RF Test Report

Report Number: 208726-2 **Revision Level:** 1

Client: Comma.ai, inc.
3900 Harney St., San Diego, CA92110

Equipment Under Test: 2.4/5 GHz WiFi module

Product Name: LightningHard SOM

Model: LightningHard SOM

FCC ID: 2BFC6-LIGHTNINGH

IC: 32232-LIGHTNINGH

Applicable Standards: FCC Part 15 Subpart C, § 15.407
RSS-247 Issue 3, August 2023

Report issued on: June 26, 2024

Test Result: Compliant

FOR THE SCOPE OF ACCREDITATION UNDER CERTIFICATE NUMBER: 1935.01
This report must not be used by the client to claim product certification, approval, or endorsement by A2LA, NIST, or any agency of the Federal Government.

Prepared by: A. Gillmeier
Andreas Gillmeier, Sr. Engineer, Wireless

Reviewed by: Alex Chang
Alex Chang, Sr. Regulatory Laboratory Manager – EMC/RF

Remarks: This document is issued by the Company subject to its General Conditions of Service printed overleaf, available on request or accessible at http://www.sgs.com//en/Terms-and-Conditions.aspx. And for electronic format documents, subject to Terms and Conditions for Electronic Documents at http://www.sgs.com/en/Terms-and-Conditions/terms-e-document.aspx.

Attention is drawn to the limitation of liability, indemnification and jurisdiction issues defined therein. Any holder of this document is advised that information contained hereon reflects the Company's findings at the time of its intervention only and within the limits of Client's instructions, if any. The Company's sole responsibility is to its Client and this document does not exonerate parties to a transaction from exercising all their rights and obligations under the transaction documents. This document cannot be reproduced except in full, without prior written approval of the Company. Any unauthorized alteration, forgery or falsification of the content or appearance of this document is unlawful, and offenders may be prosecuted to the fullest extent of the law. Unless otherwise stated the results shown in this test report refer only to the sample(s) tested and such sample(s) are retained for a maximum of 30 days only.

Table of Contents

1 SUMMARY OF TEST RESULTS 3

1.1 MODIFICATIONS REQUIRED FOR COMPLIANCE 3

2 GENERAL INFORMATION 3

2.1 CLIENT INFORMATION 3
2.2 TEST LABORATORY 3
2.3 GENERAL INFORMATION OF EUT 4
2.4 EUT CONNECTION BLOCK DIAGRAM 5
2.5 SYSTEM CONFIGURATIONS 5

3 OCCUPIED BANDWIDTH 6

3.1 TEST RESULT 6
3.2 TEST METHOD 6
3.3 TEST SITE 7
3.4 TEST EQUIPMENT 7
3.5 TEST SETUP PHOTOGRAPHS 7
3.6 TEST DATA 8

4 CONDUCTED OUTPUT POWER 39

4.1 TEST RESULT 39
4.2 TEST METHOD 39
4.3 TEST SITE 39
4.4 TEST EQUIPMENT 39
4.5 TEST SETUP PHOTOGRAPHS 39
4.6 DUTY CYCLE TEST DATA 40
4.7 CONDUCTED POWER TEST DATA 65

5 UNDESIRABLE EMISSIONS 84

5.1 TEST RESULT 84
5.2 TEST METHOD 84
5.3 TEST SITE 84
5.4 ADDITIONAL OBSERVATION 84
5.5 TEST EQUIPMENT 85
5.6 TEST SETUP PHOTOGRAPHS 85
5.7 TEST DATA 86
5.8 POWER SPECTRAL DENSITY 358
5.9 TEST RESULT 358
5.10 TEST METHOD 358
5.11 TEST SITE 359
5.12 TEST EQUIPMENT 359
5.13 TEST DATA 360

7 FREQUENCY STABILITY 393

7.1 TEST RESULT 393
7.2 APPLICABLE REQUIREMENT 393
7.3 CONFORMANCE 393

8 CONDUCTED EMISSIONS 394

8.1 TEST RESULT 394
8.2 TEST METHOD 394
8.3 ADDITIONAL INFORMATION 394

9 MEASUREMENT UNCERTAINTY 395

10 REVISION HISTORY 396

1 Summary of Test Results

Test Description	Test Specification	Test Result
Occupied Bandwidth	15.403(i) / 15.407(e) / RSS-247 6.2.4(1)	Compliant
Spectral Density	15.407(a)(1)(iv), (a)(2), (a)(3)(iii) / RSS-247 6.2.1(1) and 6.2.4(1)	Compliant
Peak Power Output	15.407(a)(1)(iv), (a)(2), (a)(3)(iii) / RSS-247 6.2.1(1) and 6.2.4(1)	Compliant
Radiated Spurious Emissions	15.407(b)(1), (b)(2), (b)(3), (4)(i) / 15.209 / RSS-247 6.2.1(2) and 6.2.4(2)	Compliant
Frequency Stability	15.407(g)	Compliant

1.1 *Modifications Required for Compliance*

None

2 General Information

2.1 *Client Information*

Name: Comma.ai, inc.
Address: 3900 Harney St.
City, State, Zip, Country: San Diego, CA92110, USA

2.2 *Test Laboratory*

Name: SGS North America, Inc.
Address: 12310 World Trade Drive, Suite 106/107
City, State, Zip, Country: San Diego, CA 92128, USA

Accrediting Body: A2LA
Type of lab: Testing Laboratory
Certificate Number: 1935.01
Designation Number: US1346
CAB Identifier: US0236

2.3 *General Information of EUT*

Marketing Name:	LightningHard SOM
Model:	LightningHard SOM
Serial Number:	N/A
Firmware Version:	V1
FCC ID:	2BFC6-LIGHTNINGH
Frequency Range:	5150 to 5825 MHz
Modulation type:	OFDM
Channel spacing:	20 MHz
Antenna/Gain*:	PCB Omnidirectional Antenna (TE 2344654-7); peak gain 5.7 dBi*
Rated Voltage:	3.6 to 4.8V_{DC} to module PCB
Sample Received Date:	January 30, 2024
Dates of testing:	February 9 – May 30, 2024

* SGS is not responsible for accuracy of Data that was not measured by SGS laboratory, e.g. Data that was obtained via customer, specification sheet, previous filing or other.

Operating Modes and Conditions

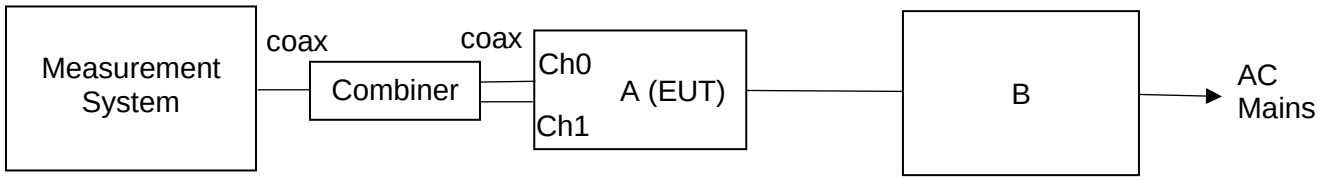
Modulations used: For fundamental and spurious measurements, the EUT was configured to operate continuously with Wi-Fi modulation enabled.

As specified in Section 5.10.5 of ANSI C63.10:2013:

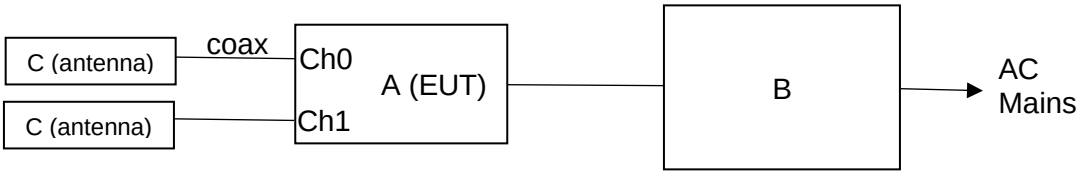
- The software allowed configuration and operation on all available unlicensed wireless device channels.
- The software allowed configuration and operation using all available modulations and data rates
- The software allowed configuration and operation on all available power out levels

2.4 *EUT Connection Block Diagram*

Conducted:



Radiated:



2.5 *System Configurations*

Device reference	Manufacturer	Description	Model Number	Serial Number
A	Comma.ai	Test Board	LightningHard Test Board 10/19/2023	N/A
B	TMEZON	AC/DC power adapter	MZ-12V2A-2.4M	N/A
C	TE	Dual Band WLAN antenna	2344654-7	N/A

3 Occupied Bandwidth

3.1 *Test Result*

Test Description	Basic Standards	Test Limit
26 dB bandwidth	15.407(1) (2)(3)	Reference Only (UNII1, UNII2a, UNII2c)
6 dB bandwidth	15.407(1) (2)(3)	Compliant

3.2 *Test Method*

The procedures from ANSI C63.10 (2009) clause 6.9 were used to determine the 26/6 dB bandwidth.

1. Place the EUT on the table and set it in transmitting mode.
2. Remove the antenna from the EUT and then connect a low loss RF cable from the Antenna port to the spectrum analyzer.
3. 26dB Bandwidth Measurement:
   The testing follows FCC KDB 789033 D02 General UNII Test Procedures New Rules.
   Set the spectrum analyzer as 1% of emission
   BW Sweep=auto, Detector = Peak, Trace Mode = Max Hold,
   Manually readjust RBW until the RBW/EBW ratio is 1% based on EBW as observed on the result of pre-sequence measurement.
   Mark the peak frequency and –26dB (upper and lower) frequency.
   Repeat the procedures as list above until all test default channels (low, middle, and high) are completed.
4. Minimum Emission Bandwidth (6dB) for the UNII3 band (5.725-5.850GHz).
   The testing follows the measurement procedure listed in FCC KDB 558074 D01.
   Set the spectrum analyzer as
   RBW = 100 kHz,
   VBW = 3 x RBW,
   Span = large enough to capture all products of the modulation process,
   Detector=Peak, Sweep=auto
   Mark the peak frequency and –6dB (upper and lower) frequency.
   Repeat above procedures until all the default channel is completed.
5. For 99% Bandwidth:
   The testing follows the measurement procedure listed in RSS-Gen section 6.7.
   Set the spectrum analyzer as
   RBW = 1% to 5% of 99% bandwidth,
   VBW ≥ 3 x RBW,
   Span = large enough to capture all products of the modulation process,
   Sweep=auto, Detector=Peak, Trace Mode = Max Hold,
   Turn on the 99% bandwidth function, max reading.
   Repeat above procedures until all the default channel is completed.

<u>Limit</u>
Reference only (UNII1, UNII2a, UNII2c)
>=0.5 MHz (UNII3)

3.3 *Test Site*

EMC Laboratory, San Diego, CA

Environmental Conditions

Temperature: 18.4 – 24.7 °C

Relative Humidity: 46 - 58 %

3.4 *Test Equipment*

Test Dates: Feb. 26 to 28, 2024 Tester: Andreas Gillmeier

Asset No.	Type of Equipment	Model	Serial No.	Manufacturer	Cal Date	Cal Due Date
Conducted Testing						
2003	Signal Analyzer	N9030B	MY61330812	Keysight	01/29/2024	01/29/2025
-	Test Software	Radio Test Software	v.23	SGS Taiwan	N/A	-
2036	Temp/Humidity Data Logger	GSP-8	CMA231100002	Elitech	05/24/2023	

3.5 *Test Setup Photographs*

Test setup photographs are located in a separate exhibit.

