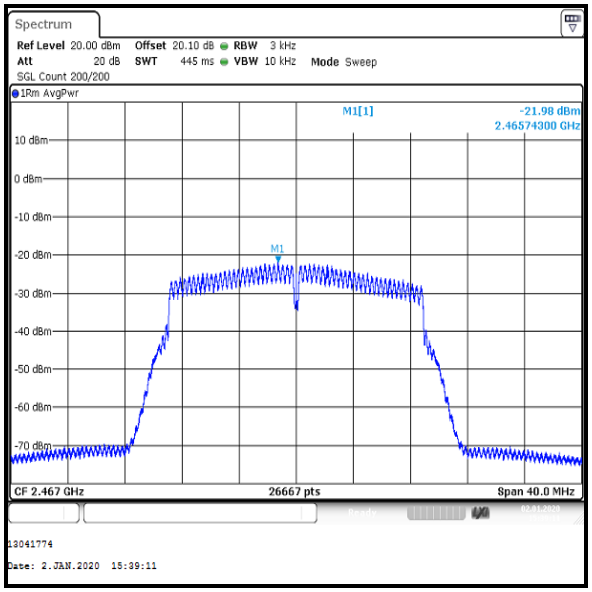
Results: 802.11n / HT20 / SISO / BPSK / MCS0 / Core 2



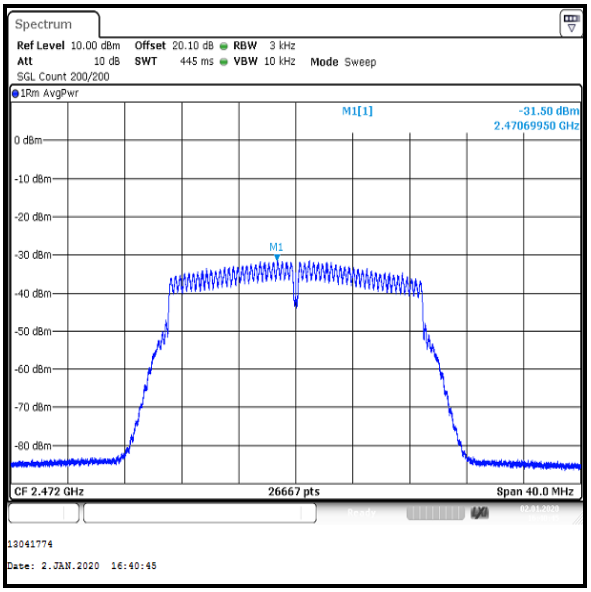
Channel 7



Channel 11



Channel 12



Channel 13

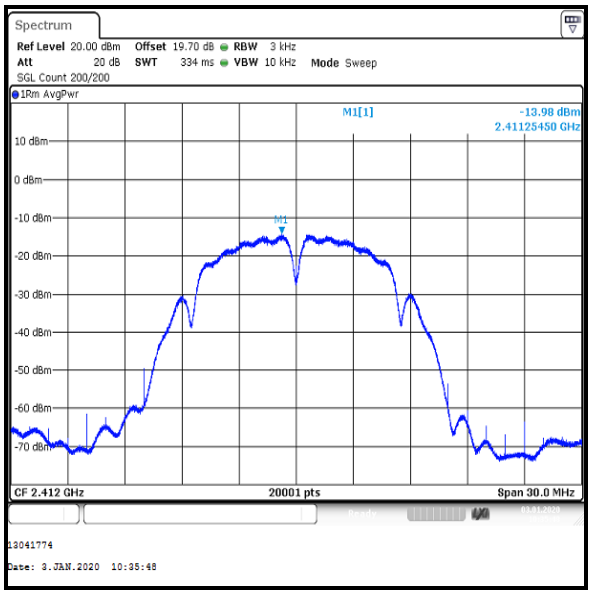
Transmitter Power Spectral Density (continued)

Results: 802.11b / 20 MHz / MIMO / 2Tx CDD / DBPSK / 1 Mbps

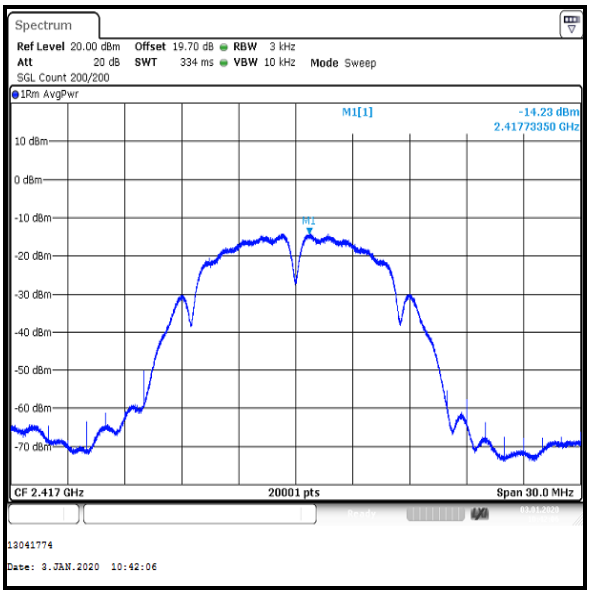
Channel	PSD / Core 0 (dBm / 3 kHz)	PSD / Core 2 (dBm / 3 kHz)	Combined PSD (dBm / 3 kHz)	Limit (dBm / 3 kHz)	Margin (dB)	Result
1	-14.0	-13.5	-11.0	8.0	19.0	Complied
2	-14.2	-13.7	-11.1	8.0	19.1	Complied
3	-14.1	-13.2	-10.8	8.0	18.8	Complied
6	-14.2	-13.9	-11.2	8.0	19.2	Complied
7	-14.1	-13.4	-10.7	8.0	18.7	Complied
11	-13.7	-13.6	-10.9	8.0	18.9	Complied
12	-17.3	-17.0	-14.2	8.0	22.2	Complied
13	-20.5	-20.7	-17.9	8.0	25.9	Complied

Transmitter Power Spectral Density (continued)

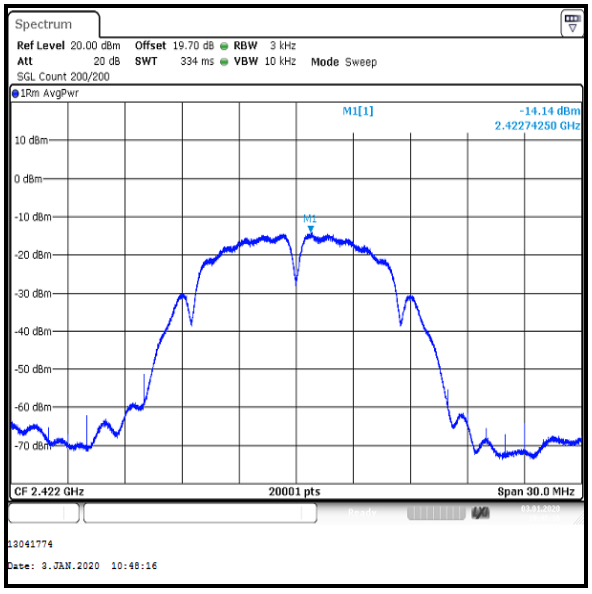
Results: 802.11b / 20 MHz / MIMO / 2Tx CDD / DBPSK / 1 Mbps / Core 0



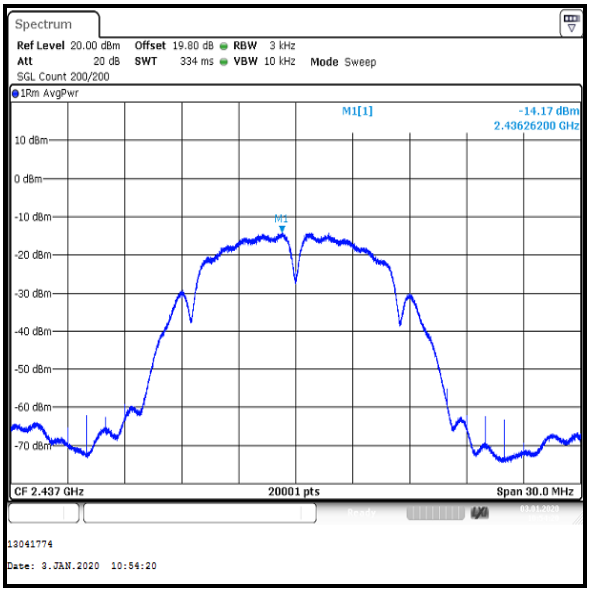
Channel 1



Channel 2



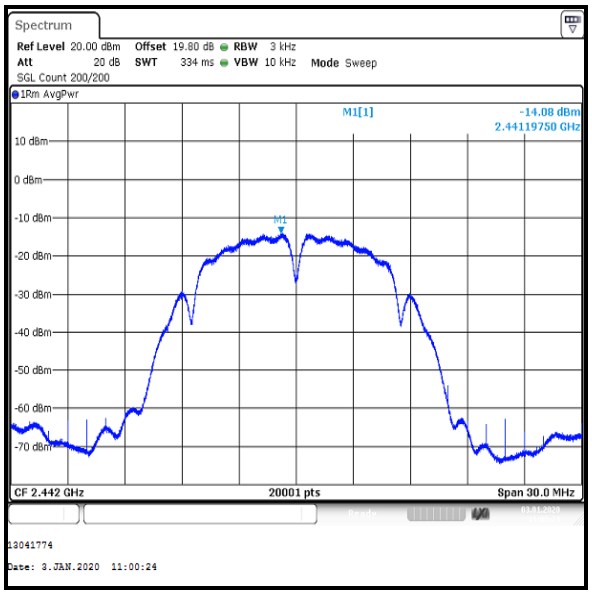
Channel 3



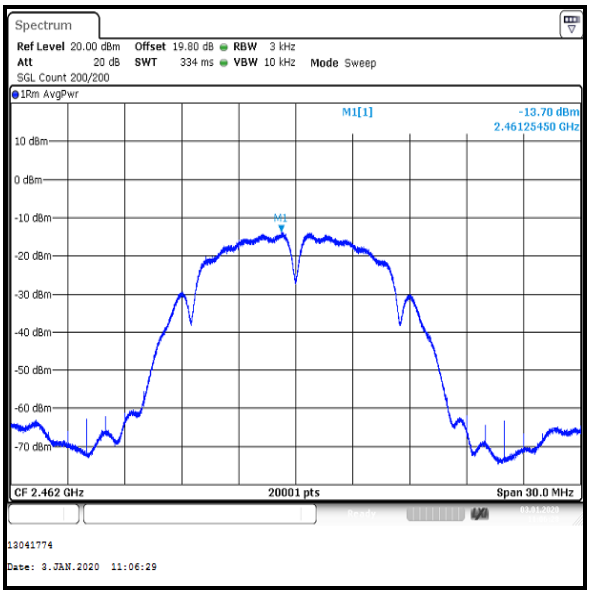
Channel 6

Transmitter Power Spectral Density (continued)

