ALION

MEASUREMENT REPORT

AMT INTERFERENCE CHARACTERIZATION AT EDWARDS AIR FORCE BASE

Prepared for

Edwards Air Force Base - 412th Test Wing
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307 E. Popson Ave
Edwards AFB, CA 93521

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Alion Science & Technology has characterized the emissions of two AT&T Long Term Evolution sites, just outside of Edwards Air Force Base, California. The nearest AT&T site was suspected of causing interference with the local Air Force's Aeronautical Mobile Telemetry system. Radio frequency emissions were measured at the Aeronautical Mobile Telemetry system site. Recorded radio frequency emissions data was used to recommend improvements to the Air Force system's front-end components, to mitigate both existing and future interference caused by commercial operations in neighboring frequency bands.

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GLOSSARY

3GPP	3rd Generation Partnership Project
AC	Alternating Current
ACU	Antenna Control Unit
AFB	Air Force Base
AMT	Aeronautical Mobile Telemetry
AWS-3	Advanced Wireless Services 3
AWS-4	Advanced Wireless Services 4
B4795	Building 4795
CW	Continuous Wave
DANL	Displayed Average Noise Level
FCC	Federal Communications Commission
GPS	Geospatial Positioning System
GUI	Graphical User Interface
LHCP	Left Hand Circular Polarized
LTE	Long Term Evolution
LTE-A	Long Term Evolution Advanced
NTIA	National Telecommunications and Information Administration
OOB	Out of Band
RF	Radio Frequency
RSA	Real-time Spectrum Analyzer
RSL	Received Signal Level
S1	Site 1
S2	Site 2
SNR	Signal-to-Noise Ratio
WCS	Wireless Communication Services

1.0 INTRODUCTION

1.1 BACKGROUND

In June of 2010, the President of the United States signed a memorandum calling for the National Telecommunications and Information Administration (NTIA), in collaboration with the Federal Communications Commission (FCC), to make 500 MHz of spectrum newly available for fixed and mobile wireless broadband by 2020 as part of the National Broadband Plan. After considerable negotiations among spectrum regulators, members of the commercial wireless industry, and representatives from affected federal agencies, the FCC identified 1695-1710, 1755-1780, and 2155-2180 MHz as Advanced Wireless Services-3 (AWS-3) frequency bands to be licensed by auction for fixed and mobile broadband commercial wireless services. The bands 1695-1710 and 1755-1780 MHz, formerly allocated for federal primary use only, were reallocated to include non-federal primary fixed and mobile use.

The reallocation of the AWS-3 bands required that certain federal incumbent operations in the bands relocate to alternative spectrum or cease operations. The FCC AWS-3 Report & Order stipulated a transition period to allow federal operations currently in an AWS-3 band, to transition out of the band as commercial wireless services deployed. It is expected that the 3rd Generation Partnership Project (3GPP) Long Term Evolution Advanced (LTE-A) cellular technology will be the predominant wireless technology deployed in AWS-3 frequency bands. To accommodate the deployment of commercial systems utilizing AWS-3 uplink spectrum, Air Force Aeronautical Mobile Telemetry (AMT) operations have begun the relocation out of 1755-1780 MHz into several other bands including the 2200-2290 MHz and 2360-2395 MHz bands[1].

A recent pre-deployment LTE-A site-loading test performed by AT&T in close proximity to Edwards Air Force Base (AFB) caused interference to AF AMT operations. AT&T confirmed with Edwards AFB personnel that site-loading tests in the 2160-2170 MHz AWS-3 downlink band were performed on the date and time of the suspected interference. Informal observations of received signal levels (RSL) during the site-loading test indicated that existing AMT radio frequency (RF) front-end filters would not adequately protect AMT operations in the 2200-2290 MHz and 2360-2395 MHz bands once the AT&T AWS-3 site became operational. Further, there is the potential for additional interference from future commercial wireless services deployments within the adjacent 2180-2200 MHz Advanced Wireless Services-4 (AWS-4) band. Finally, RF front-end overload of AMT receivers is not the only interference mechanism of concern. Certain antenna coupling configurations and proximate antenna locations

[1] During a teleconference on Dec 12, 2019, Edwards AFB personnel stated that the AMT frequency bands of operation targeted for indefinite use are 1435-1525 MHz, 1780-1850 MHz, 2200-2290 MHz and 2360-2395 MHz.

increase the likelihood that the out-of-band (OOB) emissions from AWS base stations may cause small-signal interference to AMT receivers, resulting in receiver desensitization. As the occurrence of both the RF front-end overload and OOB small-signal interference mechanisms are possible, further investigation was required to determine the contribution of each to the problems experienced by Edwards AFB AMT operations. The results of the investigation will support future mitigation approaches required for each interference mechanism, as improving the RF front-end performance may not solve OOB small-signal problems.

1.2 OBJECTIVE

The primary objective of this measurement effort was to characterize fundamental and OOB RF emissions of AWS-3 and Wireless Communication Services (WCS) band operations, over a span of 2155-2440 MHz, to provide information pertinent to the RF front-end filtering design requirements to mitigate potential interference to AMT receiver systems operating in the 2200-2290 and 2360-2395 MHz bands. The secondary objective of this measurement was to characterize the radiation pattern of the AMT system's dish antenna, known as Antenna 5, at Edwards AFB to enable more accurate signal-level analysis of AMT receiver system operation.

1.3 APPROACH

A nominal representation of the frequency response of the existing AMT RF front-end at Edwards AFB is shown in Figure 1[2]. Signals incident on the AMT RF front-end, radiated in the 2155-2180 MHz AWS-3 and 2180-2200 MHz AWS-4 bands, are attenuated at approximately 1 to 6 dB, compared to the 1dB attenuation across the 2200-2400 MHz passband. Alion Science & Technology conducted a series of measurements to characterize two RF emission sources suspected of interfering with AMT operations in 2200-2290 MHz, namely an LTE-A downlink services transmitter in the AWS-3 band and broadband a fixed/mobile services transmitter in the WCS band. Alion worked with Edwards AFB AMT personnel to coordinate AWS-3 (2160-2170 MHz) and WCS (2345-2360 MHz) band measurements from two AT&T sites operated nearest the boundaries of the base.

[2] Temple, Kenneth F. "Re: Edwards Antenna Information." Message to Eric Germann. 4 Oct 2018. E-mail; the Alion team plotted the frequency response by interpolating between data points provided by Edwards AFB personnel as the exact nature of the frequency response across the span indicated is unknown to the Alion team.

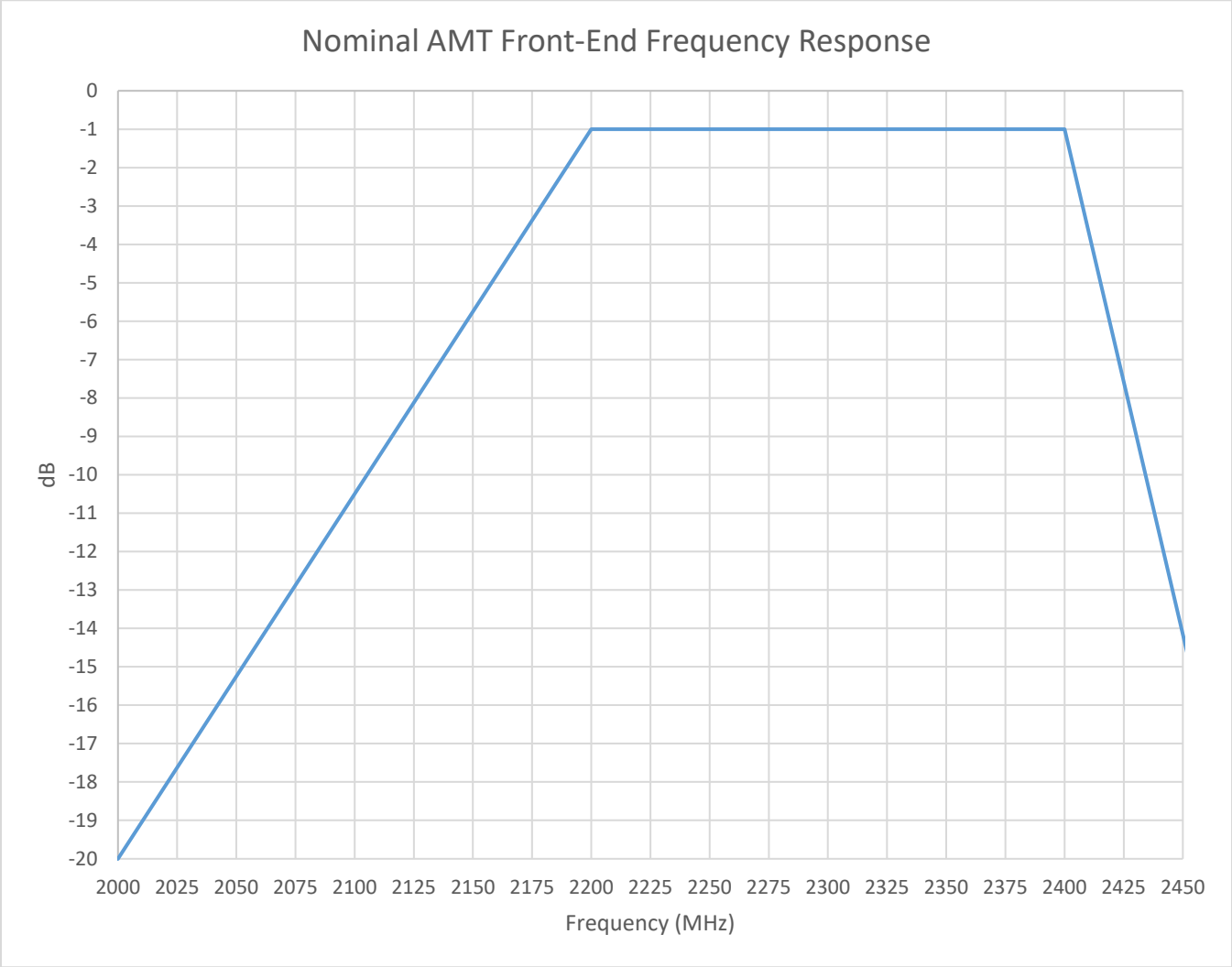

Figure 1. Nominal representation of the AMT front-end RF filter frequency response

1.3.1 AWS-3, WCS & 2200-2290 MHz BAND MEASUREMENT APPROACH

The characterization of the AWS-3 downlink LTE-A and WCS emissions was performed by deploying a spectrum monitoring system at the victim AMT site in Building 4795 (B4795), henceforth referred to as the AMT spectrum monitoring system. The deployed spectrum monitoring system was connected to a feed from the AMT receiver chain, set to continuously record spectral data in a 2155-2440 MHz frequency span, and enabled RSL recording with respect to the overall system gain of the AMT receive system. The frequency span selected for spectrum monitoring enabled the capture of the fundamental and OOB RF emissions originating within the AT&T LTE-A channel (2160-2170 MHz), the AT&T WCS channel (2345-2360 MHz), and the AMT system's bands of operation (2200-2290 and 2360-2395 MHz) as detailed in Figure 2.

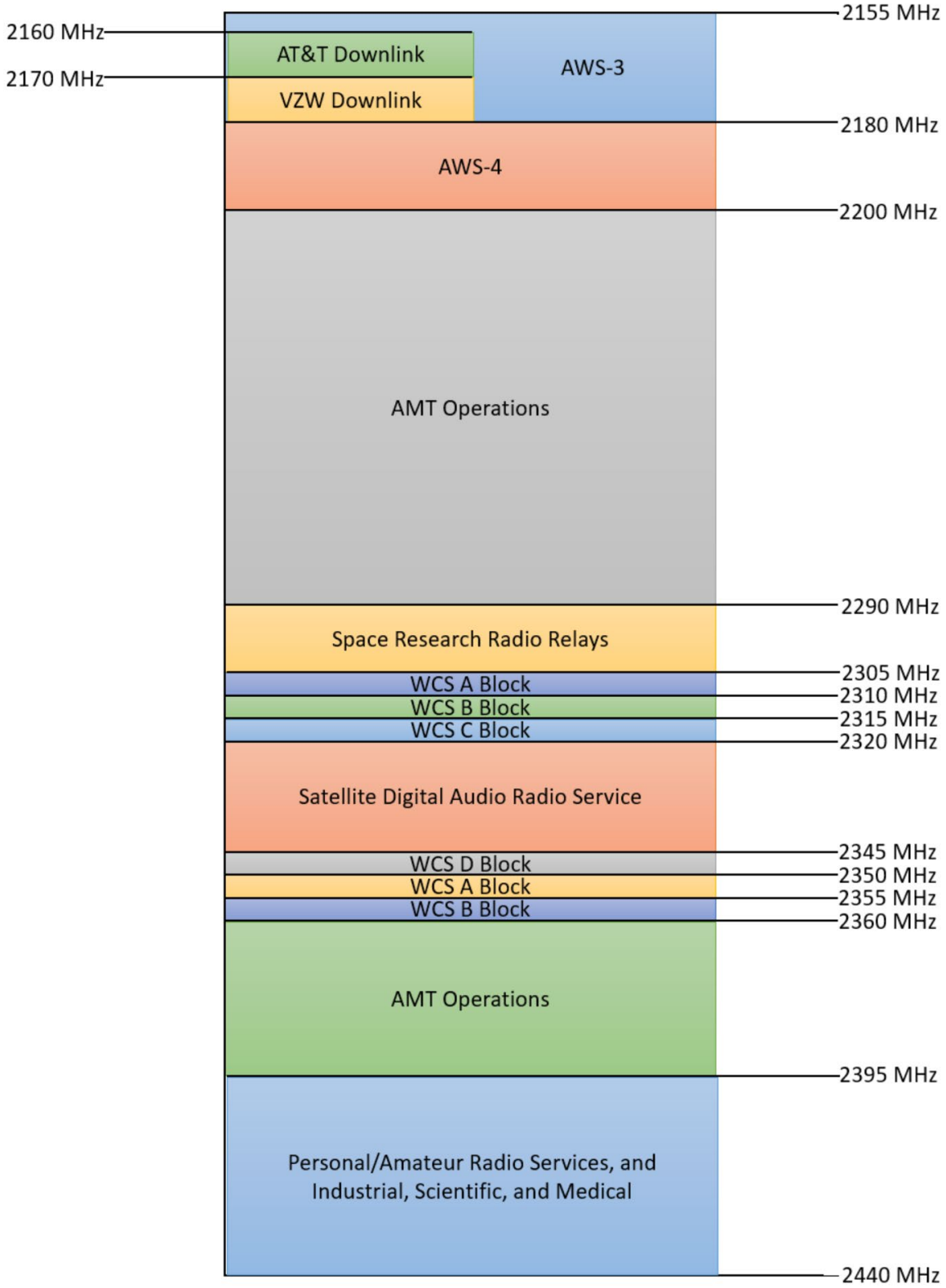

Figure 2. AMT operations in 2200-2290 and 2360-2395 MHz bands with neighboring radio services[3]

[3] During this measurement effort, AT&T also temporarily utilized the 2170-2180 MHz AWS-4 band.

Long-Term-Evolution (LTE) characterization focused on two AT&T LTE sites, close to Antenna 5's location. The nearest site, suspected to be the primary source of interference, shall be referred to as site 1 (S1). The further site, to be observed for comparative analysis purposes, shall be referred to as site 2 (S2). Details regarding the two LTE sites of interest are further discussed in Section 2.3, with depictions of their locations. An initial 24-hour RF environment measurement was performed to evaluate the persistence of interference while Antenna 5 was pointed directly at S1.

Additional measurements were performed under various scenarios involving: changes to the pointing angle of Antenna 5, toggling of the AMT feed between a high-gain and low-gain antenna, and temporary deactivation of specific AT&T band activity (discussed in Section 3.2). These scenarios were achieved through coordinated support from both AMT and AT&T personnel. The various measurement scenarios were selected in an attempt to identify the primary source of AMT interference. Analysis of the spectral data captured from each site was then used to evaluate the impact of AT&T AWS-3 LTE-A downlink and WCS band emissions on the AMT receiver system performance.

1.3.2 ANTENNA 5 CHARACTERIZATION MEASUREMENT APPROACH

Characterization of the Antenna 5 relative radiation pattern was performed via measurements of a continuous wave (CW) signal, transmitted from a directional horn antenna mounted on the boresight tower nearest B4795. To represent the 2200-2290 MHz and 2300-2395 MHz AMT bands, a CW center frequency of 2240 MHz and 2395 MHz, respectively was selected based on observed minimal spectrum usage. An Air Force signal generator was set to transmit a CW signal at an output power level of +20 dBm (not including cable loss or antenna gain) to provide adequate signal-to-noise (SNR) ratio while avoiding overdriving the front end of the AMT system. The AMT spectrum monitoring system used in LTE characterization measurements was also used to performed high-speed sampling of the RSL from the CW transmission. During the RSL sampling, Antenna 5 was rotated 360 degrees in azimuth, to measure different combinations of vertical and horizontal angles. At a rotational speed of 1 degree per second, elevation angles from range of -5 degrees to +5 degrees in 1-degree increments, relative to the antennas horizontal plane, were measured. Based on values of signal generator power, transmit antenna system gain, and calculated values of free-space path loss along the slant range distance, the Alion team normalized the measured values to represent the relative gain of the AMT receiver system. This was done with respect to the dish antenna input, at each vertical and horizontal pointing angle pair, to yield the relative antenna radiation pattern for Antenna 5. The Measured pattern will be used to support future analyses of signals received by the AMT system.

2.0 LTE CHARACTERIZATION MEASUREMENTS

2.1 MEASUREMENT SYSTEM

Alion deployed the AMT spectrum monitoring system in B4795 and connected the system's input to an RF output from the AMT receive system, which is connected to Antenna 5 through the AMT receiver chain. Figure 3 is a photo of Antenna 5, taken from a platform on top of B4795. Appendix A lists the provided specifications for Antenna 5. The spectrum monitoring system consisted of a software-defined, real-time spectrum analyzer (RSA), a test controller configured with proprietary software for control of the RSA, and an LTE router[4] to allow remote operation of the test controller. The RSA was connected to the AMT system using a ruggedized coaxial cable with N-type connectors. Power for each of these components was sourced from a local NEMA 5-15 alternating current (AC) outlet in B4795, nearest to the Antenna 5 AMT receiver equipment cabinet. Table 1 contains the general equipment list for the AMT spectrum monitoring system with additional component specifications presented in Appendix B. Figure 4 shows an equipment block diagram of the spectrum monitoring system. Figure 5 illustrates the compact physical setup, from a previous deployment, used for the spectrum monitoring system that interfaced to the AMT receive system in B4795.

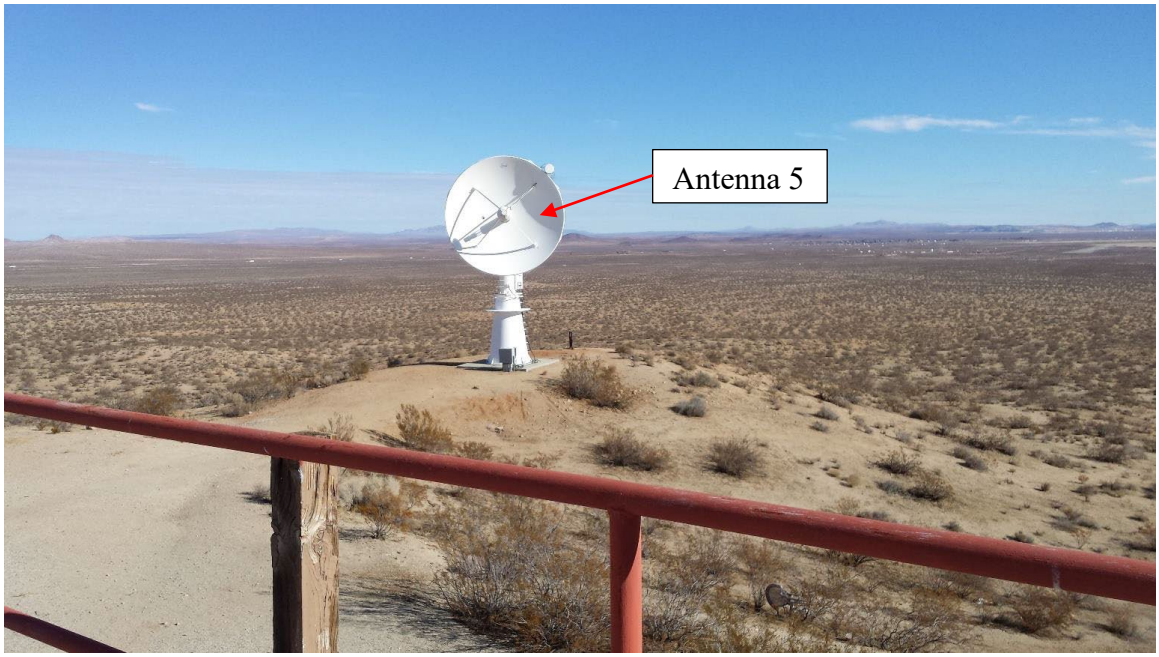

Figure 3. Antenna 5 viewed from platform on B4795

[4] The LTE router was band locked to only operate on 700 MHz Verizon Wireless band and the internal WiFi radio was disabled.

Table 1. General equipment list for the AMT spectrum monitoring system

Component Description	Manufacturer	Model
RSA	Tektronix	RSA507A
Test Controller	NUC	NUC8i7BEH
LTE Router	Pepwave	MAX BR1
Coaxial Cable	Megaphase	F520 Warrior

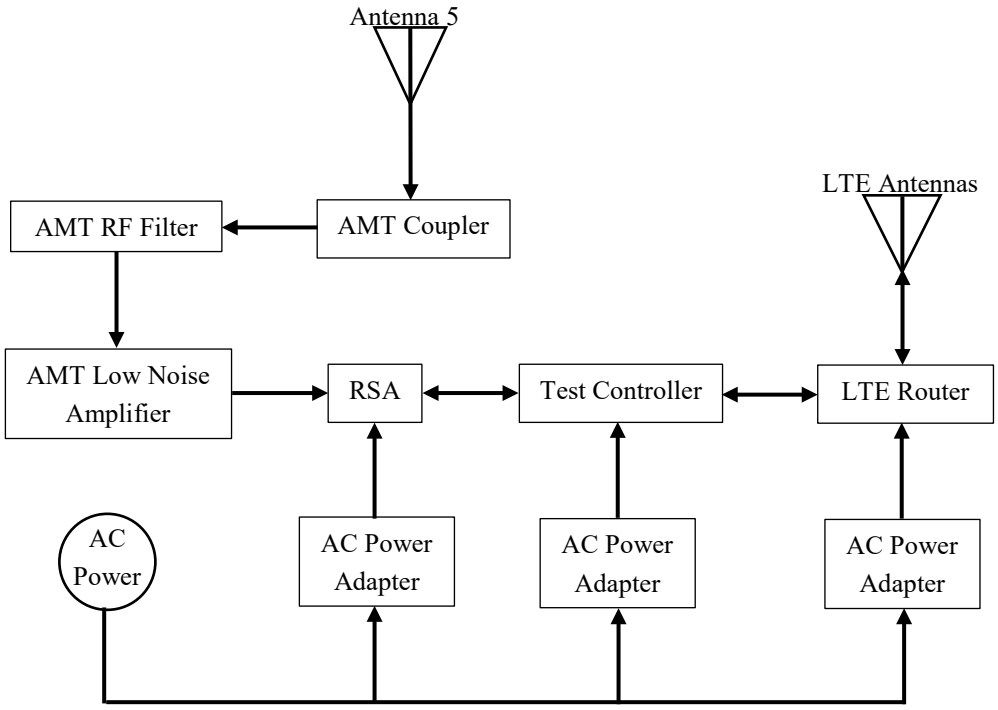

Figure 4. AMT spectrum monitoring system block diagram

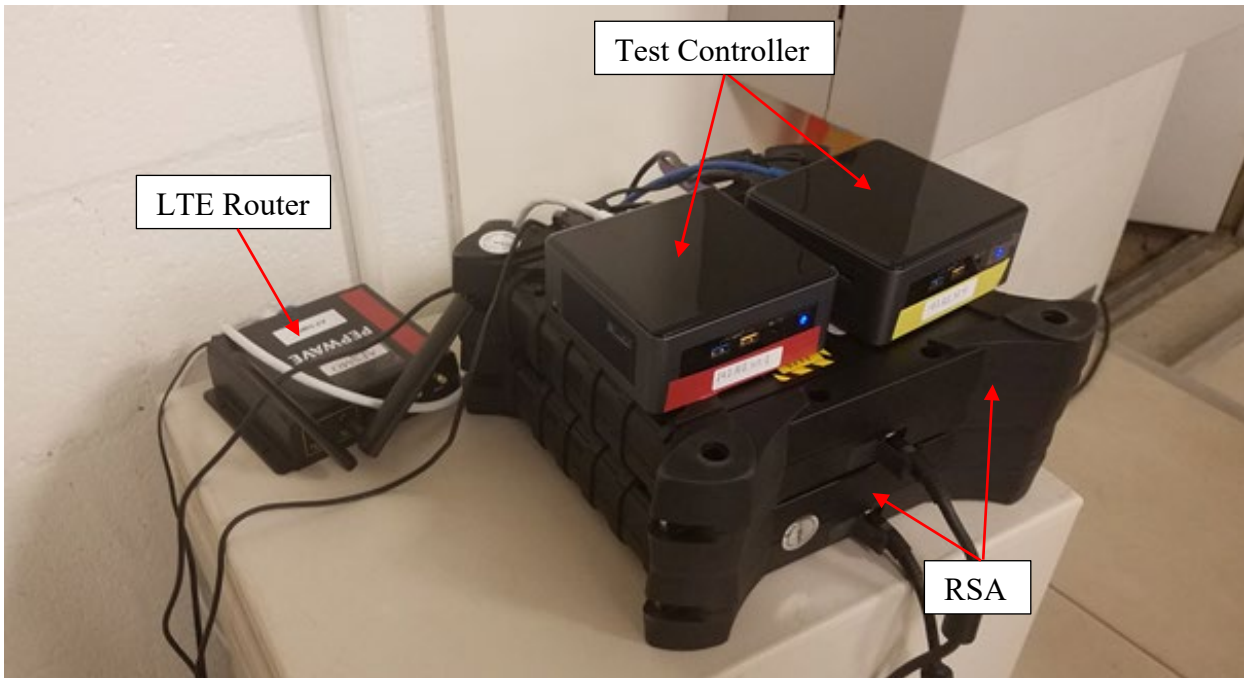

Figure 5. Representative Alion spectrum monitoring system as previously deployed

2.2 MEASUREMENT SOFTWARE

The Alion team developed and deployed proprietary software, using LabVIEW, to enable the high-speed capture of raw RF spectrum data utilizing a Tektronix RSA-series spectrum analyzer. The software allows a user to configure RSA capture settings by either a manual input, or a configuration (.ini) file upload. Techniques such as parallel processing loops and binary data storage maximized data capture speeds. Several indicators and a live-trace capture display allows for monitoring of the measurement and the ability to quickly verify proper system operation. Figure 6 shows a screenshot of the software's graphical user interface (GUI).