3.6 *Test Data*

UNII1:

Mode	Frequency (MHz)	Power Level	Data Rate (Mbps)	26dB Bandwidth (MHz)		99% Bandwidth (MHz)		Verdict
				Both Antennas Combined	Limit	Both Antennas Combined	Limit	
802.11a NOHT	5180	15	18	20.65	N/A	16.345		Pass
	5200	15	18	21.19	N/A	16.285		Pass
	5240	15	9	20.59	N/A	16.361		Pass
802.11 n20	5180	15	mcs0	20.26	N/A	17.595		Pass
	5200	15	mcs0	21.56	N/A	17.574		Pass
	5240	15	mcs0	20.75	N/A	17.425		Pass
802.11 n40	5190	13	mcs8	41.66	N/A	36.363		Pass
	5230	13	mcs2	40.91	N/A	36.462		Pass
802.11 ac20	5180	15	mcs3	21.41	N/A	17.740		Pass
	5200	15	mcs0	20.96	N/A	17.766		Pass
	5240	15	mcs0	21.62	N/A	17.717		Pass
802.11 ac40	5190	13	mcs0	40.96	N/A	36.352		Pass
	5230	13	mcs0	40.42	N/A	36.349		Pass
802.11 ac80	5210	13	mcs0	83.10	N/A	75.931		Pass

UNII2a:

Mode	Frequency (MHz)	Power Level	Data Rate (Mbps)	26dB Bandwidth (MHz)		99% Bandwidth (MHz)		Verdict
				Both Antennas Combined	Limit	Both Antennas Combined	Limit	
802.11a NOHT	5260	15	6	22.18	N/A	16.337		Pass
	5280	15	9	21.57	N/A	16.357		Pass
	5320	15	6	20.77	N/A	16.754		Pass
802.11 n20	5260	15	mcs0	20.27	N/A	17.440		Pass
	5280	15	mcs9	20.98	N/A	17.816		Pass
	5320	15	mcs0	22.9	N/A	18.023		Pass
802.11 n40	5270	13	mcs1	40.97	N/A	36.420		Pass
	5310	13	mcs1	40.44	N/A	36.505		Pass
802.11 ac20	5260	15	mcs0	21.53	N/A	17.747		Pass
	5280	15	mcs0	21.94	N/A	17.769		Pass
	5320	15	mcs0	21.93	N/A	17.811		Pass
802.11 ac40	5270	13	mcs0	40.62	N/A	36.403		Pass
	5310	13	mcs0	40.77	N/A	36.378		Pass
802.11 ac80	5290	13	mcs0	83.18	N/A	75.923		Pass

UNII2c:

Mode	Frequency (MHz)	Power Level	Data Rate (Mbps)	26dB Bandwidth (MHz)		99% Bandwidth (MHz)		Verdict
				Both Antennas Combined	Limit	Both Antennas Combined	Limit	
802.11a NOHT	5500	15	18	20.76	N/A	16.309		Pass
	5600	15	9	21.55	N/A	16.486		Pass
	5700	15	9	22.16	N/A	16.309		Pass
802.11 n20	5500	13	mcs0	21.56	N/A	17.974		Pass
	5600	13	mcs0	20.35	N/A	17.388		Pass
	5700	13	mcs8	20.83	N/A	17.711		Pass
802.11 n40	5510	13	mcs8	41.83	N/A	36.344		Pass
	5590	13	mcs1	40.39	N/A	36.484		Pass
802.11 ac20	5500	13	mcs0	21.17	N/A	17.760		Pass
	5600	13	mcs0	20.97	N/A	17.685		Pass
	5700	13	mcs0	21.45	N/A	17.754		Pass
802.11 ac40	5510	13	mcs0	41.08	N/A	36.343		Pass
	5670	13	mcs0	41.04	N/A	36.364		Pass
	5590	13	mcs0	40.77	N/A	36.400		Pass
802.11 n40	5530	13	mcs8	83.23	N/A	75.997		Pass
	5610	13	mcs1	86.22	N/A	75.841		Pass

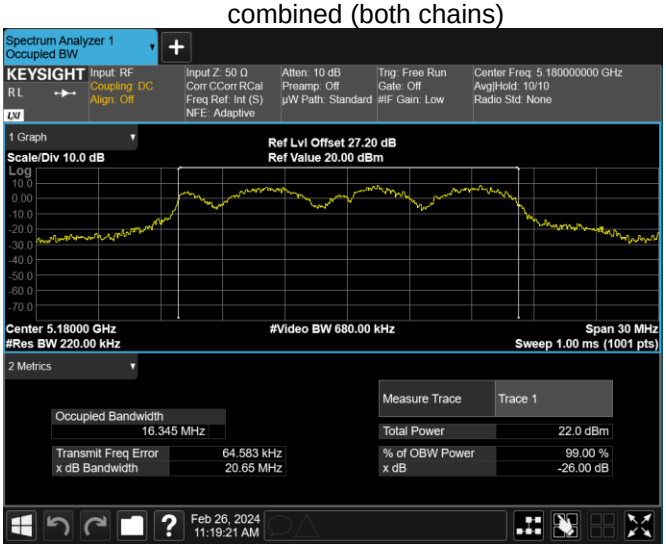
UNII3:

Mode	Frequency (MHz)	Power Level	Data Rate (Mbps)	6dB Bandwidth (MHz)		99% Bandwidth (MHz)		Verdict
				Both Antennas Combined	Limit	Both Antennas Combined	Limit	
802.11a NOHT	5745	15	6	16.09	>=0.5	16.543		Pass
	5785	15	6	16.35	>=0.5	16.549		Pass
	5825	15	6	16.34	>=0.5	16.543		Pass
802.11 n20	5745	15	mcs0	17.17	>=0.5	17.789		Pass
	5785	15	mcs0	17.22	>=0.5	17.816		Pass
	5825	15	mcs0	17.6	>=0.5	17.825		Pass
802.11 n40	5755	15	mcs0	35.34	>=0.5	36.035		Pass
	5795	15	mcs0	35.38	>=0.5	35.956		Pass
802.11 ac20	5745	15	mcs0	17.59	>=0.5	17.676		Pass
	5785	15	mcs0	16.34	>=0.5	17.662		Pass
	5825	15	mcs1	16.88	>=0.5	17.688		Pass
802.11 ac40	5755	15	mcs0	35.77	>=0.5	35.258		Pass
	5795	15	mcs0	36.35	>=0.5	36.276		Pass
802.11 ac80	5775	15	mcs0	75.31	>=0.5	75.690		Pass

UNII1:

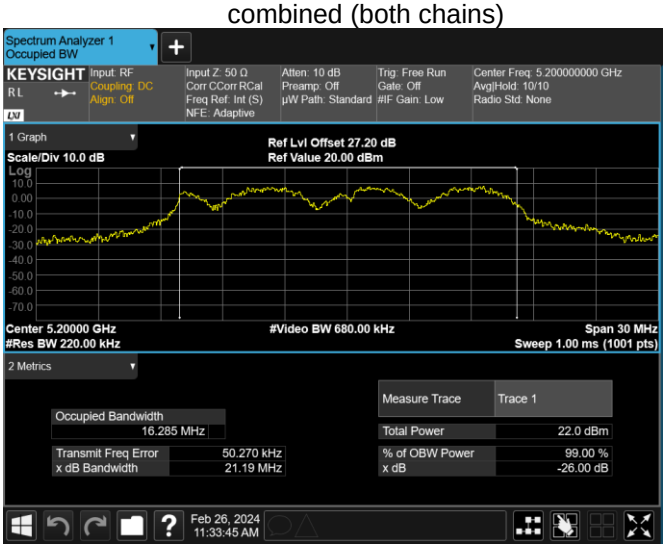
Low Channel – 802.11a NOHT, (5180MHz)

combined (both chains)

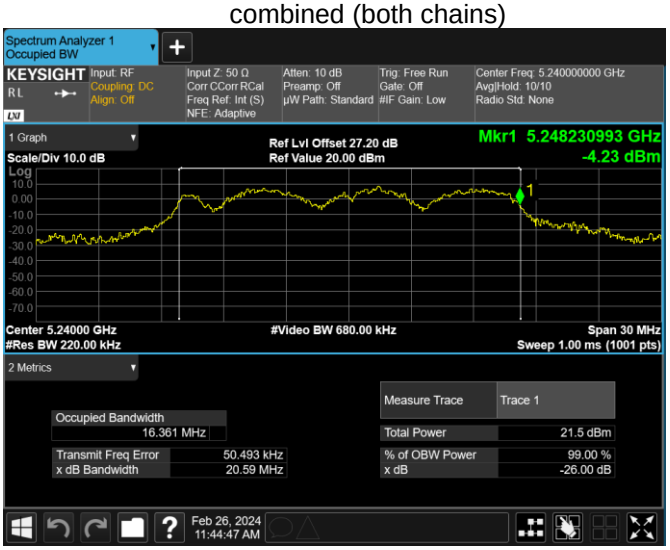


Mid Channel – 802.11a NOHT, (5200MHz)

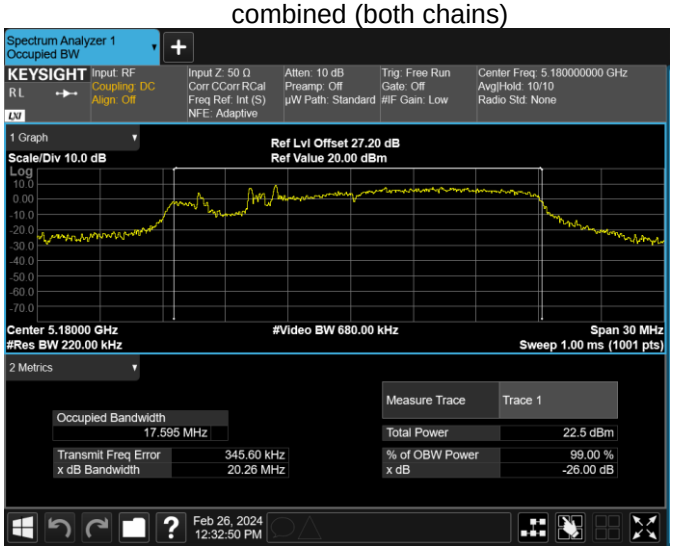
combined (both chains)



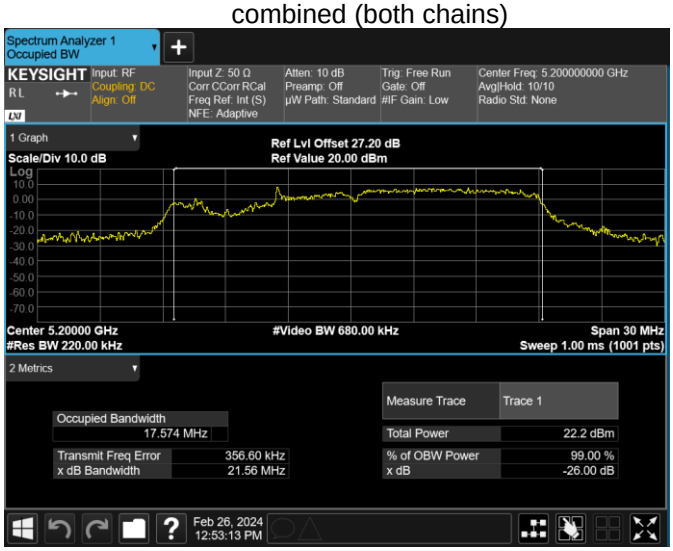
High Channel – 802.11a NOHT, (5240MHz)
combined (both chains)