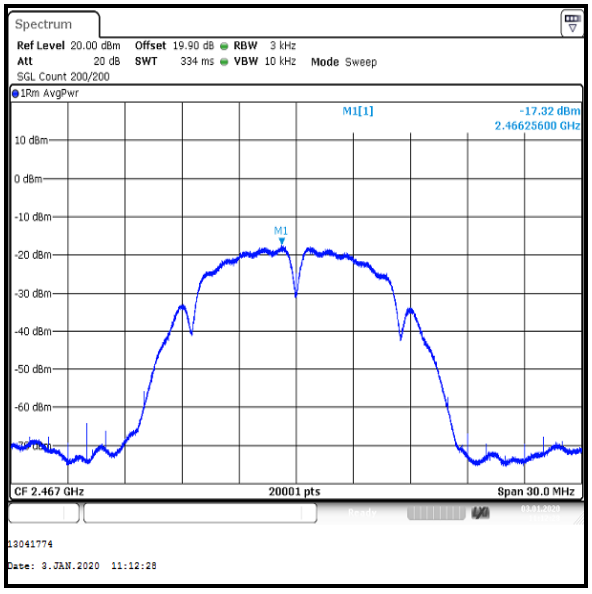
Results: 802.11b / 20 MHz / MIMO / 2Tx CDD / DBPSK / 1 Mbps / Core 0



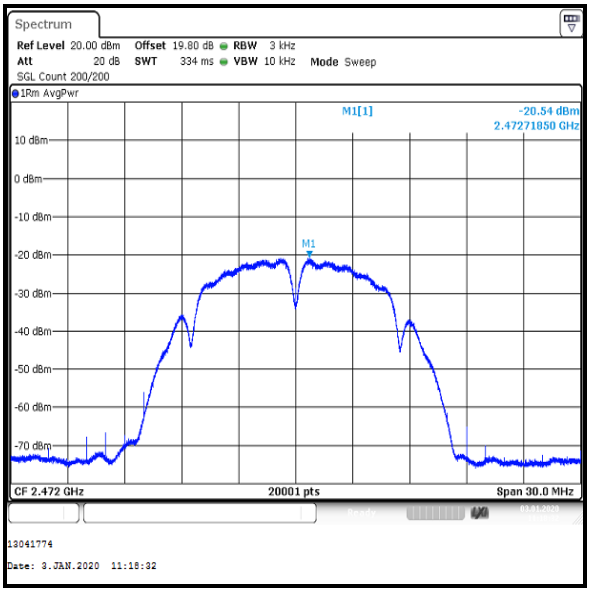
Channel 7



Channel 11



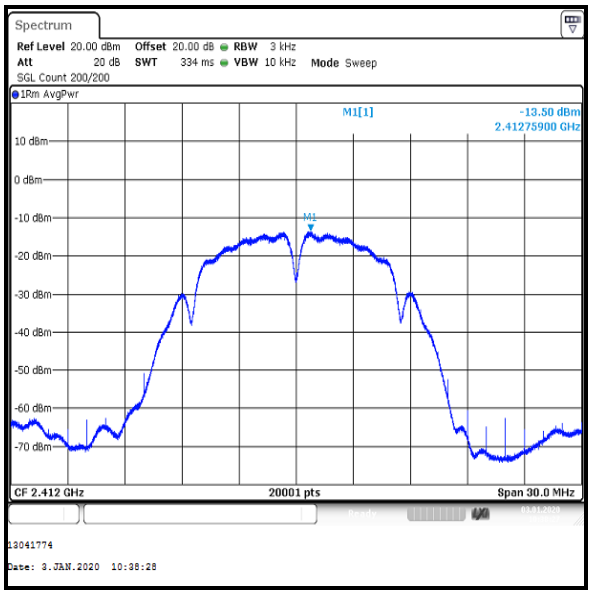
Channel 12



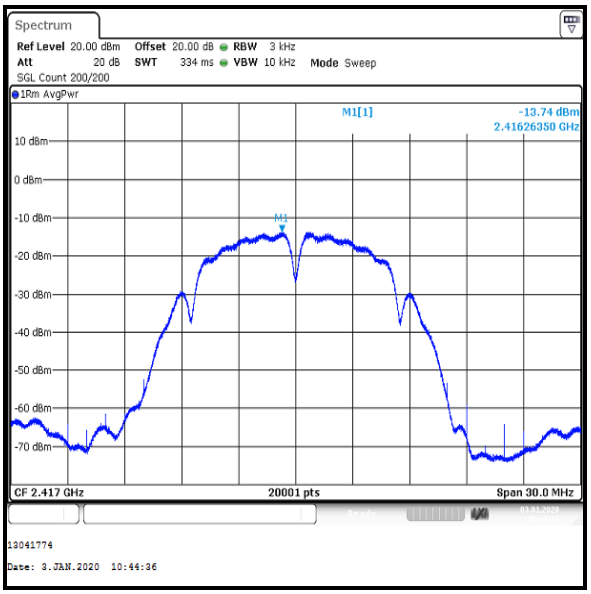
Channel 13

Transmitter Power Spectral Density (continued)

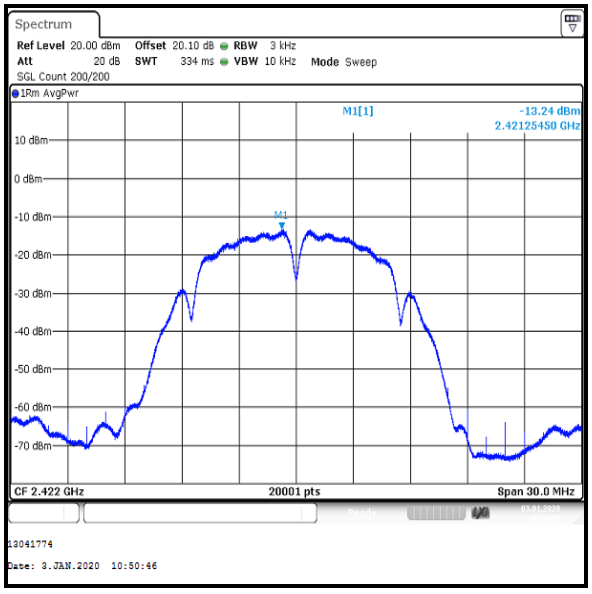
Results: 802.11b / 20 MHz / MIMO / 2Tx CDD / DBPSK / 1 Mbps / Core 2



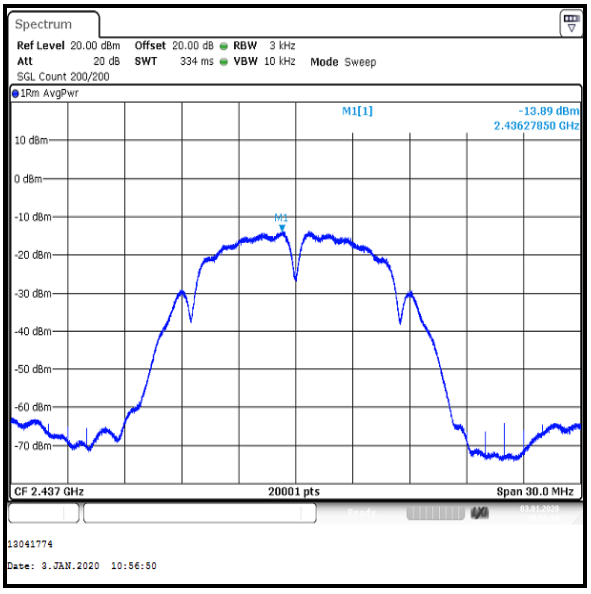
Channel 1



Channel 2



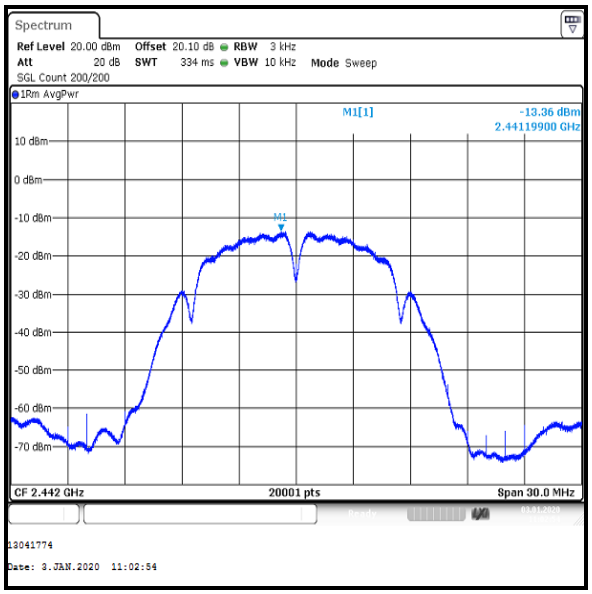
Channel 3



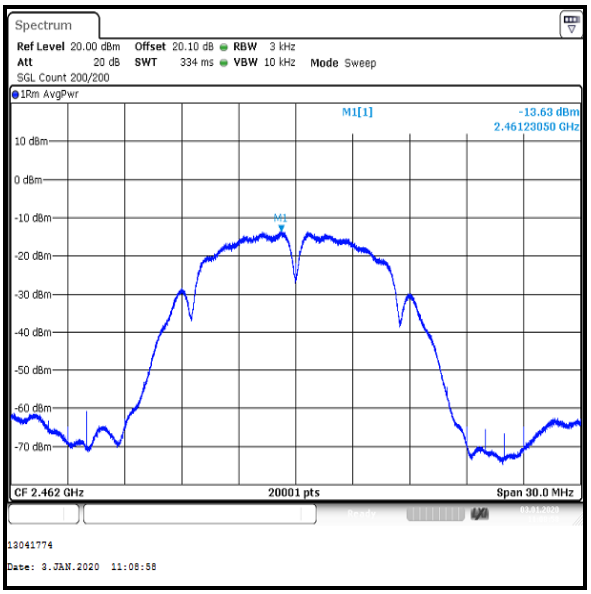
Channel 6

Transmitter Power Spectral Density (continued)