Figure 6. Screenshot of measurement software GUI

2.3 MEASUREMENT LOCATIONS

Coordinating with AT&T, the two nearest towers to the AMT receiver were selected for measurements. Preliminary geospatial analysis, using Google Earth software, determined the approximate distance between Antenna 5 and the two AT&T sites based on their global positioning system (GPS) coordinates as listed in Table 2. For S1, a distance of 10.15 kilometers (6.31 miles) was calculated , with no terrain blockages, as shown in Figure 7. S2 was calculated to be 17.2 kilometers (11 miles) from Antenna 5, without a direct line of sight as shown in Figure 8. The AMT spectrum monitoring system was deployed in B4795 nearest to Antenna 5, as satellite imagery shows in Figure 9.

Table 2. Measurement location GPS coordinates

Location	Coordinates (Latitude, Longitude)
Antenna 5	34° 58'14.67"N, 117° 55'52.03"W
AT&T Site 1	35° 02'16.90"N, 118° 00'21.40"W
AT&T Site 2	35° 07'39.96"N, 117° 57'31.65"W

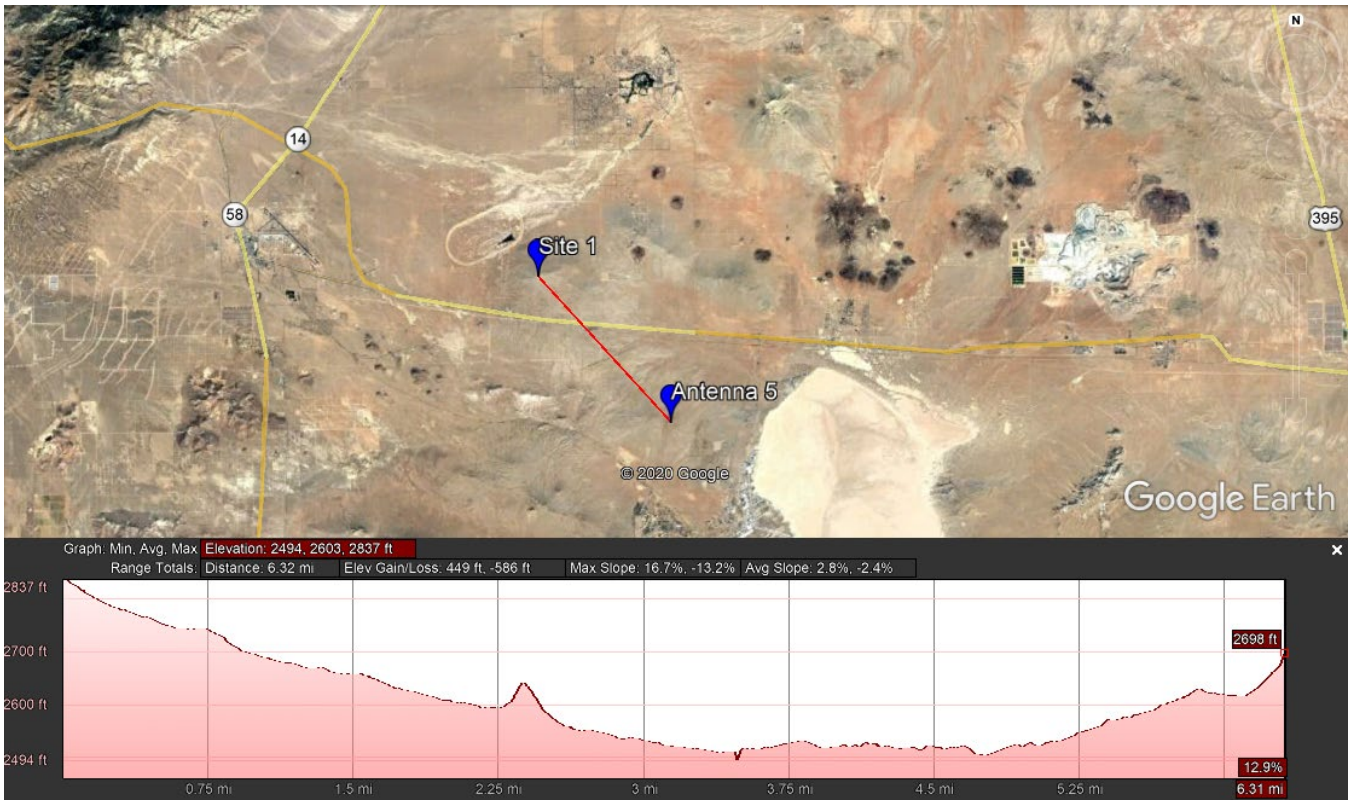

Figure 7. Screenshot of Google Earth path analysis from S1 to Antenna 5

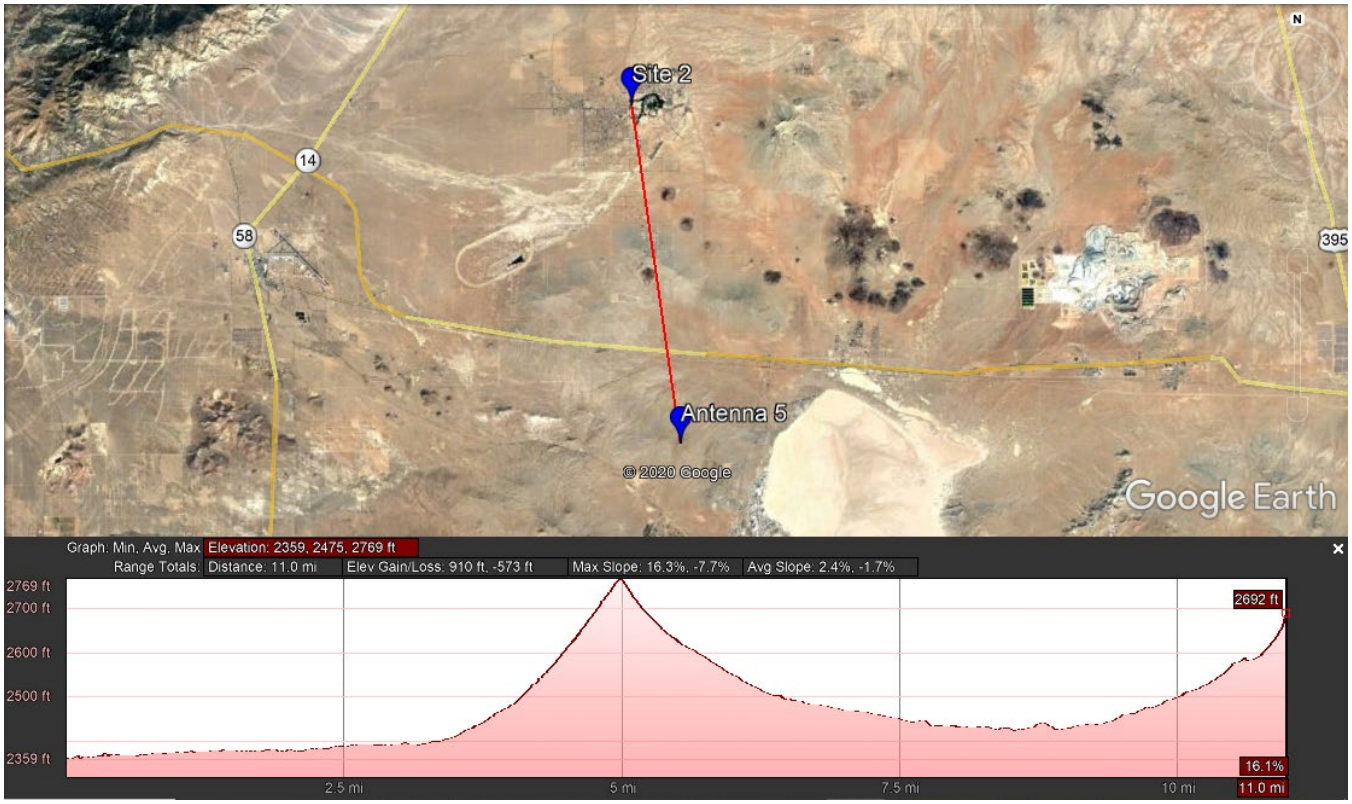

Figure 8. Screenshot of Google Earth path analysis from S1 to Antenna 5

Figure 9. Screenshot of Google Earth indicators for proximity of Antenna 5 and B4795

2.4 MEASUREMENT PROCEDURES

2.4.1 24-HOUR RF ENVIRONMENT MEASUREMENT

1. Apply power to the Alion AMT spectrum monitoring system and allow 2 minutes for the test controller to fully boot up.
2. Connect the spectrum monitoring system to the AMT receive system's left-hand circular polarized (LHCP) RF output via coaxial cable.
3. Power on Antenna 5's front-end components and aim the antenna in the approximate direction of the AT&T site of interest.
4. Access the system's test controller and open the LabVIEW-based Alion spectrum monitoring software via desktop shortcut.
5. Configure the Alion software using the settings listed in Table 3.
6. Coordinate with AMT operating personnel to orient the dish in the direction of S1.
7. Click the Alion software's START button and allow the software to run for a 24-hour period.
8. Upon completion of measurements, click the Alion software's STOP button, and wait five seconds to allow the software to complete operation.

Table 3. RSA settings for 24-hour RF environment measurement

Parameter	Value
Center Frequency	2.2975 GHz
Span	285 MHz
Number of Points	3,001
Resolution Bandwidth	100 kHz
Video Bandwidth	1 kHz
Attenuation	0 dB
Reference Level	-30 dBm
Preamp	Enable
Detector Type	Positive Peak

2.4.2 SCENARIO INTERFERENCE MEASUREMENTS

1. Apply power to the Alion AMT spectrum monitoring system and allow 2 minutes for the test controller to fully boot up.
2. Connect the spectrum monitoring system to the AMT receive system's LHCP RF output via coaxial cable.
3. Power on Antenna 5's front-end components and aim the antenna in the approximate direction of the AT&T site of interest.
4. Access the system's test controller and open the LabVIEW-based Alion spectrum monitoring software via desktop shortcut.
5. Configure the Alion software using the settings listed in Table 4.
6. Coordinate with both AMT and AT&T operating personnel to configure their systems for Scenario 1, listed in Table 5.
7. Click the Alion software's START button and allow the software to run for at least 1 minute.
8. Click the Alion software's STOP button and wait a few moments to allow the software to complete operation.
9. Repeat Steps 6 through 8 for the remaining measurement scenarios listed in Table 7.

Table 4. RSA settings for scenario interference measurements

Parameter	Value
Center Frequency	2.2975 GHz
Span	285 MHz
Number of Points	30,001
Resolution Bandwidth	10 kHz
Video Bandwidth	1 kHz

Attenuation	0 dB
Reference Level	-30 dBm
Preamp	Enable
Detector Type	Positive Peak

2.4.3 ANTENNA 5 RADIATION PATTERN CHARACTERIZATION

1. Apply power to the Alion AMT spectrum monitoring system and allow 2 minutes for the test controller to fully boot up.
2. Connect the spectrum monitoring system to the AMT receive system's LHCP RF output via coaxial cable.
3. Turn on Antenna 5's front-end components and set the antenna to an elevation-pointing angle of -5 degrees, relative to the Antenna 5's horizontal plane, and a continuous azimuth rotational speed of 1 degree per second.
4. Verify there are no interfering signals in the environment near the CW measurement center frequencies of 2240 MHz and 2395 MHz. If an interfering signal is found, adjust the center frequencies as needed.
5. Connect a signal generator to the boresight tower horn antenna feed and configure it to transmit a CW signal with a center frequency of 2240 MHz, and power level of +20 dBm (relative to signal generator settings).
6. Activate the CW signal transmitter's signal generator output and verify that it is not overdriving the AMT receiver's front-end components. If Edwards AFB personnel observe that the signal overdrives the receiver's front-end, decrease power until it is no longer doing so.
7. Access the system's test controller and open its LabVIEW-based Alion spectrum monitoring software via desktop shortcut.
8. Configure the Alion software for measurement of a CW signal with a center frequency of 2240 MHz using the settings listed in Table 5.
9. While Antenna 5 is continuing to rotate, activate the logging function of the AMT antenna control unit (ACU) to record time-stamped azimuth and elevation pointing angle data.
10. Click the Alion software's START button to begin recording the time-stamped spectrum data for the duration of the measurement.
11. After Antenna 5 has performed a minimum 360-degree rotation at the set elevation angle, increase the elevation pointing angle by 2 degrees.
12. Repeat Step 11 until the antenna has performed a 360-degree azimuth rotation at each 2-degree increment, up to an elevation pointing angle of 10 degrees.
13. Complete the recording of the AMT system's ACU pointing angle logging software and export the data file.
14. Click the Alion software's STOP button to complete the current measurement.

15. Deactivate the CW signal transmitter's signal generator output.
16. Reconfigure the transmitter's signal generator for a CW with a center frequency of 2395 MHz, and power level of -20 dBm. Then repeat Step 6.
17. Reconfigure the Alion software for measurement of a CW signal with a center frequency of 2395 MHz using the settings listed in Table 6.
18. Repeat Steps 9 through 15 for the additional measurement frequency.
19. Stop the rotation of Antenna 5, and power down its front-end components.

Table 5. RSA settings for antenna characterization (frequency 1)

Parameter	Value
Center Frequency	2.24 GHz
Span	20 MHz
Number of Points	801
Resolution Bandwidth	1 kHz
Video Bandwidth	1 kHz
Attenuation	0 dB
Reference Level	-30 dBm
Preamp	Enable
Detector Type	Positive Peak

Table 6. RSA settings for antenna characterization (frequency 2)

Parameter	Value
Center Frequency	2.395 GHz
Span	20 MHz
Number of Points	801
Resolution Bandwidth	1 kHz
Video Bandwidth	1 kHz
Attenuation	0 dB
Reference Level	-30 dBm
Preamp	Enable
Detector Type	Positive Peak

3.0 RESULTS

3.1 24-HOUR RF ENVIRONMENT MEASUREMENT

On June 2, 2020, a 24-hour data collection was conducted to monitor the RF environment in and around Edwards AFB. The AMT spectrum monitoring system was utilized while Antenna 5 was pointed in the direction of the nearest LTE tower, S1. The results of the data collection are shown in Figure 10, in the

form of a persistence plot. The persistence plot shows the number of times a signal occurred in the 24-hour data collection period, with respect to its signal level and frequency, as displayed by the RSA.

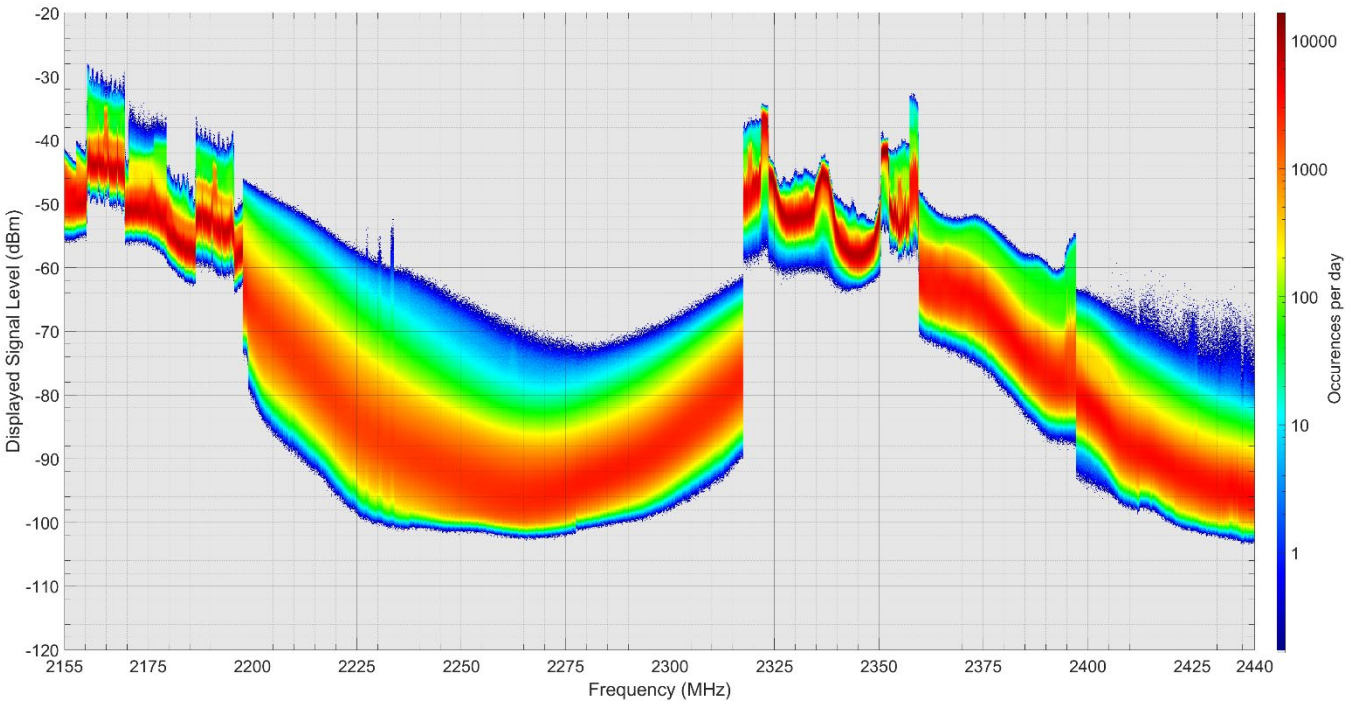

Figure 10. June 2nd, 2020, 24-hour RF environment data capture persistence plot

The results shown in Figure 10 indicate relatively high levels of apparent LTE activity in both AWS and WCS bands, with occasional signals in the lower AMT band. The constant LTE activity in the AWS-3 and -4 bands is expected; however, the signal-level roll-off outside the LTE bands should have a drastic reduction in signal level immediately adjacent to the band. The large variability in the AMT system noise floor, along with the gradual roll off from LTE signals, indicates that RF components in the AMT receiver chain are likely being saturated. Saturation in a receiver occurs when there is too much input power applied to an active component causing it to operate non-linearly. In this mode of operation, the system no longer produces a constant gain at all frequencies and creates spurious responses which degrade receiver performance and causes inaccuracies in the displayed signal envelope.

3.2 SCENARIO INTERFERENCE MEASUREMENTS

On June 18, 2020, various measurement scenarios were executed with the support of AMT and AT&T personnel, to pinpoint and validate the expected source of saturation. AT&T supported the measurements by turning on and off the base stations for the AWS and WCS bands of the two nearest LTE sites to the AMT receiver, S1 and S2. AMT personnel supported measurements by toggling the receiver feed between a high-gain, narrow beam width antenna (standard operations) and low-gain (approx. 20 dB less), wide beam width antenna, as well as changing the AMT antenna pointing angle

between the two AT&T LTE sites. In order to ensure that the effect of changing each of the variables above is captured, measurements were performed with the scenarios listed in Table 7.

Table 7. Summary of measurement scenarios

Scenario	WCS	S1 LTE	S2 LTE	Antenna Gain	Pointing
1	On	On	On	Low	S1
2	On	On	On	High	S1
3	On	On	On	Low	S2
4	On	On	On	High	S2
5[5]	On	On	On	Low	S1
6[6]	On	On	Off	Low	S1
7	On	On	Off	High	S1
8	On	On	Off	Low	S2
9	On	On	Off	High	S2
10	On	Off	Off	Low	S2
11	On	Off	Off	High	S2
12	On	Off	Off	Low	S1
13	On	Off	Off	High	S1
14	Off	Off	Off	Low	S1
15	Off	Off	Off	High	S1

Testing started with Scenarios 1 and 2 to confirm that the saturation observed during the 24-hour RF environment data collection was still present. Scenario 2, the results of which are shown in Figure 11, was executed with the same parameters to the 24-hour data collection, but with a lower RBW. A comparison of Figure 10 and Figure 11, shows that the AMT receiver is saturated in both cases i.e. the source of saturation is consistent and independent of the time of collection. During initial testing, it was observed by AMT personnel that switching the receiver to the low-gain antenna would eliminate the effect of saturation; Figure 12 captures this observed effect.

[5] Scenario 5 is a repetition of Scenario 1 in an effort to collect additional data.

[6] A review of Scenario 6 revealed that the recorded data was corrupted and was therefore excluded from analysis.

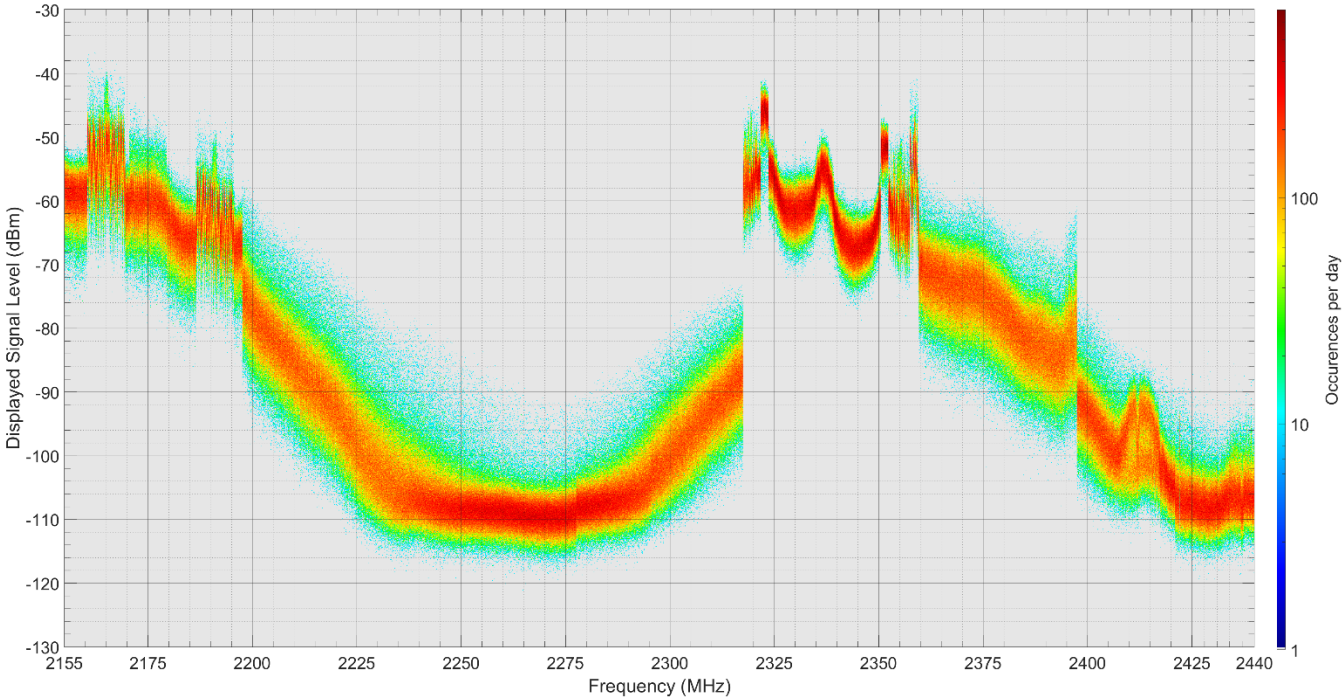

Figure 11. Measurement Scenario 2 persistence plot

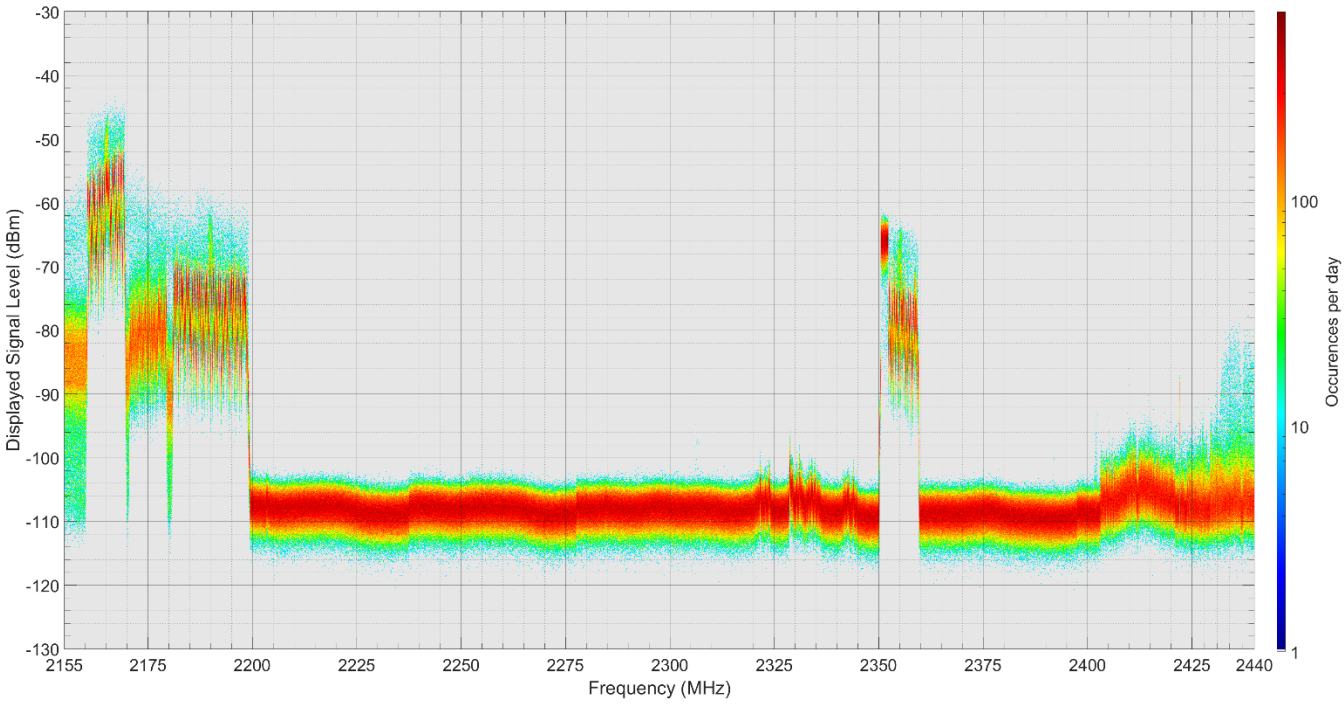

Figure 12. Measurement Scenario 1 persistence plot

For Scenarios 1 and 2, the AMT dish was pointed at S1, from where the saturation was expected to be originating. In order to show that the saturation is due to signals originating from a localized area, the dish was pointed at S2. Measurements for Scenarios 3 and 4 produced similar results to the

measurement pointing at S1 with the low-gain antenna. Figure 13 and Figure 14 show no signs of saturation despite using the high-gain dish for Figure 14. Since the saturation occurred only with the dish pointing directly at S1, it can be concluded that the observed saturation does not happen solely due to the presence of LTE signals in the AMT receiver. The LTE emissions must be at a sufficient power level before it can cause saturation of the AMT receiver. It can be observed in Figure 13 and Figure 14, that the signal power levels do not change significantly when switching between the high gain and low gain antenna. The high gain antenna has a narrow bandwidth, as a result, signals may be received outside the main beam, at a lower gain. This lower gain could be nearly the same as the gain of the low gain antenna, allowing the signal value to show no change in signal level between antennas used.