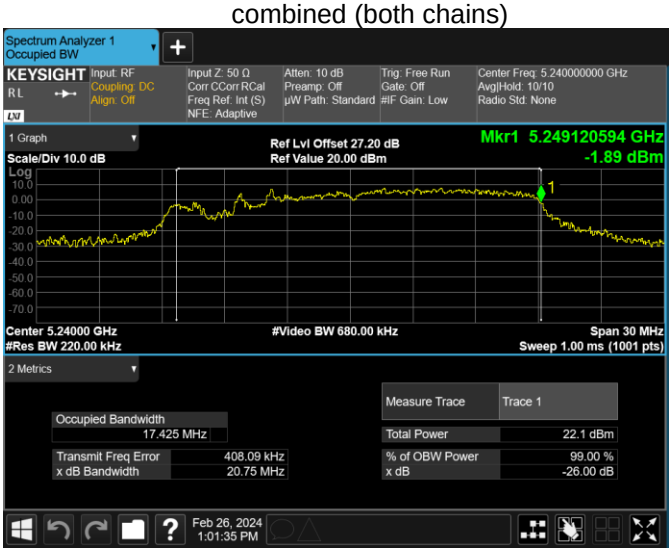
Low Channel – 802.11n20, (5180MHz)
combined (both chains)



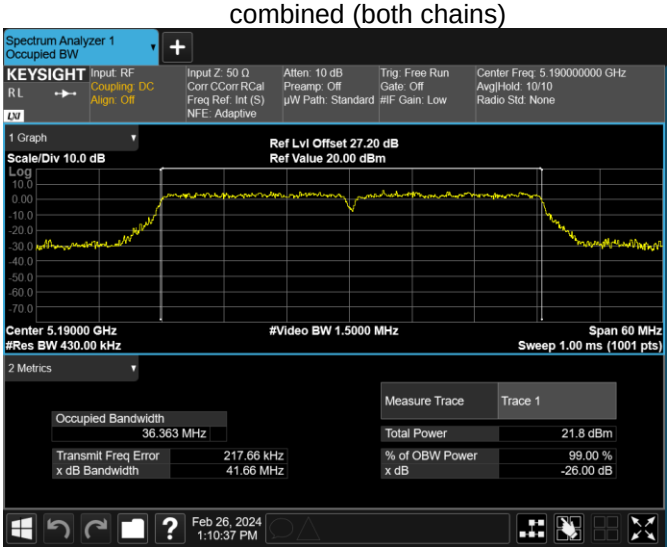
Mid Channel – 802.11n20, (5200MHz)
combined (both chains)



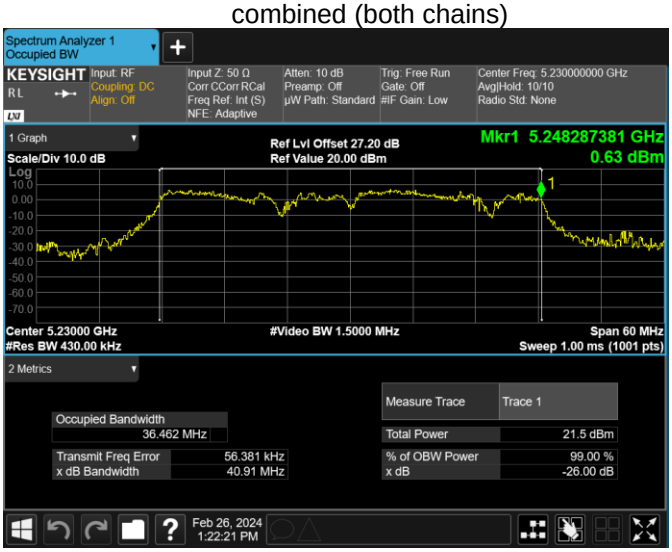
High Channel – 802.11n20, (5240MHz)
combined (both chains)



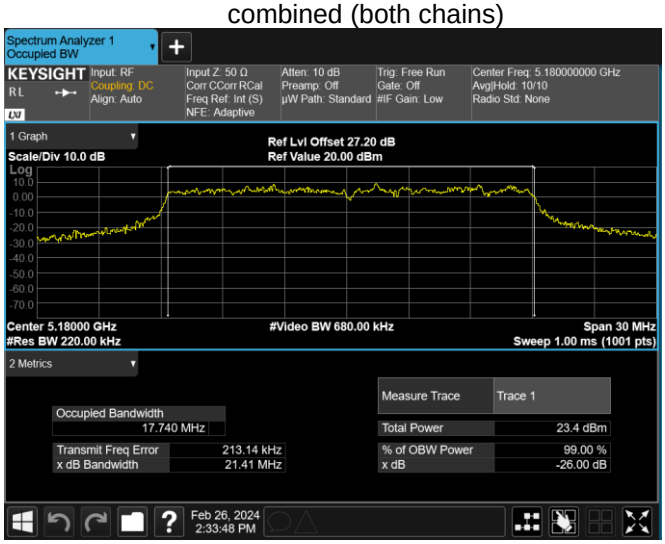
Low Channel – 802.11n40, (5190MHz)
combined (both chains)



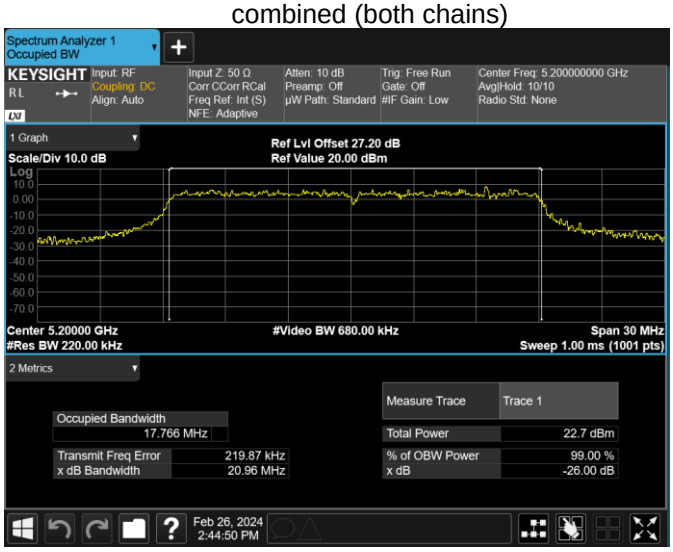
High Channel – 802.11n40, (5230MHz)
combined (both chains)



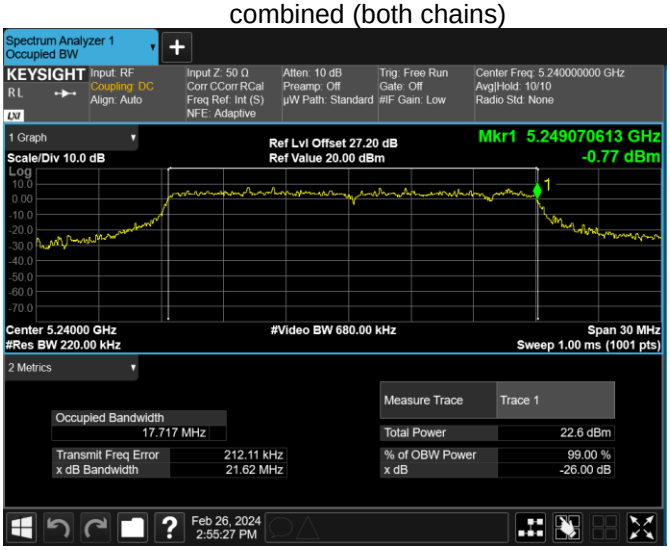
Low Channel – 802.11ac20, (5180MHz)
combined (both chains)



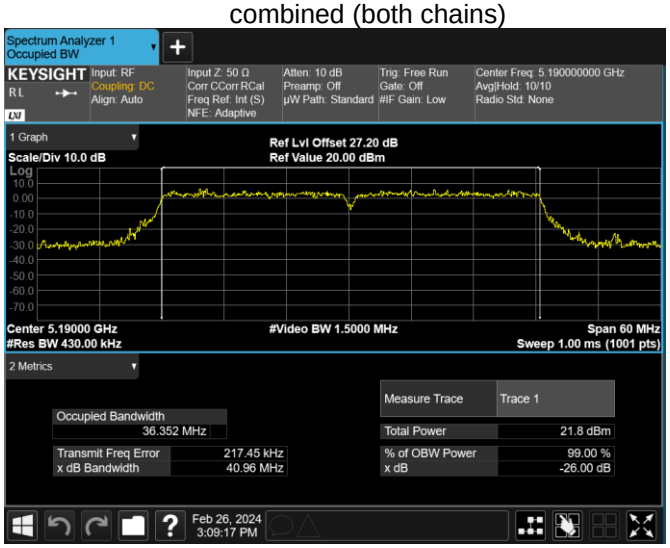
Mid Channel – 802.11ac20, (5200MHz)
combined (both chains)



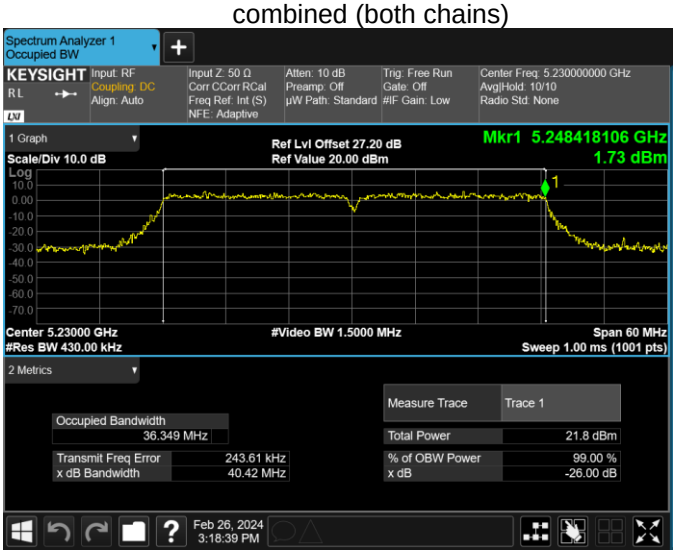
High Channel – 802.11ac20, (5240MHz)
combined (both chains)



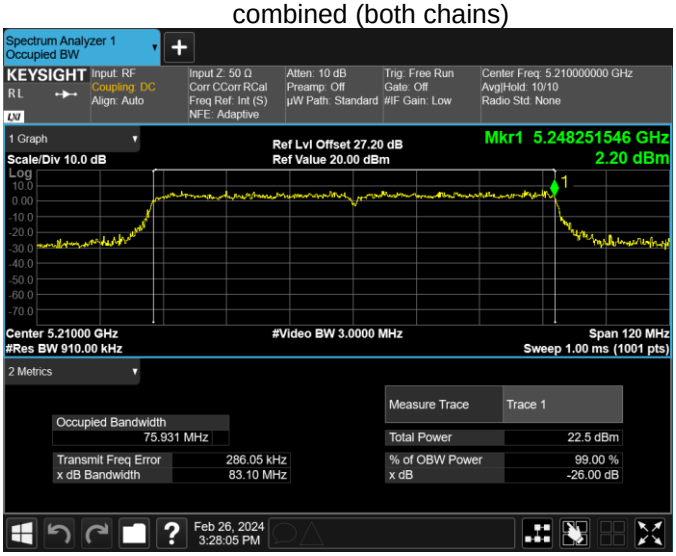
Low Channel – 802.11ac40, (5190MHz)
combined (both chains)



High Channel – 802.11ac40, (5230MHz)
combined (both chains)