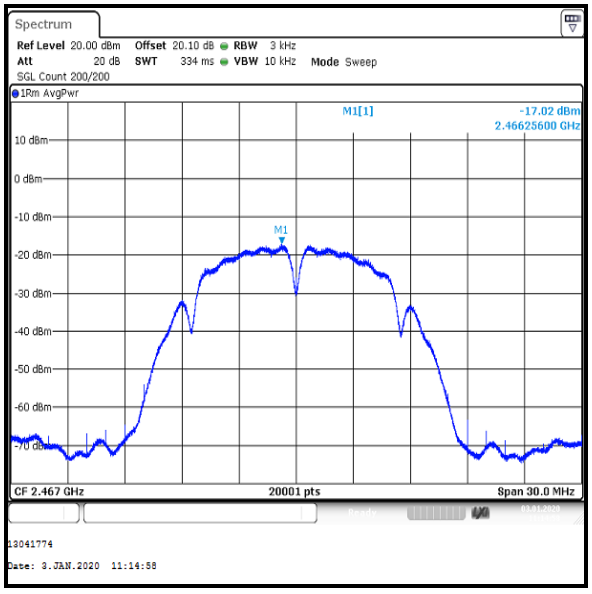
Results: 802.11b / 20 MHz / MIMO / 2Tx CDD / DBPSK / 1 Mbps / Core 2



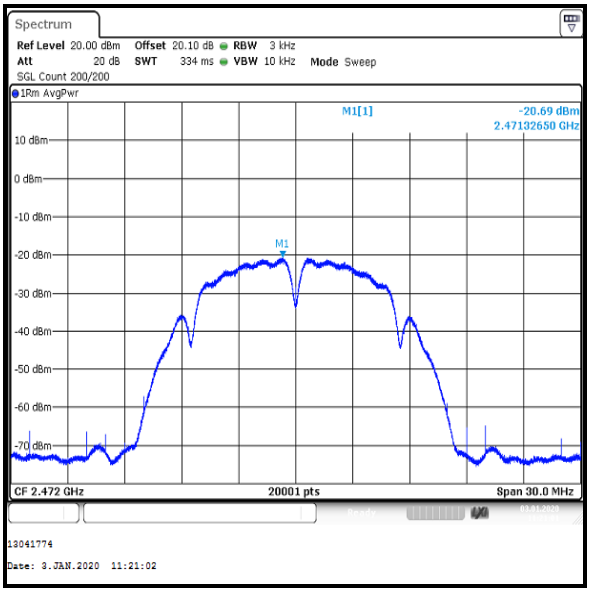
Channel 7



Channel 11



Channel 12



Channel 13

Transmitter Power Spectral Density (continued)

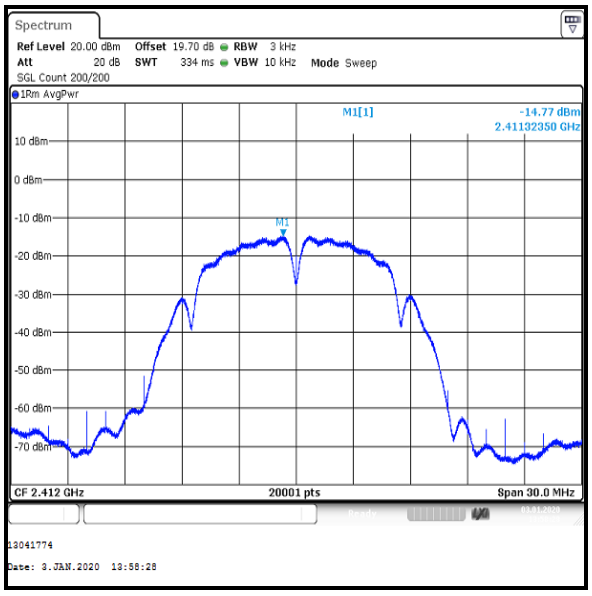
Results: 802.11b / 20 MHz / MIMO / 3Tx CDD / DBPSK / 1 Mbps

Channel	PSD / Core 0 (dBm / 3 kHz)	PSD / Core 1 (dBm / 3 kHz)	PSD / Core 2 (dBm / 3 kHz)
1	-14.8	-14.7	-14.2
2	-14.0	-14.2	-13.4
3	-13.9	-14.3	-13.4
6	-13.8	-14.1	-13.1
7	-14.0	-14.2	-14.0
11	-14.7	-14.5	-14.5
12	-17.6	-18.2	-17.9
13	-22.1	-22.3	-22.0

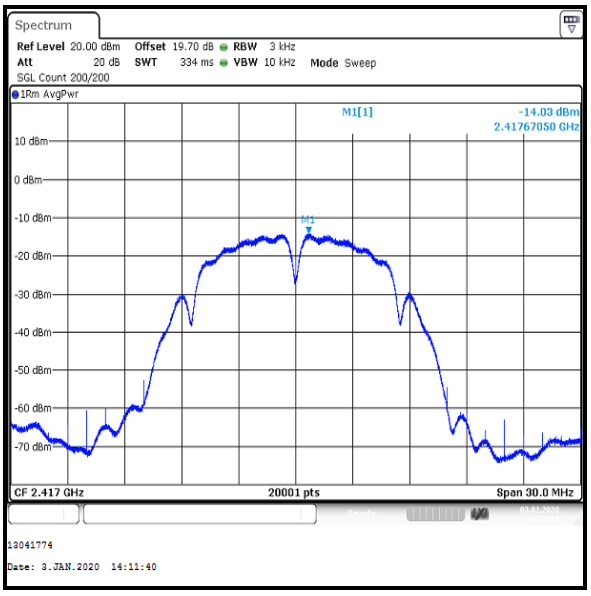
Channel	Combined PSD (dBm / 3 kHz)	PSD Limit (dBm / 3 kHz)	Margin (dB)	Result
1	-10.1	8.0	18.1	Complied
2	-9.4	8.0	17.4	Complied
3	-9.2	8.0	17.2	Complied
6	-9.3	8.0	17.3	Complied
7	-9.4	8.0	17.4	Complied
11	-10.3	8.0	18.3	Complied
12	-13.3	8.0	21.3	Complied
13	-17.6	8.0	25.6	Complied

Transmitter Power Spectral Density (continued)

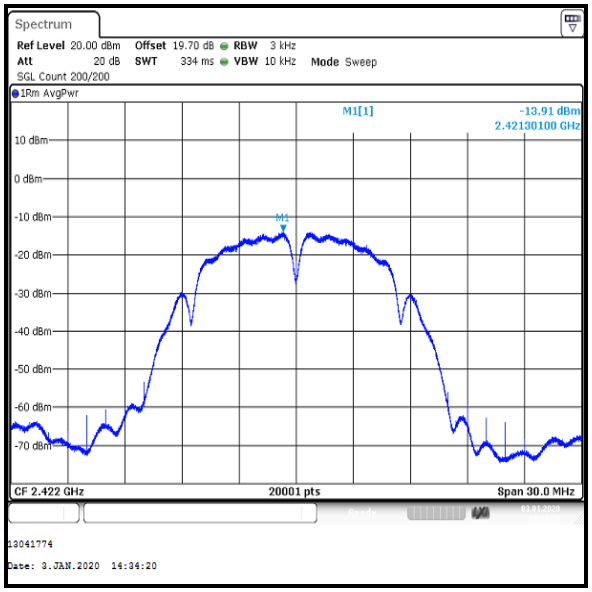
Results: 802.11b / 20 MHz / MIMO / 3Tx CDD / DBPSK / 1 Mbps / Core 0



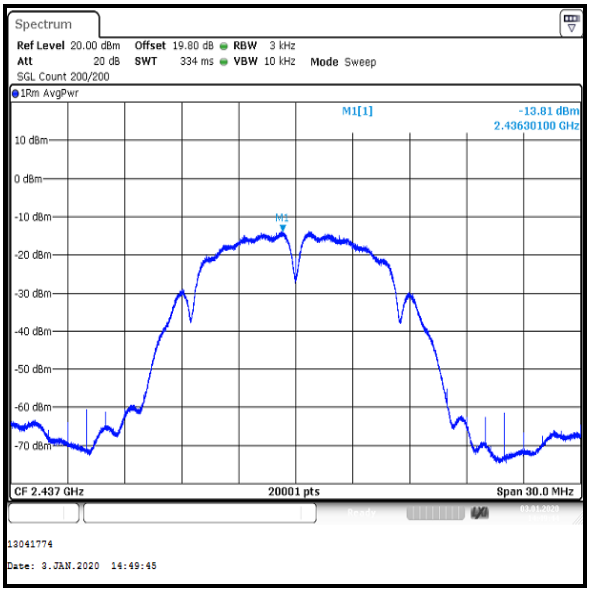
Channel 1



Channel 2



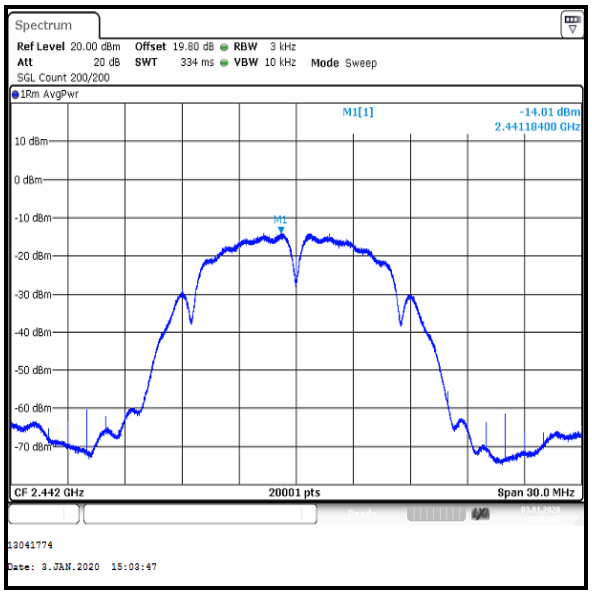
Channel 3



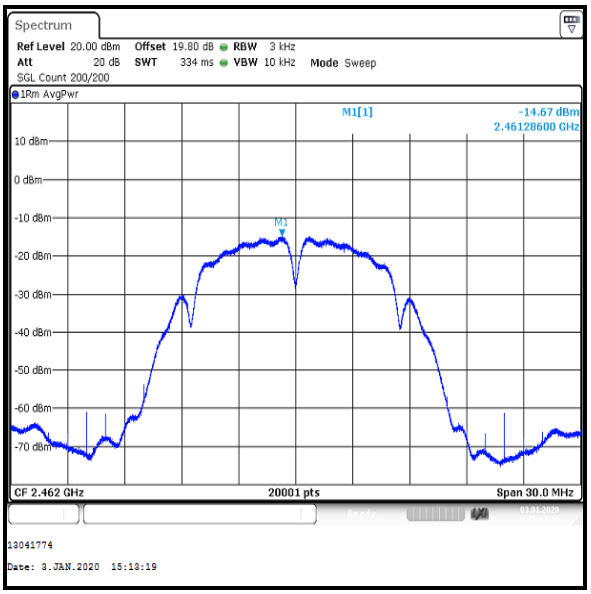
Channel 6

Transmitter Power Spectral Density (continued)