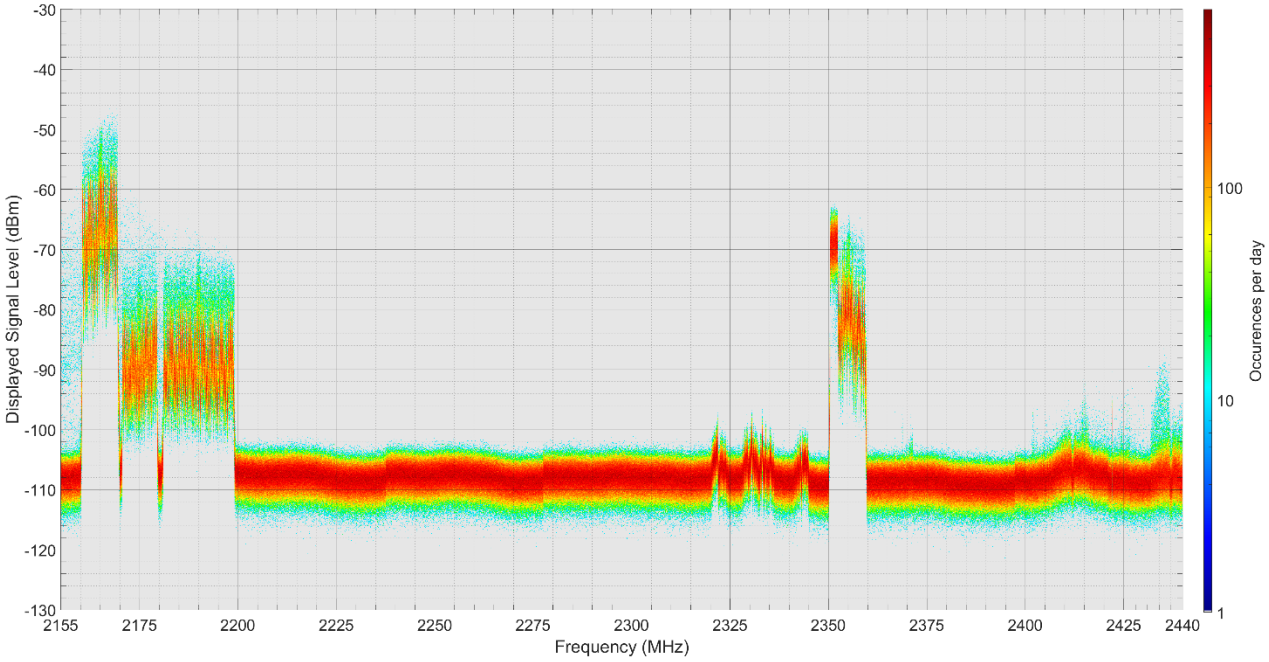

Figure 13. Measurement Scenario 3 persistence plot

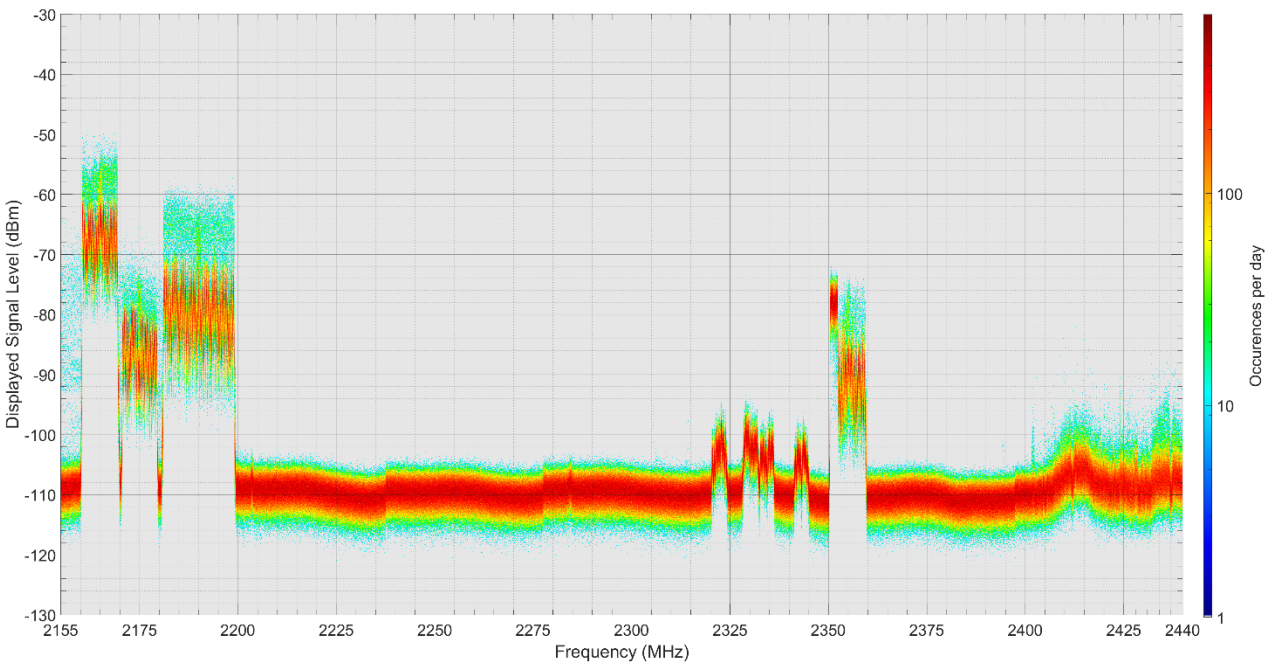

Figure 14. Measurement Scenario 4 persistence plot

After completing Scenarios 6 through 13, in which different combination of AWS signals were turned off at both towers, a trend became clear; the AMT receiver system would saturate when pointing at S1 independent of the configuration of LTE at S1. Scenario 13, shown in Figure 15, shows a similar result to that of the 24-hour RF environment data collection; despite AT&T turning off the AWS-3 and AWS-4 signals, the AMT system was still being saturated. It was concluded that simply turning off S1 AT&T service would not prevent saturation, either due to additional nearby towers in the direction of S1 or an LTE signal from another carrier on the S1 tower.

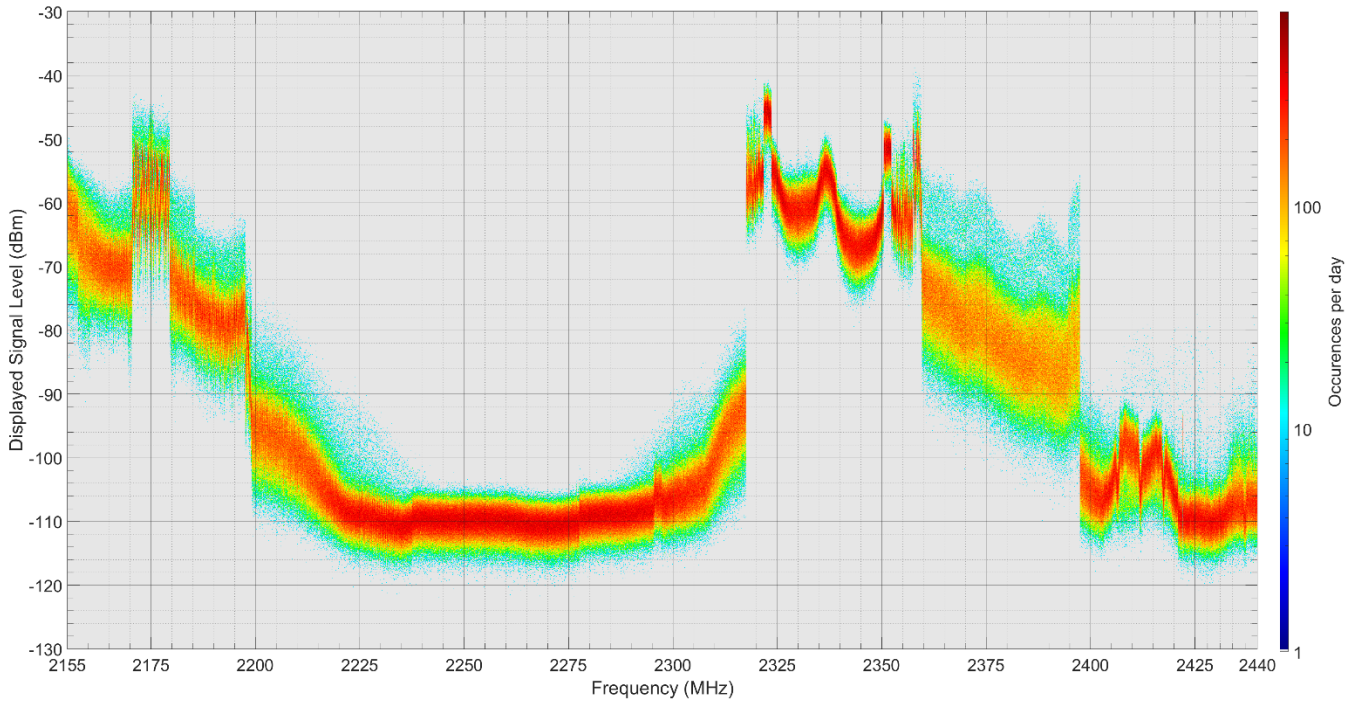

Figure 15. Measurement Scenario 13 persistence plot

For Scenarios 14 and 15, AT&T turned off the WCS transmission at both sites. This, however, had no effect; the AMT receiver saturated when pointing at S1 with the high-gain antenna, as shown in Figure 16, and no effects of saturation were noticed when using the low-gain antenna, as shown in Figure 17. Therefore, the saturation of the AMT system is not being caused by just AT&T's AWS and WCS activity at S1, but by any LTE transmissions in the direction of S1. Additional plots for each scenario can be found in Appendix C, D, and E.

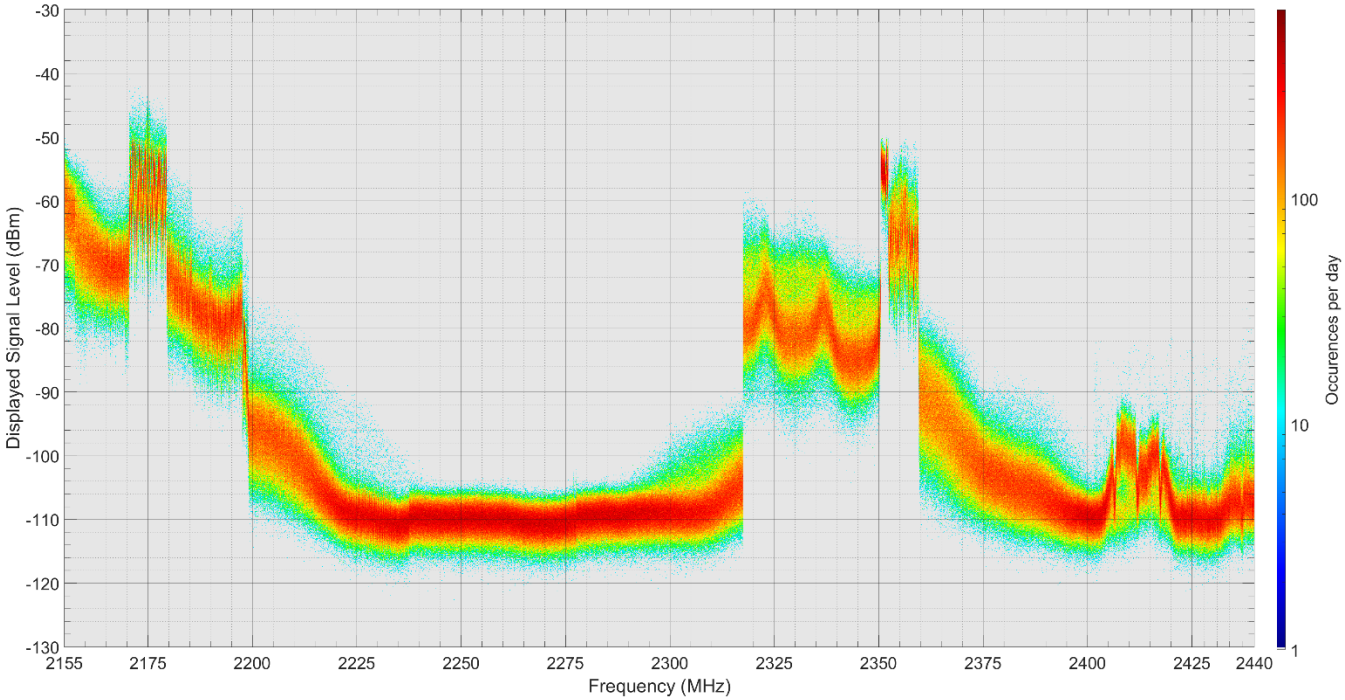

Figure 16. Measurement Scenario 15 persistence plot

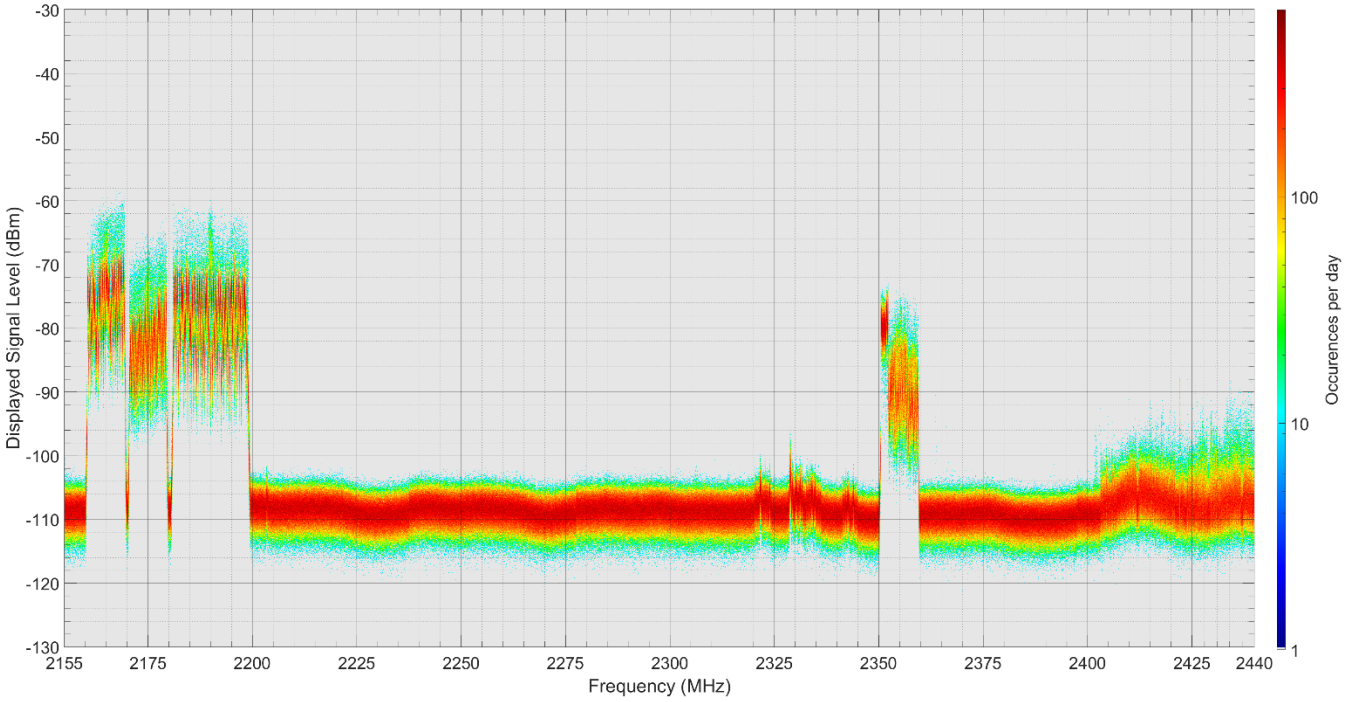

Figure 17. Measurement Scenario 14 persistence plot

3.3 OOB MEASUREMENTS

Prior to measurements it was postulated that the OOB emissions of signals in frequency bands adjacent to AMT operations could be a source of interference to the AMT receive system. After completing the RF field measurements, it was observed that the primary mechanism of interference was saturation of the AMT receive system by relatively high-power LTE signals of close proximity. Within those measurements, the OOB could not be measured during the scenarios that caused receiver saturation. However, during scenarios where saturation was not evident, OOB emissions received from adjacent bands were below the noise level of the measurement system. Using scenario 4 as an example, the displayed average noise level (DANL) in the capture is approximately -110 dBm per 10 Khz while using the high-gain antenna. During a previous Alion measurement effort, the system gain of the AMT Receive chain was determined to be approximately 53 dB. Accounting for the system gain, the measurement system was able to display signals that were above – 163 dBm per 10 Khz. In the interest of prioritizing efforts within a limited measurement timeline, it was decided that additional measurements of OOB emissions would not be feasible given the noise floor limitation of the available measurement system.

3.4 ANTENNA CHARACTERIZATION

In addition to the collection of RF environmental data, it was important to measure a relative antenna pattern of the AMT high-gain dish antenna to isolate the effects of the dish in the measurements performed. On June 2, 2020, antenna pattern measurements of the AMT dish antenna were performed. A CW signal was radiated at a constant power from a calibrated directional antenna, mounted to the boresight tower nearest the AMT dish. The AMT dish was then rotated 360 degrees in the azimuthal angle, while keeping the elevation angle constant at -5 degrees relative to horizontal. During this rotation, the CW signal level was recorded over time using an RSA connected to the output of the AMT receiver system. This process was repeated for elevation angles -5 to 5 degrees, in 1-degree steps. The pointing angle of the dish and the collected spectral data were both timestamped for correlation during post processing. After correlating the two data sets, a relative antenna radiation pattern was generated. The data was normalized to remove negative values and create a relative polar plot.

With execution of various measurement scenarios, it was determined that the high-gain dish did not cause the AMT receiver to saturate when pointing at S2. This suggests that the relative difference in received power between the main beam of the dish and the side lobes was enough to prevent saturating the receiver. Using the generated antenna radiation pattern, this difference in power can be calculated. The antenna radiation pattern was rotated so that the apparent main beam in the pattern was pointed in the direction of S2, or approximately a heading of 352 degrees relative to north, as shown in Figure 18. From Figure 18, it is observed that when pointing at S2, signals entering the dish from S1, a heading of

318 degrees, received 21 dB less gain from the dish. Therefore, using the pattern suggests that 21 dB of loss in AWS signals will prevent the AMT receiver from saturating.

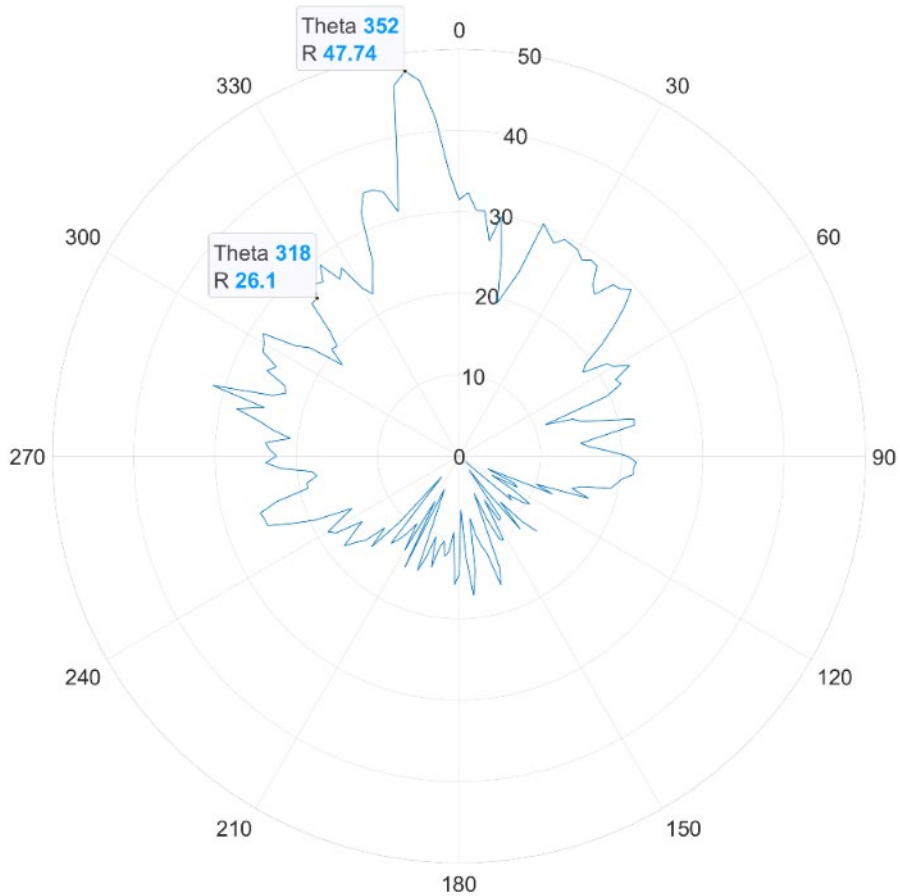

Figure 18. Relative antenna pattern for Scenario 4

4.0 RECOMMENDATIONS

Based on the previously stated observations, it was determined that to prevent saturation of the AMT receiver, a filter must be added to the front end of the receive chain, to reduce LTE signal levels. Comparing the results from the different scenarios showed that saturation did not occur when using an antenna of approximately 20 dB lower gain. Additionally, the relative antenna pattern suggests that 21 dB of rejection also prevented saturation. Based on these two observations, it is assumed that the filter would need a minimum of 20 dB of rejection in the AWS bands at 2.2 GHz and below. It is possible that less than 20 dB of rejection may be sufficient, but additional testing would be required to determine the exact value. The simulated filter shown in Figure 19 is an example of the type of OOB rejection that the filter would have to provide. The blue trace shows an example filter response that could help prevent saturating the AMT system. The red dotted lines are specified frequencies for requirements of the filter, with 20-dB of attenuation at 2.2 GHz and 2.3 GHz.

The results of this report suggest that all AMT stations operating within relatively close RF-proximity to downlink cellular services perform similar measurements to understand the potential effect on telemetry operations. The measurement procedure derived for the Edwards AFB AMT stations should be adapted to the scenario in question and when possible include working cooperatively with the respective carrier community.

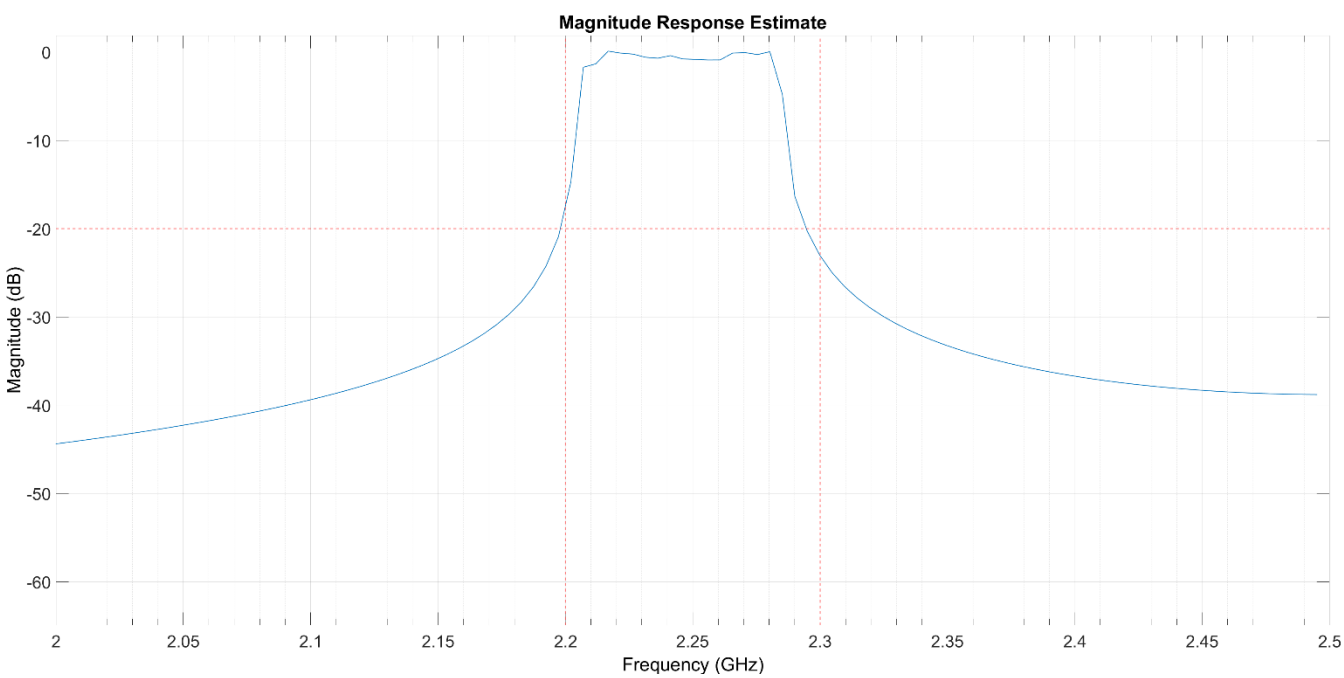

Figure 19. Estimated required filter

APPENDIX A – ANTENNA 5 SPECIFICATIONS

Edwards AFB personnel has provided Alion with the slide shown in Figure 20, listing the primary specifications of the AMT receive system's dish antenna, Antenna 5.