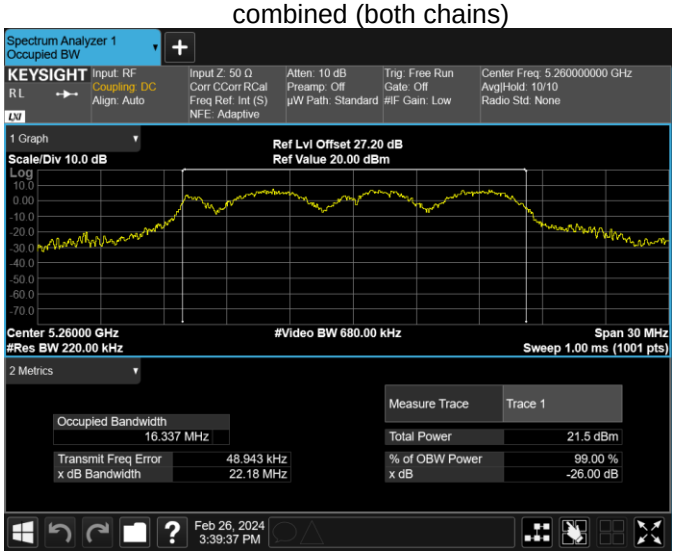
Mid Channel – 802.11ac80, (5210MHz)
combined (both chains)



UNII2a:

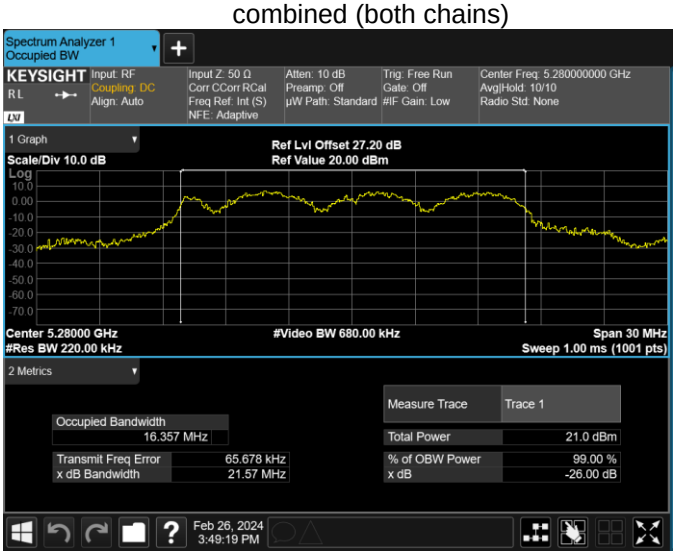
Low Channel – 802.11a NOHT, (5260MHz)

combined (both chains)

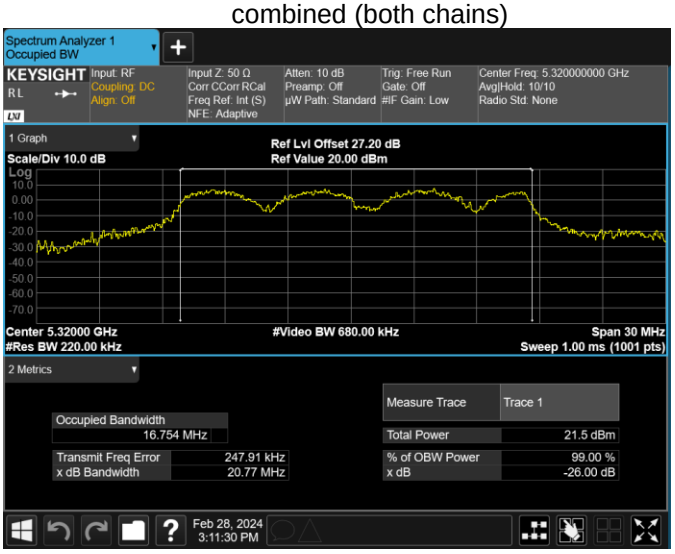


Mid Channel – 802.11a NOHT, (5280MHz)

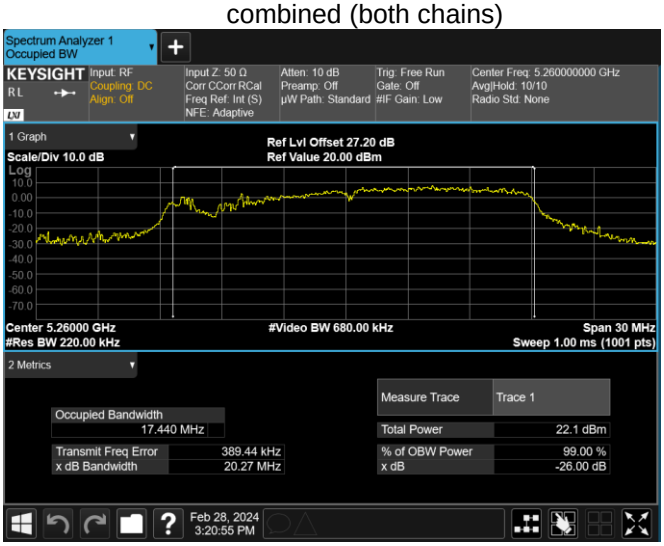
combined (both chains)



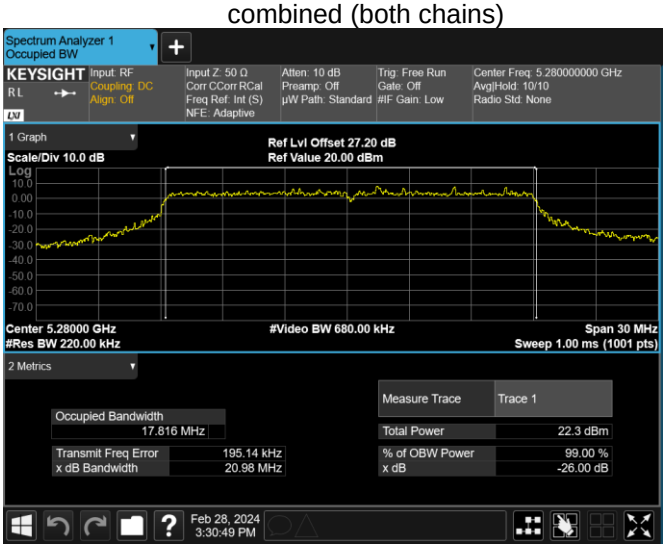
High Channel – 802.11a NOHT, (5320MHz)
combined (both chains)



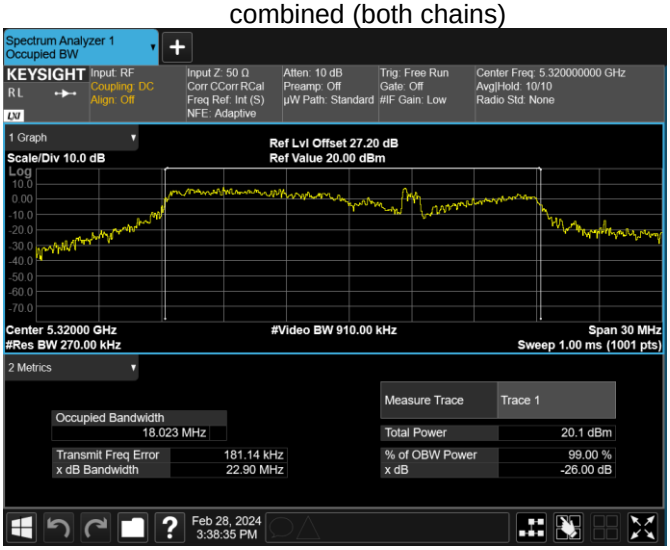
Low Channel – 802.11n20, (5260MHz)
combined (both chains)



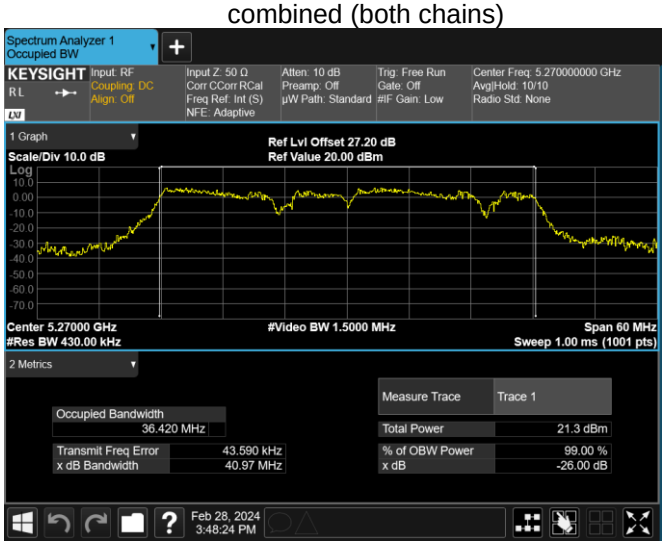
Mid Channel – 802.11n20, (5280MHz)
combined (both chains)



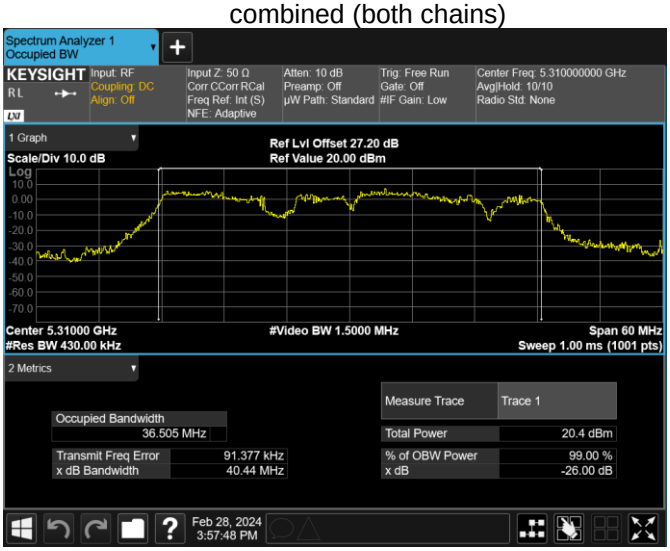
High Channel – 802.11n20, (5320MHz)
combined (both chains)



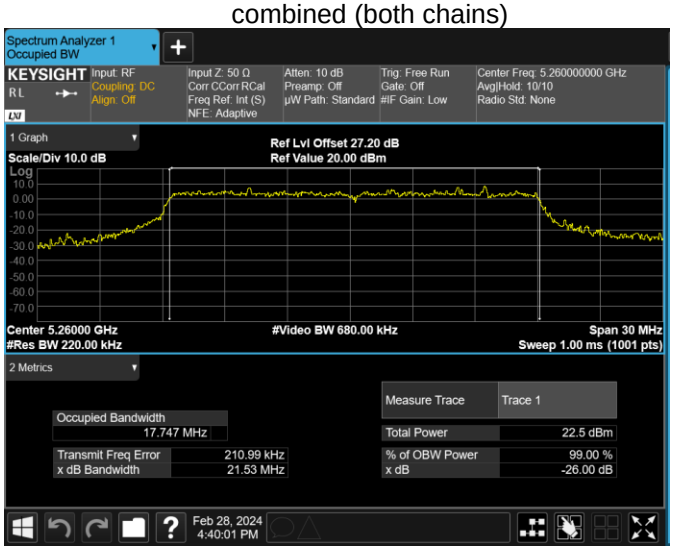
Low Channel – 802.11n40, (5270MHz)
combined (both chains)



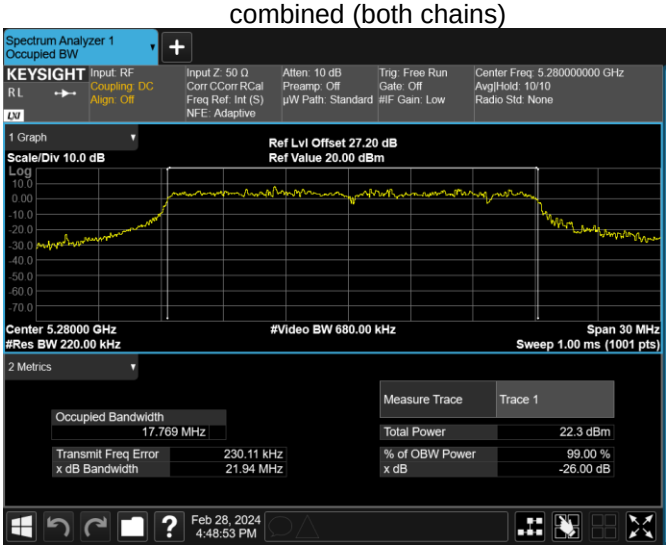
High Channel – 802.11n40, (5310MHz)
combined (both chains)