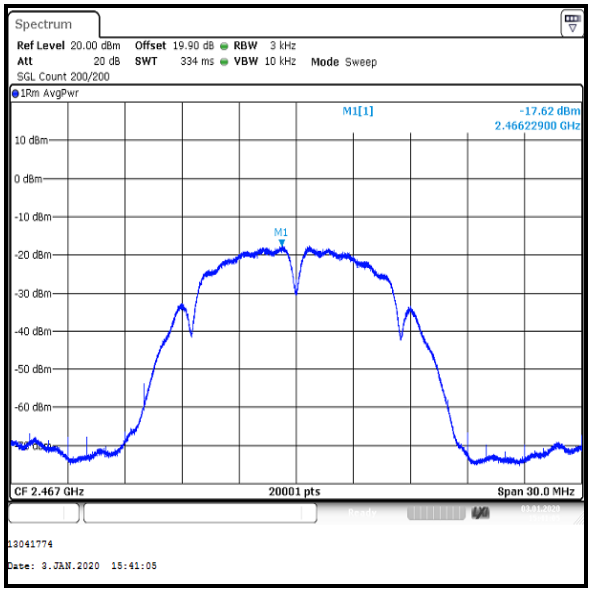
Results: 802.11b / 20 MHz / MIMO / 3Tx CDD / DBPSK / 1 Mbps / Core 0



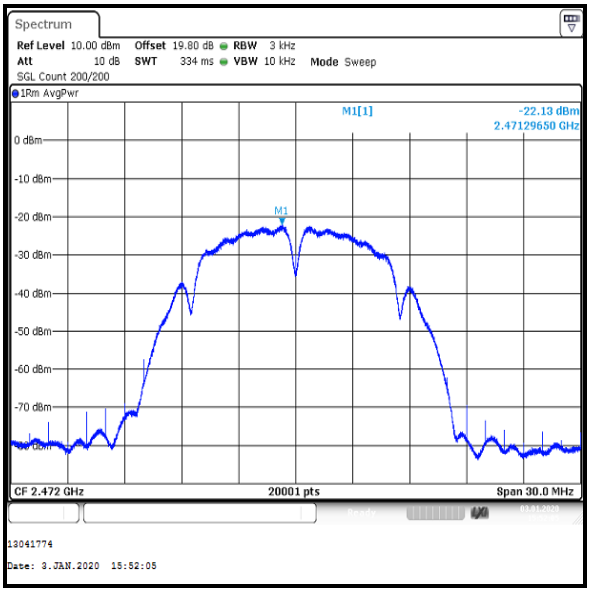
Channel 7



Channel 11



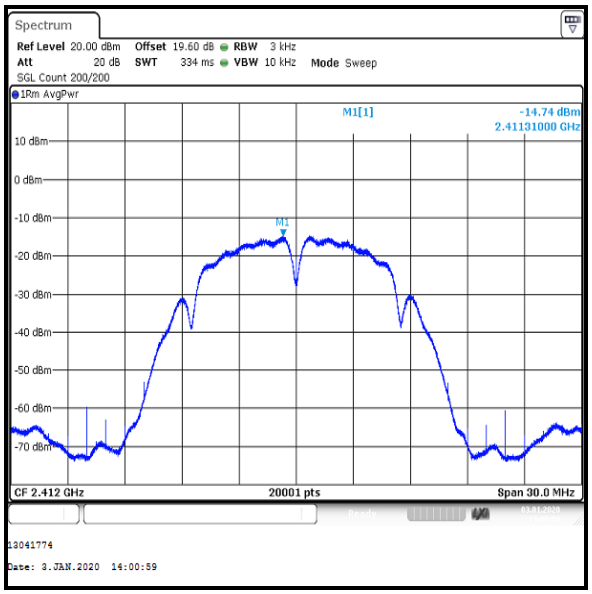
Channel 12



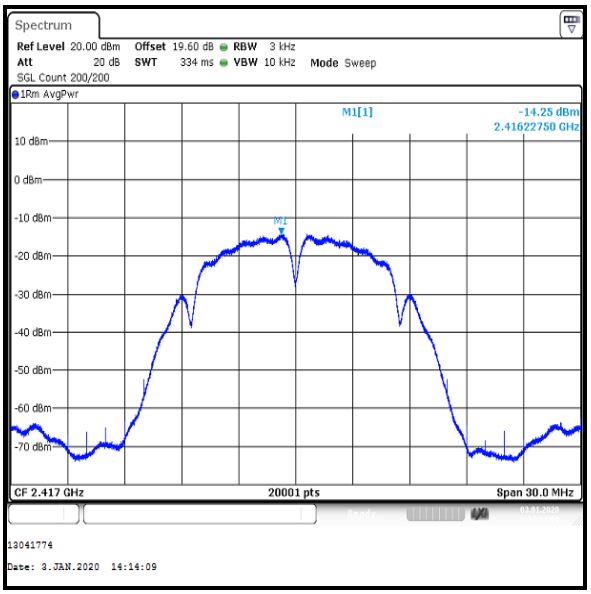
Channel 13

Transmitter Power Spectral Density (continued)

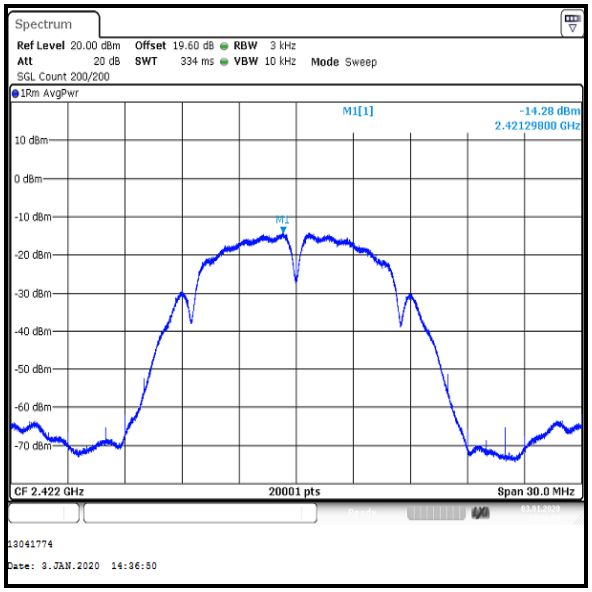
Results: 802.11b / 20 MHz / MIMO / 3Tx CDD / DBPSK / 1 Mbps / Core 1



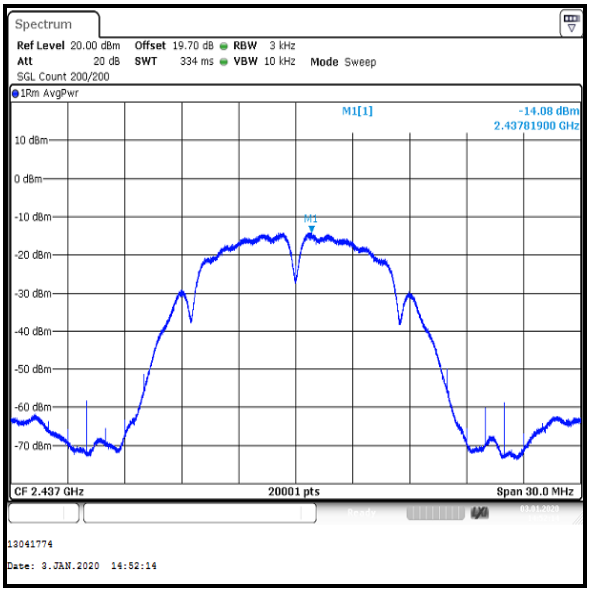
Channel 1



Channel 2



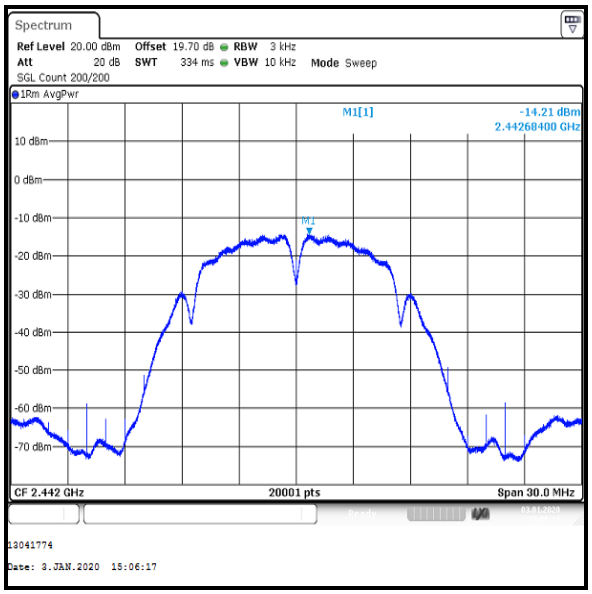
Channel 3



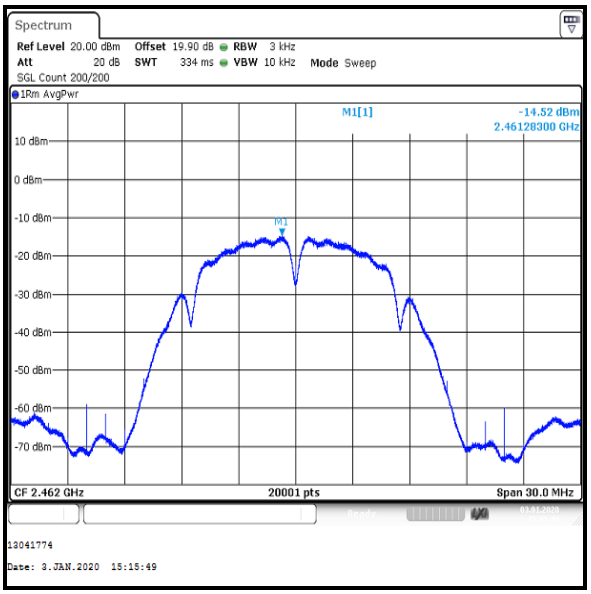
Channel 6

Transmitter Power Spectral Density (continued)