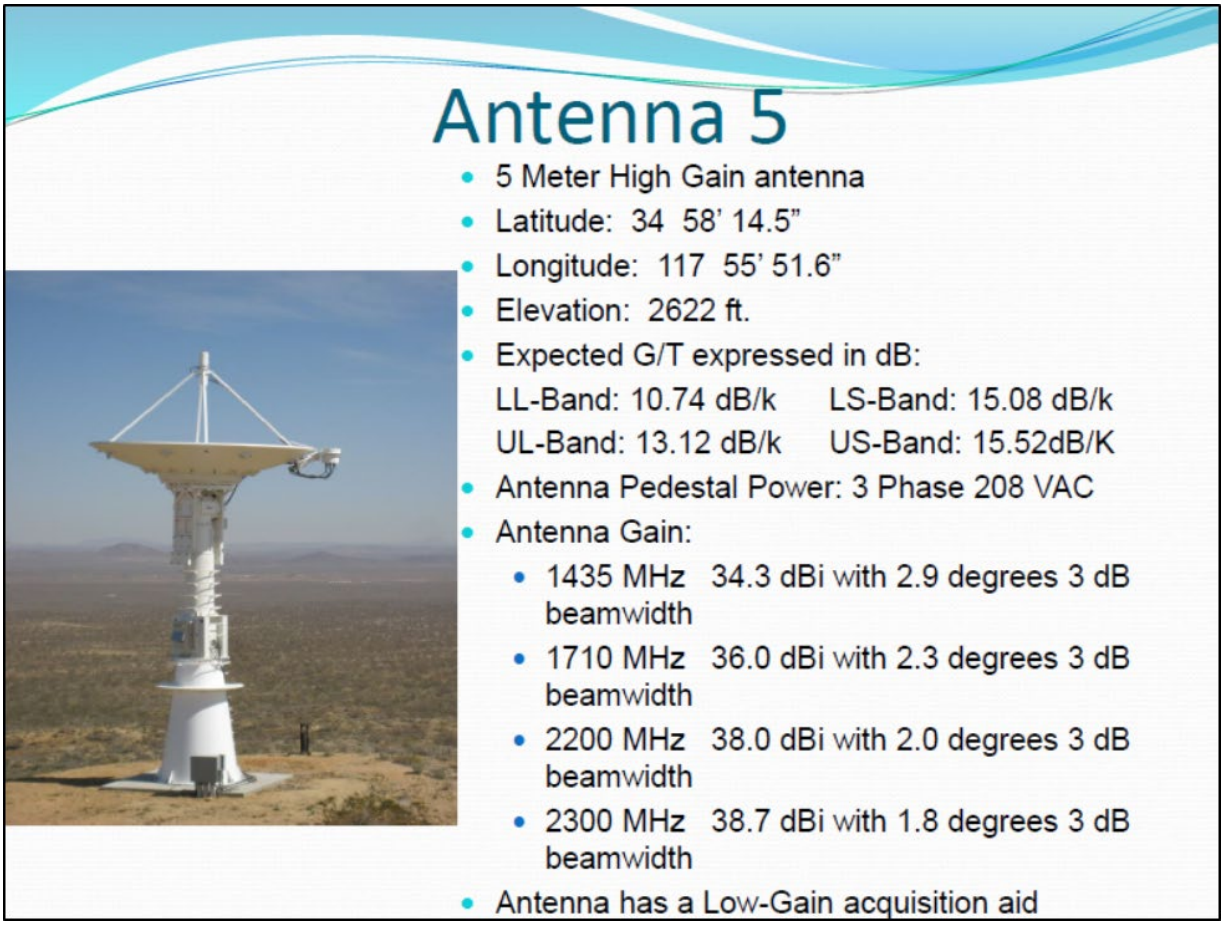

Figure 20. AMT receiver system's Antenna 5 specifications

APPENDIX B – DETAILED EQUIPMENT LIST

Table 8 lists the equipment used for this measurement effort.

Table 8. Detailed equipment list

Component	Manufacturer	Model	System	Owner	Specifications
RSA (x2)	Tektronix	RSA503A	AMT receiver and stand-alone spectrum monitoring systems	Test Equity	• Frequency operating range of 9 kHz to 7.5 GHz • Reference frequency accuracy of ±1 x 10^{-6} • Frequency accuracy of ±([reference frequency error] × [marker frequency] + 0.001 × Span) Hz • Max RF input level of +13 to +33 based on settings • Amplitude accuracy of ±0.8 dB (Up to 3 GHz) or ±1.0 dB (up to 3 GHz with preamp on) • Preamp gain of 27 dB at 2 GHz and 21 dB at 6 GHz • Displayed average noise level (DANL) for 1 GHz to 2 GHz of -159 dBm/Hz maximum with preamp on, -162 dBm/Hz typical with preamp on, and -138 dBm/Hz typical with preamp off
Test Controller (x2)	Intel	NUC8i7BEH (Customized)	AMT receiver and stand-alone spectrum monitoring systems	Alion	• 4.5 GHz, Quad Core Processor • 32 GB, 2400 MHZ RAM • 1 TB m.2 PCIE Solid State Drive • Windows 10 Pro operating system • Gen 2 USB 3.1 ports
LTE Router	Pepwave	MAX BR1-LTE	AMT receiver and stand-alone spectrum monitoring systems	Alion	• Throughput of 100 Mbps • LTE service provided by Verizon
Coaxial Cables (x2)	MegaPhase	F520 Warrior Cable	AMT receiver and stand-alone spectrum monitoring systems	Alion	• Frequency Operating Range of DC to 18 GHz • Minimum shielding effectiveness of -110 dB • Cable loss of 0.178 dB/ft (0.585 dB/m) at 2 GHz
Telescoping Tripod Antenna Mast	Northwest Instruments	NAT96	Stand-alone spectrum monitoring system	Alion	• Closed length of 46 inches • Extended length of 108 inches (9 feet) • Weighs 17 lbs.
Bandpass Filter	Southwest Antennas	1080-080	Stand-alone spectrum monitoring system (optional)	Alion	• 2,200 to 2,290 MHz Passband • 0.5 dB of insertion loss • 30 dB of attenuation at 2180 MHz • 30 dB of attenuation at 3500 MHz

Component	Manufacturer	Model	System	Owner	Specifications
Omnidirectional Antenna	MARS Antennas & RF Systems LTD.	MA-WO-UWB	Stand-alone spectrum monitoring system	Alion	• Frequency Operating range of 138 MHz to 6 GHz • Antenna gain of 8 dBi from 1200 MHz to 2700 MHz • Length of 21 inches • Weights 0.77 lbs.
CW Transmitting Antenna	A.H. Systems, Inc.	SAS-571	AMT Calibration System	Edwards AFB	• Directional Horn Antenna • Frequency operating range of 700 MHz to 18 GHz • Antenna Gain of 1.4 to 15 dBi based on frequency • Azimuthal 3 dB beam width of 30 degrees • Elevation 3 dB beam width of 48 degrees
Signal Generator	Agilent	MXG	N5181B	Edwards AFB	• Frequency Operating range to 6GHz • +20dBm output power

APPENDIX C – PERSISTANCE PLOTS

Figure 21 through Figure 34 are the persistence plots for all the test scenarios. The persistence plot shows the number of times a signal occurred in a roughly one-minute data capture, with respect to its signal level and frequency, as displayed by the RSA.