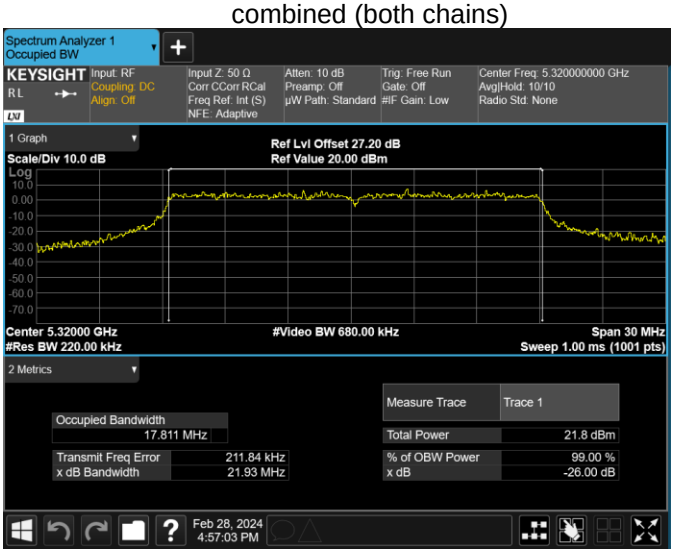
Low Channel – 802.11ac20, (5260MHz)
combined (both chains)



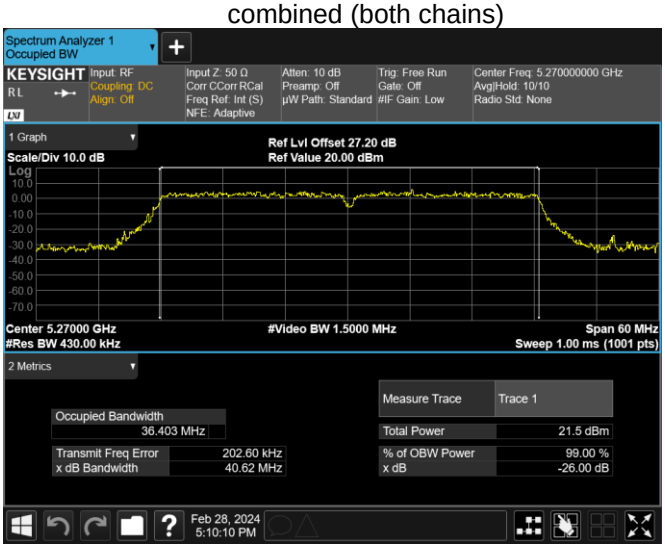
Mid Channel – 802.11ac20, (5280MHz)
combined (both chains)



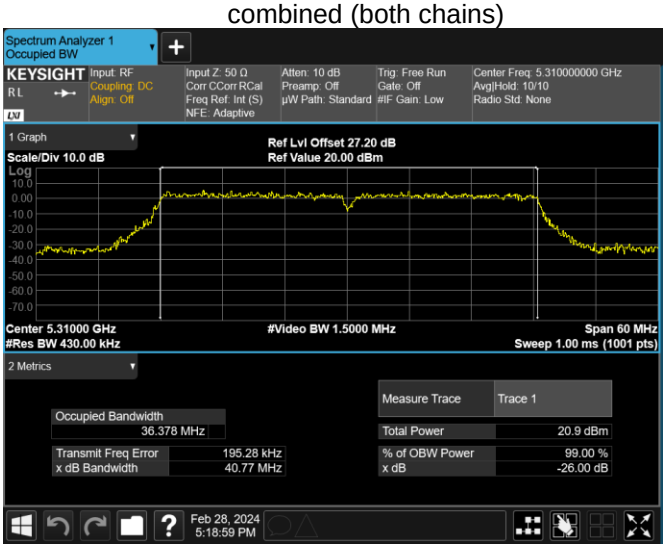
High Channel – 802.11ac20, (5320MHz)
combined (both chains)



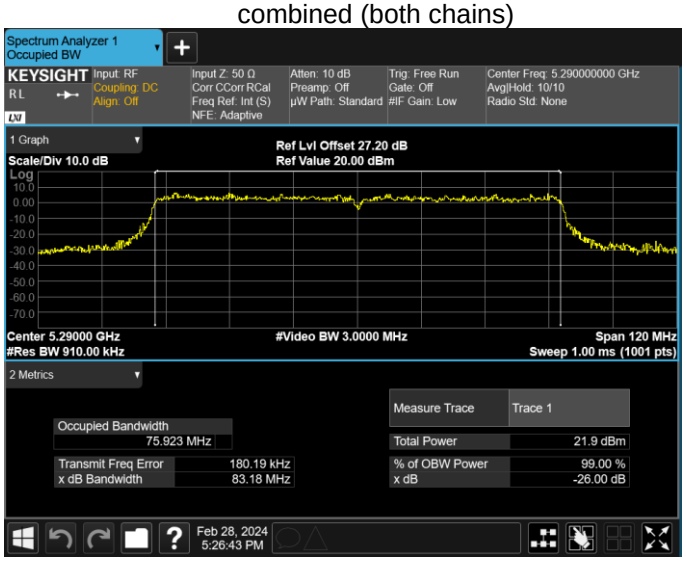
Low Channel – 802.11ac40, (5270MHz)
combined (both chains)



High Channel – 802.11ac40, (5310MHz)
combined (both chains)



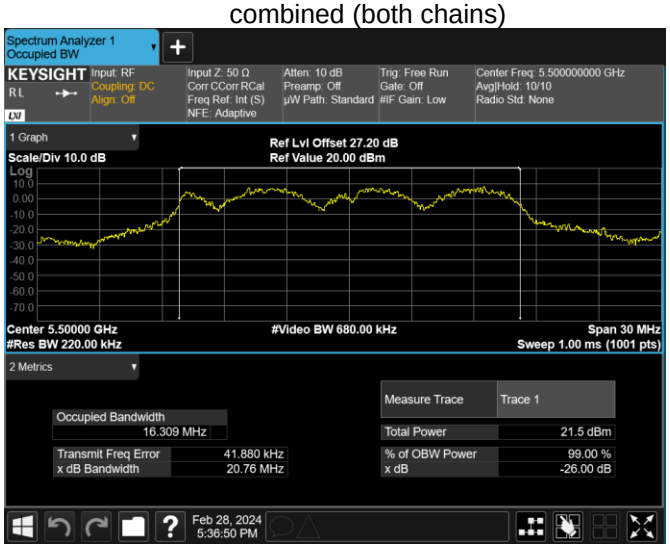
Mid Channel – 802.11ac80, (5290MHz)
combined (both chains)



UNII2c:

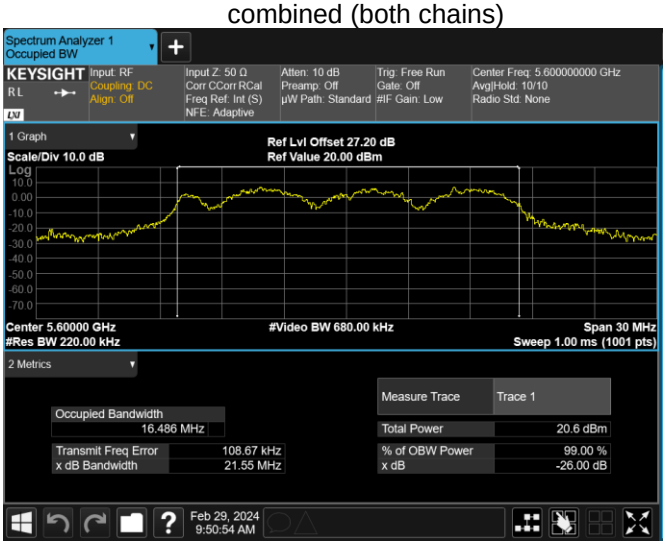
Low Channel – 802.11a NOHT, (5500MHz)

combined (both chains)

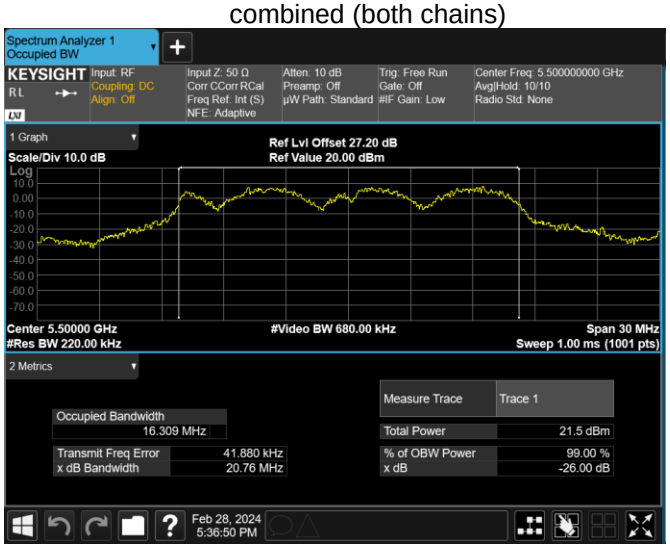


Mid Channel – 802.11a NOHT, (5600MHz)

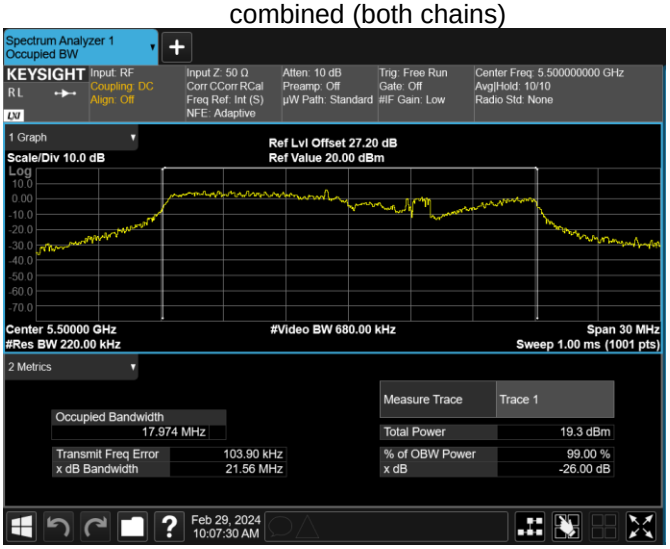
combined (both chains)



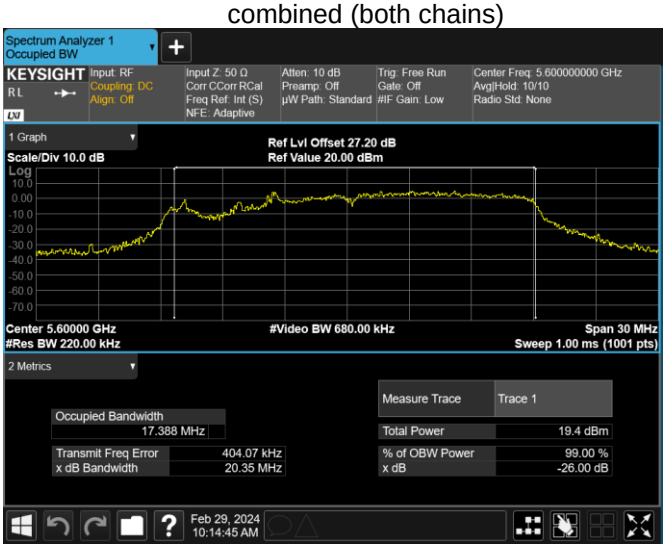
High Channel – 802.11a NOHT, (5700MHz)
combined (both chains)