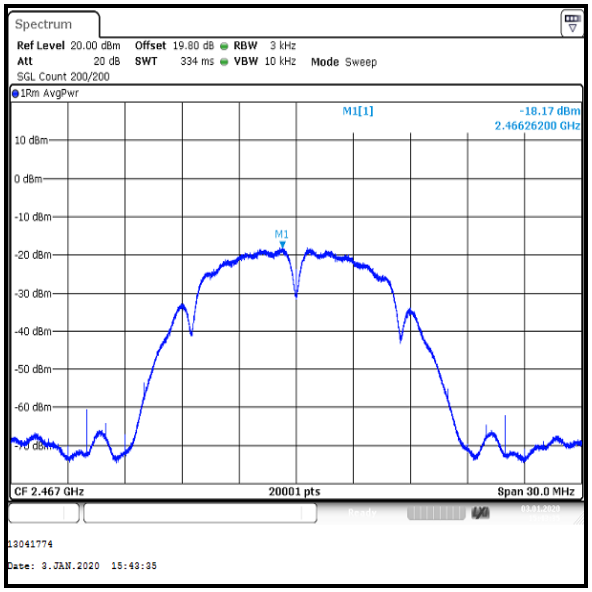
Results: 802.11b / 20 MHz / MIMO / 3Tx CDD / DBPSK / 1 Mbps / Core 1



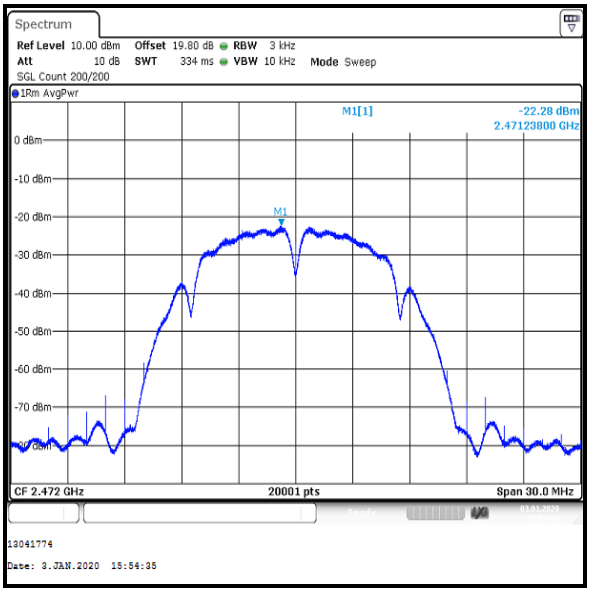
Channel 7



Channel 11



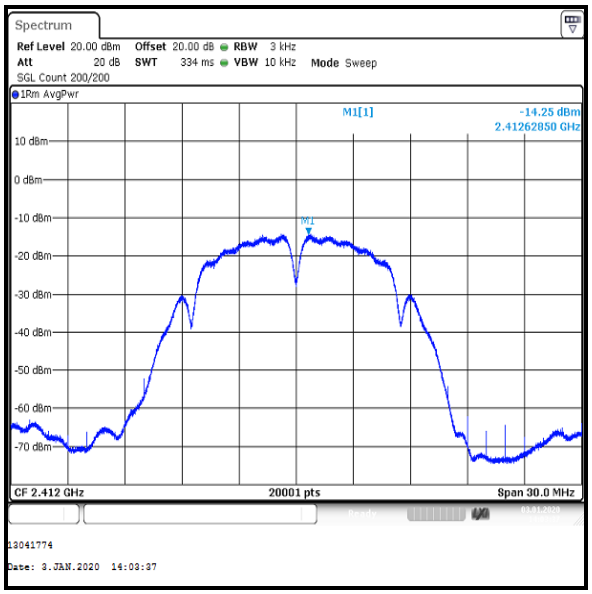
Channel 12



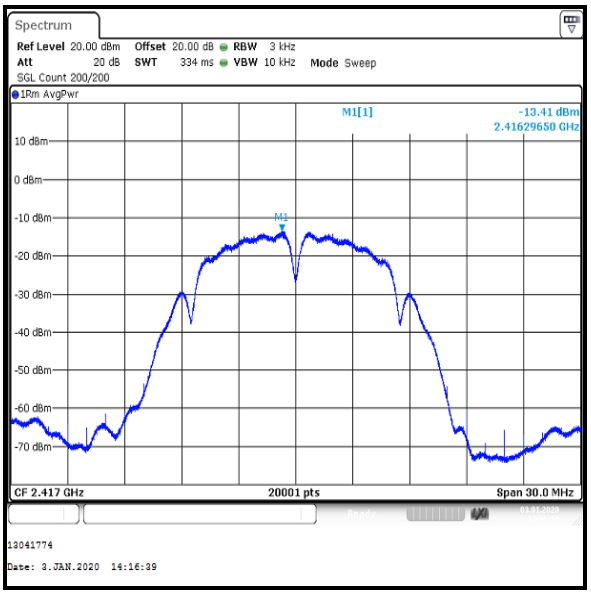
Channel 13

Transmitter Power Spectral Density (continued)

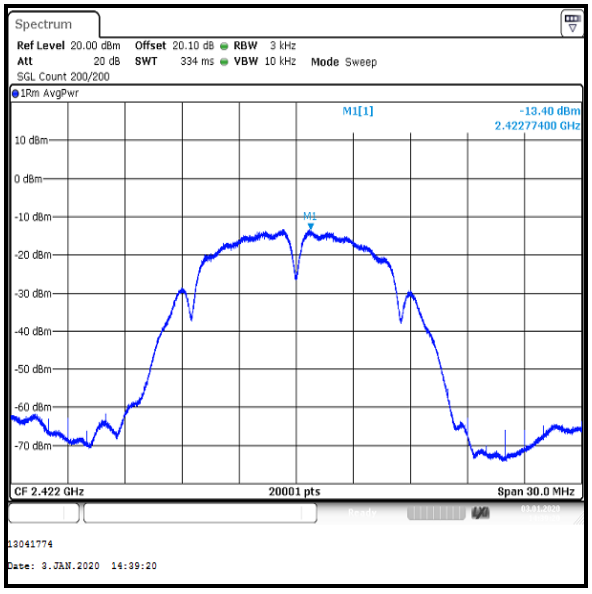
Results: 802.11b / 20 MHz / MIMO / 3Tx CDD / DBPSK / 1 Mbps / Core 2



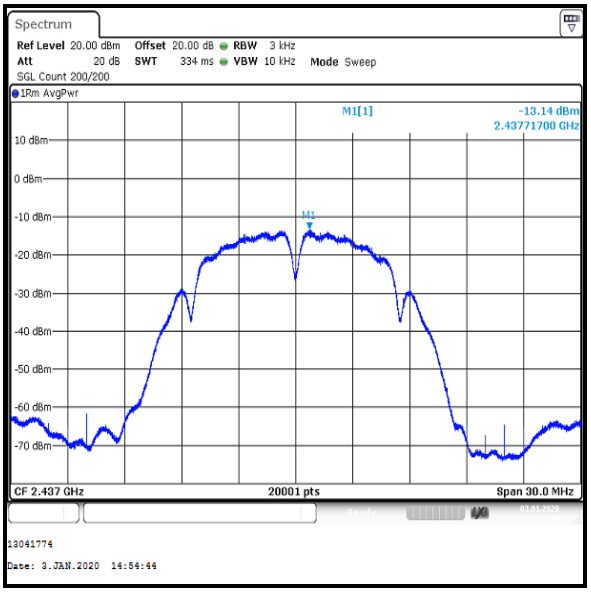
Channel 1



Channel 2



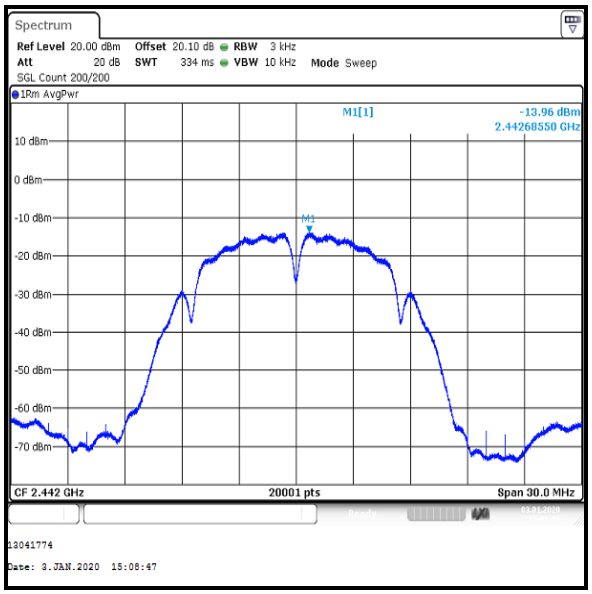
Channel 3



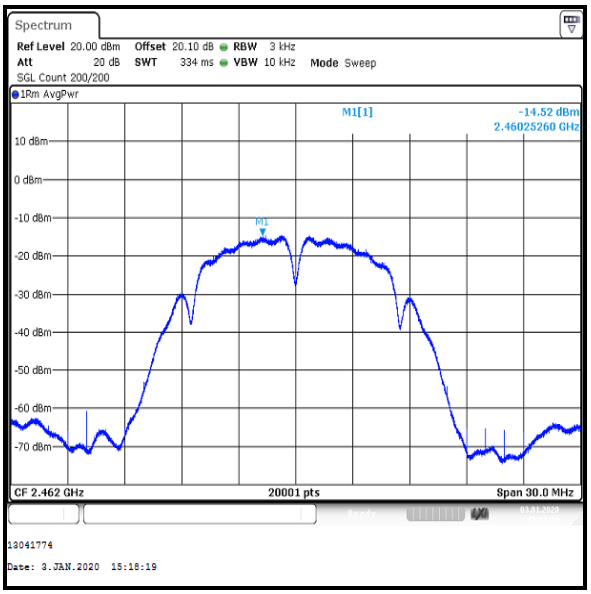
Channel 6

Transmitter Power Spectral Density (continued)