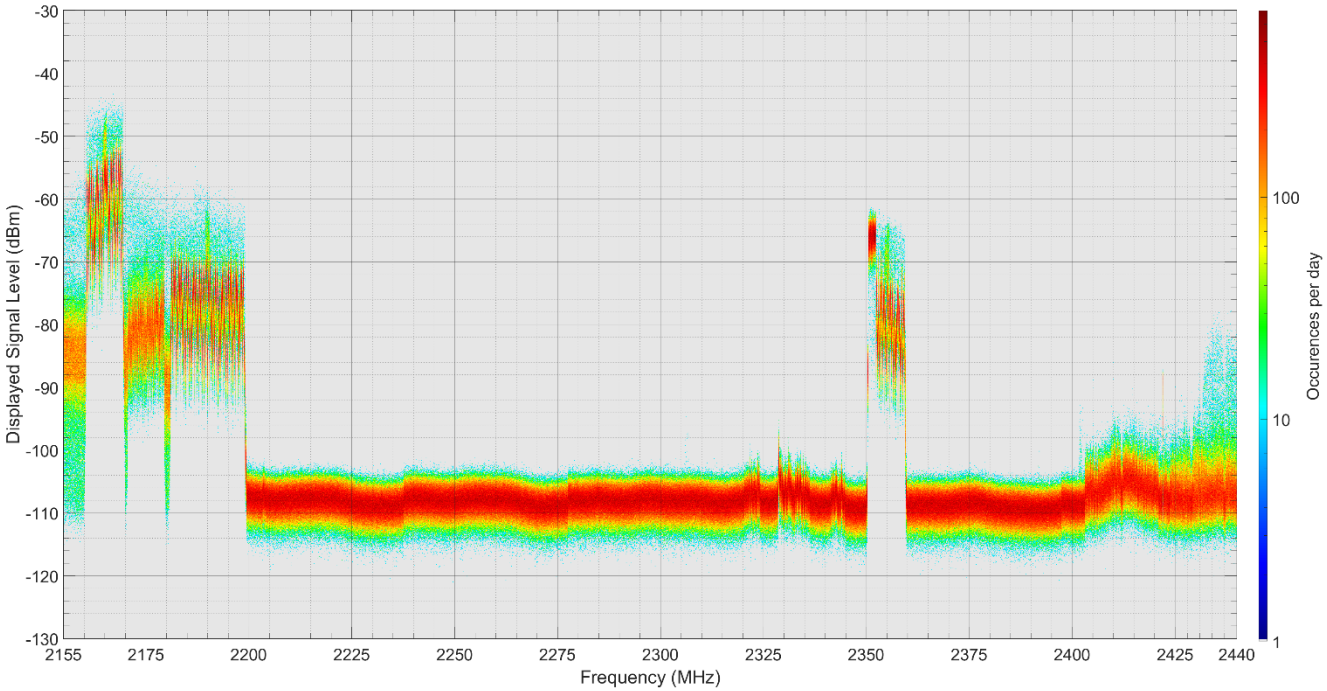

Figure 21. Measurement Scenario 1 persistence plot

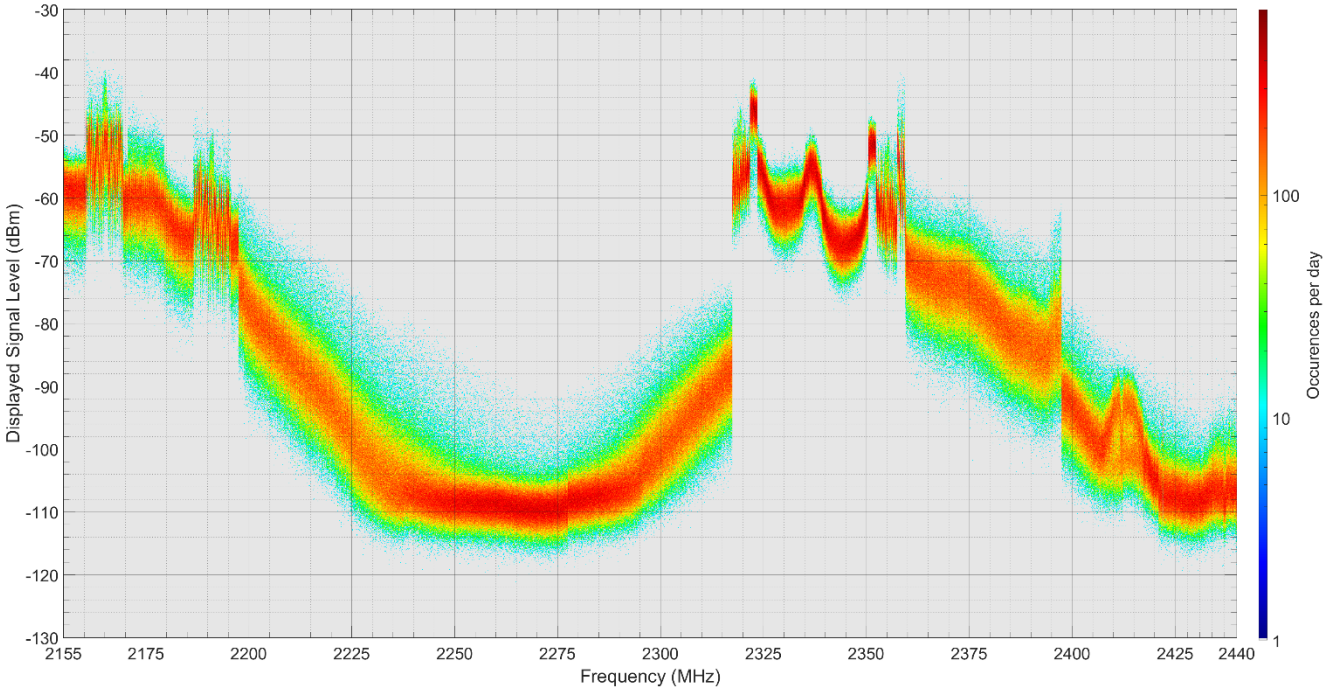

Figure 22. Measurement Scenario 2 persistence plot

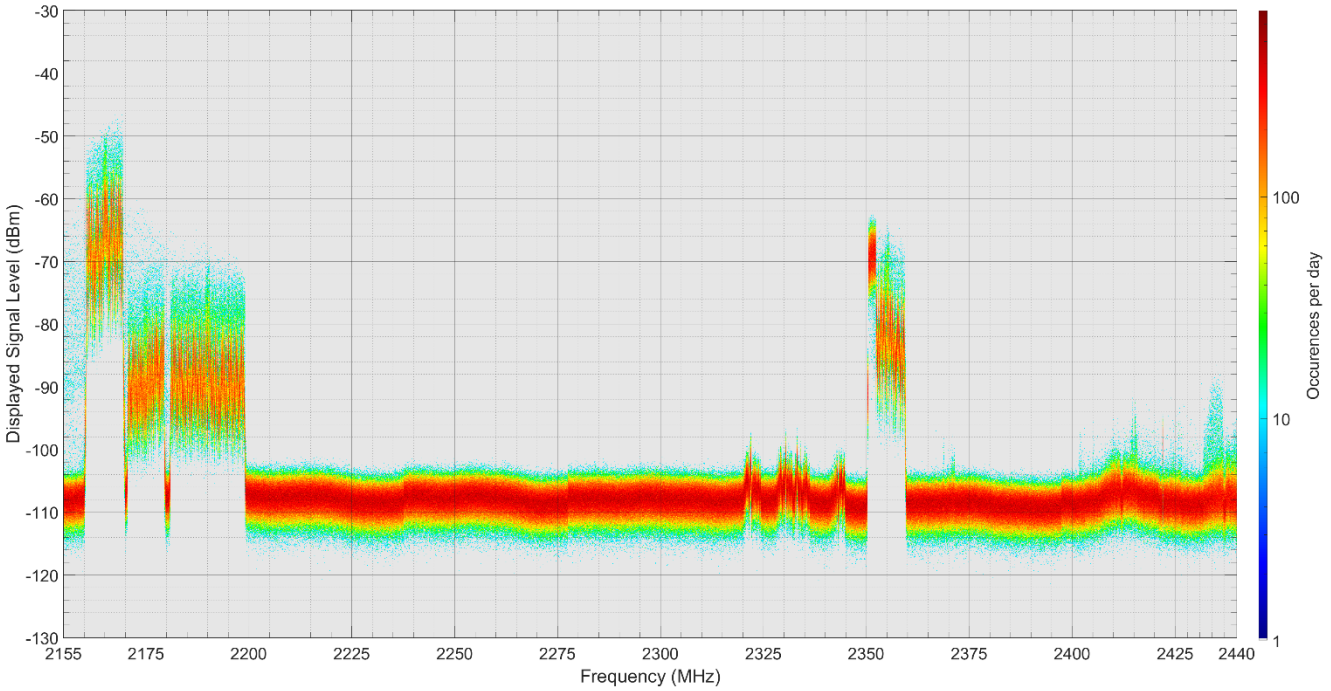

Figure 23. Measurement Scenario 3 persistence plot

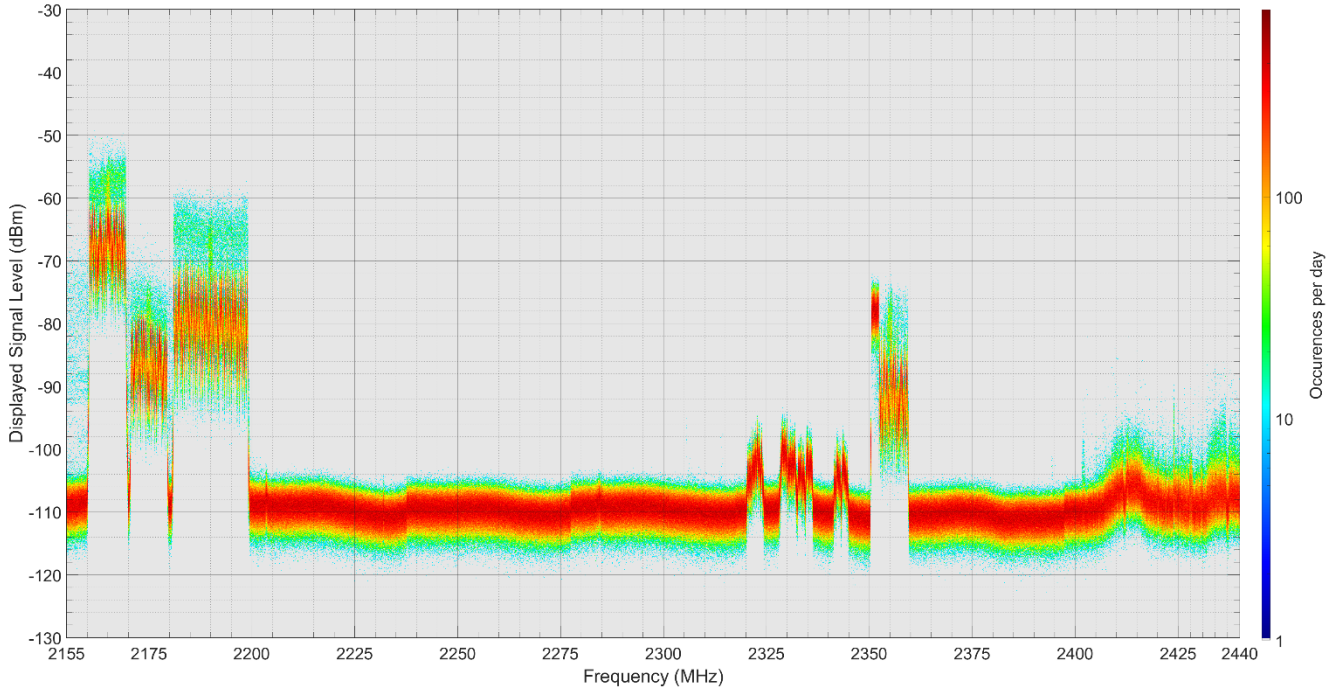

Figure 24. Measurement Scenario 4 persistence plot

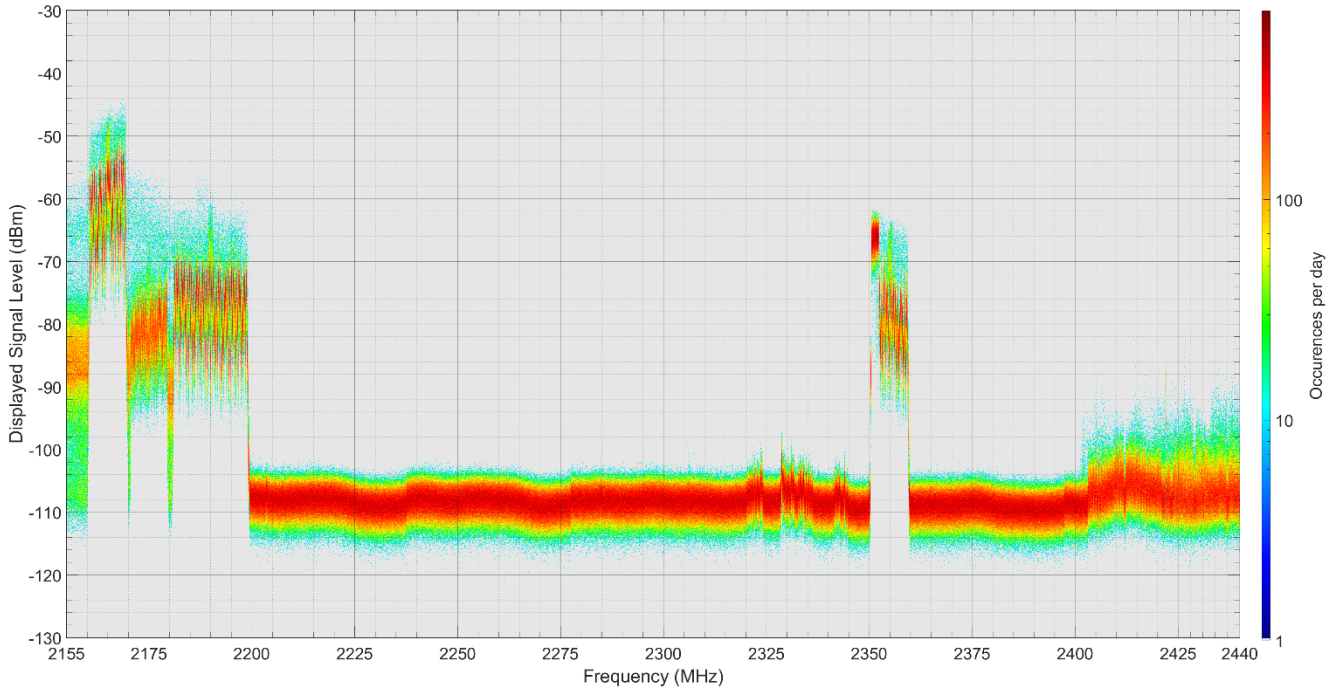

Figure 25. Measurement Scenario 5 persistence plot

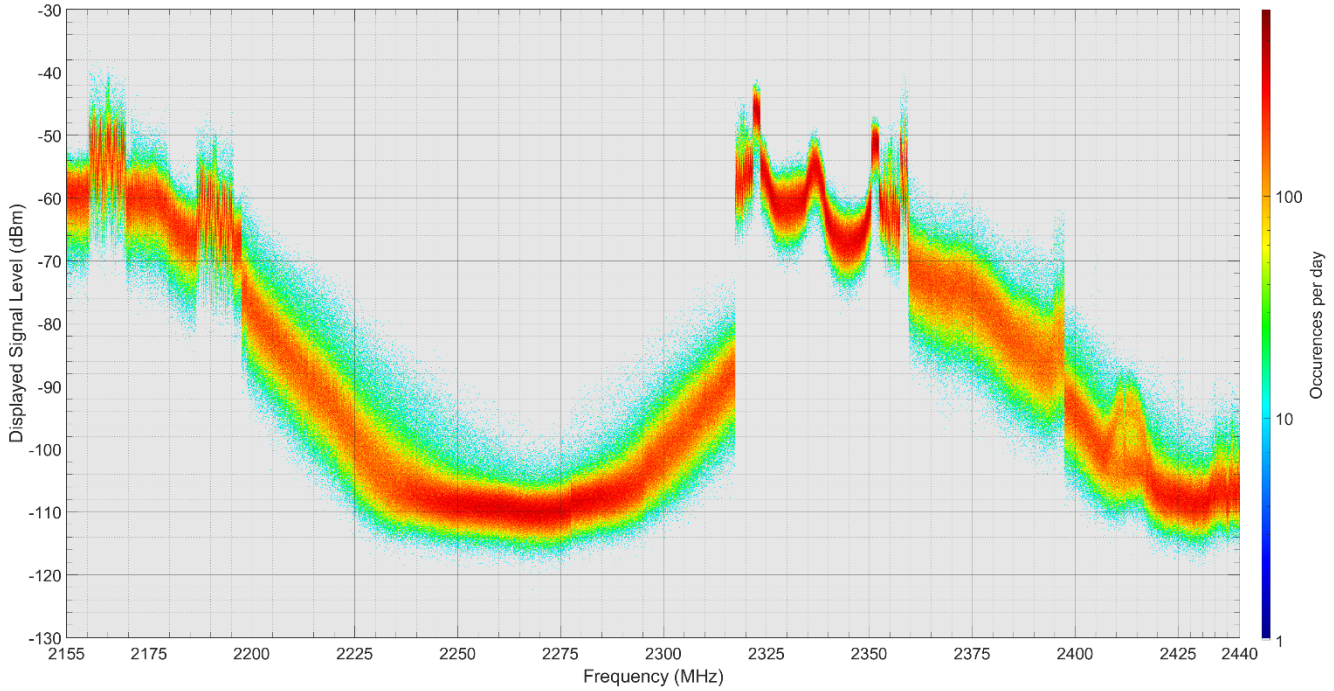

Figure 26. Measurement Scenario 7 persistence plot

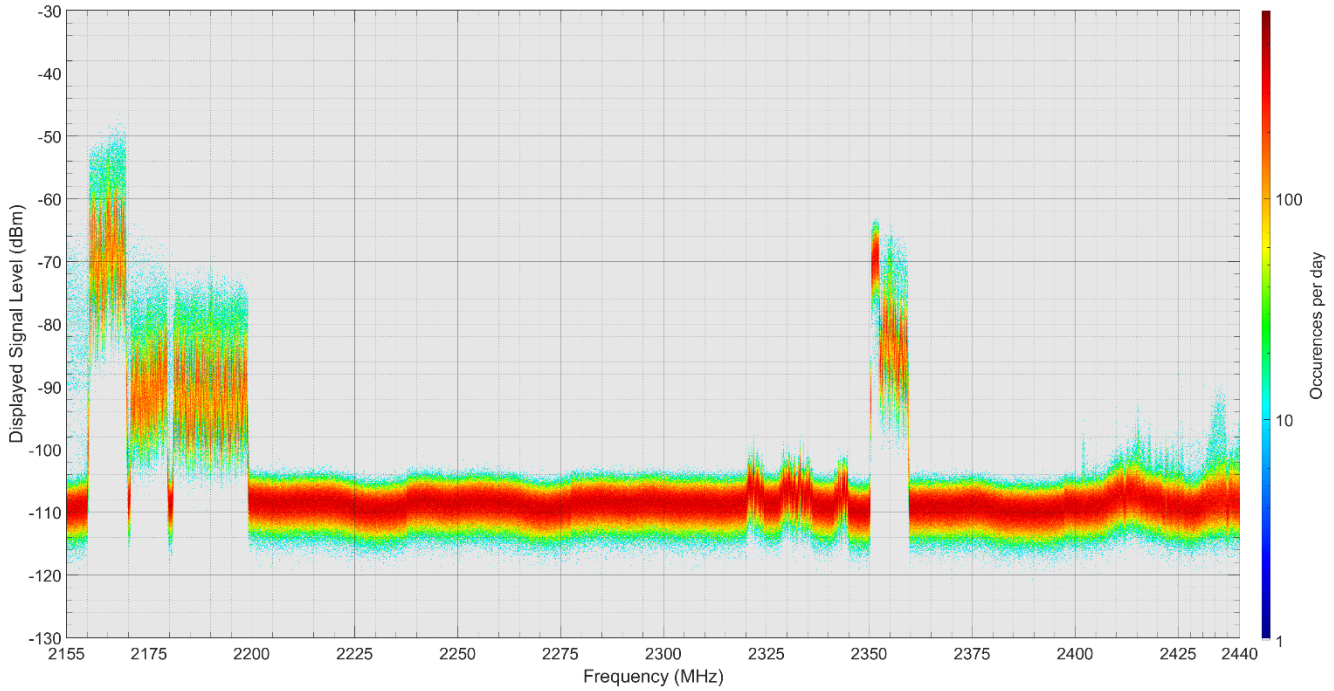

Figure 27. Measurement Scenario 8 persistence plot

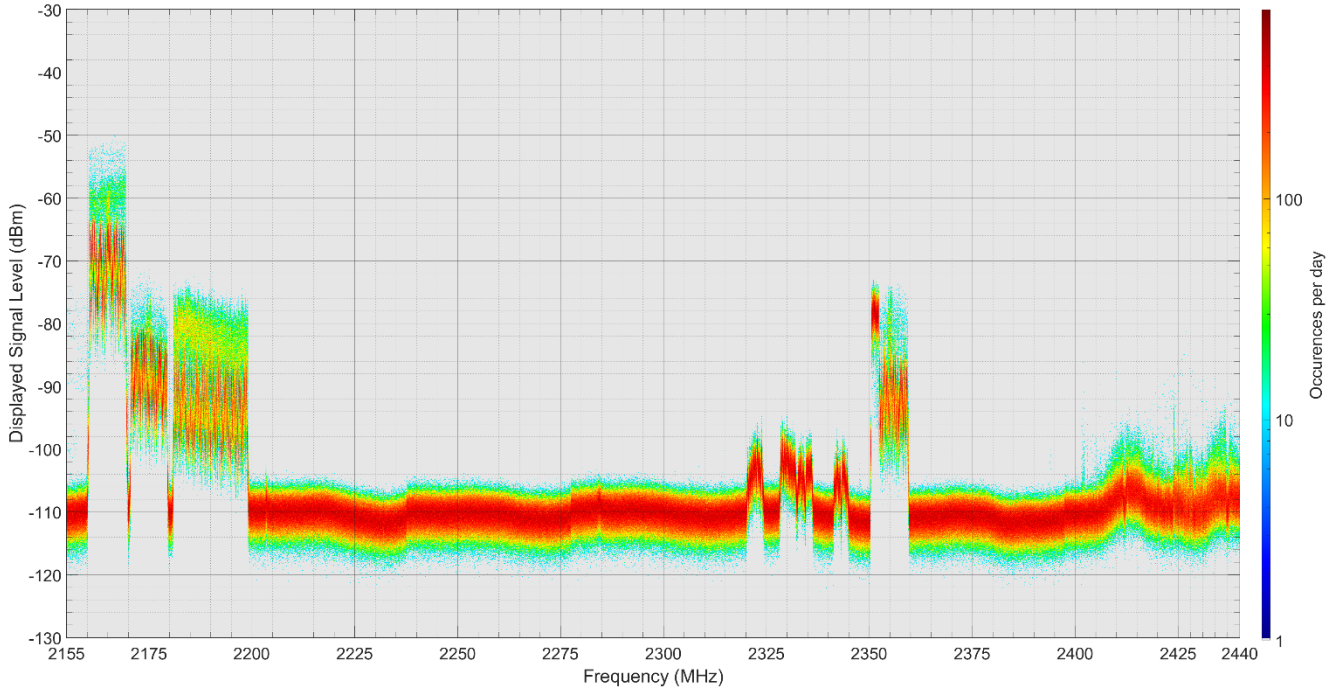

Figure 28. Measurement Scenario 9 persistence plot

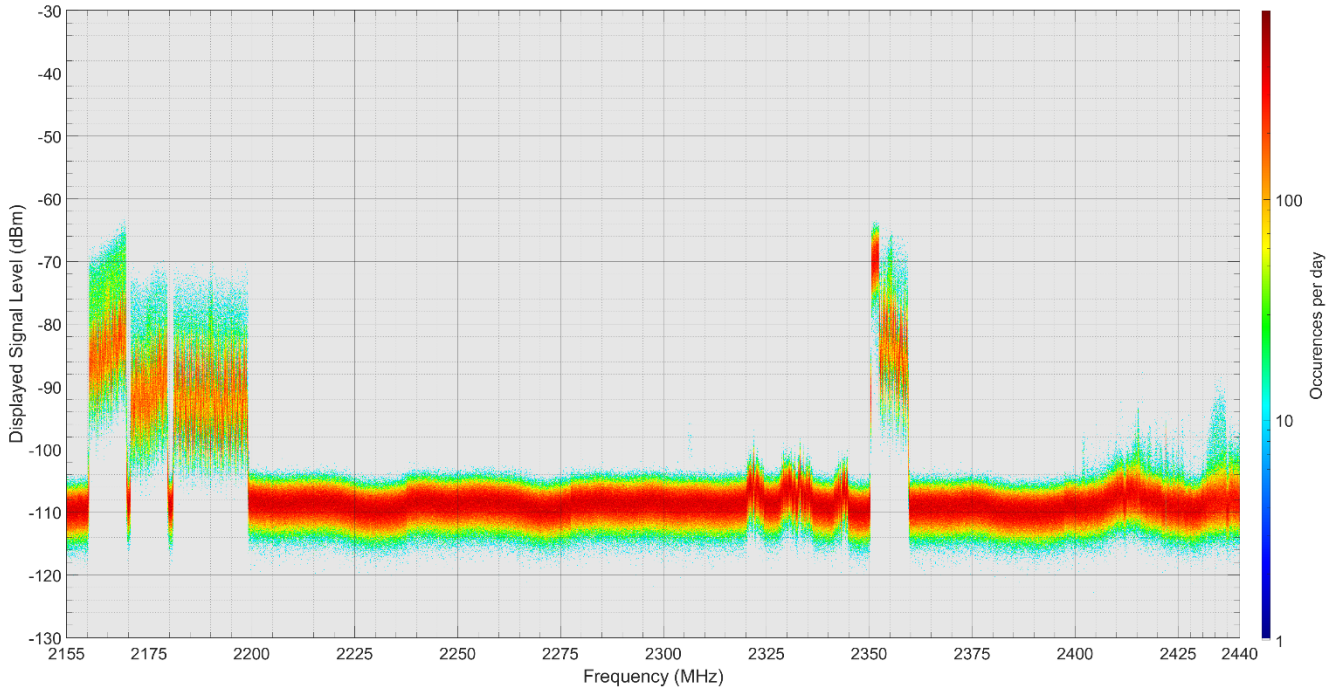

Figure 29. Measurement Scenario 10 persistence plot

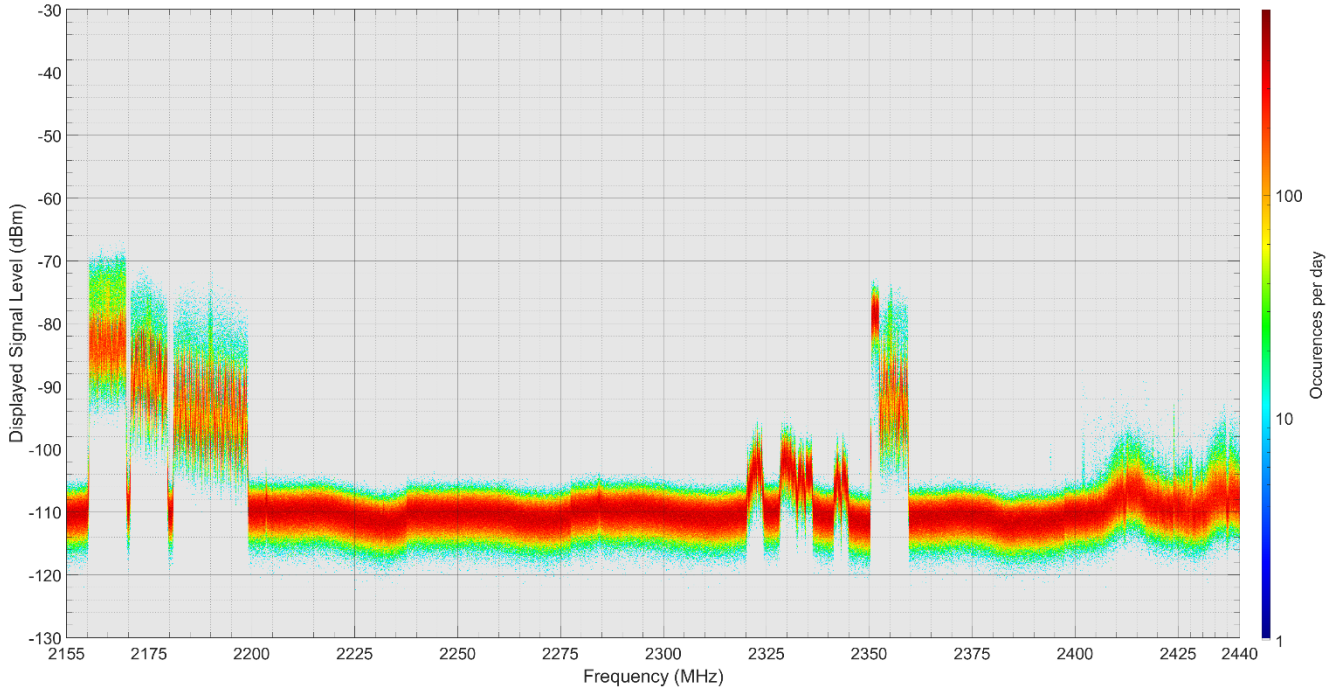

Figure 30. Measurement Scenario 11 persistence plot

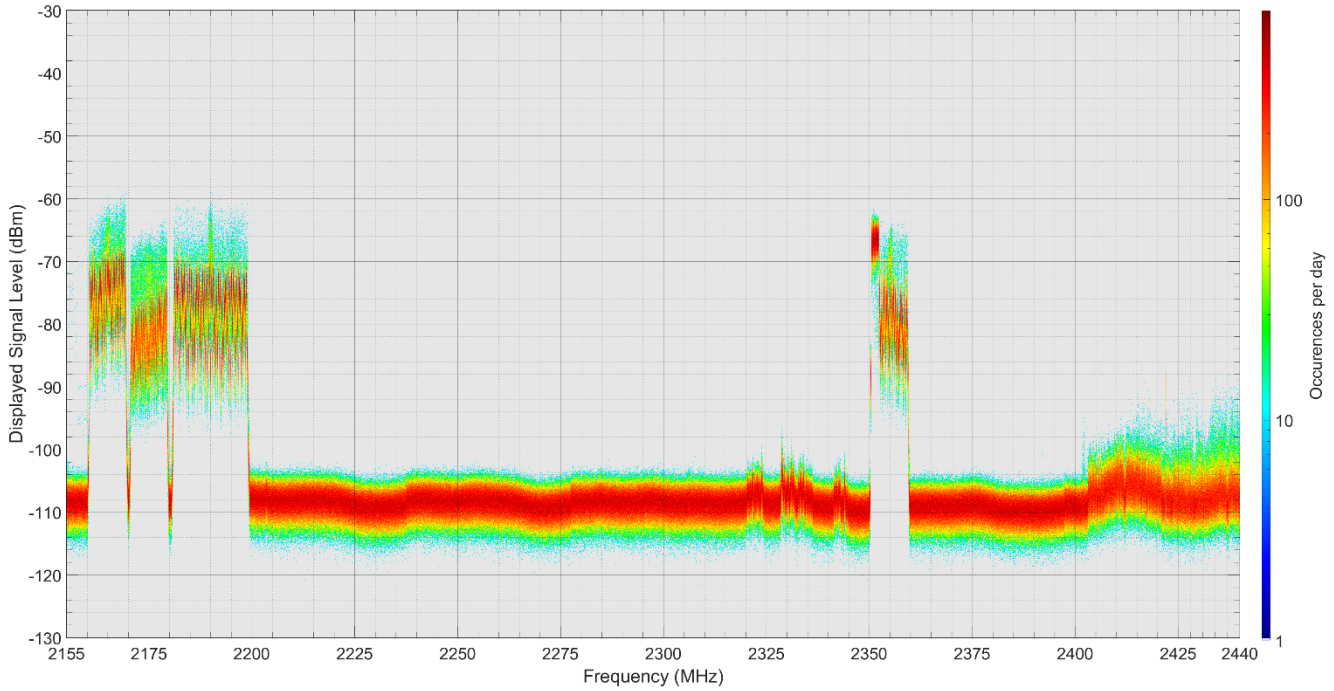

Figure 31. Measurement Scenario 12 persistence plot

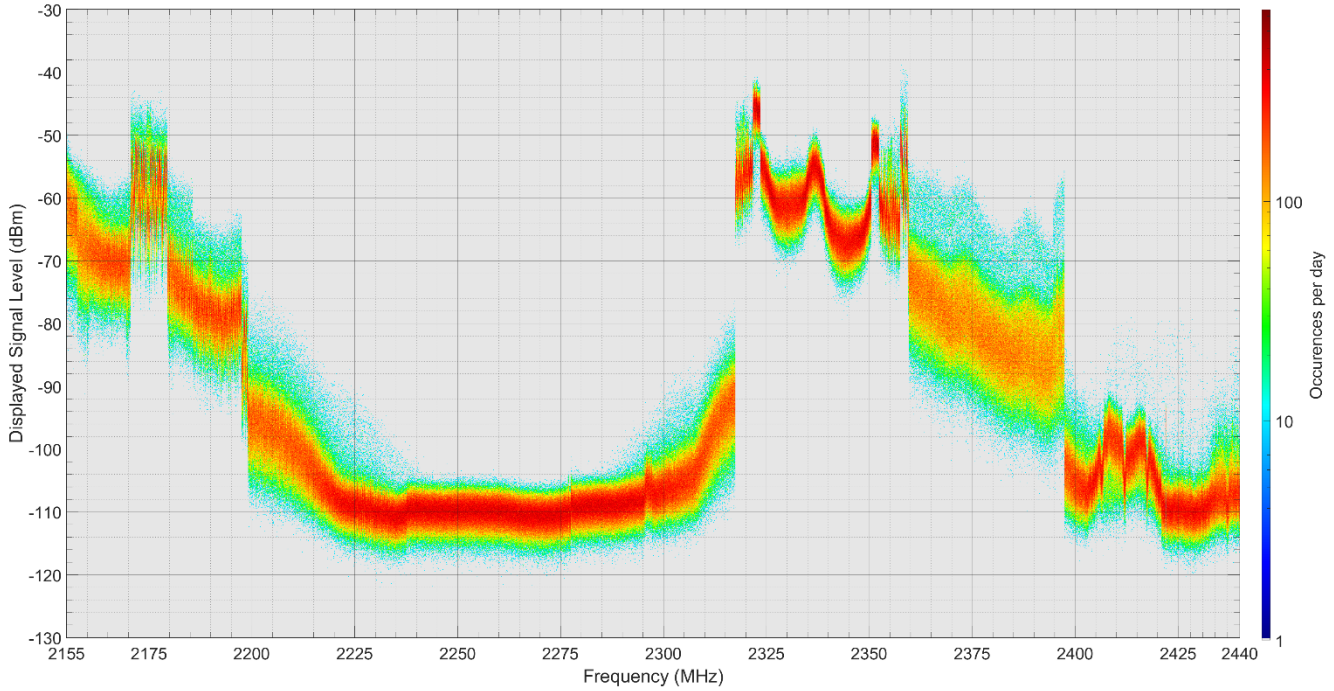

Figure 32. Measurement Scenario 13 persistence plot

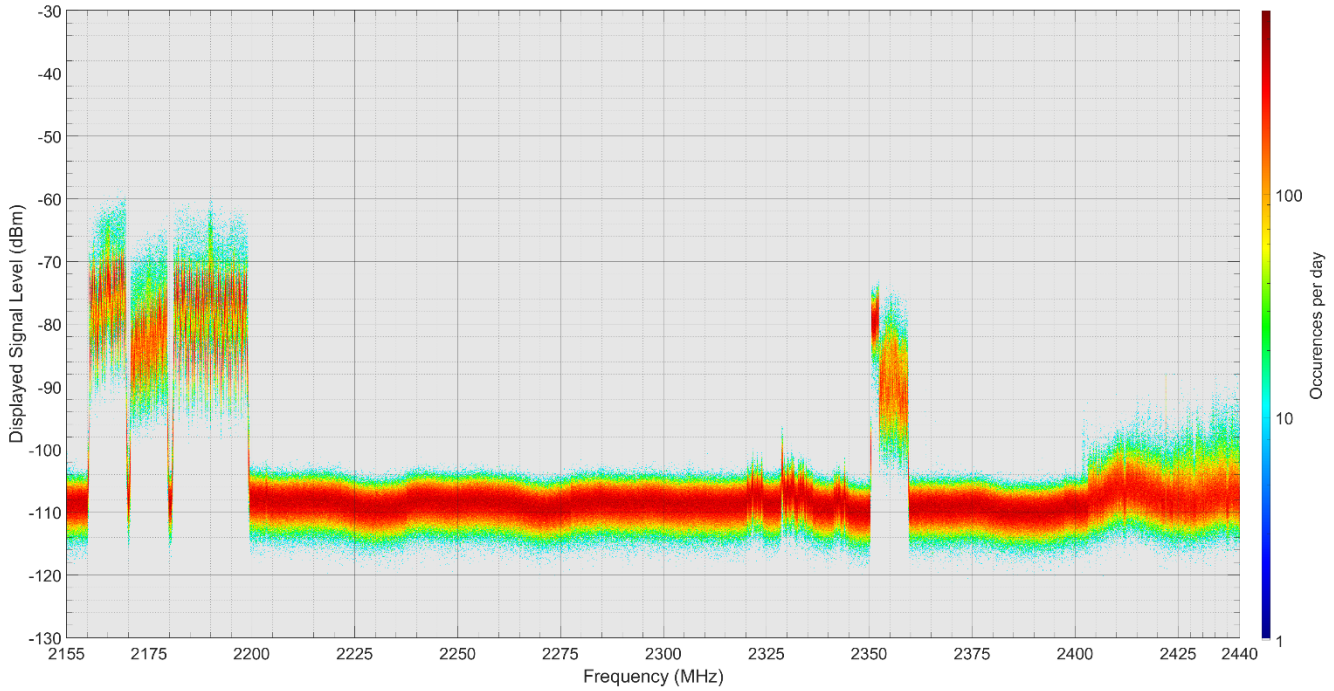

Figure 33. Measurement Scenario 14 persistence plot

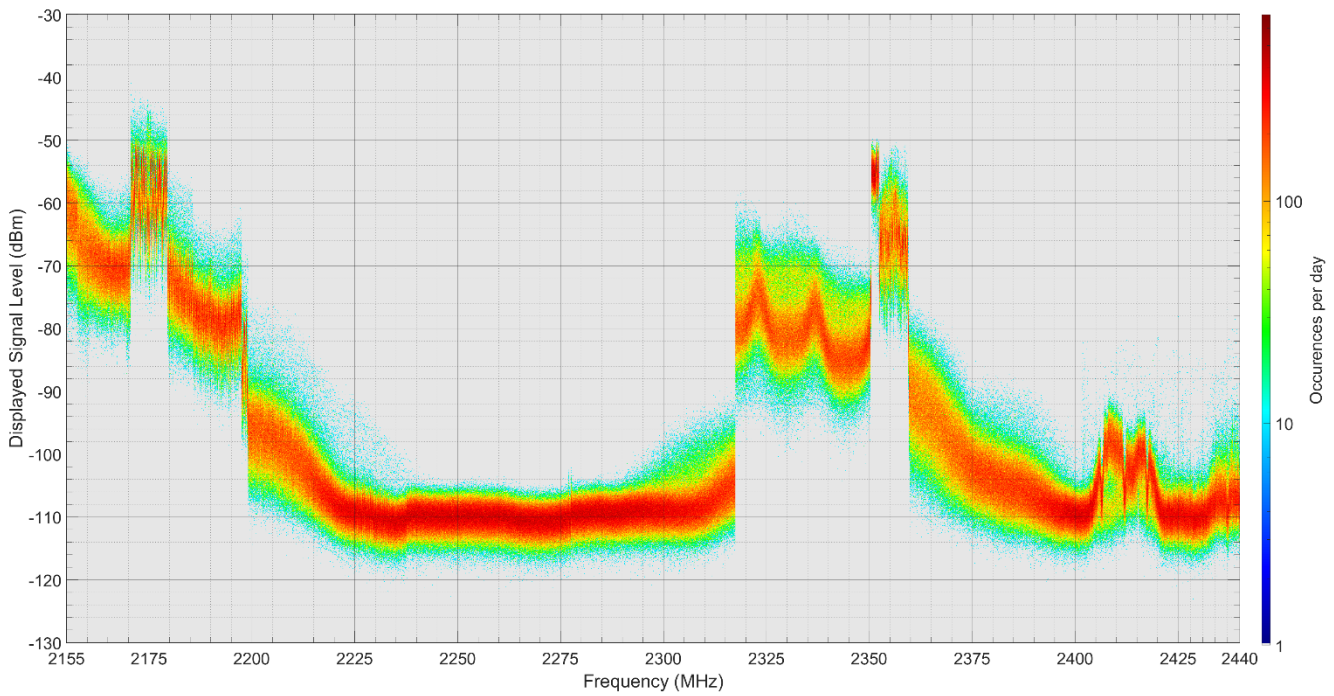

Figure 34. Measurement Scenario 15 persistence plot

APPENDIX D – WATERFALL PLOTS

Figure 35 through Figure 48 are waterfall plots for each test scenario completed. The waterfall plots show the change in signal power over time and the signal power represented by the color.