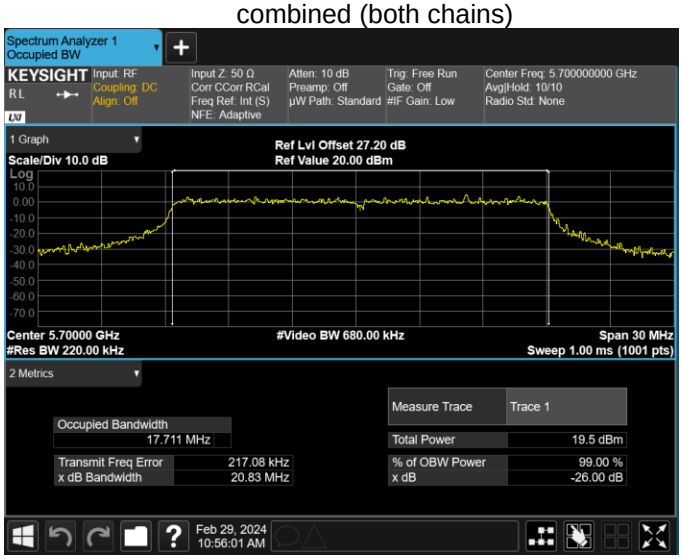
Low Channel – 802.11n20, (5500MHz)
combined (both chains)



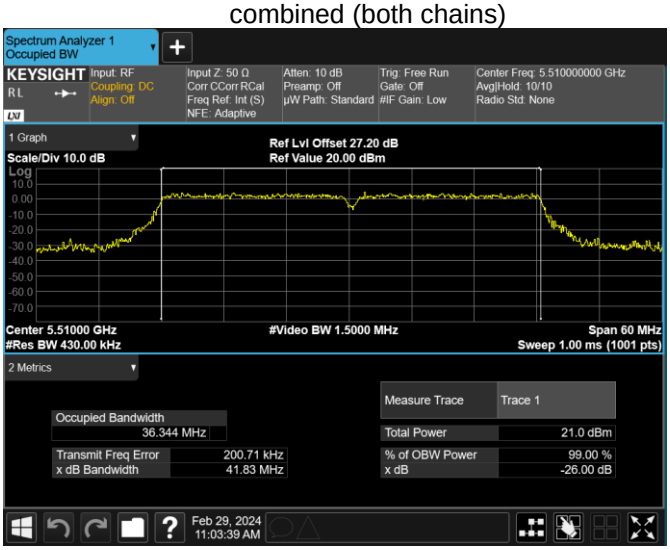
Mid Channel – 802.11n20, (5600MHz)
combined (both chains)



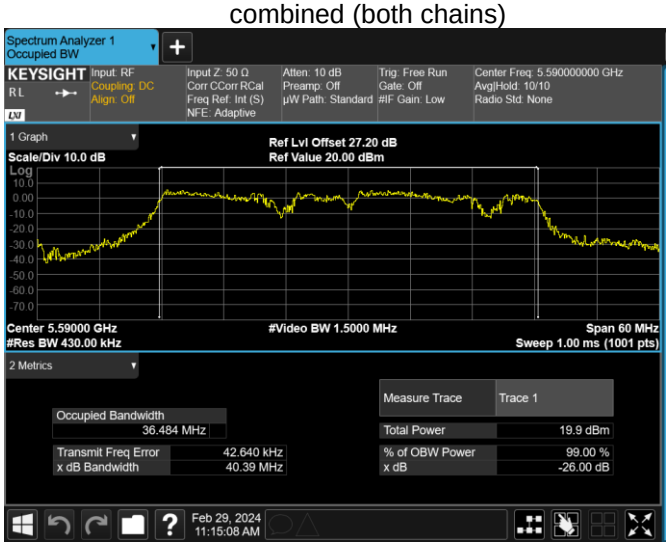
High Channel – 802.11n20, (5700MHz)
combined (both chains)



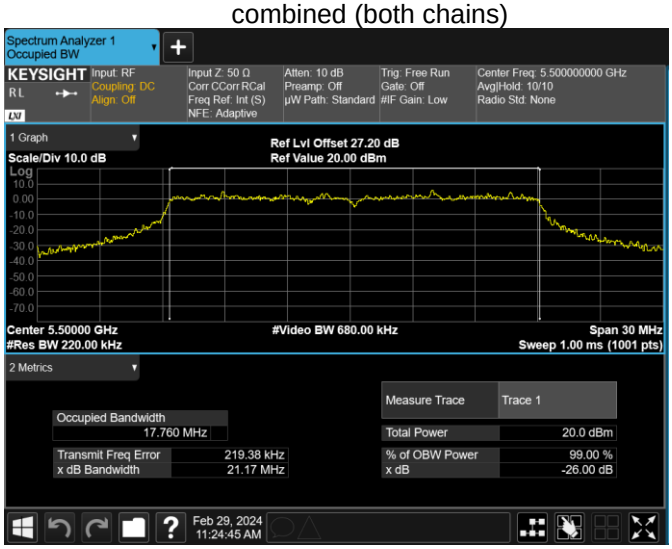
Low Channel – 802.11n40, (5510MHz)
combined (both chains)



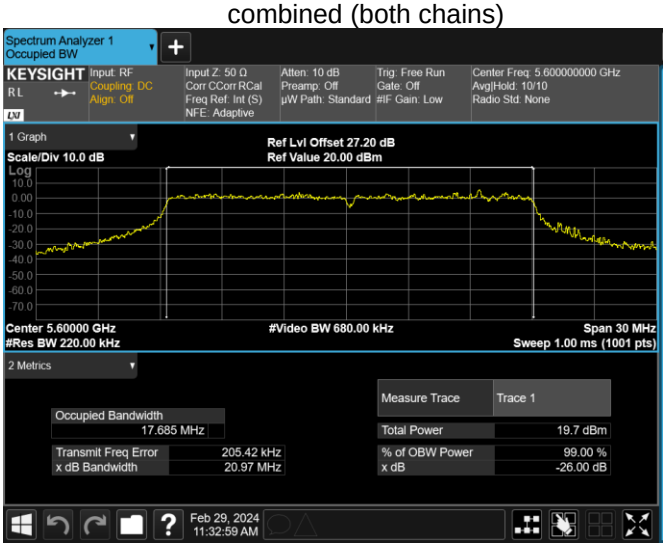
High Channel – 802.11n40, (5590MHz)
combined (both chains)



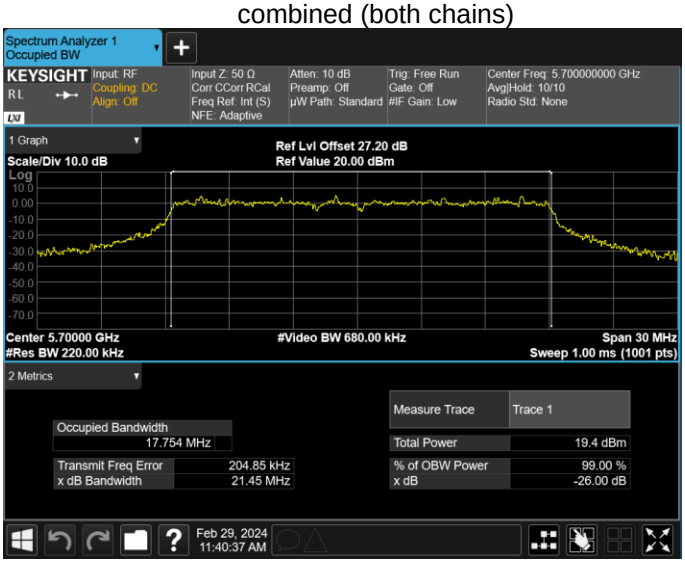
Low Channel – 802.11ac20, (5500MHz)
combined (both chains)



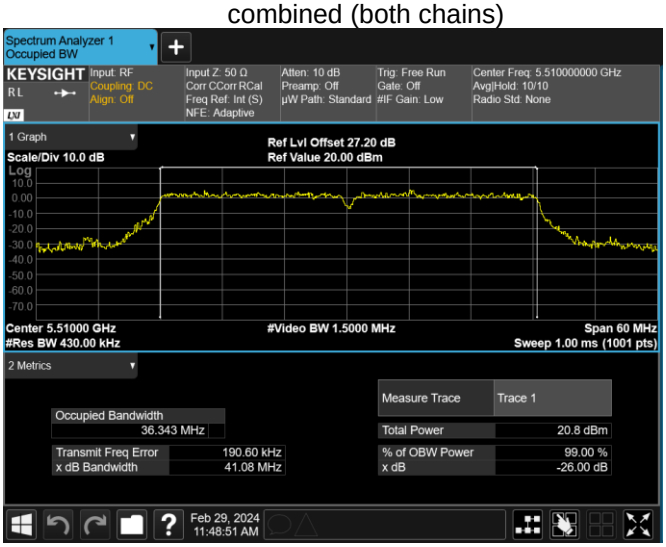
Mid Channel – 802.11ac20, (5600MHz)
combined (both chains)



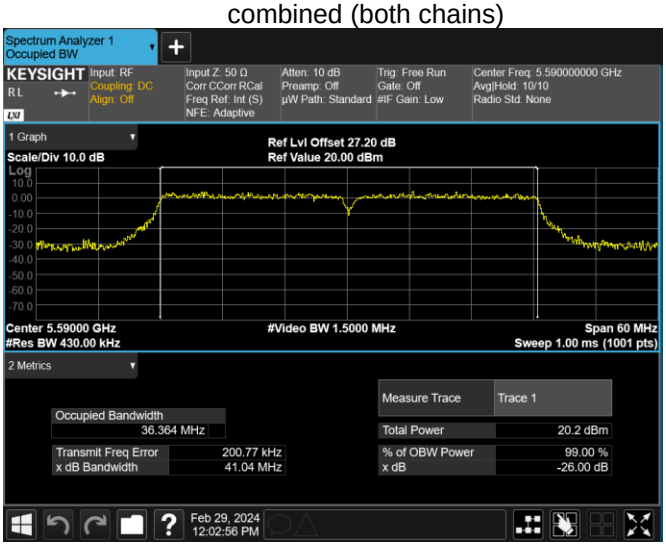
High Channel – 802.11ac20, (5700MHz)
combined (both chains)



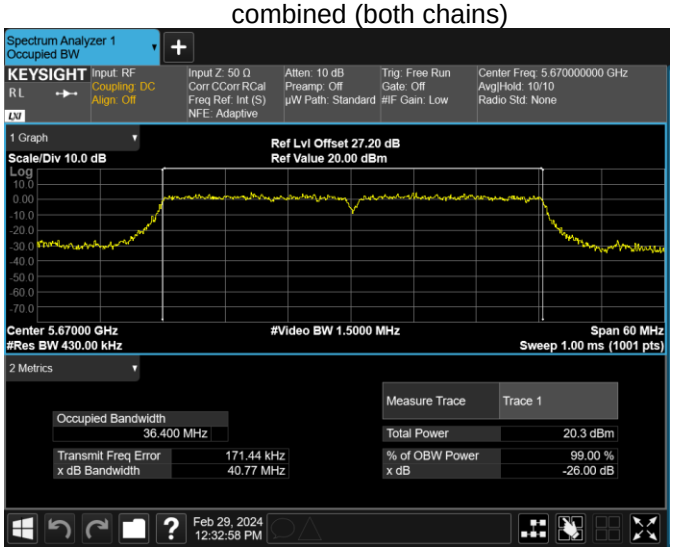
Low Channel – 802.11ac40, (5510MHz)
combined (both chains)