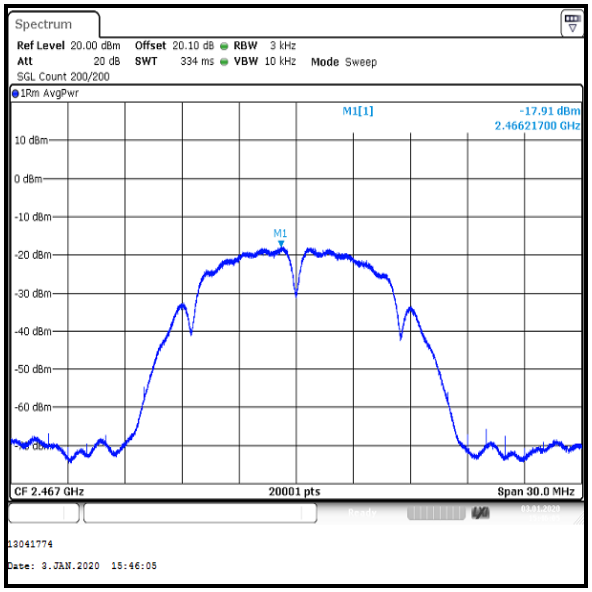
Results: 802.11b / 20 MHz / MIMO / 3Tx CDD / DBPSK / 1 Mbps / Core 2



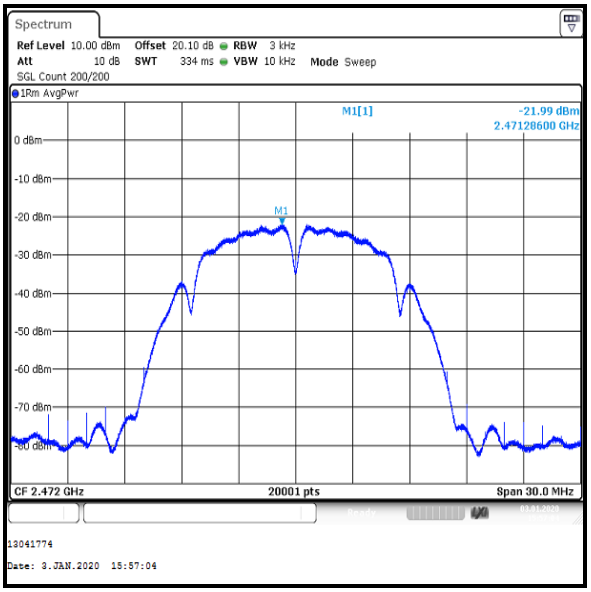
Channel 7



Channel 11



Channel 12



Channel 13

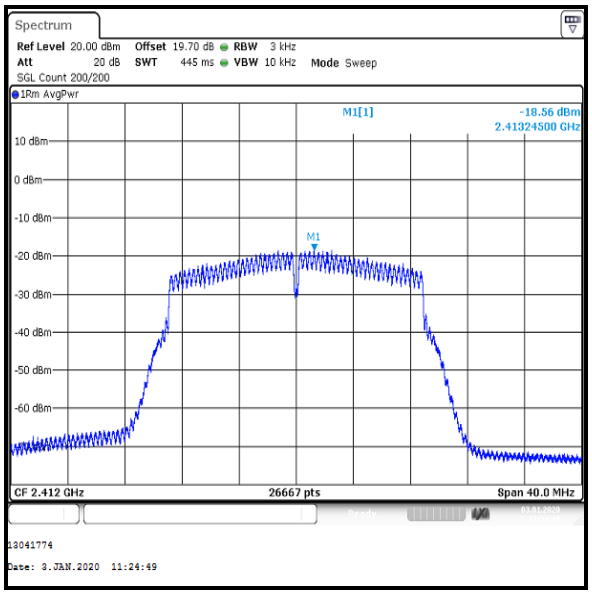
Transmitter Power Spectral Density (continued)

Results: 802.11n / HT20 / MIMO / 2Tx CDD / BPSK / MCS0

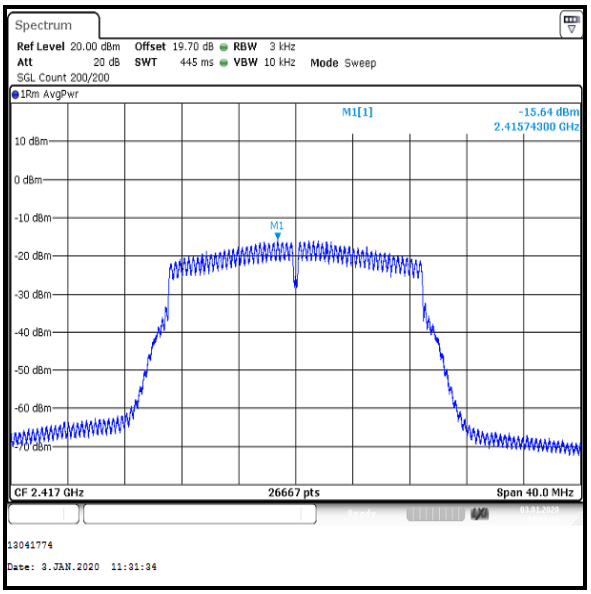
Channel	PSD / Core 0 (dBm / 3 kHz)	PSD / Core 2 (dBm / 3 kHz)	Combined PSD (dBm / 3 kHz)	Limit (dBm / 3 kHz)	Margin (dB)	Result
1	-18.6	-18.4	-15.6	8.0	23.6	Complied
2	-15.6	-15.9	-13.0	8.0	21.0	Complied
3	-15.3	-15.1	-12.4	8.0	20.4	Complied
6	-15.7	-15.7	-12.9	8.0	20.9	Complied
7	-15.6	-15.4	-12.8	8.0	20.8	Complied
11	-19.5	-19.5	-16.6	8.0	24.6	Complied
12	-21.8	-21.4	-18.9	8.0	26.9	Complied
13	-32.5	-32.5	-30.0	8.0	38.0	Complied

Transmitter Power Spectral Density (continued)

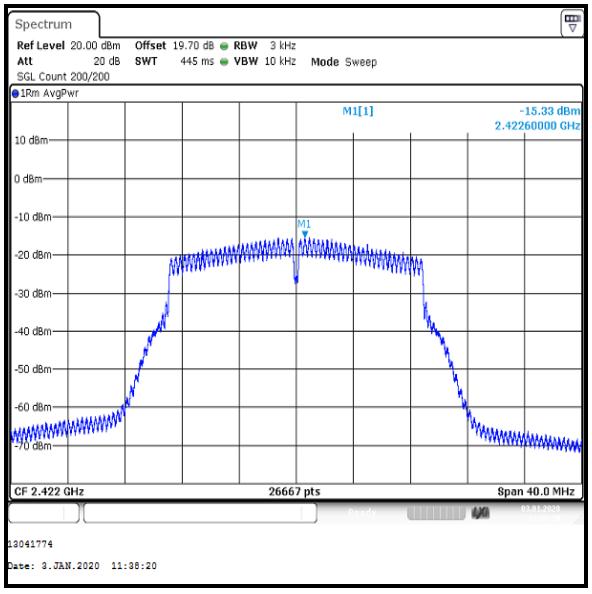
Results: 802.11n / HT20 / MIMO / 2Tx CDD / BPSK / MCS0 / Core 0