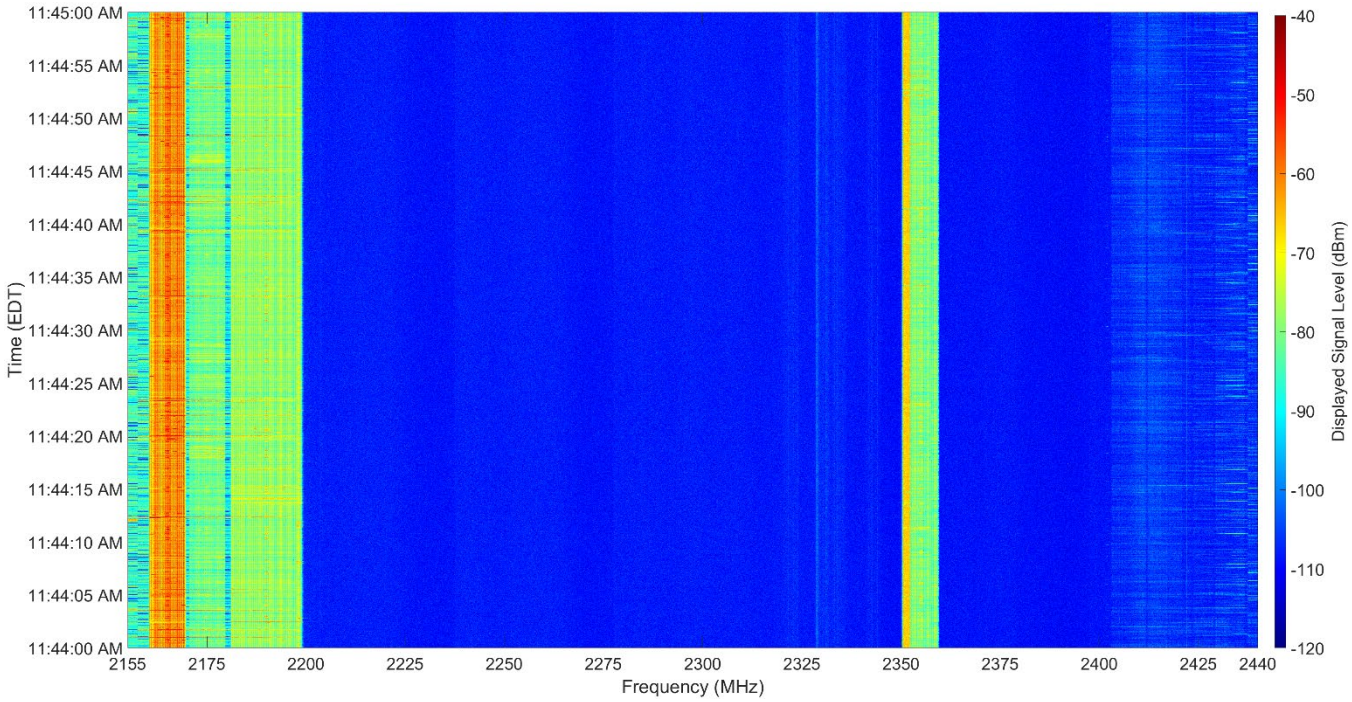

Figure 35. Measurement Scenario 1 waterfall plot

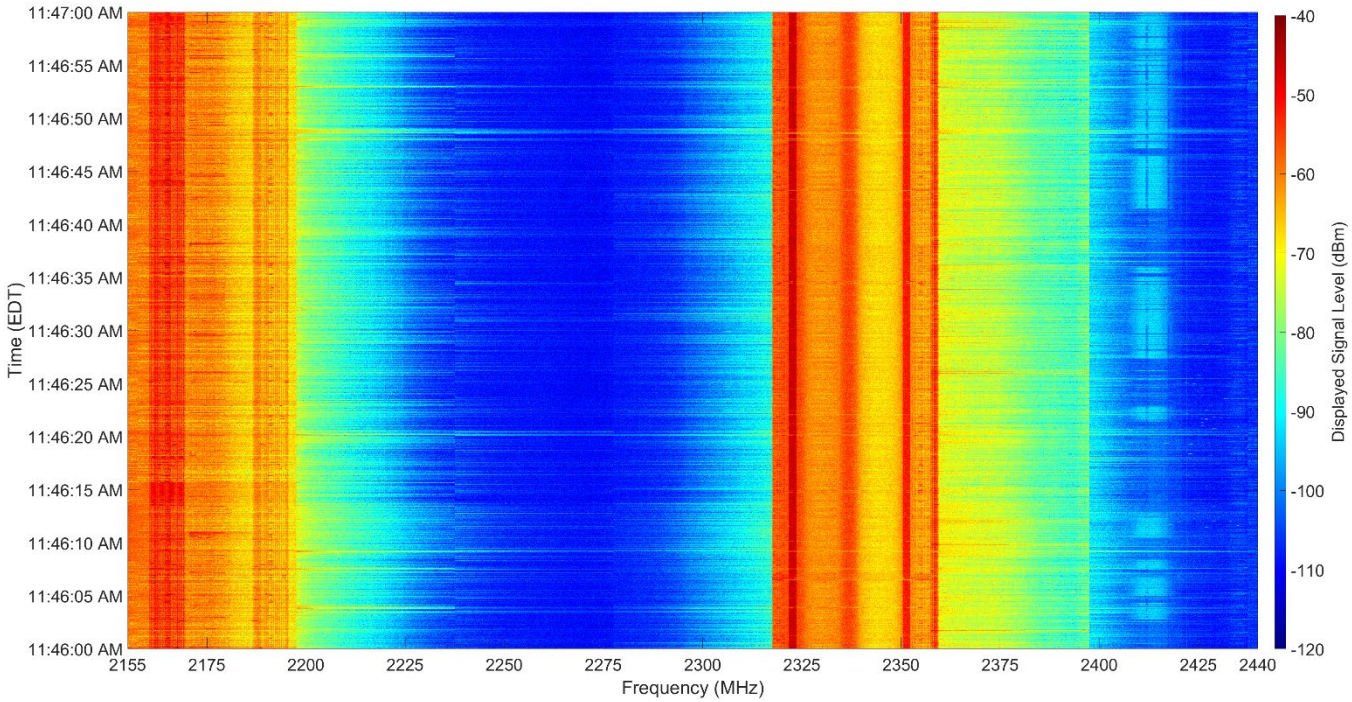

Figure 36. Measurement Scenario 2 waterfall plot

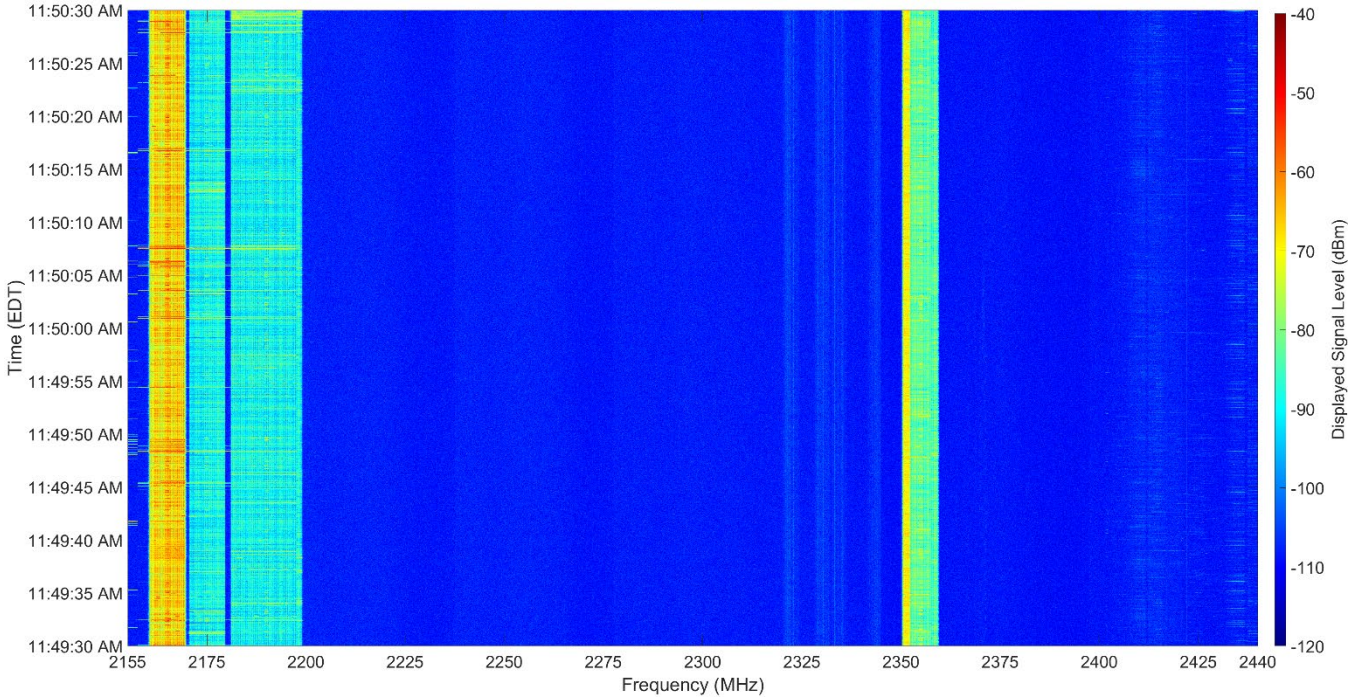

Figure 37. Measurement Scenario 3 waterfall plot

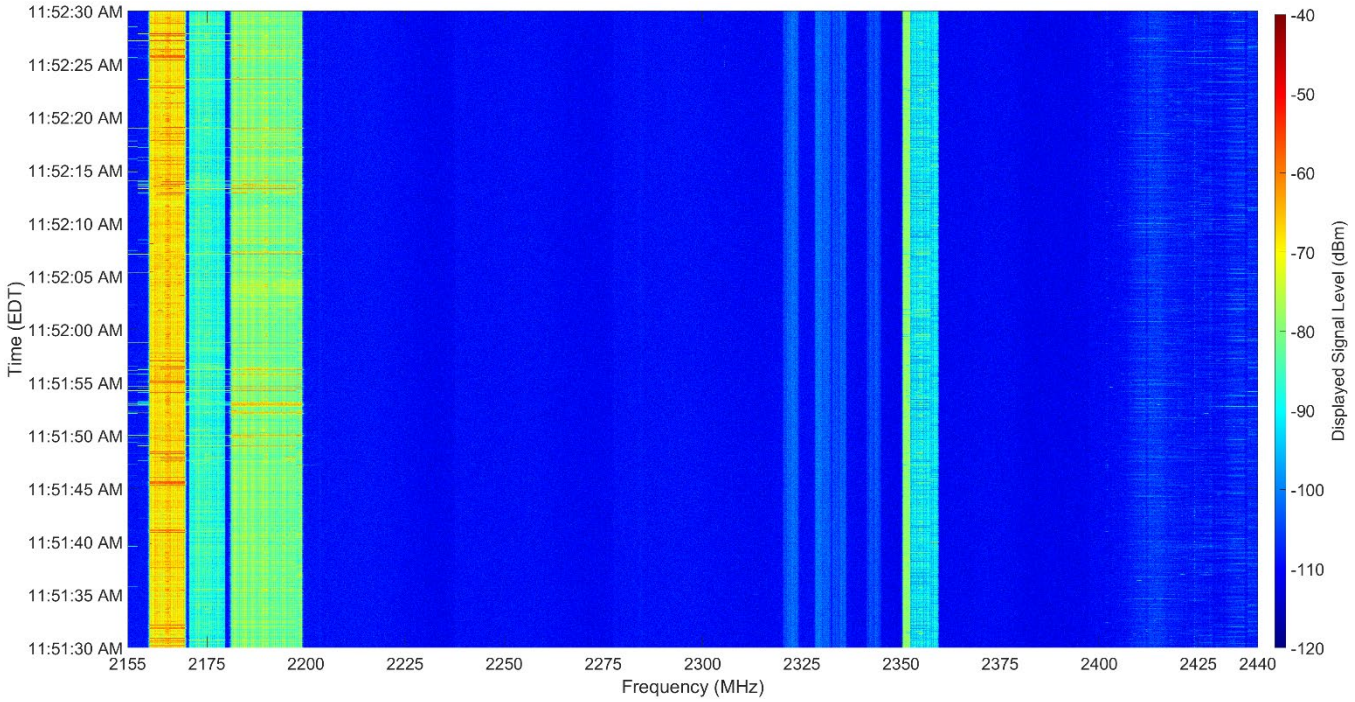

Figure 38. Measurement Scenario 4 waterfall plot

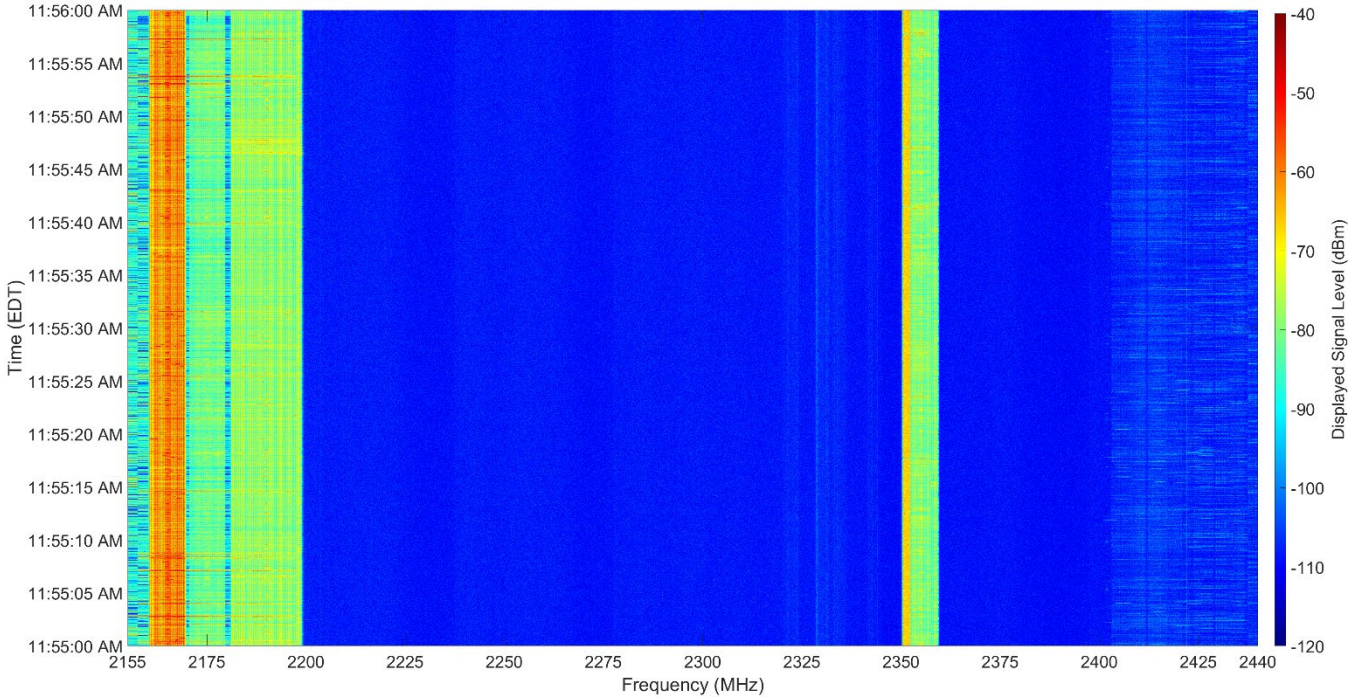

Figure 39. Measurement Scenario 5 waterfall plot

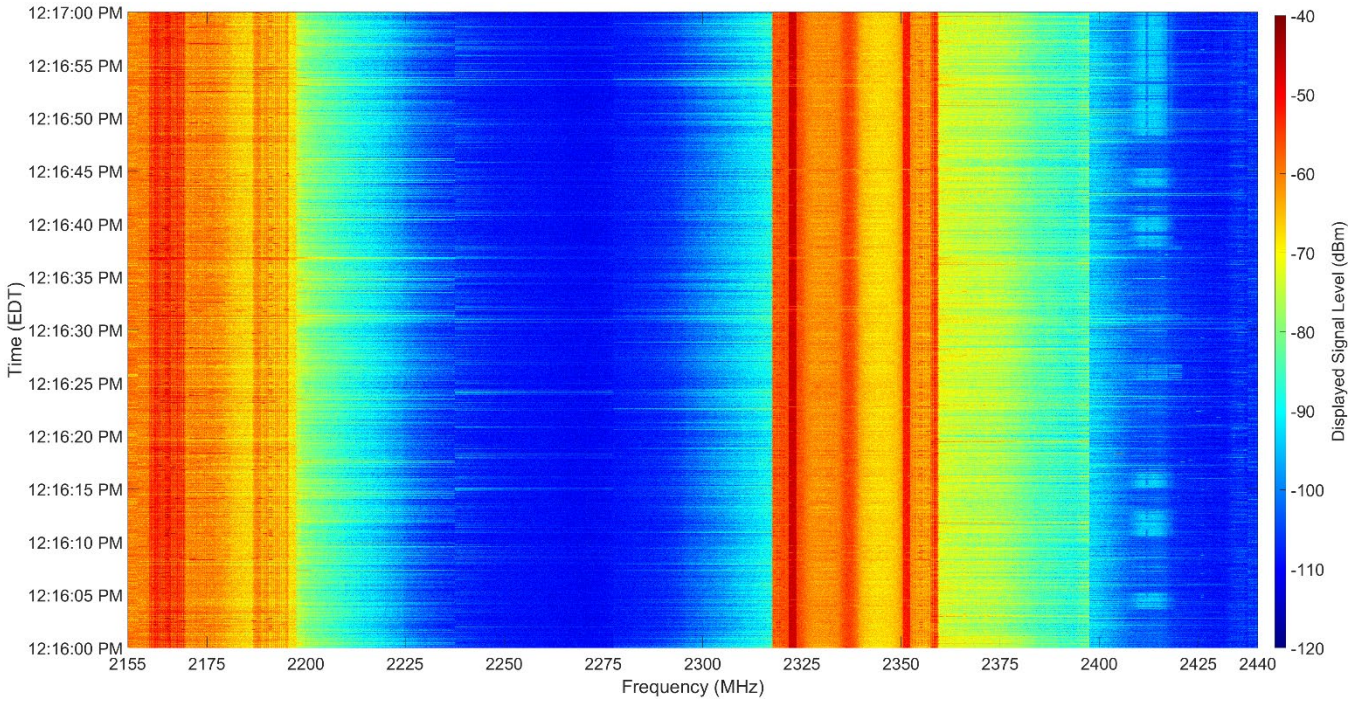

Figure 40. Measurement Scenario 7 waterfall plot

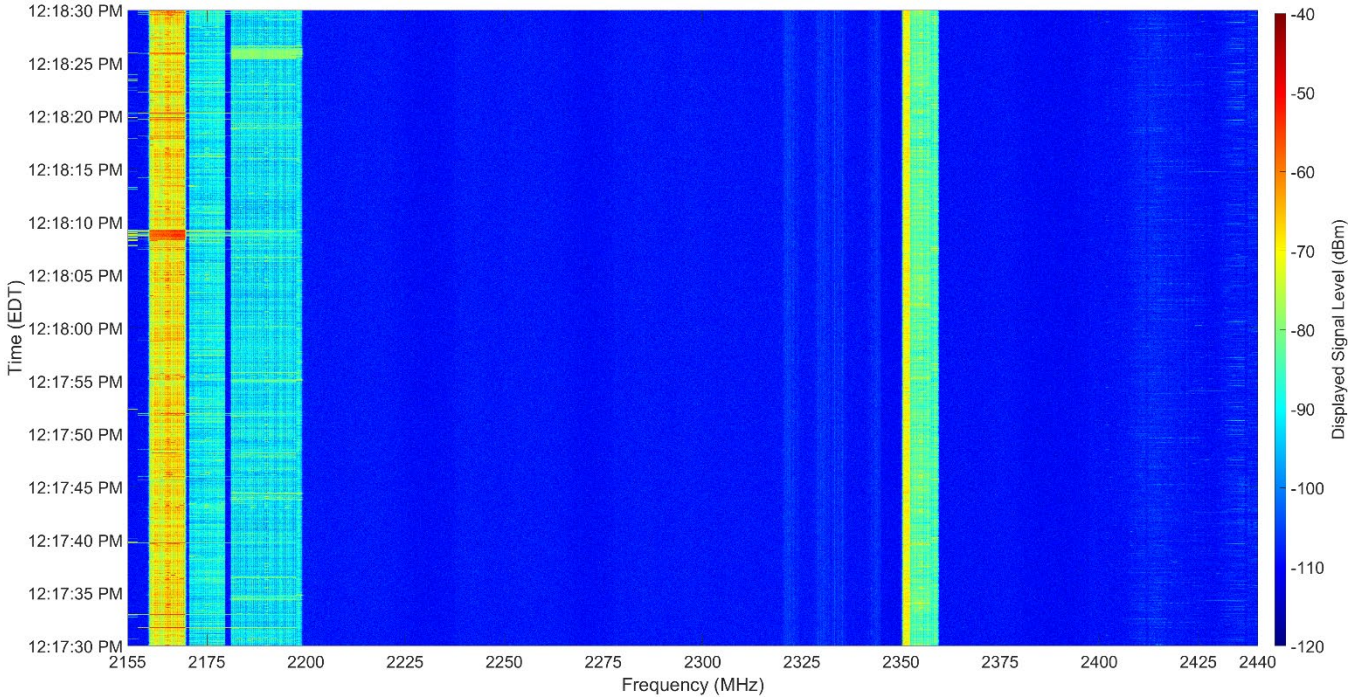

Figure 41. Measurement Scenario 8 waterfall plot

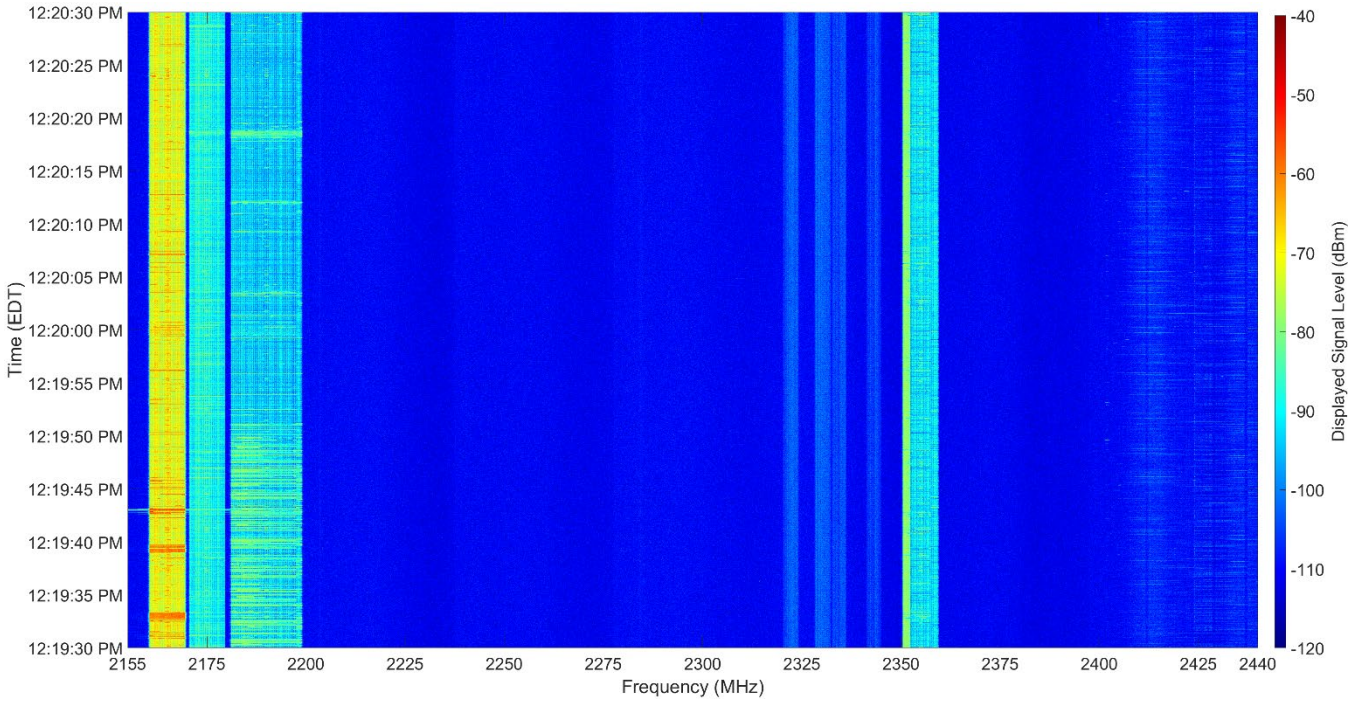

Figure 42. Measurement Scenario 9 waterfall plot