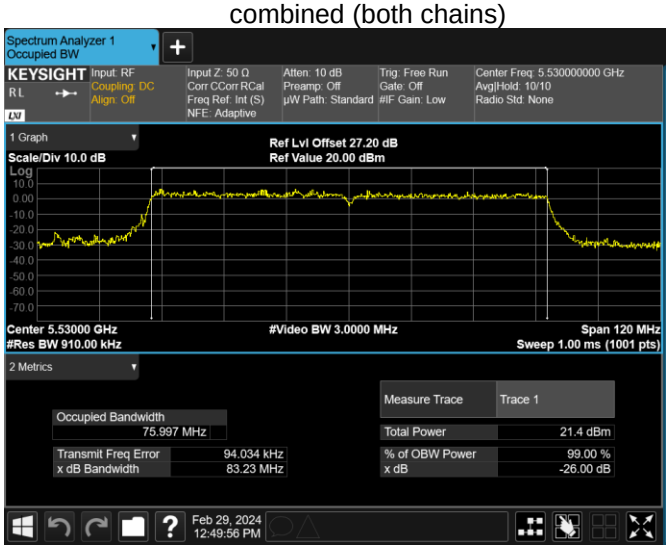
Mid Channel – 802.11ac40, (5590MHz)
combined (both chains)



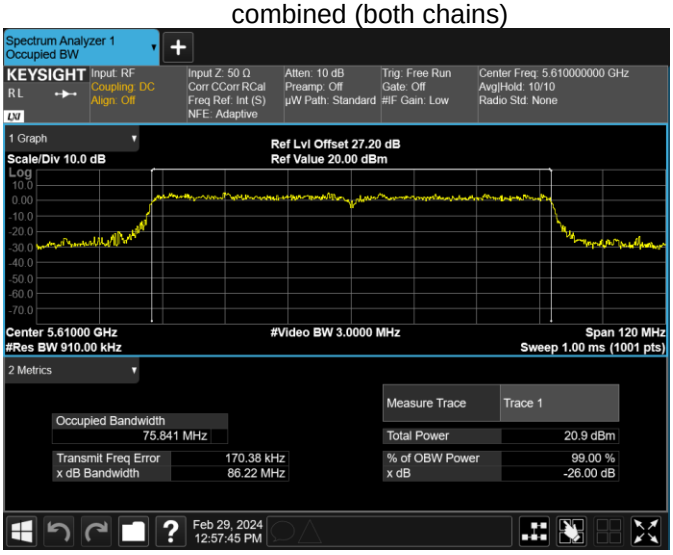
High Channel – 802.11ac40, (5670MHz)
combined (both chains)



Low Channel – 802.11ac80, (5530MHz)
combined (both chains)



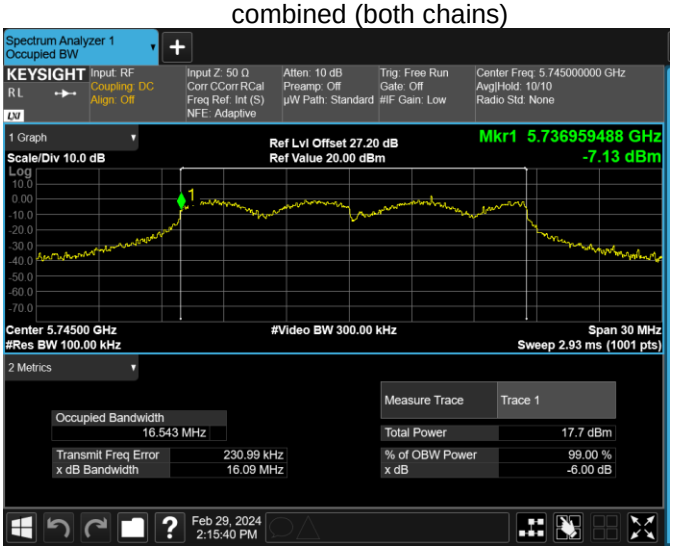
High Channel – 802.11ac80, (5610MHz)
combined (both chains)



UNII3:

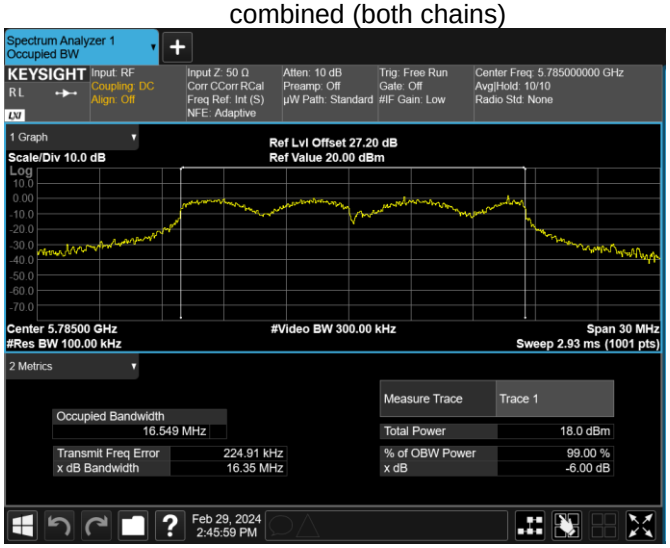
Low Channel – 802.11a NOHT, (5745MHz)

combined (both chains)

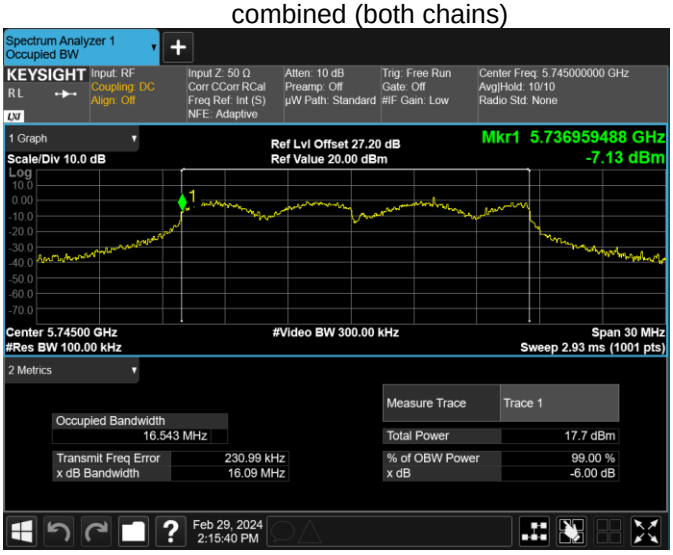


Mid Channel – 802.11a NOHT, (5785MHz)

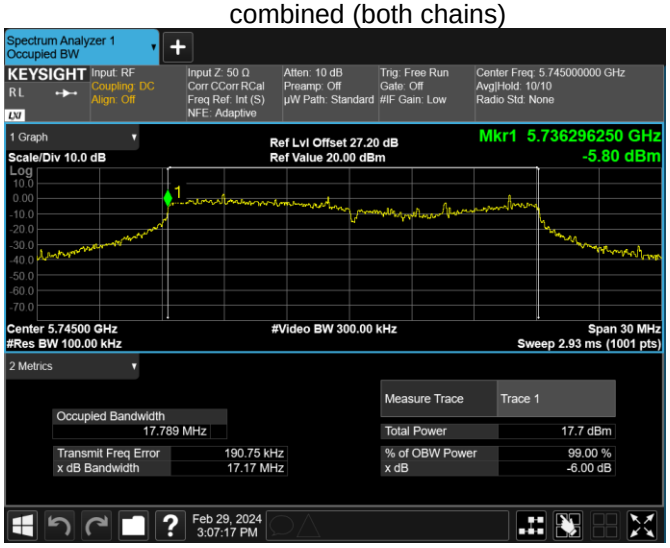
combined (both chains)



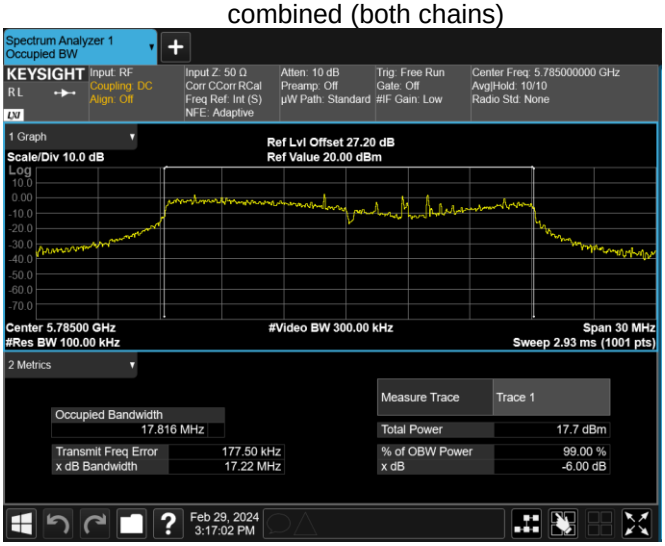
High Channel – 802.11a NOHT, (5825MHz)
combined (both chains)



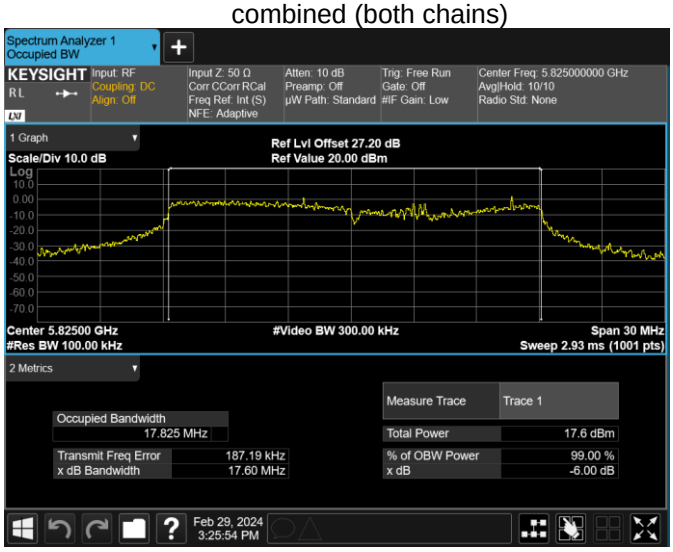
Low Channel – 802.11n20, (5745MHz)
combined (both chains)



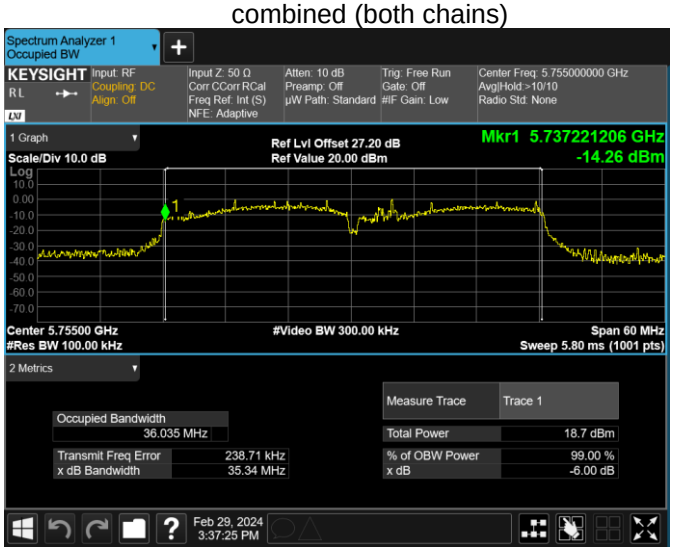
Mid Channel – 802.11n20, (5785MHz)
combined (both chains)