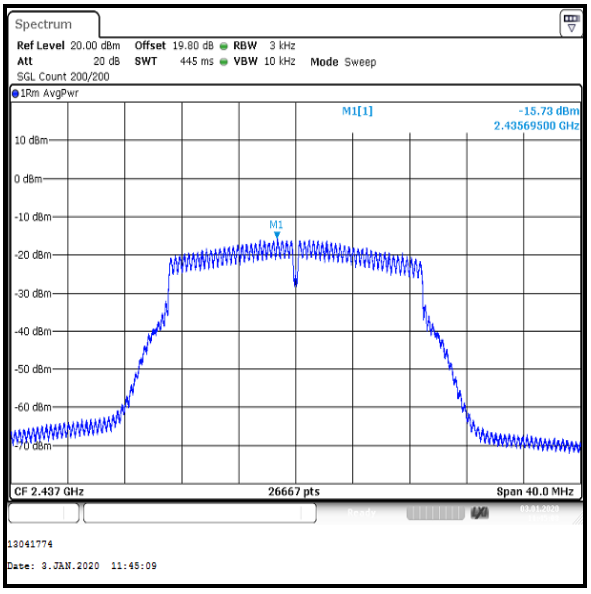
Channel 1



Channel 2



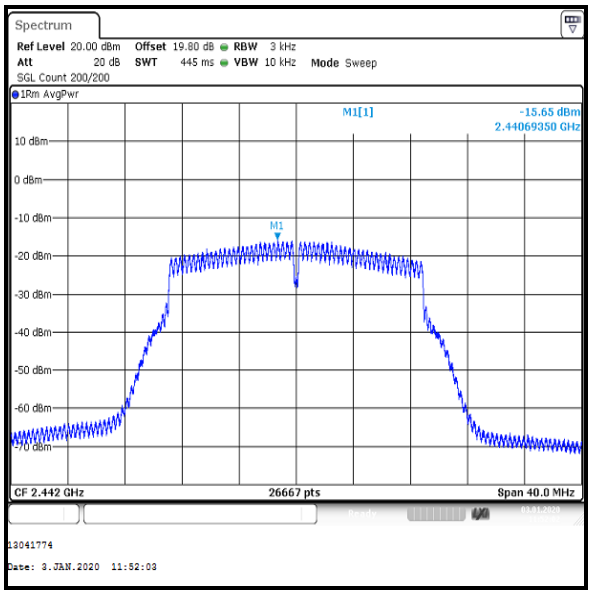
Channel 3



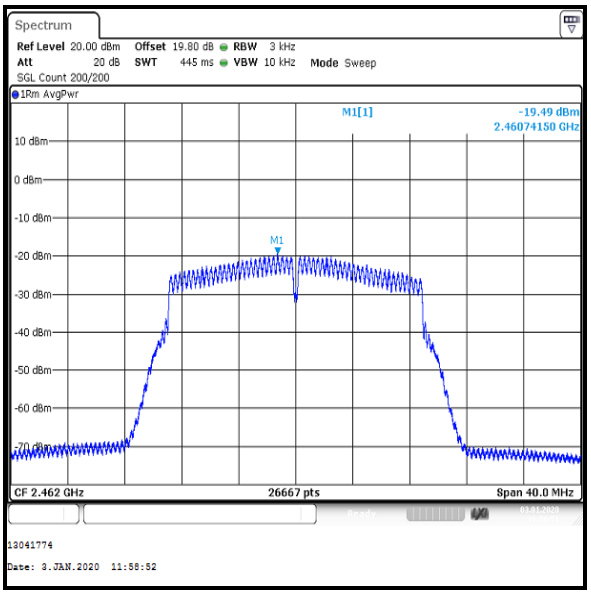
Channel 6

Transmitter Power Spectral Density (continued)

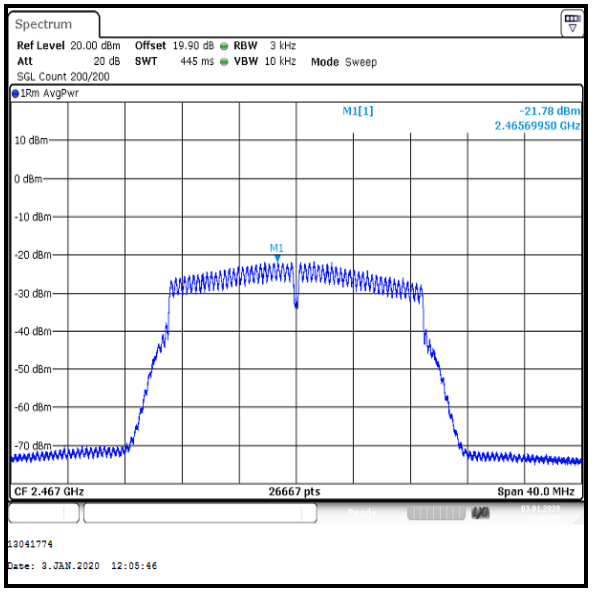
Results: 802.11n / HT20 / MIMO / 2Tx CDD / BPSK / MCS0 / Core 0



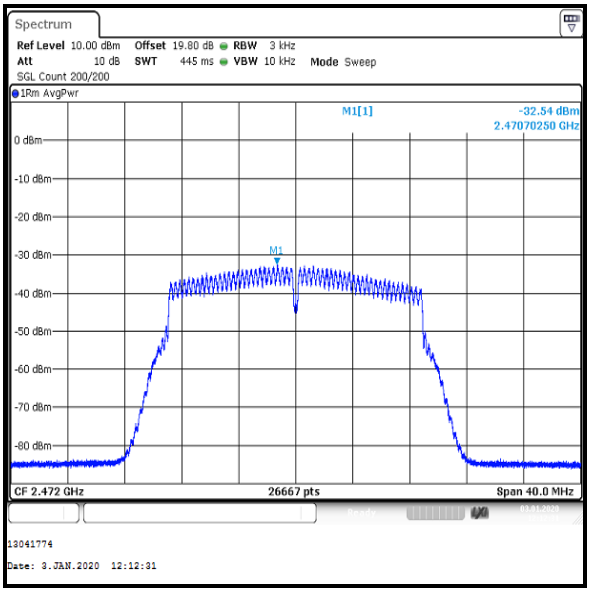
Channel 7



Channel 11



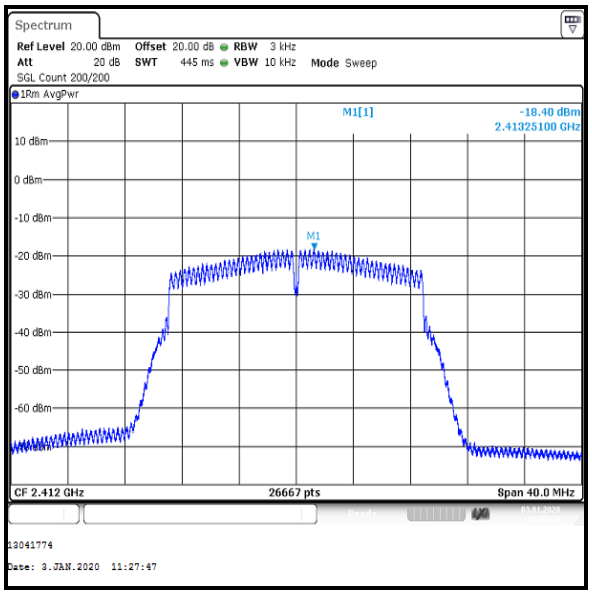
Channel 12



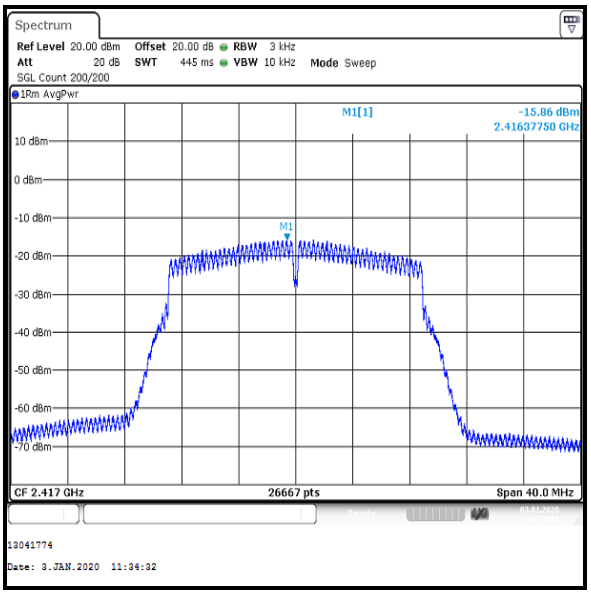
Channel 13

Transmitter Power Spectral Density (continued)

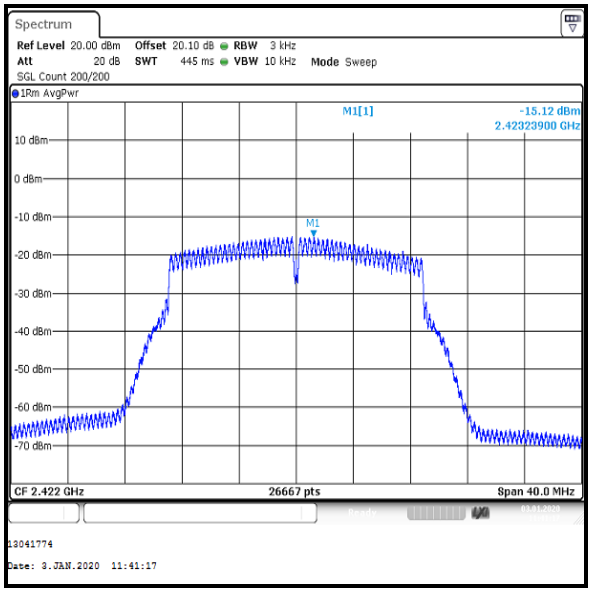
Results: 802.11n / HT20 / MIMO / 2Tx CDD / BPSK / MCS0 / Core 2



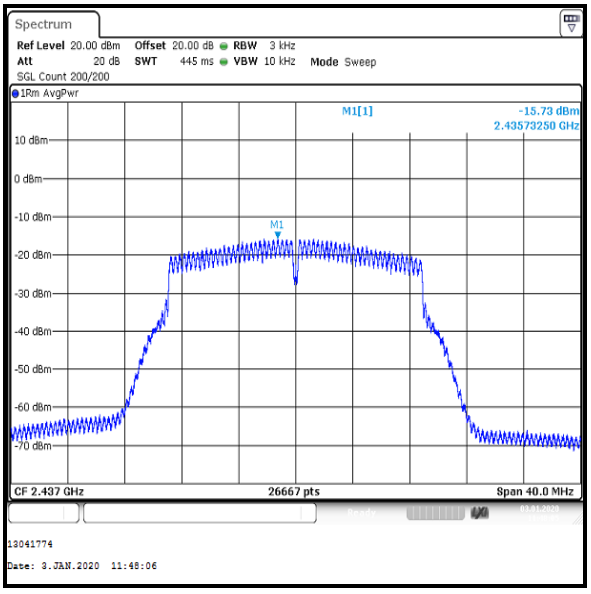
Channel 1



Channel 2



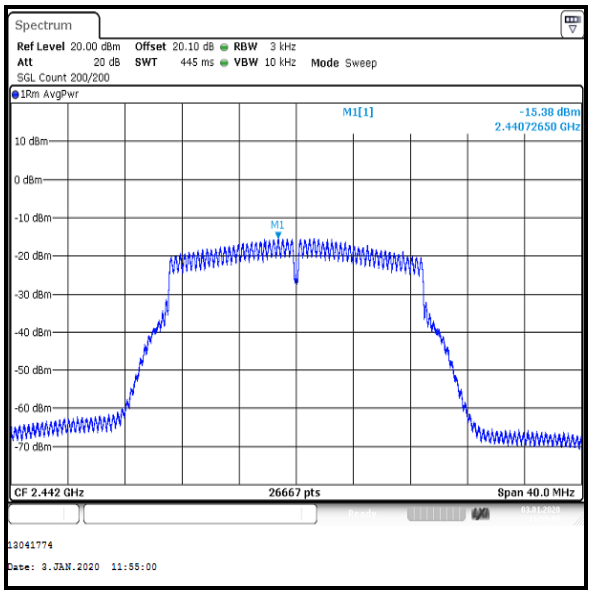
Channel 3



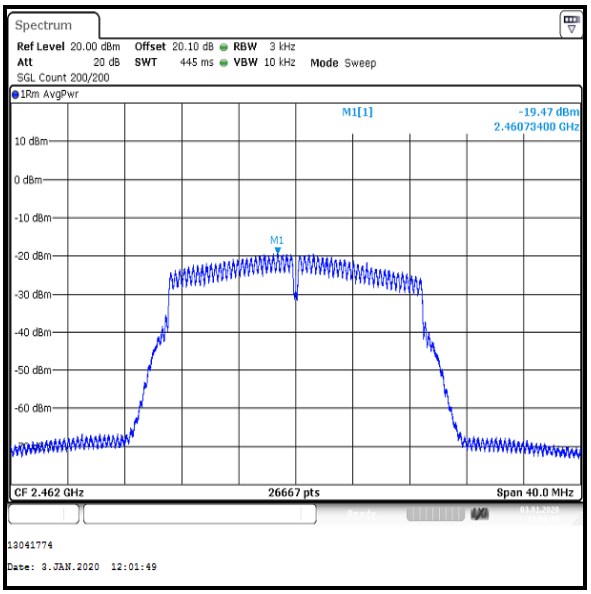
Channel 6

Transmitter Power Spectral Density (continued)