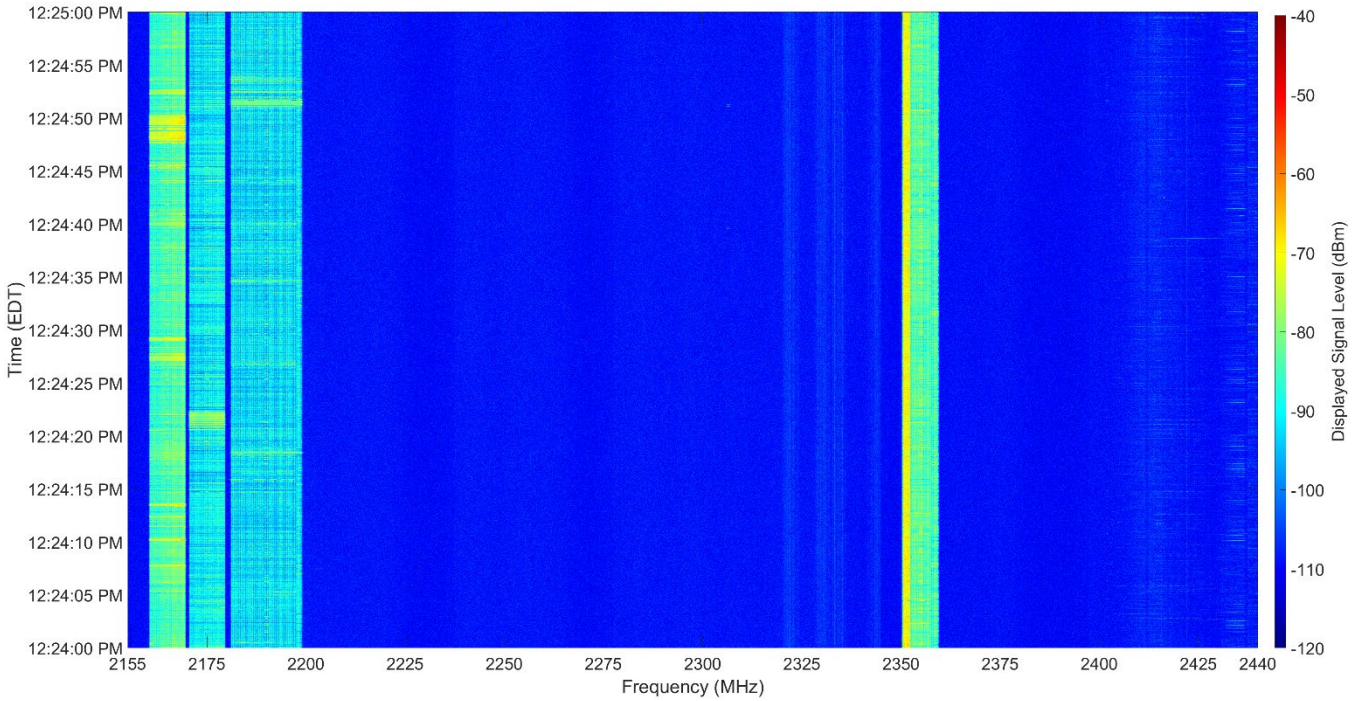

Figure 43. Measurement Scenario 10 waterfall plot

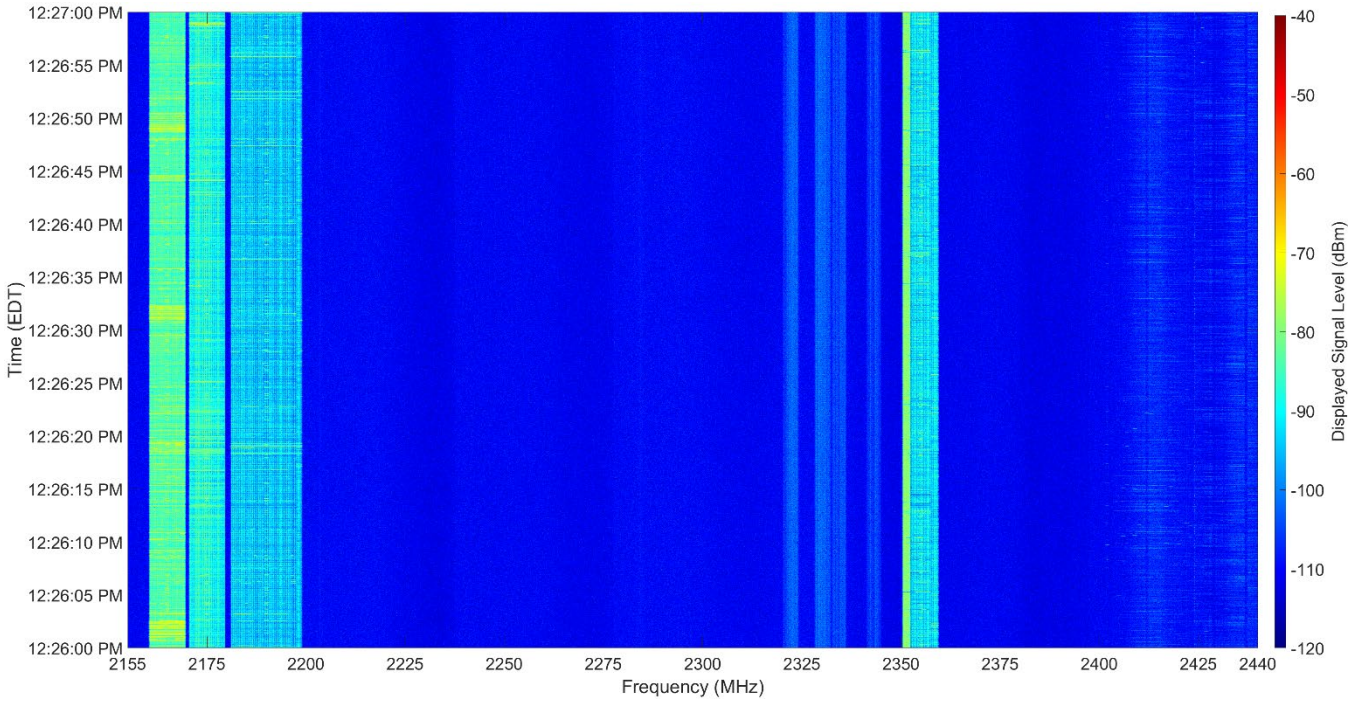

Figure 44. Measurement Scenario 11 waterfall plot

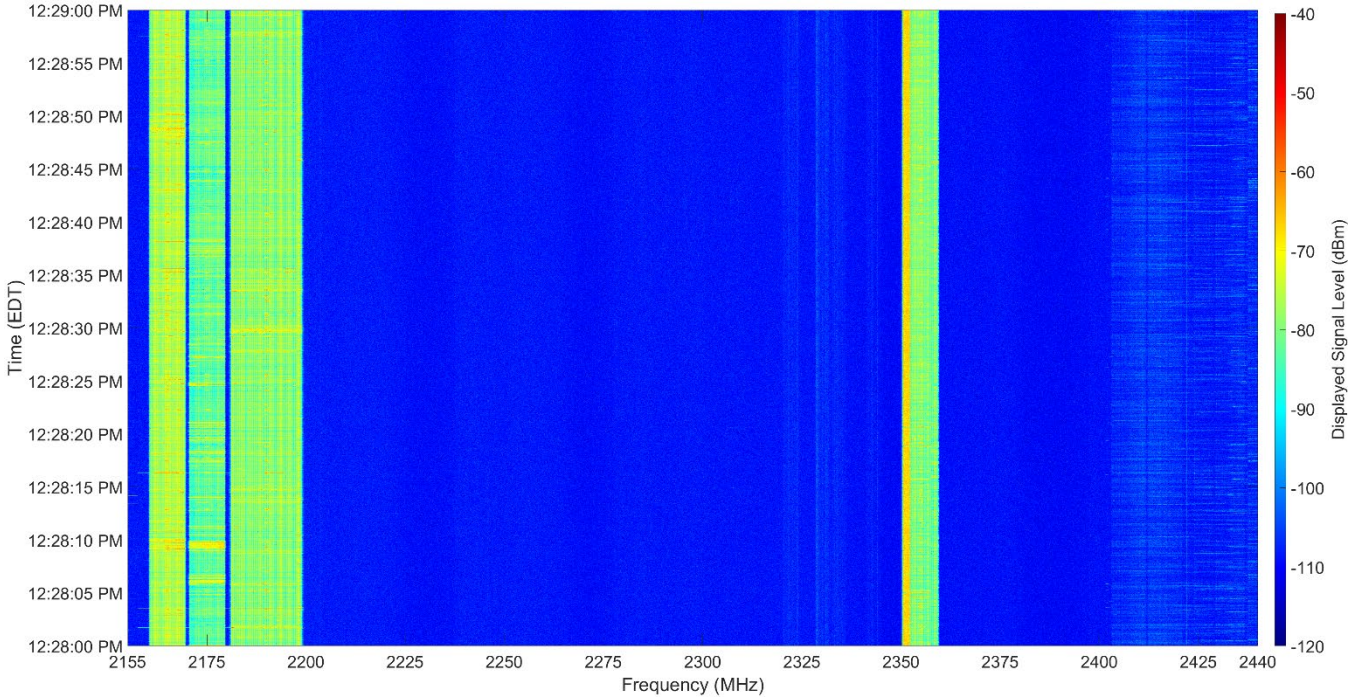

Figure 45. Measurement Scenario 12 waterfall plot

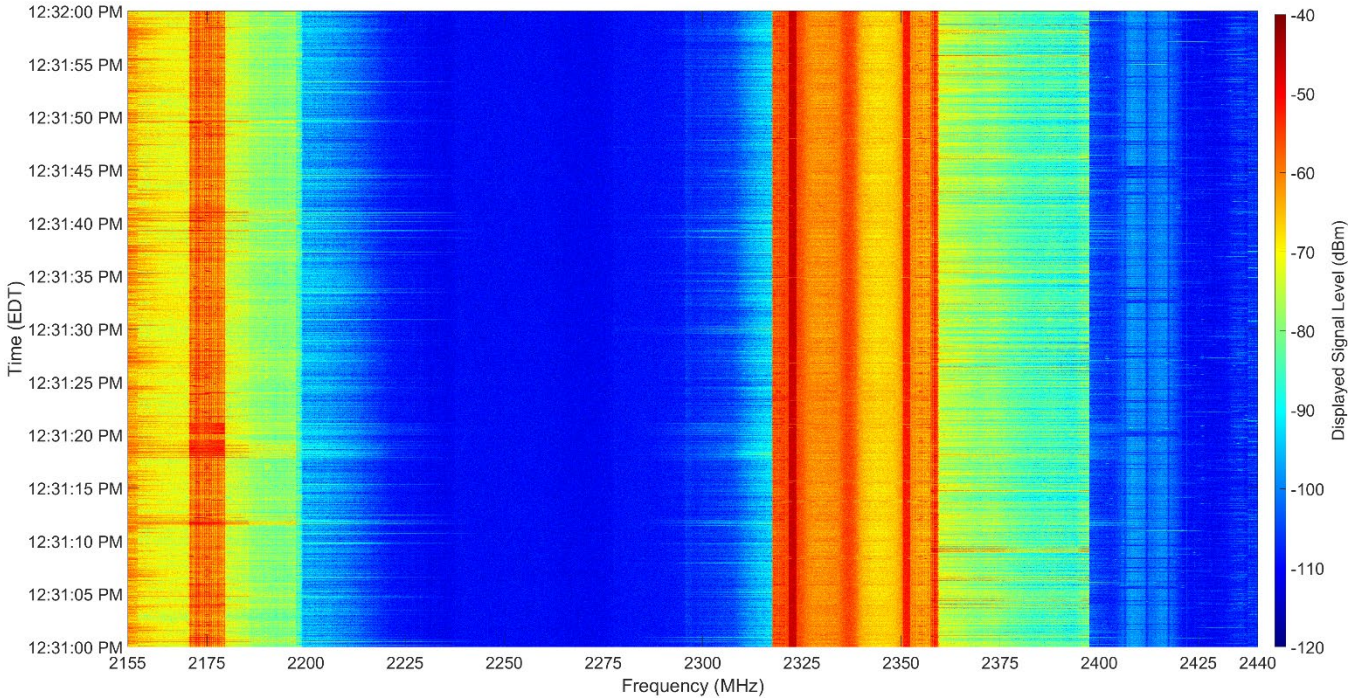

Figure 46. Measurement Scenario 13 waterfall plot

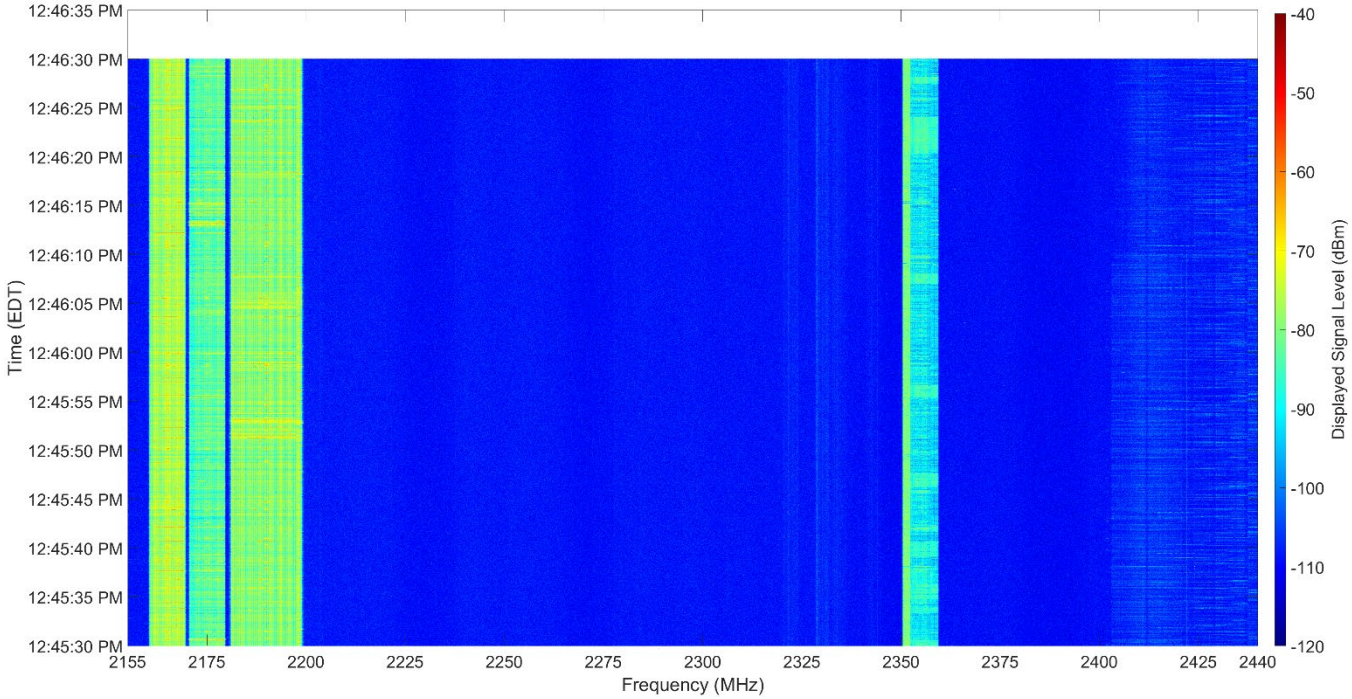

Figure 47. Measurement Scenario 14 waterfall plot

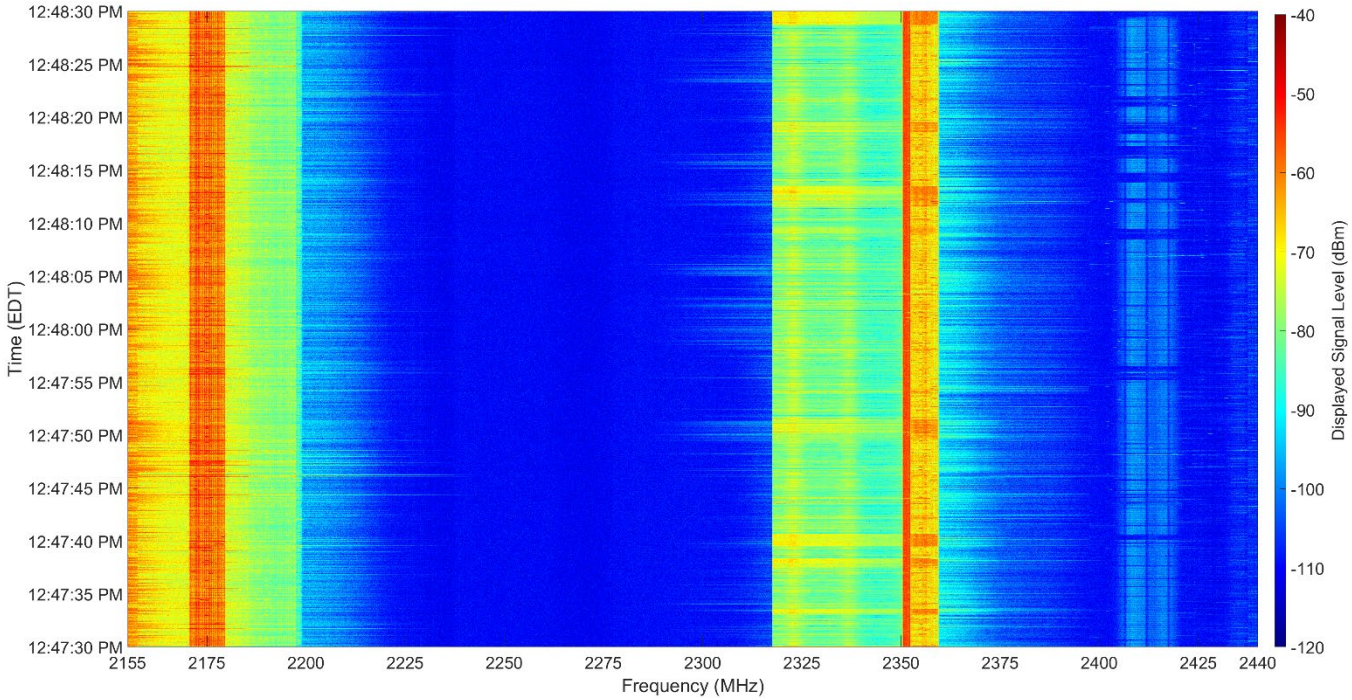

Figure 48. Measurement Scenario 15 waterfall plot

APPENDIX E – MAXHOLD AND AVERAGE PLOTS

Figure 49 through Figure 62 show the MAXHOLD of the data collected for each scenario shown in orange, and the AVERAGE value for each scenario shown in blue.