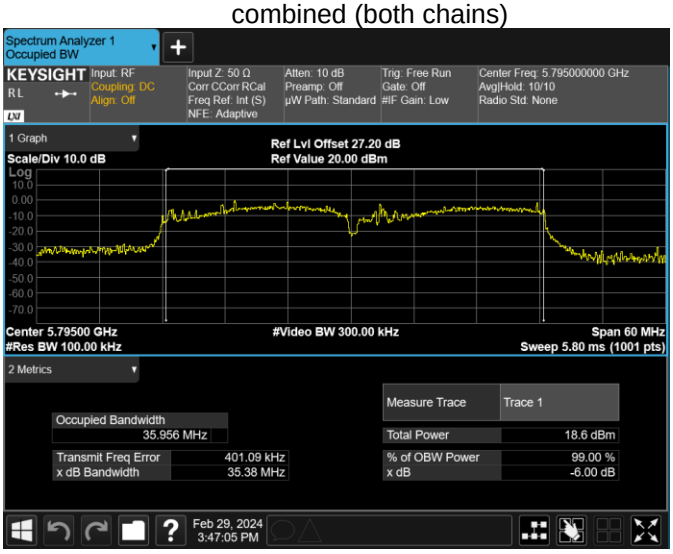
High Channel – 802.11n20, (5825MHz)
combined (both chains)



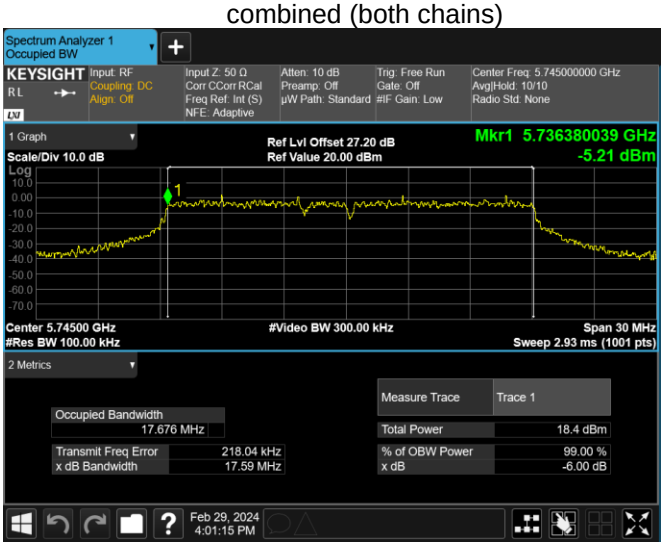
Low Channel – 802.11n40, (5755MHz)
combined (both chains)



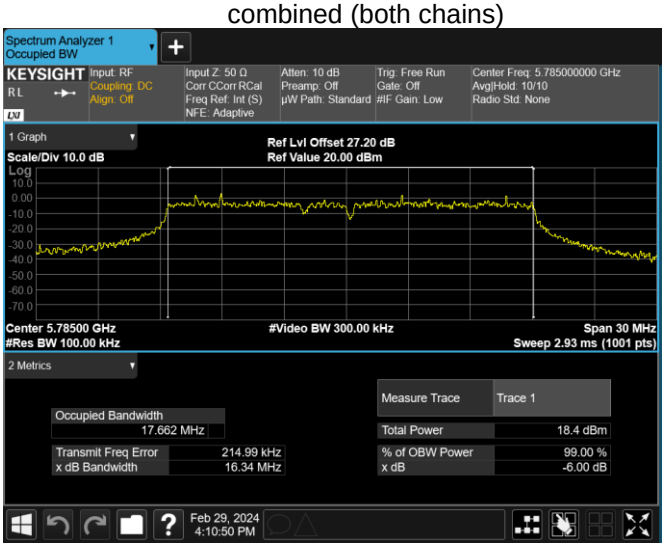
High Channel – 802.11n40, (5795MHz)
combined (both chains)



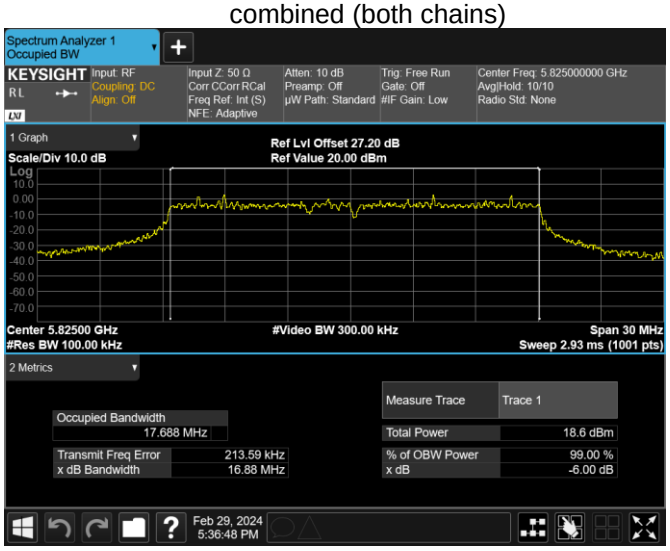
Low Channel – 802.11ac20, (5745MHz)
combined (both chains)



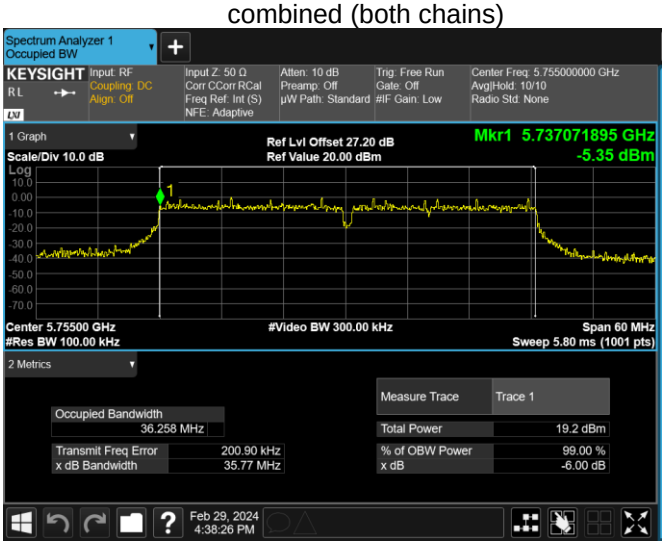
Mid Channel – 802.11ac20, (5785MHz)
combined (both chains)



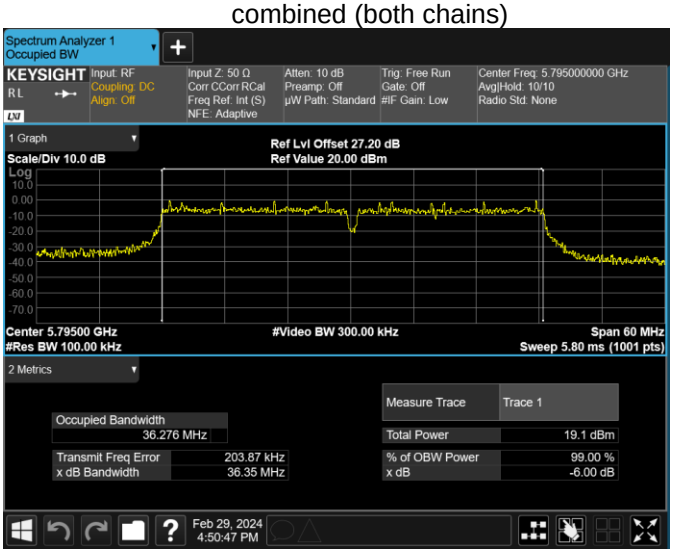
High Channel – 802.11ac20, (5825MHz)
combined (both chains)



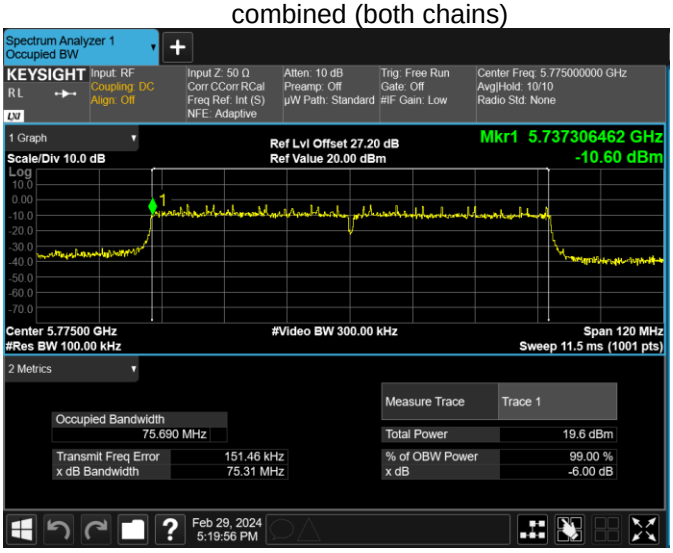
Low Channel – 802.11ac40, (5755MHz)
combined (both chains)



High Channel – 802.11ac40, (5795MHz)
combined (both chains)



Mid Channel – 802.11ac80, (5775MHz)
combined (both chains)



4 Conducted Output Power

4.1 *Test Result*

Test Description	Test Specification	Test Result
Conducted Output Power	15.407 (1)(2)(3)	Compliant

4.2 *Test Method*

The test data was measured using a power meter with Peak and Average detector.

Duty cycle was measured using a spectrum analyzer. Average detector data was compensated with the duty cycle correction factor.

Limit
24 dBm (UNII1, UNII2a, UNII2c)
30 dBm (UNII3)

4.3 *Test Site*

EMC Laboratory, San Diego, CA

Environmental Conditions

Temperature: 12.7 -27.9 °C
Relative Humidity: 27 – 64 %

4.4 *Test Equipment*

Test End Date: Jan. 30 – Feb. 23, 2024 Tester: Minsung Kang

Asset No.	Type of Equipment	Model	Serial No.	Manufacturer	Cal Date	Cal Due Date
Conducted Testing						
2013	Power Meter	N1911A	MY62310007	Keysight	01/29/2024	01/29/2025
2015	Wideband Power Sensor	N1921A	MY62220017	Keysight	01/29/2024	01/29/2025
-	Test Software	Radio Test Software	v.23	SGS Taiwan	N/A	-
2036	Temp/Humidity Data Logger	GSP-8	CMA231100002	Elitech	05/24/2023	

4.5 *Test Setup Photographs*

Test setup photographs are located in a separate exhibit.

4.6 *Duty Cycle Test Data*

UNII 1

Antennas Combined							
Mode	**Power Level**	**Data Rate (Mbps)/**	**Frequency (MHz)**	**T_on (ms)**	**T_on + T_off (ms)**	**Duty Cycle (%)**	**Duty Cycle Correction Factor (dB)**
802.11a NOHT	15	18	5180	0.704	0.74	95.14	0.22
	15	18	5200	0.704	0.74	95.14	0.22
	15	9	5240	1.384	1.42	97.46	0.11
802.11 n20	15	mcs0	5180	1.924	1.96	98.16	0.00
	15	mcs0	5200	1.924	1.96	98.16	0.00
	15	mcs0	5240	1.924	1.96	98.16	0.00
802.11 n40	13	mcs8	5190	0.496	0.532	93.23	0.30
	13	mcs2	5230	0.356	0.392	90.96	0.41
802.11 ac20	15	mcs3	5180	0.284	0.32	88.75	0.52
	15	mcs0	5200	0.99	1.028	96.3	0.16
	15	mcs0	5240	0.992	1.028	96.5	0.15
802.11 ac40	13	mcs0	5190	0.5	0.536	93.28	0.30
	13	mcs0	5230	0.502	0.536	93.66	0.28
802.11 ac80	13	mcs0	5210	0.256	0.292	87.67	0.57