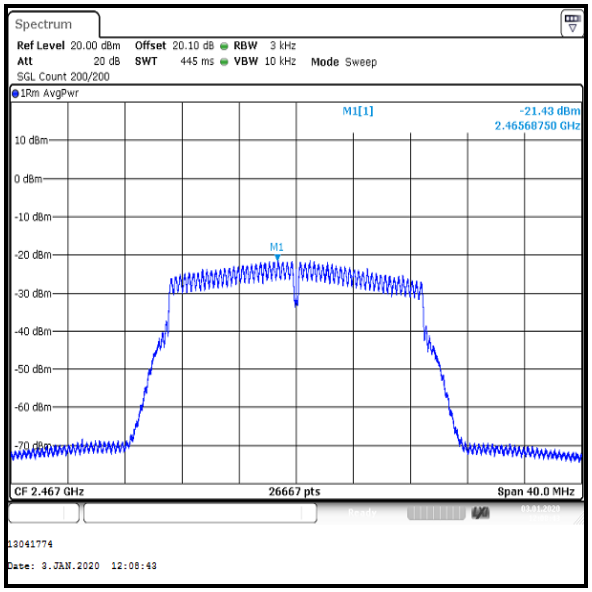
Results: 802.11n / HT20 / MIMO / 2Tx CDD / BPSK / MCS0 / Core 2



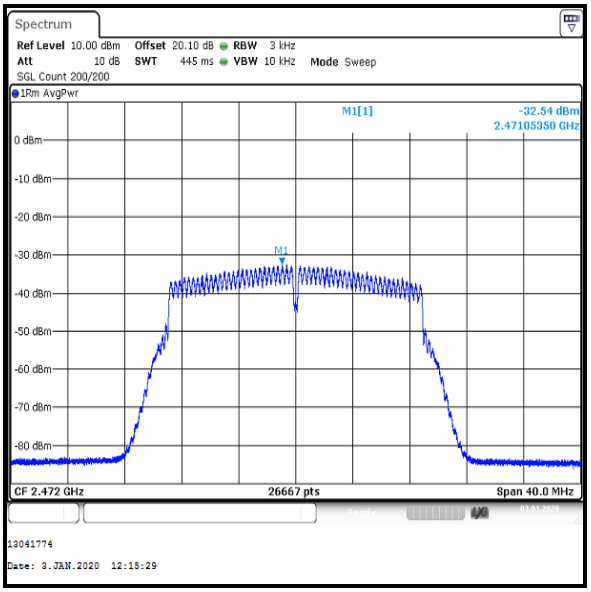
Channel 7



Channel 11



Channel 12



Channel 13

Transmitter Power Spectral Density (continued)

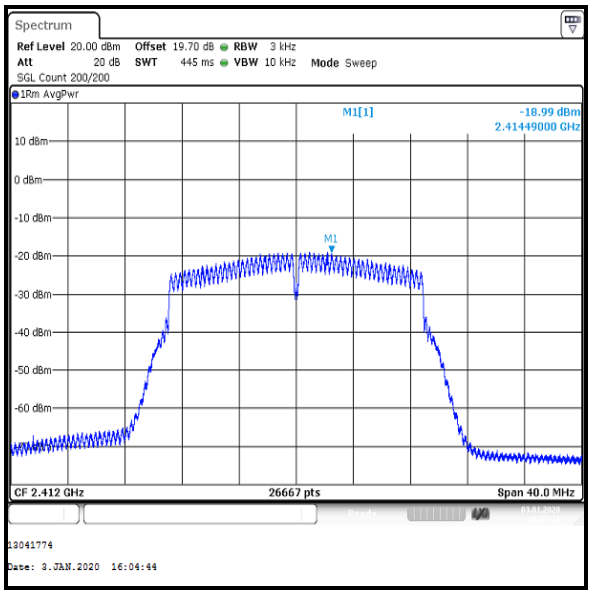
Results: 802.11n / HT20 / MIMO / 3Tx CDD / BPSK / MCS0

Channel	PSD / Core 0 (dBm / 3 kHz)	PSD / Core 1 (dBm / 3 kHz)	PSD / Core 2 (dBm / 3 kHz)
1	-19.0	-19.4	-18.7
2	-17.6	-17.6	-17.2
3	-16.8	-17.0	-15.9
6	-15.6	-16.1	-15.3
7	-15.7	-16.2	-15.0
11	-21.1	-21.3	-20.5
12	-22.6	-22.7	-22.1
13	-33.7	-34.1	-32.8

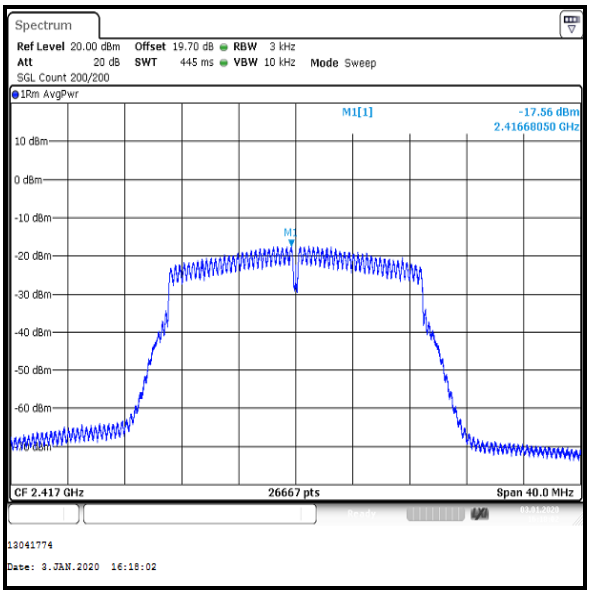
Channel	Combined PSD (dBm / 3 kHz)	Limit (dBm / 3 kHz)	Margin (dB)	Result
1	-14.5	8.0	22.5	Complied
2	-13.0	8.0	21.0	Complied
3	-12.3	8.0	20.3	Complied
6	-11.0	8.0	19.0	Complied
7	-11.0	8.0	19.0	Complied
11	-16.4	8.0	24.4	Complied
12	-18.0	8.0	26.0	Complied
13	-29.1	8.0	37.1	Complied

Transmitter Power Spectral Density (continued)

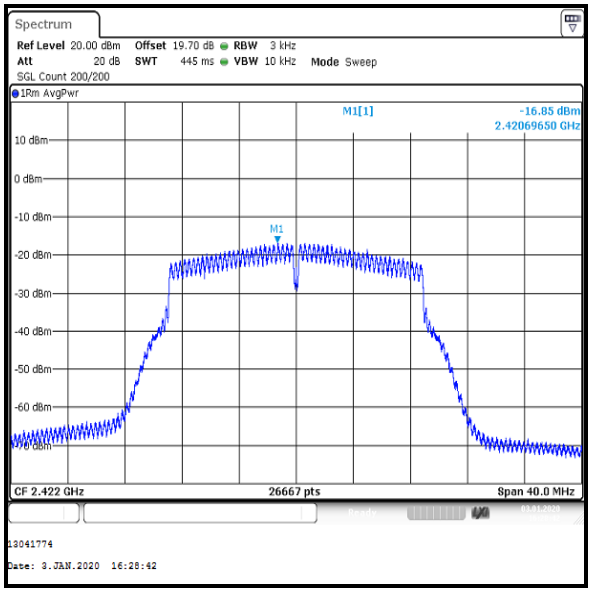
Results: 802.11n / HT20 / MIMO / 3Tx CDD / BPSK / MCS0 / Core 0



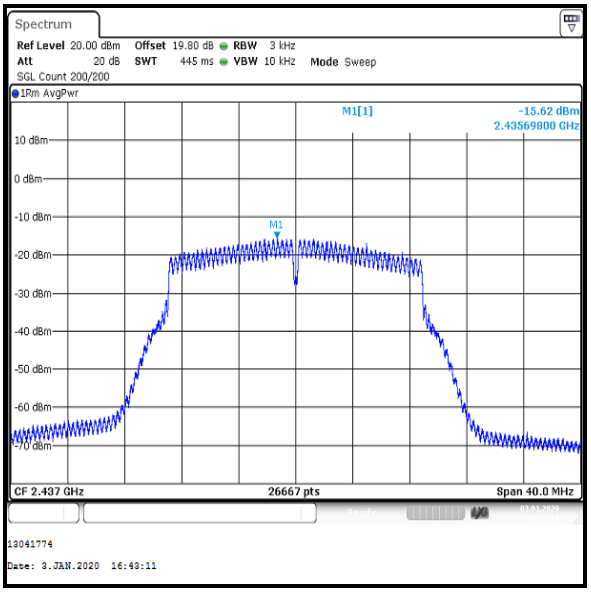
Channel 1



Channel 2



Channel 3



Channel 6