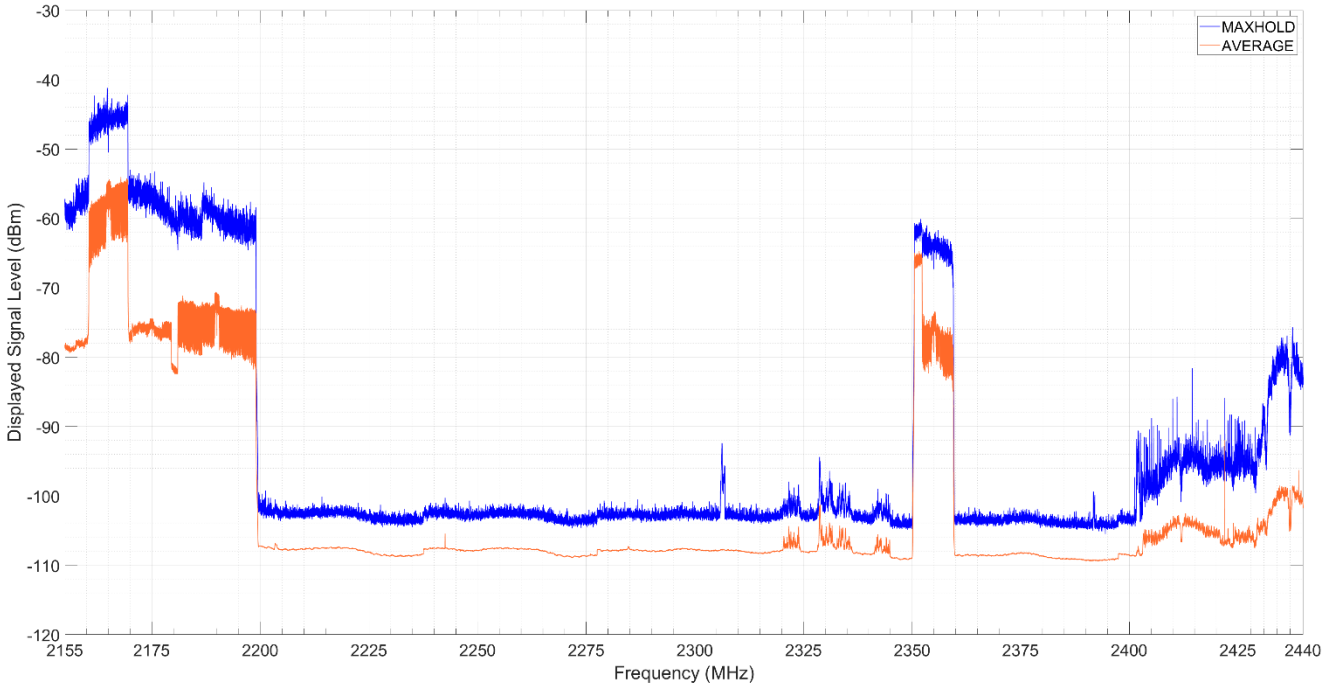

Figure 49. Measurement Scenario 1 MAXHOLD and AVERAGE plot

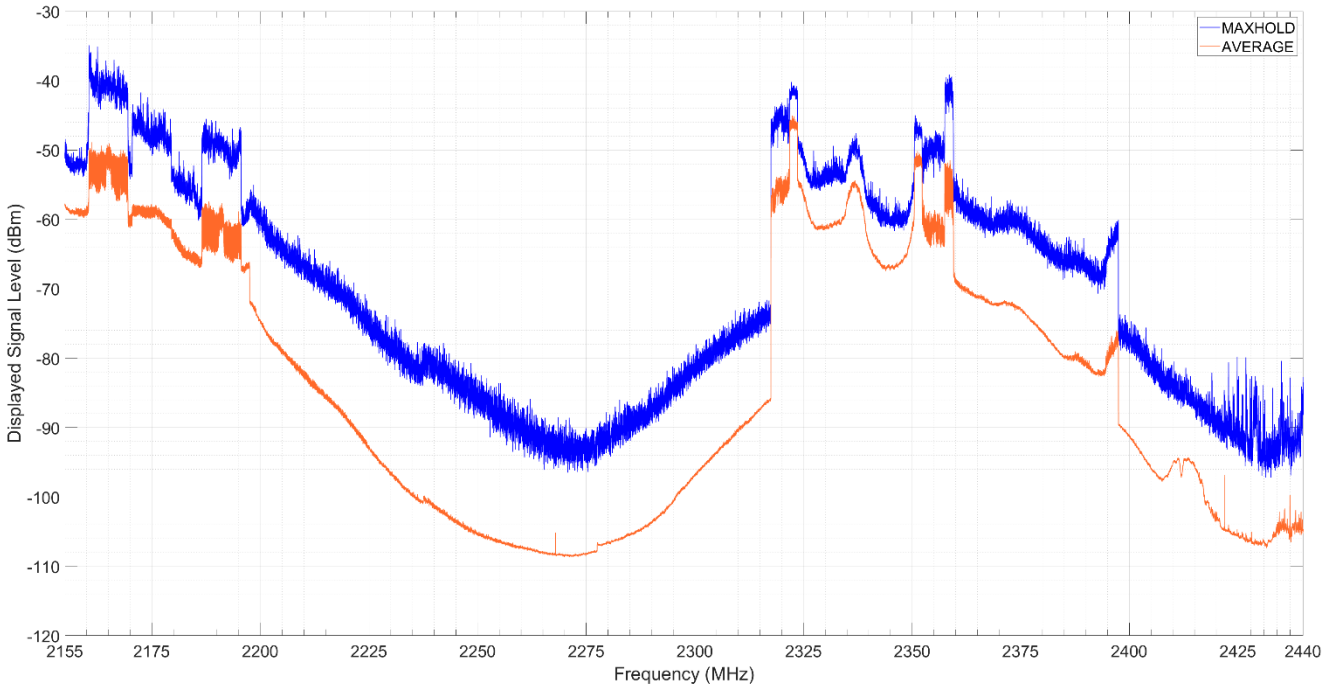

Figure 50. Measurement Scenario 2 MAXHOLD and AVERAGE plot

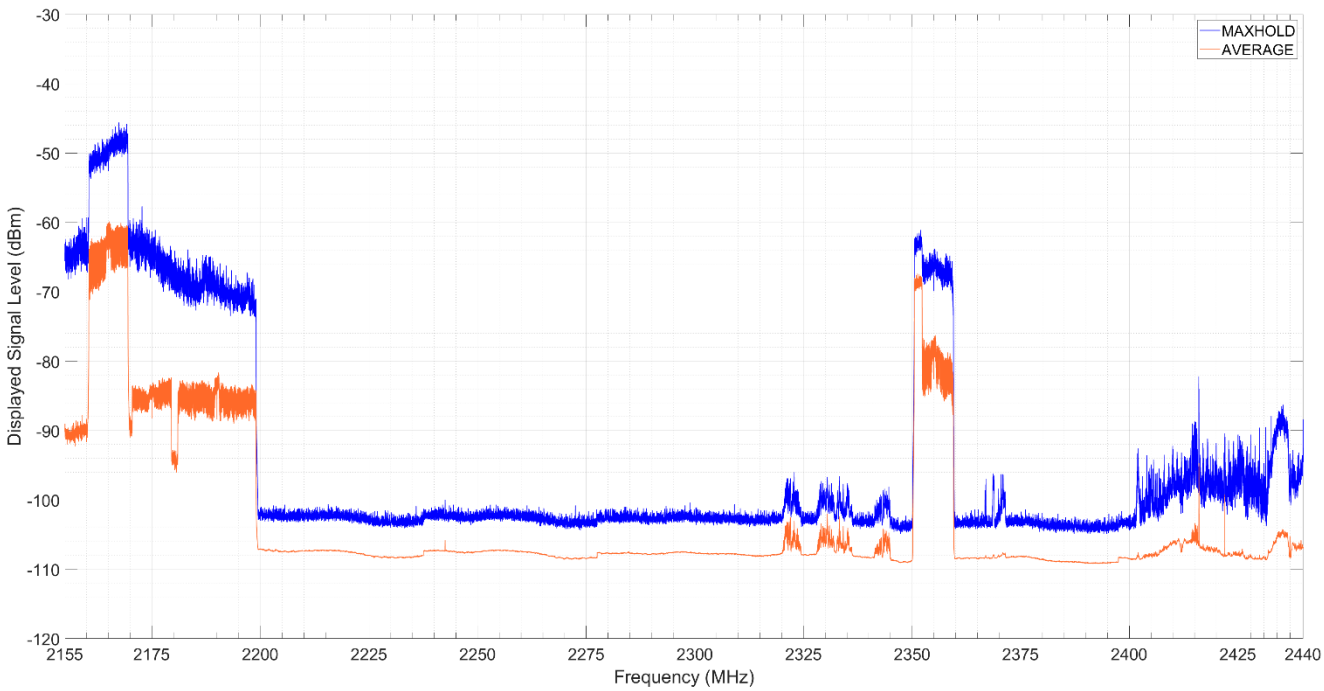

Figure 51. Measurement Scenario 3 MAXHOLD and AVERAGE plot

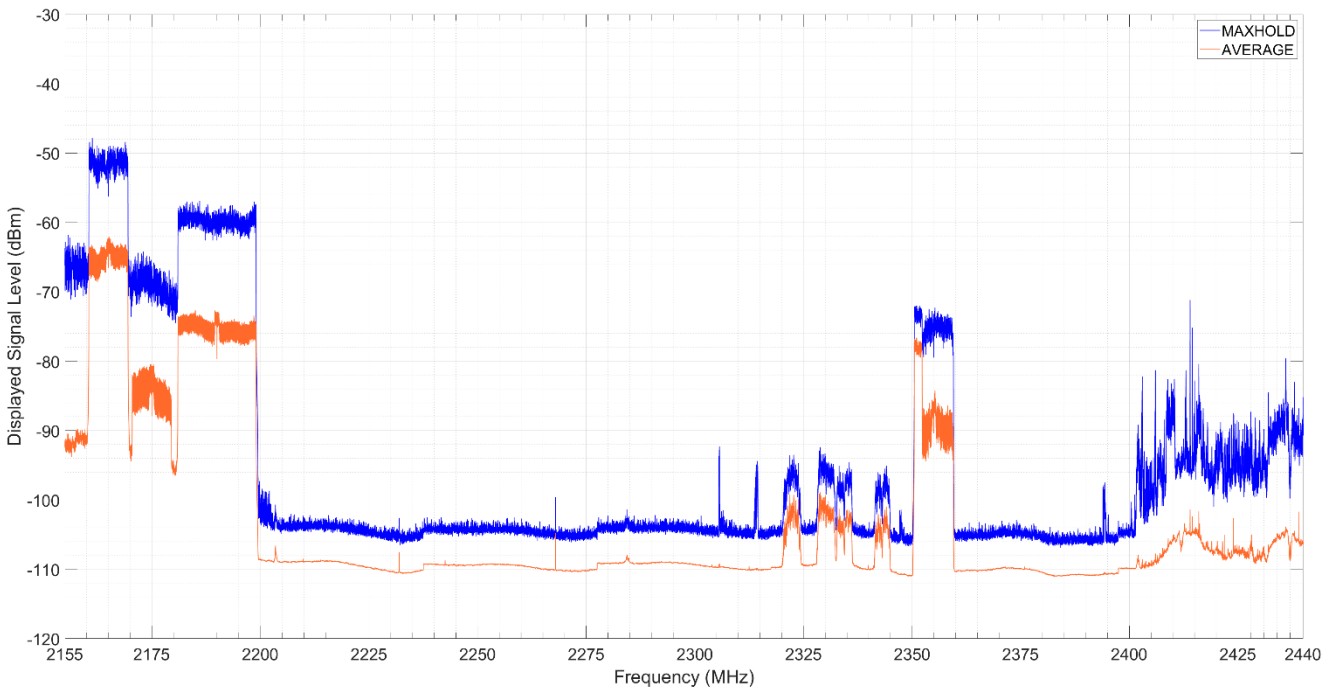

Figure 52. Measurement Scenario 4 MAXHOLD and AVERAGE plot

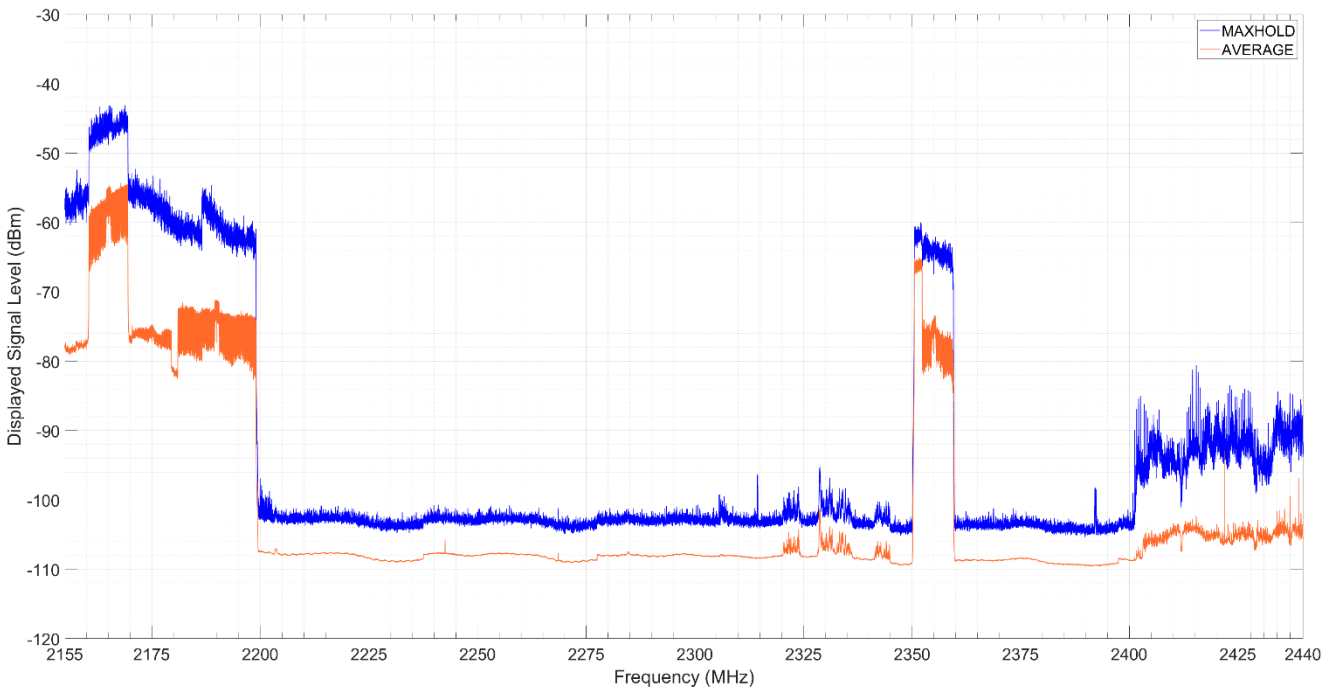

Figure 53. Measurement Scenario 5 MAXHOLD and AVERAGE plot

Figure 54. Measurement Scenario 7 MAXHOLD and AVERAGE plot

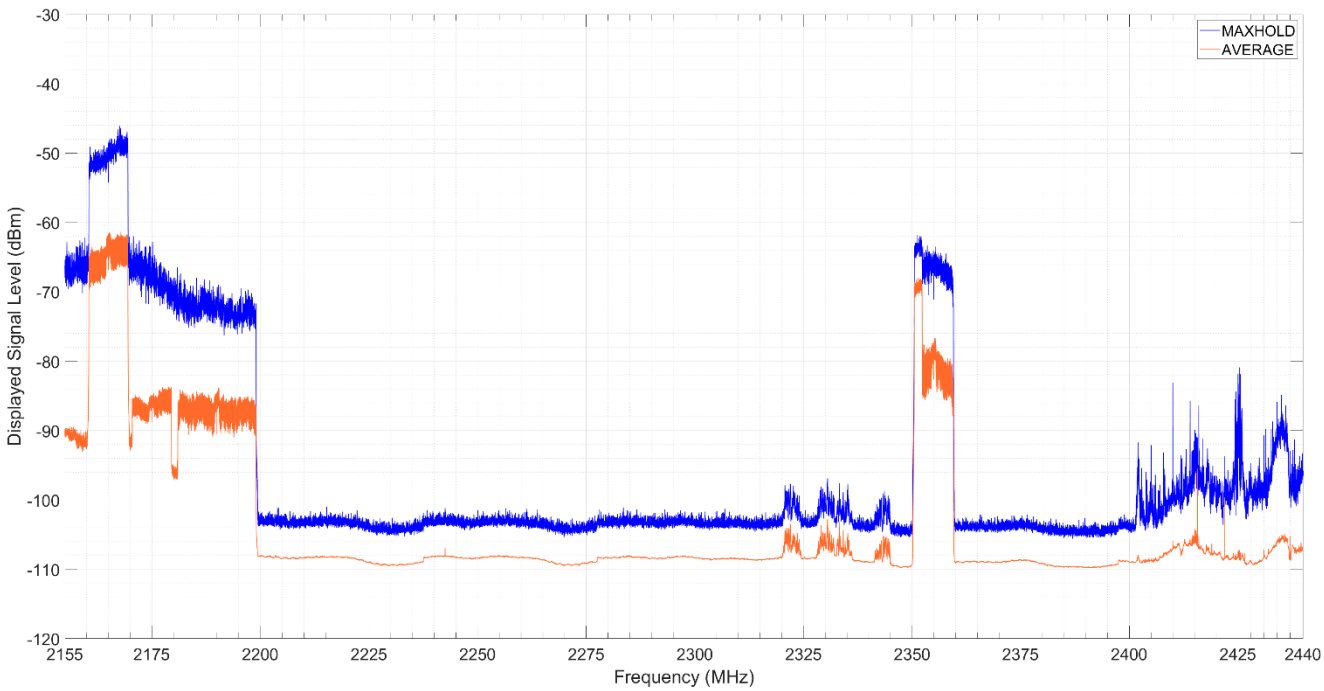

Figure 55. Measurement Scenario 8 MAXHOLD and AVERAGE plot

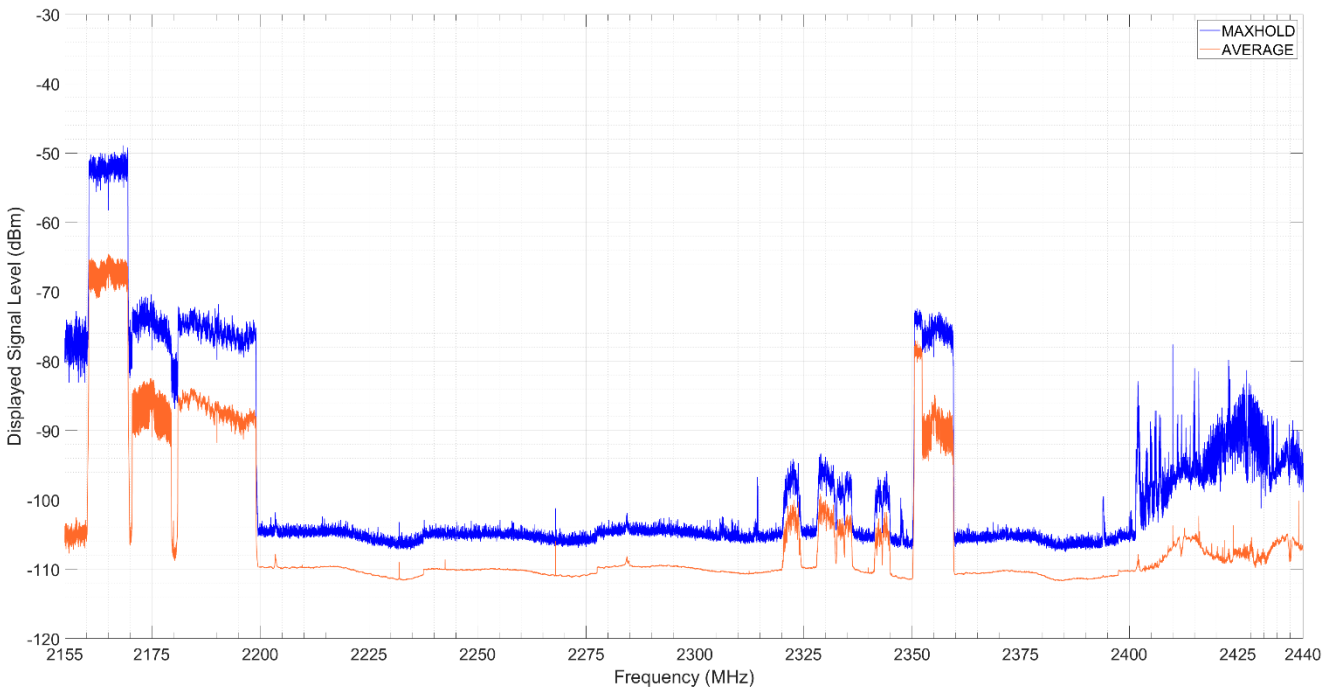

Figure 56. Measurement Scenario 9 MAXHOLD and AVERAGE plot

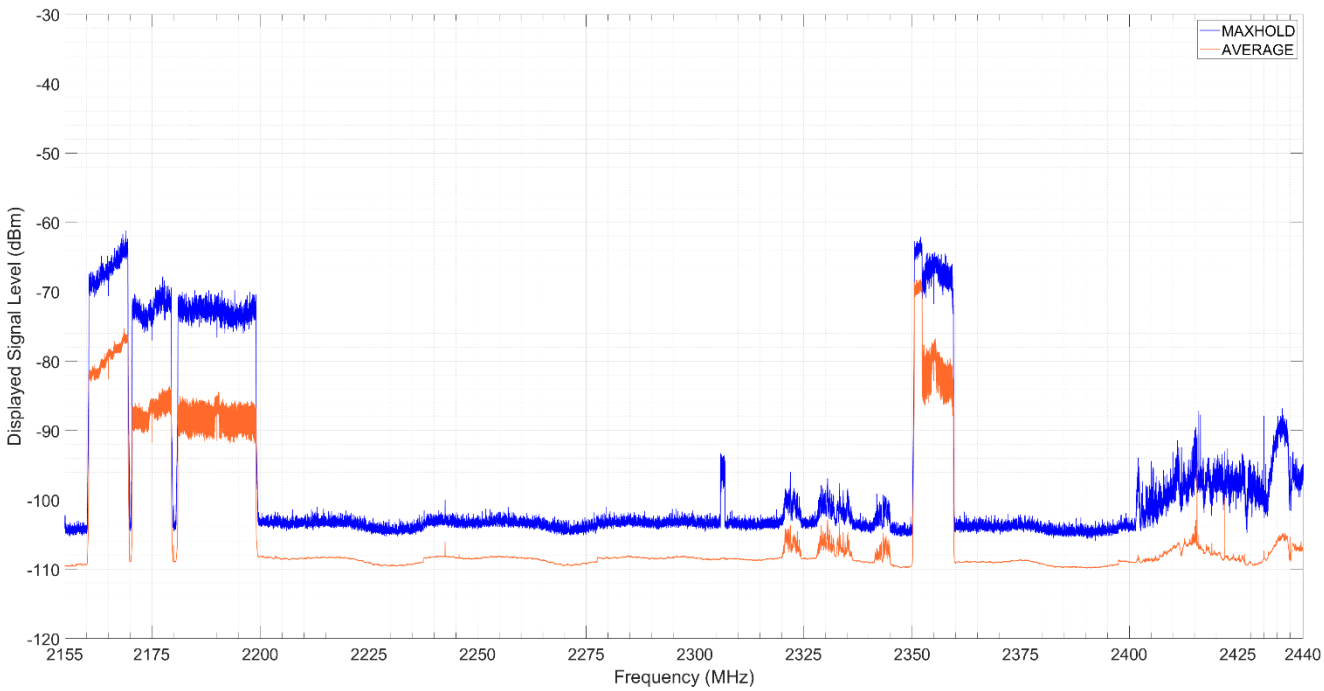

Figure 57. Measurement Scenario 10 MAXHOLD and AVERAGE plot

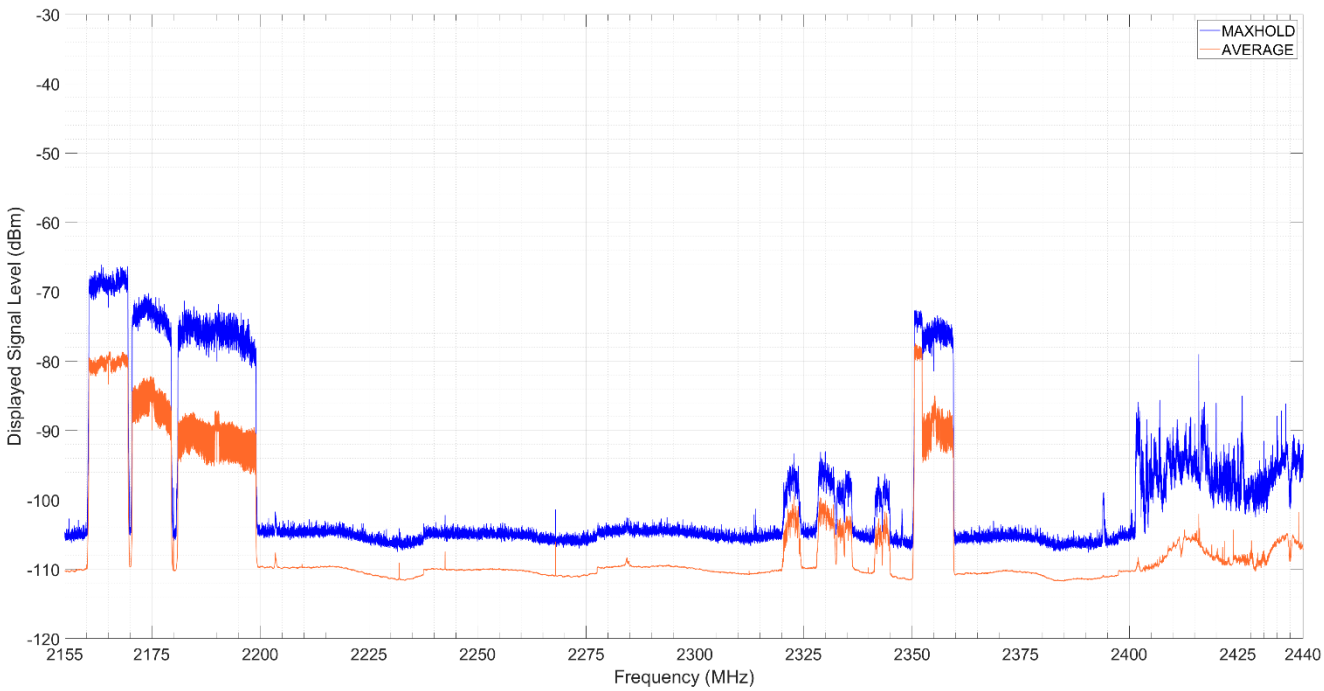

Figure 58. measurement Scenario 11 MAXHOLD and AVERAGE plot

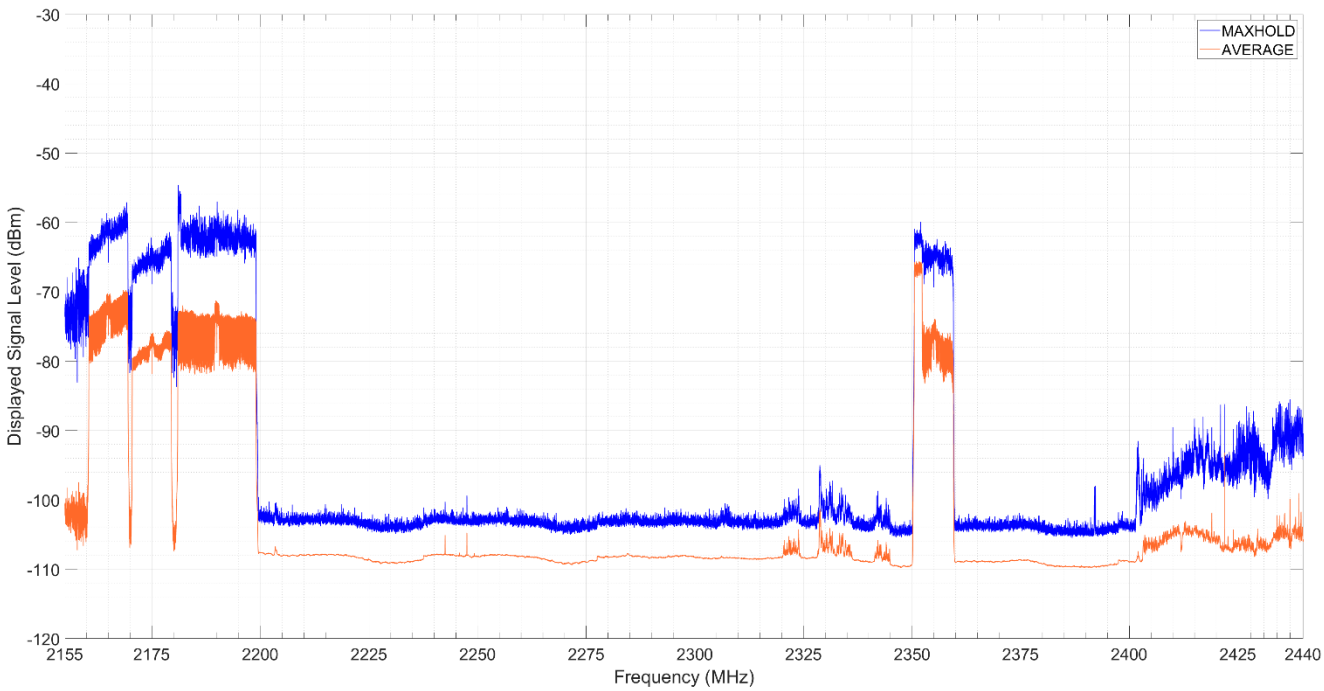

Figure 59. Measurement Scenario 12 MAXHOLD and AVERAGE plot

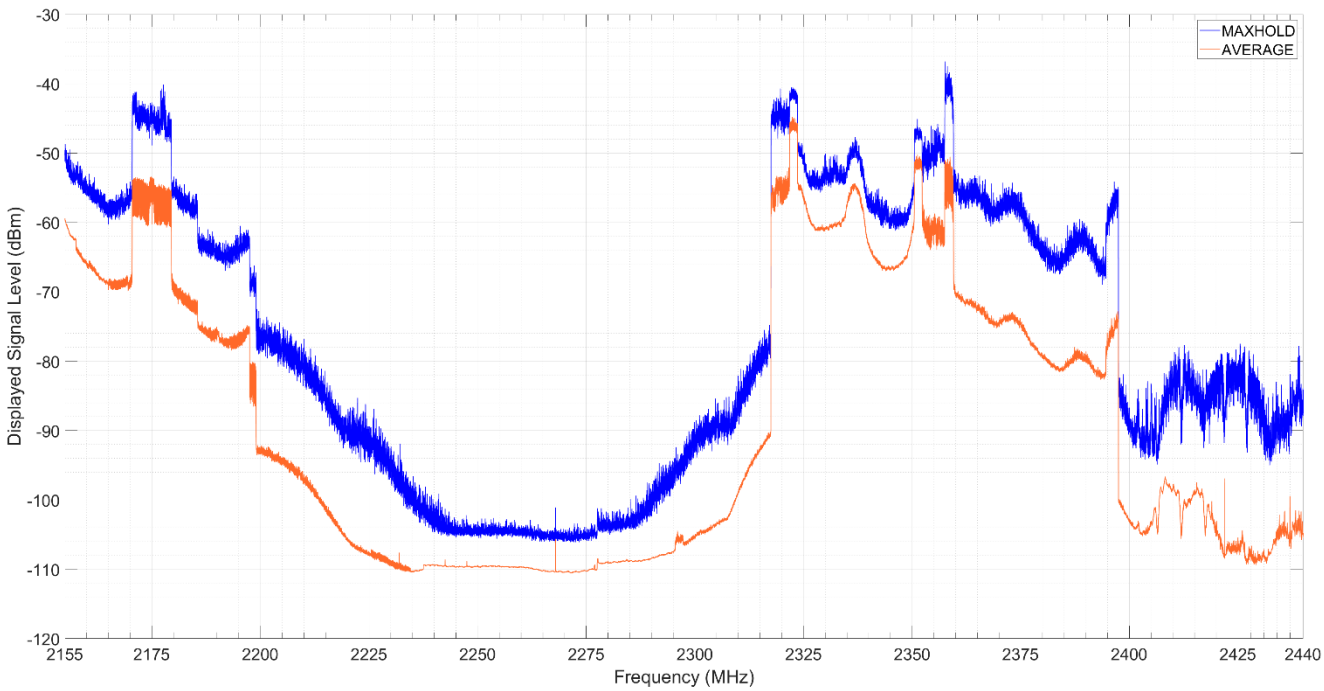

Figure 60. Measurement Scenario 13 MAXHOLD and AVERAGE plot

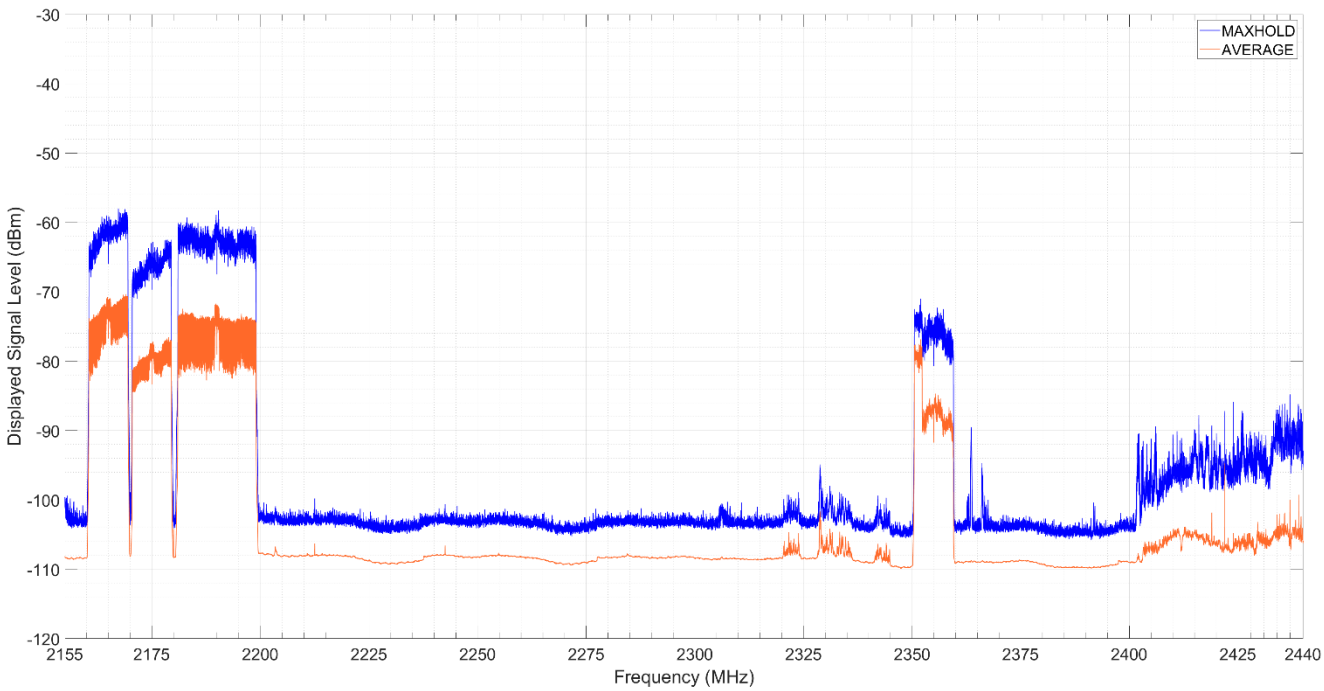

Figure 61. Measurement Scenario 14 MAXHOLD and AVERAGE plot

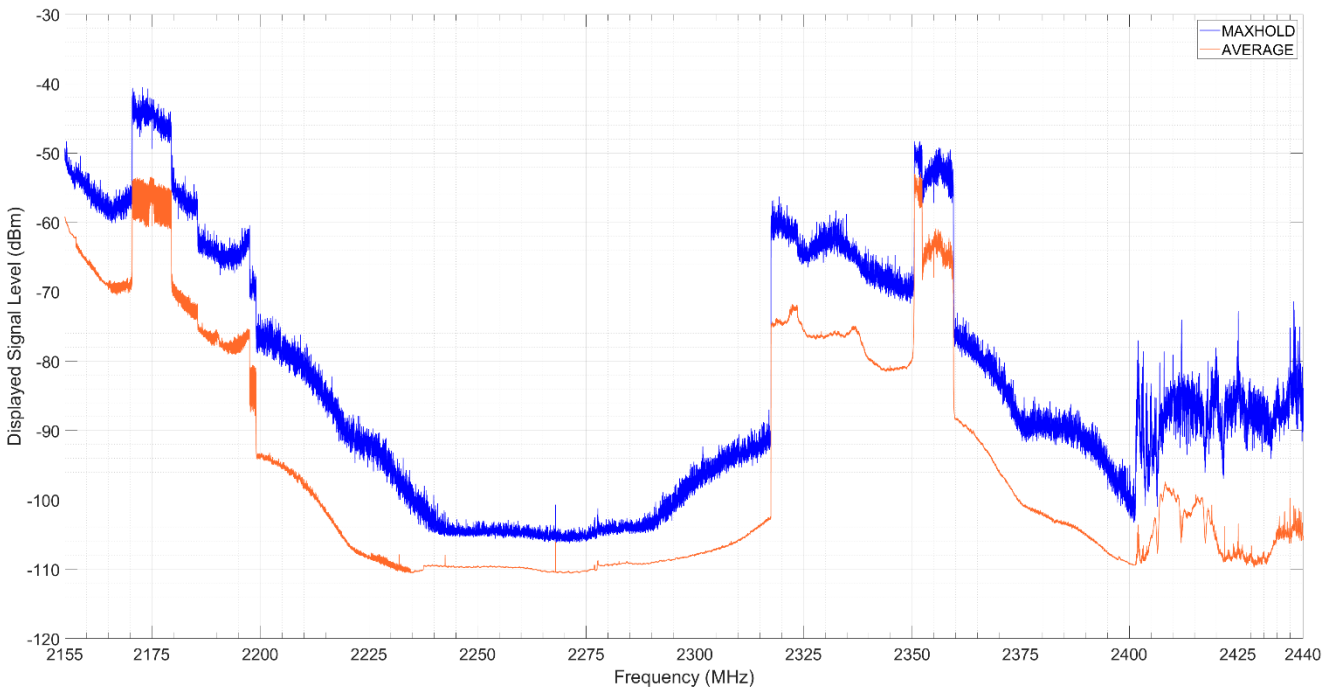

Figure 62. Measurement Scenario 15 MAXHOLD and AVERAGE plot

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